REMEDIAL INVESTIGATION REPORT
SITE-WIDE GROUNDWATER OPERABLE UNIT (OU-1)

ANACONDA COPPER MINE SITE
LYON COUNTY, NEVADA

OCTOBER 20, 2017

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LIST OF ACRONYMS AND ABREVIATIONS

AFCEE	Air Force Center for Environmental Excellence
AHA	Applied Hydrology Associates
Anaconda	Anaconda Companya
ARC	Atlantic Richfield Company
BC	Brown and Caldwell
BCL	Background Concentration Limit
BGQA	Background Groundwater Quality Assessment
BLM	Bureau of Land Management
CFC	Chlorofluorocarbon
COI	Chemical of Interest
DO	Dissolved Oxygen
DPT	Direct Push Technology
DSR	Data Summary Report
DQO	Data Quality Objective
DWMP	Domestic Well Monitoring Program
EA-IRMS	Elemental Analyzer-Isotopic Ratio Mass Spectrometer
EC	Electrical Conductivity
EPA	U.S. Environmental Protection Agency
ESI	Environmental Standards, Inc.
FEP	Finger Evaporation Ponds
FMS	Fluid Management System
FS	Feasibility Study
GC-ECD	Gas Chromatography with Electron Capture Detection
GMP	Groundwater Monitoring Plan
GMR	Groundwater Monitoring Report
HCSM	Hydrogeologic Conceptual Site Model
HDPE	High-Density Polyethylene
HFA	Hydrogeologic Framework Assessment
HLP	Heap Leach Pad
HHRA	Human Health Risk Assessment
HSR	Historical Summary Report
IAOC	Interim Administrative Settlement Agreement and Order on Consent
ICP-MS	Inductively Coupled Plasma Mass Spectroscopy
J	Estimated Concentration
K	Hydraulic Conductivity
Kd	Partition (or Distribution) Coefficient
LEP	Lined Evaporation Pond
MAROS	Monitoring and Remediation Optimization System
MCL	Maximum Contaminant Level
MFR	Mountain Front Recharge
NA	Not Applicable/Not Available
NAC	Nevada Administrative Code
NDEP	Nevada Division of Environmental Protection
NDWR	Nevada Division of Water Resources
NR	Not Recorded
NSA	North Study Area
NS	No Sample
O&M	Operation and Maintenance
ORP	Oxidation-Reduction Potential
OU	Operable Unit
PLS	Pregnant Leach Solution
POD	Point of Diversion
POU	Place of Use
PV	Pore Volume
PWS	Pumpback Well System
Q	Quarter
QA/QC	Quality Assurance/Quality Control
QAPP	Quality Assurance Project Plan
R	Retardation Coefficient
RAO	Remedial Action Objective
RER	Replicate Error Ratio
RI/FS	Remedial Investigation and Feasibility Study
RPD	Relative Percent Difference
RSIL	USGS Reston Stable Isotope Laboratory
RSL	Regional Screening Level
SCM	Surface Complexation Model
SERA	Southeast Recharge Area
SOP	Standard Operating Procedure
SOW	Scope of Work
SSPA	S.S. Papadopulos & Associates, Inc.
START	Superfund Technical Assessment and Response Team
STORET	STOrage and RETrieval
SWRA	Southwest Recharge Area
TC	Total Carbon
SX/EW	Solvent Extraction /Electrowinning
TIC	Total Inorganic Carbon
TDS	Total Dissolved Solids
TIMS	Thermal Ionization Mass Spectrometer
TOC	Total Organic Carbon
TU	Tritium Unit
U	Chemical not detected at the indicated sample detection limit
UAO	Unilateral Administrative Order
Ue	Uranium Excess
UEP	Unlined Evaporation Pond
UJ	Chemical not detected at the indicated estimated sample detection limit
USCS	Unified Soil Classification System
USGS	United States Geological Survey
UTL	Upper Tolerance Limit
VLT	Vat Leach Tailings
WRCC	Western Regional Climate Center

LIST OF ACRONYMS AND ABREVIATIONS - CONTINUED

WRD	Walker River Decree
WRID	Walker River Irrigation District
YPT	Yerington Paiute Tribe

%	percent
‰	per mil
amsl	above mean sea level
bgs	below ground surface
cu ft	cubic feet
cfs	cubic feet per second
°F	degrees Fahrenheit
°C	degrees Celsius or Centigrade
ft	foot/feet
ft/day	feet per day
ft/yr	feet per year
fmol/kg	femtomole per kilogram
gal	gallons
g/L	grams per liter
gpd	gallons per day
gpm	gallons per minute
L	liter
L/kg	liters per kilogram
µg	microgram
µm	micron or micrometer
mg	milligram
pCi/g	picocuries per gram
pCi/L	picocuries per liter
pCi	picocurie
pmol/kg	picomoles per kilogram
s.u.	standard units (pH)

MINERALS, CHEMICAL FORMULAS, AND ABBREVIATIONS

Barium Arsenate	$Ba_3(AsO_4)_2$
Ferric oxide	$Fe(OH)_3(a)$
Gypsum	$CaSO_4$
Hydroxy-green rust	$Fe_3(OH)_7(s)$ and $Fe_2(OH)_5(s)$
Jarosite (ss)	$(K_{0.77}Na_{0.03}H_{0.2})Fe_3(SO_4)_2(OH)_6(s)$
K-jarosite	$KFe_3(SO_4)_2(OH)_6(s)$
Na-jarosite	$NaFe_3(SO_4)_2(OH)_6(s)$
Schwertmannite	$Fe_8O_8(OH)_{4.8}(SO_4)_{1.6}(s)$
Scorodite	$FeAsO_4(s)$

(a)	Amorphous
(aq)	Aqueous
(s)	Solid
(ss)	Solid Solution

$\delta^{13}B$	Boron isotopes in water samples
$\delta^{36}Cl$	Chloride isotopes in water samples
$\delta^{34}S_{SO4}$	Sulfur isotopes in dissolved sulfate
$\delta^{34}O_{SO4}$	Oxygen isotopes in dissolved sulfate
$\delta^{15}N_{NO3}$	Nitrogen isotopes in dissolved nitrate
$\delta^{18}O_{NO3}$	Oxygen isotopes in dissolved nitrate

Nitric Acid	HNO_3
Sulfuric Acid	H_2SO_4
Sulfur Hexafluoride	SF_6
Sulfur Dioxide	SO_2

EXECUTIVE SUMMARY

This *Site-Wide Groundwater Operable Unit (OU-1) Remedial Investigation Report* (OU-1 RI Report) has been prepared by Atlantic Richfield Company (ARC) pursuant to Section 7.0 of the Scope of Work (SOW) attached to the Administrative Order for Remedial Investigation and Feasibility Study (RI/FS), CERCLA Docket No. 9-2007-0005 (2007 Order) for the Anaconda Copper Mine Site (Site). The 2007 Order (EPA 2007a) was issued to ARC by the U.S. Environmental Protection Agency - Region 9 (EPA) on January 12, 2007. Future work on the OU-1 RI/FS will proceed under oversight by the Nevada Division of Environmental Protection (NDEP) pursuant to the "Interim Administrative Settlement Agreement and Order on Consent for: (i) Remedial Design/Remedial Action, (ii) Site-Wide Remedial Investigation/Feasibility Study, and (iii) Fluid Management" entered into with NDEP (the IAOC) and the attached Statement of Work for RI/FS.

The term "Site" refers to the area where copper mining and ore processing activities historically occurred. The term "Study Area" in this document refers to a larger area encompassing both on-Site and off-Site areas in which OU-1 RI-related investigations have been conducted. The Site is a former copper mine that is located west and northwest of the City of Yerington. The 2007 Order identified eight OUs at the Site, which include:

- Site-Wide Groundwater (OU-1);
- Pit Lake (OU-2);
- Process Areas (OU-3);
- Evaporation Ponds (OU-4a) and Sulfide Tailings (OU-4b);
- Waste Rock Areas (OU-5);
- Oxide Tailings Areas (OU-6);
- Wabuska Drain (OU-7); and
- Arimetco Facilities (OU-8).

Consistent with the SOW attached to the 2007 Order (EPA 2007a) and general RI report objectives established by EPA (EPA 1988), this OU-1 RI Report:

- Summarizes activities conducted to characterize and monitor groundwater (including on- and off-Site locations), establish background groundwater quality, and determine the nature, extent, and transport of mine-related chemicals of interest (COIs) in groundwater;
- Integrates relevant historical operations and aspects of other OUs that represent potential sources of chemical loading to groundwater or have the potential to influence groundwater flow conditions;
- Describes the program for long-term monitoring of Site-wide groundwater conditions;
- Summarizes the domestic well monitoring program, which characterized the quality of groundwater used for drinking water or other domestic water supply purposes and determined eligibility for receiving bottled water as part of an interim response action; and
- Describes the process for completing the human health risk assessment, which is being addressed in a separate OU-1 Human Health Risk Assessment (HHRA) report, per EPA direction during a groundwater technical meeting held on June 30, 2016 attended by ARC, EPA, the NDEP, the Yerington Paiute Tribe (YPT), and other stakeholders.

The information provided in this OU-1 RI Report is considered sufficient to characterize the groundwater system, define the nature and extent of mine-related groundwater contamination, perform a risk assessment, and conduct a feasibility study. Numerous investigations and monitoring activities conducted by ARC and others provide substantial geologic, hydrogeologic, and water quality information relevant to OU-1. However, this OU-1 RI Report relies primarily on data obtained after 2005 to address the study elements specified in Section 7.0 of the SOW, characterize groundwater conditions, and refine the hydrogeologic conceptual site model (HCSM) to support the OU-1 RI/FS. Data obtained after 2005 have been selected for these purposes because: 1) data collection was performed pursuant to EPA-approved quality assurance/quality control (QA/QC) planning documents and OU-1 specific work plans that were developed with input from other stakeholders including the NDEP, YPT, and the Bureau of Land Management (BLM); 2) the spatial coverage and amount of data increased substantially after 2005; and 3) post-2005 sampling results better represent current conditions and potential risks at the Site, which is the proper focus of the RI and risk assessment.

The dataset obtained during August 2014 is emphasized in this OU-1 RI Report for the reasons previously cited, and because a variety of data types were concurrently collected (e.g., groundwater level data, groundwater quality data, and hydrologic tracer data) and/or evaluated (e.g., geochemical speciation modeling to help assess COI transport). Consequently, the August 2014 dataset is particularly useful for characterizing spatial aspects of OU-1 groundwater conditions.

Recognizing that groundwater characterization activities would largely involve monitor well installation, ARC and EPA adopted a multi-step sequential approach to field data collection to maximize usable data and optimize the design of a monitor well network intended to serve the data needs for both OU-1 RI characterization and long-term Site-Wide groundwater monitoring. In total, the groundwater RI characterization activities resulted in drilling 133 boreholes, logging approximately 33,000 linear feet of core, collecting and analyzing 624 zonal groundwater samples, installing 299 new monitor wells, and hydraulic (slug) testing of 296 wells.

After installation and development, new monitor wells were incorporated along with select existing monitor wells into the Site-Wide Groundwater Monitoring Program. Within the Study Area, the alluvial aquifer is up to 700 feet thick and is subdivided into Shallow, Intermediate and Deep zones (Deep zones 1 through 5). Underlying the alluvial aquifer is a bedrock groundwater flow system. The current monitor well network includes 360 wells at 170 locations: 133 wells in the Shallow zone, including 11 Pumpback Well System (PWS) wells formerly used for groundwater extraction that are currently inactive; 55 wells in the Intermediate zone; 105 wells in the Deep zone; and 67 bedrock wells. Of the 360 monitor wells, seven are used only for water level measurements, and the remaining 353 are monitored for both water levels and water quality.

The Site and Study Area are in the Mason Valley, a north-south trending structural valley (graben) in the Basin and Range Province that is filled with up to 1,000 feet of unconsolidated alluvial sediments. The valley is bordered to the west by the Singatse Range, to the east by the Wassuk Range, and to the north by the Desert Mountains. Regional metals mineralization and hydrothermal alteration associated with localized porphyry and skarn copper deposits occur throughout the Singatse Range and nearby portions of the Mason Valley.

Depositional processes have resulted in a complex sequence of laterally-discontinuous, heterogeneous, unconsolidated alluvial sediments that exhibit spatially-variable hydraulic properties (Brown and Caldwell [BC] 2014a). Clay layers or other low-permeability sediments are laterally discontinuous resulting in unconfined or semi-confined alluvial aquifer groundwater conditions. Based on groundwater flow model results (S.S. Papadopulos & Associates, Inc. [SSPA] 2014), the alluvial aquifer is primarily recharged by downward percolation of water from irrigated fields (49 percent [%]), leakage from irrigation ditches (29%), infiltration from the channel of the Walker River (20%), and mountain front recharge (2%) resulting from infiltration through bedrock of precipitation that falls on surrounding mountain ranges and minor tributary surface flows in ephemeral drainages. Recharge from precipitation falling directly on the valley floor is negligible (Huxel and Harris 1969; Lopes and Allander 2009a, 2009b).

The alluvial aquifer in the Mason Valley yields significant quantities of groundwater and the groundwater resource is pumped extensively for irrigation (Carroll et al. 2010; SSPA 2014). Alluvial groundwater near the Site generally flows to the northwest, but flow directions are locally affected by bedrock outcrops within and along the margins of the valley, drawdown from pumped wells (particularly in deeper zones of the alluvial aquifer), and recharge sources such as the Walker River, the West Campbell Ditch, and irrigation on the Hunewill Ranch and other agricultural fields. Groundwater in the alluvial aquifer moves relatively slowly, with flow velocities estimated to be less than 100 feet per year (BC 2014a). Agricultural pumping seasonally results in strong downward vertical gradients that are often 10 to 100 times greater than horizontal gradients.

Historic mining and copper ore beneficiation activities involved the use of sulfuric acid (H_2SO_4). The major past and/or ongoing sources of COIs to groundwater include: 1) OU-4a, the Evaporation Ponds (BC 2014a, 2014d); 2) OU-8, the Arimetco Facilities (CH2M Hill 2010, 2011a, 2011b); and 3) OU-3, the Process Areas (BC 2014a, 2014e). Concentrations of COIs in groundwater beneath OU-4b (Sulfide Tailings) are generally at least 10 to 100 times lower than COI concentrations in groundwater beneath OU-4a. Furthermore, OU-4b is located hydraulically upgradient or cross-gradient of OU-4a, and groundwater beneath OU-4b flows toward the higher COI concentrations under OU-4a.

The Pit Lake (OU-2), which was studied as part of the OU-1 RI (BC 2014a), is not a source of COIs to Site-wide groundwater because the lake elevation is lower than the surrounding potentiometric surface and the pre-mining groundwater level. The Pit Lake surface is projected to reach a steady-state level, where water inflow and evaporation are balanced, prior to 2030. The steady-state Pit Lake elevation is estimated to be in the range of 4,249 to 4,253 feet above mean sea level, and is projected to remain lower than the surrounding potentiometric surface even after reaching steady-state conditions. Consequently, the lake is and will continue to be a groundwater sink that does not discharge into the Site-wide groundwater system.

Results of the ongoing RI for the Wabuska Drain (OU-7) will be reported separately. Available data indicate that concentrations of mine-related chemicals decrease with distance from the Site and depth in the soil profile (EPA 2007, BC 2015b).

Mine-related COIs include acidity (i.e., low pH), total dissolved solids (TDS), major ions including sulfate, metals/metalloids (hereinafter referred to as metals), and radiochemicals including uranium (BC 2014a). Concentrations of mine-related chemicals in groundwater are most elevated in the Shallow zone of the alluvial aquifer beneath OU-4a features that include the Lined Evaporation Pond (LEP), Unlined Evaporation Pond (UEP), Finger Ponds, Phase IV Vat Leach Tailings (VLT) Heap Leach Pad (HLP), Phase IV VLT Pond, and the northern end of the Calcine Ditch. Chemical concentrations in groundwater generally decrease with vertical depth and horizontal distance from these facilities. To the extent localized downgradient increases in chemical concentrations are observed, they result from non-mine-related factors.

Hydraulic assessments and chemical distributions indicate that the PWS was only partially effective in capturing Shallow zone mine-impacted groundwater during its operational life from 1989 to 2009 (BC 2010), when it was shut down with EPA approval.

Geochemical evaluations of groundwater quality data (BC 2016a) indicate that sulfate and dissolved uranium form neutral or negatively-charged aqueous ionic complexes in groundwater throughout the Study Area (except beneath the Evaporation Ponds) and, thus, undergo very limited (if any) geochemical attenuation due to mineral precipitation or adsorption to aquifer materials during groundwater transport. Dissolved uranium in Study Area groundwater is predominantly present in complexes with carbonate plus or minus calcium, which reflect oxidizing, carbonate-rich groundwater conditions. Locally, dissolved uranium is also complexed with sulfate in Shallow zone groundwater beneath the Evaporation Ponds where pH is less than 5 and sulfate concentrations exceed 1,500 milligrams per liter (mg/L).

The spatial distributions of elevated concentrations of mobile parameters such as sulfate and uranium are significantly more extensive than the spatial distributions of acidity (as indicated by pH) and metals. The limited spatial extent of low pH values and elevated metal concentrations indicates that geochemical attenuation processes in Study Area groundwater limit the mobility of acidity and metals relative to the more mobile chemicals such as sulfate and uranium (EPA 2007b; BC 2016a, 2016b). Elevated metal concentrations in groundwater correlate strongly with low pH. Geochemical evaluations of groundwater quality data (BC 2016a) also indicate the likely precipitation of solid mineral phases (e.g., jarosite) primarily in the Shallow zone beneath the LEP, UEP, Thumb Pond, and Phase IV HLP. These mineral phases likely represent a potential ongoing source of COIs to groundwater.

Sulfate, uranium and arsenic (and other COIs) occur naturally in groundwater in Mason Valley because of groundwater contact with naturally-mineralized and/or hydrothermally-altered bedrock associated with copper deposits and/or alluvial sediments derived from mineralized bedrock (BC 2009a, 2014b). These regional groundwater conditions, unrelated to mining, affect COI concentrations at two key locations within the OU-1 groundwater Study Area. To the west of the Site and adjacent to the Singatse Range, naturally-occurring arsenic, other COIs, and elevated groundwater temperatures in alluvial aquifer groundwater are associated with subsurface water transmitted along fractures and faults (especially oblique range-front faults such as the Sales Fault).

These faults occur in arsenic-bearing volcanic and granitic bedrock formations that provide conduits for bedrock groundwater to discharge into the overlying alluvial aquifer. In the North Study Area (NSA), which refers to the portion of the OU-1 groundwater Study Area located northeast of West Campbell Ditch and north of the Sunset Hills, naturally-occurring arsenic concentrations as high as 83 micrograms per liter (µg/L) occurs in Deep zone groundwater. The elevated arsenic in this portion of the Study Area is likely related to bedrock discharge to the alluvial aquifer and is not related to agricultural activities that source COIs to the Shallow through Deep 2 zones of the alluvial groundwater, as discussed further below.

Groundwater quality in the NSA is influenced by agricultural activities but not by mining activities (BC 2016b). Multiple lines of evidence (including groundwater flow patterns, chemical distributions, groundwater age estimates, hydrologic tracers, and sulfur isotopes) confirm that groundwater in the NSA has been affected by agricultural practices and not by mining activities, resulting in concentrations of sulfate and uranium that are elevated above background values and/or Maximum Contaminant Levels (MCLs) or exhibit increasing trends.

Monitor well data from the NSA indicate that concentrations of nitrate, sulfate, calcium, uranium, and alkalinity in alluvial groundwater in the Shallow through Deep 2 zones increase along the flow path beneath the agricultural fields. Increases in nitrate are associated with fertilizer application on crop fields. Increases in sulfate and calcium concentrations are associated with application of gypsum ($CaSO_4$) as a soil amendment on crop fields, which dissolves in irrigation water that percolates down to the water table. Increases in uranium concentrations are associated with crop irrigation. Percolation of irrigation water through soils increases alkalinity in the soil moisture, which mobilizes and desorbs naturally-occurring uranium from sediments (as soluble complexes with sulfate, carbonate plus or minus calcium) resulting in elevated uranium concentrations in groundwater (Jurgens et al. 2010; Brown et al. 2007).

Alluvial sediments in the Mason Valley contain naturally-occurring uranium (BC 2009b). The impact of agricultural activities on uranium mobility in NSA groundwater within or near irrigated land is illustrated by the strong correlation between uranium, alkalinity and calcium. Increases in alkalinity and calcium are associated with increases in uranium concentrations that can exceed 100 µg/L. Evaporation of irrigation water derived from surface water and groundwater sources also serves to increase chemical concentrations in water that infiltrates and percolates to the water table.

The extent of mine-impacted groundwater has been defined using sulfate, dissolved uranium, and sulfur isotopes in sulfate because these parameters undergo very limited (if any) geochemical attenuation during groundwater transport and, thus, have traveled the farthest downgradient distance in the alluvial aquifer (BC 2016b). As noted by EPA (2016c), the background assessment conservatively over-estimated the area of mine-impacted groundwater and may not fully account for the range of chemical concentrations that occur naturally in groundwater within the Study Area. Portions of the aquifer where sulfate and uranium exceed background concentrations include: 1) all groundwater zones beneath portions of the Site; 2) Shallow zone groundwater extending north/northwest to the Sunset Hills located approximately three miles north of the Site boundary; and 3) deeper groundwater beneath the Site and extending northeast beneath portions of the Hunewill Ranch. The estimated volume of mine-impacted groundwater (i.e., the portion of the downgradient aquifer where sulfate and uranium exceed background concentrations) is 385,327 acre-feet, and contains an estimated 500,000 tons of sulfate and 100 tons of dissolved uranium.

Bedrock characterization information indicates: 1) a high degree of fracture heterogeneity and vertical hydraulic connection between the bedrock and alluvial groundwater systems; and 2) limited horizontal hydraulic connectivity and transmissivity of bedrock fractures, especially over horizontal distances that are relevant to the scale of the Site and the surrounding Study Area. In addition to a high degree of three-dimensional (i.e., anisotropic) variability in hydraulic characteristics and hydrologic tracer signatures, the bedrock groundwater system also exhibits high, three-dimensional spatial variability in chemical concentrations.

Concentrations of mine-related chemicals in the alluvial aquifer are most elevated in the Shallow zone beneath OU-4a, as noted previously. COI concentrations generally decrease with vertical depth and horizontal distance from the Site sources, resulting in values in bedrock groundwater that are 10 to over 1,000 times lower than the values in overlying alluvial groundwater. In addition, areas of elevated mine-related COIs in bedrock groundwater are small in comparison to the alluvial aquifer, highly localized, and found mostly on-Site.

The localized areas of elevated mine-related COIs in bedrock groundwater indicate that bedrock fractures have limited hydraulic connectivity and transmissivity over horizontal distances relevant to the scale of the Study Area. Despite localized areas of relatively high hydraulic conductivity, bedrock groundwater flow velocities, average volumetric flow rates and chemical fluxes through the bedrock groundwater system are low, and the bedrock groundwater system is not considered to be an important migration pathway at the Site (EPA 2015a). It is however an important source for elevated concentrations of arsenic, originating from bedrock and transported with mountain front recharge over much longer timescales.

Water quality monitoring of domestic, commercial, and irrigation wells (collectively referred to as domestic wells) located near the Site began in late 1983 and evolved over time. Results of domestic well monitoring have been used to: 1) characterize the quality of groundwater used for drinking water or other domestic uses; 2) assess potential risk, if any, to human health and the environment from the use of domestic well water for drinking water or agricultural purposes; and 3) determine eligibility for receiving bottled water as part of an interim response action.

The number of wells/properties included in the domestic well monitoring program (BC 2010) and receiving bottled water was substantially reduced in 2016 (ARC 2016a; EPA 2016f). As part of a settlement entered in the class action lawsuit *Roeder et al. v. Atlantic Richfield Company et al.*, D. Nev., Case No. 3-11-cv-00105-RCJ-WGC ("Roeder Settlement Agreement") ARC provided funding to the City of Yerington to extend municipal water service to then-existing residences located within that part of the settlement class area that was also within the City's projected future service area.

Domestic well owners who connected to the City of Yerington's municipal water system could elect to either abandon their well or apply for a state permit to authorize withdrawals of groundwater for outdoor use only (landscape watering). Each property owner who received a connection to the City Water System executed and recorded an environmental covenant either prohibiting future domestic use of groundwater altogether or limiting it to outdoor purposes. Construction of the expanded water system began in the fall of 2014, and the construction of new mains and service connections was completed in June 2016.

The first phase of well abandonments and system testing was completed as of August 1, 2016. The water system is functional, and domestic wells for all participating property owners have been abandoned or disconnected from the residences within the expansion area. A relatively small number of domestic wells located within the area of mine-impacted groundwater were not disconnected or converted to outdoor use in 2016. ARC has been in communication with the owners of most of these wells, and disconnections for all but a few are scheduled to occur in 2017.

There are no irrigation wells or municipal drinking water wells located within the plume of mine-impacted groundwater that was delineated during the background assessment.

The plume of mine-impacted groundwater is generally stable based on evaluations of changes in the estimated volume of contaminated groundwater, sulfate and uranium masses, and chemical centers-of-mass through time. A more comprehensive plume stability evaluation (including a statistical evaluation of chemical concentration trends in individual monitor wells) will be provided in a separate report. Plume stability is the result of very slow groundwater velocities and attenuation by dilution. The dilution occurs primarily as the result of recharge on the agricultural fields (specifically on the fields of the Hunewill Ranch) and leakage from irrigation ditches (specifically the West Campbell Ditch), and dispersion within the groundwater plume. Consequently, the plume is not currently adversely affecting and is not expected to affect the use of groundwater by agricultural irrigation and municipal drinking water wells. In addition, the plume of mine-impacted groundwater does not discharge to surface water.

SECTION 1.0
INTRODUCTION

Atlantic Richfield Company (ARC) prepared this *Site-Wide Groundwater Operable Unit (OU-1) Remedial Investigation Report* (OU-1 RI Report) pursuant to Section 7.0 of the Scope of Work (SOW) attached to the Administrative Order for Remedial Investigation and Feasibility Study (RI/FS), CERCLA Docket No. 9-2007-0005 (2007 Order) for the Anaconda Copper Mine Site (Site). The 2007 Order (EPA 2007a) was issued to ARC by the U.S. Environmental Protection Agency - Region 9 (EPA) on January 12, 2007. Future work on the OU-1 RI/FS will proceed under oversight by the Nevada Division of Environmental Protection (NDEP) pursuant to the "Interim Administrative Settlement Agreement and Order on Consent for: (i) Remedial Design/ Remedial Action, (ii) Site-Wide Remedial Investigation/Feasibility Study, and (iii) Fluid Management" entered into with NDEP (the IAOC) and the attached Statement of Work for RI/FS.

The term "Site" refers to the area where copper mining activities historically occurred. The Site is located west and northwest of the City of Yerington (Figure 1-1). Figure 1-2 depicts the Study Area boundary for OU-1 and the boundaries for the seven other OUs at the Site that were identified in the 2007 Order. The eight OUs identified in the 2007 Order include:

- Site-Wide Groundwater (OU-1);
- Pit Lake (OU-2);
- Process Areas (OU-3);
- Evaporation Ponds and Sulfide Tailings (OU-4);
- Waste Rock Areas (OU-5);
- Oxide Tailings Areas (OU-6);
- Wabuska Drain (OU-7); and
- Arimetco Facilities (OU-8).

Since the 2007 Order (EPA 2007a), substantial Site characterization activities have resulted in a better understanding of the nature and extent of chemicals of interest (COIs) within the various Site OUs, and the past and/or ongoing impacts to OU-1. Consequently, the EPA approved a subdivision of OU-4 into OU-4a (Evaporation Ponds) and OU-4b (Sulfide Tailings), as well as the transfer of the southern portion of the Calcine Ditch from OU-3 to OU-4a.

The EPA-approved OU-4 subdivision and transfer of a portion of the Calcine Ditch to OU-4a was based on a recognition of: 1) the different types of mine-waste materials in the Evaporation Ponds and Sulfide Tailings; 2) the similarity of mine-waste materials in the Calcine Ditch and portions of the Evaporation Ponds; and 3) the differences in the presence and magnitude of COIs in groundwater underlying the Evaporation Ponds and Sulfide Tailings. This OU-1 RI Report retains the OU-based framework in the 2007 Order (updated to include the EPA-approved restructuring). However, ARC, EPA and NDEP recognize that significant closure efficiencies will likely result from integrating EPA-designated OUs into geographic-based closure management units.

The term "Study Area" refers to on-Site and off-Site areas in which OU-1 RI-related investigations have been conducted. The Study Area boundary is based on the OU-1 hydrogeologic conceptual site model (HCSM) that was described in the EPA-approved *Site-Wide Groundwater Operable Unit (OU-1) Remedial Investigation Work Plan - Revision 1* (Revised Groundwater RI Work Plan; Brown and Caldwell [BC] 2014a).

1.1 Purpose of Report

Consistent with the SOW attached to the 2007 Order (EPA 2007a) and EPA (1988) guidance, this OU-1 RI Report: 1) summarizes activities conducted to "characterize and monitor groundwater in the vicinity of the Site (study area to be determined), including on- and off-Site locations"; 2) describes the nature and extent of mine-related COIs in groundwater; and 3) integrates relevant aspects of other OUs that represent potential sources of chemical loading to groundwater or have the potential to influence groundwater flow conditions. Additionally, this OU-1 RI Report addresses the fifteen study elements specified in Section 7.0 of the SOW (EPA 2007a), which served as the principal bases for RI planning, data collection, and analysis.

Given the complexity of Site-Wide groundwater conditions, several phases of investigations have been approved by EPA and conducted by ARC since 2005. During this time period, ARC, EPA, and other stakeholders including the Yerington Piaute Tribe (YPT), NDEP, and Bureau of Land Management (BLM) have periodically held groundwater technical meetings to discuss field data collection activities, technical findings, and remaining data gaps relative to: 1) the 15 study elements specified in Section 7.0 of the SOW attached to the 2007 Order; and 2) the Data Quality Objectives (DQOs) established in the draft and final versions of the remedial investigation work plans for OU-1 (BC and Integral Consulting, Inc. 2007 and BC 2014a, respectively). Table 1-1 relates the 15 study elements specified in the 2007 SOW to the DQOs presented in the Revised Groundwater RI Work Plan (BC 2014a).

Table 1-1. Comparison of Study Elements Specified in the SOW to the 2007 Order to DQOs Presented in the Revised Groundwater RI Work Plan

DQO	DQO Title	SOW Study Element														
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	Discriminate Background and Mine-Impacted Groundwater		X									X			X	
2	Identify Potential Chemical Loading Sources to Groundwater		X									X		X		X
3	Determine Geochemical Mobilization/Attenuation Processes											X				
4	Characterize Chemical Distribution and Migration Pathways	X						X	X	X	X	X			X	X
5	Determine Aquifer Properties								X				X			
6	Determine Groundwater Flow and Chemical Transport Rates	X	X		X	X	X	X		X	X	X				
7	Assess Anthropogenic Influences on Groundwater and Surface Water/Groundwater Interactions	X	X	X			X									
8	Determine Pumpback Well System Efficiency	X														
9	Assess Human Health and Ecological Effects							X	X	X	X	X		X	X	

Numerous investigations and monitoring activities conducted by ARC and others provide substantial geologic, hydrogeologic, and water quality information relevant to OU-1. However, this OU-1 RI Report relies primarily on data obtained after 2005 to address the study elements specified in Section 7.0 of the SOW, characterize groundwater conditions, and refine the HCSM to support the OU-1 RI/FS. Data obtained after 2005 have been selected for these purposes because: 1) data collection was performed pursuant to EPA-approved quality assurance/quality control (QA/QC) planning documents and OU-1 specific work plans that were developed with input from other stakeholders including the YPT, NDEP, and BLM; 2) the spatial coverage and amount of data increased substantially after 2005; and 3) post-2005 sampling results better represent current conditions and potential risks at the Site, which is the proper focus of the RI and risk assessment.

The August 2014 dataset is emphasized in this OU-1 RI Report for the reasons previously cited and because a variety of data types were concurrently collected (e.g., groundwater level data, groundwater quality data, and hydrologic tracer data) and/or evaluated (e.g., geochemical speciation modeling to help asses COI transport). Consequently, the August 2014 dataset is particularly informative for characterizing spatial aspects of OU-1 groundwater conditions. Temporal aspects of OU-1 groundwater conditions are based on post-2005 data, which indicate that the August 2014 dataset is generally representative of post-2005 groundwater conditions.

Long-term monitoring of Site-wide groundwater conditions is conducted pursuant to the *Site-Wide Groundwater Monitoring Plan - Revision 2* (GMP; BC 2012a), which was prepared by ARC pursuant to Section 6.0 of the 2007 SOW. The development of the monitoring program and a description of the monitor well network are also provided in this OU-1 RI Report.

Potential human health risks will be addressed more comprehensively in a separate OU-1 Human Health Risk Assessment (HHRA) report. This OU-1 RI Report provides the basis for ARC to identify remedial action objectives (RAOs) and screen/evaluate remedial alternatives for OU-1, which will occur during the feasibility study (FS).

1.2 Site and Study Area Description

The Site and Study Area are located in the Mason Valley in Lyon County, Nevada. The Site boundary includes portions of Township 13 North, Range 25 East, Sections 4, 5, 8, 9, 16, 17, 20, and 21 (Mount Diablo Baseline and Meridian) on the Mason Valley and Yerington United States Geological Survey (USGS) 7.5 minute quadrangles. The Site covers approximately 3,017 acres (4.7 square miles) of land altered by copper mining and processing activities. Including the Site, the Study Area covers approximately 19,300 acres (30.2 square miles).

The Mason Valley Basin (Basin no. 108, as defined by the Nevada Division of Water Resources [NDWR]) is located within the larger Walker River Hydrographic Basin (no.9). Mason Valley covers about 510 square miles, and the valley floor occurs at an elevation between 4,300 and 4,700 feet above mean sea level (amsl). The principal agricultural activities in the valley include farming (hay, grain, and onions) and cattle ranching (Lopes and Allander 2009a, 2009b; Carroll et al. 2010). Irrigation water is provided by surface water diversions from the Walker River and from pumped groundwater. The Walker River flows northerly and northeasterly between the Site and the City of Yerington. The river is within a quarter-mile of the southern portion of the Site (Figure 1-1).

1.3 Groundwater Zone Designations

Groundwater zone designations based on elevation have been used in previous groundwater-related reports, as well as this OU-1 RI Report, to identify and group monitor wells with similar screen interval elevations in the alluvial aquifer, as follows:

- Shallow (S): screen intervals that straddle the water table, or are within 50 feet of the water table when a shallower well does not exist, typically >4,300 feet amsl
- Intermediate (I): 4,250 to 4,300 feet amsl
- Deep (D): <4,250 feet amsl; given the thickness of alluvium, the Deep zone is further subdivided as follows:
    - Deep 1 (D1): 4,200 to 4,250 feet amsl
    - Deep 2 (D2): 4,120 to 4,200 feet amsl
    - Deep 3 (D3): 4,000 to 4,120 feet amsl
    - Deep 4 (D4): 3,900 to 4,000 feet amsl
    - Deep 5 (D5): <3,900 feet amsl

Monitor wells with screen intervals in bedrock, regardless of elevation, are designated as bedrock ("B") wells. The groundwater zone designation is included as a suffix to the monitor well identification number (e.g., the "S" suffix in monitor well identification B/W-1S indicates that the screen for this well is positioned in the Shallow zone).

1.4 Report Organization

Consistent with EPA guidance (EPA 1988) and recommendations provided during groundwater technical meetings in 2015 and 2016, the content and organization of this OU-1 RI Report is presented in this section.

Section 2.0 summarizes the Site operation history. Section 3.0 details the investigations related to OU-1 and relevant Site-wide studies and evaluations. Section 4.0 describes the physical characteristics of the Study Area. Section 5.0 describes the background groundwater quality assessment. This assessment served as the basis for determining the extent of mine-impacted groundwater, identifying agriculturally-affected groundwater, and assessing the occurrence of naturally-occurring COIs in groundwater. Section 5.0 also discusses the primary sources of past and/or ongoing releases of mine-related COIs to groundwater. Section 6.0 describes the fate and transport of contaminants in Study Area groundwater. Section 7.0 summarizes the HCSM for OU-1. Section 8.0 discusses the risk evaluation process and status. Section 9.0 lists the references cited in this OU-1 RI Report.

Appendix A provides historical mining-related information including the *Final Historical Summary Report* (HSR; CH2M Hill 2010) and historic Anaconda water supply and use information. Appendix B provides the *Shallow Zone Data Summary Report - Revision 1* (BC 2010a), which refined the distributions of select COIs in Shallow zone groundwater north of the Site and helped guide subsequent monitor well installation efforts. Appendix C presents information on the groundwater monitor wells including lithologic logs, well construction information, and depth-specific (zonal) groundwater quality data obtained during borehole drilling and well installation.

Appendix D presents water level and groundwater quality information. Appendix E provides soil sampling data. Appendix F presents hydraulic conductivity information and analyses. Appendix G presents regional and local surface water data. Appendix H presents hydrologic tracer data and supplemental information. Appendix I presents the *Bedrock Groundwater Assessment Technical Memorandum* (BC 2015a). Appendix J provides various groundwater studies, evaluations, and reports that were conducted to fulfill certain study elements specified in Section 7.0 of the SOW attached to the 2007 Order (EPA 2007a) and have been previously submitted to the EPA. These include an evaluation of the effectiveness of the Pumpback Well System (PWS), a Pit Lake water balance, public information pertaining to agricultural water use, the groundwater flow model report, the *Geochemical Characterization Data Summary Report - Revision 2* (BC 2016a), Site-specific chemical distribution coefficients, and the *Background Groundwater Quality Assessment - Revision 3* (BC 2016b). Appendix K presents maps illustrating the distributions of select COIs (including pH, sulfate, dissolved uranium, alkalinity, nitrate, and dissolved arsenic) in groundwater. Appendix L presents maps illustrating groundwater temperatures.

SECTION 2.0
SITE HISTORY

The following summary of the operational history of the Site paraphrases and/or is derived from the HSR (CH2M Hill 2010), which is provided in Appendix A-1. Topics covered in detail in the HSR include: 1) Site chronology; 2) processing operations utilized by the various owners and operators; 3) historic mine Site water usage and quality information; 4) uses and releases of chemicals; and 5) current Site status since 2000 focusing on removal actions conducted by EPA.

The following discussion focuses on key historic mining practices, releases, and features relevant to the historic and/or current aspects of the HCSM for OU-1. This summary is not intended to comprehensively cover all the information provided in the HSR. Historic mining-related features are shown on Figure 1-2. Historic ore processing facilities located within the Process Areas (OU-3) are shown on Figure 2-1.

2.1 Mining and Processing Operations

Copper in the Yerington district was initially discovered in the late 1860s, with large-scale exploration of the porphyry copper system occurring in the early 1900s when the area was organized into a mining district by Nevada-Empire Copper Mining and Smelting Company. Mining and ore processing operations at the Site were conducted by various owners from 1953 to November 1999.

2.1.1 Anaconda Operations

The Anaconda Company (Anaconda) became involved in the Site when it entered into a lease agreement and acquired the claims in 1941. Anaconda purchased the property in 1951 and the mine began producing copper in 1953, producing approximately 1.7 billion pounds of copper during its operations. Anaconda divested itself of the Site on June 30, 1978. Anaconda mining operations generated approximately 360 million tons of ore, 15 million tons of overburden and waste rock (400 acres), 3,000 acres of tailings, and 1,377 acres of disposal ponds.

Mined materials included oxide ore, sulfide ore, low-grade dump-leach ore, low-grade sulfide ore, and alluvium and waste rock overburden. Several processes were required to extract copper from the ore, as discussed further below. Briefly, all oxide and sulfide ore were crushed prior to leaching or processing in the various plant facilities. Copper was extracted from oxide ore using a sulfuric acid leach solution. The vast majority of leaching was conducted in vat leach tanks. A leach dump was operated over a much shorter period (discussed below). Pregnant copper solutions from the tanks and dump were stored in large solution tanks. Copper extracted from the oxide ore was recovered from the acidic leach solutions in the precipitation plant by precipitating (i.e., cementing) the copper onto iron scraps. A concentration/flotation process was used to extract copper from the sulfide minerals.

Dump Oxide Ore Processing

Crushed oxide ore was bedded into vat leach tanks capable of holding 12,000 dry tons of ore and 800,000 gallons of sulfuric acid leach solution. Spent ore, known as oxide tailings or vat leach tailings (VLT), was excavated from the vat leach tanks and disposed in the Oxide Tailings. The vats typically operated on a 96-hour or 120-hour leaching cycle, with an additional 32- to 40-hour wash period, and 24 hours required to excavate and refill. The entire cycle required approximately 8 days. Thus, eight leach vats were installed and used to process ore.

Following the leaching process, the ore underwent three wash cycles. Acidic leach solutions were recirculated and pumped at a rate of 2,000 gallons per minute (gpm). Copper-enriched wash solutions were put into three of the four open solution storage tanks located between the vat leach tanks and precipitation plant. The three solution tanks used for storing pregnant copper solutions had a total storage capacity of 1.4 million gallons. The additional storage tank, referred to as the wash water sump, stored up to 845,000 gallons of wash water from the leaching circuit, which included slurry from the scrubber in the sulfuric acid plant. Copper was recovered from the leach solution in the precipitation plant, which consisted of the iron launders, solution sumps, an adjacent launder pump station, scrap iron storage, and trommel screens.

The iron launders consisted of 20 parallel launders that were filled with scrap iron used to precipitate (i.e., cement) copper from the sulfuric acid leach solution pumped out of the leach vats and temporarily stored in the solution tanks. The waste product from the precipitation plant was an iron-sulfate solution that was conveyed in unlined ditches (such as the Calcine Ditch) to lined and unlined evaporation ponds in the northern portion of the Site (as further discussed in Section 2.2). Pregnant copper solution from dump leaching activities (discussed below) was also sent to the precipitation plant, but was kept separate from the vat leach solutions. Historical information on flows and chemical concentrations of solutions in various stages of the cementation circuit are provided in Table 2-1. Following cementation, the copper cement product was washed and dried to reduce moisture content prior to shipment off-Site for final smelting (Skillings 1972).

Table 2-1. Average Assay Values of Solutions at Various Stages in the Cementation Circuit

	Flow (gpm)	Cu (g/L)	H_2SO_4 (g/L)	Fe (g/L)	Fe^{3+} (g/L)
Primary and Scavenger Launders					
New Solution	700	20.0	5.8	7.2	5.4
Recirculated Solution	900	3.5	2.4	23.6	0.5 [a]
Total Feed (new solution plus recirculated solution)	1,600	10.7	3.8	16.4	2.6
Discharge	1,600	3.8	2.5	23.2	Trace
Secondary Launders					
Recirculated Solution (feed)	900	3.5	2.4	23.6	0.5
Discharge	900	1.0	2.1	26.4	[b]
Stripping/Settling Launders					
Feed	700	1.0	2.1	26.4	- -
Discharge	700	0.5	2.0	28.1	- -

Notes:
[a] The recirculated solution in the primary launders is the same strength as the recirculated solution in the secondary launders.
[b] The discharge solution in the secondary launders is the same strength as the feed solution to the stripping bank (U.S. Bureau of Mines 1958).
Cu = copper; H_2SO_4 = sulfuric acid; Fe = iron; Fe^{3+} = ferric iron; gpm = gallons per minute, g/L = grams per liter

Dump Leaching

In February 1965, Anaconda began dump leaching low-grade oxide ore in the W-3 Waste Rock Area. Copper-enriched solutions were stored in the Dump Leach Surge Pond (Figure 2-1) prior to conveyance to the iron launders for copper recovery. Copper extraction by heap leaching was in in its infancy at the time and recovery from the W-3 Waste Rock Area was inefficient because there were large quantities of ore that never came into contact with the acid-bearing leach solutions. Due to poor copper recovery, Anaconda ceased dump leaching in 1968.

Sulfide Ore Processing

To process sulfide ore, a froth flotation system was constructed and began operating on September 25, 1961. Flotation separation was accomplished by mixing very finely ground ore (pulp) with water and a chemical "collector" (typically xanthates and aerofloats) to make sulfide minerals hydrophobic, and then sparging air and a surfactant chemical "frother" (typically pine oil) through the mixture to create froth. The collector attaches to the sulfide mineral making it hydrophobic and susceptible to attachment to the stabilized air bubbles in the froth mixture, which was skimmed off as copper concentrate. The concentrate was further beneficiated in a scavenger flotation circuit, dewatered and dried, and subsequently hauled by truck to the Wabuska railroad spur and transported to the Washoe Smelter in Anaconda, Montana (Skillings 1972). Excess pulp after the flotation separation was disposed in the Sulfide Tailings area as a slurry mixture. Operation of the concentrator required approximately 3,000 gpm of water.

Acid Plant

Sulfuric acid was produced at the Site in the fluosolids and acid plant from 1952 to 1978. Raw sulfur ore (predominantly native sulfur and sulfide minerals) was hauled by truck to the Site from the Leviathan Mine located in Alpine County, California until 1962. The fluosolids system roasted the sulfur ore to generate sulfur dioxide (SO_2) gas, which was converted to sulfuric acid (H_2SO_4) in the contact acid plant. In 1962, Anaconda ceased mining sulfur ore from the Leviathan Mine. Between 1962 and 1978, previously stockpiled sulfur ore was blended with liquid sulfur, which was purchased from several suppliers and hauled to the Site where it was used as feed to the Acid Plant to generate sulfuric acid.

The final product was a 93 percent (%) sulfuric acid solution that was used in the vat leach tanks and dump leach of oxide ores. Byproducts such as selenium, were generated during production of sulfuric acid (CH2M Hill 2010). Operation of the sulfuric acid plant was discontinued in 1978 and the plant was dismantled by Arimetco, Inc. (Arimetco) in 1992. For its leaching operations, Arimetco purchased liquid sulfuric acid from off-Site vendors and stored it in tanks at the Site. The Acid Plant and surrounding area has subsequently been buried under the Arimetco Phase III South Heap Leach Pad (HLP).

2.1.2 Post-Anaconda Operations

Subsequent operators and lessees used some of the buildings within the Process Areas for operational support, storage, and various light industrial activities; however, the Anaconda-constructed processing components remained inactive after 1978.

In 1982, Copper Tek Corp. operated the mine under the ownership of Don Tibbals, and leased the Site for reprocessing tailings and low-grade copper ore using heap leaching and solvent extraction/electrowinning (SX/EW) processes in the area to the south of the Process Areas. In 1988, Don Tibbals sold his interests (except for the Weed Heights community and certain other parcels) to Arimetco. Prior to the sale, Arimetco (operating under the name Arizona Metals Company) had leased a large portion of the mine Site from Don Tibbals. By 1989, Arimetco had also acquired 90% of Copper Tek.

2.1.3 Arimetco Operations

From 1989 to November 1999, Arimetco conducted the following SX/EW operations on the Site:

- Phase I/II HLP: operated from 1990 to 1996, plus five months in 1997;
- Phase III South HLP: operated from August 1992 to early 1997, plus a few months in 1998;
- Phase III 4X HLP: operated from August 1995 to 1999;
- Phase IV Slot HLP: operated from March 1996 to November 1998; and
- Phase IV VLT HLP: operated from August 1998 to November 1998.

The HLPs (Figure 1-2) were constructed over high-density polyethylene (HDPE) liners with leak detection systems. The HLPs were leached with a sulfuric acid solution and the acidic, copper-laden draindown fluids were collected in HDPE-lined perimeter ditches, routed to HDPE-lined collection ponds, and conveyed to the SX/EW Plant. The copper-laden acid solution was then stripped of copper in a solvent extraction circuit using a mixture of kerosene and an organic hydroxyamine-based chelating agent (tradename ACORGA) in three process vats (total of approximately 200,000 gallons).

In the SX circuit, the copper in the dump leach liquor was concentrated by the organic in exchange for hydrogen ions producing a strong acid that became the electrolyte for the EW circuit. In the EW circuit, the copper was electroplated to stainless-steel sheets to produce 99.999% fine copper and in the process, additional sulfuric acid was generated. It was this strong acid in the EW circuit that was used to exchange copper from the loaded organic chelating agent.

Arimetco recirculated the acid solution from the EW vats back into the HLPs, which currently continue to drain fluids to the present. The electrolyte circulated between the EW plant and the tail end of the SX plant (called raffinate). The kerosene and organic reagent were also recirculated within the SX/EW circuit, being loaded and stripped repeatedly.

In January 2000, Arimetco, on the verge of bankruptcy and unable to make payroll, abandoned operations at the Site. From 2000 to 2004, NDEP managed HLP drain-down fluids by re-circulation and evaporation. In 2005, ARC was required by EPA to assume responsibility for fluid management operations at the Site. Since 2006, EPA has conducted various RI/FS and closure-related activities associated with the Arimetco Facilities (OU-8).

Inactive Arimetco HLPs that continue to produce drain-down fluids include the Phase I/II HLP, two Phase III HLPs, the Phase IV Slot HLP, and the Phase IV VLT HLP (BC 2014b). HLP drain-down fluids are currently stored and conveyed in a network of ponds, ditches, and 25,000 feet of pipe, collectively referred to as the fluid management system (FMS). The HLPs and associated FMS components are briefly described below. Additional FMS details are provided in annual operation and maintenance (O&M) reports for the FMS (e.g., BC 2014b).

Phase I/II Heap Leach Pads

The Phase I/II HLP covers an area of approximately 14 acres (Phase II was extended to the west and north of Phase I). A solution ditch with eleven leak detection points was constructed around the HLP. A variable two- to ten-foot-thick layer of VLT was placed on a single 40-mil (0.04-inch-thick) HDPE liner. The solution ditch that surrounds the Phase I/II HLPs drained to the Phase I Pond.

Phase III Heap Leach Pads

The 46-acre Phase III South HLP and the 50-acre Phase III 4X HLP were constructed by Arimetco to leach low-grade oxide ores. A single 40-mil HDPE liner was installed by Arimetco to recover drain-down solution, and the drainage ditch was designed with a leak detection system over a second, 40-mil HDPE liner. The solution ditches surrounding the Phase III South HLP and the Phase III 4X HLP drained to the Phase III Bathtub Pond and to the Mega Pond, respectively.

Phase IV Slot Heap Leach Pad

The approximate 86-acre Phase IV Slot HLP was constructed by Arimetco on a pad excavated into the W-3 waste rock dump and an asphalt-lined area, and was expanded northward between 1993 and 1996 on a 40-mil HDPE liner over a secondary liner of compacted clay. This HLP is surrounded by a berm and double HDPE-lined collection ditch with leak detection between the membranes and seven leak detection monitoring points. Drain-down solutions flow to one of two pregnant leach solution (PLS) ponds.

Until late 2003, drain-down solutions were pumped by NDEP from the PLS ponds to the surface of the HLP for evaporation. In 2006, EPA relined the northern Phase IV Slot PLS Pond, and solutions from this pond were routinely conveyed to the FMS Evaporation Pond (also known as the EPA 4-Acre Pond) constructed by EPA in 2007.

Phase IV VLT Heap Leach Pad

The 54-acre Phase IV VLT HLP was constructed by Arimetco on the southern portion of the former finger evaporation ponds, and on native alluvial soils, north of the Oxide Tailings OU, and consists of oxide tailings, and run-of-mine and crushed ore from the MacArthur Mine. The Phase IV VLT HLP was constructed on a 40-mil HDPE liner overlying a secondary liner of compacted clay. The solution drainage ditch includes a leak detection system over a 40-mil HDPE liner designed with five leak detection points, and drains to the northeast corner of the HLP to a single PLS pond (5.04 million-gallon capacity).

Drain-down solutions from the Phase IV VLT HLP flow by gravity to the VLT Pond and, as needed to improve evaporation efficiency of the FMS, are pumped to one of two new FMS Evaporation Ponds (B and C) described below. EPA completed a VLT pond liner replacement project in October 2012 (BC 2014b).

2.2 Evaporation Ponds

From the Process Areas, spent process solutions resulting from the beneficiation of copper oxide and sulfide ores were conveyed in unlined trenches to the lined and unlined evaporation ponds, and ponds in the northern portion of the Site. The evaporation ponds in the northern portion of the Site are identified on Figure 1-2 as the Unlined Evaporation Pond (UEP), the Lined Evaporation Pond (LEP), and the Finger Ponds. The Sulfide Tailings were also used to dispose spent oxide ore process solutions prior to the mining of sulfide ores. A brief description of these ponds follows:

- <u>UEP</u>: consists of a large northern section (98 acres) and a much smaller southern section (4.1 acres) constructed on alluvial soils without a liner surrounded by berms constructed of VLT. The volume of pond sediments contained in the UEP is approximately 270,230 cubic yards based on average thicknesses of approximately 1.5 and five feet in the northern and southern sections, respectively.
- <u>LEP</u>: consists of three sections (North, Middle and South), which were lined with a relatively thin (0.5 to one-inch-thick) liner consisting of a mixture of asphalt tar and crushed gravel. The asphalt liner was placed over one to 2.5 feet of VLT materials. The LEP has a total combined area of approximately 101 acres. The thickness of the pond sediments averages three to six inches, with a maximum measured thickness of approximately 12 inches within the central, topographically lower portion of the LEP. The volume of pond sediments contained in the LEP is approximately 65,800 cubic yards.
- <u>Finger Ponds</u>: consist of four narrow “Finger Ponds” and one larger “Thumb Pond”. The four Finger Ponds (17.8 acres) were lined similar to the LEP without the VLT sub-base. The estimated volume of sediments within the Finger Ponds is 5,838 cubic yards based on an average thickness of four inches. The unlined Thumb Pond has elevated embankments along its north and east margins. The exposed portion of the Thumb Pond (i.e., not covered by the Arimetco Phase IV VLT HLP) covers about 69 acres and was capped in 2010 with VLT materials. The volume of pond sediments contained within the Thumb Pond is 95,000 cubic yards based on an average thickness of 3.5 feet.

In 1955, the flow rate to the evaporation ponds averaged approximately 2,000,000 gallons per day or 1,385 gpm and water quality characteristics of the fluid showed a free acid concentration of 1.0 g/L, total soluble salts concentration of 171 g/L, and total iron concentration of 37.5 g/L (Nesbitt 1955; Dalton 1998).

Infiltration of process solutions at these locations due to increased hydraulic heads associated with impounded fluids, likely raised groundwater elevations and created mounding effects that influenced groundwater gradients, flow directions and velocities, and groundwater quality. Due to the net evaporative character of the Site, significantly less flux (if any) of residual process-related chemicals to groundwater occurs at the Site at present relative to historic periods when the mine facilities were operational. The term “evaporation ponds” used in the following sections refers to the LEP and UEP.

2.3 Historical Mine Site Groundwater Pumping, Distribution and Use

Details of Anaconda’s historical groundwater pumping, distribution, and water management at the Site are provided in Appendix A-2 and summarized below.

Mine Site Water

Gill (1951) conducted a groundwater investigation to support open pit mining, and reported that the groundwater table around the proposed open pit was approximately 4,350 to 4,380 feet amsl, with variable water levels a result of bedrock compartmentalization of groundwater. Gill (1951) also reported that most groundwater in the proposed open pit was recharged by the Walker River. Dewatering of the pit in advance of mining operations in the early 1950s resulted in a depressed water table.

Groundwater produced from the pit area wells and other supply wells was primarily used in the beneficiation of copper oxide and sulfide ores in the Process Areas. Pit dewatering ended in 1978. The resulting Pit Lake functions as a hydraulic sink that captures alluvial and bedrock groundwater, as discussed in Section 3.3.2.

Historical Groundwater Pumping and Water Management

The known locations of historic wells used for mining-related activities are shown on Figure 2-2. These wells include those that have been abandoned per the State of Nevada Administrative Codes (NAC) 534.420, 534.4365 or 534.4371 and others that have not been abandoned but are not currently in active use.

Groundwater pumped by Anaconda was used for four general purposes: 1) to depress the water level in the open pit to achieve safe working conditions for mining operations; 2) copper ore beneficiation activities in the Process Areas; 3) residential use at Weed Heights, commonly referred to as the "Townsite" in archived documents (Anaconda 1953, 1955, and 1957); and 4) ancillary operations at the Site (e.g., fire protection, dust control, drilling, blasting, and supply to shops).

Groundwater use was less during the period from 1952 through 1963 when only oxide ores were leached than in the period from 1963 through 1978 when the copper sulfide ore milling circuit was added to the existing copper oxide ore leaching operations, which resulted in an increased demand for groundwater. References in archived documents to the "Plant" generally refer to oxide leaching facilities prior to 1963, and combined copper oxide and copper sulfide ore beneficiation operations after 1963. Groundwater supplies were obtained from four geographic areas: open pit area wells; evaporation area wells; well WW-10 in the Process Areas; and off-Site area wells. Excess pumped water, from pit dewatering activities, was discharged to the Walker River.

Discharge of water to the Walker River peaked in 1953 at 2,373 acre-feet per year, which is equivalent to approximately 1,471 gpm, and generally declined through 1963. At this point, pumped water to the combined Townsite and Plant rose steadily until 1974 at which time it reached 11,388 acre-feet per year (7,058 gpm). There was a general decline in total water pumped during the last four years of Anaconda operations. The annual average pumping rate at the Site ranged from 1,658 gpm in 1978 (the final year of operations) to 7,119 gpm in 1974 (the peak year of water production).

Although the monthly water reports did not specify on-Site water use, some details of water distribution to operational areas are available for 1964 and the first half of 1978 (Table 2-2). In 1964, the Plant received 2,055 acre-feet (45% of total) and the sulfide milling circuit (Concentrator) received 1,511 acre-feet (33% of total).

Table 2-2. Water Distributed to Operational Areas During 1964 and 1978

Operational Area or Use	1964 (acre-feet)	1964 Percent of Total	Jan-Jun 1978 (acre-feet)	Jan-Jun 1978 % of Total
Townsite	455	9.9%	58	4.3%
Roads	51	1.1%	31	2.3%
Leach Vats	2,055	44.7%	271	20.2%
Precipitation Plant	---	---	15	1.1%
Sulfide Concentrator	1,511	32.9%	---	---
Acid Plant	481	10.5%	538	40.1%
Water Discharged to Walker River	46	1.0%	0	---
W-3 Waste Rock Dump	---	---	259	19.3%
Dust System	---	---	169	12.6%
Total	4,600	100%	1,340	100%

Open pit area wells were installed during the period 1952-1954 (WW-1 through WW-7) and in 1959 (WW-36) to dewater the pit, supply water to the Townsite, and supply water for copper oxide ore beneficiation. During July 1955, the combined flow from six of the open pit area wells was estimated to be 2,454 gpm, and the total demand was 2,553 gpm. The use of recycled process water during this period made up for the approximate 100 gpm difference. In 1966, combined demand at the Plant and Townsite was 2,600 gpm.

Evaporation area wells were installed during the period 1959-1961 (WW-8, WW-9 and WW-11) and in 1965 (WW-12C) to provide the required make-up water (i.e., approximately 1,000 gpm) for the Sulfide Concentrator, which began operation in 1963. Based on 1964 monthly water reports, evaporation area wells had a combined pumping rate that ranged from 442 to 1,390 gpm with an annual average rate of 690 gpm. Well WW-10 was installed in the Process Areas in 1960 to provide additional water for the copper oxide and copper sulfide ore beneficiation operations.

Per the well log on file with the NDWR, the well was drilled to a depth of 610 feet, and penetrated 200 feet of alluvial materials before reaching bedrock. At that time, the depth to groundwater was 100 feet below ground surface (bgs). The well casing was perforated from 105 to 505 feet bgs, resulting in about 95 feet of alluvial materials and 305 feet of bedrock that could yield groundwater. When tested for two hours at a rate of 595 gpm, WW-10 exhibited a drawdown of 81 feet (close to the alluvium-bedrock contact).

Historical pumping records for WW-10 are limited. Table 2-3 summarizes 1964 monthly water reports for well WW-10. The monthly pumping rate was calculated by dividing the monthly volume by the number of days in each month and the number of minutes in each day. The pumping rate ranged from 102 gpm in January 1964 to 254 gpm in October 1964, with an average annual rate of approximately 169 gpm for the 10 months with pumping data.

Table 2-3. 1964 Monthly Pumping Volumes and Rates for Mine-Water Supply Well WW-10

Month, 1964	Volume Pumped (cu ft)	Volume Pumped (gal)	Average Pumping Rate (gpm)
January	606,470	4,537,000	102
February	NA	NA	NA
March	NA	NA	NA
April	1,135,410	8,494,000	190
May	1,230,851	9,208,000	206
June	1,329,595	9,946,700	223
July	1,134,621	8,488,100	190
August	1,362,839	10,195,400	228
September	1,227,109	9,180,000	206
October	1,514,771	11,332,000	254
November	1,220,291	9,129,000	205
December	1,139,420	8,524,000	191
Annual Values	11,901,377	89,034,200	169

NA = not available; cu ft = cubic feet; gpm = gallons per minute; gal = gallons

Groundwater quality samples were obtained from WW-10 from August 1991 to June 2006. From August 1991 through 1994, at least three samples were collected during each year. From 1995 through June 2006, samples were collected quarterly. Not all parameters were monitored in each sampling event. Results for sulfate, uranium and arsenic are discussed below.

Concentrations of sulfate in the 49 samples collected from August 1991 to June 2006 ranged from 457 to 2,485 milligrams per liter (mg/L). Concentrations of uranium in the 10 samples collected from September 2003 to June 2006 ranged from 190 to 310 micrograms per liter (µg/L). From August 1991 to June 2006, 95% (i.e. 35 of the 37) reported arsenic results were less than or approximately equal to the laboratory analytical reporting limits. Laboratory reporting limits for arsenic were commonly higher (i.e., 25 µg/L) during the early part of the monitoring history and lower (as low as 4 µg/L) during the latter part of the monitoring history. In September and October 1991, arsenic concentrations were reportedly 1,040 and 3,475 µg/L, respectively. The arsenic results for these two sampling events are inconsistent with and three orders of magnitude greater than the results for the other 35 sampling events.

2.4 Pumpback Well System

The PWS and associated monitor wells were constructed under an Administrative Order on Consent issued by NDEP on October 1, 1985. ARC operated the PWS located along the northern margin of the Site to collect shallow groundwater beginning in March 1986 (Piedmont 2001). The initial PWS consisted of five extraction wells (PW-1 through PW-5; see Figure 3-3) and a clay-lined 23-acre evaporation pond for containment of extracted groundwater.

In 1998, six additional extraction wells (PW-6 through PW-11; see Figure 3-3) were installed and operated as part of the PWS. Other improvements to the PWS included partitioning the 23-acre evaporation pond into three cells and installing an HDPE liner on top of the clay liners in the middle and south cells to protect the clay liners from desiccation during the summer dry season. No HDPE liner was placed on the north cell.

The pumpback wells are approximately 40 to 60 feet deep and are spaced at intervals ranging from approximately 380 feet (PW-2 to PW-3) to 1,400 feet (PW-5 to PW-6). Prior to March 25, 2009, the PWS operated continuously (i.e., 24 hours per day, 7 days per week), with individual wells temporarily taken off-line for maintenance and repairs of pumps and related equipment. For example, in 2006, individual well production rates ranged from 0.5 to 16.7 gpm with a total combined pumping rate of 56.4 gpm. Approximately 29.7 million gallons (91.1 acre-feet) of groundwater were pumped from the Shallow zone in 2006 (Norwest Applied Hydrology 2007).

EPA approved the shutdown of the PWS on March 25, 2009 to allow for a characterization of groundwater conditions at the northern Site margin. Subsequently, the pumpback wells were used as part of an aquifer test to characterize hydraulic properties of the Shallow zone (ARC 2010). The test data were used to: 1) delineate the hydraulic capture zones of the PWS; and 2) assess the historical effectiveness of the PWS in limiting the off-Site migration of Shallow groundwater. The PWS evaluation is discussed in Section 3.3.1. Since completion of hydraulic testing, the PWS has been shut down and wells PW-1 to PW-11 have been monitored pursuant to the Groundwater Monitoring Plan (GMP) (BC 2012a).

2.5 Wabuska Drain

The Wabuska Drain is a 13.8-mile long unlined ditch that extends from the Site to the Walker River. The grade of the Wabuska Drain between the Site and the southern margin of the YPT Reservation is approximately 0.15% over 4.1 miles. The grade increases to about 0.16% along the 1.1-mile length within the YPT Reservation. From the northern margin of the YPT Reservation to its intersection with the Walker River, the average grade is approximately 0.04% (BC 2015b). Adjacent surrounding agricultural fields slope gently toward the Wabuska Drain, or connect to the drain through lateral ditches that feed into the drain by gravity flow. The drain was constructed in the late 1930s, when the regional groundwater table was higher, to intercept shallow groundwater to stabilize areas north of the Site adjacent to the tracks of the former Nevada Copper Belt Railroad and several farms. The Wabuska Drain alignment near the Site has changed over time (BC 2015b; CH2M Hill 2010), as shown on Figure 2-3. Portions of these former alignments are now buried beneath the Evaporation Ponds and the Hunewill Ranch agricultural fields.

Currently the drain functions as one of many irrigation return-flow ditches in the northern Mason Valley. These drains collect irrigation tail water and run-off from agricultural fields, and convey water to downgradient agricultural areas for further irrigation uses and/or discharge to the Walker River (CH2M Hill 2010).

Historically, the Wabuska Drain alignments near the Site intercepted shallow groundwater (CH2M Hill 2010). However, the various drain alignments near the Site no longer intercept shallow groundwater due to basin-wide groundwater level declines (Section 4.9). In the northern part of the Wabuska Drain, inputs also include intercepted shallow groundwater and deeper water associated with alluvial groundwater discharge and geothermal springs that coincide with a series of northwest trending faults referred to as the Wabuska lineament (Stewart 1988). Other potential past and/or current inputs include discharges from, or groundwater influenced by, the Thompson smelter and various geothermal power production activities.

Details regarding the Wabuska Drain are provided in the HSR (CH2M Hill 2010; Appendix A-1). Results of the ongoing RI for the Wabuska Drain will be reported separately. Available data indicate that concentrations of mine-related chemicals decrease with distance from the Site and depth in the soil profile (EPA 2007a, BC 2015b).

SECTION 3.0
GROUNDWATER INVESTIGATIONS AND RELATED STUDIES

Numerous investigations and monitoring activities conducted prior to 2005 have provided substantial geologic, hydrogeologic, and water quality information pertaining to OU-1. These pre-2005 activities were primarily associated with a limited number of monitor wells (having screens positioned across the water table) located around the northern Site margin. Sampling methods and the quality of laboratory analytical results prior to 2005 were not well documented.

Pre-2005 investigations and reports for the Site and surrounding area are summarized in Section 3.1. Post-2005 investigations and reports performed and/or prepared by ARC are summarized in Section 3.2. Pre-2005 data are used to address historical aspects of the HCSM because historical conditions (e.g., groundwater elevations and flow directions) were different from current conditions due to mine operations, agricultural activities, groundwater and surface water usage, and weather conditions (BC 2014a). Historical aspects of the HCSM are generally more qualitative relative to aspects of the HCSM developed using data collected after 2005 because the historical data are typically limited (especially with respect to spatial coverage) and data quality is often not well documented.

Since 2005, numerous investigations and monitoring activities have been conducted by ARC with EPA and stakeholder involvement, and the sampling methods and quality of the laboratory analytical results since 2005 have been well documented. A draft Quality Assurance Project Plan (QAPP) that included standard operating procedures (SOPs) for sampling and field data collection methods was prepared in 2003 to establish and implement strict QA/QC procedures and, subsequently, was periodically revised to result in the current *Quality Assurance Project Plan - Revision 5* (Environmental Standards, Inc. [ESI] and BC 2009). Other QA planning documents that were prepared pursuant to the 2007 Order included the: 1) *Data Management Plan for the Yerington Mine Site* (BC 2007a); 2) GMP (BC 2012a); and 3) EPA-approved work plans specific to OU-1.

3.1 Pre-2005 Investigations

Investigations and reports relevant to the OU-1 Study Area that were conducted prior to 2005 are provided below, generally listed in chronological order:

- Gill, D.K., 1951. Groundwater at the Yerington Mine, Lyon County, Nevada, a consultant report prepared for The Anaconda Company that describes the results of aquifer testing, and provides projections of groundwater inflows and dewatering rates for the open pit.
- Huxel, C.J., Jr. and E.E. Harris, 1969. Water Resources and Development in Mason Valley, Lyon and Mineral Counties, Nevada, 1948-1965, NDWR Bulletin No. 38 prepared in cooperation with the USGS. This is a comprehensive hydrologic study of the Mason Valley area including water budgets and effects of agriculture on surface water and groundwater quality and quantity.
- Seitz, H., A.S. Van Denburgh, and R.J. La Camera, 1982. Ground Water Quality Downgradient from Copper Ore Milling Wastes at Weed Heights, Lyon County, Nevada, USGS Open File Report 80-1217. This study presents hydrologic and geochemical data on the effects of mining on groundwater quality from several monitor wells, most of which are no longer operational.
- Applied Hydrology Associates (AHA), 1983. Evaluation of Water Quality and Solids Leaching Data, a consultant report prepared for Anaconda Minerals Company. This report includes surface water and solids leaching data in addition to groundwater sampling data that are compared to the data reported by Seitz et al. (1982).
- Anaconda Minerals Company, 1984. Water Quality Investigation and Mitigation Plan, Yerington Mine Site, Yerington, Nevada, a report prepared for NDEP that summarized additional field data and groundwater conditions north of the Site.
- Proffett, J.M., Jr., and J.H. Dilles, 1984. Geologic Map of the Yerington District, Nevada, Nevada Bureau of Mines and Geology, Map 77.
- Nork, W., 1989. MacArthur Project Hydrogeologic Investigation, Lyon County, Nevada, a consultant report prepared for MacArthur Mining and Processing Co. that describes the general hydrogeologic conditions associated with a proposed project to develop an open pit mine located to the northwest of the Site.
- Dalton, D., 1998. *Arimetco Yerington Mine and Process Facility Site Assessment of Groundwater Quality*, a consultant report prepared for Arimetco for submittal to NDEP in response to NDEP’s Finding of Alleged Violation and Order of February 1997.
- Lewis, B., 2000. *Geophysical Survey Results of the Yerington Mine, Mason Valley, Nevada*, a BLM report on electro-magnetic and resistivity surveys north of the Site.
- Superfund Technical Assessment and Response Team (START), 2000 and 2001. *Expanded Site Inspection: Yerington Mine* and *Anaconda, Yerington Mine Site Emergency Response Assessment Final Report,* reports prepared for the EPA that describe Site conditions including groundwater quality.

- Piedmont Engineering, Inc., 2001. *Yerington Shallow Aquifer Data Evaluation Report*, consultant prepared for ARC. Interpretations of data presented in this report related to the nature and extent of mine-impacted groundwater.
- AHA and Norwest Applied Hydrology, 2000 through 2007. *Annual Monitoring and Operation Summary: Pumpback Well System, Yerington Nevada*, annual consultant reports prepared for ARC. These reports provide groundwater elevation and water quality data for the pumpback system and associated monitor wells. The reports also include pumping rates and time-concentration plots for select chemicals.
- Brown and Caldwell, 2002. *Installation of Two Monitor Wells at the Yerington Mine Site, Lyon County, Nevada.* This letter report described the drilling and well construction activities of two monitor wells, which was an interim action required by NDEP, EPA, and BLM.

3.2 Post-2005 Investigations

A generalized chronology of the phased, groundwater-related field investigations conducted since 2005 is provided in Figure 3-1. The following subsections describe the post-2005 investigations and related evaluations by media. Groundwater characterization activities largely involved monitor well installation. Monitor wells installation procedures are described in Section 3.2.1. After installation, initial sampling and testing for OU-1 characterization purposes, these wells were subsequently incorporated into the Site-Wide Groundwater Monitoring Program, which is described in Section 3.2.3.

3.2.1 Monitor Well Installations

Recognizing that groundwater characterization activities would largely involve monitor well installation, ARC and EPA adopted the following sequential approach to field data collection to maximize usable data and optimize the design of a monitor well network intended to serve the data needs for both OU-1 RI characterization and long-term Site-Wide groundwater monitoring.

- Borehole drilling using a roto-sonic core drilling rig and lithologic logging of continuous cores to identify coarse-grained or potentially transmissive intervals where chemicals could potentially migrate.
- Depth-specific (zonal) groundwater sample collection in the alluvial aquifer at nominal 20-foot intervals from the top of the water table to the target depth of each borehole using low-flow, minimal drawdown purging and sampling procedures approved by EPA.

- Collection of field measurements from zonal samples including pH, specific conductivity, temperature, dissolved oxygen (DO), oxidation-reduction potential (ORP), sulfate, alkalinity, and total and ferrous iron, using routinely-calibrated field meters and accuracy-checked water quality field test kits.
- Laboratory analyses of zonal samples for total and dissolved uranium, total and dissolved arsenic, total organic carbon (TOC), and uranium isotopes (^{234}U, ^{235}U, and ^{238}U).
- Based on the zonal groundwater sample results, construction of new monitor wells in various groundwater zones using methods and materials specified in EPA-approved SOPs and work plans, with EPA approval of well screen lengths and positions.
- Surveying of well location coordinates and reference point elevations, followed by measurement of groundwater elevations in all new and existing monitor wells.
- Hydraulic (slug) testing of monitor wells and analysis of hydraulic test data.
- Deployment of pressure transducers and data loggers in select monitor wells with EPA approval to collect groundwater elevation data at four-hour intervals and assess temporal water level fluctuations.
- Collection of hydrologic tracers from monitor wells.
- Incorporation of the new monitor wells into the GMP (BC 2012a), discussed below in Section 3.2.3.

In total, the groundwater RI characterization activities described above resulted in drilling 133 boreholes, logging approximately 33,000 linear feet of core, collecting and analyzing 624 zonal groundwater samples, installing 299 new monitor wells, and hydraulic (slug) testing 296 wells. Appendix C provides monitor well information including: 1) borehole lithologic information and well construction diagrams; 2) well construction and location information for the active monitor wells; 3) construction information for abandoned and inactive wells not used for routine groundwater monitoring; and 4) zonal groundwater sample results.

The various investigations involving monitor well installations are integrated into the discussion of the Site-Wide groundwater monitoring program in the following section. Appendix D provides OU-1/Site-Wide groundwater monitoring information including water level and chemical data, water-level hydrographs, charts illustrating temporal changes in vertical gradients at monitor well clusters, and charts illustrating temporal changes in chemical concentrations at monitor wells.

3.2.2 Shallow Zone Groundwater Investigation

The 2009 Shallow zone investigation is detailed in the *Shallow Zone Data Summary Report - Revision 1* (BC 2010a; Appendix B) and summarized below. The Shallow zone investigation was designed to improve the understanding of hydrogeologic and geochemical conditions in the Shallow zone of the alluvial aquifer to the north of the Site by refining the distributions of sulfate, uranium, uranium isotopes, dissolved metals, TOC and alkalinity in Shallow zone groundwater. This information was used to evaluate potential sources of chemicals in groundwater in this portion of the Study Area and identify portions of the Intermediate or Deep zones in the alluvial aquifer that would warrant the installation of monitor wells.

Shallow zone characterization activities during 2009 included:

- Direct push technology (DPT) with Geoprobe® equipment was used to obtain continuous, high-resolution electrical conductivity (EC) measurements of subsurface materials at 93 locations. EC profiling was initially conducted at four locations (OU1-DPT-18, OU1-DPT-40, OU1-DPT-16, and OU1-DPT-24) where lithologic logging and zonal sampling had been previously conducted during borehole drilling and well installation at the B/W-2, B/W-3, B/W-18, and USGS-13S/W32DC-D well clusters, respectively, and one location (OU1-DPT-13) where geophysical logging had been conducted in 1983 (W5AB-2). This comparison was intended to help correlate EC data with clays and/or elevated solute concentrations in groundwater. In addition, EC data were also used to make decisions regarding the number and depths of sampling intervals at each individual DPT location.
- Field parameters were measured in groundwater samples collected from the sampled intervals within the Shallow zone including pH, specific conductivity, temperature, sulfate and total alkalinity (alkalinity) using routinely-calibrated field meters and accuracy-checked water quality field test kits.
- DPT equipment was used to collect groundwater samples at each location from as many as three intervals within the Shallow zone, and samples were submitted to the analytical laboratory for chemical analyses including total and dissolved uranium, TOC, 28 metals, uranium isotopes, and sulfur and oxygen isotopes in dissolved sulfate at EPA-selected locations.
- DPT locations were surveyed by a registered Nevada surveyor.
- Upon completion of EC profiling and/or groundwater sample collection, all boreholes were abandoned in compliance with Nevada regulatory requirements.

In 2010, DPT equipment and identical sample collection methods were used at 10 additional locations to obtain groundwater samples for laboratory analysis (BC 2013a). EC profiling was not conducted during the 2010 investigation. Both the 2009 and 2010 DPT locations are shown on Figure 3-2. Chemical distributions in the Shallow zone of the alluvial aquifer are shown on figures provided in Appendix B and are described as follows:

- The highest concentrations of major ions and metals (e.g., aluminum, copper, iron, manganese, nickel, vanadium and zinc) and uranium in the Shallow zone were typically detected beneath the central portion of the UEP, and the south-central and north-central portions of the LEP. Low pH values occur beneath the LEP and UEP. Alkalinity was depressed or non-detectable beneath the UEP. Elevated alkalinity (e.g., >500 mg/L) occurred down-gradient of the Weed Heights sewage lagoons.
- The high chemical concentrations beneath the evaporation ponds decrease laterally by varying orders of magnitude because of past and current physical and chemical attenuation processes. West of the LEP, concentrations of sulfate, other mobile chemicals, and metals decrease rapidly with distance from the Site. To the east beneath the agricultural fields, chemical concentrations are generally lower than other locations beneath or near the Site. Localized occurrences of elevated concentrations of select constituents in groundwater samples were observed from sample locations on the agricultural fields and included: alkalinity, manganese, molybdenum, nickel, potassium, selenium, sodium, uranium, vanadium, and zinc.

  The distribution of dissolved (i.e., filtered) uranium in the Shallow zone is generally consistent with the distribution of many other Site chemicals in that: 1) the highest concentrations occur beneath the central portion of the UEP, and the south-central and north-central portions of the LEP; 2) elevated concentrations extend beyond the Site boundary along a northwest alignment from the Evaporation Ponds; and 3) elevated chemical concentrations beneath the Evaporation Ponds decrease laterally by varying orders of magnitude. However, there are important differences that suggest that alkalinity and calcium influence the mobility/attenuation of uranium. Uranium concentrations rapidly decrease laterally to the west, similar to other chemicals, but do not decrease as rapidly to the east beneath the irrigated agricultural fields. Elevated concentrations of uranium in DPT locations including OU1-DPT-41, OU1-DPT-42, OU1-DPT-46, OU1-DPT-49, OU1-DPT-61, and OU1-DPT-72 are roughly coincident with: 1) the areas of locally high concentrations of alkalinity (over 300 mg/L) in Shallow zone groundwater at the northwest and northern edge of the agricultural fields; and 2) high calcium concentrations to the northwest of the agricultural fields and general widespread distribution of calcium throughout the agricultural fields.

- The distribution of arsenic in Shallow zone groundwater differs from the distributions of the parameters and chemicals described above. The highest concentrations of arsenic were detected in Shallow zone groundwater at OU1-DPT-23 (up to 620 ug/L), OU1-DPT-28 (up to 580 ug/L), and other nearby locations, which are located approximately 3,000 to 3,500 feet north of the Evaporation Ponds. Beneath the Evaporation Ponds, arsenic concentrations were much lower and typically ranged from approximately 10 to 160 ug/L. In this area, the lowest arsenic concentrations in Shallow zone groundwater occur along a northwest trend from the Weed Heights sewage lagoons. To the west of the LEP, arsenic occurs in Shallow groundwater at concentrations at or slightly above 50 ug/L.

3.2.3 Site-Wide Groundwater Monitoring Program

Groundwater monitoring in the Study Area has evolved over time in response to regulatory requirements and incorporation of new wells installed during the OU-1 RI. Currently, long-term Site-Wide groundwater monitoring is conducted in accordance with the GMP (BC 2012a) and EPA-approved modifications listed in Table 3-1. Provided below is a summary of the: 1) development of the monitoring program; 2) current active monitor well network; 3) water level monitoring activities; and 4) groundwater quality monitoring activities.

Monitoring Program Development

Table 3-1 provides a chronological summary of groundwater characterization and monitoring activities at the Site and the evolution of the monitor well network over time.

Table 3-1. Chronology of Groundwater Characterization and Monitoring Activities

Date	Activity
1976-1982	The USGS conducted groundwater investigations north of the Site boundary, which culminated in a report entitled: *Ground-water quality down-gradient from copper-ore milling wastes at Weed Heights, Lyon County, Nevada* (Seitz et al. 1982).
1982-1985	1982 – An NDEP Order required groundwater investigations near the Sulfide Tailings and Evaporation Ponds, and initial groundwater monitoring. 1985 – An NDEP Order required construction of the PWS and performance of associated O&M and groundwater monitoring activities.
1997	An NDEP Order was issued that required Arimetco to conduct groundwater investigations and monitoring of the Site, requesting both a complete hydrogeological assessment for the Yerington Mine (including existing and projected Pit Lake conditions), and a facility assessment to identify all areas where constituent concentrations in groundwater exceed the drinking water standards or background.
1999	Implementation of a Geoprobe® investigation of Shallow zone alluvial aquifer conditions north of the Site, which consisted of collecting 29 samples from 18 locations (AHA 2000).
2002	Two groundwater monitor wells, MW-2002-1 (subsequently re-named B/W-2S) and MW-2002-2, were installed (BC 2002) under an interim action directed by NDEP.
2004	Several groundwater characterization boreholes were drilled to collect groundwater grab samples, and three groundwater monitor wells were installed in the Process Areas, pursuant to the *Final Draft Process*

Table 3-1. Chronology of Groundwater Characterization and Monitoring Activities

Date	Activity
	Areas Work Plan (BC 2003).
2005	Implementation of the *First-Step Hydrogeologic Framework Assessment* (HFA; BC 2005) under the Unilateral Administrative Order (UAO) issued by EPA for Initial Response Activities, EPA Docket No. 9-2005-0011, including the installation of the first phase of B/W wells.
2007-2008	Implementation of the Second-Step HFA (BC 2007b) included a second phase of well installations, and the preparation of OU-specific work plans that describe additional on-Site monitor well installations under the 2007 Order. ARC submitted the *Draft Site-Wide Groundwater Monitoring Plan* (BC 2007c).
2008	Monitor well identification numbers modified to include a suffix designating the groundwater zone in which the well screen is positioned, including the Shallow, Intermediate, Deep and bedrock zones.
2008	EPA approved the elimination of well MW-1S from the monitoring network due to an obstruction well.
2008	Collection of groundwater grab samples and groundwater levels beneath the Anaconda Evaporation Ponds pursuant to the *Anaconda Evaporation Ponds Removal Action Characterization Work Plan* (BC 2008a).
2009	-Shutdown of the pumpback wells on March 25, 2009 with EPA approval. -Implementation of activities pursuant to the *Pumpback Well System Characterization Work Plan* (ARC 2008) including: 1) installation of nine groundwater monitor wells north of the PWS and the LEP; and 2) pumpback well aquifer testing pursuant to the *PWS Characterization Work Plan Addendum - Revision 2* (ARC 2010), which was performed in 2010. - Implementation of activities pursuant to the *Shallow Alluvial Aquifer Characterization Work Plan for Northern Portion of the Yerington Mine Site* (BC 2008b). -EPA approved the QAPP - Revision 5 dated May 20, 2009 (ESI and BC 2009), which contains SOPs for groundwater monitoring. -Implementation of a separate Domestic Well Monitoring Plan (BC 2010b) as a revision to the QAPP per EPA direction. The Domestic Well Monitoring Plan and related Bottled Water Program are discussed further in Section 3.4. -ARC submitted the *Site-Wide Groundwater Monitoring Plan - Revision 1* (BC 2009a).
2010-2011	Installation of 123 wells per the *2010 Groundwater Monitoring Well Work Plan - Revision 2* (BC 2010c) and the *Agricultural Fields Characterization Work Plan - Revision 2* (BC 2010d).
2011	-Installation of 58 wells per the the *On-Site Monitor Well Installation Work Plan - Revision 1* (BC 2011a). -Aquifer testing of an agricultural well (WDW019) north of the Site, including a 96-well observation network, pursuant to the *Aquifer Test Work Plan - Revision 1* (BC 2011b).
2012	Submittal of the *Site-Wide Groundwater Monitoring Plan - Revision 2* (BC 2012a). Addition of new well YPT-MW-15I to the monitoring program in November 2012.
2013	-Installation of 58 monitor wells per the *Additional Monitor Well Work Plan - Revision 1* (BC 2013b). -Addition of five EPA Arimetco wells, nine YPT wells, and the one MacArthur mine well (MMW-2) to the monitoring program after the 4Q 2011 event. -EPA (2013a) approved of eliminating well USEPA2S from the active monitor well network. EPA (2013b) approves of abandoning well USEPA2S and eliminating the following five metals from the analyte list for wells having at least four quarters of data: lead, silver, thallium, tin, and titanium. EPA (2013b) also approved of reducing the sampling frequency of 118 wells from quarterly to semi-annually, with sampling to be conducted in the first and third quarters of subsequent years.
2014	-EPA (2013c) approved the abandonment of well B/W-14S and the well was abandoned in January 2014. -Well USEPA2S was abandoned in April 2014 and was moved from the inactive to abandoned well list. -ARC submitted the *Technical Memorandum: Site-Wide Groundwater Monitoring Optimization* (ARC 2014) proposing several modifications to the GMP (BC 2012a). -EPA approved of reducing the frequency of manual water level monitoring in wells installed before 2013 from monthly to quarterly, to coincide with the quarterly sampling events (EPA 2014a). EPA also approved reducing the frequency of collecting groundwater samples from wells installed before 2013 for nitrate analysis from quarterly to semi-annually, with sampling to be conducted in the first and third quarters of subsequent years (EPA 2014a).
2015	Installation of six additional monitor wells (B/W-63 cluster) in the third quarter of 2015 (3Q 2015), pursuant to the *Additional Monitor Well Work Plan - Revision 1* (BC 2013b). Initial water level monitoring and sampling of these six wells in 4Q 2015.

The network development detailed in Table 3-1 included the addition and elimination of monitor locations as summarized in Table 3-2.

Table 3-2. Inventory of Monitor Well and Piezometer Locations (2007 - 2015)

Date (Through)	Total (1)	Monitor Wells and/or Piezometers	Pumpback Wells
2007	87	76	11
2008	101	90	11
1Q 2009	110	99	11
2Q 2009	114(2)	103(2)	11
3Q 2009	114(2)	103(2)	11
4Q 2009	114(2)	103(2)	11
1Q 2010	114(2)	103(2)	11
2Q 2010	114(2)	103(2)	11
3Q 2010	114(2)	103(2)	11
4Q 2010	114(2)	103(2)	11
1Q 2011	237(3)	226(3)	11
2Q 2011	237(3)	226(3)	11
3Q 2011	237(3)	226(3)	11
4Q 2011	242(4)	231(4)	11
1Q 2012	309(5)	298(5)	11
2Q 2012	309(5)	298(5)	11
3Q 2012	309(5)	298(5)	11
4Q 2012	310(6)	299(6)	11
1Q 2013	309(7)	298(7)	11
2Q 2013	309(7)	298(7)	11
3Q 2013	309(7)	298(7)	11
4Q 2013	309(7)	298(7)	11
1Q 2014	308(8)	297(8)	11
2Q 2014	325(9)	314(9)	11
3Q 2014	354(10)	343(10)	11
4Q 2014	354(10)	343(10)	11
1Q 2015	354(10)	343(10)	11
2Q 2015	354(10)	343(10)	11
3Q 2015	360(11)	349(11)	11
4Q 2015	360(11)	349(11)	11

Notes:

1) Total does not include domestic/supply wells that were part of the network until 2010. Total does include the eleven pumpback wells.
2) Includes four Lyon County wells.
3) Includes four Lyon County wells and 123 wells installed in 2010/2011.
4) Includes four Lyon County wells, 123 wells installed in 2010/2011, and five EPA Arimetco wells (sampled in 3Q 2011 and added to the monitoring program after the 4Q 2011 event).

5) Includes four Lyon County wells, 123 wells installed in 2010/2011, 58 wells installed in 2011/2012, five EPA Arimetco wells, eight YPT wells (excluding YPT-MW-7), and one MacArthur mine well (MMW-2). Prior to 1Q 2012, these wells were or may have been sampled; however, sample collection methods were either inconsistent with EPA-approved sample collection methods or were not documented.
6) Includes four Lyon County wells, 123 wells installed in 2010/2011, 58 wells installed in 2011/2012, five EPA Arimetco wells, nine YPT wells (including new well YPT-MW-15I in November 2012), and one MacArthur mine well (MMW-2).
7) With EPA approval, well USEPA2S moved to inactive well list in March 2013, subsequently proposed for abandonment in August 2013, and abandoned in April 2014.
8) With EPA approval, well B/W-14S was abandoned in January 2014.
9) Includes 17 wells installed in 2013/2014 and first sampled in 2Q 2014.
10) Includes 29 wells installed in 2013/2014 and first sampled in 3Q 2014.
11) Includes six wells (B/W-63 cluster) installed in 3Q 2015 and first sampled in 4Q 2015.

Active Monitor Well Network

The active monitor well network included 360 wells at 170 locations: 133 wells in the Shallow zone, including 11 PWS wells formerly used for groundwater extraction (currently in shutdown mode); 55 wells in the Intermediate zone; 105 wells in the Deep zone; and 67 bedrock wells (Table 3-3 and Figure 3-3). Of the 360 monitor wells, seven are used only for water level measurements, and the remaining 353 are monitored for both water levels and water quality.

A generalized cross-section that depicts alluvial monitor well screen intervals and groundwater zone designations for active wells within the monitoring network is presented in Figure 3-4. A generalized cross-section that depicts bedrock monitor well screen intervals is presented in Figure 3-5. All monitor wells in the network were surveyed by a Nevada-registered surveyor. Project datum is Nevada State Plane West Zone coordinate system (NAD27).

Table 3-3. Well Construction Details for the Active Groundwater Monitoring Network

Well Name (1)	Completion Date	Groundwater Zone	Well Type	Well Screen Interval
				feet amsl
Pumpback Wells				
PW-1S	10/1/85	Shallow	Sampling	4335.02 - 4312.52
PW-2S	10/1/85	Shallow	Sampling	4335.73 - 4315.23
PW-3S	10/1/85	Shallow	Sampling	4333.88 - 4313.38
PW-4S	10/1/85	Shallow	Sampling	4331.48 - 4311.98
PW-5S	10/1/85	Shallow	Sampling	4334.23 - 4313.73
PW-6S	10/21/98	Shallow	Sampling	4340.11 - 4323.11
PW-7S	10/22/98	Shallow	Sampling	4339.32 - 4319.82
PW-8S	10/22/98	Shallow	Sampling	4336.63 - 4316.63
PW-9S	10/23/98	Shallow	Sampling	4337.38 - 4317.38
PW-10S	10/23/98	Shallow	Sampling	4338.46 - 4318.46
PW-11S	10/24/98	Shallow	Sampling	4339.68 - 4319.68

Table 3-3. Well Construction Details for the Active Groundwater Monitoring Network

Well Name [1]	Completion Date	Groundwater Zone	Well Type	Well Screen Interval feet amsl
Shallow Zone Monitor Wells				
B-2S	5/18/89	Shallow	Water Level	NR - NR
B-3S	5/18/89	Shallow	Water Level	NR - NR
B/W-1S	1/23/08	Shallow	Sampling	4334.71 - 4314.71
B/W-2S	6/13/02	Shallow	Sampling	4330.95 - 4320.95
B/W-3S	9/26/07	Shallow	Sampling	4332.50 - 4312.50
B/W-4S	1/21/08	Shallow	Sampling	4316.74 - 4296.74
B/W-5RS	11/16/07	Shallow	Sampling	4326.12 - 4306.12
B/W-6S	1/30/08	Shallow	Sampling	4326.78 - 4306.78
B/W-8S	10/9/07	Shallow	Sampling	4325.95 - 4305.95
B/W-9S	11/7/07	Shallow	Sampling	4331.77 - 4311.77
B/W-10S	1/23/08	Shallow	Sampling	4321.56 - 4301.56
B/W-11S	11/4/07	Shallow	Sampling	4330.42 - 4310.42
B/W-13S	7/13/05	Shallow	Sampling	4364.14 - 4344.14
B/W-15S	7/22/05	Shallow	Sampling	4348.48 - 4328.48
B/W-16S	10/7/07	Shallow	Sampling	4328.68 - 4308.68
B/W-18S	2/19/08	Shallow	Sampling	4333.87 - 4308.87
B/W-19S	1/9/08	Shallow	Sampling	4331.43 - 4311.43
B/W-20S	7/13/07	Shallow	Sampling	4377.44 - 4357.44
B/W-21S	7/24/07	Shallow	Sampling	4338.99 - 4318.99
B/W-22S	7/18/07	Shallow	Sampling	4309.55 - 4289.55
B/W-25S	1/31/08	Shallow	Sampling	4322.63 - 4302.63
B/W-27S	2/7/08	Shallow	Sampling	4338.98 - 4318.98
B/W-28S	1/15/08	Shallow	Sampling	4331.67 - 4311.67
B/W-29S	1/6/08	Shallow	Sampling	4314.97 - 4294.97
B/W-30S	10/25/10	Shallow	Sampling	4325.10 - 4305.10
B/W-31S1	12/8/10	Shallow	Sampling	4330.77 - 4315.77
B/W-31S2	12/8/10	Shallow	Sampling	4304.95 - 4294.95
B/W-32S	1/11/11	Shallow	Sampling	4328.60 - 4308.60
B/W-33S	8/4/10	Shallow	Sampling	4328.23 - 4308.23
B/W-34S	12/5/10	Shallow	Sampling	4337.68 - 4317.68
B/W-36S	8/11/10	Shallow	Sampling	4329.76 - 4319.76
B/W-37S	6/6/10	Shallow	Sampling	4331.62 - 4311.62
B/W-38RS	10/11/10	Shallow	Sampling	4320.17 - 4300.17
B/W-40S	1/10/11	Shallow	Sampling	4318.41 - 4298.41
B/W-41S	2/8/11	Shallow	Sampling	4324.54 - 4304.54
B/W-42S	11/9/10	Shallow	Sampling	4326.05 - 4306.05
B/W-43S	12/17/10	Shallow	Sampling	4323.75 - 4303.75
B/W-44S	9/24/10	Shallow	Sampling	4324.88 - 4304.88

Table 3-3. Well Construction Details for the Active Groundwater Monitoring Network

Well Name (1)	Completion Date	Groundwater Zone	Well Type	Well Screen Interval
				feet amsl
B/W-45S	1/17/11	Shallow	Sampling	4331.84 - 4311.84
B/W-46S	11/8/10	Shallow	Sampling	4327.09 - 4307.09
B/W-50S (2)	2/11/14	Shallow	Sampling	4337.83 - 4317.83
B/W-51S	8/25/10	Shallow	Sampling	4303.87 - 4293.87
B/W-52S	8/18/10	Shallow	Sampling	4329.90 - 4309.90
B/W-53S1	1/20/11	Shallow	Sampling	4310.26 - 4290.26
B/W-53S2	1/19/11	Shallow	Sampling	4265.87 - 4255.87
B/W-54S	8/20/10	Shallow	Sampling	4298.38 - 4288.38
B/W-55S	10/20/10	Shallow	Sampling	4327.27 - 4307.27
B/W-56S	3/13/12	Shallow	Sampling	4334.12 - 4314.12
B/W-57S	3/15/12	Shallow	Sampling	4325.36 - 4305.36
B/W-58S	3/14/12	Shallow	Sampling	4294.04 - 4284.04
B/W-59S (2)	11/20/13	Shallow	Sampling	4338.55 - 4318.55
B/W-60S	1/8/11	Shallow	Sampling	4342.73 - 4322.73
B/W-61S	8/27/10	Shallow	Sampling	4342.05 - 4322.05
B/W-62S	11/22/10	Shallow	Sampling	4333.94 - 4313.94
B/W-63S (3)	8/9/15	Shallow	Sampling	4325.73 - 4305.73
B/W-64S	12/6/10	Shallow	Sampling	4348.03 - 4328.03
B/W-65S	9/29/10	Shallow	Sampling	4325.29 - 4305.29
B/W-66S	12/5/10	Shallow	Sampling	4313.88 - 4293.88
B/W-67S	1/23/11	Shallow	Sampling	4329.26 - 4309.26
B/W-68S (2)	4/30/14	Shallow	Sampling	4325.57 - 4305.57
B/W-69S (2)	4/15/14	Shallow	Sampling	4319.18 - 4299.18
B/W-70S	10/20/11	Shallow	Sampling	4338.80 - 4318.80
B/W-71S	10/12/11	Shallow	Sampling	4342.25 - 4322.25
B/W-73S	9/10/11	Shallow	Sampling	4357.74 - 4337.74
B/W-74S	10/26/11	Shallow	Sampling	4342.98 - 4322.98
B/W-75S	12/20/11	Shallow	Sampling	4346.69 - 4326.69
B/W-76S	12/15/11	Shallow	Sampling	4335.33 - 4315.33
B/W-77S (2)	4/24/14	Shallow	Sampling	4320.30 - 4300.30
B/W-78S (2)	4/23/14	Shallow	Sampling	4329.30 - 4309.30
B/W-79S (2)	4/25/14	Shallow	Sampling	4335.29 - 4315.29
B/W-81S (2)	3/10/14	Shallow	Sampling	4308.10 - 4288.10
B/W-82RS (2)	11/3/13	Shallow	Sampling	4310.40 - 4290.40
B/W-83S (2)	2/5/14	Shallow	Sampling	4326.66 - 4306.66
D4BC-1S	10/1/85	Shallow	Sampling	4333.98 - 4313.98
D5AC-1S	5/6/84	Shallow	Sampling	4332.48 - 4327.48
FMS-05S (4)	10/20/13	Shallow	Sampling	4335.34 - 4315.34
FMS-06S (4)	11/6/13	Shallow	Sampling	4336.55 - 4316.55

Table 3-3. Well Construction Details for the Active Groundwater Monitoring Network

Well Name (1)	Completion Date	Groundwater Zone	Well Type	Well Screen Interval
				feet amsl
FMS-07S (4)	11/14/13	Shallow	Sampling	4337.75 - 4317.75
HLP-03S (4)	11/16/13	Shallow	Sampling	4341.79 - 4321.79
HLP-04S (4)	10/8/13	Shallow	Sampling	4340.55 - 4320.55
HLP-08S (4)	10/21/13	Shallow	Sampling	4331.83 - 4311.83
LC-MW-1S (5)	1/18/06	Shallow	Sampling	NR - 4303.80(6)
LC-MW-2S (5)	1/18/06	Shallow	Sampling	NR - 4313.90(6)
LC-MW-3S (5)	1/18/06	Shallow	Sampling	NR - 4323.70(6)
LC-MW-5S (5)	NR	Shallow	Sampling	NR - 4323.10(6)
LEP-MW-1S	2/26/09	Shallow	Sampling	4330.92 - 4320.92
LEP-MW-2S	2/27/09	Shallow	Sampling	4331.46 - 4321.46
LEP-MW-3S	2/28/09	Shallow	Sampling	4333.75 - 4323.75
LEP-MW-5S	3/2/09	Shallow	Sampling	4336.35 - 4326.35
LEP-MW-6S	3/2/09	Shallow	Sampling	4327.51 - 4317.51
LEP-MW-7S	3/3/09	Shallow	Sampling	4342.81 - 4332.81
MW2002-2S	6/14/02	Shallow	Sampling	4323.78 - 4313.78
MW-2S	12/13/92	Shallow	Sampling	4326.61 - 4311.61
MW-4S	12/10/92	Shallow	Sampling	4325.68 - 4310.68
MW-5S	10/20/95	Shallow	Sampling	4330.79 - 4315.79
MW-SXN	7/26/09	Shallow	Sampling	4355.39 - 4335.39
MW-SXS	8/28/09	Shallow	Sampling	4354.32 - 4334.32
PA-MW-1S	1/20/05	Shallow	Sampling	4347.32 - 4327.32
PA-MW-2S	1/21/05	Shallow	Sampling	4347.37 - 4327.37
PA-MW-3S1	1/19/05	Shallow	Sampling	4348.13 - 4328.13
PA-MW-3S2	11/19/11	Shallow	Sampling	4309.85 - 4299.85
PA-MW-4S	10/18/11	Shallow	Sampling	4348.09 - 4328.09
PA-MW-5S1	11/17/11	Shallow	Sampling	4344.01 - 4324.01
PA-MW-5S2	11/14/11	Shallow	Sampling	4311.16 - 4301.16
PA-MW-7S	10/25/11	Shallow	Sampling	4317.46 - 4297.46
PLMW-2S	8/3/11	Shallow	Sampling	4369.05 - 4349.05
PLMW-4S	10/31/11	Shallow	Sampling	4319.72 - 4289.72
PW10-P1	9/27/05	Shallow	Water Level	4339.10 - 4319.10
USGS-13S	6/10/76	Shallow	Sampling	4342.06 - 4332.06
USGS-2BS	6/8/76	Shallow	Sampling	4326.34 - 4324.44
UW-1S	10/1/85	Shallow	Sampling	4333.32 - 4313.32
W5AA-2S	10/26/83	Shallow	Water Level	4333.65 - 4313.65
W5AA-3S	10/24/98	Shallow	Sampling	4342.86 - 4332.86
W5AB-2S	10/1/83	Shallow	Sampling	4337.68 - 4322.68
W5AD-1S	5/2/82	Shallow	Water Level	4330.91 - 4325.91
W5BB-S	10/23/83	Shallow	Sampling	4337.12 - 4307.12

Table 3-3. Well Construction Details for the Active Groundwater Monitoring Network

Well Name (1)	Completion Date	Groundwater Zone	Well Type	Well Screen Interval feet amsl
W5DB-S	10/9/10	Shallow	Sampling	4345.06 - 4325.06
WRP-1S	6/19/07	Shallow	Water Level	4382.53 - 4372.53
WRP-2S	6/19/07	Shallow	Water Level	4382.29 - 4372.29
YPT-MW-6S	1/11/02	Shallow	Sampling	4320.21 - 4315.21
YPT-MW-8S	1/9/02	Shallow	Sampling	4322.26 - 4317.26
YPT-MW-11S	1/11/02	Shallow	Sampling	4317.43 - 4312.43
Intermediate Zone Monitor Wells				
B/W-2I	10/17/07	Intermediate	Sampling	4279.78 - 4259.78
B/W-3I	9/27/07	Intermediate	Sampling	4266.40 - 4246.40
B/W-4I	1/21/08	Intermediate	Sampling	4276.50 - 4256.50
B/W-5RI	11/16/07	Intermediate	Sampling	4278.65 - 4258.65
B/W-6I	9/26/05	Intermediate	Sampling	4259.84 - 4249.84
B/W-7I	8/14/05	Intermediate	Sampling	4304.69 - 4284.69
B/W-8I	8/21/05	Intermediate	Sampling	4284.16 - 4264.16
B/W-9I	11/7/07	Intermediate	Sampling	4281.19 - 4261.19
B/W-19I	1/11/08	Intermediate	Sampling	4281.40 - 4261.40
B/W-27I	8/17/10	Intermediate	Sampling	4274.77 - 4254.77
B/W-28I	1/17/08	Intermediate	Sampling	4277.23 - 4257.23
B/W-29I	12/19/07	Intermediate	Sampling	4288.07 - 4278.07
B/W-30I	10/25/10	Intermediate	Sampling	4267.63 - 4247.63
B/W-31I	12/7/10	Intermediate	Sampling	4287.82 - 4246.82
B/W-32I	1/10/11	Intermediate	Sampling	4286.67 - 4266.67
B/W-33I	8/3/10	Intermediate	Sampling	4265.02 - 4255.02
B/W-34I	12/5/10	Intermediate	Sampling	4303.85 - 4283.85
B/W-37I	8/10/10	Intermediate	Sampling	4296.85 - 4276.85
B/W-38RI	10/9/10	Intermediate	Sampling	4287.91 - 4267.91
B/W-41I	2/7/11	Intermediate	Sampling	4278.31 - 4268.31
B/W-42I	11/8/10	Intermediate	Sampling	4266.21 - 4246.21
B/W-46I	11/7/10	Intermediate	Sampling	4276.66 - 4256.66
B/W-51I	9/9/10	Intermediate	Sampling	4264.06 - 4244.06
B/W-52I	8/20/10	Intermediate	Sampling	4296.06 - 4276.06
B/W-54I	8/21/10	Intermediate	Sampling	4277.24 - 4267.24
B/W-57I	3/14/12	Intermediate	Sampling	4270.47 - 4250.47
B/W-63I (3)	8/9/15	Intermediate	Sampling	4285.58 - 4265.58
B/W-65I	9/29/10	Intermediate	Sampling	4285.30 - 4265.30
B/W-66I	12/5/10	Intermediate	Sampling	4268.85 - 4248.85
B/W-67I	1/22/11	Intermediate	Sampling	4289.41 - 4269.41
B/W-70I	10/22/11	Intermediate	Sampling	4288.59 - 4268.59
B/W-71I	10/11/11	Intermediate	Sampling	4281.11 - 4261.11

Table 3-3. Well Construction Details for the Active Groundwater Monitoring Network

Well Name (1)	Completion Date	Groundwater Zone	Well Type	Well Screen Interval
				feet amsl
B/W-74I1	10/20/11	Intermediate	Sampling	4307.69 - 4297.69
B/W-74I2	10/21/11	Intermediate	Sampling	4277.50 - 4257.50
B/W-76I	12/13/11	Intermediate	Sampling	4276.82 - 4256.82
B/W-82RI (2)	11/2/13	Intermediate	Sampling	4280.35 - 4270.35
HLP-03I (4)	11/5/13	Intermediate	Sampling	4300.00 - 4280.00
HLP-08I (4)	10/20/13	Intermediate	Sampling	4296.56 - 4276.56
LEP-MW-4I	3/1/09	Intermediate	Sampling	4266.95 - 4256.95
LEP-MW-8I	3/4/09	Intermediate	Sampling	4271.83 - 4261.83
LEP-MW-9I	3/6/09	Intermediate	Sampling	4258.17 - 4248.17
MW-4I	8/30/10	Intermediate	Sampling	4285.18 - 4265.18
MW-5I	1/23/11	Intermediate	Sampling	4269.38 - 4249.38
PA-MW-2I	9/8/11	Intermediate	Sampling	4296.59 - 4276.59
PA-MW-3I	11/18/11	Intermediate	Sampling	4281.86 - 4271.86
PA-MW-4I	10/17/11	Intermediate	Sampling	4273.89 - 4253.89
W4CB-1I	10/27/83	Intermediate	Sampling	4280.31 - 4265.31
W4CB-2I	10/28/83	Intermediate	Sampling	4307.74 - 4295.74
W5AA-1I	10/26/83	Intermediate	Sampling	4293.56 - 4278.56
W5AB-3I	9/19/97	Intermediate	Sampling	4308.70 - 4284.20
W5DB-I	10/10/10	Intermediate	Sampling	4287.77 - 4267.77
YPT-MW-9I	1/8/02	Intermediate	Sampling	4282.60 - 4272.60
YPT-MW-12I	1/10/02	Intermediate	Sampling	4280.36 - 4270.36
YPT-MW-13I	7/20/04	Intermediate	Sampling	4287.78 - 4262.78
YPT-MW-15I	10/5/12	Intermediate	Sampling	4275.21 - 4270.21
Deep Zone Monitor Wells				
B/W-1D1	11/5/07	Deep	Sampling	4229.76 - 4209.76
B/W-1D2	10/22/07	Deep	Sampling	4139.92 - 4119.92
B/W-1D3	11/5/05	Deep	Sampling	4028.63 - 4018.63
B/W-1D5	1/7/11	Deep	Sampling	3877.18 - 3867.18
B/W-2D1	9/10/05	Deep	Sampling	4224.01 - 4204.01
B/W-2D3	1/23/11	Deep	Sampling	4049.28 - 4029.28
B/W-2D4	1/21/11	Deep	Sampling	3938.99 - 3918.99
B/W-3D1	8/31/05	Deep	Sampling	4221.87 - 4201.87
B/W-4D1	8/26/05	Deep	Sampling	4228.07 - 4208.07
B/W-5RD1	11/16/07	Deep	Sampling	4241.21 - 4221.21
B/W-9D2	9/14/05	Deep	Sampling	4206.72 - 4186.72
B/W-10D1	8/5/05	Deep	Sampling	4241.10 - 4221.10
B/W-11D2	9/28/05	Deep	Sampling	4197.64 - 4177.64
B/W-18D1	2/19/08	Deep	Sampling	4232.79 - 4212.79
B/W-18D2	12/15/07	Deep	Sampling	4194.17 - 4174.17

Table 3-3. Well Construction Details for the Active Groundwater Monitoring Network

Well Name (1)	Completion Date	Groundwater Zone	Well Type	Well Screen Interval
				feet amsl
B/W-19D1	6/14/07	Deep	Sampling	4216.51 - 4196.51
B/W-25D1	2/1/08	Deep	Sampling	4249.71 - 4229.71
B/W-25D2	1/19/08	Deep	Sampling	4133.82 - 4113.82
B/W-27D2	2/6/08	Deep	Sampling	4124.99 - 4104.99
B/W-27D3	1/6/11	Deep	Sampling	4022.95 - 4002.95
B/W-27D4(2)	2/21/14	Deep	Sampling	3944.83 - 3924.83
B/W-27D5(2)	2/11/14	Deep	Sampling	3879.66 - 3859.66
B/W-28D1	6/28/07	Deep	Sampling	4221.83 - 4201.83
B/W-29D1	12/16/07	Deep	Sampling	4225.24 - 4215.24
B/W-29D3	9/25/07	Deep	Sampling	4050.12 - 4030.12
B/W-30D1	10/26/10	Deep	Sampling	4228.86 - 4208.86
B/W-31D2	11/7/10	Deep	Sampling	4199.84 - 4179.84
B/W-32D2	1/9/11	Deep	Sampling	4147.42 - 4127.42
B/W-32D5	10/24/10	Deep	Sampling	3886.73 - 3866.73
B/W-33D1	7/29/10	Deep	Sampling	4239.39 - 4229.39
B/W-34D1	12/4/10	Deep	Sampling	4257.96 - 4237.96
B/W-37D1	6/5/10	Deep	Sampling	4218.80 - 4198.80
B/W-38RD1	10/10/10	Deep	Sampling	4210.93 - 4190.93
B/W-40D1	1/20/11	Deep	Sampling	4222.20 - 4202.20
B/W-40D3	11/3/10	Deep	Sampling	4057.58 - 4037.58
B/W-41D2	2/7/11	Deep	Sampling	4198.22 - 4178.22
B/W-41D4	2/5/11	Deep	Sampling	4004.14 - 3984.14
B/W-42D1	10/25/10	Deep	Sampling	4210.91 - 4190.91
B/W-44D1	9/23/10	Deep	Sampling	4229.65 - 4209.65
B/W-44D2	9/22/10	Deep	Sampling	4152.72 - 4132.72
B/W-45D1	1/18/11	Deep	Sampling	4252.78 - 4232.78
B/W-45D2	11/20/10	Deep	Sampling	4209.84 - 4189.84
B/W-46D1	11/6/10	Deep	Sampling	4219.76 - 4199.76
B/W-50D1(2)	2/10/14	Deep	Sampling	4206.81 - 4186.81
B/W-50D2(2)	2/8/14	Deep	Sampling	4125.75 - 4105.75
B/W-50D3(2)	2/5/14	Deep	Sampling	4024.73 - 4014.73
B/W-52D2	8/17/10	Deep	Sampling	4177.59 - 4157.59
B/W-55D1	10/20/10	Deep	Sampling	4251.44 - 4241.44
B/W-55D2	10/13/10	Deep	Sampling	4171.59 - 4151.59
B/W-57D1	3/14/12	Deep	Sampling	4212.37 - 4192.37
B/W-57D4	3/13/12	Deep	Sampling	3940.67 - 3920.67
B/W-58D1	3/16/12	Deep	Sampling	4234.41 - 4214.41
B/W-58D3	3/25/12	Deep	Sampling	4054.51 - 4044.51
B/W-59D3(2)	11/19/13	Deep	Sampling	4126.65 - 4106.65

Table 3-3. Well Construction Details for the Active Groundwater Monitoring Network

Well Name (1)	Completion Date	Groundwater Zone	Well Type	Well Screen Interval
				feet amsl
B/W-60D1	12/17/10	Deep	Sampling	4247.69 - 4227.69
B/W-60D3	12/16/10	Deep	Sampling	4036.75 - 4016.75
B/W-60D5	12/7/10	Deep	Sampling	3881.82 - 3861.82
B/W-61D1	8/23/10	Deep	Sampling	4247.00 - 4227.00
B/W-61D3	8/29/10	Deep	Sampling	4036.94 - 4016.94
B/W-62D1	11/21/10	Deep	Sampling	4243.89 - 4223.89
B/W-62D2	11/20/10	Deep	Sampling	4173.88 - 4153.88
B/W-62D4	11/19/10	Deep	Sampling	3953.94 - 3933.94
B/W-62D5	1/6/11	Deep	Sampling	3833.92 - 3813.92
B/W-63D1(3)	8/8/15	Deep	Sampling	4240.50 - 4220.50
B/W-63D2(3)	8/7/15	Deep	Sampling	4170.83 - 4150.83
B/W-63D3(3)	8/5/15	Deep	Sampling	4015.78 - 3995.78
B/W-63D5(3)	7/29/15	Deep	Sampling	3900.65 - 3880.65
B/W-64D1	12/5/10	Deep	Sampling	4260.09 - 4240.09
B/W-64D2	12/3/10	Deep	Sampling	4175.77 - 4155.77
B/W-65D1	9/27/10	Deep	Sampling	4213.36 - 4193.36
B/W-65D5	9/23/10	Deep	Sampling	3750.51 - 3740.51
B/W-66D1	12/4/10	Deep	Sampling	4208.81 - 4188.81
B/W-66D5	12/2/10	Deep	Sampling	3761.03 - 3751.03
B/W-67D1	1/21/11	Deep	Sampling	4245.24 - 4225.24
B/W-67D3	1/13/11	Deep	Sampling	4125.04 - 4105.04
B/W-68D1(2)	4/29/14	Deep	Sampling	4240.74 - 4220.74
B/W-68D4(2)	4/28/14	Deep	Sampling	3964.32 - 3954.32
B/W-69D1(2)	4/14/14	Deep	Sampling	4259.33 - 4239.33
B/W-69D2(2)	4/13/14	Deep	Sampling	4194.30 - 4174.30
B/W-69D5(2)	4/9/14	Deep	Sampling	3782.33 - 3772.33
B/W-70D2	10/25/11	Deep	Sampling	4143.64 - 4123.64
B/W-71D1	10/5/11	Deep	Sampling	4222.09 - 4202.09
B/W-71D3	10/3/11	Deep	Sampling	4094.16 - 4074.16
B/W-74D1	11/20/11	Deep	Sampling	4247.72 - 4227.72
B/W-76D1	10/4/11	Deep	Sampling	4251.74 - 4231.74
B/W-81D1(2)	3/9/14	Deep	Sampling	4243.06 - 4223.06
B/W-81D2(2)	3/10/14	Deep	Sampling	4153.13 - 4133.13
B/W-83D1(2)	2/4/14	Deep	Sampling	4216.67 - 4196.67
B/W-83D3(2)	1/29/14	Deep	Sampling	4066.59 - 4046.59
HLP-08D1(4)	10/19/13	Deep	Sampling	4249.87 - 4229.87
HLP-08D2(4)	10/15/13	Deep	Sampling	4174.99 - 4154.99
LEP-MW-2D1	10/25/10	Deep	Sampling	4229.98 - 4209.98
LEP-MW-2D3	10/22/10	Deep	Sampling	4100.11 - 4080.11

Table 3-3. Well Construction Details for the Active Groundwater Monitoring Network

Well Name (1)	Completion Date	Groundwater Zone	Well Type	Well Screen Interval
				feet amsl
MW-5D2	1/12/11	Deep	Sampling	4194.22 - 4174.22
MW-5D3	1/18/11	Deep	Sampling	4119.72 - 4099.72
MW2002-2D1	7/12/07	Deep	Sampling	4249.75 - 4239.75
PA-MW-4D2	10/15/11	Deep	Sampling	4192.92 - 4172.92
W32DC-D1	10/25/83	Deep	Sampling	4240.41 - 4197.41
W4CB-2D1	9/15/10	Deep	Sampling	4240.56 - 4220.56
W4CB-2D3	9/14/10	Deep	Sampling	4065.76 - 4045.76
W4CB-2D4	11/8/10	Deep	Sampling	3965.54 - 3955.54
W5DB-D1	10/19/98	Deep	Sampling	4239.49 - 4211.49
W5DB-D3	11/17/10	Deep	Sampling	4091.93 - 4071.93
W5DB-D4	10/25/10	Deep	Sampling	4009.93 - 3989.93
YPT-MW-14D1	7/21/04	Deep	Sampling	4255.83 - 4235.83
Bedrock Monitor Wells				
B/W-1B	5/19/10	Bedrock	Sampling	3700.10 - 3690.10
B/W-2B	1/12/11	Bedrock	Sampling	3839.17 - 3819.17
B/W-6B	1/25/11	Bedrock	Sampling	4172.04 - 4152.04
B/W-11B	11/3/07	Bedrock	Sampling	4132.88 - 4122.88
B/W-12RB	12/6/11	Bedrock	Sampling	4382.05 - 4302.05
B/W-17B	10/30/11	Bedrock	Sampling	4385.06 - 4365.06
B/W-22B	5/8/10	Bedrock	Sampling	4261.26 - 4241.26
B/W-23B	8/8/07	Bedrock	Sampling	4340.26 - 4330.26
B/W-26RB	11/3/11	Bedrock	Sampling	4367.92 - 4347.92
B/W-27B (2)	11/12/13	Bedrock	Sampling	3800.16 - 3780.16
B/W-33B	7/26/10	Bedrock	Sampling	4167.48 - 4157.48
B/W-34B	12/1/10	Bedrock	Sampling	4203.76 - 4183.76
B/W-36B	6/17/10	Bedrock	Sampling	4271.60 - 4261.60
B/W-37B	5/27/10	Bedrock	Sampling	4166.84 - 4146.84
B/W-38RB	10/8/10	Bedrock	Sampling	4166.90 - 4146.90
B/W-39B	10/7/10	Bedrock	Sampling	4309.10 - 4299.10
B/W-44B	9/16/10	Bedrock	Sampling	4124.48 - 4104.48
B/W-51B	6/25/10	Bedrock	Sampling	4198.79 - 4188.79
B/W-53B	12/17/10	Bedrock	Sampling	4240.77 - 4220.77
B/W-54B	7/10/10	Bedrock	Sampling	4261.30 - 4251.30
B/W-58B	2/4/12	Bedrock	Sampling	4014.50 - 3994.50
B/W-61B	7/9/10	Bedrock	Sampling	3684.05 - 3664.05
B/W-62B	9/25/10	Bedrock	Sampling	3690.87 - 3670.87
B/W-64B	12/2/10	Bedrock	Sampling	4089.75 - 4069.75
B/W-70B	8/30/11	Bedrock	Sampling	4060.86 - 4040.86
B/W-71B	9/1/11	Bedrock	Sampling	3931.06 - 3911.06

Table 3-3. Well Construction Details for the Active Groundwater Monitoring Network

Well Name (1)	Completion Date	Groundwater Zone	Well Type	Well Screen Interval
				feet amsl
B/W-73B	9/7/11	Bedrock	Sampling	4307.60 - 4287.60
B/W-74B	9/21/11	Bedrock	Sampling	4207.18 - 4187.18
B/W-75B	1/7/12	Bedrock	Sampling	4266.82 - 4246.82
B/W-82RB (2)	11/1/13	Bedrock	Sampling	4235.38 - 4215.38
B/W-83B (2)	1/24/14	Bedrock	Sampling	3943.51 - 3913.51
HLP-01B (4)	9/20/13	Bedrock	Sampling	4333.97 - 4313.97
HLP-02B (4)	9/22/13	Bedrock	Sampling	4406.47 - 4386.27
HLP-03B (4)	10/18/13	Bedrock	Sampling	4236.98 - 4206.98
HLP-05B (4)	10/5/13	Bedrock	Sampling	4346.26 - 4306.26
HLP-06B (4)	10/1/13	Bedrock	Sampling	4338.55 - 4318.55
HLP-07B (4)	9/24/13	Bedrock	Sampling	4345.04 - 4325.04
HLP-08B (4)	10/8/14	Bedrock	Sampling	4117.44 - 4097.44
LEP-MW-2B	10/13/10	Bedrock	Sampling	4040.47 - 4020.47
MMW-2	12/6/92	Bedrock	Sampling	4246.34 - 4186.34
MW-4B	8/28/10	Bedrock	Sampling	4251.41 - 4231.41
MW-5B	1/7/11	Bedrock	Sampling	3984.29 - 3964.29
MW-H12	8/6/09	Bedrock	Sampling	4353.58 - 4323.58
MW-H4SN	8/11/09	Bedrock	Sampling	4371.56 - 4341.56
MW-H4SS	8/13/09	Bedrock	Sampling	4360.63 - 4330.63
PA-MW-1B	8/6/11	Bedrock	Sampling	4290.87 - 4270.87
PA-MW-2B	9/3/11	Bedrock	Sampling	4210.44 - 4190.44
PA-MW-3B	10/11/11	Bedrock	Sampling	4246.82 - 4226.82
PA-MW-4B	9/14/11	Bedrock	Sampling	4157.96 - 4137.96
PA-MW-5B	8/20/11	Bedrock	Sampling	4281.60 - 4261.60
PA-MW-7B	9/30/11	Bedrock	Sampling	4174.49 - 4154.49
PLMW-1B	9/29/11	Bedrock	Sampling	4218.23 - 4168.23
PLMW-2B	8/2/11	Bedrock	Sampling	4313.20 - 4293.20
PLMW-3RB	11/12/11	Bedrock	Sampling	4237.72 - 4197.72
PLMW-4B	10/20/11	Bedrock	Sampling	4094.72 - 4064.72
PLMW-5B	9/18/11	Bedrock	Sampling	4243.58 - 4203.58
W4CB-2B	7/9/10	Bedrock	Sampling	3844.55 - 3824.55
W5DB-B	9/26/10	Bedrock	Sampling	3781.04 - 3761.04
WRA3-1B	10/1/11	Bedrock	Sampling	4369.32 - 4339.32
WRA3-2B	10/19/11	Bedrock	Sampling	4322.60 - 4302.60
WRA3-3B	12/5/11	Bedrock	Sampling	4330.39 - 4310.39
WW-1B	NR	Bedrock	Sampling	4364.42 - 4344.42
WW-2B	NR	Bedrock	Sampling	4342.48 - 4322.48
WW-36B	4/15/69	Bedrock	Sampling	4305.78 - 4105.78
WW-40B	NR	Bedrock	Sampling	NR - NR

Table 3-3. Well Construction Details for the Active Groundwater Monitoring Network

Well Name (1)	Completion Date	Groundwater Zone	Well Type	Well Screen Interval
				feet amsl
WW-59B	11/20/72	Bedrock	Sampling	4280.04 - 3888.04
YPT-MW-10B	1/7/02	Bedrock	Sampling	4107.46 - 4097.46

Notes:
1) The names of 117 wells for which the sampling frequency has been reduced from quarterly to semi-annually are bold and italicized. Well names for older wells reflect revisions based on their alluvial aquifer zone designations.
2) New well added to the monitor well network and first sampled in 3Q 2014.
3) New well added to the monitor well network and first sampled in 4Q 2015.
4) New well added to the monitor well network and first sampled in 4Q 2014.
5) Lyon County well.
6) The bottom of screen elevations for the Lyon County wells are based on a 2009 survey conducted for ARC and the total depth of each well measured in the field by BC. The measured well depths are not consistent with the information on the well logs provided by Lyon County (see Appendix C-1 for the well logs).
7) NR = not recorded on well construction logs. amsl = above mean sea level

Water Level Monitoring

Routine water level monitoring was initiated in 2006, to evaluate seasonal and temporal changes in groundwater flow directions and hydraulic gradients, and aquifer responses to irrigation practices. Water level elevation monitoring was historically conducted monthly, and subsequently reduced to quarterly in 2014 for wells installed before 2013, in accordance with the *Technical Memorandum: Site-Wide Groundwater Monitoring Optimization* (ARC 2014).

As outlined in the GMP (BC 2012a), water levels are measured within a three-day (or shorter) period, for representative aquifer conditions throughout the monitoring network. Water level elevations are also measured electronically using pressure transducers/data loggers, at four-hour intervals at select monitor wells, and at one-hour intervals at the Pit Lake. Water level data from transducers are typically downloaded in conjunction with monthly water level measurements. Appendix D provides groundwater level data, hydrographs, and vertical gradient information.

Groundwater Quality Monitoring

Monitor wells comprising the active monitoring network are sampled on a quarterly or semi-annual frequency pursuant to the GMP (BC 2012a) using EPA-approved low-flow, minimal drawdown purging and sampling procedures, where applicable. Groundwater samples are analyzed for the constituents listed in Table 3-4 pursuant to the data requirements presented in the QAPP (ESI and BC 2009).

Table 3-4. Analyte List for Active Monitor Well and Surface Water Sampling

Parameter or Analyte	Total/ Dissolved (1)	Method (2)	Reporting Limit (2)	Units
Physical Parameters and Major Anions/Cations				
Alkalinity, Bicarbonate (as $CaCO_3$)	Total	SM 2320B	2.0	mg/L
Alkalinity, Carbonate (as $CaCO_3$)	Total	SM 2320B	2.0	mg/L
Alkalinity, Total (as $CaCO_3$)	Total	SM 2320B	2.0	mg/L
Chloride	Total	EPA 300.0	0.5	mg/L
Fluoride	Total	EPA 300.0	0.5	mg/L
Nitrate, as N	Total	EPA 300.0	0.1	mg/L
Nitrate (NO_3 + NO_2 as N)	Total	EPA 300.0	0.1	mg/L
Nitrite, as N	Total	EPA 300.0	0.1	mg/L
Sulfate	Total	EPA 300.0	0.5	mg/L
pH (Lab)	Total	SM 4500B	0.1	sun.
Total Dissolved Solids (TDS) (3)	Total (Lab Filtered) (3)	SM 2540C	10	mg/L
Total Organic Carbon (TOC)	Total	SM 5310B	1.0	mg/L
Metals				
Aluminum	Total + Dissolved	EPA 200.7	0.05	mg/L
Antimony	Total + Dissolved	EPA 200.8	2.0	µg/L
Arsenic	Total + Dissolved	EPA 200.8	1.0	µg/L
Barium	Total + Dissolved	EPA 200.8	1.0	µg/L
Beryllium	Total + Dissolved	EPA 200.8	0.5	µg/L
Boron	Total + Dissolved	EPA 200.7	50	µg/L
Cadmium	Total + Dissolved	EPA 200.8	1.0	µg/L
Calcium	Total + Dissolved	EPA 200.7	0.1	mg/L
Chromium	Total + Dissolved	EPA 200.8	2.0	µg/L
Cobalt	Total + Dissolved	EPA 200.8	1.0	µg/L
Copper	Total + Dissolved	EPA 200.8	1.0	µg/L
Iron	Total + Dissolved	EPA 200.7	0.04	mg/L
Lead	Total + Dissolved	EPA 200.8	1.0	µg/L
Lithium	Total + Dissolved	EPA 200.7	50	µg/L
Magnesium	Total + Dissolved	EPA 200.7	0.02	mg/L
Manganese	Total + Dissolved	EPA 200.8	1.0	µg/L
Mercury	Total + Dissolved	EPA 245.1	0.2	µg/L
Molybdenum	Total + Dissolved	EPA 200.8	2.0	µg/L
Nickel	Total + Dissolved	EPA 200.8	2.0	µg/L
Phosphorus	Total + Dissolved	EPA 200.7	0.04	mg/L
Potassium	Total + Dissolved	EPA 200.7	0.5	mg/L
Selenium	Total + Dissolved	EPA 200.8	0.6	µg/L
Silica	Total + Dissolved	EPA 200.7	0.05	mg/L
Silver	Total + Dissolved	EPA 200.8	1.0	µg/L
Sodium	Total + Dissolved	EPA 200.7	0.5	mg/L
Strontium	Total + Dissolved	EPA 200.7	0.02	mg/L
Thallium	Total + Dissolved	EPA 200.8	1.0	µg/L
Tin	Total + Dissolved	EPA 200.7	100	µg/L

Table 3-4. Analyte List for Active Monitor Well and Surface Water Sampling

Parameter or Analyte	Total/ Dissolved (1)	Method (2)	Reporting Limit (2)	Units
Titanium	Total + Dissolved	EPA 200.7	0.005	mg/L
Uranium, Total	Total + Dissolved	EPA 200.8	1.0	µg/L
Vanadium	Total + Dissolved	EPA 200.8	2.0	µg/L
Zinc	Total + Dissolved	EPA 200.8	10	µg/L
Radiochemicals				
Gross Alpha	Dissolved	EPA 900.0	1.0	pCi/L
Gross Beta	Dissolved	EPA 900.0	1.0	pCi/L
Radium-226	Dissolved	EPA 903.0	1.0	pCi/L
Radium-228	Dissolved	EPA 904.0	1.0	pCi/L
Thorium-228	Dissolved	HASL 300	1.0	pCi/L
Thorium-230	Dissolved	HASL 300	1.0	pCi/L

Notes:

1) Dissolved constituents are field-filtered with a new disposable 0.45-micron (µm) filter. Dissolved (filtered) metals collected quarterly. Total (unfiltered) metals collected in two non-consecutive quarters once a well is installed and/or initially included in the GMP (BC 2012a).
2) Except for lithium and selenium, EPA laboratory analytical methods and reporting limits are consistent with those provided in Revision 5 of the QAPP (ESI and BC 2009); alternative analytical methods identified in the QAPP may also be used. For lithium, the lab was unable to get reproducible results using EPA Method 200.8 (as indicated in QAPP); therefore, the lab has used EPA Method 200.7 for lithium, which has a higher reporting limit than indicated in the QAPP. For selenium, the reporting limit of 0.6 µg/L is lower than that indicated in the QAPP (2 µg/L).
3) The samples for TDS are filtered in the analytical laboratory with a new disposable 0.45 µm filter.
4) s.u. = pH standard units; mg/L = milligrams per liter; µg/L = micrograms per liter; pCi/L = picocuries per liter.

Appendix D provides groundwater quality data associated with the Site-Wide groundwater monitoring program and charts illustrating temporal changes in chemical concentrations.

Dissolved versus Total Metals

Beginning with the 3Q 2010 sampling event, samples from monitor wells at the Site have been periodically collected in two different quarters from each well and analyzed for both dissolved (0.45 µm-filtered) and total (unfiltered) metals to determine whether the two sampling methods produce comparable results. The results of the comparative statistical analysis of the available dissolved and total metals datasets have been periodically reported in previous quarterly and annual groundwater monitoring reports (GMRs). The most recent and final sampling for dissolved and total metals occurred during the 3Q 2014 and 1Q 2015 events for 29 off-Site wells that were installed in 2013/2014 and first sampled in 3Q 2014. The statistical comparison of the complete dissolved and total metals datasets is presented in the 2015 Annual GMR (BC 2016c).

Based on the statistical analyses, differences between dissolved and total metals concentrations in groundwater samples collected from monitor wells are non-existent or are too small to be meaningful. It is concluded that groundwater sampling both with and without filtering of samples produce equivalent datasets.

3.2.4 Soil Sampling and Testing

Pursuant to the *Agricultural Fields Characterization Work Plan - Revision 2* (BC 2010d), soil samples were collected from select borehole cores in the Shallow, Intermediate and Deep zones. The types of samples collected, and a brief description of the sampling objectives, are provided below.

- Soil samples were collected for analysis of grain size distribution to generate laboratory-determined Unified Soil Classification System (USCS) soil descriptions for comparison to USCS descriptions made in the field at the time of drilling.
- Non-redox preserved soil samples were collected for bulk chemical analyses to characterize chemical concentrations in soils.
- Redox-preserved soil samples were collected using EPA-specified procedures that preserve the subsurface oxidation state of the sediments, and archived at the Site for potential testing pursuant to the *Aquifer Solids Testing Work Plan - Revision 1* (BC 2010e).

Soil sampling information is provided in Appendix E and discussed briefly below.

Grain Size Analysis

A total of 37 samples of aquifer materials were obtained from 16 borehole locations for grain size distribution analyses by sieving of material larger than 75 µm (i.e., retained on a No. 200 sieve). Laboratory reports with the grain size distribution data are provided in Appendix E-1. Grain size distribution results were used to generate laboratory-derived USCS lithologic classifications for comparison to the field-derived USCS lithologic classifications based on visual inspection of core during drilling. As shown in Table 3-5, field USCS classifications were generally consistent with laboratory USCS classifications, especially with respect to finer-grained materials.

Table 3-5. Sample Locations for Grain Size Analysis

Borehole Name	Sample Interval (feet bgs)	USCS Classification (Field)	Percent Fines (Field)	USCS Classification (Laboratory)	Percent Fines (Laboratory)
B/W-2	378-384	SW	5	SM	12.7
B/W-2	442-454	SC	35	SC	26.4
B/W-32	21-27	SM	15	SM	18.7
B/W-32	411-414	SW-SM	10	SM	13.5
B/W-36	57-71	SM	30	SM	13.5
B/W-37	111-117	CL	80	CL	82.0
B/W-38R	140-143	GW	5	SW-SM	7.8
B/W-38R	208-212	SC	35	SC	25.7
B/W-38R	249-253	SM	30	SM	18.6
B/W-40	220.5-226	SM	15	SM	19.2
B/W-40	451-456	SP	5	SM	20.9
B/W-42	159-165	SM	15	SP-SM	5.9
B/W-51	64-69	SC	35	SC	15.0
B/W-54	46-52	CL	65	CL	63.1
B/W-54	52-61	SW	10	SW-SM	8.3
B/W-55	42-51	CH	95	CL	74.4
B/W-55	118-125	SM	20	CL	51.2
B/W-55	135-145	SW	5	SP	4.9
B/W-55	175-185	SP	5	SW	2.9
B/W-60	32-36	SM	35	SM	23.3
B/W-60	132.5-136	ML	60	CL	70.1
B/W-60	450-456	SM	25	SM	22.6
B/W-61	299-306	SP	10	SP-SM	7.7
B/W-64	27-31	SP	10	SP-SM	12.0
B/W-64	43-47	CL	75	CL	93.0
B/W-64	67-77	SW	10	SP-SM	12.0
B/W-64	177-185	SW	10	SW	5.0
B/W-66	59-64	CH	70	CL	66.1
B/W-66	65.5-68	SC	40	SC	23.0
B/W-66	89-93	SC	20	SC	48.7
B/W-67	27-32	SP	5	SM	28.5
B/W-67	38-55	CL	60	CL	64.0
B/W-67	142-146	SC	40	SC	31.8
LEP-MW-2	61-66	CL	50	SC	22.1
LEP-MW-2	212-217	CH	95	SC	34.4
LEP-MW-2	266-273	SW-SM	10	SM	12.8
LEP-MW-2	341-346	CL	50	SC	36.2

Notes:
SW = Well Graded Sand or Well Graded Sand with Gravel (where gravel is more than 15%).
SP = Poorly Graded Sand or Poorly Graded Sand with Gravel (where gravel is more than 15%).
SW-SM = Well Graded Sand with Silt or Well Graded Sand with Silt and Gravel (where gravel is more than 15%).
SP-SM = Poorly Graded Sand with Silt or Poorly Graded Sand with Silt and Gravel (where gravel is more than 15%).
SC = Clayey Sand or Clayey Sand with Gravel (where gravel is more than 15%).
SM = Silty Sand or Silty Sand with Gravel (where gravel is more than 15%).
CL = Lean Clay, Lean Clay with Sand, Sandy Lean Clay or Sandy Lean Clay with Gravel (where gravel is more than 15%).
CH = Fat Clay, Fat Clay with Sand, Sandy Fat Clay or Sandy Fat Clay with Gravel (where gravel is more than 15%).
GW = Well Graded Gravel with Sand.

Solids Sampling for Bulk Chemistry

Samples of archived core were collected from select depths in boreholes B/W-1, B/W-31, B/W-32, B/W-42, B/W-46, B/W-61, B/W-62, B/W-65, B/W-66, B/W-67, and MW-5 and submitted to the laboratory for bulk chemical analysis of the parameters listed in Table 3-6. Sample collection methods conformed to SOP-11 of the QAPP. Concentrations of metal/metalloids (hereinafter referred to as metals) and radiochemicals in the solid soil samples were determined by microwave-assisted digestion using EPA Method 3051A (HNO_3). The locations, sample depths and laboratory results are summarized in Appendix E-2.

Table 3-6. Analyte List for Soil Samples

Parameter or Analyte	Method (1)	Reporting Limit (1)	Units (2)
Soil pH	EPA 9045C	0.1	s.u.
Total and Acid Soluble Sulfur	Method 9030B	0.4	mg/kg
Chloride	EPA 300.0	5	mg/kg
Nitrate (as N)	EPA 300.0	1.1	mg/kg
Sulfate	EPA 300.0 (4)	5.0	mg/kg
TOC, TC, TIC (3)	EPA LG601 (2)	1.0	mg/kg
Aluminum	EPA 6010B	10	mg/kg
Antimony	EPA 6020	1.0	mg/kg
Arsenic	EPA 6020	0.5	mg/kg
Barium	EPA 6020	0.5	mg/kg
Beryllium	EPA 6020	0.3	mg/kg
Boron	EPA 6010B	5.0	mg/kg
Cadmium	EPA 6020	0.5	mg/kg
Calcium	EPA 6010B	15	mg/kg
Chromium	EPA 6020	1.0	mg/kg
Cobalt	EPA 6020	0.5	mg/kg
Copper	EPA 6020	1.0	mg/kg
Iron	EPA 6010B	5.0	mg/kg
Lead	EPA 6020	0.5	mg/kg
Magnesium	EPA 6010B	10	mg/kg
Manganese	EPA 6020	0.5	mg/kg
Molybdenum	EPA 6020	1.0	mg/kg
Nickel	EPA 6020	1.0	mg/kg
Potassium	EPA 6010B	50	mg/kg
Selenium	EPA 6020	1.0	mg/kg
Sodium	EPA 6010B	50	mg/kg
Uranium, Total	EPA 6020	0.10	mg/kg
Vanadium	EPA 6020	1.0	mg/kg
Zinc	EPA 6020	10	mg/kg
Uranium-234, 235, 238	HASL 300 (U-02-RC)	1.0	pCi/g

Notes:

1) EPA laboratory analytical methods and reporting limits are consistent with those provided in QAPP (ESI and BC 2009); alternative analytical methods identified in the QAPP may also be used.
2) s.u. = standard units; mg/kg = milligrams per kilogram; pCi/g = picocuries per gram.
3) Total Organic Carbon (TOC), Total Carbon (TC), and Total Inorganic Carbon (TIC).
4) EPA Method LG601 (Dry Combustion, Infrared Detection) as described in EPA 2005.

Vertical profiling of chemical concentrations in soils beneath the agricultural fields was performed to help understand potential chemical loading to groundwater unrelated to mining. Other evaluations involving characterization of groundwater quality upgradient and downgradient of agricultural fields and the sulfur isotope signatures associated with gypsum, an agricultural fertilizer/soil amendment, proved more useful for evaluating groundwater impacts associated with agricultural activities (see Section 5.5).

Redox-Preserved Soil Sampling and Archiving

During the 2007 Second-Step HFA (BC 2008c) and 2010 field investigation (BC 2013a), soil samples were opportunistically collected using EPA-specified procedures that preserved the subsurface oxidation state of the sediments. Redox-preserved soil samples were collected at select borehole locations near the Evaporation Ponds (B/W-11, B/W-18, LEP-MW-9I, MW-5, and W4CB-2), the agricultural fields adjacent to the Site (B/W-61, B/W-65, and B/W-66), and at B/W-32 (i.e., at OU1-DPT-28, which was identified during the Shallow zone investigation in 2009).

The redox-preserved soil samples were archived at the Site for potential laboratory testing (BC 2010e) to evaluate geochemical processes that affect the release and/or attenuation of chemicals from/onto aquifer solids (in particular, chemical partitioning to various mineral fractions), and the mobility and transport of chemicals in groundwater at the Site. The disposition of archived, redox-preserved soil samples is described in Section 3.3.5, which addresses chemical transport evaluations.

3.2.5 Aquifer Hydraulic Properties Testing

The 2007 SOW (EPA 2007a) required "*Definition of aquifer properties (e.g., hydraulic conductivity, transmissivity, and storativity) by a program of aquifer testing to measure the hydraulic connection between areas and throughout the known extent of contamination*." In addition, characterization of aquifer hydraulic properties was identified as DQO #5 in the Revised Groundwater RI Work Plan (BC 2014a).

Hydraulic properties of the alluvial aquifer, as well as bedrock, are provided in Appendix F and have been estimated based on a variety of small- to large-scale test methods including:

- Slug testing of groundwater monitor wells;
- Analysis of steady-state drawdown data obtained during routine quarterly low-flow sampling of monitor wells;
- Constant-rate pumping tests of the eleven wells comprising the PWS during 2010;
- Slug testing of piezometers installed near the PWS that were used as observation wells during constant-rate pumping tests of the 11 wells comprising the PWS during 2010; and
- A constant-rate pumping test of agricultural well WDW019 using an observation network of 93 monitor wells, of which 61 exhibited pumping-related responses.

Small-scale test methods, such as slug testing, provide data that are useful for identifying spatial patterns related to geology, guiding characterization, and as a preliminary estimate of hydraulic conductivity. Because slug test data are available throughout the Study Area, this dataset is used to evaluate spatial patterns in hydraulic conductivity within the Study Area. Data from the pumping test at WDW019, the other large-scale pumping tests, and subsequent groundwater model development using a parameter estimation technique (Doherty 2009), have been used to develop representative field-scale estimates of hydraulic conductivity and, therefore, groundwater velocity.

3.2.6 Surface Water Characterization

The hydrology of the study area is dominated by groundwater recharge from surface water associated with agricultural irrigation (Carroll et al. 2010; Huxel and Harris 1969; Myers 2001). Therefore, understanding the flows in the Walker River and diversions for nearby agricultural activities is important for understanding and contextualizing the data collected in the Study Area. Both regional and local (i.e. Study Area) characterization activities were conducted.

To characterize regional surface water hydrology, daily stream flows for the Walker River are obtained at several gaging locations throughout the Mason Valley, both upstream and downstream of the Site. The data collected from the gaging stations are maintained by the USGS, often in cooperation with state and local agencies, and are available at the USGS website (http://waterdata.usgs.gov/nv/nwis/sw). Surface water quality in the Walker River is also routinely

monitored by various federal, state, and miscellaneous agencies/entities. Much of this data is assembled and made publicly-available through the EPA's STOrage and RETrieval (STORET) Data Warehouse. This dataset supplements the data collected by ARC.

To evaluate the quality of surface water used to irrigate the Hunewill Ranch agricultural fields next to the Site, samples were collected and analyzed from the West Campbell Ditch (SW-WCD-01) and the Walker River (SW-WR-01), pursuant to the *Agricultural Fields Characterization Work Plan - Revision 2* (BC 2010d). Sampling locations are shown on Figure 3-6. West Campbell Ditch receives its water directly from the Walker River. The Walker River monitoring point (SW-WR-01) is located less than 1,000 feet upstream of the diversion point for West Campbell Ditch. The monitoring location in West Campbell Ditch (SW-WCD-01) is located about three miles farther downstream from the diversion point. Potential temporal trends in surface water quality during non-irrigation and irrigation periods were addressed by collecting samples monthly at these locations for 12 months during 2010/2011.

Field parameters (temperature, pH, specific conductivity, DO, sulfate and turbidity) were measured at the time of sample collection, and samples were submitted for the analysis (total concentrations) of the parameters listed in Table 3-4. Surface water samples were collected using the direct-grab method described in SOP-18 in the QAPP. This surface water sample collection method is consistent with the method used by NDEP to collect samples at other surface water monitoring stations in the Mason Valley. Laboratory analyses were conducted in accordance with the QAPP. Surface water data are presented in Appendix G and summarized in Section 4.7.

3.2.7 Hydrologic Tracer Studies

Hydrologic tracer investigations were initiated to help characterize Study Area groundwater conditions, refine the HCSM, and identify background groundwater quality types (BC 2008c, 2012b, 2014a). A variety of hydrologic tracers were initially identified as having the potential to provide information on the origin, age, sources of dissolved constituents, and migration pathways of groundwater and surface water in the Study Area.

To evaluate the feasibility of using hydrologic tracers to support these objectives, samples were collected prior to 2010 from a select number of groundwater monitor wells and surface water features. Based on the apparent efficacy of using hydrologic tracers to assess Study Area groundwater conditions, additional EPA-approved hydrologic tracer sampling events were conducted. Over time, the hydrologic tracer sampling events evolved with changes primarily related to increases in the number of groundwater monitor wells that were sampled, opportunistic collection of standing rainwater samples, and elimination of select tracers considered less useful for characterizing groundwater conditions.

Table 3-7 provides a chronology of the various OU-1 hydrologic tracer sampling events.

Table 3-7. Chronology of Hydrologic Tracer Sampling Events

Date	Sampling Locations [(1)]	Hydrologic Tracers [(2)]	Information Source(s)
July/August 2008	Hydrologic tracer samples were collected from 47 of the 94 (50%) active groundwater monitor wells at the time that routine groundwater monitoring was conducted.	Uranium isotopes, sulfate isotopes, tritium, tritium/helium, $\delta^{18}O/\delta^{2}H$ in water, and nitrate isotopes.	*Second-Step Hydrogeologic Framework Assessment Data Summary Report* (BC 2008c).
February 2011	Samples were collected from the Walker River and West Campbell Ditch, and from 127 of the 223 (57%) active groundwater monitor wells at the time of sampling.	Uranium isotopes, sulfate isotopes, tritium, tritium/helium, $\delta^{18}O/\delta^{2}H$ in water, nitrate isotopes, CFCs, $\delta^{13}B$, and $\delta^{36}Cl$.	*Draft Site-Wide Groundwater Operable Unit (OU-1) Remedial Investigation Work Plan* (BC 2012b). Revised Groundwater RI Work Plan (BC 2014a).
May 2012	Samples were collected from: 1) three surface water locations (Pit Lake, Walker River and West Campbell Ditch); and 2) 279 of the 287 (97%) active groundwater monitor wells at the time of sampling.	Uranium isotopes, sulfate isotopes, tritium, tritium/helium, CFCs, and SF_6.	Conclusions about the usefulness of specific hydrologic tracers collected in 2011 were noted in correspondence between ARC and EPA (2012a). With EPA approval (2012b), samples collected during May 2012 were not analyzed for stable isotopes in water or nitrate isotopes. May 2012 results were provided in the *Background Groundwater Quality Assessment - Revision 2* (BC 2015c).
July 2013	Collection of 14 standing rain water samples following a large precipitation event.	Uranium isotopes and sulfate isotopes.	July 2013 results provided in the *Background Groundwater Quality Assessment - Revision 2* (BC 2015c).
August 2014	Groundwater samples were collected from all (100%) of the new wells installed pursuant to the Additional Monitor Well Work Plan (BC 2013b) except well HLP-02B because it was dry. Also sampled were the four wells at the B/W-65 cluster, which were inaccessible in May 2012, and monitor well YPT-MW-15I, which was installed in October 2012. Five wells were resampled to evaluate the results reported in May 2012.	Uranium isotopes, sulfate isotopes, tritium, and tritium /helium.	August 2014 results provided in the *Background Groundwater Quality Assessment - Revision 2* (BC 2015c).

Notes:

1) Hydrologic tracer samples from monitor wells were collected in conjunction with routine groundwater monitoring events associated with the GMP (BC 2012a).
2) Uranium isotopes include ^{234}U, ^{235}U, and ^{238}U; Sulfate isotopes = $\delta^{34}S/\delta^{18}O$ in dissolved sulfate; Nitrate isotopes = $\delta^{15}N/\delta^{18}O$ in dissolved nitrate; $\delta^{13}B$ = boron isotopes in the water samples; $\delta^{36}Cl$ = chloride isotopes in the water samples; CFCs = chlorofluorocarbons; SF_6 = Sulfur Hexafluoride.

Hydrologic tracer samples were collected from monitor wells in conjunction with routine Site-Wide groundwater sampling events using low-flow, minimal drawdown sample collection procedures specified in the GMP (BC 2012a), as well as tracer-specific sampling protocols specified in SOP-17 of the QAPP (ESI and BC 2009). Surface water hydrologic tracer samples were collected using the direct-grab method described in SOP-18 of the QAPP. This surface water sample collection method is consistent with the method used by the NDEP to collect samples at other surface water monitoring stations in the Mason Valley. Table 3-8 presents the parameters, analytical methods, reporting limits, and accuracy and precision goals for the hydrologic tracer analyses.

Table 3-8. Analyte List for Hydrologic Tracer Samples

Parameter	Analytical Method	Analytical Precision (1)	Reporting Limit (2)	Matrix Spike Accuracy	Lab Control Sample Accuracy
Tritium (^{3}H)	wrd (^{3}He-ingrowth)	± 0.1 TU (3)	NA	NA	NA
Tritium/Helium (^{3}H/^{3}He)	Noble Gas MS	± 1%	NA	NA	NA
^{34}S in Sulfate	EA-IRMS (Combination to SO_2) USGS RSIL Lab Code 1951	± 0.5‰	NA	NA	NA
^{18}O in Sulfate	EA-IRMS (Combination to CO_2) USGS RSIL Lab Code 1951 (4)	± 0.5‰	NA	NA	NA
^{234}U, ^{235}U, ^{238}U	HASL-300 (U-02-RC) (5)	RPD<20% or RER<2	1 pCi/L	70-130%	75-125%
Total Uranium	EPA 200.8 ICP-MS	20%	0.1 µg/L	70-130%	80-120%
Chlorofluorocarbons (CFCs)	GC-ECD	0-2%	0.001×10^{-12} pmol/kg	NA	NA
Sulfur Hexafluoride (SF_6)	GC-ECD	1-3% (6)	0.01×10^{-15} fmol/kg	NA	NA

Notes:

1) Precision is the average standard deviation (1-sigma) in per mil units (‰). Precision limit applicable for matrix spike/matrix spike duplicate, laboratory duplicate, laboratory control sample/ laboratory control sample duplicate, or reference standard analyses.
2) The method detection limits presented are laboratory-derived limits.
3) TU = tritium unit; NA = not applicable; RPD = relative percent difference; RER = replicate error ratio; EA-IRMS = elemental analyzer-isotopic ratio mass spectrometer; ICP-MS = inductively coupled plasma mass spectroscopy; TIMS = thermal ionization mass spectrometer; GC-ECD = Gas Chromatography with Electron Capture Detection; % = percent
4) USGS Reston Stable Isotope Laboratory (RSIL) Lab Code 1951 (USGS 2006).
5) Method U-02-RC: see Isotopic Uranium in Biological and Environmental Materials for water samples as documented in HASL-300 (Rev. 1, February 2000) available at URL address: http://www.eml.st.dhs.gov/publications/procman/.
6) Wanninkhof et al. (1991); Law et al. (1994).
7) mg/L = milligrams per liter; µg/L = micrograms per liter; pmol/kg = picomoles per kilogram; fmol/kg = femtomole per kilogram; pCi/L = picocuries per liter.

Laboratory analytical results for hydrologic tracers achieved the completeness, accuracy and precision goals specified in relevant planning documents including the QAPP (ESI and BC 2009) and SOP-17. Hydrologic tracer information that relates directly to the groundwater recharge aspects of the HCSM and the background groundwater assessment was obtained in May 2012 and August 2014. These data are discussed in Section 5.0. Appendix H provides supplemental information about hydrologic tracer sampling and analysis including:

- A detailed discussion of the locations where hydrologic tracer samples were collected during May 2012, July 2013, and August 2014;
- Analytical results of hydrologic tracer samples of standing rain water impounded on mine waste features after a large rain event (average of 1.55 inches on-Site) on July 4, 2013;
- A detailed description of the sample collection procedures, analytical methods, laboratory precision goals for each hydrologic tracer, and QA/QC sample results;
- An evaluation and discussion of the limited usefulness of CFC and SF_6 data for estimating groundwater ages in the Study Area;
- A discussion of the principles and application of uranium isotopes to groundwater interpretation;
- A discussion of the principles of groundwater age estimation using data for tritium and tritium/helium in groundwater;
- A discussion of the additional sources of sulfate isotope data potentially relevant to groundwater conditions in the Study Area; and
- Electronic copies of the analytical results provided by the laboratory and laboratory-calculated apparent groundwater ages.

3.2.8 Bedrock Groundwater Characterization

Since 2005, phased field investigations associated with OU-1 have included characterization of both the alluvial and bedrock groundwater systems. The Revised Groundwater RI Work Plan (BC 2014a) presented available groundwater information through May 2012, and described an updated HCSM for the bedrock and alluvial groundwater systems. The Revised Groundwater RI Work Plan also outlined the approach for completing the bedrock groundwater study elements specified in the 2007 SOW. Bedrock characterization activities that were approved by EPA are described below in Table 3-9.

Table 3-9. Chronology of Bedrock Groundwater Characterization Activities

2004-2007	Bedrock characterization (including borehole drilling, lithologic logging, well installation, hydraulic testing, water level monitoring, and groundwater quality monitoring) conducted pursuant to the First-Step HFA Work Plan (BC 2005) and Second-Step HFA Work Plan (BC 2007b).
2007	Characterization of bedrock groundwater conditions is required under the Administrative Order for Remedial Investigation and Feasibility Study (RI/FS), CERCLA Docket No. 9-2007-0005 dated January 12, 2007.
2007-2011	Bedrock characterization (including borehole drilling, lithologic logging, well installation, hydraulic testing, water level monitoring, and groundwater quality monitoring) conducted pursuant to the *2010 Groundwater Monitor Well Work Plan - Revision 2* (BC 2010c), *Agricultural Fields Characterization Work Plan - Revision 2* (BC 2010d), *On-Site Monitor Well Installation Work Plan - Revision 1* (BC 2011a), and the *Addendum to the On-Site Monitor Well Installation Work Plan* (ARC 2011).
August 17, 2011	Groundwater technical meeting with EPA, ARC and stakeholders to discuss progress of the phased approach to groundwater RI activities, which resulted in concurrence to conduct initial bedrock characterization activities to support a more comprehensive assessment of bedrock groundwater conditions as part of the RI characterization.
September 29, 2011	EPA (2011a) provided comments on the *2010 Annual Site-Wide Groundwater Monitoring Report* dated April 15, 2011, and the First and Second Quarter (1Q and 2Q) 2011 Groundwater Monitoring Reports dated July 1, 2011 and August 26, 2011, respectively, that pertained to bedrock characterization.
January 5, 2012	ARC submitted the *Proposed Initial Bedrock Characterization Activities* (ARC 2012a).
April 12, 2012	EPA (2012c) provided comments on the *Proposed Initial Bedrock Characterization Activities* (ARC 2012a).
June 18, 2012	ARC submitted preliminary responses to EPA comments on the *Proposed Initial Bedrock Characterization Activities.*
August 28, 2012	Groundwater technical meeting with EPA, ARC and other stakeholders to resolve comments on the *Proposed Initial Bedrock Characterization Activities.*
October 11, 2012	Submittal of ARC final responses to EPA comments on the *Proposed Initial Bedrock Characterization Activities,* and submittal of the *Proposed Initial Bedrock Characterization Activities - Revision 1* (ARC 2012b).
October 22, 2012	EPA (2012d) approval of the *Proposed Initial Bedrock Characterization Activities - Revision 1,* included as Attachment D to the Revised Groundwater RI Work Plan (BC 2014a).
March 2013	ARC began implementation of the EPA-approved *Proposed Initial Bedrock Characterization Work Plan - Revision 1.*
November 20, 2013	ARC submitted the *Initial Bedrock Characterization Data Summery Report* (BC 2013c).
February 7, 2014	ARC submitted the *Site-Wide Groundwater Remedial Investigation Work Plan - Revision 1* (BC 2014a), which presented available groundwater information through May 2012, and described an updated HCSM for the bedrock and alluvial groundwater systems.
January 28, 2015	ARC submitted the *Bedrock Groundwater Assessment Technical Memorandum* (BC 2015a).
June 11, 2015	ARC submitted the *Additional Monitor Well Installation Data Summary Report* (BC 2015d) detailing installation and testing of bedrock and alluvial wells installed in 2013 and 2014.
July 31, 2016	EPA (2016a) approved the *Bedrock Groundwater Assessment Technical Memorandum* (BC 2015a).

After installation and testing of new bedrock monitor wells in late 2013 and 2014, and a technical meeting in May 2015 to discuss the full set of bedrock information, EPA (2015a) concluded that sufficient data had been collected to conclude that bedrock is not an important migration pathway

at the Site, and requested preparation of a technical memorandum to update the bedrock HCSM. The *Bedrock Groundwater Assessment Technical Memorandum* (BC 2015a) is provided in Appendix I and bedrock information is summarized in Section 4.9.

3.3 Site-Wide Groundwater Studies and Evaluations

Studies and evaluations relying on OU-1 RI data that were conducted to fulfill certain study elements specified in Section 7.0 of the SOW attached to the 2007 Order (EPA 2007a) are described below. Reports describing the approach, analysis, and results of these groundwater related studies and evaluations are provided in Appendix J.

3.3.1 Pumpback Well System Effectiveness

The effectiveness of the PWS in limiting the off-Site migration of mine-impacted groundwater was evaluated in accordance with the *Pumpback Well System Characterization Work Plan Addendum - Revision 2* (ARC 2010).

The 11 pumpback wells ceased pumping on March 25, 2009 and were subsequently hydraulically tested to generate information to support a capture zone analysis using an analytical element model. These activities provided a preliminary assessment sufficient to conclude that the PWS was only partially effective in capturing Shallow zone mine-impacted groundwater during its operational life. The PWS effectiveness evaluation is described in the *Summary of PWS Aquifer Testing* (BC 2010f), which is included as Appendix J-1.

3.3.2 Pit Lake Water Levels

The Pit Lake (OU-2), which is currently refilling with groundwater from bedrock and alluvial flow systems (BC 2014a), has been studied to better understand its influence on Site-wide groundwater conditions. Pit Lake studies related to OU-1 include routine monitoring of the Pit Lake water level elevation beginning in September 2007 and a water balance evaluation (Appendix J-2) to predict the future “steady-state” elevation of the Pit Lake.

Groundwater inflow, based on the lake water balance study, is estimated to be slightly greater than the current rate of evaporation. Thus, the lake level is slowly rising with time. The Pit Lake water balance and projection of the pit refilling curve (Figure 3-7) indicate that the lake is expected to reach a steady-state level, where water inflow and evaporation are balanced, prior to 2030. The steady-state Pit Lake elevation is estimated to be in the range of 4,249 to 4,253 feet amsl, with more recent data indicating that the steady-state elevation may fall within the lower end of this range. The steady-state Pit Lake elevation is approximately: 1) 100 feet lower than the pre-mining groundwater elevation range of 4,350 to 4,375 feet amsl reported by Gill (1951); 2) 140 feet lower than current groundwater levels in the alluvial aquifer adjacent to the Walker River just east of the Pit Lake; 3) 65 feet lower than the current groundwater levels beneath the Evaporation Ponds; and 4) 150 and 340 feet below the east and west pit rim elevations, respectively.

The steady-state Pit Lake level is projected to be lower than the pre-mining water level as the result of the significant evaporation that occurs from the Pit Lake surface. Consequently, the lake is and will continue to be a groundwater sink that creates a localized cone of depression (extending as far north as the Process Areas) with local groundwater flow toward the pit. Because the Pit Lake does not and will not in the future discharge into the Site-wide groundwater system, the Pit Lake is not a source of COIs to Site-Wide groundwater.

3.3.3 Groundwater Pumping and Surface Water Points of Diversion

Groundwater conditions in the Study Area are influenced by groundwater pumping and surface water diversion associated primarily with irrigation and, to a lesser extent, stock watering and mining/milling (BC 2014a; S.S. Papadopulos & Associates, Inc. [SSPA] 2014).

Publicly-available groundwater pumping and surface water diversion information applicable to the Study Area is provided in the *Revised Public Information for the Northern Portion of the Background Groundwater Study Area* (BC 2013d) included in Appendix J-3. That document also includes: well ownership, location and construction; underground and surface water rights and points of diversion (PODs); well pumping records from 1993 to 2010; sub-surface lithology and, as applicable, depth to bedrock; and groundwater elevations from the NDWR and the USGS.

PODs from an underground source (i.e., groundwater) for the wells with water rights within and adjacent to the Study Area are shown on Figure 3-8, along with diversion rates and annual duties. All agricultural wells within and near the Study Area are screened in the alluvial aquifer. Although well construction varies greatly, agricultural wells used to extract groundwater for crop irrigation are either screened beginning at or near the water table to the total depth of installation and/or have been installed with a permeable filter pack from above the water table surface to the total depth of installation. Annual pumping inventories (i.e., actual total amounts pumped each year) for wells in the Mason Valley from 1994 to 2003 and from 2004 to 2010 have been reported by Gallagher (2004) and Gallagher (2013), respectively.

Within the Study Area, there are 20 wells used for irrigation, four wells used for stock watering, one used for mining/milling, and one used for commercial purposes (Gallagher 2013). The 20 irrigation wells are currently permitted to irrigate a total of 5,509 acres using an annual duty of 15,788 acre-feet with a combined diversion rate of 46.36 cubic feet per second (cfs). Of the 36 active water rights, 26 allow for pumping to occur on a year-round basis, nine of the rights can only be pumped during the irrigation season, and one right can only be used in the winter.

The place of use (POU) of 37 surface water rights within and adjacent to the Study Area that are identified in the amended Walker River Decree (WRD), Case in Equity, C-125, filed April 24, 1940 (WRD C-125; WRD, 1940) are shown on Figure 3-9. This figure also shows the POUs of surface water rights approved by NDWR as either new appropriations or applications to change WRD rights. Additional information about the distribution and routing of surface water is included in the discussion of surface water hydrology in Section 4.7.

The POUs of flood waters permitted by NDWR Application 5528, Certificate 8859 are shown on Figure 3-10 by quarter-section. Application 5528 was filed by the Walker River Irrigation District (WRID) to divert flood waters from the Walker River for irrigation from May 1 to July 31 of each year. Application 5528 was certificated for 491.2 cfs, not to exceed 89,612 acre-feet per season (the total duty of water cannot exceed 4.0 acre-feet per acre per season from any and/or all sources). The lands irrigated under this Certificate during any one season cannot exceed 30,000 acres.

3.3.4 Groundwater Model Development

The 2007 SOW (EPA 2007a) specified that the OU-1 RI “extrapolate the future contaminant transport using a comprehensive groundwater flow and fate-and-transport model”. In addition, determining groundwater flow and chemical transport rates was identified as DQO #6 in the Revised Groundwater RI Work Pan (BC 2014a).

The technical and programmatic framework to address quantitative numerical modeling of groundwater flow and chemical transport was developed during iterative technical discussions with the EPA, ARC, and other stakeholders, and documented in the Revised Groundwater RI Work Plan (BC 2014a). Table 3-10 summarizes the chronology of investigations, evaluations, communications, and documents related to groundwater flow modeling.

Table 3-10. Chronology of Groundwater Modeling Activities

2004-2007	Characterization of groundwater conditions in the Study Area pursuant to the First-Step HFA Work Plan (BC 2005) and Second-Step HFA Work Plan (BC 2007b).
2007	Characterization of bedrock groundwater conditions is required under the Administrative Order for Remedial Investigation and Feasibility Study (RI/FS), CERCLA Docket No. 9-2007-0005 dated January 12, 2007.
2007-2011	Characterization of groundwater conditions in the Study Area pursuant to the various work plans and related correspondence (BC 2008c, 2010c, 2010d, 2011a; ARC 2011).
May 16, 2011	Conference call with EPA, ARC and other stakeholders to discuss groundwater flow modeling.
August 17, 2011	Groundwater technical meeting with EPA, ARC and stakeholders to discuss the status of RI activities, which resulted in concurrence to conduct groundwater modeling to support a quantitative evaluation of groundwater flow and chemical transport.
June 4, 2012	Conference call with EPA, ARC and other stakeholders to discuss groundwater flow modeling activities, which resulted in a request by EPA that ARC submit a document describing key groundwater modeling deliverables and milestones, and a draft table of contents for a groundwater modeling work plan.
June 25, 2012	ARC submitted the *Groundwater Flow Modeling Deliverables* (ARC 2012c), which included: 1) a preliminary summary of key groundwater modeling deliverables and milestones; and 2) a draft table of contents for a groundwater flow model work plan.
July 11, 2012	EPA (2012e) provided comments on the *Groundwater Flow Modeling Deliverables* (ARC 2012c).
July 17, 2012	Groundwater technical meeting with EPA, ARC and stakeholders to discuss findings of the 2011 Monitor Well Installation investigation, and related RI activities, which resulted in an EPA request that ARC submit a document summarizing groundwater modeling objectives.
August 14, 2012	ARC submitted the *Objectives for Groundwater Modeling in the RI/FS Process, Yerington Mine Site* (SSPA 2012a).
August 29, 2012	Groundwater technical meeting with EPA, ARC, and other stakeholders to discuss the groundwater modeling objectives.
October 15, 2012	ARC submittal of the *Objectives for Groundwater Modeling in the RI/FS Process - Revision 1, Yerington Mine Site* (SSPA 2012b).
October 26, 2012	EPA (2012f) approval of the *Objectives for Groundwater Modeling in the RI/FS Process - Revision 1, Yerington Mine Site* (SSPA 2012b).

Table 3-10. Chronology of Groundwater Modeling Activities	
December 28, 2012	ARC submittal of the *Draft Groundwater Flow Model Work Plan for the Yerington Mine Site* (SSPA 2012c).
March 29, 2013	EPA (2013d) provided comments on the *Draft Groundwater Flow Model Work Plan for the Yerington Mine Site* (SSPA 2012c).
May 21, 2013	ARC submittal of the *Groundwater Flow Model Work Plan - Revision 1* (SSPA 2013) included as Attachment E to the Revised Groundwater RI Work Plan, along with responses to EPA comments on the *Draft Groundwater Flow Model Work Plan* (SSPA 2012c).
March 18, 2014	ARC submittal of the *Groundwater Flow Model Yerington Mine Site* (SSPA 2014). This report synthesized available hydrologic and geochemical information into a quantitative representation of the current and historic HCSM. The report also contained: 1) documentation of the study goals; 2) a discussion of the modeling strategy and assumptions; 3) details about model construction, calibration and validation; 4) a summary of model predictions; and 5) an analysis of the uncertainty associated with the model predictions.
October 28, 2014	EPA provided comments on the *Groundwater Flow Model Yerington Mine Site* (SSPA 2014).
February 3, 2015	ARC submits the *Flow Model "Supplemental" Materials* (SSPA 2015) in response to EPA comments.
May 18, 2015	EPA (2015b) provided comments on the *Flow Model "Supplemental" Materials* (SSPA 2015) and approved the *Groundwater Flow Model Yerington Mine Site* (SSPA 2014).

Based on review of the *Flow Model Supplemental Materials* (SSPA 2015), EPA (2015b) constrained the modeling objective and approved the groundwater flow model, noting that: "The primary goal foreseen for the Yerington groundwater model is to provide a management tool that can be used to evaluate possible remediation options. As such, its greatest value will be in allowing short-term comparisons of remedial designs and possible effectiveness of different remediation scenarios using a common tool and less so in predicting long-term migration of contaminants. It appears that this tool is adequate for that purpose".

The groundwater flow model is provided in Appendix J-4. The flow model domain, which encompasses an area of approximately 86 square miles, consists of that portion of the Mason Valley west of the Walker River and north of Mason that is underlain by saturated alluvium (Regional Domain). Nested within the model domain is the Study Area which encompasses an area of approximately 23 square miles that is bounded to the north by Campbell Lane, to the west by the Singatse Range, to the east by a north-south trending line located one mile east of Highway 95, and to the southeast by the Walker River (Local Domain). The Local Domain is nested within the Regional Domain so that appropriate boundary conditions along the northern and eastern boundaries of the overall model domain can be calculated. In addition, the model domain is subdivided to reflect two different sources of data, which may differ in data quality.

The vertical extent of the model domain extends from the ground surface to the alluvial/bedrock contact and into the portions of the bedrock groundwater system in hydrologic communication with the alluvial aquifer. The model domain extends laterally to include monitor well locations for identifying background groundwater quality and groundwater impacted by mining and other anthropogenic activities.

Since 2005, hydrogeologic data within the Local Domain have been and continue to be collected as part of the RI process, pursuant to EPA-approved planning documents and work plans. Thus, these data are high quality and there is a high degree of confidence in the data. Hydrogeologic data from outside the Local Domain but within the Regional Domain are from multiple sources and are of uncertain quality. Much of these data are from the USGS (e.g., water-level data) and the NDWR (e.g., well logs).

Temporal (e.g., seasonal, annual) variations in groundwater flow patterns and chemical concentrations continue to be assessed due to variability in hydrologic stresses on the groundwater system. Monitor wells installed for groundwater characterization purposes continue to be routinely monitored pursuant to the GMP (BC 2012a) to address temporal aspects of the study within the Local Domain. Within the Regional Domain, available water-level and surface water flow data from the USGS and NDWR will be used to assess temporal variations in groundwater conditions.

3.3.5 Chemical Transport Evaluations

The technical and programmatic framework for characterizing groundwater geochemical conditions and assessing geochemical processes that affect the release and subsequent mobility or attenuation of COIs during groundwater transport in the Study Area was presented as DQO #3 in Revised Groundwater RI Work Plan (BC 2014a).

Table 3-11 summarizes the chronology of investigations, evaluations, communications, and documents related to chemical transport evaluation.

Table 3-11. Chronology of Activities to Determine Geochemical Mobilization/Attenuation Processes	
2008	The Second-Step HFA Work Plan (BC 2007b) included collecting and archiving redox-preserved samples of saturated and unsaturated alluvium. EPA technical staff observed the redox-sample collection and archiving methods, and provided input on locations and depth intervals for collecting an initial set of samples. These initial samples were collected for use in a "methods development" phase of work intended to develop Site-specific testing procedures.
June 21, 2010	ARC submitted the *Draft Aquifer Solids Testing Work Plan* (BC 2010g).
September 13, 2010	EPA (2010a) provided comments on the *Draft Aquifer Solids Testing Work Plan* (BC 2010g).
September 21, 2010	ARC submitted the *Aquifer Solids Testing Work Plan - Revision 1* (BC 2010e), which was revised in response to EPA comments.
September 30, 2010	EPA (2010b) approved the *Aquifer Solids Testing Work Plan - Revision 1* (BC 2010e).
2011	ARC developed Site-specific procedures and methods to physically separate redox-preserved samples into solid and liquid fractions for subsequent characterization of total metals concentrations, mineralogy, and porewater chemistry.
February 28, 2012	EPA technical staff visited the testing laboratory (Hazen Research, Inc. in Golden, Colorado) and observed the Site-specific testing procedures.
August 17, 2012	ARC submittal of *SOP-23: Aquifer Solids Testing SOP - Redox-Preserved Sample Preparation and Testing* (BC 2012c).
September 26, 2012	EPA (2012g) transmitted comments on *SOP-23: Aquifer Solids Testing SOP- Redox-Preserved Sample Preparation and Testing* (BC 2012c).
October 15, 2012	ARC submittal of *SOP-23: Aquifer Solids Testing SOP - Redox-Preserved Sample Preparation and Testing - Revision 1* (BC 2012d).
October 22, 2012	EPA (2012d) approval of SOP-23 Revision 1, pending minor changes. These minor changes were incorporated into SOP-23 Revision 2*,* included as Appendix H-1 to the Revised Groundwater RI Work Plan (BC 2014a).
February 7, 2014	ARC submitted the Revised Groundwater RI Work Plan (BC 2014a), which included: 1) DQO #3 pertaining to geochemical attenuation/mobilization; 2) the thermodynamic data for Site-specific geochemical modeling; and 3) Site-specific distribution coefficients (a simple, lumped-parameter variable that describes either the relative affinity of the aquifer matrix for a particular ion or the mobility of the ion in a groundwater flow system) based on chemical concentrations in co-located aquifer sediment and groundwater samples.
October 9, 2014	EPA (2014b) approved the Revised Groundwater RI Work Plan including the thermodynamic data presented in Appendix H-4 for Site-specific geochemical modeling, and directed ARC to prepare a Groundwater Geochemical Characterization Data Summary Report.
December 30, 2014	ARC submitted the *Groundwater Geochemical Characterization Data Summary Report* (BC 2014c). As noted in ARC's transmittal letter, the document partially fulfilled the requirements for the geochemical characterization and ARC recommended additional refinements to the thermodynamic database for geochemical modeling.
April 27, 2015	ARC transmitted recommendations to EPA for refining the thermodynamic database to be used for geochemical modeling (via e-mail).
May 4, 2015	EPA approved ARC's recommendations on refining the thermodynamic database to be used for geochemical modeling (also via e-mail).
September 23, 2015	EPA, ARC and other stakeholders agreed during a conference call that geochemical characterization to be performed for the OU-1 RI should focus on geochemical modeling of: 1) controls on the fate and transport of key COIs anticipated to drive decision-making in the FS; and 2) other chemicals that may affect their mobility and transport in groundwater.
December 11, 2015	ARC submitted the *Groundwater Geochemical Characterization Data Summary Report – Revision 1* (BC 2015e).

Table 3-11. Chronology of Activities to Determine Geochemical Mobilization/Attenuation Processes	
July 2016	EPA conditionally approved the document on July 31, 2016 (EPA 2016b) subject to minor editorial changes and revision of statements referencing COI concentrations and spatial extent relative to background chemical concentrations presented in the *Background Groundwater Quality Assessment - Revision 2* (BC 2015c). EPA recommended that a revised version of the report be included as an appendix to the OU-1 RI Report.

The *Groundwater Geochemical Characterization Data Summary Report - Revision 2* (BC 2016a) is provided in Appendix J-5. The chemical speciation model and approach to calculating Site-specific distribution coefficients is summarized below.

Chemical Speciation Model Development

The specific objectives of the *Groundwater Geochemical Characterization Data Summary Report - Revision 2* are as follows:

- Describe the occurrence and distributions of select chemicals in Study Area groundwater based on the comprehensive set of monitor well data obtained during August 2014; and
- Using the EPA-approved thermodynamic database developed for the Site and geochemical modeling, evaluate the aqueous geochemical speciation of select COIs and potential formation of solid mineral phases in Study Area groundwater to assess chemical mobility/attenuation.

The primary geochemical data inputs used to identify the geochemical processes controlling chemical transport consist of: 1) groundwater chemical data from monitor wells installed in the groundwater zones in the alluvial aquifer and bedrock; 2) field parameter measurements that characterize the pH and redox status of the groundwater system (because these affect the aqueous speciation of inorganic chemicals and formation of mineral phases); and 3) thermodynamic data describing chemical reactions for each of the important aqueous species, minerals comprising the aquifer solids, gases, and adsorbed species. The geochemical assessment primarily relied on groundwater information associated with the August 2014 groundwater monitoring event. Approximately 2% of the August 2014 dataset had speciated charge imbalances outside the acceptable range of ±10%, and groundwater data obtained in October 2014 were substituted for August 2014 data.

Geochemical modeling using the Site-specific thermodynamic database with PHREEQC version 3.1.5 was conducted to determine the chemical speciation of aqueous constituents and the saturation indices of solid mineral phases in equilibrium with the groundwater samples. The geochemical modeling did not involve adsorption to aquifer soil/sediments or organics in aquifer materials. Details regarding the development of the Site-specific thermodynamic database are provided in Appendix J-5 and key modifications are discussed briefly below.

The WATEQ4F database was used as the starting point for database development because its major-element data are consistent with the Nordstrom et al. (1990) data compilation, which is a reliable and internally-consistent data set. Subsequently, the WATEQ4F database was modified by replacing aqueous speciation and solid-phase solubility data for uranium, phosphate, vanadium, sulfide, arsenic and copper with new data that have been critically reviewed by federal agencies (e.g., compilations prepared by the Nuclear Energy Agency were the principal sources of the uranium data in the ARC database) or in the peer-reviewed literature (e.g., Dong and Brooks 2006). Uranyl species $Ca_2UO_2(CO_3)_3^0$, $CaUO_2(CO_3)_3^{-2}$, $Mg_2UO_2(CO_3)_3^0$ and $MgUO_2(CO_3)_3^{-2}$ are of particular importance in evaluating the mobility of uranium; therefore, the thermodynamic data for these constituents were added to the Site-specific database. Thermodynamic solubility data for schwertmannite (an oxyhydroxide sulfate mineral) reported by Bigham et al. (1996) and confirmed by Sánchez-España et al. (2011) were included in the database. In addition, thermodynamic solubility data reported by Bourrié et al. (1999) for three hydroxy-green rusts were included in the database.

PHREEQC is a geochemical software model distributed by the USGS. The model assumes equilibrium mass transfer and does not account for the kinetics of mineral precipitation and dissolution reactions using applicable reaction rate laws (Parkhurst and Appelo 1999; EPA 2007b). Chemical speciation modeling describes the distribution of chemical mass between aqueous and solid mineral phases, and hence, predicts the geochemical conditions under which various constituents might be sequestered by mineral precipitation or remain mobile in the groundwater flow system. Both chemical speciation and mineral precipitation are pertinent data for evaluating the mobility of constituents in the groundwater system.

Information generated from the geochemical assessment is incorporated into the discussion of contaminant fate and transport in Section 6.0, and will be used to guide the development of quantitative approaches to representing chemical transport in the numerical groundwater flow model (SSPA 2014) to evaluate various remedial alternatives during the FS. As noted by the EPA (2016b), decisions will be made during the FS regarding the most appropriate reactive transport modelling approach and whether it will be necessary and/or beneficial to integrate the models or how that can be accomplished to efficiently meet the technical needs of the OU-1 RI/FS without introducing unnecessary complexity to the modeling efforts.

Distribution Coefficients

The partition (distribution) coefficient (K_d) is a simple, lumped-parameter variable that is used to assess contaminant transport by describing either the relative affinity of the aquifer matrix for a particular ion or the mobility of the ion in a groundwater flow system (EPA 2007b; Freeze and Cherry 1979).

The initial approach to developing Site-specific distribution coefficients based on chemical concentrations in co-located groundwater and aquifer sediment samples was presented in the Revised Groundwater RI Work Plan (BC 2014a) and is reproduced in this OU-1 RI Report as Appendix J-6. The approach to developing the distribution coefficients is summarized below.

Distribution coefficients were calculated for a variety of chemicals in Site groundwater including aluminum, arsenic, barium, boron, calcium, chloride, chromium, cobalt, copper, fluoride, iron, lead, lithium, magnesium, manganese, molybdenum, nickel, nitrate, potassium, selenium, sodium, sulfate, uranium, vanadium, and zinc. Distribution coefficients were not calculated for parameters that were only infrequently detected in groundwater or are not likely to be the subject of FS transport modeling including alkalinity, antimony, beryllium, cadmium, mercury, phosphorous, silica, silver, strontium, thallium, tin, and titanium.

Site-specific distribution coefficients were calculated using data from a single set of soil samples that were collected during the borehole drilling for monitor well installation and two distinct sets of water quality data. Soil samples were analyzed for a variety of bulk chemical concentrations (analyses were performed on liquid extracts from treatment of the solid samples by microwave-assisted digestion using EPA Method 3051A).

The first set of water quality data used in K_d calculations was the zonal water quality data that were collected at the time of borehole drilling. As discussed in Section 3.2.1, zonal groundwater samples were analyzed only for sulfate, uranium and arsenic. These data were collected over small depth intervals, typically ranging from three to five feet. Co-located zonal groundwater and soil samples were collected at multiple depth intervals in 13 locations throughout the Site that included B/W-1, B/W-2, B/W-3, B/W-4, B/W-11, B/W-31, B/W-32, B/W-42, B/W-46, B/W-61, B/W-62, B/W-65, and B/W-66.

The second set of water quality data used in K_d calculations included groundwater quality data obtained during quarterly sampling events from 15 monitor wells typically having a screen interval length of 20 feet. Monitor well samples were analyzed for the broader set of constituents listed in Table 3-4. The soil sample data used in the calculations were selected such that the sample intervals were within the screened interval of the well. The wells considered in this portion of the analysis were B/W-2D1, B/W-3I, B/W-4I, B/W-4D1, B/W-11D2, B/W-31S1, B/W-31S2, B/W-32S, B/W-42S, B/W-46S, B/W-61S, B/W-62S, B/W-65S, B/W-66S, and B/W-67S. The quarterly groundwater quality results collected closest to the date of the zonal soil sample collection for each particular well were used to calculate K_d values to minimize potential effects from variability in groundwater concentrations over time.

The distribution coefficient is calculated as the ratio of the concentration of a chemical adsorbed onto the solid phase (commonly expressed as milligrams [mg] of chemical per kilogram [kg] of solid) to the dissolved concentration of the chemical in the water (mg of chemical per liter [L] of solution) at equilibrium (Freeze and Cherry 1979). Based on the formulation below, K_d values are expressed in units of L/kg.

$$K_d = \frac{C_{adsorbed}}{C_{water}}$$

where: $C_{adsorbed}$ = adsorbed chemical concentration (mg/kg)
C_{water} = dissolved chemical concentration in water (mg/L)

Initially, distribution coefficients were calculated using water chemical data and chemical concentrations in the aquifer sediment sample that were determined using EPA digestion Method 3051A. Because of the relatively aggressive digestion method, the aquifer sediment data represent the bulk (i.e., total) chemical concentration in the solid rather than the adsorbed chemical concentration. As recommended by EPA (1999), trace metals that are present in crystalline lattice sites of minerals present in soils do not participate in adsorption/desorption reactions and should not be included in the K_d calculation. Consequently, the original K_ds were revised for this OU-1 RI Report. To better estimate K_ds, the adsorbed amount of a chemical was estimated by subtracting the average chemical concentration in Sub-area A-1 soils (BC 2009b) from the bulk (i.e., total) chemical concentration in the individual aquifer sediment sample, as follows:

$$K_d = \frac{C_{soil} - C_{bkgd}}{C_{water}}$$

where: $C_{adsorbed} = C_{soil} - C_{bkgd}$
C_{soil} = bulk chemical concentration in the solid (mg/kg)
C_{bkgd} = average background chemical concentration in the solid (mg/kg)
C_{water} = dissolved chemical concentration in water (mg/L)

The revised Site-specific distribution coefficient values are presented in the contaminant fate and transport discussion in Section 6.0.

3.3.6 Background Groundwater Quality Assessment

Identifying background water types and defining the extent of mine-impacted groundwater was specified in the 2007 SOW (EPA 2007a) and identified as DQO #1 in the Revised Groundwater RI Work Plan (BC 2014a). The background groundwater quality assessment (BGQA) has been integrated into groundwater characterization activities performed in the Study Area since 2007.

Table 3-12 summarizes the chronology of the BGQA and other background-related orders, investigations and documents.

Table 3-12. Chronology of Activities Related to Establishing Background Groundwater Quality

2004-2008	Monitor wells B/W-13S, B/W-14S, B/W-15S, B/W-20S, and B/W-21S installed adjacent to Walker River and hydraulically up-gradient of the Site, pursuant to the First-Step HFA Work Plan (BC 2005) and the Second-Step HFA Work Plan (BC 2007b).
2007	Characterization of background groundwater quality is required under the Administrative Order for Remedial Investigation and Feasibility Study (RI/FS), CERCLA Docket No. 9-2007-0005 dated January 12, 2007.
2007-2011	Background characterization conducted pursuant to the *2010 Groundwater Monitor Well Installation Work Plan - Revision 2* (BC 2010c), *Agricultural Fields Characterization Work Plan - Revision 2* (BC 2010d), *On-Site Monitor Installation Work Plan - Revision 1* (BC 2011a), and the *Addendum to the On-Site Monitor Well Installation Work Plan* (ARC 2011).
August 17, 2011	Groundwater technical meeting with EPA, ARC and stakeholders to discuss progress of the phased approach to groundwater RI activities, which resulted in concurrence to accelerate background groundwater characterization activities and an EPA request for ARC to prepare and submit a BGQA. Also discussed were installation of additional well clusters (B/W-12R, B/W-17, and B/W-22R) in areas south and southwest of the Site, pursuant to the *On-Site Monitor Well Installation Work Plan* (BC 2011a), to support background groundwater characterization.
September 7, 2011	ARC submitted the *Addendum to the On-Site Monitor Well Installation Work Plan* (ARC 2011) proposing additional well clusters at B/W-12R, B/W-17, and B/W-26R to support background groundwater characterization.
September 28, 2011	ARC submitted the *Draft Background Groundwater Quality Assessment* (BC 2011c), which recommended the installation of three monitor well clusters (B/W-56, B/W-57 and B/W-58) located in the northern portion of the Study Area.
September 30, 2011	The *Addendum to the On-Site Monitor Well Installation Work Plan* (ARC 2011) was approved by EPA (2011b).
December 7, 2011	Via e-mail communication, ARC requests and receives EPA approval to install well clusters B/W-56, B/W-57, and B/W-58 proposed in the Draft BGQA during implementation of the *On-Site Monitor Well Installation Work Plan - Revision 1*.
February 7, 2012	EPA (2012a) provided comments on the Draft BGQA.
March 19, 2012	ARC (2012d) submitted a request to implement a comprehensive hydrologic tracer sampling event that was larger in scope than the sampling event proposed in the *On-Site Monitor Well Installation Work Plan - Revision 1* (BC 2011a) and to eliminate select hydrologic tracers. Hydrologic tracers are considered one line of evidence that may be useful for determining background groundwater quality.
April 18, 2012	ARC (2012e) submitted responses to EPA comments on the Draft BGQA.
April 27, 2012	EPA approved the comprehensive hydrologic tracer sampling event and request to eliminate select tracers (EPA 2012b).
May 2012	Comprehensive hydrologic tracer sampling event conducted concurrent with the 2Q 2012 quarterly groundwater monitoring event.
August 28, 2012	Groundwater technical meeting with EPA, ARC, and other stakeholders to clarify and resolve comments on the Draft BGQA.
November 19, 2012	Submittal of final ARC responses to EPA comments on the *Draft BGQA* and the *Background Groundwater Quality Assessment - Revision 1* as Attachment A to the *Draft Site-Wide Groundwater Operable Unit (OU-1) Remedial Investigation Work Plan* (BC 2012b).

Table 3-12. Chronology of Activities Related to Establishing Background Groundwater Quality

June 26, 2013	Submittal of the *Draft Additional Monitor Well Work Plan* (BC 2013e) as Attachment B to the *Draft Site-Wide Groundwater Operable Unit (OU-1) Remedial Investigation Work Plan* (BC 2012b), to address data gaps identified by ARC and EPA, including groundwater conditions in the north and northeastern portion of the Study Area. ARC recommended sampling of all wells proposed for hydrologic tracers to supplement data from the May 2012 hydrologic tracer sampling event.
July 29, 2013	EPA (2013e) provided comments on the *Draft Additional Monitor Well Work Plan*.
October 8, 2013	ARC submitted the *Additional Monitor Well Work Plan - Revision 1* (Additional Well Work Plan; BC 2013b). This work plan was also included as Attachment B to the Revised Groundwater RI Work Plan (BC 2014a). EPA (2014b) approved the Revised Groundwater RI Work Plan including Attachment B on October 9, 2014.
September 2013 to July 2014	Installation, development, and hydraulic testing of new wells installed pursuant the Additional Well Work Plan (BC 2013b).
August 2014	Hydrologic tracer sampling of new wells installed pursuant to the Additional Well Work Plan (BC 2013b).
May 2015	Receipt of hydrologic tracer laboratory analytical results for new wells installed pursuant to the Additional Well Work Plan (BC 2013b).
June 11, 2015	ARC submitted the *Additional Monitor Well Installation Data Summary Report* (BC 2015d).
July 2, 2015	ARC submitted the *BGQA – Revision 1 - Revision 2* (BC 2015c), which described: 1) the technical approach, scope, rationale and methods to establish background groundwater quality; and 2) multiple supporting lines of evidence for defining the extent of mine-impacted groundwater and identifying other anthropogenic groundwater impacts.
February 11, 2016	EPA (2016c) provided comments on the *Background Groundwater Quality Assessment - Revision 2*.
June 14, 2016	ARC (2016b) provided responses to EPA Comments on the *Background Groundwater Quality Assessment - Revision 2*.
June 29, 2016	EPA, ARC and other project stakeholders held a groundwater technical meeting to discuss the background assessment.
September 27, 2016	EPA (2016d) letter to ARC providing final direction on the background groundwater quality assessment including an attachment (EPA 2016e) dated September 2, 2016 and titled EPA Memorandum, Subject: Yerington Mine Site, Yerington Nevada (16-R09-003) Responses to ARC Responses to Comments on the Background Groundwater Quality Assessment - Revision 2.
November 11, 2016	ARC submitted the *Background Groundwater Quality Assessment - Revision 3* (BC 2016b).
February 16, 2017	EPA (2017) approved the *Background Groundwater Quality Assessment - Revision 3*.

The *Background Groundwater Quality Assessment - Revision 3* is provided in Appendix J-7 and the results of the background assessment are integrated into the discussion of the nature and extent of contamination in Section 5.0.

3.4 Former Domestic Well Monitoring and Bottled Water Programs

Water quality monitoring of domestic, commercial, and irrigation wells (collectively referred to as domestic wells) located near the Site has evolved over time.

Domestic well monitoring began in late 1983. Up through early 2009, domestic well monitoring activities were performed pursuant to:

- Paragraphs 15(e) and 15(f) of the Unilateral Administrative Order for Initial Response Activities, Docket No. 9-2005-0011 (2005 Order);
- Section 6.0 of the 2007 SOW; and
- The Administrative Order on Consent and Settlement Agreement for Removal Actions and Past Response Costs, Docket No. 09-2009-0010 (2009 Order).

In March 2009, EPA requested that ARC expand the domestic well monitoring program because of the EPA-approved shutdown of the PWS to evaluate OU-1 hydrogeologic conditions. The expanded domestic well monitoring program has been conducted pursuant to the *Domestic Well Monitoring Plan - Revision 3* (DWMP; BC 2010b), which was prepared as an addendum to the Site-Wide QAPP (ESI and BC 2009). Results of domestic well monitoring have been used to: 1) characterize the quality of groundwater used for drinking water or other domestic water supply purposes; 2) assess potential risk, if any, to human health and the environment by the use of groundwater extracted by domestic wells for drinking water or agricultural purposes; and 3) determine eligibility for receiving bottled water as part of an interim response action.

The Bottled Water Program was initiated in March 2004. Domestic well owners were deemed eligible to receive bottled water if uranium concentrations measured during domestic well monitoring exceeded 25 µg/L.

The number of wells/properties included in the DWMP and Bottled Water Program was substantially reduced in 2016 (ARC 2016a; EPA 2016f). As part of the settlement entered in the class action lawsuit *Roeder et al. v. Atlantic Richfield Company et al.*, D. Nev., Case No. 3-11-cv-00105-RCJ-WGC ("Roeder Settlement Agreement"), ARC provided funding to the City of Yerington to extend municipal water service to then-existing residences located within that part of the settlement class area that was also within the City's projected future service area. Domestic well owners who connected to the City of Yerington's municipal water system could elect to either abandon their well or apply for a state permit to authorize withdrawals of groundwater for outdoor use only (landscape watering). Each property owner who received a connection to the City Water System executed and recorded an environmental covenant either prohibiting future domestic use of groundwater altogether or limiting it to outdoor purposes.

Construction of the expanded water system began in the fall of 2014 and the construction of new mains and service connections was completed in June 2016. The first phase of well abandonments and system testing was completed as of August 1, 2016. The water system is functional, and domestic wells for all participating property owners have been abandoned or disconnected from the residences within the expansion area. A relatively small number of domestic wells located within the area of mine-impacted groundwater (see Figure 3-11) were not disconnected or converted to outdoor use only in 2016. ARC has been in communication with the owners of most of these wells, and disconnections for all but a few are scheduled to occur in 2017.

SECTION 4.0
PHYSICAL CHARACTERISTICS OF THE STUDY AREA

This section describes the physical characteristics of the Study Area including demographics, land use, climate, topography, geology and soils, hydrology and groundwater, ecological setting, and vegetation.

4.1 Demographics and Study Area Land Use

Lyon County, Nevada covers approximately 1,993 square miles, and its population in 2013 was 51,585 (U.S. Census Bureau 2015). Communities near the Site include Yerington (population 3,486), Weed Heights (population 500), and the YPT (approximate population 575). The regional population and industrial centers near the Site include Fernley (47 miles north), Fallon (59 miles northwest), Hawthorne (57 miles southeast), and Reno (85 miles northwest). Yerington's economic base is primarily agriculture.

Land use has included mine operations, ranching, agriculture, urban development, establishment of the YPT colony, BLM range land, and residential development. Mason Valley has long been the largest agricultural area in the Walker River basin and the most productive area in Nevada. In 2000, a total of 88,600 acres of irrigated land was mapped in the Walker River basin. Total irrigated land included 39,100 acres (44%) in Mason Valley (USGS 2009a).

4.2 Climate

Nevada is located on the leeward side (rain shadow) of the Sierra Nevada mountain range, which results in a dry climate. The climate in Lyon County is warm and arid. Snow melt is the primary natural source of streamflow and groundwater recharge in the Walker River Basin (USGS 2009b). The average annual precipitation in Yerington is approximately 5.1 inches, and average snowfall is 6.7 inches (Western Regional Climate Center [WRCC] 2015). The annual average precipitation rate is low relative to the regional pan evaporation rate of about 69 inches per year. The average monthly temperature for the period of record (March 1, 1894 through January 20, 2015) ranges from a maximum of 92.4 degrees Fahrenheit (°F) in July to a minimum of 17.8°F in January.

Tables 4-1 and 4-2 summarize monthly climate data for the City of Yerington weather station for the period from 1894 through 2015 (WRCC 2015). Table 4-1 summarizes monthly minimum and maximum temperatures, and monthly precipitation. Table 4-2 provides monthly average, maximum, and minimum precipitation values, and the one-day maximum rainfall event.

Table 4-1. Average Monthly Climate Data for the Yerington Weather Station #269229 (1894 - 2015)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Average Maximum. Temperature (°F) [1]	46.2	52.5	59.7	67.0	75.1	83.8	92.4	91.0	83.1	70.8	56.8	47.1	68.8
Average Minimum Temperature (°F) [1]	17.8	22.6	27.0	32.4	40.2	46.8	52.7	50.4	42.3	33.3	23.5	17.9	33.9
Average Total Precipitation[2]	0.57	0.53	0.42	0.41	0.63	0.46	0.26	0.25	0.24	0.35	0.42	0.52	5.06
Average Snow Fall [2]	1.9	1.2	1.0	0.4	0.1	0.0	0.0	0.0	0.0	0.1	0.8	1.2	6.7

Notes:

1) °F = Degrees Fahrenheit;
2) Precipitation values in inches

Table 4-2. Precipitation Data for the Yerington Weather Station #269229 (1894 - 2012)

Month	Mean	Maximum	Year	Minimum	Year	1-Day Maximum (Year)
January	0.57	3.67	1916	0.00	1915	1.40 (1943)
February	0.53	2.62	1962	0.00	1953	1.28 (1962)
March	0.42	1.83	1991	0.00	1914	0.98 (1941)
April	0.41	1.80	1990	0.00	1916	1.30 (1990)
May	0.63	3.04	1995	0.00	1916	1.90 (1939)
June	0.46	2.01	1997	0.00	1895	1.02 (1997)
July	0.26	2.00	2003	0.00	1916	1.75 (1984)
August	0.25	2.37	1983	0.00	1895	1.46 (1983)
September	0.24	2.15	1955	0.00	1920	2.02 (1955)
October	0.35	3.02	1993	0.00	1895	1.83 (1993)
November	0.42	2.39	1965	0.00	1894	1.04 (1974)
December	0.52	3.51	1955	0.00	1917	2.00 (1955)
Annual	5.06	10.58	1983	1.61	1947	2.02 (1955)

Notes:

1) Precipitation values presented in inches.
2) Most minimum values (11 of 12 months) of 0.00 inches were recorded prior to 1920.

Wind speed and direction at the Site vary on the local scale due, in part, to the heterogeneous natural topography (i.e., micro-climates) and modified topography due to surface mining operations. Meteorological data collected since 2002 indicate that wind direction is variable at the Site with no quadrant representing over 50% of the total measurements. However, when wind speeds are above 15 miles per hour, a predominant wind direction from southwest to northeast has been documented (BC, 2008c).

4.3 Topography

The Site is in Mason Valley, which is a north-south trending structural valley (graben) within the Basin and Range physiographic province filled with up to 1,000 feet of unconsolidated sediments. Mason Valley occupies a structural graben (i.e., down-dropped faulted basin) immediately east of the Singatse Range, Desert Mountains to the north, and the Wassuk Range to the east. Elevations in the Wassuk and Singatse Ranges reach 9,000 and 6,700 feet amsl, respectively (Huxel and Harris 1969). The valley ranges in width from about nine miles in the south to nearly 20 miles in the central part, and is about 40 miles long. The valley floor ranges from approximately 4,600 feet amsl in elevation at the south end to 4,290 feet amsl at the north end. The center of the Process Areas is at an elevation of approximately 4,450 feet amsl.

4.4 Ecological Setting

The Study Area is part of the Great Basin sagebrush-steppe ecosystem (Lopes and Allander 2009a). The Singatse Range to the west and the Mason Valley are dominated by a scrub brush community, except along the Walker River with s riparian community. These communities support resident and migrating birds, mammals, reptiles, amphibians and invertebrates. The Walker River flows within 0.25 mile of the southeastern end of the Site. Although riparian systems comprise an extremely small fraction of the Great Basin region, they are critical centers of biodiversity; more than 75% of the species in the region are strongly associated with riparian vegetation. The Study Area ecosystem has been impacted by anthropogenic activity, including mining, cattle ranching and agriculture. Site activities have resulted in the large piles of tailings and waste rock, which could be used as vantage points for predators surveying the surrounding area, and steep-sloped piles may potentially be used by nesting birds (e.g., swallows).

4.5 Vegetation

The terrestrial ecosystem in the Study Area not disturbed by anthropogenic activities supports an arid sagebrush-steppe vegetative community that is dominated by sagebrush and other low-lying woody vegetation, interspersed with a variety of forbs and grasses. The scrub brush community in the Study Area is predominately sparse greasewood, sagebrush, and rabbitbrush (Lopes and Allander 2009a). Livestock and wildlife preference for grasses contributes to the domination of vegetation in this system by sagebrush and other shrubs (Ricketts et al. 1999).

The riparian community along the Walker River supports a variety of trees, shrubs and grasses (USGS 2009b). Vegetation can be dense with large trees such as Freemont cottonwood, Russian olive, and invasive Tamarisk (Salt Cedar). Saltbush may be abundant where riverbank soil is saline. As previously stated, many areas on the Site have been disturbed to varying degrees by historical mining activities, but still retain areas of sandy soil interspersed with vegetation typical of the sagebrush-steppe vegetative mix of shrubs, forbs, and grasses. Mason Valley has long been the most agricultural part of the Walker River basin and remains one of the most productive agricultural areas in Nevada (Lopes and Allander 2009a). During the growing season, agricultural fields to the north may include onions, alfalfa, winter wheat and sorghum.

4.6 Regional and Site Geology

Mason Valley is a structural graben that has been filled with unconsolidated alluvial deposits derived by erosion of the emerging mountain horst blocks, and from materials transported into the valley by the East and West Walker Rivers (Huxel and Harris 1969). The alluvial apron and the valley floor are the two major land-forms comprising the lowland area. The mountain blocks, and bedrock beneath the basins, are primarily composed of granitic, metamorphic, and volcanic rocks of Precambrian to Tertiary age and, to a lesser extent, of consolidated to semi-consolidated sedimentary rocks of Paleozoic to Cenozoic age (Heath 1984; Proffett and Dilles 1984; Proffett 1977). Faults along the eastern margin of the Singatse Range are gently- to steeply-dipping normal faults that generally trend north-northeast (Figure 4-1) and dip to the east (Proffett and Dilles 1984; Proffett 1977). Faulting caused moderate to steeply westward tilting of the bedrock.

Unconsolidated deposits underlying the valley floor are collectively termed valley-fill deposits and, where saturated, constitute the valley-fill alluvial aquifer. Huxel and Harris (1969) reported that the valley-fill deposits include four stratigraphic units: 1) younger alluvium, including lacustrine deposits associated with Pleistocene Lake Lahontan (Reheis 1999); 2) younger alluvial fan deposits resulting from the uplift of mountain blocks; 3) older alluvium; and 4) older alluvial fan deposits.

Older and younger alluvial fan deposits are generally coarse-grained, poorly-sorted, and have relatively few inter-bedded clay lenses (Huxel and Harris 1969; Plume 1996; Mifflin 1988). The grain size of the valley-fill deposits generally decreases toward the center of Mason Valley (Huxel and Harris 1969; Plume 1996), and transitional facies have been identified in the Study Area (BC 2008c). Basin-scale variability in valley-fill deposits leads to variation in hydraulic properties of the alluvial aquifer, which is discussed in Section 4.9.6.

Bedrock and alluvial deposits in Mason Valley, and their associated hydrologic characteristics, are summarized in Table 4-3, which is reproduced from Huxel and Harris (1969). Lake Lahontan lacustrine deposits of Pleistocene age have been eroded or reworked by the Walker River as it meandered across Mason Valley. Lake Lahontan strandline units, consisting of beach, bar, and beach-ridge deposits, were formed for the most part on alluvial aprons between altitudes of 4,340 and 4,375 feet amsl (Huxel and Harris 1969). The occurrence of Lake Lahontan within Mason Valley had a relatively short life, and probably was less than 60 feet deep during much of its existence (Morrison 1964).

Table 4-3. Mason Valley Geologic Units: Lithologic and Hydrologic Characteristics (from Huxel and Harris, 1969)

Geologic Age		Geologic Unit		Thickness (feet)	Lithology	Hydrologic Characteristics
Quaternary	Pleistocene to Holocene	Valley Fill	Younger Alluvium	0-100±	Loose, well-sorted sand, gravel, cobbles, and boulders, with layers of silt or sandy clay. Comprises channel, flood-plain, and terrace deposits laid down by the Walker River and its major tributaries, plus strand-line and bottom deposits of Pleistocene Lake Lahontan. Bottom deposits consist of silt, fine sand, and clay.	Channel and flood-plain deposits are highly permeable and are good aquifers. Significant infiltration of surface waters, which recharges the alluvial-fill aquifer, occurs through the coarse deposits in the Holocene channels of the Walker River.
			Younger Fan Deposits	0-100±	Poorly-sorted gravelly clay, sandy clay, and fine sand with occasional stringers and lenses of sand and gravel. Locally, derived from erosion of older rocks and deposits in Mason Valley; generally equivalent to younger alluvium.	In general, younger and older fan deposits are of low permeability. However, stock watering and mining wells penetrating buried sand and gravel deposits yield small to moderate amounts of water. Properly constructed, large-diameter wells may yield up to several hundred gpm.
	Pleistocene		Older Fan Deposits	0-700±	Sandy- to gravelly-clay with abundant cobbles and boulders and occasional lenses of semi-consolidated to cemented sand and gravel. Locally-derived from erosion of consolidated rocks of the surrounding mountains. Equivalent in part to older alluvium.	
			Older Alluvium	0-500±	Similar in lithology to younger alluvium described above. Deposited by ancestral Walker River; underlies valley floor at depths greater than 100 feet. Not exposed at land surface.	Constitutes largest and most productive aquifer in the area, with tested transmissibility as high as 270,000 gallons per day/foot. Wells yield up to 3,000 gpm.
Tertiary	Miocene and Pliocene	Consolidated Rocks	Sedimentary Rocks	--	Sandstone, mudstone, shale, marl, diatomite, and limestone. Includes interbedded tuffaceous rocks, lava flows, and breccia.	Consolidated rocks generally have low permeability. However, where they are fractured or jointed, they yield small to moderate amounts of water to wells.
	Oligocene to Pliocene		Volcanic Rocks	--	Rhyolite flows and tuff, andesite and dacite lava flows, breccia, and agglomerate. Includes interbedded sedimentary rocks and, locally, thin basalt flows with interbeds and scoriaceous basalt breccia.	
Cretaceous			Granitic Rocks	--	Granodiorite, quartz monzonite, and granite porphyry.	
Permian to Jurassic			Metamorphic Rocks	--	Metamorphosed andesite, basalt, and rhyolite flows, tuff and breccia, metamorphosed limestone, lime shale, dolomite, and gypsum and volcanically-derived sedimentary rocks.	

Bedrock in the Study Area forms a U-shaped graben structure that reaches its lowest point beneath the north end of the Hunewill Ranch, at an elevation of approximately 3,600 feet amsl (700 feet bgs). The elevations of the alluvium-bedrock contact, shown in plan view on Figure 4-2, clearly depict this graben structure in the Study Area. From its lowest elevation, bedrock rises in elevation south toward the Site. The U-shaped graben ends at the open pit and the alluvial-bedrock contact is exposed on the pit walls. The bedrock exposed in the open pit is the host rock for the Yerington copper porphyry deposit. East and west of the Site, bedrock rises to mapped outcroppings associated with the Singatse Range (west) and Singatse Spur (east; this term refers to two adjacent bedrock outcrops located east of the Site called the Ground Hog Hills and McLeod Hills as shown on Figure 4-2. At the north end of the Study Area, bedrock outcrops occur in the Sunset Hills area. In the northeast portions of the Study Area (i.e., toward the Mason Butte bedrock outcrop), bedrock rises in elevation. Range-bounding faults in the Study Area include steeply-dipping and shallower-dipping normal faults (Proffett and Dilles 1984).

The unconsolidated alluvial deposits in the Study Area were derived primarily from erosion of the uplifted mountain block of the Singatse Range, with minor deposition of fluvial sediments in the Walker River flood-plain. In addition, lacustrine deposits derived from ancestral Lake Lahontan occur north of the Site (Reheis 1999). Uplift and erosion of the Singatse Range formed the east-dipping alluvial fan deposits, which include distal facies that extend into the transitional environment. Concurrent with the development of the alluvial fan, flat-lying fluvial sediments (e.g., sands and gravels) were deposited in the Walker River flood-plain. Flat-lying clay-rich deposits have been preserved in the transitional setting, and these deposits are interpreted to have formed within the ancestral Lake Lahontan depositional environment.

Regional metal mineralization and hydrothermal alteration occurs in portions of Mason Valley, and the Singatse Range in particular, in areas of localized porphyry and skarn copper deposits. The Yerington copper porphyry district is located within the productive Walker Lane mineralized belt in western Nevada (Tetra Tech 2010). The Walker Lane is a northwest-trending zone of active crustal movement (i.e., right-slip transcurrent faulting) that extends for more than 500 miles from Las Vegas, Nevada to beyond Honey Lake, California (Bell and Slemmons 1979).

In addition to the Yerington and MacArthur open pit mines along the eastern margin of the Singatse Range, other areas of mineralization include the Bluestone and Ann Mason mines, and the Bear deposit. Areas of known mineralization and ore deposits in the Mason Valley are shown on Figure 4-3. The Bear deposit is located beneath the Sulfide Tailings and Hunewill Ranch, in a structurally-uplifted segment of the Singatse Range. The Pumpkin Hollow copper skarn deposit, located across Mason Valley from the Site, occurs along the margin of the intrusive rocks that host the Yerington porphyry copper deposit.

4.7 Surface Water Hydrology

The Mason Valley Basin (Basin no. 108, as defined by the NDWR) is located within the larger Walker River Hydrographic Basin (no. 9). The Walker River Hydrographic Basin extends from the Sierra Nevada Mountain Range above Bridgeport, California and Topaz Lake to Walker Lake located north of Hawthorne, Nevada. Most streamflows in the basin originate as snowmelt in the Sierra Nevada, with headwaters at elevations of more than 12,000 feet amsl (Lopes and Allander 2009a, 2009b).

The Walker River originates in two distinct headwater areas in the Sierra Nevada that source the East and West Walker Rivers (Figure 3-6). The East Walker River is sourced above Bridgeport, California. Streamflows are regulated before flowing into the Mason Valley. The West Walker River is sourced above Topaz Lake, a reservoir located along the California-Nevada border, and passes through the town of Wellington, Nevada on its way to the Mason Valley. The confluence of the East and West Walker Rivers occurs in Mason Valley at a location approximately seven miles upstream (three miles directly south) of the Site. The main stem of the Walker River flows north past the Site at the City of Yerington, traverses the geothermal discharge area near the town of Wabuska, exits the north end of Mason Valley at Walker Gap approximately 4.5 miles east of the town of Wabuska, and then turns south and empties into Walker Lake (a terminal lake with no outlet).

4.7.1 Surface Water Flows

Mason Valley is the largest irrigated agricultural area within the Walker River Basin including irrigated areas along the West and East Forks, and the main stem, of the Walker River. Key documents providing information on stream flows and water budgets in the Mason Valley include Huxel and Harris (1969), Lopes and Allander (2009b), and Carroll et al. (2010).

Each of these three documents present information on streamflows and water budgets for different periods of time. Appendix G-1 presents surface water flow information for 1948 to 2001, a period longer than addressed in these three documents. Streamflow and water budget information from these three documents and Appendix G-1 are summarized in Table 4-4 and discussed below.

Table 4-4. Summary of Mason Valley Streamflow and Water Budget Information

	Huxel and Harris (1969)	Lopes and Allander (2009b)	Carroll et al. (2010)	Flow Data Appendix G-1
Period of Record	1948 - 1965	1971 - 2000	1996 - 2006	1948 - 2011
	18-year Average	30-year Average	11-year Average	48-year Average (1)
Stream Inflows (acre-feet) (2)	216,000	269,000	277,832	207,900
Stream Diversions (acre-feet)	140,000	117,000	139,643	NA
Stream Outflows (acre-feet) (3)	107,200	138,000	129,471	80,400
Total Stream Loss (acre-feet) (4)	109,300	131,000	148,361	127,500
Stream Loss as Percent of Inflow	50%	49%	62%	NA
Irrigated Area (acres)	30,000	38,964	38,721	NA
Surface Water Diversion Rate (ft/yr) (5)	3.6	3.4	3.8	NA
Groundwater Pumpage (acre-feet/yr)	4,000	40,000	77,423	NA
Groundwater Application Rate (ft/yr) (6)	0.1	1.0	2.0	NA
Crop Consumption Rate (ft/yr)	1.0	1.6 (7)	2.9 - 3.1	NA

Notes:

1) Excludes 1979 - 1994 because flow data were not collected during winter months (October through March).
2) Sum of streamflow at Hudson (East Walker River) and Strosnider Ditch (West Walker River) gages (USGS gages 10300000 and 10293500, respectively).
3) Streamflow at Wabuska gage (USGS gage 10301500).
4) Total Stream Loss = Stream Inflows - Stream Outflows.
5) Surface Water Diversion Rate = Total Stream Loss/Irrigated Area.
6) Groundwater Application Rate = Groundwater Pumpage/Irrigated Area.
7) Value of 1.6 ft/yr from Myers (2001) cited by Lopes and Allander (2009b).
8) ft/yr = feet per year; % = percent; NA = not available

Lopes and Allander (2009b) provide a surface water budget for Mason Valley based on data collected from 1971 to 2000. Combined average annual inflows to Mason Valley were estimated to be 269,000 acre-feet per year. The average annual outflow from Mason Valley was estimated to be 138,000 acre-feet per year. The average net annual diverted surface water in Mason Valley was estimated to be 117,000 acre-feet per year. Stream infiltration and riparian evapotranspiration was estimated to be 14,000 acre-feet per year (Lopes and Allander 2009b).

An analysis of Walker River streamflow data from 1948 to 2011 (Appendix G-1) indicates a median annual flow at the confluence of the East and West Walker Rivers of 207,900 acre-feet. The minimum recorded flow was 65,900 acre-feet per year, and the maximum recorded flow was 596,500 acre-feet per year. Outflows from the Mason Valley are recorded near Wabuska, north of the Study Area. The median annual outflow was 80,400 acre-feet. The minimum recorded outflow was 15,800 acre-feet per year. The maximum recorded out flow was 417,900 acre-feet per year. In all months of all years, combined flows at the confluence of the East and West Walker Rivers were greater than outflows from the Mason Valley, with greater differences observed in summer months compared to winter months. Differences between inflows and outflows are accounted for by seepage losses, evapotranspiration and diversions for crop irrigation.

The disposition and routing of surface water within the Mason Valley is complex. Detailed information is provided in appendices to the *Groundwater Flow Model Yerington Mine Site* (SSPA 2014).

4.7.2 Recharge to the Alluvial Aquifer

Percolation of surface water is the primary source of groundwater recharge to the alluvial aquifer in the Mason Valley, with mountain-front recharge contributing significantly less (Carroll et al. 2010; Huxel and Harris 1969; Myers 2001; SSPA 2014). The amount of recharge derived by infiltration from stream channels, ditches, and percolation from flooded agricultural fields varies from year to year, depending upon the volume of Walker River flow entering the basin, the amount of surface water diverted from the river for irrigation, and the amount of available groundwater storage.

Huxel and Harris (1969) estimated that the annual recharge from the sources listed above ranged from 30,000 to 100,000 acre-feet, with an average of about 70,000 acre-feet, for the period from 1948 to 1965. These estimates were calculated as inflows minus the sum of surface-water outflows and consumptive use by crops and pastures, and assumed that all stream flows not consumptively used for irrigation or flowing out of the valley recharged the valley-fill alluvial aquifer. Carroll et al. (2010) estimated that recharge from the sources listed above ranged from 60,400 to 99,400 acre-feet per year for the time period 1996 to 2006, and noted the consistency between their more recent estimates and those provided by Huxel and Harris (1969).

The groundwater flow model water budget (SSPA 2014) indicates that the alluvial aquifer is primarily recharged by downward percolation from irrigated fields (49%), leakage from irrigation ditches such as the West and East Campbell Ditches (29%), infiltration from the channel of the Walker River (20%), and infiltration through bedrock of precipitation that falls on surrounding mountain ranges and minor tributary surface flows in ephemeral drainages (2%). Recharge from precipitation falling directly on the valley floor is negligible based on work by Huxel and Harris (1969) and Lopes and Allander (2009a, 2009b), as well as data from stable isotope (i.e., oxygen/deuterium) analysis of precipitation and groundwater (BC 2014a; EPA 2012b).

4.7.3 Surface Water Quality

Surface water quality is discussed below with a focus on data at sample locations SW-WR-01 (Walker River) and SW-WCD-01 (West Campbell Ditch), and chemicals considered primary indicators of mine-impacted groundwater (i.e., sulfate and uranium). A detailed analysis of the surface water quality data is presented in Appendix G-2. Chemical concentrations in Walker River and West Campbell Ditch samples are similar with low total dissolved solids (TDS) (110 to 300 mg/L; average: 194 mg/L) and relatively low sulfate (7.7 to 54 mg/L; average: 29 mg/L) and dissolved uranium (3.7 to 19 µg/L; average 9.3 µg/L). Surface water pH is slightly alkaline (7.72 to 8.36 s.u.; average: 8.05 s.u.). Temporal trends indicate more elevated major ion (e.g., sulfate, calcium and chloride) values and trace metal (e.g., dissolved arsenic and dissolved uranium) values in samples at both locations during the winter months relative to the summer months. Overall, the STORET surface water quality data are similar to the surface water quality data collected by ARC.

Shallow alluvial groundwater near the Walker River and West Campbell Ditch exhibits similar chemical characteristics to surface water quality, which is the primary source of groundwater in Mason Valley (Carroll et al. 2010; Huxel and Harris 1969; Myers 2001; SSPA 2014). General ion chemistry in groundwater was found to be statistically similar to surface water for five of eight major ions. Calcium, chloride, and sulfate were found to be higher in groundwater than surface water. Dissolved metals in groundwater were found to be statistically similar to surface water for some parameters (14 of 27) but different for others (13 of 27). However, differences between surface water and Shallow alluvial groundwater in major ions and dissolved metals reflect changes in geochemical conditions in groundwater arising from the effects of residence time, presence (or absence) of dissolved atmospheric gasses, localized mineralization, and influences from land-surface features that alter groundwater quality as it recharges from surface water sources.

4.8 Mason Valley Regional Hydrogeology

Groundwater conditions in Mason Valley are based on: 1) general characteristics of groundwater flow for the Basin and Range province; 2) investigations specific to the Mason Valley and/or the Walker River Basin; and 3) groundwater data available from the USGS and/or NDWR. The general conceptual model for groundwater flow in the Basin and Range province (Heath 1984; Maurer et al. 2004) is movement of groundwater in unconsolidated sediments deposited within the basins that occur between uplifted mountain blocks comprised of consolidated bedrock.

The groundwater flow system in Mason Valley consists of: 1) a heterogeneous valley-fill alluvial aquifer system comprised of laterally-discontinuous confining units of clay or other low-permeability sediments, and unconfined (i.e., water table), semi-confined, and confined aquifers; and 2) a relatively impermeable bedrock flow system underlying and bounding the alluvial aquifer with limited primary permeability and groundwater flow focused along faults and fractures (Maurer et al. 2004; Thomas 1995; Tetra Tech 2010; Huxel and Harris 1969).

Groundwater in the alluvial aquifer within Mason Valley generally flows from south to north toward the topographically lowest part of the valley at the northern end of the valley (Figure 4-4).

Similar water-level patterns are depicted in Huxel and Harris (1969, Plate 2), Lopes and Allander (2009a, Plate 1), and Tetra Tech (2010, Figure 24-3). Locally, groundwater flow directions are affected by: 1) bedrock outcrops within and along the margins of the valley; 2) drawdown from pumped wells; and 3) irrigation activities on cultivated fields. The Walker River is generally a losing stream except in the far northeastern portion of the valley where it is generally a gaining stream. Water level elevations shown on Figure 4-4 are based on USGS monitor well data from October through December 2010 when agricultural pumping was limited or non-existent. Table 4-5 summarizes the USGS wells and water level data used to develop the water table (i.e., alluvial aquifer potentiometric surface) map shown on Figure 4-4.

Table 4-5. 2010 USGS Monitor Well Data for Mason Valley

USGS Site Number	Site Name	Latitude	Longitude	Surface Elev. (feet amsl)	Vertical Datum	Measure-ment Date	Depth to Water (feet)	Water Elev. NGVD29 (feet amsl)	Well Depth (feet bgs)	Boring Depth (feet bgs)	Number of Measurements
391655119330901	103 N16 E22 06ACD1 HIWAY 50	39.28200000	119.5524167	4352.1	NAVD88	10/13/10	55.4	4293.29	96	96	154
391729119294501	103 N17 E22 34DBDD1 EUREKA	39.29147220	119.4957500	4283.8	NAVD88	10/14/10	10.06	4270.35	35	35	101
391711119303301	103 N16 E22 04AAAD1 RA-4	39.28647220	119.5091667	4288.5	NAVD88	10/14/10	4.8	4280.30	14	14	69
391625119324801	103 N16 E22 07AAAA1 R-3	39.27352778	119.5468056	4303.9	NAVD88	10/14/10	9.07	4291.42	35	35	66
391605119331901	103 N16 E22 07ACCB1 R-2	39.26797220	119.5551389	4308.1	NAVD88	10/14/10	8.27	4296.41	30	30	64
384942119100801	108 N11 E25 10DBCD1	38.82802778	119.1703610	4565	NGVD29	11/23/10	98.14	4466.86	597	597	42
390715119095901	108 N15 E25 34ACDD1	39.12075170	119.1673767	4292	NGVD29	11/22/10	13.48	4278.52	370	370	41
390006119043901	108 N13 E26 09DBCC1	39.00158530	119.0784852	4396	NGVD29	11/24/10	60.37	4335.63	166	166	39
390011119060201	108 N13 E26 08CACA1	39.00297394	119.1015412	4367	NGVD29	11/24/10	21.88	4345.12	130	130	37
390127119030001	108 N13 E26 02BBCC1	39.02408569	119.0509851	4406	NGVD29	11/24/10	87.92	4318.08	203	203	36
390203119055101	108 N14 E26 32BDDD1	39.03408520	119.0984860	4352	NGVD29	11/30/10	13.56	4338.44	104	104	32
385903119073001	108 N13 E25 13DDDD1	38.98408457	119.1259859	4380	NGVD29	11/24/10	16.92	4363.08	280	280	32
390531119115901	108 N14 E25 08ADDC1	39.09186235	119.2007101	4320	NGVD29	11/22/10	30.73	4289.27	523	523	32
385720119085001	108 N13 E25 26DDCC1	38.95547285	119.1482085	4409	NGVD29	11/24/10	26.14	4382.86	160	NA	31
385255119090501	108 N12 E25 23DCC 1	38.88186075	119.1523750	4462	NGVD29	11/23/10	15.84	4446.16	325	325	31
385456119091901	108 N12 E25 11CACD1	38.91547224	119.1562641	4439	NGVD29	11/23/10	21.5	4417.50	245	245	31
390137119065402	108 N14 E26 31DCCC2	39.02686280	119.1159861	4357	NGVD29	11/30/10	13.44	4343.56	400	400	30
390558119094701	108 N14 E25 03DDDC1	39.09936270	119.1640431	4323	NGVD29	11/22/10	20.54	4302.46	85	258	30
390611119110301	108 N14 E25 04DACC1	39.10297367	119.1851545	4321	NGVD29	11/22/10	20.75	4300.25	451	451	30
385447119075901	108 N12 E25 12CDAA1	38.91297248	119.1340414	4476	NGVD29	11/23/10	59.94	4416.06	102	102	28
390004119103001	108 N13 E25 10CDB 1	39.00102868	119.1759868	4380	NGVD29	11/30/10	9.19	4370.81	328	328	27
390026119090401	108 N13 E25 11ACBD1	39.00714008	119.1520976	4370	NGVD29	11/24/10	13	4357.00	435	435	25
385717119080901	108 N13 E25 25CDDA2	38.95463960	119.1368194	4419	NGVD29	11/24/10	33.88	4385.12	106	106	21
385109119085601	108 N12 E25 35DCDD2	38.85241595	119.1498750	4505	NGVD29	11/22/10	35.38	4469.62	NA	NA	20

Table 4-5. 2010 USGS Monitor Well Data for Mason Valley

USGS Site Number	Site Name	Latitude	Longitude	Surface Elev. (feet amsl)	Vertical Datum	Measure-ment Date	Depth to Water (feet)	Water Elev. NGVD29 (feet amsl)	Well Depth (feet bgs)	Boring Depth (feet bgs)	Number of Measurements
385003119085201	108 N11 E25 11AACC1	38.83408240	119.1487638	4565	NGVD29	11/23/10	97.14	4467.86	256	256	19
390057119080001	108 N13 E25 01DBCC1	39.0157514	119.1343196	4365	NGVD29	11/19/10	19.96	4345.04	570	570	19
385047119080401	108 N11 E25 01ACCB1	38.84630495	119.1354302	4547	NGVD29	11/23/10	75.13	4471.87	526	526	18
385018119091101	108 N11 E25 02CDDD1	38.83813889	119.1538889	4544	NGVD29	11/23/10	73.59	4470.41	554	560	17
385718119101301	108 N13 E25 27DCCD2	38.95491700	119.1712645	4409	NGVD29	11/23/10	19	4390.00	440	440	17
390152119104401	108 N14 E25 34CBCA2	39.03102880	119.1798760	4362	NGVD29	11/30/10	25.56	4336.44	415	430	14
391741119150601	102 N17 E24 35DAAB1 OLD BUCKLANDS STATION	39.29472220	119.2516667	4203	NGVD29	10/12/10	16.23	4186.77	93	93	14
391610119115801	102 N16 E25 05DCCA1 USBLM	39.27464167	119.2004333	4219	NGVD29	10/12/10	70.24	4148.76	127	NA	12
391757119151801	102 N17 E24 35ACAA1 OLD WEEKS SIDING	39.29916667	119.3050000	4206	NGVD29	10/12/10	18.28	4187.72	23	23	11
392522119101901	102 N18 E25 15CBCA1 STUCCO	39.42288889	119.1718889	4213	NAVD88	10/12/10	57.72	4152.13	200	200	11
392546119121201	102 N18 E25 17BDAA TRAILER GRAVEYARD	39.42947220	119.2034167	4201	NAVD88	10/12/10	14.92	4182.94	170	170	11
392222119075101	103 N17 E25 01BAB1 E OF LAHONTAN	39.37283330	119.1307222	4202	NAVD88	10/12/10	61.18	4137.68	72	72	9
390416119112401	108 N14 E25 16DCCB1 CMPBLL SHALLOW	39.07097220	119.1900833	4336	NGVD29	11/22/10	20.14	4315.86	25	25	8
385249119221401	107 N12 E23 26ABAD1 85471	38.8803611	119.3706667	4729	NGVD29	11/18/10	13.76	4715.24	340	340	8
391727119190701	103 N17 E24 32CDBB1 BULL CANYON	39.29088889	119.3184722	4250.5	NAVD88	11/15/10	27.8	4219.363	41	41	8
391706119322601	103 N16 E22 05BACD1	39.28488889	119.5405556	4345	NAVD88	10/23/10	59.9	4281.691	182	182	8
391709119314001	103 N16 E22 04BBCB1 CARDELLI	39.28569444	119.5278333	4304.5	NAVD88	11/15/10	15.85	4285.244	39	39	2

Notes:

1) All groundwater elevation data downloaded from USGS website http://nwis.waterdata.usgs.gov/nv/nwis/gwlevels, accessed on August 15, 2011.
2) amsl = above mean sea level; bgs = below ground surface; NA = not available.

Hydraulic properties of the basin-fill sediments of Mason Valley vary both laterally and vertically because of variable depositional facies and environments observed in the valley. The transmissivity of the basin fill deposits was stated by Huxel and Harris (1969) to generally range from 6,700 ft^2/day to 27,000 ft^2/day. Based on an average basin-fill thickness of 500 feet, this is equivalent to average hydraulic conductivities in the range of 13 ft/day to 53 ft/day. Based on unspecified geotechnical investigations, Nork (1989) reported hydraulic conductivity values ranging from 0.35 to 0.50 feet per day (ft/day) for older alluvial fan deposits. Consolidated rocks beneath the unconsolidated basin-fill sediments and/or comprising the adjacent mountain ranges have low hydraulic conductivities, but may transmit water where fractures are open and interconnected (Lopes and Allander 2009a). Nork (1989) reported hydraulic conductivity values ranging from 0.23 to 1.5 ft/day for weathered intrusive rocks in the Mason Valley area.

Groundwater in Mason Valley is primarily recharged by downward percolation of surface water diverted from the Walker River to irrigation ditches and irrigated fields, downward percolation of groundwater applied to irrigated fields, and infiltration of surface water from the channel of the Walker River. To a lesser degree, valley-fill sediments are also recharged by mountain-front recharge (MFR), which includes a variety of hydrologic processes such as partitioning of precipitation and snowmelt into deep infiltration through bedrock (i.e., along faults and fractures), surface runoff, focused flow and subflow along mountain stream channels and alluvial fans, and diffuse movement of groundwater through the underlying mountain block (Wilson and Guan 2004; Huxel and Harris 1969; Myers 2001). Huxel and Harris (1969) considered recharge from direct precipitation on the valley floor to be negligible. Recharge from irrigation water and seasonal pumping of irrigation wells affects the vertical flow of groundwater in the alluvial aquifer (i.e., a seasonal increase in the downward vertical gradient in the alluvial aquifer).

Discharge from the Walker River Basin occurs as evapotranspiration from irrigated crops and natural vegetation (e.g., phreatophytes and wetland vegetation) as described by Heath (1984) and Carroll et al. (2010), and as direct evaporation from shallow groundwater (Huxel and Harris 1969; Lopes and Allander 2009a). Huxel and Harris (1969, Plate 2) identified an area of artesian

conditions (17 flowing wells) in the northern portion of Mason Valley where the alluvial aquifer thins and pinches out, and reported that groundwater in this area exhibited elevated specific conductance values (i.e., dissolved solids concentrations) due to evapoconcentration and possible effects of geothermal discharge associated with the Wabuska Lineament.

Lopes and Allander (2009a, 2009b) report that: 1) in 2008, no flowing wells were observed in the Wabuska area due to groundwater pumping; 2) water depths in this area were less than five feet, and efflorescent salts formed where groundwater evaporated from the shallow water table; and 3) pumping in Mason Valley since the early 1960s had caused groundwater levels to decline as much as 60 feet. The long-term decline in water levels is reflected in Site hydrographs for select monitor wells that cover the time period from 1985 to 2015, as shown on Figure 4-5. In addition to factors described above, the sharp decline in the 1980's in water levels in well UW-1S, located near the northern end of the Process Areas, is in part attributed to cessation of mining activities in 1978. Discharge of groundwater through bedrock from the Mason Valley Basin to other groundwater basins may occur, but is limited (Thomas 1995; Tetra Tech 2010).

4.9 Site and Study Area Local Hydrogeology

A generalized hydrogeologic south-north cross-section with a vertical exaggeration of 20V:1H is presented in Figure 4-7 (location shown on Figure 4-6). This cross-section (A-A') transects the Study Area and extends from well B/W-13S, which is the southernmost well in the Study Area, to a monitor well cluster, B/W-82R, which is located at the north end of the Study Area.

The south-north cross-section depicts: 1) the alluvial materials in the valley-fill alluvial aquifer within the Study Area; 2) the alluvial aquifer zone designations; 3) the occurrence of bedrock outcrops at the open pit and the north end of the Study Area; 4) the water table elevation in the alluvial aquifer in August 2015; 5) the depth of the open pit and the Pit Lake level in August 2015; and 6) the cone-of-depression associated with the open pit. The water table in the Shallow zone of the alluvial aquifer generally slopes toward the north on this cross-section, though the elevation of the water is relatively flat in much of the Site.

4.9.1 Depth to Groundwater

Contour maps of the depth to groundwater (i.e., depth to water table) below the ground surface in February 2015 and August 2015 are presented on Figures 4-8 and 4-9, respectively. February 2015 and August 2015 represent the non-irrigation and irrigation seasons, respectively. The depth to groundwater is typically less than 20 feet beneath irrigated areas such as the Hunewill Ranch and between monitor wells B/W-59S and B/W-68S. In areas beneath the Site, beneath the Sunset Hills neighborhood, and in the northern portions of the Study Area, the depth to groundwater is greater than 20 feet. To the west of the Site and beneath the Process Areas, the depth to groundwater exceeds 100 feet. Between February 2015 and August 2015, the depth to groundwater beneath irrigated portions of the Study Area as well as beneath the Evaporation Ponds uniformly increased by up to three feet (i.e., the water table declined) due to depletion of groundwater by agricultural pumping. Depth to groundwater fluctuations in other parts of the Study Area were minor.

4.9.2 Saturated Alluvial Thickness

The thickness of saturated alluvium in the Study Area in August 2015 is shown on Figure 4-10, which is similar in shape to the alluvium-bedrock contact map shown on Figure 4-2 (the similarity results from a relatively flat water table beneath the Study Area). On Figure 4-10, the line denoting the approximate lateral extent of saturated alluvium represents the zero-foot contour line (i.e., saturated alluvium does not occur outside of this contour line). Saturated alluvium is bounded to the west by the Singatse Range, to the northwest by the bedrock outcrops in the Sunset Hills area, to the northeast by the Mason Butte bedrock outcrop, to the east by the Singatse Spur, and to the south by the local bedrock high exposed within the open pit and, locally, by that portion of the Singatse Range located south of the Site. As shown on Figure 4-10, saturated alluvium is thickest (more than 700 feet) beneath the northern portion of the Hunewill Ranch.

4.9.3 Alluvial Groundwater

Potentiometric surface maps for the various alluvial aquifer zones in August 2015 are provided in Figure 4-11. Groundwater flow in August 2015 in the Study Area was generally to the north/northwest in the Shallow, Intermediate, and Deep 1 zones, and to the northeast in the Deep

2 through Deep 5 zones. Locally, the flow of groundwater in the Study Area is affected by: 1) the cone-of-depression around the Pit Lake, which is a hydraulic sink for alluvial and bedrock groundwater; 2) recharge sources such as the Walker River, the West Campbell Ditch and irrigation on the Hunewill Ranch; 3) bedrock in the Singatse Range to the west of the Site, which serves as a low flux boundary condition; 4) bedrock outcrops on the eastern margin of the Site (the Singatse Spur, comprised of the Ground Hog Hills and McLeod Hill), which impede groundwater flow from the West Campbell Ditch and the Walker River to the alluvium beneath the Site; 5) bedrock ridges north of the Site associated with the Sunset Hills and Mason Butte, which affect the direction of groundwater flow in the northeastern portions of the Study Area; and 6) drawdown from pumped wells (particularly in deeper zones of the alluvial aquifer).

As seen on the Shallow zone potentiometric surface map (Figure 4-11a), the Pit Lake is currently a hydraulic sink that is refilling with groundwater predominantly derived from alluvial groundwater recharged locally from the Walker River and, to a lesser extent, bedrock groundwater (Hershey 2002). As noted in Section 3.3.2, the lake is and will continue to be a groundwater sink due to the large amount of evaporation that occurs from the lake surface.

Saturated alluvium is in contact with the Pit Lake on the western margin of the open pit (Figure 4-11a). However, groundwater gradients in this area are toward the Pit Lake, and alluvial groundwater recharges the Pit Lake rather than the Pit Lake recharging the alluvial aquifer. On the eastern margin of the open pit, groundwater derived from seepage from the Walker River flows into the pit. Beneath the Process Areas, the Pit Lake cone-of-depression creates a groundwater divide in the Shallow zone (Figure 4-11a). Because of local bedrock elevations, only the Shallow, Intermediate, and a limited portion of the Deep 1 zones exist in this area (Figures 4-11 a through c, respectively).

North of the Site, recharge from the Walker River and its surface water diversions, as well as irrigation practices in the Study Area, are the primary influences on groundwater flow directions. In the Shallow, Intermediate, and Deep 1 zones, groundwater flow directions are away from, or parallel to, the Walker River and West Campbell Ditch (i.e., north/northwest), indicating recharge

of the alluvial aquifer from these features. In addition, groundwater mounding beneath irrigated areas is observed in these zones. As this recharged water percolates deeper into the Deep 2 through Deep 5 zones of the alluvial aquifer, the groundwater flow direction rotates to the northeast as relatively impermeable bedrock results in alluvial groundwater flow toward the trough in the alluvial-bedrock contact between the Sunset Hills and Mason Butte.

Irrigation practices on the Hunewill Ranch, located immediately north of the Site, locally affect groundwater flow conditions. Historically, irrigation practices on the Hunewill Ranch included seasonal diversion of surface water from the Walker River via the West Campbell Ditch and pumped groundwater, as necessary, from up to three wells. These three wells were located within 2,500 feet of the B/W-1 monitor well cluster and included Well Log No. 82983 (also referred to as WDW019), Well Log No. 26694, and Well Log No. 78925. Well WDW019 and other underground water rights points of diversion are shown on Figure 3-8. Groundwater pumping from the Hunewill Ranch wells to support agricultural irrigation ceased in September 2009. In 2011 and subsequent years, crops on the Hunewill Ranch were irrigated with surface water diverted from the Walker River and groundwater pumped from a nearby parcel located near the Walker River to the east. Additional information about these wells is provided in the *Aquifer Test Data Summary Report - Revision 1* (BC 2012e).

Potentiometric surface maps for the Shallow through Deep 2 zones (Figures 4-11a through 4-11d) have been outfitted with rose diagrams at select locations to illustrate seasonal changes in groundwater flow directions resulting from the historical and current irrigation practices on the Hunewill Ranch. Rose diagrams indicate the relative frequencies of groundwater flow directions over a period of time. Monthly groundwater flow directions were calculated by using water level measurements in sets of three monitoring wells to estimate the slope and direction of slope of a plane connecting the water levels in the three wells. This approach is commonly referred to as a "three-point problem" (EPA 2014c). Rose diagrams were generated for two time periods: 1) 2008 - 2009 to illustrate historical irrigation practices associated with operation of the Hunewill Ranch pumping wells; and 2) 2010 - 3Q 2015 to illustrate current irrigation practices.

Both historical and current irrigation practices for the Hunewill Ranch created a groundwater mound in the Shallow, Intermediate, and Deep 1 zones of the alluvial aquifer due to infiltration of applied irrigation water. Mounding was most pronounced beneath the Hunewill Ranch fields, and the mound extended beyond the edges of the fields including beneath the Wabuska Drain, which collects and diverts agricultural runoff. The rose diagrams for the Shallow, Intermediate, and Deep 1 zones (Figures 4-11a through 4-11c) indicate that, in both time periods, the mound beneath Wabuska Drain predominantly acted as a groundwater divide, directing recharged groundwater: 1) to the west/southwest beneath the Evaporation Ponds; and 2) to the east/northeast beneath the Hunewill Ranch. The rose diagrams also indicate that, in a small number of months, the groundwater divide was not present and groundwater flow directions were from the east beneath the Hunewill Ranch to the west beneath the Evaporation Ponds. This east-to-west flow predominantly occurred in winter months when irrigation was not occurring.

Historical irrigation practices for the Hunewill Ranch prior to 2010, which included seasonal groundwater pumping and surface application to the fields, created a cone-of-depression around WDW019 that was most pronounced in the Deep 1 through Deep 3 zones but was also manifested in the Shallow and Intermediate zones (BC 2014a). The cone-of-depression in the combined Deep 1 through Deep 3 zones extended beneath the Sulfide Tailings area and the Evaporation Ponds, and as far north as the Sunset Hills neighborhood. Figure 4-12 provides monthly water level hydrographs of Shallow and Deep monitor wells in the B/W-1 and B/W-27 well clusters (located beneath and adjacent to the Hunewill Ranch, respectively) that illustrate the hydraulic head drawdown during and after operation of the Hunewill Ranch pumping wells. Although agricultural pumping in the Study Area continues to affect hydraulic head in wells B/W-1D3 and B/W-27D2, hydraulic head drawdown in these wells was up to three times greater during operation of the Hunewill Ranch pumping wells than it has been in recent years.

The rose diagrams for the Deep 2 zone (Figure 4-11d) indicate that, under both historical and current irrigation practices, groundwater between the Site and the B/W-1 well cluster has been toward the northeast as the result of agricultural pumping, with occasional periods of northward groundwater flow corresponding with winter months when irrigation was not occurring. Beneath

the Evaporation Ponds, the rose diagrams indicate differing distributions of groundwater flow directions between historical and current irrigation practices. Groundwater flow directions in the Deep 2 zone beneath the Evaporation Ponds have been predominantly to the west/northwest in both time periods. However, the large cone of depression that was present during operation of the Hunewill Ranch pumping wells caused on-Site water beneath the Evaporation Ponds to occasionally flow east/northeast to off-Site areas beneath the Hunewill Ranch.

Figure 4-13 presents monthly vertical groundwater gradients in the alluvial aquifer at select locations. Vertical gradients were calculated as the difference in water levels between the shallowest and deepest alluvial monitoring wells in a cluster divided by the distance between the midpoints of the screened intervals of the wells. If a well was screened across the water table, then the water table elevation was used in place of the midpoint of the screened interval for that well. Monthly vertical gradients were calculated using water level measurements from 2013, which was the last full calendar year during which water levels in all active monitor wells were measured monthly. For wells installed after 2013 pursuant to the Additional Monitor Well Work Plan (BC 2013b), monthly vertical gradients were calculated using water level measurements from September 2014 through August 2015. Where available, monthly vertical gradients were also calculated using water level measurements from 2009 to illustrate groundwater conditions during operation of the Hunewill Ranch pumping wells.

Alluvial vertical gradients beneath the Process Areas are generally upward (PA-MW-4 well cluster), reflecting potential discharge of bedrock groundwater to alluvium as a potential source of groundwater to this portion of the Site (i.e., mountain-front recharge). Beneath the Evaporation Ponds (B/W-11 well cluster) and Hunewill Ranch (B/W-1 well cluster), alluvial vertical gradients are downward, with stronger vertical gradients corresponding to months when irrigation, and thus groundwater recharge and pumping, occurs. In addition, alluvial vertical gradients were even more strongly downward in these areas in 2009 when the Hunewill Ranch pumping wells were operating. In other irrigated areas (i.e., B/W-68 and B/W-81 well clusters), alluvial vertical gradients are also consistently downward, again with stronger vertical gradients in months when irrigation occurs.

Immediately northwest of the Site at the B/W-41 well cluster, vertical gradients are upward in the winter months, reflecting potential discharge of bedrock groundwater to alluvium (i.e., mountain-front recharge), and downward in the summer months, reflecting the influences of agricultural pumping. Downward vertical gradients at the B/W-41 well cluster are approximately two orders of magnitude smaller than the downward vertical gradients in irrigated areas, reflecting the greater distance of B/W-41 from irrigated areas. The B/W-28 well cluster (located in the Sunset Hills neighborhood) also exhibits seasonal changes in the direction of vertical gradients - upward vertical gradients occur in the winter (reflecting the non-irrigation season) and downward vertical gradients occur in the summer (reflecting the influences of agricultural pumping). In 2009, the effects of operation of the Hunewill Ranch pumping wells, in addition to other agricultural pumping in the Study Area, caused strongly downward vertical gradients that resulted in water levels in monitor well B/W-28S to decline below the bottom of the screened interval in August and September.

4.9.4 Groundwater Recharge

Recharge to the alluvial aquifer in the Mason Valley primarily occurs from surface water diverted from the Walker River within unlined irrigation ditches, infiltration of surface water and groundwater applied to irrigated fields, and infiltration of surface water from the channel of the Walker River. Recharge to the alluvial aquifer also occurs along the range front via a variety of hydrologic processes.

As indicated above, infiltration of surface water is the primary source of groundwater recharge to the alluvial aquifer in the Mason Valley, with MFR contributing significantly less (Carroll et al. 2010; Huxel and Harris 1969; Myers 2001; SSPA 2014). The annual amount of recharge derived by infiltration from stream channels, ditches, and agricultural fields is a function of Walker River flows, the volumes of surface water and groundwater used for irrigation, and water table depths within Mason Valley.

Hydrologic tracer data for tritium/helium ($^3H/^3He$) groundwater age estimates (Figure 4-14) and uranium isotopes (Figure 4-15) are consistent with the two principal recharge components of the HCSM: 1) seepage from the Walker River and irrigation ditches, and infiltration from irrigated fields on the east margins of the Study Area; and 2) MFR on the west side of the Study Area adjacent to the Singatse Range.

The use of groundwater uranium isotopes (and their relationship to tritium/helium groundwater age estimates) is briefly summarized as follows. In groundwater systems, ^{234}U is more environmentally mobile than ^{238}U due to physical recoil of the atom following alpha decay of ^{238}U, and the subsequent displacement of the ^{234}U atom to weaker binding sites within the crystalline lattice of the mineral in which it is contained. Thus, the two isotopes are released (weathered) at different rates, and the $^{234}U/^{238}U$ ratio is generally greater than unity in natural waters. Changes in the isotopic ratios (and uranium excess [Ue] values derived from the ratios) are assumed to be solely associated with transport/contact time between groundwater and aquifer solids. Consequently, high Ue values are associated with “long” periods of contact between groundwater and aquifer solids (i.e., “old” water) whereas low Ue values are associated with “short” periods of contact between groundwater and aquifer solids (i.e., “young” water). However, $^{234}U/^{238}U$ ratios in mine-impacted groundwater are also close to unity (resulting in low Ue values) because acidic process solutions leach both isotopes from ore material with equal effectiveness (Iles et al. 1995).

On the east side of the Study Area, Shallow zone alluvial groundwater directly recharged by surface water commonly exhibits younger, more modern age estimates and low Ue values. Low Ue values are also observed in mine-impacted Shallow zone groundwater beneath the Evaporation Ponds. In contrast, the older groundwater age estimates and highest Ue values commonly occur on the west side of the Study Area adjacent to the Singatse Range, in Deep alluvial groundwater, and in bedrock groundwater. An exception to the typical vertical distribution of higher Ue values and older groundwater age estimates is evident at the B/W-1 well cluster where younger groundwater age estimates and lower Ue values occur locally in the Deep groundwater zones.

This local pattern of Ue values and groundwater age estimates around the B/W-1 well cluster is consistent with the HSCM, which recognizes groundwater mixing due to agricultural pumping, especially former pumping at (which is located adjacent to the B/W-1 well cluster). Pumping at WDW019 has resulted in the migration of mine-impacted groundwater present beneath the Evaporation Ponds into the Intermediate and Deep zones of the alluvial aquifer beneath the Hunewill Ranch.

4.9.5 Alluvial Aquifer Hydraulic Property Data

Hydraulic conductivity values in alluvium from slug tests (Appendix F-1) range from 0.04 to 157 ft/day, with a median value of 6.8 ft/day. The 25th and 75th percentiles are 3.1 ft/day and 22.0 ft/day, respectively. Hydraulic conductivity values in alluvium calculated from an analysis of low-flow sampling data (Appendix F-2) range from 0.08 to 240 ft/day, with a median value of 18.4 ft/day. The 25th and 75th percentiles are 6.8 ft/day and 33.6 ft/day, respectively. Statistical analyses indicate that: 1) hydraulic conductivity values in each alluvial zone exhibit similar ranges, median values, and distributional shapes; and 2) hydraulic conductivity values throughout the alluvial aquifer are statistically equivalent in their distributions from zone to zone. Hydraulic conductivity estimates for the individual groundwater zone are provided in Table 4-6.

Table 4-6. Hydraulic Conductivity by Groundwater Zone (from Slug Test Data)

Zone	Median K (ft/day)	Standard Deviation (ft/day)	Count
Shallow	6	24	81
Intermediate	6	23	35
Deep 1	8	25	38
Deep 2	4	11	15
Deep 3	4	16	13
Deep 4	31	33	5
Deep 5	14	7	6
Bedrock	2	74	32

Notes: K = hydraulic conductivity.

Constant-rate testing of the eleven pumpback wells in 2010, which are screened in the Shallow zone (Appendix F-3), resulted in hydraulic conductivity estimates ranging from 0.9 to 47 ft/day (median of 9.4 ft/day). Slug testing of piezometers (33 in total, all screened in the Shallow zone) installed near the PWS, that were used as observation wells during constant-rate pumping tests of the 11 pumpback wells during 2010 (Appendix F-4), provided hydraulic conductivity estimates ranging from 1.1 to 83ft/day (median of 4.1 ft/day). Testing of five pumpback wells (PW-6, PW-7, PW-9, PW-10 and PW-11) in 2000 yielded hydraulic conductivity estimates that ranged from 6.4 to 33 ft/day, with a geometric mean of 16 ft/day, based on an assumed aquifer thickness of 50 feet (AHA 2000).

A constant-rate test of well WDW019, using an observation network of 93 monitor wells, resulted in estimated values for hydraulic conductivity and specific storage at 61 observation wells that exhibited pumping-related responses (Appendix F-5). Hydraulic conductivity values in alluvium derived from constant-rate pumping tests of WDW019 ranged from 4.9 to 1,200 ft/day, with a median value of 77 ft/day. The 25th and 75th percentiles are 38 ft/day and 195 ft/day, respectively. Five hydraulic conductivity values in bedrock ranged from 13.0 to 92 ft/day.

Specific storage values in alluvium from constant-rate pumping tests of WDW019 range from 1.45×10^{-8} to 1.46×10^{-3} $(\text{feet})^{-1}$, with a median value of 1.14×10^{-5} $(\text{feet})^{-1}$. The 25th and 75th percentiles are 5.16×10^{-6} $(\text{feet})^{-1}$ and 2.73×10^{-5} $(\text{feet})^{-1}$, respectively.

4.9.6 Spatial Variation in Hydraulic Conductivity

The spatial distributions of slug-test hydraulic conductivities in each alluvial groundwater zone are shown on Figure 4-16, and bedrock slug-test hydraulic conductivities are shown on Figure 4-17. Slug-test hydraulic conductivities represent the largest hydraulic conductivity dataset for evaluating spatial variation within the Study Area. To date, 295 measurements of hydraulic conductivity have been obtained using slug-test methods (Appendix F-1).

Although analysis of drawdown measurements during low-flow sampling of monitor wells has yielded more measurements of hydraulic conductivity than slug testing (318 measurements versus 295 measurements through August 2015), the approach has limitations that that do not capture the highest and lowest values of hydraulic conductivity in the Study Area. Due to the low flow rates used, measurable drawdown (i.e., drawdown exceeding 0.01 feet) does not occur during the sampling of many monitor wells that have sufficiently high hydraulic conductivities. In practice, hydraulic conductivities of greater than 100 ft/day cannot be determined with this method. Conversely, most monitor wells that have hydraulic conductivities less than 0.1 ft/day never achieve steady-state drawdown conditions during low-flow sampling (i.e., the water level in the monitor well continues to fall during the entire sampling period).

Spatial variation in slug-test hydraulic conductivities reflects the heterogeneous lithology of the alluvium underlying the Study Area. Alluvial slug-test hydraulic conductivities beneath the Site (i.e., beneath the Process Areas, Sulfide Tailings, and the Evaporation Ponds) are generally in the range of 1 to 10 ft/day, with some infrequent exceptions. To the west of the Site, along the margin of the Singatse Range, alluvial slug-test hydraulic conductivities extend into the range of 10 to 100 ft/day, with some locations still in the range of 1 to 10 ft/day. This trend continues north to towards the Sunset Hills. Beneath the Hunewill Ranch, alluvial aquifer slug-test hydraulic conductivity values generally range from 1 to 50 ft/day, with noted high conductivity exceptions at monitor wells B/W-60S, B/W-61S, and B/W-60D1.

Alluvial slug-test hydraulic conductivities near the Walker River (east of the Pit Lake) are generally higher than alluvial slug-test hydraulic conductivities beneath the Site, as evidenced by monitor wells B/W-13S, B/W-14S, B/W-15S, B/W-21S, and PLMW-2S. In this area, alluvial slug-test hydraulic conductivities are in the range of 10 to 50 ft/day. North of the Site and east of the West Campbell Ditch, alluvial slug-test hydraulic conductivities are also high, generally ranging from 10 to 100 ft/day or higher.

The spatial variability of alluvial slug-test hydraulic conductivity values reflects the varied depositional environments in Mason Valley, which are discussed in Section 4.8. The areas beneath the Site represent older fan deposits, which typically display lower permeability compared to the valley-fill sediments (i.e., younger and older alluvium). North of the Site, a transitional environment with higher permeability exists between the older fan deposits and the valley-fill sediments. Areas near the Walker River and generally to the east of West Campbell Ditch appear to represent valley-fill sediments, which exhibit the highest overall permeability. To the west of the Site, a narrow north-south trending band of higher permeability aquifer materials occurs along the flank of the Singatse Range, which represents coarser-grained alluvial fan materials eroded from the Singatse Range.

4.9.7 Bedrock Groundwater

The conceptual model of OU-1 bedrock groundwater flow conditions is based on regional and Site-specific information, including: 1) the lithologic and structural geology information presented in Proffett and Dilles (1984), and Proffett (1977); 2) a general understanding of bedrock groundwater flow in the Great Basin portion of the Basin-and-Range Physiographic Province; 3) hydrogeologic information obtained from drilling, lithologic logging, testing, and monitoring of 67 bedrock groundwater monitor wells located in the OU-1 Study Area (typically installed with 20-30 foot long screen intervals positioned in the upper 50 feet of bedrock); 4) evaluation of hydraulic head data in the bedrock and alluvial groundwater systems; 5) hydrologic tracer data for stable isotopes of oxygen and hydrogen in water ($^{18}O/^{2}H$), tritium/helium ($^{3}H/^{3}He$) groundwater age estimates, and uranium isotopes; and 6) bedrock monitor well chemical data.

As noted previously, the Site and surrounding Study Area are in a U-shaped graben structure on the western margin of Mason Valley. Within the Study Area, the depth to bedrock is highly variable and ranges from 0 to 750 feet bgs. Bedrock within the Mason Valley and Study Area is comprised of consolidated granitic, metamorphic, and volcanic rocks. The bedrock groundwater system consists of a fractured rock aquifer where water moves predominantly through fracture porosity, and matrix permeability is considered negligible. The fractures occupy only a small fraction of the bedrock.

Large-scale geologic structures (i.e., faults) result in structural compartmentalization of the bedrock groundwater system in the Study Area, with limited groundwater flow across and along faults that are commonly characterized as containing fine-grained, low-permeability fault gouge and brittle or plastic clay. The fractured rock aquifer exhibits high, three-dimensional (i.e., anisotropic) spatial variability in hydraulic conductivity (and hence groundwater flow rate). Hydraulic conductivity (K) values in bedrock monitor wells have been derived from slug tests performed after the wells were constructed, and from an analysis of low-flow sampling of bedrock monitor wells during groundwater monitoring activities (BC 2015a). Both methods yield comparable results. In addition, both methods provide estimates of hydraulic properties local to the test well and, consequently, are primarily used to assess the spatial distribution of bedrock hydraulic properties in the Study Area. Mapping of the hydraulic conductivity values indicate a high degree of spatial variability with significant changes (often greater than three orders of magnitude) over distances that are small relative to the size of the Study Area.

In bedrock, estimated conductivities range from approximately 0.002 to 334 feet/day, with the higher values measured in wells located near faults and the open pit (Figure 4-17). The 25th and 75th percentiles were 0.15 and 11.7 feet/day, respectively. The median bedrock slug-test K value was 1.7 feet/day. The lowest bedrock K values are up to two orders of magnitude lower than the lowest K values in alluvium in the Study Area. The minimum measured low-flow sampling K value in bedrock was 0.013 feet/day, and the maximum value was 67 feet/day. The 25th and 75th percentiles were 0.485 feet/day and 16.6 feet/day, respectively. The median bedrock low-flow sampling K value was 4.3 feet/day. Consistent with the slug-test data set, the lowest K values in bedrock are up to two orders of magnitude lower than the lowest K values in alluvium in the Study Area.

Similar water level responses in paired bedrock/alluvial monitor wells at any given location throughout the Study Area result from: 1) the interconnectivity between the bedrock and overlying alluvial groundwater flow systems (except locally around the B/W-1 well cluster where an aquitard separates the two flow systems); and 2) the transmission of stresses through the skeletal structure

of the aquifer solids. Seasonal fluctuations in bedrock groundwater levels (and vertical gradients between the bedrock and alluvial groundwater systems) due to agricultural pumping from the alluvial aquifer are observed beneath the Hunewill Ranch and Evaporation Ponds, and in the Sunset Hills area. Both the bedrock and alluvial groundwater systems exhibit similar long-term water level declines.

Vertical interconnection between bedrock and overlying alluvial groundwater is indicated by water level data (and the presence of locally-elevated concentrations of sulfate and uranium in bedrock groundwater that are sourced from overlying mine-impacted alluvial groundwater). Spatially, vertical gradients between bedrock and alluvium generally reflect the recharge components of the alluvial groundwater HCSM (BC 2014a), with downward vertical gradients east and north of the Site driven by recharge of surface water and irrigation water on crop fields, and upward vertical gradients in western portions of the Study Area driven by mountain-front recharge.

The largest vertical gradients between bedrock and alluvium occur: 1) within the Pit Lake cone of depression; and 2) beneath the Hunewill Ranch fields and Evaporation Ponds. In all other portions of the Study Area, vertical gradients between bedrock and alluvium are relatively small. Seasonal crop irrigation effects are observed near the Hunewill Ranch fields, Evaporation Ponds, and Sunset Hills, as represented by locations with both upward and downward vertical gradients.

Stable isotopes ($^{18}O/^{2}H$) in bedrock groundwater are generally more depleted with respect to Walker River surface water and alluvial groundwater (BC 2014a). The most depleted stable water isotope signatures in the bedrock groundwater are associated with the oldest apparent groundwater ages, as determined by $^{3}H/^{3}He$ age dating (Figure 4-18). The youngest groundwater ages are associated with the least depleted bedrock groundwater samples, which also overlap the region of cool season Walker River flows. Walker River samples display an evaporative fractionation signature, with less fractionated values occurring during periods of snowmelt runoff and more fractionated values occurring during periods of lower flows during the summer.

The greater degree of $^{18}O/^{2}H$ depletion of bedrock groundwater compared to the alluvial aquifer and Walker River surface water suggests different recharge processes. The depleted stable isotope signature indicates that bedrock groundwater is: 1) sourced from snowmelt recharged directly in the Singatse Range, which does not undergo the same evaporative fractionation as Walker River water, and/or fossil water recharged during the Pleistocene (a cooler and more humid climate than the current climate); and 2) older and of a different origin than surface water and alluvial groundwater. Bedrock groundwater ages are older than 1954, and essentially pre-date Site mining activities, occur throughout most the Study Area. Younger bedrock groundwater within and downgradient of the Singatse Spur, proximal to the Walker River, exhibits isotopic similarities between younger bedrock groundwater and cool season Walker River water.

Although groundwater ages exhibit some degree of spatial association, groundwater ages are not correlated with hydraulic conductivity. The widespread occurrence of older groundwater ages and localized occurrence of younger groundwater ages, irrespective of hydraulic conductivity, suggests slow and limited movement of bedrock groundwater. The spatial distribution of Ue values generally comports with the spatial distribution of $^{3}H/^{3}He$ groundwater ages. This pattern of widespread higher Ue values (i.e., “old” water) with localized areas of lower Ue values (i.e., “young” water), irrespective of hydraulic conductivity, again suggests slow/limited movement of bedrock groundwater.

In addition to a high degree of anisotropy in hydraulic characteristics and hydrologic tracer signatures, the bedrock groundwater system also exhibits three-dimensional (i.e., anisotropic) spatial variability in chemical concentrations. As noted in Brown and Caldwell (2014a) and discussed further in Section 5.0, concentrations of mine-related chemicals in groundwater are most elevated in the Shallow zone of the alluvial aquifer beneath the LEP, UEP, Finger Ponds, Phase IV VLT HLP, and Phase IV VLT Pond. COI concentrations decrease with vertical depth and horizontal distance from the Site sources, resulting in values in bedrock groundwater that are one to several orders of magnitude lower than the values in overlying alluvial groundwater.

In addition, areas of elevated COIs in bedrock groundwater are small in comparison to the alluvial aquifer, highly localized, and found mostly on-Site. The localized areas of elevated COI concentrations in bedrock groundwater indicate that bedrock fractures have limited hydraulic connectivity and transmissivity over horizontal distances relevant to the scale of the Study Area.

Collectively, the bedrock characterization information indicates: 1) a high degree of vertical hydraulic connection between the bedrock and alluvial groundwater systems; and 2) limited horizontal hydraulic connectivity and transmissivity of bedrock fractures, especially over horizontal distances that are relevant to the scale of the Site and the surrounding Study Area. Despite localized areas of relatively high hydraulic conductivity, bedrock groundwater flow velocities, average volumetric flow rates and chemical fluxes through the bedrock groundwater system are low.

SECTION 5.0
NATURE AND EXTENT OF GROUNDWATER CONTAMINATION

Identifying background groundwater quality and defining the extent of mine-impacted groundwater have been elements of the phased OU-1 groundwater characterization activities since 2005. This activity, referred to as the background assessment, was specifically identified as DQO #1 in both the draft and final versions of the remedial investigation work plans for OU-1 (BC and Integral Consulting, Inc. 2007 and BC 2014a, respectively).

5.1 Background Assessment Approach

The conventional approach to a background assessment described by EPA (2012a) involves obtaining groundwater chemical data from areas that were not impacted by Site sources to establish background chemical concentration ranges and background concentration limits (BCLs) for the COIs. Typically, the chemical concentration data are obtained from locations that are hydraulically upgradient or cross-gradient of Site sources. However, EPA and ARC recognized that there are constraints to relying solely on this conventional, statistical approach at the Site because locations where background wells can be installed hydraulically upgradient or cross-gradient of the Site sources do not fully account for all of the factors affecting groundwater quality downgradient of the Site, such as the following: 1) naturally-occurring variations in groundwater chemistry associated with geologic formations; 2) chemical inputs associated with application of agricultural fertilizers (e.g., nitrate and sulfate) and/or crop irrigation (e.g., uranium and sulfate); 3) increases in dissolved chemical concentrations associated with longer periods of contact between groundwater and aquifer sediments (i.e., longer groundwater residence times); and 4) spatial variations in groundwater flow conditions and the groundwater geochemical regime, which affect dissolved chemical concentrations.

Consequently, multiple lines of evidence are used to differentiate background groundwater quality from mine-impacted groundwater, including:

- Hydrogeologic Conceptual Site Model: The hydrogeologic information defines the current and plausible historic groundwater flow and chemical transport pathways, and related anthropogenic activities (including mining and agriculture). The HCSM: 1) incorporates observed temporal variations in groundwater flow conditions and chemical concentrations in groundwater based on an extensive Site-wide groundwater monitoring network, aquifer testing, and a groundwater flow model; and 2) constrains how chemical distributions in groundwater can be reasonably interpreted and related to mining and agricultural activities.
- Contoured Chemical Distributions: Chemical distributions outline distinct plumes of off-Site impacted groundwater that have physical continuity along plausible flow pathways linked to Site features that are known sources of groundwater impacts. Other areas where chemicals occur in groundwater at concentrations above Maximum Contaminant Levels (MCLs), such as the North Study Area (NSA; i.e., that portion of the Study Area located northeast of the West Campbell Ditch and north of Sunset Hills), are separate from and do not physically connect along groundwater flow pathways to the Site.
- Sulfur Isotope Signatures: Distinct sulfur isotope ($\delta^{34}S_{SO4}$) signatures associated with sulfate in the acidic process leach solutions are used to differentiate mine-impacted groundwater from groundwater that is unaffected by mining operations, and to delineate the extent of groundwater contamination associated with mining. Specifically, the extent of mine-impacted groundwater is constrained where the $\delta^{34}S_{SO4}$ value in alluvial groundwater downgradient of the Site exceeds the minimum background value of +4.93‰ at locations that are within predominant recharge areas to the alluvial aquifer. Such background areas of the alluvial aquifer are also consistent with contoured or numerically-modeled flow pathways from the Site.
- Conventional Approach: The conventional approach to defining background groundwater quality for the Site (EPA 2012a) relies on chemical data from the background monitor wells and EPA-recommended statistical procedures (EPA 2009) to calculate BCLs for COIs. BCLs are computed for each COI in three geographic recharge areas identified in the Study Area HCSM: 1) the Southeast Recharge Area (SERA) - representing recharge by infiltration and percolation of water associated with streams, ditches and agricultural fields; 2) the Southwest Recharge Area (SWRA) - representing mountain-front recharge; and 3) the NSA - representing groundwater lateral to the Site flowing into the NSA.

The BCLs are used for two purposes. BCLs for sulfate and dissolved uranium in the SERA and SWRA are used to confirm the extent of mine-impacted groundwater defined by $\delta^{34}S_{SO4}$ signatures. Sulfate and dissolved uranium are suitable chemicals for this purpose because these two chemicals are typically more mobile in groundwater relative to other indicators of mine-impacted groundwater such as iron and other metals (BC 2014a; EPA 2010d). BCLs are computed for other COIs, which can then be used to define areas within the extent of mine-impacted groundwater where chemical concentrations exceed background chemical concentrations.

Because the NSA BCLs characterize groundwater quality flowing into the NSA, they are not used to define the extent of mine-impacted groundwater but can instead be used to evaluate chemical loading to groundwater due to agricultural practices in this part of the Study Area. The steps identified in the BGQA - Revision 3 (BC 2016b) for performing the background groundwater assessment are illustrated on Figure 5-1 and summarized in Table 5-1.

Table 5-1. Site-Wide Background Groundwater Quality Assessment Approach

Step	Information Source(s)
Obtain and evaluate available OU-1 hydrogeologic and geochemical data with respect to data quality and relevance.	▪ Brown and Caldwell (BC 2014a) ▪ Brown and Caldwell (BC 2015e)
Refine the HCSM based on recent information obtained in 2013 and 2014 from existing wells and new wells installed pursuant to the Additional Well Work Plan (BC 2013b).	▪ Brown and Caldwell (BC 2015d) ▪ Brown and Caldwell (BC 2016b). Summarized below; see Section 3.0 in Appendix J-7 for details.
Define hydrogeologic areas that are considered representative of background conditions and/or other water quality types.	▪ Brown and Caldwell (BC 2016b). Summarized below; see Section 3.0 in Appendix J-7 for details.
Specify the types and quality of RI groundwater data selected as relevant and appropriate for the background assessment.	▪ Brown and Caldwell (BC 2016b). See Section 4.0 in Appendix J-7 for details.
Use hydrologic tracer results to refine the HCSM, especially as the results relate to the information inputs identified in DQO #1 for the background groundwater assessment. Use $\delta^{34}S_{SO4}$ signatures to differentiate mine-impacted groundwater from groundwater impacted by other anthropogenic activities.	▪ Brown and Caldwell (BC 2016b). Summarized below; see Section 6.0 in Appendix J-7 for details.
Establish quantitative background concentration ranges and calculate groundwater BCLs for each background area. Use sulfate and uranium BCLs to evaluate the extent of mine-impacted groundwater. Use BCLs for other COIs to define areas within the extent of mine-impacted groundwater where chemical concentrations exceed background chemical concentrations.	▪ Brown and Caldwell (BC 2016b). Summarized below; see Section 6.0 in Appendix J-7 for details.
Evaluate the consistency of the two approaches (i.e., $\delta^{34}S_{SO4}$ signatures tracers and BCLs) to identifying the extent of mine-impacted groundwater. Integrate the results of the two approaches along with other RI characterization information into a single boundary representing the extent of mine-impacted groundwater in each zone of the alluvial aquifer.	▪ Brown and Caldwell (BC 2016b). Summarized below; see Section 7.0 in Appendix J-7 for details.

Ultimately, the identification of the extent of mine-impacted groundwater in the Study Area integrates the three major elements of boundary delineation (i.e., $\delta^{34}S_{SO4}$ signatures, and BCLs for the two most mobile, aerially extensive, indicators of mine-impacted groundwater, sulfate and uranium), as well as other lines of evidence that include hydrogeologic information, chemical concentration data, and other hydrologic tracer data.

5.2 Contoured Chemical Distributions

The following sections discuss the distributions of select parameters and COIs in Study Area groundwater.

5.2.1 Alluvial Aquifer

To illustrate aspects of the HCSM discussed below, the distributions of six chemicals (pH, sulfate, uranium, alkalinity, nitrate, and arsenic) in groundwater during August 2014 are illustrated on cross sections (cross section locations shown on Figure 4-6) and plan view maps for the Shallow and Deep 3 groundwater zones (Figures 5-2 through 5-7). The distributions of the six chemicals in all the groundwater zones are shown on plan view maps in Appendix K. The distributions of the six chemicals have routinely been presented in various groundwater reports for the following reasons.

Historical operational information and groundwater quality data indicate that elevated acidity (i.e., low pH), sulfate, and uranium are indicator parameters for mine-impacted groundwater at the Site. Because sulfate and uranium, which are naturally-occurring in the Study Area, are more mobile in groundwater relative to other indicators of mine-impacted groundwater (e.g., iron), these mine-related chemicals have been used to preliminarily evaluate the extent of mine-impacted groundwater (BC 2014a). Alkalinity in groundwater is important because complexation of dissolved uranium with bicarbonate enhances its solubility and mobility in groundwater (EPA 2010d; BC 2014a).

Given their association with agricultural amendments and fertilizer, sulfate and nitrate in groundwater are also important indicators of agricultural-impacted groundwater (BC 2014a). Although arsenic is detected at locally high concentrations in both on-Site and off-Site locations, it occurs naturally in the Study Area (and throughout Nevada) and exhibits complex geochemical transport behavior, which limits its usefulness as an indicator of mine-impacted groundwater (EPA 2016e).

pH

The distributions of pH values in the Shallow and Deep 3 groundwater zones in August 2014 are shown on Figures 5-2a and 5-2b, respectively. The lowest pH values are observed in Shallow zone groundwater beneath the Evaporation Ponds and downgradient of the Phase IV VLT HLP and VLT Pond, and pH values increase laterally and vertically away from these structures by orders of magnitude.

Sulfate and Uranium

The distributions of sulfate and uranium in groundwater in August 2014 are illustrated on Figures 5-3 and 5-4, respectively. The most elevated concentrations of sulfate and uranium are also observed in Shallow zone groundwater beneath the Evaporation Ponds and downgradient of the Phase IV VLT HLP and VLT Pond, and concentrations decrease laterally and vertically away from these features by orders of magnitude.

In particular, elevated concentrations of sulfate and uranium in the alluvial aquifer occur in: 1) Shallow zone groundwater where sulfate (Figure 5-3a) and uranium (Figure 5-4a) distributions exhibit a northwest longitudinal orientation consistent with the northwest direction of groundwater flow across the Study Area; and 2) Deep zone alluvial groundwater where sulfate (Figure 5-3b) and uranium (Figure 5-4b) distributions exhibit a northeast longitudinal orientation from the northern portion of the Site to beneath the Hunewill Ranch toward former (e.g., WDW019) and existing agricultural wells used seasonally to extract groundwater for crop irrigation.

In addition, elevated concentrations of sulfate and uranium (as well as alkalinity and nitrate discussed below) occur in Shallow, Intermediate, and Deep 1 groundwater zones beneath agricultural fields in the NSA. Given the low concentrations of sulfate and uranium detected in all groundwater zones at well cluster B/W-27 (Figures 5-3d and 5-4d, respectively), elevated concentrations of these chemicals in groundwater beneath the agricultural fields located in the NSA are not physically connected along current and plausible historic groundwater flow paths back to known sources of mine-impacted groundwater beneath the Site. A more detailed discussion of data specific to the NSA is provided in Section 5.5.

Alkalinity

The distribution of alkalinity in groundwater in August 2014 is illustrated on Figure 5-5. The most elevated values of alkalinity occur beneath the Evaporation Ponds in the northern portion of the Site. In the Shallow zone beneath the UEP and downgradient of the Phase IV VLT HLP and VLT Pond, pH values are generally less than 4 s.u.. Similar to sulfate and uranium, elevated alkalinity occurs in: 1) Shallow zone groundwater where the distribution (Figure 5-5a) exhibits a northwest longitudinal orientation consistent with the northwest direction of groundwater flow across the Study Area; and 2) Deep zone alluvial groundwater where the distribution (Figure 5-5b) exhibits a northeast longitudinal orientation from the Evaporation Ponds, Phase IV VLT HLP and VLT Pond to beneath the Hunewill Ranch toward former (e.g., WDW019) and existing agricultural wells used seasonally to extract groundwater for crop irrigation. Alkalinity values above 200 mg/L occur beneath the Hunewill Ranch and other agricultural fields located in the northeastern portion of the Study Area.

Nitrate

The distribution of nitrate in groundwater in August 2014 is illustrated on Figure 5-6. The most elevated nitrate concentrations occur in groundwater beneath the Hunewill Ranch and other agricultural fields located in the northeast portion of the Study Area (Figure 5-6a). Beneath the Hunewill Ranch, nitrate concentrations in Shallow zone groundwater were as high as 42 mg/L during August 2014. Former groundwater extraction from high-capacity wells (especially WDW019) for irrigation of crops on the Hunewill Ranch has mobilized nitrate from the Shallow zone into the Intermediate and Deep zones of the alluvial aquifer system. Nitrate is subsequently transported in groundwater that flows northwest to the Sunset Hills area.

Nitrate concentrations in Shallow zone groundwater beneath the agricultural fields in the northeast Study Area were as high as 38 mg/L during August 2014 (Figure 5-6a). Groundwater extraction from high-capacity agricultural wells for crop irrigation on fields located in the northeastern portion of the Study Area has mobilized nitrate from the Shallow zone into the Intermediate and Deep zones of the alluvial aquifer system. Nitrate beneath these agricultural fields is subsequently transported in groundwater that flows north and northwest.

Nitrate concentrations in groundwater samples from the B/W-27 cluster have consistently been at low concentrations throughout their monitoring history. In August 2014, nitrate concentrations ranged from 0.13J to 0.88J mg/L. The nitrate data from the B/W-27 well cluster shows that the nitrate concentrations beneath the Hunewill Ranch and other agricultural fields in the northeast Study Area are physically separate. The horizontal and vertical patterns in nitrate concentrations in groundwater indicate that application of fertilizer on the agricultural fields has resulted in downward vertical migration of agricultural nitrate rather than horizontal transport of nitrate in the groundwater system. A more detailed discussion of data specific to the NSA is provided in Section 5.5.2.

Arsenic

The distribution of arsenic in alluvial groundwater in August 2014 (Figure 5-7) differs from the distributions observed for sulfate, nitrate, and alkalinity. The most elevated arsenic values occur in Shallow zone groundwater at off-Site wells B/W-77S (560 µg/L) and B/W-32S (420 µg/L), which are located approximately 2,500 feet north of the Evaporation Ponds (Figure 5-7a). Arsenic values decrease laterally and vertically from these two wells by at least an order of magnitude. In contrast to the elevated arsenic values at these two off-Site wells, the most elevated arsenic values in groundwater beneath the Site are approximately 3.5 times lower.

The most elevated arsenic concentrations in on-Site groundwater range from approximately 120 to 160 µg/L in Shallow zone wells MW-5S, FMS-06S, and MW-2S (Figure 5-7a). These three wells are located near the Thumb Pond and the Phase IV VLT HLP and VLT Pond. Historic process solutions discharged to the Thumb Pond were reported to contain 42 mg/L of arsenic (Seitz et al., 1982). Arsenic values in the range of 50 to 80 µg/L occur in the Shallow, Intermediate and Deep zones west and northwest of the Evaporation Ponds and below the Phase IV VLT HLP and VLT Pond.

In addition, data from zonal groundwater samples and monitor wells installed in the NSA indicate elevated concentrations of arsenic in Deep zone groundwater that inflows (i.e., recharges) the NSA and migrates beneath the agricultural fields. Groundwater arsenic concentrations in this portion of the Study Area increase as a function of depth in the alluvial aquifer (at a relatively uniform pH) as indicated best by the zonal groundwater sample data from wells B/W-56 and B/W-69 (Figure 5-8) where arsenic concentrations are as high as 83 ug/L. At other NSA monitoring locations (such as B/W-59, B/W-57 and B/W-68), chemical profiling did not extend as deep as the B/W-56 and B/W-69 locations. Nonetheless, arsenic concentrations at these three locations began increasing as a function of depth below 4,200 feet amsl. Had sampling been conducted to greater depths at these locations, elevated arsenic concentrations are expected since no known plausible hydrologic/geochemical explanation would limit arsenic enrichments strictly to those areas around B/W-56 and B/W-69.

Because profile locations B/W-56 and B/W-69 represents background (i.e., characterize groundwater inflows to the NSA), chemical concentrations at these locations represent naturally-occurring concentrations and are not related to advancement of mine-impacted groundwater from the south. Furthermore, the elevated arsenic concentrations at this depth are not associated with agricultural activity, which is shown in Section 5.5.2 to affect the Shallow, Intermediate and Deep1 zones in the NSA. Instead, these elevated arsenic concentrations appear to be associated with regional groundwater conditions in the Mason Valley, likely associated with deep bedrock discharge to the alluvial basin aquifer.

5.2.2 Bedrock Groundwater

Most of the bedrock wells have 20- to 30-foot long screens that are positioned in the upper 50 feet of the bedrock to straddle fractures that yield groundwater for monitoring purposes. The pH measurements and concentrations of sulfate, uranium, alkalinity, nitrate and arsenic in the bedrock groundwater system in August 2014 are shown on Figure 5-9. Most pH measurements in bedrock groundwater are near-neutral (i.e., approximately 7.0).

Sulfate and uranium were detected in bedrock groundwater during August 2014 at concentrations as high as 1,600 mg/L and 950J µg/L, respectively. For both chemicals, the most elevated concentrations were detected in bedrock groundwater within the mine Site, and somewhat lower concentrations were detected immediately west of the Evaporation Ponds below the VLT Pond. The most elevated sulfate concentrations in bedrock groundwater occurred beneath the Sulfide Tailings at well B/W-36B. Off-Site, sulfate was detected in bedrock groundwater at a concentration above 500 mg/L in well B/W-58B, which monitors groundwater emanating from the MacArthur Mine. The most elevated uranium concentrations in bedrock groundwater occurred at on-Site wells MW-5B and B/W-74B. Similarly, the most elevated alkalinity concentrations in bedrock groundwater occurred at on-Site wells MW-5B and B/W-74B (as well as MW-H4SN).

Nitrate concentrations were most elevated in bedrock groundwater at wells B/W-73B and HLP-06B, which are located to the west and southwest of the mine Site.

Elevated arsenic concentrations in bedrock groundwater occurred in three distinct areas. Elevated arsenic concentrations were detected in: 1) four wells (PA-MW-2B, PA-MW-4B, HLP-03B, and HLP-06B) located around the Phase III 4X HLP and nearby Calcine Ditch; 2) six wells (MW-4B, B/W-34B, B/W-6B, B/W-44B, LEP-MW-2B, and B/W-33B) located to the immediate west of the Evaporation Ponds in an area potentially influenced by MFR; and 3) in two wells (B/W-54B and YPT-MW-10B) located north of Sunset Hills.

5.3 Identification of Groundwater Impacts

5.3.1 Differentiating Groundwater Impacts Using Sulfur Isotopes

Sulfur Isotope Signature in Background Groundwater

The $\delta^{34}S_{SO4}$ signature used to differentiate mine-impacted groundwater from non-mine-impacted groundwater reflects the dominant background groundwater types in off-Site areas. Groundwater modeling (SSPA 2014) indicates that recharge to groundwater in the alluvial aquifer (98% of all recharge) in the Study Area results from irrigation field percolation (49%), leakage from irrigation ditches (29%), and seepage from the Walker River (20%).

Background wells associated with these water types include some, but not all, of the wells in the SERA and NSA recharge areas. Eight background wells that represent the dominant background groundwater types in off-Site areas, based on their locations in the groundwater flow field relative to the Walker River and agricultural features, include: B/W-15S, B/W-20S, B/W-21S, B/W-56S, B/W-59S, B/W-59D3, PLMW-2S and PLMW-2B. Values of $\delta^{34}S_{SO4}$ in groundwater samples from these wells range from +4.93 to +6.62‰.

Sulfur Isotope Signature in Mine-Impacted Groundwater

Sulfur isotopes in groundwater were used to differentiate the leading edge of mine-impacted groundwater from background groundwater or groundwater impacted by other anthropogenic activities within the Study Area because: 1) sulfur isotopes in dissolved sulfate can be used to infer groundwater movement because these isotopes are mobile tracers whose movement is not strongly retarded by the aquifer matrix in groundwater settings similar to the Study Area; and 2) early copper extraction operations at Yerington (during the 1950s and 1960s) primarily relied on sulfuric acid derived from sulfur ores (i.e., pyrite) from the Leviathan Mine in California (BC 2014a), which had a distinct sulfur isotopic signature (Taylor and Wheeler 1994). Sulfur sources with different (higher) isotopic signatures were used during later operations in the 1970s, 1980s, and 1990s. These different isotopic signatures may be used, along with chemical data and other information, to differentiate groundwater impacts associated with Anaconda and Arimetco operations.

Delineation of mine-impacted groundwater reasonably assumes that groundwater affected by the earliest operations at the Site has traveled the farthest downgradient distance in the alluvial aquifer. Therefore, the isotopic signature for sulfur sources used during the 1950s and 1960s serves as a potentially reliable tool for characterizing the leading edge of the plume and for differentiating mine-impacted water at the leading edge of the plume from background conditions. The median value reported by Taylor and Wheeler (1994) for $\delta^{34}S_{SO4}$ in aqueous samples collected from seeps and adit discharge at the Leviathan Mine is -17.6‰ (Table 5-5 in Appendix J-7).

Distinct $\delta^{34}S_{SO4}$ signatures associated with sulfate in the sulfuric acid process leach solutions used during early Site operations (most evident in groundwater at well W5DB-D3) and groundwater from the background monitor wells are used to evaluate the extent of mine-impacted groundwater. This approach conceptualizes initial infiltration of acidic process leach solutions exhibiting a diagnostic $\delta^{34}S_{SO4}$ signature of approximately -17‰ into originally un-impacted groundwater beneath the Evaporation Ponds.

The conceptual approach assumes a simplified aquifer geometry and flow configuration that account for mixing of a conservative (i.e., geochemically unreactive) tracer within the aquifer. Again, the isotope signature for the sulfur source used during the earliest processing operations at the Site would be representative of any mine-impacted water first entering the alluvial aquifer and now present at the leading, downgradient edge of the plume. The leading edge of mine-impacted groundwater is identified as locations where the $\delta^{34}S_{SO4}$ signature in groundwater associated with mining impacts cannot be differentiated from the $\delta^{34}S_{SO4}$ signature in background groundwater.

Quantitatively, mine-impacted groundwater can no longer be differentiated from background groundwater when the $\delta^{34}S_{SO4}$ value at a given location falls within the background $\delta^{34}S_{SO4}$ range (i.e., exceeds the minimum background value of +4.93‰). Higher isotope signatures measured inside the leading edge of the plume may be indicative of mixing with groundwater, subsequent sulfur releases derived from sources having a different isotopic signature, or some combination of these two processes.

Lateral and vertical patterns in $\delta^{34}S_{SO4}$ groundwater data are illustrated on Figure 5-10. The distinctly negative $\delta^{34}S_{SO4}$ signature of -17.6‰ associated with sulfate in the sulfuric acid process leach solutions used for copper recovery at Yerington is evident in Deep zone alluvial groundwater beneath the Evaporation Ponds, especially at well W5DB-D3, which has a strongly negative $\delta^{34}S_{SO4}$ signature of -17.12‰.

The low $\delta^{34}S_{SO4}$ values in Deep zone alluvial groundwater beneath the Evaporation Ponds also extend off-Site toward the Hunewill Ranch, particularly in the Deep 3, Deep 4, and Deep 5 zones. The region of low $\delta^{34}S_{SO4}$ values beneath the Evaporation Ponds is displayed on cross section A-A' (Figure 5-10c), centered around the W5DB well cluster. The low values of $\delta^{34}S_{SO4}$ that extend off-Site toward the Hunewill Ranch are visible on cross section B-B' (Figure 5-10d).

5.3.2 Differentiating Groundwater Impacts Using BCLs

A conventional approach to a BGQA emphasizes the groundwater flow regime to identify wells that are located hydraulically up-gradient and/or cross-gradient to sources of chemical loading to groundwater, as noted by the EPA (2012a) in comments on the Draft BGQA (BC 2011c). A background assessment may also consider groundwater recharge sources, the different geologic materials through which groundwater flows, and the residence time because these factors are recognized to naturally affect groundwater composition (BC 2014a; Hem 1985; Freeze and Cherry 1979). Key HCSM elements that are relevant to identifying background monitor wells include:

- Groundwater Flow Direction: Groundwater in the alluvial aquifer within the Study Area generally flows to the northwest, with flow directions locally affected by a variety of factors discussed previously in Section 4.0.
- Recharge Sources: The alluvial aquifer within the Study Area is primarily recharged by infiltration and percolation of water associated with stream channels, ditches, and irrigated agricultural fields located to the east of the mine Site. Limited recharge to the alluvial aquifer also occurs as mountain-front recharge to the west of the Site.
- Chemical Loading Sources: The northern portion of the Site (including the Evaporation Ponds, the Phase IV VLT HLP and the VLT Pond) is considered the primary source of chemicals that migrate off-Site. The most elevated acidity and chemical concentrations are observed in Shallow zone groundwater beneath this area, and concentrations decrease laterally away from this area by orders of magnitude. Furthermore, other Site sources are located hydraulically upgradient of the northern portion of the Site.

Based on these considerations, background monitor wells for the Study Area are categorized by geographic recharge area and described below.

- SERA: This background groundwater quality type is represented by seven monitor wells (B/W-15S, B/W-20S, B/W-21S, PLMW-2S, PLMW-2B, WRA3-1B and WRA3-2B) that are located up-gradient of the mine Site and near the Walker River. Data from these wells represent recharge of groundwater having a short residence time in the flow system.

- NSA: This background groundwater quality type is represented by three monitor wells (B/W-56S, B/W-59S and B/W-59D3) that are located upgradient of the NSA and represent both Shallow and Deep zone alluvial groundwater quality.
- SWRA: This background groundwater quality type is represented by six monitor wells (B/W-12RB, B/W-13S, B/W-23B, B/W-26RB, PLMW-3RB, and PLMW-4B) that are located up-gradient and west/southwest of the Site and, thus, represent mountain-front recharge.

The BCL for each COI for each background water quality type was calculated as the 95% upper tolerance limit (UTL) with 95% confidence, consistent with the sampling and statistical comparison strategy recommended in EPA guidance (EPA 1992). The 95% UTL is the numerical value below which 95% of the background data are expected to fall, with 95% confidence. That is, one can be 95% sure that 95% of data in the background population fall below this value. The upper bound of this interval is the 95/95 UTL.

The 95/95 UTL is calculated from a sample dataset and depends on the distribution, central tendency, and variability of the dataset, as well as sample size (EPA 2009). The statistical test used to calculate the 95/95 UTL also depends on the distribution of the dataset, the sample size, and the percentage of non-detects present. The ProUCL software program (version 5.0.00) (EPA 2013f) was used to perform statistical calculations of the 95/95 UTL. ProUCL evaluates a dataset to determine the likely form (or forms) of the distribution, calculates UTLs using numerous appropriate statistical methods, and provides a recommendation as to which method is most appropriate for a particular dataset.

Distributional testing in ProUCL is performed using the Shapiro-Wilk (S-W) test for normality on the untransformed data, the log-transformed data, and the gamma-transformed data. The S-W test may conclude that the data set conforms to multiple parametric distributions. In this case, the distribution with the highest probability of association (calculated p-value from the S-W test) is selected as the underlying parametric distribution. When an insufficient sample size or insufficient number of detected results existed to statistically calculate a 95/95 UTL, the maximum value of the dataset was selected, as is common practice in selecting upper threshold values in the absence

of adequate sample sizes (EPA 2009). For datasets with 100% non-detects, the lowest detection limit in the dataset was selected as the BCL. The calculated 95/95 UTLs for each constituent and background water quality type are provided in Table 5-2.

Table 5-2. Summary of Calculated Background Concentration Limits

Chemical	Units	Groundwater Standard	SERA	NSA Inflows	SWRA
pH (field)	s.u.	6.5-8.5	7.96	7.65	8.35
Alkalinity, Bicarbonate (as $CaCO_3$)	mg/L	--	180	160	210
Alkalinity, Carbonate (as $CaCO_3$)	mg/L	--	2	2	2
Alkalinity, Hydroxide (as $CaCO_3$)	mg/L	--	2	2	2
Alkalinity, Total (as $CaCO_3$)	mg/L	--	180	160	210
Total Dissolved Solids	mg/L	500	570	304	561
Total Organic Carbon (TOC)	mg/L	--	1.8	1.5	1.8
Calcium	mg/L	--	71	38	72
Magnesium	mg/L	--	13	11	16
Potassium	mg/L	--	5	7	5
Sodium	mg/L	--	96	51	130
Chloride	mg/L	250	59	17	72
Fluoride	mg/L	2	1	0.9	1.5
Sulfate	mg/L	250	160	57	180
Nitrate (as N)	mg/L	10	1.5	0.1	0.8
Nitrite (as N)	mg/L	1	0.1	0.2	0.4
Nitrate-Nitrite (as N)	mg/L	--	1.5	0.3	0.8
Aluminum	mg/L	0.2	0.04	0.03	0.05
Antimony	µg/L	6	0.41	0.31	0.96
Arsenic	µg/L	10	12	38	20
Barium	µg/L	2,000	50	141	41
Beryllium	µg/L	4	0.17	0.25	0.25
Boron	µg/L	--	680	410	920
Cadmium	µg/L	5	0.11	0.25	0.17
Chromium	µg/L	100	0.9	1.0	1.8
Cobalt	µg/L	--	1.5	1.4	2
Copper	µg/L	1,300	0.9	0.9	4.3
Iron	mg/L	0.3	0.1	0.3	1.4
Lead	µg/L	15	0.28	0.20	0.2
Lithium	µg/L	--	65	49	44
Manganese	µg/L	50	870	2,825	303
Mercury	µg/L	2	0.35	0.10	1.1
Molybdenum	µg/L	--	18	20	140
Nickel	µg/L	--	1.1	1.6	19
Phosphorus	mg/L	--	0.16	0.91	0.12
Selenium	µg/L	50	1.1	0.5	20
Silica	mg/L	--	44	40	55
Silver	µg/L	100	0.12	0.14	0.36
Strontium	mg/L	--	0.74	0.4	0.47

Table 5-2. Summary of Calculated Background Concentration Limits

Chemical	Units	Groundwater Standard	SERA	NSA Inflows	SWRA
Thallium	µg/L	2	0.2	0.2	0.2
Tin	µg/L	--	14	12	30
Titanium	mg/L	--	0.002	0.002	0.002
Uranium	µg/L	30	20	10	27
Vanadium	µg/L	--	8	5	16
Zinc	µg/L	5,000	6	4	120
Gross Alpha	pCi/L	15	12.2	6.7	21.3
Gross Beta	pCi/L	--	10.8	10.0	11.9
Radium-226	pCi/L	5 (combined 226 + 228)	0.8	1.0	1
Radium-228	pCi/L	5 (combined 226 + 228)	1	0.9	1.5
Thorium-228	pCi/L	--	0.5	0.4	0.5
Thorium-230	pCi/L	--	0.4	0.4	0.7

Notes:

1) SERA = Southeast Recharge Area; NSA = North Study Area; SWRA = Southwest Recharge Area
2) s.u. = standard units; µg/L = milligrams per liter; µg/L = micrograms per liter; pCi/L = picocuries per liter

5.3.3 Comparison of Methods

The extent of mine-impacted groundwater based on sulfate and uranium BCLs is generally similar to the extent of mine-impacted groundwater based on $\delta^{34}S_{SO4}$ signatures. Furthermore, the extent of mine-impacted groundwater in each zone of the alluvial aquifer varies in ways that are consistent with flow directions, chemical distributions, and other hydrologic tracer data presented in the HCSM. Differences in the spatial extent of mine-impacted groundwater delineated by the two background assessment approaches are considered minor and likely associated with local variations in transport behavior and locally variable evapoconcentration and chemical loading processes.

5.4 Extent of Mine-Impacted Groundwater

The extent of mine-impacted groundwater presented in this OU-1 RI Report reflects the outcome of discussions during a groundwater technical meeting on June 29, 2016 and EPA’s subsequent direction to conservatively establish the extent of mine-impacted groundwater because “is in the best interest of the overall progress for completing the OU-1 Groundwater Remedial Investigation Report” (EPA 2016e).

EPA (2016e) noted that professional judgement is an inherent component of estimating the extent of mine-impacted groundwater in this complex setting, and that tools used in the background assessment to estimate the area of mine-impacted groundwater may not fully account for the range of chemical concentrations that occur naturally in groundwater within the Study Area. However, as noted during previous submittals (e.g., ARC 2016b) and during groundwater technical meetings, further refinements to the mine-impacted groundwater boundary may be warranted based on additional evaluations of monitoring data and other new information to better account for naturally-occurring chemical concentrations in Study Area groundwater.

As previously described, the identification of the extent of mine-impacted groundwater in the Study Area integrates the three major elements of boundary delineation (i.e., $\delta^{34}S_{SO4}$ signatures, and BCLs for the two most mobile, aerially extensive, indicators of mine-impacted groundwater, sulfate and uranium), as well as other lines of evidence that include hydrogeologic information, chemical concentration data, and other hydrologic tracer data. Also, the boundary delineating mine-impacted groundwater from unimpacted groundwater is conceptualized as a zone on a plan view map rather than a distinct line due to many factors including the size of the Study Area, age and complexity of the contaminant releases, occurrence and variability of naturally-occurring chemical concentrations, and complexities of subsurface contaminant transport and fate.

The extent of mine-impacted alluvial groundwater is shown on Figure 5-11, and can be generally described as follows, recognizing that mine-impacted groundwater is spatially more extensive in the Shallow, Intermediate and Deep 1 zones of the alluvial aquifer relative to the Deep 2 through Deep 5 zones. The northernmost extent of mine-impacted groundwater in the Shallow, Intermediate and Deep 1 zones of the alluvial aquifer is located near the Sunset Hills between well clusters B/W-10 and B/W-52. The eastern extent of mine-impacted groundwater in the Shallow, Intermediate and Deep 1 zones of the alluvial aquifer is approximately located near or beneath the West Campbell Ditch alignment. To the west of the Site, mine-impacted groundwater extends almost to the western extent of saturated alluvium between unimpacted wells/clusters B/W-16S and B/W-40, and impacted well clusters B/W-33, B/W-6 and B/W-22.

Mine-impacted groundwater in the deeper zones does not extend as far north as the upper three zones. In the Deep 2 through Deep 5 zones, the maximum northern extent of mine-impacted groundwater is near the northern end of the Hunewill Ranch fields. The eastern extent of mine-impacted groundwater in the Deep 2 through Deep 5 zones of the alluvial aquifer is located between well clusters B/W-27 and B/W-50. Particularly on the east, the area of mine-impacted groundwater in the Deep 3 through Deep 5 zones reflect the former influence of seasonal groundwater extraction for crop irrigation from agricultural wells (e.g., WDW019, located adjacent to the B/W-1 well cluster). To the west of the Site, mine-impacted groundwater in the Deep 3 through Deep 5 zones extends almost to the western extent of saturated alluvium.

Based on the background assessment methodology, the plume of mine-impacted groundwater in the various zones of the alluvial aquifer does not discharge to surface water. Estimates of the volume of mine-impacted groundwater and masses of sulfate and uranium in each groundwater zone are provided in Table 5-3.

Table 5-3. Estimated Volume and Masses of Sulfate and Uranium in Mine-Impacted Alluvial Groundwater

Zone	Zone Thickness (feet)	Volume of Mine-Impacted Alluvial Groundwater (acre-feet)	Sulfate Mass (tons)	Uranium Mass (tons)
Shallow	35	45,899	140,116	11.1
Intermediate	50	65,905	96,501	9.9
Deep 1	50	62,238	52,346	5.3
Deep 2	80	64,611	80,610	20.7
Deep 3	120	48,032	79,397	22.5
Deep 4	100	35,669	23,414	12.8
Deep 5	200	62,973	25,374	16.5
Total		**385,327**	**497,758**	**98.8**

The estimates in Table 5-3 are based on the thickness of each groundwater zone within the plume of mine-impacted groundwater shown on Figure 5-11 and the areas/average concentrations within the chemical concentration contouring. The volume of mine-impacted groundwater and masses of sulfate and uranium are large, and the following two analyses provide insights to FS considerations about aquifer cleanup.

Simple Analysis

In this simple analysis, PWS performance monitoring information and a simplifying assumption regarding chemical removal from aquifer sediments are used to estimate the time frame for aquifer cleanup.

From the early 2000s to March 25, 2009, the PWS operated continuously (i.e., 24 hours per day, 7 days per week), except during periods when individual wells were temporarily taken off line for maintenance and repairs of pumps and related equipment. The average pumping rate from the PWS from 1999 through 2008 was about 52 gpm. During this 10-year time period, approximately 800 acre-feet of water and approximately 5,000 tons of sulfate (average sulfate concentration in the pumped water of approximately 4,000 mg/L) were removed from the Shallow zone.

If it is assumed that three times the volume of mine-impacted Shallow zone groundwater (which is 45,899 acre-feet) must be removed to achieve aquifer cleanup, then at least 137,697 acre-feet of water would need to be removed from the Shallow zone. (This volume is about 172 times the volume of water removed by the PWS over the 10-year period). This volume does not address aquifer cleanup in the deeper zones of the alluvial aquifer or ongoing chemical loading to groundwater from impacted sediments and vadose zone soils, and dissolving sulfate or other minerals. Recognizing that the total volume of mine-impacted groundwater in the aquifer is 385,327 acre-feet, approximately 285 years of pumping at 2,500 gpm would be required to potentially achieve aquifer cleanup assuming that a volume of only three times the contaminated volume of mine-impacted groundwater would need to be removed. In reality, this estimate likely underestimates the actual time to cleanup.

Groundwater Modeling

In this analysis, the “batch flush” model (EPA 1988; Zheng et al. 1991) is used to estimate the minimum time (with an efficient extraction system) to restore groundwater quality to 500 mg/L sulfate. In this approach, the number of pore volumes (PV) of water that must be circulated through the contaminated zone having an initial concentration (Ci) to achieve cleanup to the specified standard (Cs) is calculated from the relationship:

$$\mathrm{PV} = -\mathrm{R}\ln \mathrm{Cs}/\mathrm{Ci}$$

In this relationship, R is the retardation coefficient for the target constituent. Based on this modeling approach, groundwater restoration to 500 mg/L sulfate would require approximately 100 years at a pumping rate of 2,300 gpm.

5.5 Sources of Impacted Groundwater

OU-1 RI characterization activities indicate that the past and/or ongoing major sources of COIs to Study Area groundwater include:

- Mine waste facilities, which have been grouped into the various Site OUs for individual RI/FS investigations;
- Agriculture activities that contribute COIs or affect the release of naturally occurring COIs in geologic materials (BC 2014a, 2016b); and
- Geologic materials containing naturally-occurring COIs (BC 2009a, 2014a, 2016b).

Section 7.0 of the 2007 SOW notes that the groundwater OU underlies all other OUs identified at the Site, and recommends that relevant elements of the other OUs be integrated with the OU-1 RI. Consistent with the SOW, this OU-1 RI Report discusses relevant source-related information for the other Site OUs that represent past or ongoing sources of chemical loading to groundwater (Section 5.5.1). In addition, the other major non-mining sources of COIs to groundwater are discussed in Sections 5.5.2 and 5.5.3.

5.5.1 Mine Waste Facilities

The major past and/or ongoing sources of COIs to groundwater include: 1) OU-4a, the Evaporation Ponds (BC 2014a); OU-8, the Arimetco Facilities (CH2M Hill 2010, 2011a, 2011b); and 3) OU-3, the Process Areas (BC 2014a). Concentrations of COIs in groundwater beneath OU-4b (Sulfide Tailings) are generally at least 10 times lower than COI concentrations in groundwater beneath OU-4a. Furthermore, OU-4b is located hydraulically upgradient or cross-gradient of OU-4a, and groundwater beneath OU-4b flows toward the higher COI concentrations under OU-4a.

Evaporation Ponds (OU-4a)

OU-4a RI field activities and characterization data are presented in reports by BC (e.g., 2009a, 2017a). OU-1 RI information that is particularly relevant to OU-4a includes the following: 1) the most elevated concentrations of mine-related chemicals occur in groundwater in this area; 2) concentrations of mine-related chemicals in groundwater beneath OU-4a are 100 or more times greater than chemical concentrations in groundwater beneath other OUs (Figures 5-2 to 5-7); and 3) the depth to water beneath OU-4a (i.e., vadose zone thickness) is generally smaller than the depth to water beneath other OUs. The depth to water beneath OU-4a ranges from approximately 20 to 40 feet bgs, except beneath the southern portion of the Calcine Ditch where the depth to water is up to approximately 70 feet bgs (Figures 4-8 and 4-9).

The summary below focuses on the magnitude and distribution of COIs in OU-4a mine waste materials and vadose zone soils, extent of contamination based on a comparison of OU-4a data to applicable soil BCLs, and the potential for vadose zone transport and chemical loading to groundwater based on vadose zone modeling and soil moisture probe data obtained during 2016. The highest COI concentrations in OU-4a mine waste materials are most commonly associated with pond sediments and calcines, which are typically located at depths ranging from approximately 0-3 feet bgs. Relative to the overlying pond sediments and calcines, the underlying alluvial soils generally exhibit lower concentrations of COIs.

Based on Site background soil concentrations presented in Table 5-3 of the *Background Soils Data Summary Report - Revision 1* (BC 2009b) for Sub-area A-1, located directly west of the Evaporation Pond and Calcine Ditch areas, approximate maximum depths of soil exceeding applicable BCLs within OU-4a include: 1) 17 to 20 feet bgs beneath the LEP; 2) 15 to 20 feet bgs beneath the UEP; 3) 47 to 52 feet bgs beneath the Finger Ponds; 4) 38 to 43 feet bgs beneath the Thumb Pond; and 5) 45 to 50 feet bgs at the north end of the Calcine Ditch and 75 to 80 feet bgs at the south end of the Calcine Ditch. These approximate maximum depths of alluvial soil contamination beneath the ponds and Calcine Ditch are primarily based on uranium, arsenic, selenium, iron, and copper.

Vadose zone model simulations were performed using the variably-saturated modeling code SVFlux™ to understand the potential for transport and chemical loading to groundwater beneath OU-4a. Vadose zone model results are summarized below (values presented in meters, input and output unit of measurement in the SVFlux™ modeling code):

- The LEP 'wet' areas simulation indicated a fairly constant downward net flux of soil water toward the water table. The cumulative flux at the deepest flux line in the profile was approximately 0.16 meters after 5 years of simulation.
- LEP 'dry' (non-ponded) areas showed a small downward net flux of water, approximately 0.013 meters after 15 years of simulation. Because the same soil moisture conditions for the 'wet' areas simulation was used for the 'dry' areas simulation, and because the soil moisture conditions for the 'dry' areas of the LEP are more likely to be similar to the conditions observed in the UEP, the numerical simulation likely over-predicted downward flux to the water table.
- The UEP simulation indicated a continuous upward net flux of water. The cumulative flux at the deepest flux line in the model was approximately 1.8 meters for 15 years of simulation (approximately 0.12 meters per year when averaged over the 15-year simulation period). For the 10-year period following the equilibration of the model, the cumulative flux was approximately 1.5 meters (approximately 0.15 meters per year).
- The Thumb Pond simulation indicated a very small upward net flux of water. The cumulative flux rate was approximately 4.0E-04 meters after 15 years of simulation (approximately 2.7E-05 meters per year when averaged over the simulation period). The simulation indicated both upward and downward flux of soil water in the upper portion of the profile, and a relatively constant upward flux in the deeper portion of the profile.
- The vadose zone simulation for the Finger Evaporation Ponds (FEPs) indicated a small downward flux of soil water during the 15-year simulation period, with a cumulative flux rate at the deepest flux line in the profile of approximately 0.043 meters after 15 years (approximately 2.9E-03 meters per year when averaged over the simulation period).

Integration of these estimated flux rates over the Pond acreages result in the following annual estimated volumes of soil water that could potentially flux to groundwater:

- Approximately 0.31 acre-feet per year (ac-ft/yr) for the LEP 'dry' areas, based on an estimated flux rate of 0.0012 m/yr and an area of 79.5 acres, equivalent to 0.19 gallons per minute (gpm);
- Approximately 1.13 ac-ft/yr for the LEP 'wet' areas, based on an estimated flux rate of 0.016 m/yr and an area of 21.5 acres, equivalent to 0.70 gpm; and

- Approximately 0.15 ac-ft/yr for FEP 1-4, based on an estimated flux rate of 0.0026 m/yr and an area of 17.8 acres, equivalent to 0.09 gpm.

Vadose zone modeling results indicated that: 1) the Thumb Pond and UEP exhibit an upward vertical flux of soil moisture to the atmosphere (i.e., no cumulative flux of soil moisture toward groundwater); and 2) the ‘wet’ areas of the LEP and FEPs 1-4 exhibit a cumulative downward flux of soil moisture toward the water table. Model results for the dry (peripheral) portions of the LEP indicate: 1) a net evaporative flux to the atmosphere; and 2) a downward flux of soil moisture during the latter third of the simulation period, resulting from wetter climate conditions.

Soil moisture data provide additional insights to the potential for transport and chemical loading to groundwater. Soil moisture has been monitored continuously since August 2016 and is ongoing. As part of the 2015–2016 field activities, soil moisture probes and porous cup lysimeters were installed at four locations. Further description of the installed equipment and the installation process is provided in the *Phase 1 Evaporation Ponds Characterization Data Summary Report* (BC 2017b). The monitoring locations are located at EP-VZC-2 (Thumb Pond), EP-VZC-3 (northern edge of the UEP), EP-VZC-6 (near the southern portion of the UEP and next to the Calcine Ditch), and EP-VZC-8 (northern edge of the LEP). Each location has soil moisture probes at three or four depth intervals, depending on the thickness of the vadose zone.

During the initial soil moisture monitoring period, a significant precipitation event occurred between January 4 and January 13, 2017, when 2.35 inches of precipitation fell over the 10-day period (WRCC 2017).

Soil moisture probe readings for EP-VZC-2 at the Thumb Pond, with the shallowest monitoring interval of 10 feet bgs, did not register any changes in vadose zone soil moisture at all monitored depths during and after the 10-day precipitation event. Soil moisture readings at EP-VZC-6, located near the southern tip of the UEP, registered moisture content increases in the shallow probes (2 and 6 feet bgs), but not at any greater depth during and following the January 2017 event. Soil moisture readings at EP-VZC-3, located in the northern portion of the UEP, registered a response to the January 2017 storm event at only the shallowest probe depth (1.5 feet bgs), but not

at the two deeper probes (5 and 15 feet bgs). Similarly, soil moisture readings at EP-VZC-8, located at the northern end of the LEP, registered a response to the January 2017 storm event at only the shallowest probe (3 feet bgs), but not at the two deeper probe depths (10 and 20 feet bgs).

In summary, there were no observable changes in soil moisture at depths greater than 6 feet bgs resulting from this significant precipitation event. At most locations, soil moisture data at the shallowest monitoring intervals (1.5 to 3 feet bgs) illustrate an abrupt increase in soil moisture immediately following the January 4-13 storm event. At some stations, soil moisture at 5 feet and 6 feet bgs also experienced changes following the January precipitation event, but were less pronounced than soil moisture changes at shallower intervals. Based upon these data, there does not appear to be evidence indicating moisture changes in deeper probes that result from an infiltration front moving vertically through the vadose zone.

Future data collection and evaluation may provide additional insight into the: 1) potential advancement of the wetting front to depths of 10 feet bgs and deeper; 2) effects of underlying native clay-rich alluvial layers on potential advancement of the wetting front and pore water chemistry; and 3) potential migration of chemicals within and between vadose zone materials based on lysimeter data from multiple points in time. However, the existing information suggests that: 1) the groundwater impacts beneath OU-4a are the result of past mining operations and fluid management; and 2) chemical loading to the groundwater system under current climatic conditions is very limited, based on vadose zone modeling and soil moisture probe data.

Arimetco Facilities (OU-8)

OU-8 components located throughout the Site include five HLPs (Phase I/II, Phase III South, Phase III 4X, Phase IV Slot, and Phase IV VLT), the FMS (which stores and conveys drain-down solution via a network of ponds, ditches, and 25,000 feet of pipe), and the SX/EW Plant.

RI activities characterized the nature and extent of radiochemicals, metals, and physical properties of the OU-8 HLPs and their associated ponds and ditches. Sources of contamination include:

- Leachable metals (aluminum, copper, iron, and manganese and, to a lesser extent, arsenic, beryllium, cadmium, chromium, cobalt mercury, and nickel) and other COIs on the surface and within the HLPs;
- Acidic draindown solutions containing COIs entrained within the HLPs;
- Acidic drain-down solutions containing COIs stored at the base of the HLPs or contained within their associated ponds and ditches; and
- Historic spills and releases containing COIs.

The OU-8 RI/FS determined that the areas affected by Arimetco operations include the footprints of each HLP and their associated drain-down FMS components, the SX/EW Plant, and historical spill areas (CH2M Hill 2011b). The environmental release or migration pathways of drain-down fluids are infiltration into the subsurface from unlined areas, through tears/breaches in liner systems and FMS components, and through tears/breaches due to potential settling/structural failure of the HLP liner systems (Ecology and Environment, Inc. 2013).

On the basis of groundwater monitoring results, these impacts are thought to extend vertically down to OU-1 groundwater (CH2M Hill 2011b). Furthermore, the OU-8 FS (CH2M Hill 2011b) also notes that additional characterization efforts are needed to fully determine the nature and extent of contamination in: 1) in OU-8 surface and subsurface soil due to releases of drain-down fluids from the Arimetco Facilities; and 2) OU-1 groundwater that may be attributed to OU-8 releases.

Numerous spills of process solution in connection with past Arimetco operations have been recorded, and all of the recorded spills report limited to no confirmation sampling data or post-remedial efforts (CH2M Hill 2010, 2011b). As noted by CH2M Hill (2011b), the spill report documentation in the HSR (CH2M Hill 2010) only generally describes the location and type of materials spilled, along with the estimated quantity of each spill and general response action that was taken. In some instances, these records appear to underestimate the overall quantity of materials spilled. On the basis of the existing spill reports and the suspected quantities of fluids released to the environment, further investigations may be required (CH2M Hill 2011b).

Process Areas (OU-3)

The OU-3 RI has involved extensive characterization to determine the vertical extent of impacted soils beneath known source areas and above known areas of impacted groundwater in the underlying alluvial aquifer (e.g., BC 2011a, 2014e). OU-3 RI activities have included: 1) soils and groundwater characterization in 2004-2005; 2) a variety of radiometric surveys; 3) groundwater monitor well installations in 2005; 4) sub-surface utility and dry well investigations during the period 2010-2013; 5) step-out (vertical and horizontal) soil characterization activities during the period 2013-2014; and 6) sampling and analysis of standing water in select locations during the 2013-2014 field program.

During the RI, a total of 3,385 samples of vadose zone alluvial soils were collected and analyzed from metals (57,764 analyses) and radiochemicals (9,172 analyses). Analytical results are discussed in the context of exceedances relative to the EPA Industrial regional screening level (RSL), a background level, and the maximum depth below ground surface that such exceedances occurred. A total of 198 metals exceedances, primarily arsenic and chromium, occurred in near-surface soils to approximately 15 feet bgs in every sub-area of OU-3. Metals exceedances also occurred at depths to 80 feet bgs at three primary waste solution conveyance ditches (Overflow, East Solution and Calcine Ditches) and the Acid Plant Pond. Fifty-one radiochemical exceedances, primarily for radium-226 and -228, occurred in shallow soils to depths of up to five feet bgs throughout OU-3. Three exceedances occurred in the southern Calcine Ditch (now included in OU-4a) to a depth of 20 feet.

COI concentrations in OU-3 groundwater are highest beneath the Precipitation Plant (Sub-area 5 on Figure 2-1), and are typically 10 times less than the concentrations in groundwater beneath OU-4a (Figures 5-2 to 5-7). The depth to groundwater beneath OU-3 ranges from 90 to more than 120 feet bgs (Figures 4-8 and 4-9). Vadose zone alluvial materials beneath OU-3 do not differ substantially from the vadose zone alluvial materials beneath OU-4a. Thus, to the extent that insights from the OU-4a vadose zone modeling results and soil moisture profiling are applicable to OU-3, groundwater impacts beneath OU-3 appear to be the result of past mining operations and fluid management rather than post-mining ambient Site climate conditions.

5.5.2 Agriculture

Agricultural influences on Study Area groundwater were identified and quantified during the background assessment and are summarized below.

Benson and Spencer (1983) noted that "agricultural practices strongly influence the concentration of uranium in Walker River and its East and West Forks. Irrigation practices induce significant losses of fluid through evaporation and evapotranspiration processes. This results in artificial increases in concentrations of uranium and other elements." Percolation of crop irrigation water through soils increases alkalinity in soil moisture, which has been shown at other sites (Jurgens et al. 2010; Brown et al. 2007) to solubilize and desorb naturally-occurring uranium from sediments resulting in elevated uranium concentrations in Shallow zone groundwater. Application of agricultural amendments and fertilizer on crop fields contributes sulfate, calcium, nitrate and other COIs to groundwater (Benson and Spencer 1983; BC 2014a, 2016b). Nitrate originating primarily from surface-applied fertilizers also plays a role in uranium solubilization leading to uranium mobilization (Nolan and Weber 2015).

Groundwater data from the NSA show that agricultural activities contribute sulfate, uranium, nitrate, alkalinity, and other COIs to groundwater. The NSA refers to the portion of the groundwater Study Area located northeast of West Campbell Ditch and north of the Sunset Hills. Monitor wells and well clusters located in the NSA include B/W-10(S, D1), B/W-50(S, D1, D2, D3), B/W-53(S1, S2, B), B/W-54(S, I, B), B/W-55(S, D1, D2), B/W-56S, B/W-57(S, I, D1, D4), B/W-58(S, D1, D3, B), B/W-59(S, D3), B/W-68(S, D1, D4), B/W-69(S, D1, D2, D5), B/W-81(S, D1, D2), B/W-82R(S, I, B), YPT-MW-(8S, 9I, 10B), YPT-MW-(11S, 12I), YPT-MW-(13I, 14D1) and MMW-2. Groundwater flow data and chemical distributions from monitor wells and clusters B/W-56, B/W-57, B/W-59, B/W-68, B/W-69, and B/W-81 discussed below illustrate the effects of agricultural practices on groundwater quality near agricultural fields in the northeastern part of the Study Area. The locations of these wells are shown on Figure 3-3 and potentiometric surface maps for the alluvial aquifer (Figures 4-11a through g) indicate that groundwater in the NSA flows to the north and northwest.

Groundwater near these wells in the NSA is recharged by infiltration from the East Campbell Ditch and irrigation on a series of agricultural fields (BC 2014a; SSPA 2014). During drilling and installation of monitor wells, zonal groundwater samples were collected to profile vertical chemical gradients in the alluvial aquifer upgradient and downgradient of the fields. Chemical profiles for sulfate, uranium, alkalinity, and arsenic in groundwater are provided on Figure 5-12 for B/W-59, B/W-68, and B/W-69, and on Figure 5-13 for B/W-56, B/W-57, and B/W-81. The wells are grouped in this manner to illustrate changes in groundwater chemistry along two parallel flow paths beneath the agricultural fields.

Except for arsenic, chemical concentrations in alluvial groundwater in the Shallow through Deep 2 zones (i.e., above 4,120 feet amsl) increase along the flow path beneath the agricultural fields (i.e., from B/W-59 and B/W-56 upgradient of the agricultural fields to B/W-68 and B/W-57 immediately downgradient of the agricultural fields). B/W-69 and B/W-81, located farther along their respective flow paths, also exhibit elevated values above 4,120 feet amsl, although the values are not as high as in B/W-68 and B/W-57 immediately downgradient of the agricultural fields. From B/W-56 to B/W-57, sulfate values exhibit more than a four-fold increase from about 30 mg/L at B/W-56 to a maximum of 137 mg/L at B/W-57. Uranium values exhibit more than a ten-fold increase from about 2 µg/L at B/W-56 to a maximum of 73 µg/L at B/W-57. Alkalinity exhibits a 2.5-fold increase from about 100 mg/L at B/W-56 to a maximum of 257 mg/L at B/W-57. From B/W-59 to B/W-68, sulfate values exhibit a two-fold increase from about 75 mg/L at B/W-59 to a maximum of 140 mg/L at B/W-68. Uranium values exhibit almost a two-fold increase from about 25 µg/L at B/W-59 to a maximum of 44 µg/L at B/W-68. Alkalinity exhibits a 20% increase from about 190 mg/L at B/W-59 to a maximum of 235 mg/L at B/W-68.

Arsenic exhibits increasing concentrations with depth at all locations, with the greatest increases observed in the Deep 3 through Deep 5 zones (i.e., below 4,120 feet amsl). Arsenic values generally increase from about 5 µg/L in the Shallow zone to approximately 80 µg/L in the Deep 5 zone. Arsenic values decrease along the flow path beneath the agricultural fields (the highest values are observed in B/W-59 and B/W-56, and the lowest values are observed in B/W-69 and B/W-81).

Data from well clusters B/W-59, B/W-68, B/W69, B/W-56, B/W-57 and B/W-81 indicate that concentrations of other constituents in addition to sulfate, uranium and alkalinity also increase in groundwater above 4,120 feet amsl along the flow path beneath the agricultural fields (Table 5-4). These constituents include TDS, calcium, chloride, magnesium, potassium, nitrate, and strontium. The average horizontal groundwater flow gradient in Shallow zone groundwater beneath the agricultural fields is approximately 0.002 feet/foot. Vertical (downward) groundwater flow gradients beneath the agricultural fields range between 0.02 feet/foot when agricultural pumping is not occurring and 0.1 feet/foot during pumping periods (calculated using water levels in B/W-57S and B/W-57D4).

Increasing alkalinity and calcium concentrations are important controls on mobilization of naturally-occurring uranium from aquifer solids (Bernhard et al. 2001). The correlation between increasing concentrations of alkalinity and calcium associated with agricultural activities, and increasing uranium concentrations as groundwater flows beneath agricultural fields in the NSA is discussed in Section 6.2.2.

Table 5-4. Concentrations of Constituents that Increase Beneath the Agricultural Fields in the North Study Area

Constituent	Units	Average Concentration in Monitor Well (May 2012 - October 2014)				
		B/W-59S	B/W-68S	B/W-68D1	B/W-69S	B/W-69D1 & B/W-69D2
Sulfate	mg/L	48	110	79	125	79
Uranium	µg/L	9	30	41	29	30
Alkalinity, bicarbonate (as $CaCO_3$)	mg/L	140	260	230	275	188
Total Dissolved Solids (TDS)	mg/L	260	530	440	540	400
Calcium	mg/L	31	49	76	78	64
Chloride	mg/L	16	20	20	25	20
Magnesium	mg/L	9	12	19	20	15
Potassium	mg/L	4	5	6	6	6
Nitrate (as N)	mg/L	0.06	5.0	2.9	1.2	0.9
Strontium	mg/L	0.3	0.5	0.6	0.7	0.6
Constituent	**Units**	**Average Concentration in Monitor Well (May 2012 - October 2014)**				
		B/W-56S	**B/W-57S**	**B/W-57I & B/W-57D1**	**B/W-81S**	**B/W-81D1 & B/W-81D2**
Sulfate	mg/L	41	62	142	70	62
Uranium	µg/L	4	11	75	4	36
Alkalinity, bicarbonate (as $CaCO_3$)	mg/L	140	174	293	160	213
Total Dissolved Solids (TDS)	mg/L	254	345	620	350	370
Calcium	mg/L	31	41	103	50	64
Chloride	mg/L	15	18	32	21	20
Magnesium	mg/L	8	11	25	13	15
Potassium	mg/L	5	3	9	5	7
Nitrate (as N)	mg/L	0.08	1.3	1.4	1.4	0.7
Strontium	mg/L	0.3	0.4	0.9	0.4	0.6

Notes: mg/L = milligrams per liter; µg/L = micrograms per liter

5.5.3 Naturally-Occurring Sources

Sulfate, uranium, arsenic, and other COIs occur naturally in groundwater in Mason Valley because of groundwater contact with naturally-mineralized and/or hydrothermally-altered bedrock associated with copper deposits and/or alluvial sediments derived from mineralized bedrock (BC 2014a, 2016b).

As noted in Section 5.4, the extent of mine-impacted groundwater was conservatively estimated under EPA direction because it "is in the best interest of the overall progress for completing the OU-1 Groundwater Remedial Investigation Report" and that the tools used in the background assessment to estimate the area of mine-impacted groundwater may not account for the full range of chemical concentrations that occur naturally in Study Area groundwater (EPA 2016c).

Extensive evidence of naturally-occurring sulfate, uranium, arsenic and other COIs in Mason Valley groundwater includes detectable concentrations of these chemicals in: 1) surface water, which is the primary component of alluvial aquifer recharge, at sampling points located upstream of the Site (Benson and Spencer 1983; BC 2014a); 2) groundwater and geothermal water in the discharge area at the northern end of Mason Valley (Benson and Leach 1979); 3) groundwater samples from Yerington municipal water supply wells that are located hydraulically upgradient and/or cross-gradient of the Site; 4) groundwater samples from monitor wells installed by ARC that are located hydraulically upgradient and/or cross-gradient of the Site (BC 2016b), with concentrations of sulfate and uranium occasionally above MCLs; 5) groundwater from private wells sampled by the USGS located hydraulically upgradient and/or cross-gradient of the Site, with concentrations of sulfate, uranium and arsenic occasionally above MCLs (Benson and Spencer 1983); and 6) groundwater samples from monitor wells installed by ARC that are located outside of the plume of mine-impacted groundwater in the NSA (BC 2016b), with concentrations of uranium as high as 100 µg/L or more.

Further evidence of naturally-occurring COIs in groundwater near the Site occurs in the SWRA where elevated arsenic, and possibly other COIs, appears to be associated with MFR hydrologic processes. These MFR processes include: 1) subsurface water transmitted along fractures and

faults (especially oblique range-front faults such as the Sales Fault) in arsenic-bearing volcanic and granitic bedrock that connect subsurface water in the mountain block and the basin aquifer; and 2) contributions of water at the mountain front from surface stream runoff and shallow subsurface water transmitted in stream bed sediments. Elevated arsenic in SWRA groundwater is associated with low concentrations of sulfate and uranium (the two primary indicators of mine-impacted groundwater), and hydrologic tracer data yield groundwater age estimates that pre-date mining (BC 2016b; EPA 2016b). Collectively, this information indicates that elevated arsenic and possibly other COIs in groundwater in this part of the Study Area are not associated with mining activities. Instead, elevated arsenic in this part of the Study Area is likely naturally-occurring. Elevated arsenic values have been associated with MFR, geothermal groundwater, and stagnant groundwater systems (Smedley and Kinniburgh 2001), and these characteristics apply to the sub-geothermal groundwater present in all groundwater zones to the west of the Site. The elevated temperature of groundwater to the west of the Site and adjacent to the Singatse Range, where MFR hydrologic processes predominate, are shown on figures provided in Appendix L.

SECTION 6.0
CONTAMINANT FATE AND TRANSPORT

The medium of concern in the OU-1 Study Area is groundwater and the mine-related COIs include acidity (i.e., low pH), TDS, major ions including sulfate, metals, and radiochemicals including uranium. The physical transport mechanisms and geochemical attenuation/mobilization processes that affect the movement of COIs in Study Area groundwater are discussed below.

6.1 Contaminant Transport

Transport mechanisms are physical processes controlling the movement of COIs from points of origin through the groundwater system. In the Study Area, COIs are (were) sourced to groundwater from Site sources and/or agricultural practices, and occur naturally in groundwater in Mason Valley because of groundwater contact with naturally-mineralized and/or hydrothermally-altered bedrock associated with copper deposits and/or alluvial sediments derived from mineralized bedrock.

The dominant solute transport mechanisms for COIs in groundwater are advection and dispersion. Advective transport is the migration of the COI with the groundwater. Groundwater moves from areas of recharge (i.e., high hydraulic head) to areas of discharge (i.e., low hydraulic head) and groundwater velocities are determined by solving the groundwater flow equation, which is a function of hydraulic conductivity, hydraulic gradient, and porosity. Groundwater levels in monitor wells provide hydraulic head and groundwater flow velocity information. Hydrodynamic dispersion describes the spread of COIs around an average groundwater flow path, beyond the region they would normally occupy due to advection alone. Hydrodynamic dispersion is the sum of two processes: mechanical dispersion and molecular diffusion. Mechanical dispersion results from mixing that occurs because of local variations in groundwater velocity and the aquifer's matrix. Molecular diffusion results from variations in solute concentrations within the groundwater system.

The primary influences on groundwater movement in the Study Area are subsurface lithology and structure, and local groundwater pumpage and irrigation associated with agriculture. Agricultural activities influence groundwater flow rates and directions, chemical migration pathways and transport rates, and contribute chemicals to groundwater via leaching of soil amendments and subsequent transport through the vadose zone to groundwater. Irrigation practices near the mine Site, including groundwater extraction using high-capacity wells and conveyance/irrigation of both water from the Walker River and groundwater, alter groundwater flow rates and directions during the irrigation season due to the alteration of the natural recharge/discharge rates and locations. These alterations in groundwater flow affect contaminant transport rates and directions.

6.2 Geochemical Attenuation/Mobilization Processes

Geochemical processes that affect the release and subsequent mobility/attenuation of mine-related COIs such as sulfate, uranium and metals during groundwater transport in the Study Area have been evaluated (BC 2016b; Appendix J-7) using: 1) Study Area groundwater data from August 2014 including field parameter measurements (i.e., pH, ORP and DO) and chemical concentrations; 2) the EPA-approved thermodynamic database developed for geochemical modeling Site geochemical attenuation/mobilization processes; and 3) correlations between common groundwater chemicals that affect uranium mobility.

6.2.1 Groundwater Geochemical Conditions and Chemical Speciation

Geochemical oxidation/reduction (redox) conditions within alluvial aquifer groundwater are variable; however, certain general trends and patterns are observed. In general, oxic conditions (i.e., DO > 1 mg/L and higher Eh values) occur in Shallow zone groundwater and suboxic to anoxic conditions (i.e., DO < 1 mg/L and lower Eh values) occur in Intermediate and Deep groundwater zones (Figure 6-1). Exceptions to this general pattern include the following: 1) in Shallow zone groundwater beneath much of the Site and off-Site to the north of the Evaporation Ponds, anoxic (rather than oxic) conditions occur; 2) in Deep groundwater zones beneath the Hunewill Ranch, oxic (rather than anoxic) conditions occur; and 3) on the west side of the Study Area adjacent to the Singatse Range, oxic conditions occur in the Shallow zone, as well as all deeper zones in this part of the Study Area.

Dissolved iron and the iron-system mineralogy, of all the metals present in groundwater, provide the most important constraints on pH, redox, and other metal solubilities in Study Area groundwater (BC 2016b; Appendix J-5). Ferric hydroxide solids in the aquifer sediments can adsorb significant concentrations of dissolved metals and metalloids such as uranium and arsenic, attenuating transport of these constituents. The importance of iron mineralogy and its widespread influence on the Study Area fluid chemistry are illustrated with two Eh-pH diagrams (Figures 6-2 and 6-3). The mineral stability fields in each diagram were constructed for groundwater pH values below, and above, 5.5 respectively, using chemical data from discrete groundwater populations. The individual samples were then plotted on each diagram. The populations were selected from similar chemical environments (samples from two or more unrelated populations are scattered and often obscure the trends).

Groundwater samples from two populations with strong mining impact (pH values below 5.5; Figure 6-2) clearly plot along the K-jarosite and schwertmannite phase boundaries and triple points. Sample alignment near and along the aqueous-mineral boundaries demonstrates the important role these minerals play in dominating and buffering the acidic groundwater at relatively oxidizing Eh levels, as noted above. Also shown on the figure is the specific sample from which the phase boundaries in the figure were computed.

Groundwater samples from two off-Site and more alkaline populations (pH values above 5.5; Figure 6-3) are aligned along the aqueous Fe^{2+} - $Fe(OH)_3(a)$ phase boundary. The mineral $Fe(OH)_3(a)$ is an important adsorptive phase that limits/attenuates the concentrations of other groundwater metals.

As noted previously, the strong alignment demonstrates the impact of the ferric hydroxide phase upon the groundwater redox and pH. The phase boundaries for this diagram were computed from the cluster centroid composition. Based on the groundwater redox conditions and geochemical modeling (BC 2016a; Appendix J-5), chemicals in Study Area groundwater exhibit the following:

- The dominant aqueous redox states determined in virtually all August 2014 groundwater samples were As(V), Fe(II), Mn(II) Se(IV) and U(VI). Vanadium was present in the V(V) redox state in all August 2014 groundwater samples from the Intermediate, Deep and bedrock wells. In Shallow zone groundwater, the V(IV) redox state predominated below a pH of about 5 and the V(V) redox state predominated above a pH of 5.
- Sulfur dissolved in Study Area groundwater is present as sulfate (a negatively-charged ion) and gypsum saturation is observed only in groundwater samples with sulfate concentrations exceeding approximately 1,500 mg/L.
- In the absence of sulfate reduction or gypsum precipitation, the negatively-charged sulfate ion is minimally attenuated in groundwater systems by adsorption. Consequently, in Study Area groundwater with sulfate concentrations less than approximately 1,500 mg/L, sulfate can be expected to be transported as a conservative constituent.
- U(VI) is the dominant oxidation state of dissolved uranium in all August 2014 groundwater samples. Differences in the aqueous speciation of uranium are related to the pH and availability of cations in solution, not redox conditions. Dissolved uranium in Study Area groundwater is predominantly present in complexes with sulfate, carbonate and/or calcium that form neutral or negatively-charged ions (e.g., $Ca_2UO_2(CO_3)_3^0$, $CaUO_2(CO_3)_3^{-2}$, $UO_2(SO_4)_2^{-2}$, and UO_2SO_4) (Figure 6-4). Samples with dominant calcium-uranyl-carbonate ligands reflect oxidizing, carbonate-rich groundwater conditions. Samples with dominant uranyl-sulfate ligands reflect oxidizing conditions with no detectable amounts of alkalinity and pH <5.
- Formation of neutral or negatively-charged aqueous uranium species has been shown to limit uranium adsorption and increase uranium mobility (Fox et al. 2006; Stewart et al. 2010). Since limited uranium adsorption onto hydrous ferric hydroxide solids and soils is expected in neutral to slightly alkaline groundwater (Hsi and Langmuir 1985; Echevarria et al. 2001), uranium attenuation during groundwater transport in off-Site portions of the Study Area can be assumed to be negligible as a conservative first approximation.
- As(V) arsenate is the dominant oxidation state for all August 2014 groundwater samples indicating oxic groundwater conditions, and arsenic speciation is dominated by the negatively-charged $H_2AsO_4^-$ and $HAsO_4^{-2}$ species. Geochemical modeling indicates the potential for precipitation of several arsenic mineral phases including scorodite and barium arsenate.
- Arsenate adsorption on sediments tends to decrease with increasing pH because of competition for adsorption sites between the negatively-charged arsenate aqueous species and OH^- or bicarbonate (Sø et al. 2008; Stachowicz et al. 2007).
- Geochemical modeling predicts the potential for jarosite mineral precipitation primarily in the Shallow zone under the LEP, UEP, Thumb Pond, and Phase IV HLP (Figure 6-5). Uranium and other metals associated with predicted jarosite mineral phases and aquifer sediments beneath these features potentially represent a persistent source of chemicals to groundwater.

- The spatial distributions of elevated concentrations of mobile parameters such as sulfate and uranium are significantly more extensive than the spatial distributions of acidity (as indicated by pH) and metals. The limited spatial extent of low pH values and elevated metal concentrations indicates that geochemical attenuation processes in Study Area groundwater reduces acidity and limits the mobility of metals relative to the more mobile chemicals such as sulfate and uranium. Elevated metal concentrations in groundwater correlate strongly with low pH.

6.2.2 Controls on Uranium Mobility in North Study Area Groundwater

As noted previously in Section 5.5.2, the concentrations of numerous COIs in groundwater increase along groundwater flowpaths beneath agricultural fields in the NSA. The correlation between increasing concentrations of alkalinity and calcium associated with agricultural activities, and increasing uranium concentrations as groundwater flows beneath agricultural fields in the NSA is shown on Figure 6-6. Increasing alkalinity and calcium concentrations are important controls on the formation of uranium species that have a low tendency to bind to aquifer solids (Bernhard et al. 2001) and, thus, uranium is mobilized from aquifer solids to adjacent groundwater as alkalinity and calcium concentrations increase. In addition, the observed correlation between increasing concentrations of alkalinity, calcium and uranium is consistent with the previously-noted geochemical modeling predictions of uranium speciation in Study Area groundwater.

The upper panel in Figure 6-6 displays data for all the alluvial monitor wells in the NSA that are located near agricultural fields. The lower panel in Figure 6-6 displays a subset of the data presented in the upper panel. Specifically, this lower panel displays data along a groundwater flow path from wells upgradient of the NSA agricultural fields (i.e., wells B/W-56 and B/W-59) to wells/well clusters located downgradient of the NSA agricultural fields (i.e., well cluster B/W-57 and well YPT-MW-12I). In wells located upgradient of the NSA, uranium concentrations are less than 12 µg/L. However, as groundwater flows beneath the NSA agricultural fields and concentrations of alkalinity and calcium increase, naturally-occurring uranium attached to aquifer solids is released. At well B/W-57I, elevated uranium concentrations range from approximately 48 to 72 µg/L and at well B/W-57D1 elevated uranium concentrations range from 73 to 110 µg/L.

Well YPT-MW-12I is located hydraulically downgradient of well cluster B/W-57, which provides additional information about chemical loading to alluvial groundwater associated with agricultural activities in the NSA. The influence of agricultural activities on chemical concentrations in YPT-MW-12I is shown on Figure 6-7. Although concentrations of uranium in groundwater at YPT-MW-12I have increased recently (upper panel), the trends in chemical concentrations in groundwater at this well are consistent with geochemical projections based on the control that calcium and alkalinity have on uranium mobility, and are not related to the Site.

As indicated in the lower panel, sulfate concentrations in well YPT-MW-12I are greater than 71 mg/L and exhibit seasonal variability, with elevated concentrations occurring in February of each year. Plume advancement cannot account for the magnitude of sulfate concentrations or seasonality observed in this well because sulfate concentrations are lower in wells to the southwest that demarcate the leading edge of mine-impacted groundwater (i.e., well clusters B/W-10, B/W-52, and B/W-55). Instead, the concentrations of sulfate in well YPT-MW-12I can only be accounted for by sulfate concentrations in upgradient wells B/W-57I and B/W-57D1, which are impacted by agricultural activities.

6.2.3 Site-Specific Distribution Coefficients

As groundwater migrates within the Study Area, certain geochemical reactions occur between the COIs in groundwater and the alluvial aquifer sediments. These reactions determine the relative rates at which chemicals migrate with respect to the advective front of groundwater. The primary process associated with the attenuation of inorganic COIs, particularly metals, in groundwater is adsorption onto the surfaces of minerals or organic material in the aquifer sediments.

The Site-specific distribution coefficient (K_d) discussed in Section 3.3.5 may be used to quantify adsorption reactions between COIs in groundwater and the alluvial aquifer sediments during groundwater flow and chemical transport simulations. It should be noted that the distribution coefficient is a bulk measurement and provides only indirect information on the type of adsorption interactions taking place on the alluvial aquifer sediments. Summary statistics for the revised K_d values calculated using zonal groundwater sample data are shown in Table 6-1.

Table 6-1. Summary Statistics for Zonal Sample K_d Values

Analyte	Distribution Coefficient Statistics (L/kg)				
	Minimum	Maximum	Mean	Geometric Mean	Median
Sulfate	0.05	0.62	0.18	0.15	0.16
Uranium	0.42	289	49	17	33
Arsenic	108	6,412	1,763	957	800

Notes: L/kg = liters per kilogram

K_d values less than 1 L/kg, as is the case for sulfate, indicate little if any partitioning of this negatively-charged ion from the dissolved (i.e., liquid) phase to the solids phase. The uranium K_d values are higher than K_d values for sulfate, indicating some tendency for uranium adsorption on aquifer sediments. Dissolved uranium in Study Area groundwater is predominantly present in neutral or negatively-charged complexes (Figure 6-4), which has been shown to limit uranium adsorption (Fox et al. 2006; Stewart et al. 2010). However, limited uranium adsorption onto hydrous ferric hydroxide solids and soils is expected in neutral to slightly alkaline groundwater (Hsi and Langmuir 1985; Echevarria et al. 2001; Li and Kaplan 2012), and likely explains the higher uranium K_d values.

K_d values for arsenic are substantially greater than 1 L/kg. These high K_d values reflect much higher concentrations of those chemicals in the solid phase versus the dissolved phase, which indicates a strong tendency for arsenic to partition from the dissolved to the solid phase.

Summary statistics for the K_d values calculated for the 25 chemicals and compounds using monitor well groundwater samples are shown in Table 6-2.

Table 6-2. Summary Statistics for Monitor Well K_d Values

Analyte	Distribution Coefficient Statistics (1)				
	Minimum	**Maximum**	**Mean**	**Geometric Mean**	**Median**
Aluminum	10,850	214,670	88,830	64,851	98,350
Arsenic	18.4	1,311	461.2	277.2	421
Boron	0.40	9.26	4.39	3.15	3.36
Barium	93.8	6,676	1,937	959	1,000
Calcium	0.38	20.6	7.62	3.47	4.74
Chloride	0.07	1.56	0.22	0.18	0.17
Cobalt	192.3	4,643	2,462	1,869	2625
Chromium	316	1,182	689	626	579
Copper	83.3	13,684	4,645	2,662	3,333
Fluoride	1.56	17.2	4.52	3.73	3.26
Iron	8.6	541,880	22,112	146,061	242,733
Potassium	5.1	292.4	109.0	72.7	97.5
Lithium	46.0	379.3	126.6	116.1	113.8
Magnesium	0.34	76.8	26.2	12.5	23.5
Manganese	56.8	3,838	795	351	291
Molybdenum	0.14	2,130	176.9	21.0	63.1
Sodium	0.21	1.3	0.78	0.64	0.88
Nickel	300	1,736	1,142	1030	1,200
Nitrate	0.03	4.0	0.30	0.16	0.15
Lead	1,000	48,100	14,983	8,355	9,600
Selenium	35.9	9,180	3,084	1,202	2154
Sulfate	0.03	1.04	0.186	0.15	0.17
Uranium	1.0	238.2	41.7	20.2	25.6
Vanadium	43.5	4,717	1,115	673	917
Zinc (2)	1,385	1,385	1,385	1,385	1,385

Notes:

1) L/kg = liters per kilogram.
2) For zinc, only one set of co-located sediment and water samples were available for calculating a K_d.

The majority of the K_d values calculated using the monitor well groundwater samples are greater than 1 L/kg. Chloride, nitrate, and sulfate (negatively charged ions in groundwater) and sodium were the only chemicals where the K_d values were consistently less than 1 L/kg. Boron, calcium and fluoride had K_d values in the range of 1 to 10 L/kg. All other chemicals and compounds had K_d values ranging from 10 L/kg up to approximately 500,000 L/kg.

The values at the high end of the range are influenced by the presence of non-detects in the data for the groundwater concentrations. In particular, groundwater concentrations for aluminum, iron and lead were almost universally below the detection limits. However, the concentrations in the soil samples for those same chemicals were nearly all above the detection limit. In these cases, the groundwater concentrations used to calculate K_d values typically represented the reporting limit for that particular chemical. Given that, the K_d values can be thought of as upper bounds for that particular chemical and indicate very little mobility in groundwater.

The variability between the K_d values for the same chemical or compound was, in general, consistent. Only a few chemicals had K_d values with variabilities of more than one order of magnitude. Typically, the wider-ranging K_d variabilities were expressed for those chemicals with non-detect results that were incorporated into the calculation.

Statistical parameters characterizing the uranium K_d values derived from zonal and monitor well groundwater sample data are similar. Uranium K_d values based on monitor well data vary by approximately two orders of magnitude. A correlation of uranium K_d values with Site geochemical data shows that uranium adsorption varies as a function of changes in pH and concentrations of alkalinity, calcium and magnesium. Consequently, use of a constant K_d approach to simulate uranium adsorption during predictive transport modeling may not accurately represent actual adsorption processes.

Instead, a surface complexation model (SCM), such as the general composite approach described by Davis et al. (2009), may be more suitable for modeling adsorption processes during transport at the Site because it can describe changes in adsorption reactions at mineral surfaces as chemical conditions and aqueous speciation(s) change. However, in off-Site portions of the Study Area where aqueous concentrations are lower and hydrous ferric hydroxide solid concentrations are more sporadic, it may be appropriate to assume negligible uranium attenuation during groundwater transport as a conservative first-order approximation.

6.3 Mine-Impacted Groundwater Plume Dynamics

Summarized below are the initial evaluations of mine-impacted groundwater plume dynamics that have been presented in previous reports (BC 2014f, 2015f) and/or discussed with EPA, NDEP and other stakeholders during groundwater technical meetings in 2015 and 2016. The results of these initial evaluations will be provided in a separate report, along with: 1) a statistical evaluation of chemical concentration trends in individual monitor wells, as requested by EPA; and 2) flow model predictions of future changes in plume dimensions and chemical concentrations.

Multiple approaches consisting of center-of-mass calculations and trend evaluations of the total masses and average concentrations of sulfate and uranium have been used to evaluate the dynamics of the plume of mine-impacted groundwater.

Methods

This evaluation was conducted using the Monitoring and Remediation Optimization System (MAROS) software that was developed by the U.S. Airforce Center for Environmental Excellence (AFCEE 2006). MAROS uses the Delaunay Triangulation/Voronoi Diagrams method (George and Borouchaki 1998) to partition the interpolation area into polygon-shaped sub-regions associated with each monitor well. The chemical concentration in an entire sub-region is represented by the concentration in the associated monitor well in a given sampling event. MAROS then calculates the location of the center-of-mass of the interpolated chemical distribution.

MAROS software allows for efficient and consistent computation of large groundwater datasets and depictions of the chemical center-of-mass over time, as well as providing output for computation of changes in chemical mass and average chemical concentration over time. However, the MAROS computation method uses polygon-shaped sub-areas that do not fully encompass the curvilinear area of mine-impacted groundwater. Consequently, although the MAROS output is consistently computed over time, the computed volumes (and derived chemical masses and average concentrations) are underestimated relative to the method used in Section 5.4 to estimate plume statistics.

Center-of-Mass Evaluation

The center-of-mass of plumes of the mine-related constituents sulfate and uranium and the total chemical mass in these plumes were evaluated over the three-year period 2012 through 2015 to assist in the evaluation of plume dynamics. The center-of-mass analysis requires a consistent set of data over time to make meaningful inferences about plume movement. Therefore, only wells that were monitored in every quarter from 1Q 2012 through 1Q 2016 were included in the analysis. Centers-of-mass for sulfate and uranium were calculated for the Shallow, Intermediate, Deep 1, Deep 2, Deep 3, and combined Deep 4 and 5 zones of the alluvial aquifer. The Deep 4 and 5 zones of the alluvial aquifer were combined due to the limited number of monitor wells in these zones.

In the evaluation, monitor well B/W-27D3a was included in the list of Deep 2 zone wells and monitor well B/W-41D4 was included in the list of Deep 3 zone wells to address areas within each zone that were lacking adequate spatial coverage. Monitor wells in the B/W-65 well cluster, located in the middle of an agricultural field, were not included in the analysis because the wells have been sampled sporadically due to lack of access during the irrigation season.

Prior to interpolation, chemical data from the 261 monitor wells were reviewed using time-concentration plots to screen for potential outliers. When outliers were identified for a particular sampling event, the value of the data point was replaced with the average value of the previous and subsequent sampling events. The number of outliers identified represents less than 0.2 percent of the data used in the analysis.

The calculated centers-of-mass for sulfate and uranium are located beneath the Evaporation Ponds (Figure 6-8), with the following exceptions:

- The uranium center-of-mass in the Deep 1 zone is located beneath the Hunewill Ranch (about 3,000 feet northwest of the monitor well B/W-25D1). This is consistent with the presence of collocated elevated concentrations of uranium and alkalinity beneath the agricultural fields in the Deep 1 zone compared to areas beneath the Site.
- The uranium center-of-mass in the Deep 4/5 zone is located beneath the Hunewill Ranch within a few hundred feet of the Site boundary.

From February 2012 to February 2016, the centers-of-mass for the sulfate and uranium plumes exhibit very little relative movement, an indication of stable plume behavior.

Total Mass and Average Concentrations

Over the 3-year monitoring period from February 2012 to February 2015, the masses of sulfate and uranium in each of the groundwater zones remained relatively stable, with typically less than five percent variation between the initial and more recent monitoring events (Figure 6-9). Also, clear trends (either increasing or decreasing) are not evident, with the exception of decreasing sulfate trends observed in the Shallow zone and decreasing sulfate and uranium trends in combined Deep 4 and Deep 5 zones. During the monitoring period, the calculated mass of sulfate in the Shallow zone decreased from about 97,000 to 85,000 tons (i.e., 12%) and the mass of sulfate in the Deep 4/5 zones decreased from about 13,000 to 10,000 tons (i.e., 25%). The mass of uranium in the combined Deep 4 and Deep 5 zones decreased from about 5.2 to 3.7 tons (i.e., 29%).

Because the various alluvial groundwater zones have different thicknesses and volumes, the total chemical masses in each individual zone are not directly comparable. For example, the Intermediate zone contains the smallest sulfate mass because it is the thinnest groundwater zone. Consequently, changes in average concentrations over time in the various groundwater zones are a more appropriate comparison. Changes over time in average concentrations of sulfate and uranium in the alluvial aquifer groundwater zones are also shown on Figure 6-9.

Clear trends (either increasing or decreasing) are not evident, with the exception of decreasing average sulfate concentrations in the Shallow zone and decreasing sulfate and uranium concentrations in the combined Deep 4 and 5 zones. During the monitoring period, the average concentration of sulfate in the Shallow zone decreased from 1,518 mg/L to 1,330 mg/L (i.e., 12%) and the average concentration of sulfate in the Deep 4/5 zones decreased from 90 mg/L to 67 mg/L (i.e., 25%). The concentration of uranium in the Deep 4/5 zone decreased from 35 to 25 ug/L (i.e., 29%).

The decrease in sulfate mass and average concentration in the Shallow zone is interpreted as dilution effects from irrigation practices in the agricultural fields north of the mine boundary. The cause of the observed decrease in calculated average uranium concentrations in the combined Deep 4 and Deep 5 zones is likely due to dilution and dispersion. The calculated decrease in total sulfate and uranium mass is likely an apparent effect due to the fewer data points for calculating chemical mass.

The results of these evaluations indicate that, in general, the plume of mine-impacted groundwater is stable. The plume stability is the result of very slow groundwater velocities and attenuation by dilution. The dilution occurs primarily as the result of recharge on the agricultural fields (specifically on the fields of the Hunewill Ranch) and leakage from irrigation ditches (specifically the West Campbell Ditch), and dispersion within the groundwater plume.

SECTION 7.0

HYDROGEOLOGIC CONCEPTUAL SITE MODEL

The Site is a former copper mine located in the west-central portion of the Mason Valley, a Basin-and-Range-type graben filled with up to 1,000 feet of unconsolidated valley-fill deposits of Tertiary and Quaternary age lying unconformably on a weathered surface of hydrothermally-altered Tertiary volcanic and Mesozoic intrusive bedrock. The valley is bordered to the west by the Singatse Range, to the east by the Wassuk Range, and to the north by the Desert Mountains. Regional metals mineralization and hydrothermal alteration associated with localized porphyry and skarn copper deposits occur in the Singatse Range and nearby portions of the Mason Valley.

The unconsolidated valley fill deposits were derived primarily from erosion of the uplifted mountain blocks and from deposition in the floodplain of the Walker River. In addition, lacustrine deposits derived from ancestral Lake Lahonton occur north of the Site. Depositional processes have resulted in a complex interbedded sequence of alluvial sediments.

Historically, regional groundwater flow patterns in the Mason Valley prior to Anaconda/Arimetco mining operations were similar to current conditions with groundwater moving generally from south to north, and discharging to surface seeps and geothermal springs in the northern portion of the basin. Locally, though, current flow patterns have been significantly altered from historical patterns by agricultural activities. The alluvial aquifer in the Mason Valley is very productive and groundwater is currently pumped extensively for irrigation (Carroll et al. 2010; SSPA 2014).

The alluvial aquifer is primarily recharged by downward percolation from irrigated fields (49%), leakage from irrigation ditches (29%), infiltration from the channel of the Walker River (20%), and MFR (2%), consisting of infiltration through bedrock of precipitation that falls on surrounding mountain ranges and minor tributary surface flows in ephemeral drainages (SSPA 2014). Recharge from precipitation falling directly on the valley floor is negligible (Huxel and Harris 1969; Lopes and Allander 2009a, 2009b).

Within the Study Area, the alluvial sediments are up to 700 feet thick and comprise a single aquifer. The alluvial aquifer is subdivided into a Shallow, an Intermediate and a Deep zone (which is further subdivided into Deep zones 1 through 5). These groundwater zone designations are based on elevation and used only to identify and group monitor wells with similar screen intervals at the same relative depth in the aquifer. Clay layers or other low-permeability sediments are laterally discontinuous resulting in unconfined or semi-confined alluvial aquifer groundwater conditions.

Alluvial groundwater near the Site generally flows to the northwest, but flow directions are locally affected by bedrock outcrops within and along the margins of the valley, drawdown from pumped wells (particularly in deeper zones of the alluvial aquifer), and recharge sources including the Walker River, the West Campbell Ditch and irrigation on the Hunewill Ranch and other agricultural fields. Groundwater in the alluvial aquifer moves relatively slowly, with flow velocities estimated to be less than 100 feet per year (BC 2014a).

Anthropogenic activities within the Study Area, especially agricultural activities, influence groundwater flow rates and directions, chemical migration pathways and transport rates, and contribute chemicals to groundwater via evapoconcentration and leaching of soil amendments and naturally-occurring chemicals in alluvial sediments, and subsequent transport through the vadose zone to groundwater. Irrigation practices near the mine Site, including groundwater extraction using high-capacity wells and conveyance/irrigation of both water from the Walker River and groundwater, alter groundwater flow rates and directions during the irrigation season due to the alteration of the natural recharge/discharge rates and locations. Agricultural pumping seasonally results in strong downward vertical gradients that are often 10 to 100 times greater than horizontal gradients.

Past and/or ongoing sources of COIs to Study Area groundwater include: 1) the mine waste facilities, which have been grouped into the various Site OUs; 2) naturally-occurring chemicals; and 3) agriculture. The major past and/or ongoing mine-related sources of COIs to groundwater include: 1) OU-4a, the Evaporation Ponds (BC 2014a, 2014d); OU-8, the Arimetco Facilities (CH2M Hill 2010, 2011a, 2011b); and 3) OU-3, the Process Areas (BC 2014a, 2014e).

Mine-related COIs include acidity (i.e., low pH) and elevated concentrations of TDS, major ions including sulfate, metals, and radiochemicals including uranium. Concentrations of mine-related chemicals in groundwater are most elevated in the Shallow zone of the alluvial aquifer beneath OU-4a features that include the LEP, UEP, Finger Ponds, Phase IV VLT HLP, Phase IV VLT Pond, and the Calcine Ditch. Chemical concentrations in groundwater decrease with vertical depth and horizontal distance from these facilities.

Hydraulic assessments and chemical distributions indicate that the PWS was only partially effective in capturing Shallow zone mine-impacted groundwater during its operational life from 1989 to 2009, when it was shut down with EPA approval.

Geochemical evaluations of groundwater quality data (BC 2016a) indicate that sulfate and dissolved uranium form neutral or negatively-charged aqueous ionic species in groundwater throughout Study Area (except beneath the Evaporation Ponds) and, thus, undergo very limited (if any) geochemical attenuation due to mineral precipitation or adsorption to aquifer materials during groundwater transport. Dissolved uranium in Study Area groundwater is predominantly present in complexes with carbonate plus or minus calcium, which reflect oxidizing, carbonate-rich groundwater conditions. Locally, dissolved uranium is also complexed with sulfate in Shallow zone groundwater beneath the Evaporation Ponds where pH is less than 5 and sulfate concentrations exceed 1,500 mg/L.

The spatial distributions of elevated concentrations of mobile parameters such as sulfate and uranium are significantly more extensive than the spatial distributions of acidity (as indicated by pH) and metals. The significantly more limited spatial extent of low pH values and elevated metal concentrations indicates that geochemical attenuation processes in Study Area groundwater reduce acidity and limit the mobility of metals relative to the more mobile chemicals such as sulfate and uranium (EPA 2007b; BC 2016a, 2016b). Elevated metal concentrations in groundwater correlate strongly with low pH.

Geochemical evaluations of groundwater quality data (BC 2016a) also indicate the likely precipitation of solid mineral phases (e.g., jarosite) primarily in the Shallow zone beneath the LEP, UEP, Thumb Pond and Phase IV HLP. These mineral phases likely represent a potential, ongoing source of COIs to groundwater.

Sulfate, uranium, and arsenic (and other COIs) occur naturally in groundwater in Mason Valley because of groundwater contact with naturally-mineralized and/or hydrothermally-altered bedrock associated with copper deposits and/or alluvial sediments derived from mineralized bedrock (BC 2014a, 2016b). To the west of the Site where sulfate and uranium concentrations are low, elevated concentrations of arsenic are associated with MFR and elevated groundwater temperatures. In addition, sulfate, uranium, and other COIs are sourced to groundwater due to agricultural activities (BC 2016b; EPA 2016c). The assessment of background groundwater quality conservatively established the maximum extent of mine-impacted groundwater and identified an area of groundwater in the northern part of the Study Area (i.e., the NSA) that has been impacted by agricultural activities rather than mining activities.

The extent of mine-impacted groundwater has been defined using sulfate, dissolved uranium, and sulfur isotopes in sulfate because these parameters are more mobile in groundwater relative to other mine-related COIs such as metals (EPA 2007b) and, thus, have traveled the farthest downgradient distance in the alluvial aquifer (BC 2016b). The extent of mine-impacted groundwater in the Study Area can be generally described as follows, recognizing that mine-impacted groundwater is spatially more extensive in the Shallow, Intermediate and Deep 1 zones of the alluvial aquifer relative to the Deep 2 through Deep 5 zones. The northernmost extent of mine-impacted groundwater in the Shallow, Intermediate and Deep 1 zones of the alluvial aquifer is located near the Sunset Hills between well clusters B/W-10 and B/W-52. The eastern extent of mine-impacted groundwater in the Shallow, Intermediate and Deep 1 zones of the alluvial aquifer is approximately located near or beneath the West Campbell Ditch alignment. To the west of the Site, mine-impacted groundwater extends almost to the western extent of saturated alluvium between unimpacted wells/clusters B/W-16S and B/W-40, and impacted well clusters B/W-33, B/W-6 and B/W-22.

Mine-impacted groundwater in the deeper zones does not extend as far north as the upper three zones. In the Deep 2 through Deep 5 zones, the maximum northern extent of mine-impacted groundwater is near the northern end of the Hunewill Ranch fields. The eastern extent of mine-impacted groundwater in the Deep 2 through Deep 5 zones of the alluvial aquifer is located between well clusters B/W-27 and B/W-50. On the east, the area of mine-impacted groundwater in the Deep 3 through Deep 5 zones reflects the former influence of seasonal groundwater extraction for crop irrigation from agricultural wells (e.g., WDW019, located adjacent to the B/W-1 well cluster). To the west of the Site, mine-impacted groundwater in the Deep 3 through Deep 5 zones extends almost to the western extent of saturated alluvium.

The estimated volume of mine-impacted groundwater (i.e., the portion of the downgradient aquifer where sulfate and uranium exceed background concentrations) is 385,327 acre-feet, and contains an estimated 0.5 million tons of sulfate and 100 tons of dissolved uranium. Irrigation wells and municipal wells are located outside of the plume of mine-impacted groundwater (Figure 3-13). In addition, the plume of mine-impacted groundwater does not discharge to surface water.

The plume of mine-impacted groundwater appears stable based on evaluations of changes in the estimated volume of contaminated groundwater, sulfate/uranium masses, and chemical centers-of-mass through time. Plume stability is the result of very slow groundwater velocities and attenuation by dilution. The dilution occurs primarily as the result of recharge on the agricultural fields (specifically on the fields of the Hunewill Ranch) and leakage from irrigation ditches (specifically the West Campbell Ditch), and dispersion within the groundwater plume.

Groundwater quality in the NSA has been impacted by agricultural activities rather than mining activities (BC 2016b) based on multiple lines of evidence including groundwater flow patterns, chemical distributions, groundwater age estimates, hydrologic tracers, and sulfur isotopes. These agricultural practices have resulted in concentrations of sulfate and uranium that are elevated above background values and/or MCLs and/or exhibit increasing trends.

Monitor well data from the NSA indicate that concentrations of nitrate, sulfate, calcium, uranium, and alkalinity in alluvial groundwater in the Shallow through Deep 2 zones increase along the flow path beneath the agricultural fields. Increases in nitrate are associated with organic fertilizer application on crop fields. Increases in sulfate and calcium concentrations are associated with application of gypsum ($CaSO_4$) as a soil amendment on crop fields, which dissolve in irrigation water that percolates down to the water table. Increases in uranium concentrations are associated with crop irrigation. Percolation of irrigation water through soils increases alkalinity in the soil moisture, which mobilizes and desorbs naturally-occurring uranium from sediments (as soluble complexes with sulfate, carbonate plus or minus calcium) resulting in elevated uranium concentrations in groundwater (Jurgens et al. 2010; Brown et al. 2007). Alluvial sediments in Mason Valley contain naturally-occurring uranium (BC 2009b). The impact of agriculture activities on uranium mobility in NSA groundwater within or near irrigated land is illustrated by the strong correlation between uranium, alkalinity and calcium. Increases in alkalinity and calcium are associated with increases in uranium concentrations that can exceed 100 µg/L.

SECTION 8.0
RISK EVALUATION

In a groundwater technical meeting held on June 30, 2016 attended by ARC, EPA and other stakeholders, EPA directed ARC to proceed with preparation and submittal of this OU-1 RI Report without including the risk evaluation. The risk evaluation is ongoing and will proceed on a separate but parallel path from this document. Potential human health risks are generally described herein, but will be addressed more comprehensively in a separate OU-1 HHRA report.

This OU-1 RI Report, in conjunction with the OU-1 HHRA, will provide the basis for ARC to identify RAOs and potential remedies for OU-1, which would occur during future FS scoping discussions.

SECTION 9.0
REFERENCES

Air Force Center for Environmental Excellence (AFCEE), 2006. Monitoring and Remediation Optimization System (MAROS), User's Guide, March 2006.

Anaconda Mining Company, 1958. Engineering Drawing WHE-201, Tailing Disposal Sulphide Plant - Tailings Pond General Arrangement. March 24.

Anaconda Mining Company, 1966. Engineering Drawing YG-20, Water Supply & Distribution - Daily Water Balance Diagram. Prepared July 15, 1953. Revised July 28.

Anaconda Mining Company, 1967. Engineering Drawing WHN-1208, Sulphide Plant Quantitative Flow Diagram. Prepared May 19, 1966. Revised January 9.

Anaconda Minerals Company, 1984. Water Quality Investigation and Mitigation Plan. Yerington Mine.

Applied Hydrology Associates, 1983. Evaluation of Water Quality and Solids Leaching Data. Yerington Mine. Prepared for Atlantic Richfield Company.

Applied Hydrology Associates (also Norwest Applied Hydrology), 2000-2007. 2000-2007 Annual Monitoring and Operation Summary reports, Prepared for Atlantic Richfield Company.

Atlantic Richfield Company, 2008. Pumpback Well System Characterization Work Plan. Yerington Mine Site, Lyon County, Nevada.

Atlantic Richfield Company, 2010. Pumpback Well System Characterization Work Plan Addendum - Revision 2. Yerington Mine Site, Lyon County, Nevada. February 17.

Atlantic Richfield Company, 2011. Addendum to the On-Site Monitor Well Installation Work Plan. Yerington Mine Site, Lyon County, Nevada. September 7.

Atlantic Richfield Company, 2012a. Proposed Initial Bedrock Characterization Activities, Yerington Mine Site, Lyon County, Nevada. January 5.

Atlantic Richfield Company, 2012b. Proposed Initial Bedrock Characterization Activities - Revision 1, Yerington Mine Site, Lyon County, Nevada. October 11.

Atlantic Richfield Company, 2012c. Groundwater Flow Modeling Deliverables, Yerington Mine Site, Lyon County, Yerington, Nevada. June 25.

Atlantic Richfield Company, 2012d. Comprehensive Hydrologic Tracer Sampling Event and Request to Eliminate Select Tracers, Yerington Mine Site, Lyon County, Nevada. March 19.

Atlantic Richfield Company, 2012e. Preliminary Responses to February 7, 2012 EPA Comments on the 2011 Background Groundwater Quality Assessment, Yerington Mine Site dated September 28, 2011; Administrative Order on Consent, EPA Region 9 CERCLA Docket No. 9-2007-0005. April 18.

Atlantic Richfield Company, 2014. Technical Memorandum: Site-Wide Groundwater Monitoring Optimization, Yerington Mine Site, Lyon County, Nevada. April 14.

Atlantic Richfield Company, 2016a. Letter to D. Seter, Subject: Yerington Mine Site, Lyon County Nevada, Site ID #09GU, Request to Modify Domestic Well Monitoring Program and Bottled Water Program. September 1.

Atlantic Richfield Company, 2016b. Responses to EPA Comments dated February 11, 2016 on the Background Groundwater Quality Assessment - Revision 2 dated July 2, 2015; Administrative Order on Consent, EPA Region 9 CERCLA Docket No. 9-2007-0005. June 14.

Bell, E.J. and D.B. Slemmons, 1979. Recent crustal movements in the central Sierra Nevada-Walker Lane region of California-Nevada--Part II, The Pyramid Lake right-slip fault zone segment of the Walker Lane: Tectonophysics, v. 52, p. 571-583.

Benson, L.V. and D. L. Leach, 1979. Uranium Transport in the Walker River Basin, California and Nevada. Journal of Geochemical Exploration, vol. 11, p. 227-248.

Benson, L.V. and R.J. Spencer, 1983. A Hydrochemical Reconnaissance Study of the Walker River Basin, California and Nevada. USGS Open-File Report 83-740.

Bernhard, G., G. Geipel, T. Reich, V. Brendler, S. Amayri, and H. Nitsche, 2001. Uranyl(VI) carbonate complex formation: Validation of the $Ca_2UO_2(CO_3)_3$ (aq) species. Radiochimica Acta, 89:511-518.

Bigham, J.M., U. Schwertmann, S.J. Traina, R.L. Winland, and M. Wolf, 1996. Schwertmannite and the chemical modeling of iron in acid sulfate waters. Geochimica et Cosmochimica Acta, Vol. 60, pp. 2111-2121.

Bourrié, G., F. Trolard, J.M. Génin, A. Jaffrezic, V. Maître, and M. Abdelmoula, 1999. Iron control by equilibria between hydroxy-green rusts and solutions in hydromorphic soils. Geochimica et Cosmochimica Acta, Vol. 63, pp. 3417-3427.

Brown, C.J., B.C. Jurgens, B.G. Katz, M.K. Landon, and S.E. Eberts, 2007. Arsenic and Uranium in Four Aquifer Settings: Occurrence, Distribution, and Mechanisms for Transport to

Supply Wells. NGWA Naturally Occurring Contaminants Conference: Arsenic, Radium, Radon, Uranium. March 22-23.

Brown and Caldwell, 2002. Installation of Two Monitor Wells at the Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company.

Brown and Caldwell, 2003. Final Draft Process Areas Work Plan. Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. December 15.

Brown and Caldwell, 2005. First-Step Hydrogeologic Framework Assessment Work Plan North of the Anaconda Mine Site. Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. April 22.

Brown and Caldwell, 2007a. Data Management Plan for the Yerington Mine Site, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. April 24.

Brown and Caldwell, 2007b. Second-Step Hydrogeologic Framework Assessment Work Plan, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. February 28.

Brown and Caldwell, 2007c. Draft Site-Wide Groundwater Monitoring Plan, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. August 8.

Brown and Caldwell, 2008, Anaconda Evaporation Ponds Removal Action Characterization Work Plan, Yerington Mine Site. Prepared for Atlantic Richfield Company. September 15.

Brown and Caldwell, 2008a. Anaconda Evaporation Ponds Removal Action Characterization Work Plan, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. September 15.

Brown and Caldwell, 2008b. Shallow Alluvial Aquifer Characterization Work Plan for the Northern Portion of the Yerington Mine Site, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. December 30.

Brown and Caldwell, 2008c. Second-Step Hydrogeologic Framework Assessment Data Summary Report, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. October 15.

Brown and Caldwell, 2009, Evaporation Ponds Removal Action Characterization Data Summary Report. June 12.

Brown and Caldwell, 2009a. Site-Wide Groundwater Monitoring Plan - Revision 1, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. December 15.

Brown and Caldwell, 2009b. Background Soils Data Summary Report - Revision 1, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. March 9.

Brown and Caldwell, 2010a. Shallow Zone Characterization Data Summary Report - Revision 1, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. January 29.

Brown and Caldwell, 2010b. Addendum to the Site-Wide Quality Assurance Project Plan, Domestic Well Monitoring Plan - Revision 3, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. July 1.

Brown and Caldwell, 2010c. 2010 Groundwater Monitor Well Work Plan - Revision 2, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. July 22.

Brown and Caldwell, 2010d. Agricultural Fields Characterization Work Plan - Revision 2, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. July 20.

Brown and Caldwell, 2010e. Aquifer Solids Testing Work Plan - Revision 1, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. September 21.

Brown and Caldwell, 2010f. Summary of PWS Aquifer Testing, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. September 24.

Brown and Caldwell, 2010g. Draft Aquifer Solids Testing Work Plan, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. June 21.

Brown and Caldwell, 2011a. On-Site Monitor Well Installation Work Plan - Revision 1, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. August 29.

Brown and Caldwell, 2011b. Aquifer Solids Testing Work Plan - Revision 1, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. September 21.

Brown and Caldwell, 2011c. Draft Background Groundwater Quality Assessment, Site-Wide Groundwater Operable Unit, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. September 28.

Brown and Caldwell, 2012a. Site-Wide Groundwater Monitoring Plan - Revision 2, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. July 19.

Brown and Caldwell, 2012b. Draft Site-Wide Groundwater Operable Unit (OU-1) Remedial Investigation Work Plan, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. November 19.

Brown and Caldwell, 2012c. SOP-23 Aquifer Solids Testing SOP - Redox-Preserved Sample Preparation and Testing, Yerington Mine Site, Hazen Research, Inc. Laboratory Facility, Golden, CO. Prepared for Atlantic Richfield Company. August 17.

Brown and Caldwell, 2012d. SOP-23 Aquifer Solids Testing SOP - Redox-Preserved Sample Preparation and Testing - Revision 1, Yerington Mine Site, Hazen Research, Inc. Laboratory Facility, Golden, CO. Prepared for Atlantic Richfield Company. October 15.

Brown and Caldwell, 2012e. Aquifer Test Data Summary Report - Revision 1, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. December 13.

Brown and Caldwell, 2013a. 2010 Monitor Well Installation and Agricultural Fields Characterization Data Summary Report - Revision 1. Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. January 18.

Brown and Caldwell, 2013b. Additional Monitor Well Work Plan - Revision 1, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. October 8.

Brown and Caldwell, 2013c. Initial Bedrock Characterization Data Summary Report, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. November 20.

Brown and Caldwell, 2013d. Revised Public Information for the Northern Portion of the Background Groundwater Study Area, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. August 5.

Brown and Caldwell, 2013e. Draft Additional Monitor Well Work Plan, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. June 26.

Brown and Caldwell, 2014a. Site-Wide Groundwater Operable Unit (OU-1) Remedial Investigation Work Plan - Revision 1, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. February 7.

Brown and Caldwell, 2014b. 2013 Annual Operations and Maintenance Report for the Arimetco Fluid Management System, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. June 9.

Brown and Caldwell, 2014c. Groundwater Geochemical Characterization Data Summary Report, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. December 30.

Brown and Caldwell, 2014d. Phase 1 Field Sampling and Analysis Plan Anaconda Evaporation Ponds, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. July 31.

Brown and Caldwell, 2014e. OU-3 Step-out Soils Characterization Data Summary Report, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. December 12.

Brown and Caldwell, 2014f. 2013 Annual Groundwater Monitoring Report, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. May 12.

Brown and Caldwell, 2015a. Bedrock Groundwater Assessment Technical Memorandum, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. January 28.

Brown and Caldwell, 2015b. Draft Wabuska Drain (OU-7) Remedial Investigation Work Plan - Conceptual Site Model and Data Quality Objectives, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. July 14.

Brown and Caldwell, 2015c. Background Groundwater Quality Assessment - Revision 2, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. July 2.

Brown and Caldwell, 2015d. Additional Monitor Well Installation Data Summary Report, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. June 11.

Brown and Caldwell, 2015e. Groundwater Geochemical Characterization Data Summary Report - Revision 1, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. December 11.

Brown and Caldwell, 2015f. Technical Memorandum: Draft Initial Screening of Remedial Alternatives, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. December 2.

Brown and Caldwell, 2016a. Groundwater Geochemical Characterization Data Summary Report - Revision 2, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company.

Brown and Caldwell, 2016b. Background Groundwater Quality Assessment - Revision 3, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. November 11.

Brown and Caldwell, 2016c. 2015 Annual Groundwater Monitoring Report, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. May 16.

BC, 2017. Technical Memorandum: Phase 1 Evaporation Ponds Characterization Data Summary Report. Prepared for Atlantic Richfield Company, March 16

Brown and Caldwell, 2017a. Technical Memorandum: Wabuska Drain (OU-7) Field Sampling and Analysis Plan Data Summary Report and Conceptual Site Model Update. Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. January 3

Brown and Caldwell, 2017b. Technical Memorandum: Phase 1 Evaporation Ponds Characterization Data Summary Report. Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. January 20.

Brown and Caldwell and Integral Consulting, Inc., 2007. Draft Remedial Investigation Work Plan for Site-Wide Groundwater Operable Unit 1, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. November 16.

Carroll, R.W.H., G. Pohll, D. McGraw, C. Garner, A. Knust, D. Boyle, T. Minor, S. Bassett, and K. Pohlmann, 2010. Mason Valley Groundwater Model: Linking Surface Water and Groundwater in the Walker River Basin, Nevada. Journal of American Water Resources Association.

CH2M Hill, 2010. Final Historical Summary Report, Anaconda-Yerington Mine Site, Yerington, Nevada. October.

CH2M Hill, 2011a. Final Supplemental Remedial Investigation Report Arimetco Facilities Operable Unit 8, Anaconda-Yerington Copper Mine. Yerington, Nevada. October.

CH2M Hill, 2011b. Feasibility Study for Arimetco Facilities Operable Unit 8 Heap Leach Pads and Drain-down Fluids, Anaconda-Yerington Copper Mine. Yerington, Nevada. July.

Dalton, D., 1998. Arimetco Yerington Mine and Process Facility Site Assessment of Groundwater Quality, Yerington, Nevada. Prepared for Arimetco, Inc. July.

Davis, J.A., S.P. Hyun, P.M. Fox, and K.F. Hayes, 2009. A surface complexation modeling approach for Uranium (VI) transport in groundwater. Abstracts of the International Mine Water Conference, Proceedings. October.

Doherty, J., 2009. PEST - Model-Independent Parameter Estimation & Uncertainty Analysis, Version 12.2. Watermark Computing. Brisbane, Australia.

Dong, W. and S.C. Brooks, 2006. Determination of the formation constants of ternary complexes of uranyl and carbonate with alkaline earth metals (Mg^{2+}, Ca^{2+}, Sr^{2+}, and Ba^{2+}) using anion exchange method. Environmental Science and Technology Vol. 40, pp. 4689–4695.

Echevarria, G., M.I. Sheppard, and J.L. Morel, 2001. Effect of pH on the sorption of uranium in soils. Journal of Environmental Radioactivity, Vol. 53, pp. 257-264.

Ecology and Environment, Inc., 2013. Technical Memorandum and Report of START Activities, Arimetco Pond Design and Perimeter Ditch Repair Field Observations and Operation and

Maintenance Recommendations, Yerington, Nevada. Prepared for the Atlantic Richfield Company. April 29.

Environmental Standards, Inc. and Brown and Caldwell, 2009. Quality Assurance Project Plan Yerington Mine Site, Revision 5. Prepared for Atlantic Richfield Company. May 20.

EPA, 1988. Interim Final Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA. EPA/540/G-89/004.

EPA, 1992. Guidance for Data Usability for Risk Assessment. (Part B). Final. Office of Emergency and Remedial Response. Washington D.C.

EPA, 1999. Understanding Variation in Partition Coefficient, Kd, Values. Volume I: The k_d Model, Methods of Measurement, and Application of Chemical Reaction Codes. EPA 402-R-99-004A.

EPA, 2005. Standard Operating Procedure for Analysis of Total Organic Carbon in Sediments (Dry Combustion, Infrared Detection). Method LG601. Revision 04. March.

EPA, 2007a. Administrative Order for the Remedial Investigation and Feasibility Study. In the matter of Anaconda / Yerington Mine Site, Yerington, Lyon County, Nevada. Atlantic Richfield, Respondent. U.S. EPA Region 9, Docket No. 9-2007-0005. Proceeding under Section 106(a) of CERCLA, as amended, 42 USC § 9606(a). Including Attachment A: Scope of Work for the Remedial Investigations / Feasibility Studies Continued Response Action. January 12, 2007.

EPA, 2007b. Monitored Natural Attenuation of Inorganic Constituents in Ground Water, Volume 1 Technical Basis for Assessment. EPA/600/R-07-139.

EPA, 2008. A Systematic Approach to Evaluation of Capture Zones at Pump and Treat Systems, Final Project Report. EPA 600/R-8/003.

EPA, 2009. Statistical Analysis of Groundwater Monitoring Data at RCRA Facilities, Unified Guidance. EPA/530/R-09-007.

EPA, 2010a. Letter from EPA to Atlantic Richfield Company RE: Comments on the Draft Aquifer Solids Testing Work Plan. September 13.

EPA, 2010b. Letter from EPA to Atlantic Richfield Company RE: Aquifer Solids Testing Work Plan - Revision 1. September 30.

EPA, 2010d. Monitored Natural Attenuation of Inorganic Constituents in Ground Water, Volume 3, Assessment for Radionuclides Including Tritium, Radon, Strontium, Technetium, Uranium, Iodine, Radium, Thorium, Cesium, and Plutonium-Americium. EPA/600/R-10/039.

EPA, 2011a. Letter from EPA to Atlantic Richfield Company RE: Comments on the 2010 Annual Groundwater Monitoring Report (April 15, 2011), the First Quarter 2011 Groundwater Monitoring Report (July 1, 2011), and the Second Quarter 2011 Groundwater Monitoring Report (August 26, 2011) for the Anaconda Mine Site. September 29.

EPA, 2011b. Letter from EPA to Atlantic Richfield Company RE: Approval of the Addendum to the On-Site Monitor Well Installation Work Plan. September 30.

EPA, 2012a. Letter from EPA to Atlantic Richfield Company RE: Comments on the Draft Background Groundwater Quality Assessment, Yerington Mine Site, Nevada. February 7.

EPA, 2012b. Letter from EPA to Atlantic Richfield Company RE: Comprehensive Hydrologic Tracer Sampling Event and Request to Eliminate Select Tracers, Yerington Mine Site, Nevada. April 27.

EPA, 2012c. Letter from EPA to Atlantic Richfield Company RE: Comments on the Proposed Initial Bedrock Characterization Activities for the Anaconda Mine Site. April 12.

EPA, 2012d. Letter from EPA to Atlantic Richfield Company. October 22.

EPA, 2012e. Letter from EPA to Atlantic Richfield Company RE: Groundwater Flow Modeling Deliverables Anaconda Mine Site, Nevada. July 11.

EPA, 2012f. Letter from EPA to Atlantic Richfield Company. October 26.

EPA, 2012g. Letter from EPA to Atlantic Richfield Company RE: Comments on SOP-23 Aquifer Solids Testing - Redox-Preserved Sample Preservation and Testing Dated August 14, 2012. September 26.

EPA, 2013a. Letter from EPA to Atlantic Richfield Company RE: Comments on 2011 Annual Groundwater Monitoring Report, Anaconda Yerington Mine Site. March 27.

EPA, 2013b. Letter from EPA to Atlantic Richfield Company RE: Comments on 2012 Annual Groundwater Monitoring Report, Anaconda Yerington Mine Site. August 1.

EPA, 2013c. Letter from EPA to Atlantic Richfield Company RE: EPA Approval to Abandon Well B/W-14S, Anaconda Yerington Mine Site. November 22.

EPA, 2013d. Letter from EPA to Atlantic Richfield Company RE: Comments on the Draft Groundwater Flow Model Work Plan, Anaconda Yerington Mine Site. March 29.

EPA, 2013e. Letter from EPA to Atlantic Richfield Company RE: Comments on the Draft Additional Monitor Well Work Plan, Anaconda Yerington Mine Site. July 29.

EPA, 2013f. Statistical Software ProUCL 5.0.00 for Environmental Applications for Data Sets with and without Nondetect Observations.

EPA, 2014a. Letter from EPA to Atlantic Richfield Company RE: EPA Approval of Site-Wide Groundwater Monitoring Optimization, Anaconda Yerington Mine Site. June 26.

EPA, 2014b. Letter from EPA to Atlantic Richfield Company RE: Anaconda Yerington Mine Site OU1, Approval of Site-Wide Groundwater RI Work Plan Revision 1. October 9.

EPA, 2014c. 3PE: A Tool for Estimating Groundwater Flow Vectors. EPA 600/R-14/273.

EPA, 2015a. Letter from EPA to Atlantic Richfield Company RE: Anaconda Yerington Mine Site OU-1 Request for Bedrock Characterization DSR in Place of Work Plan. May 18.

EPA, 2015b. Letter from EPA to Atlantic Richfield Company RE: Approval of Groundwater Flow Model Report and Supplemental Materials, Anaconda Yerington Mine Site OU-1.

EPA, 2016a. Letter from EPA to Atlantic Richfield Company RE: Anaconda Copper Mine Site OU-1 Approval of Bedrock Groundwater Assessment Technical Memorandum. July 31.

EPA, 2016b. Letter from EPA to the Atlantic Richfield Company RE: Anaconda Yerington Mine Site OU-1, Approval of Geochemical Characterization DSR with Conditions. July.

EPA, 2016c. Letter from EPA to Atlantic Richfield Company RE: Anaconda Mine Site, Comments on the Background Groundwater Quality Assessment - Revision 2 dated July 2, 2015. February 11.

EPA, 2016d. Letter from EPA to Atlantic Richfield Company RE: Anaconda Copper Mine OU-1, Background Groundwater Quality Assessment. September 27.

EPA, 2016e. Memorandum from Dr. R. Ford (USEPA Land Remediation & Pollution Control Division) and Mr. S. Acree (USEPA Applied Research and Technical Support Branch) to Mr. D. Seter (USEPA Region 9), Subject: Yerington Mine Site, Yerington Nevada (16-R09-003) Responses to ARC Responses to Comments on the Background Groundwater Quality Assessment - Revision 2. September 2.

EPA, 2016f. Letter from EPA to Atlantic Richfield Company RE: Anaconda Copper Mine, Domestic Well Monitoring Program (DWMP) and Bottled Water Program (BWP). October 25.

EPA, 2017. Letter to the Atlantic Richfield Company RE: Anaconda Copper Mine Site OU-1, OU-1 Background Water Quality Assessment - Revision 3. February 16.

Fox, P.M., J.A. Davis, and J.M. Zachara, 2006. The effect of calcium on aqueous uranium(VI) speciation and adsorption to ferrihydrite and quartz. Geochimica et Cosmochimica Acta, Vol. 70, pp. 1379-1387.

Freeze, R.A. and J.A. Cherry, 1979. Groundwater. Prentice-Hall, Upper Saddle River, NJ.

Gallagher, T. K., 2004. Estimated Annual Ground-Water Pumpage 1994 - 2003, Smith Valley and Mason Valley, Lyon County, Nevada, Nevada Department of Conservation and Natural Resources, Division of Water Resources.

Gallagher, T. K., 2013. Estimated Annual Ground-Water Pumpage 2004 - 2010, Smith Valley and Mason Valley, Lyon County, Nevada, Nevada Department of Conservation and Natural Resources, Division of Water Resources.

George, P. L. and H. Borouchaki, 1998, Delaunay Triangulation and Meshing Application to Finite Elements, Paris, Hermes.

Gill, D. K., 1951. Groundwater at the Yerington Mine, Lyon County, Nevada. Report prepared for the Anaconda Mining Company. March.

Heath, R.C., 1984. Ground-Water Regions of the United States. U.S. Geological Survey (USGS) Water-Supply Paper 2242.

Hem, J., 1985. Study and Interpretation of the Chemical Characteristics of Natural Water. 3rd Ed. U.S. Geological Survey (USGS) Water-Supply Paper 2254.

Hershey, R.L., 2002. Hydrology and water quality of the Yerington Pit Lake, In: Geological Society of Nevada 2002 Spring Field Trip Guidebook Special Publication No. 35, Jurassic Magmatism and Metal Deposits in Western Nevada, Yerington Mine District, Humboldt Mafic Complex, June 15-16, 2003, Ed. Bob Thomas, pp. 93-98.

Hsi, C. K. D., and D. Langmuir, 1985. Adsorption of uranyl onto ferric oxyhydroxides: application to the surface complexation site-binding model. Geochimica et Cosmochimica Acta, Vol. 49, pp. 1931-1941.

Huxel, C.J., and E.E. Harris, 1969. Water resources and development in Mason Valley, Lyon and Mineral Counties, Nevada, 1948-65. State of Nevada Department of Conservation and Natural Resources, Division of Water Resources, Water Resources Bulletin No. 38.

Jurgens, B.C., M.S. Fram, K. Belitz, K.R. Burow, and M.K. Landon, 2010. Effects of Groundwater Development on Uranium: Central Valley, California, USA. Ground Water. Vol. 48, pp. 913-928.

Lewis, B., 2000. Geophysical Survey Results of the Yerington Mine, Mason Valley, Nevada, Prepared by the U.S. Bureau of Land Management - National Science and Technology Center. August.

Li, D., and D. I. Kaplan, 2012. Sorption coefficients and molecular mechanisms of Pu, U, Np, Am and Tc to Fe (hydr)oxides: A review. Journal of Hazardous Materials. Vol. 243, pp. 1-18.

Lopes, T.J., and K.K. Allander, 2009a. Hydrologic Setting and Conceptual Hydrologic Model of the Walker River Basin, West-Central Nevada. USGS Scientific Investigations Report 2009-5155.

Lopes, T.J., and K.K. Allander, 2009b. Water Budgets of the Walker River Basin and Walker Lake, California and Nevada. USGS Scientific Investigations Report 2009-5157.

Maurer, D.K., T.J. Lopes, R.L. Medina, and J.L. Smith, 2004. Hydrogeology and Hydrologic Landscapes of Nevada. USGS Scientific Investigations Report 2004-5131.

Mifflin, M.D., 1988. Region 5, Great Basin. In Hydrogeology, the Geology of North America, DNAG volume, vol. 0-2; ed. W. Back, J.S. Rosenshein, and P.R. Seaber, 60-78. Boulder, Colorado: Geological Society of America.

Morrison, R.B., 1964. Lake Lahontan: Geology of the southern Carson Desert. U.S. Geological Survey (USGS) Professional Paper 401.

Myers, T., 2001. Hydrogeology of the Basin Fill Aquifer in Mason Valley, Nevada: Effects of Water Rights Transferred. Prepared for the U.S. Bureau of Land Management, Carson City Field Office, Carson City, NV. Public Resources Associates, Inc., Reno, Nevada.

Nesbitt, M., 1955. Memorandum to A. J. Gould, Plant Superintendent, Anaconda Company. July 27.

Nevada Department of Conservation and Natural Resources, Division of Water Resources, 2013a, NDWR-Water Rights Database Advanced Search (Special Hydrographic Abstract), http://water.nv.gov/data/hydrographic/ June 4, 2013.

Nevada Department of Conservation and Natural Resources, Division of Water Resources, 2013b, Well Log Database Query Tool, http://water.nv.gov/data/welllog/ June 5, 2013.

Nevada Department of Conservation and Natural Resources, Division of Water Resources, 2013c, Water Level Data, http://water.nv.gov/data/waterlevel/ June 27, 2013.

Nevada Division of Water Resources, 2015. Memorandum titled “Curtailment Order in Mason and Smith Valley”. Department of Conservation and Natural Resources, Division of Water Resources. February 3.

Nolan, J., and K.A. Weber, 2015. Natural Uranium Contamination in Major U.S. Aquifers Linked to Nitrate. Environ. Sci. Technol. Lett., Vol. 2, pp. 215-220.

Nordstrom, K., L.N. Plummer, D. Langmuir, and E. Busenburg, 1990. Revised Chemical Equilibrium Data for Major Water-Mineral Reactions and Their Limitations, in "Chemical Modeling of Aqueous Systems II," Chapter 31, pp. 398-413.

Nork, W.E., 1989. MacArthur Project Hydrogeologic Investigation Lyon County, Nevada. Prepared for MacArthur Mining and Processing Company, Inc. August 14.

Norwest Applied Hydrology, 2007. Pumpback Well System 2006 Operations and Monitoring Summary, Yerington Mine Site. Prepared for Atlantic Richfield Company. April 30.

Parkhurst, D.L., and C.A.J. Appelo, 1999. User's Guide to PHREEQC (Version 2) - A Computer Program for Speciation, Batch-Reaction, One-Dimensional Transport, and Inverse Geochemical Calculations. Water-Resources Investigations Report 99-4259, U.S. Geological Survey, Denver, Colorado.

Piedmont Engineering Inc., 2001. Yerington Shallow Aquifer Data Evaluation Report. Prepared for ARCO Environmental Remediation L.L.C.

Plume, R.W., 1996. Hydrogeologic framework of the Great Basin region of Nevada, Utah, and adjacent states. USGS Professional Paper 1409-B.

Proffett, J.M., 1977. Cenozoic geology of the Yerington District, Nevada, and implications for the nature and origin of Basin and Range faulting. Geologic Society of America Bulletin, Vol. 88, pp. 247-266.

Proffett, J.M., Jr., and J.H. Dilles, 1984. Geologic Map of the Yerington District, Nevada. Nevada Bureau of Mines and Geology, Map 77.

Reheis, M., 1999. Extent of Pleistocene Lakes in the Western Great Basin. USGS Miscellaneous Field Studies Map MF-2323.

Ricketts, T.H., E. Dinerstein, D.M. Olson, and C.J. Loucks, 1999. Terrestrial ecoregions of North America: a conservation assessment. Island Press, Washington, D.C.

Sánchez-España, J. I. Yusta, and M. Diez-Ercilla, 2011. Schwertmannite and hydrobasaluminite: A re-evaluation of their solubility and control on the iron and aluminum concentration in acidic Pit Lakes. Applied Geochemistry, Vol. 26, pp.1752-1774.

Seitz, H.R., A.S. Van Denburgh, and R.J. La Carma, 1982. Ground-Water Quality Down-gradient from Copper-One Milling Wastes at Weed Heights, Lyon County, Nevada. USGS Open-File Report 80-1217.

Skillings Jr., D.N., 1972. Yerington Copper Mine. Skillings Mining review. Vol. 61, No. 21.

Smedley, P.L. and D.G. Kinniburgh, 2001. A review of the source, behavior and distribution of arsenic in natural waters. Applied geochemistry, Vol. 17, pp. 517-568

Sø, H.U., D. Postma, R. Jakobsen, and F. Larsen, 2008. Sorption and desorption of arsenate and arsenite on calcite. Geochimica et Cosmochimica Acta, Vol. 72, pp. 5871-5884.

S.S. Papadopulos & Associates, Inc., 2012a. Objectives for Groundwater Modeling in the RI/FS Process, Yerington Mine Site. Prepared for Atlantic Richfield Company. August 14.

S.S. Papadopulos & Associates, Inc., 2012b. Objectives for Groundwater Modeling in the RI/FS Process - Revision 1, Yerington Mine Site. Prepared for Atlantic Richfield Company. October 15.

S.S. Papadopulos & Associates, Inc., 2012c. Draft Groundwater Flow Model, Work Plan for the Yerington Mine Site. Lyon County, Nevada. Prepared for Atlantic Richfield Company. December 28.

S.S. Papadopulos & Associates, Inc., 2013. Groundwater Flow Model Work Plan for the Yerington Mine Site - Revision 1, Lyon County, Nevada. Prepared for Atlantic Richfield Company. May 21.

S.S. Papadopulos & Associates, Inc., 2014. Groundwater Flow Model, Yerington Mine Site, Nevada. Prepared for Atlantic Richfield Company. March 18.

S.S. Papadopulos & Associates, Inc., 2015. Flow Model Supplemental Materials, Yerington Mine Site, Nevada. Prepared for Atlantic Richfield Company. March 18.

Stachowicz, M., T. Hiemstra, and W.H. van Riemsdijk, 2007. Arsenic-bicarbonate interaction on goethite particles. Environmental Science and Technology, Vol. 41, pp. 5620-5625.

Stewart, J.H., 1988. Tectonics of the Walker Lane belt, western Great Basin: Mesozoic and Cenozoic deformation in a zone of shear. In Ernst, W.G., Metamorphism and crustal evolution of the western United States, Rubey volume VII: Prentice Hall, Englewood Cliffs, N.J.

Stewart, B.D., M.A. Mayes, and S. Fendorf, 2010. Impact of uranyl-calcium-carbonate complexes on uranium(VI) adsorption to synthetic and natural sediments. Environmental Science and Technology, Vol. 44, pp. 928-934.

Superfund Technical Assessment Response Team (START), 2000. Anaconda Copper Company, Yerington Mine Site, Expanded Site Inspection, Yerington, Lyon County, Nevada. Prepared by Ecology & Environment Incorporated. December.

Superfund Technical Assessment Response Team (START), 2001. Anaconda Copper Company, Yerington Mine Site, Emergency Response Assessment, Yerington, Lyon County, Nevada. Prepared by Ecology & Environment Incorporated. June.

Taylor, B.E., and M.C. Wheeler, 1994. Sulfur- and Oxygen-Isotope Geochemistry of Acid Mine Drainage in the Western United States. Chptr. 30. Environmental Geochemistry of Sulfide Oxidation. Eds. C.W. Alpers and D.W. Blowes.

Tetra Tech, 2010. Preliminary Economic Assessment Update Pumpkin Hollow Copper Project, Lyon County, Nevada. Prepared for Nevada Copper Corp. January 13.

Thomas, J.M., 1995. Water Budget and Salinity of Walker Lake, Western Nevada. USGS Fact Sheet FS-115-98.

U.S. Bureau of Mines, 1958. Methods and Operations at the Yerington Copper Mine and Plant of the Anaconda Company, Weed Heights, Nev., by M. Claire Smith; Information Circular 7848, Department of the Interior.

U.S. Census Bureau, 2015. State and County Quickfacts. Available at: http://www.census.gov/quickfacts/table/PST045215/32019.

U.S. Geological Survey, 2006. Determination of the Delta ($^{34}S/^{32}S$) of Sulfate in Water, RSIL Lab Code 1951. Techniques and Methods of the Reston Stable Isotope Laboratory, Chapter 10.

U.S. Geological Survey, 2008. $^{3}H/^{3}He$ Sampling. The Reston Chlorofluorocarbon Laboratory. http://water.usgs.gov/lab/3h3he/sampling/.

U.S. Geological Society, 2009a. Hydrologic Setting and Conceptual Hydrologic Model of the Walker River Basin, West-Central Nevada. U.S. Department of Interior, USGS, Scientific Investigations Report 2009-5155.

U.S. Geological Society, 2009b. Water Budgets of the Walker River Basin and Walker Lake, California and Nevada. U.S. Department of Interior, USGS, Scientific Investigations Report 2009-5157.

U.S. Geological Survey, 2013. National Water Information System, USGS Groundwater for Nevada: Water Levels, http://nwis.waterdata.usgs.gov /nv/nwis/gwlevels June 27.

Walker River Decree C-125, 1936 amended 1940. United States vs. Walker River Irrigation District, Docket C-125, District Court of the United States - District of Nevada.

Wanninkhof, R., J.R. Ledwell, and A. J. Watson, 1991. Analysis of sulfur hexafluoride in seawater. J. Geophys. Res - Oceans 96(C5), pp. 8733-8740.

Wilson, J.L., and H. Guan, 2004. Mountain-Block Hydrology and Mountain-Front Recharge. In: Groundwater Recharge in a Desert Environment: The Southwestern United States, edited by F.M. Phillips, J. Hogan, and B. Scanlon. AGU, Washington, DC.

WRCC, 2015. Yerington, Nevada (269229): Period NCDC 1894-2015 Monthly Normals. Western Regional Climate Center. http://www.wrcc.dri.edu/cgi-bin/cliMAIN.pl?nv9229.

Western Regional Climate Center (WRCC). 2017. Yerington, Nevada (269229) Period of Record Monthly Climate Summary, 1/1/1914 to 12/31/2005. http://www.wrcc.dri.edu/cgi-bin/cliMAIN.pl?nvyeri.

Zheng, C., G.D. Bennett, and C.B. Andrews, 1991. Analysis of Ground-Water Remedial Alternatives at a Superfund Site. Ground Water. Vol. 29, No. 6., pp. 838-848.

REMEDIAL INVESTIGATION REPORT
SITE-WIDE GROUNDWATER OPERABLE UNIT (OU-1)

ANACONDA COPPER MINE SITE
LYON COUNTY, NEVADA

OCTOBER 20, 2017

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LIST OF ACRONYMS AND ABREVIATIONS

AFCEE	Air Force Center for Environmental Excellence
AHA	Applied Hydrology Associates
Anaconda	Anaconda Companya
ARC	Atlantic Richfield Company
BC	Brown and Caldwell
BCL	Background Concentration Limit
BGQA	Background Groundwater Quality Assessment
BLM	Bureau of Land Management
CFC	Chlorofluorocarbon
COI	Chemical of Interest
DO	Dissolved Oxygen
DPT	Direct Push Technology
DSR	Data Summary Report
DQO	Data Quality Objective
DWMP	Domestic Well Monitoring Program
EA-IRMS	Elemental Analyzer-Isotopic Ratio Mass Spectrometer
EC	Electrical Conductivity
EPA	U.S. Environmental Protection Agency
ESI	Environmental Standards, Inc.
FEP	Finger Evaporation Ponds
FMS	Fluid Management System
FS	Feasibility Study
GC-ECD	Gas Chromatography with Electron Capture Detection
GMP	Groundwater Monitoring Plan
GMR	Groundwater Monitoring Report
HCSM	Hydrogeologic Conceptual Site Model
HDPE	High-Density Polyethylene
HFA	Hydrogeologic Framework Assessment
HLP	Heap Leach Pad
HHRA	Human Health Risk Assessment
HSR	Historical Summary Report
IAOC	Interim Administrative Settlement Agreement and Order on Consent
ICP-MS	Inductively Coupled Plasma Mass Spectroscopy
J	Estimated Concentration
K	Hydraulic Conductivity
Kd	Partition (or Distribution) Coefficient
LEP	Lined Evaporation Pond
MAROS	Monitoring and Remediation Optimization System
MCL	Maximum Contaminant Level
MFR	Mountain Front Recharge
NA	Not Applicable/Not Available
NAC	Nevada Administrative Code
NDEP	Nevada Division of Environmental Protection
NDWR	Nevada Division of Water Resources
NR	Not Recorded
NSA	North Study Area
NS	No Sample
O&M	Operation and Maintenance
ORP	Oxidation-Reduction Potential
OU	Operable Unit
PLS	Pregnant Leach Solution
POD	Point of Diversion
POU	Place of Use
PV	Pore Volume
PWS	Pumpback Well System
Q	Quarter
QA/QC	Quality Assurance/Quality Control
QAPP	Quality Assurance Project Plan
R	Retardation Coefficient
RAO	Remedial Action Objective
RER	Replicate Error Ratio
RI/FS	Remedial Investigation and Feasibility Study
RPD	Relative Percent Difference
RSIL	USGS Reston Stable Isotope Laboratory
RSL	Regional Screening Level
SCM	Surface Complexation Model
SERA	Southeast Recharge Area
SOP	Standard Operating Procedure
SOW	Scope of Work
SSPA	S.S. Papadopulos & Associates, Inc.
START	Superfund Technical Assessment and Response Team
STORET	STOrage and RETrieval
SWRA	Southwest Recharge Area
TC	Total Carbon
SX/EW	Solvent Extraction /Electrowinning
TIC	Total Inorganic Carbon
TDS	Total Dissolved Solids
TIMS	Thermal Ionization Mass Spectrometer
TOC	Total Organic Carbon
TU	Tritium Unit
U	Chemical not detected at the indicated sample detection limit
UAO	Unilateral Administrative Order
Ue	Uranium Excess
UEP	Unlined Evaporation Pond
UJ	Chemical not detected at the indicated estimated sample detection limit
USCS	Unified Soil Classification System
USGS	United States Geological Survey
UTL	Upper Tolerance Limit
VLT	Vat Leach Tailings
WRCC	Western Regional Climate Center

LIST OF ACRONYMS AND ABREVIATIONS - CONTINUED

WRD	Walker River Decree
WRID	Walker River Irrigation District
YPT	Yerington Paiute Tribe

%	percent
‰	per mil
amsl	above mean sea level
bgs	below ground surface
cu ft	cubic feet
cfs	cubic feet per second
ºF	degrees Fahrenheit
ºC	degrees Celsius or Centigrade
ft	foot/feet
ft/day	feet per day
ft/yr	feet per year
fmol/kg	femtomole per kilogram
gal	gallons
g/L	grams per liter
gpd	gallons per day
gpm	gallons per minute
L	liter
L/kg	liters per kilogram
µg	microgram
µm	micron or micrometer
mg	milligram
pCi/g	picocuries per gram
pCi/L	picocuries per liter
pCi	picocurie
pmol/kg	picomoles per kilogram
s.u.	standard units (pH)

MINERALS, CHEMICAL FORMULAS, AND ABBREVIATIONS

Barium Arsenate	$Ba_3(AsO_4)_2$
Ferric oxide	$Fe(OH)_3(a)$
Gypsum	$CaSO_4$
Hydroxy-green rust	$Fe_3(OH)_7(s)$ and $Fe_2(OH)_5(s)$
Jarosite (ss)	$(K_{0.77}Na_{0.03}H_{0.2})Fe_3(SO_4)_2(OH)_6(s)$
K-jarosite	$KFe_3(SO_4)_2(OH)_6(s)$
Na-jarosite	$NaFe_3(SO_4)_2(OH)_6(s)$
Schwertmannite	$Fe_8O_8(OH)_{4.8}(SO_4)_{1.6}(s)$
Scorodite	$FeAsO_4(s)$

(a)	Amorphous
(aq)	Aqueous
(s)	Solid
(ss)	Solid Solution

$\delta^{13}B$	Boron isotopes in water samples
$\delta^{36}Cl$	Chloride isotopes in water samples
$\delta^{34}S_{SO4}$	Sulfur isotopes in dissolved sulfate
$\delta^{34}O_{SO4}$	Oxygen isotopes in dissolved sulfate
$\delta^{15}N_{NO3}$	Nitrogen isotopes in dissolved nitrate
$\delta^{18}O_{NO3}$	Oxygen isotopes in dissolved nitrate

Nitric Acid	HNO_3
Sulfuric Acid	H_2SO_4
Sulfur Hexafluoride	SF_6
Sulfur Dioxide	SO_2

EXECUTIVE SUMMARY

This *Site-Wide Groundwater Operable Unit (OU-1) Remedial Investigation Report* (OU-1 RI Report) has been prepared by Atlantic Richfield Company (ARC) pursuant to Section 7.0 of the Scope of Work (SOW) attached to the Administrative Order for Remedial Investigation and Feasibility Study (RI/FS), CERCLA Docket No. 9-2007-0005 (2007 Order) for the Anaconda Copper Mine Site (Site). The 2007 Order (EPA 2007a) was issued to ARC by the U.S. Environmental Protection Agency - Region 9 (EPA) on January 12, 2007. Future work on the OU-1 RI/FS will proceed under oversight by the Nevada Division of Environmental Protection (NDEP) pursuant to the "Interim Administrative Settlement Agreement and Order on Consent for: (i) Remedial Design/Remedial Action, (ii) Site-Wide Remedial Investigation/Feasibility Study, and (iii) Fluid Management" entered into with NDEP (the IAOC) and the attached Statement of Work for RI/FS.

The term "Site" refers to the area where copper mining and ore processing activities historically occurred. The term "Study Area" in this document refers to a larger area encompassing both on-Site and off-Site areas in which OU-1 RI-related investigations have been conducted. The Site is a former copper mine that is located west and northwest of the City of Yerington. The 2007 Order identified eight OUs at the Site, which include:

- Site-Wide Groundwater (OU-1);
- Pit Lake (OU-2);
- Process Areas (OU-3);
- Evaporation Ponds (OU-4a) and Sulfide Tailings (OU-4b);
- Waste Rock Areas (OU-5);
- Oxide Tailings Areas (OU-6);
- Wabuska Drain (OU-7); and
- Arimetco Facilities (OU-8).

Consistent with the SOW attached to the 2007 Order (EPA 2007a) and general RI report objectives established by EPA (EPA 1988), this OU-1 RI Report:

- Summarizes activities conducted to characterize and monitor groundwater (including on- and off-Site locations), establish background groundwater quality, and determine the nature, extent, and transport of mine-related chemicals of interest (COIs) in groundwater;
- Integrates relevant historical operations and aspects of other OUs that represent potential sources of chemical loading to groundwater or have the potential to influence groundwater flow conditions;
- Describes the program for long-term monitoring of Site-wide groundwater conditions;
- Summarizes the domestic well monitoring program, which characterized the quality of groundwater used for drinking water or other domestic water supply purposes and determined eligibility for receiving bottled water as part of an interim response action; and
- Describes the process for completing the human health risk assessment, which is being addressed in a separate OU-1 Human Health Risk Assessment (HHRA) report, per EPA direction during a groundwater technical meeting held on June 30, 2016 attended by ARC, EPA, the NDEP, the Yerington Paiute Tribe (YPT), and other stakeholders.

The information provided in this OU-1 RI Report is considered sufficient to characterize the groundwater system, define the nature and extent of mine-related groundwater contamination, perform a risk assessment, and conduct a feasibility study. Numerous investigations and monitoring activities conducted by ARC and others provide substantial geologic, hydrogeologic, and water quality information relevant to OU-1. However, this OU-1 RI Report relies primarily on data obtained after 2005 to address the study elements specified in Section 7.0 of the SOW, characterize groundwater conditions, and refine the hydrogeologic conceptual site model (HCSM) to support the OU-1 RI/FS. Data obtained after 2005 have been selected for these purposes because: 1) data collection was performed pursuant to EPA-approved quality assurance/quality control (QA/QC) planning documents and OU-1 specific work plans that were developed with input from other stakeholders including the NDEP, YPT, and the Bureau of Land Management (BLM); 2) the spatial coverage and amount of data increased substantially after 2005; and 3) post-2005 sampling results better represent current conditions and potential risks at the Site, which is the proper focus of the RI and risk assessment.

The dataset obtained during August 2014 is emphasized in this OU-1 RI Report for the reasons previously cited, and because a variety of data types were concurrently collected (e.g., groundwater level data, groundwater quality data, and hydrologic tracer data) and/or evaluated (e.g., geochemical speciation modeling to help assess COI transport). Consequently, the August 2014 dataset is particularly useful for characterizing spatial aspects of OU-1 groundwater conditions.

Recognizing that groundwater characterization activities would largely involve monitor well installation, ARC and EPA adopted a multi-step sequential approach to field data collection to maximize usable data and optimize the design of a monitor well network intended to serve the data needs for both OU-1 RI characterization and long-term Site-Wide groundwater monitoring. In total, the groundwater RI characterization activities resulted in drilling 133 boreholes, logging approximately 33,000 linear feet of core, collecting and analyzing 624 zonal groundwater samples, installing 299 new monitor wells, and hydraulic (slug) testing of 296 wells.

After installation and development, new monitor wells were incorporated along with select existing monitor wells into the Site-Wide Groundwater Monitoring Program. Within the Study Area, the alluvial aquifer is up to 700 feet thick and is subdivided into Shallow, Intermediate and Deep zones (Deep zones 1 through 5). Underlying the alluvial aquifer is a bedrock groundwater flow system. The current monitor well network includes 360 wells at 170 locations: 133 wells in the Shallow zone, including 11 Pumpback Well System (PWS) wells formerly used for groundwater extraction that are currently inactive; 55 wells in the Intermediate zone; 105 wells in the Deep zone; and 67 bedrock wells. Of the 360 monitor wells, seven are used only for water level measurements, and the remaining 353 are monitored for both water levels and water quality.

The Site and Study Area are in the Mason Valley, a north-south trending structural valley (graben) in the Basin and Range Province that is filled with up to 1,000 feet of unconsolidated alluvial sediments. The valley is bordered to the west by the Singatse Range, to the east by the Wassuk Range, and to the north by the Desert Mountains. Regional metals mineralization and hydrothermal alteration associated with localized porphyry and skarn copper deposits occur throughout the Singatse Range and nearby portions of the Mason Valley.

Depositional processes have resulted in a complex sequence of laterally-discontinuous, heterogeneous, unconsolidated alluvial sediments that exhibit spatially-variable hydraulic properties (Brown and Caldwell [BC] 2014a). Clay layers or other low-permeability sediments are laterally discontinuous resulting in unconfined or semi-confined alluvial aquifer groundwater conditions. Based on groundwater flow model results (S.S. Papadopulos & Associates, Inc. [SSPA] 2014), the alluvial aquifer is primarily recharged by downward percolation of water from irrigated fields (49 percent [%]), leakage from irrigation ditches (29%), infiltration from the channel of the Walker River (20%), and mountain front recharge (2%) resulting from infiltration through bedrock of precipitation that falls on surrounding mountain ranges and minor tributary surface flows in ephemeral drainages. Recharge from precipitation falling directly on the valley floor is negligible (Huxel and Harris 1969; Lopes and Allander 2009a, 2009b).

The alluvial aquifer in the Mason Valley yields significant quantities of groundwater and the groundwater resource is pumped extensively for irrigation (Carroll et al. 2010; SSPA 2014). Alluvial groundwater near the Site generally flows to the northwest, but flow directions are locally affected by bedrock outcrops within and along the margins of the valley, drawdown from pumped wells (particularly in deeper zones of the alluvial aquifer), and recharge sources such as the Walker River, the West Campbell Ditch, and irrigation on the Hunewill Ranch and other agricultural fields. Groundwater in the alluvial aquifer moves relatively slowly, with flow velocities estimated to be less than 100 feet per year (BC 2014a). Agricultural pumping seasonally results in strong downward vertical gradients that are often 10 to 100 times greater than horizontal gradients.

Historic mining and copper ore beneficiation activities involved the use of sulfuric acid (H_2SO_4). The major past and/or ongoing sources of COIs to groundwater include: 1) OU-4a, the Evaporation Ponds (BC 2014a, 2014d); 2) OU-8, the Arimetco Facilities (CH2M Hill 2010, 2011a, 2011b); and 3) OU-3, the Process Areas (BC 2014a, 2014e). Concentrations of COIs in groundwater beneath OU-4b (Sulfide Tailings) are generally at least 10 to 100 times lower than COI concentrations in groundwater beneath OU-4a. Furthermore, OU-4b is located hydraulically upgradient or cross-gradient of OU-4a, and groundwater beneath OU-4b flows toward the higher COI concentrations under OU-4a.

The Pit Lake (OU-2), which was studied as part of the OU-1 RI (BC 2014a), is not a source of COIs to Site-wide groundwater because the lake elevation is lower than the surrounding potentiometric surface and the pre-mining groundwater level. The Pit Lake surface is projected to reach a steady-state level, where water inflow and evaporation are balanced, prior to 2030. The steady-state Pit Lake elevation is estimated to be in the range of 4,249 to 4,253 feet above mean sea level, and is projected to remain lower than the surrounding potentiometric surface even after reaching steady-state conditions. Consequently, the lake is and will continue to be a groundwater sink that does not discharge into the Site-wide groundwater system.

Results of the ongoing RI for the Wabuska Drain (OU-7) will be reported separately. Available data indicate that concentrations of mine-related chemicals decrease with distance from the Site and depth in the soil profile (EPA 2007, BC 2015b).

Mine-related COIs include acidity (i.e., low pH), total dissolved solids (TDS), major ions including sulfate, metals/metalloids (hereinafter referred to as metals), and radiochemicals including uranium (BC 2014a). Concentrations of mine-related chemicals in groundwater are most elevated in the Shallow zone of the alluvial aquifer beneath OU-4a features that include the Lined Evaporation Pond (LEP), Unlined Evaporation Pond (UEP), Finger Ponds, Phase IV Vat Leach Tailings (VLT) Heap Leach Pad (HLP), Phase IV VLT Pond, and the northern end of the Calcine Ditch. Chemical concentrations in groundwater generally decrease with vertical depth and horizontal distance from these facilities. To the extent localized downgradient increases in chemical concentrations are observed, they result from non-mine-related factors.

Hydraulic assessments and chemical distributions indicate that the PWS was only partially effective in capturing Shallow zone mine-impacted groundwater during its operational life from 1989 to 2009 (BC 2010), when it was shut down with EPA approval.

Geochemical evaluations of groundwater quality data (BC 2016a) indicate that sulfate and dissolved uranium form neutral or negatively-charged aqueous ionic complexes in groundwater throughout the Study Area (except beneath the Evaporation Ponds) and, thus, undergo very limited (if any) geochemical attenuation due to mineral precipitation or adsorption to aquifer materials during groundwater transport. Dissolved uranium in Study Area groundwater is predominantly present in complexes with carbonate plus or minus calcium, which reflect oxidizing, carbonate-rich groundwater conditions. Locally, dissolved uranium is also complexed with sulfate in Shallow zone groundwater beneath the Evaporation Ponds where pH is less than 5 and sulfate concentrations exceed 1,500 milligrams per liter (mg/L).

The spatial distributions of elevated concentrations of mobile parameters such as sulfate and uranium are significantly more extensive than the spatial distributions of acidity (as indicated by pH) and metals. The limited spatial extent of low pH values and elevated metal concentrations indicates that geochemical attenuation processes in Study Area groundwater limit the mobility of acidity and metals relative to the more mobile chemicals such as sulfate and uranium (EPA 2007b; BC 2016a, 2016b). Elevated metal concentrations in groundwater correlate strongly with low pH. Geochemical evaluations of groundwater quality data (BC 2016a) also indicate the likely precipitation of solid mineral phases (e.g., jarosite) primarily in the Shallow zone beneath the LEP, UEP, Thumb Pond, and Phase IV HLP. These mineral phases likely represent a potential ongoing source of COIs to groundwater.

Sulfate, uranium and arsenic (and other COIs) occur naturally in groundwater in Mason Valley because of groundwater contact with naturally-mineralized and/or hydrothermally-altered bedrock associated with copper deposits and/or alluvial sediments derived from mineralized bedrock (BC 2009a, 2014b). These regional groundwater conditions, unrelated to mining, affect COI concentrations at two key locations within the OU-1 groundwater Study Area. To the west of the Site and adjacent to the Singatse Range, naturally-occurring arsenic, other COIs, and elevated groundwater temperatures in alluvial aquifer groundwater are associated with subsurface water transmitted along fractures and faults (especially oblique range-front faults such as the Sales Fault).

These faults occur in arsenic-bearing volcanic and granitic bedrock formations that provide conduits for bedrock groundwater to discharge into the overlying alluvial aquifer. In the North Study Area (NSA), which refers to the portion of the OU-1 groundwater Study Area located northeast of West Campbell Ditch and north of the Sunset Hills, naturally-occurring arsenic concentrations as high as 83 micrograms per liter (µg/L) occurs in Deep zone groundwater. The elevated arsenic in this portion of the Study Area is likely related to bedrock discharge to the alluvial aquifer and is not related to agricultural activities that source COIs to the Shallow through Deep 2 zones of the alluvial groundwater, as discussed further below.

Groundwater quality in the NSA is influenced by agricultural activities but not by mining activities (BC 2016b). Multiple lines of evidence (including groundwater flow patterns, chemical distributions, groundwater age estimates, hydrologic tracers, and sulfur isotopes) confirm that groundwater in the NSA has been affected by agricultural practices and not by mining activities, resulting in concentrations of sulfate and uranium that are elevated above background values and/or Maximum Contaminant Levels (MCLs) or exhibit increasing trends.

Monitor well data from the NSA indicate that concentrations of nitrate, sulfate, calcium, uranium, and alkalinity in alluvial groundwater in the Shallow through Deep 2 zones increase along the flow path beneath the agricultural fields. Increases in nitrate are associated with fertilizer application on crop fields. Increases in sulfate and calcium concentrations are associated with application of gypsum ($CaSO_4$) as a soil amendment on crop fields, which dissolves in irrigation water that percolates down to the water table. Increases in uranium concentrations are associated with crop irrigation. Percolation of irrigation water through soils increases alkalinity in the soil moisture, which mobilizes and desorbs naturally-occurring uranium from sediments (as soluble complexes with sulfate, carbonate plus or minus calcium) resulting in elevated uranium concentrations in groundwater (Jurgens et al. 2010; Brown et al. 2007).

Alluvial sediments in the Mason Valley contain naturally-occurring uranium (BC 2009b). The impact of agricultural activities on uranium mobility in NSA groundwater within or near irrigated land is illustrated by the strong correlation between uranium, alkalinity and calcium. Increases in alkalinity and calcium are associated with increases in uranium concentrations that can exceed 100 µg/L. Evaporation of irrigation water derived from surface water and groundwater sources also serves to increase chemical concentrations in water that infiltrates and percolates to the water table.

The extent of mine-impacted groundwater has been defined using sulfate, dissolved uranium, and sulfur isotopes in sulfate because these parameters undergo very limited (if any) geochemical attenuation during groundwater transport and, thus, have traveled the farthest downgradient distance in the alluvial aquifer (BC 2016b). As noted by EPA (2016c), the background assessment conservatively over-estimated the area of mine-impacted groundwater and may not fully account for the range of chemical concentrations that occur naturally in groundwater within the Study Area. Portions of the aquifer where sulfate and uranium exceed background concentrations include: 1) all groundwater zones beneath portions of the Site; 2) Shallow zone groundwater extending north/northwest to the Sunset Hills located approximately three miles north of the Site boundary; and 3) deeper groundwater beneath the Site and extending northeast beneath portions of the Hunewill Ranch. The estimated volume of mine-impacted groundwater (i.e., the portion of the downgradient aquifer where sulfate and uranium exceed background concentrations) is 385,327 acre-feet, and contains an estimated 500,000 tons of sulfate and 100 tons of dissolved uranium.

Bedrock characterization information indicates: 1) a high degree of fracture heterogeneity and vertical hydraulic connection between the bedrock and alluvial groundwater systems; and 2) limited horizontal hydraulic connectivity and transmissivity of bedrock fractures, especially over horizontal distances that are relevant to the scale of the Site and the surrounding Study Area. In addition to a high degree of three-dimensional (i.e., anisotropic) variability in hydraulic characteristics and hydrologic tracer signatures, the bedrock groundwater system also exhibits high, three-dimensional spatial variability in chemical concentrations.

Concentrations of mine-related chemicals in the alluvial aquifer are most elevated in the Shallow zone beneath OU-4a, as noted previously. COI concentrations generally decrease with vertical depth and horizontal distance from the Site sources, resulting in values in bedrock groundwater that are 10 to over 1,000 times lower than the values in overlying alluvial groundwater. In addition, areas of elevated mine-related COIs in bedrock groundwater are small in comparison to the alluvial aquifer, highly localized, and found mostly on-Site.

The localized areas of elevated mine-related COIs in bedrock groundwater indicate that bedrock fractures have limited hydraulic connectivity and transmissivity over horizontal distances relevant to the scale of the Study Area. Despite localized areas of relatively high hydraulic conductivity, bedrock groundwater flow velocities, average volumetric flow rates and chemical fluxes through the bedrock groundwater system are low, and the bedrock groundwater system is not considered to be an important migration pathway at the Site (EPA 2015a). It is however an important source for elevated concentrations of arsenic, originating from bedrock and transported with mountain front recharge over much longer timescales.

Water quality monitoring of domestic, commercial, and irrigation wells (collectively referred to as domestic wells) located near the Site began in late 1983 and evolved over time. Results of domestic well monitoring have been used to: 1) characterize the quality of groundwater used for drinking water or other domestic uses; 2) assess potential risk, if any, to human health and the environment from the use of domestic well water for drinking water or agricultural purposes; and 3) determine eligibility for receiving bottled water as part of an interim response action.

The number of wells/properties included in the domestic well monitoring program (BC 2010) and receiving bottled water was substantially reduced in 2016 (ARC 2016a; EPA 2016f). As part of a settlement entered in the class action lawsuit *Roeder et al. v. Atlantic Richfield Company et al.*, D. Nev., Case No. 3-11-cv-00105-RCJ-WGC ("Roeder Settlement Agreement") ARC provided funding to the City of Yerington to extend municipal water service to then-existing residences located within that part of the settlement class area that was also within the City's projected future service area.

Domestic well owners who connected to the City of Yerington's municipal water system could elect to either abandon their well or apply for a state permit to authorize withdrawals of groundwater for outdoor use only (landscape watering). Each property owner who received a connection to the City Water System executed and recorded an environmental covenant either prohibiting future domestic use of groundwater altogether or limiting it to outdoor purposes. Construction of the expanded water system began in the fall of 2014, and the construction of new mains and service connections was completed in June 2016.

The first phase of well abandonments and system testing was completed as of August 1, 2016. The water system is functional, and domestic wells for all participating property owners have been abandoned or disconnected from the residences within the expansion area. A relatively small number of domestic wells located within the area of mine-impacted groundwater were not disconnected or converted to outdoor use in 2016. ARC has been in communication with the owners of most of these wells, and disconnections for all but a few are scheduled to occur in 2017.

There are no irrigation wells or municipal drinking water wells located within the plume of mine-impacted groundwater that was delineated during the background assessment.

The plume of mine-impacted groundwater is generally stable based on evaluations of changes in the estimated volume of contaminated groundwater, sulfate and uranium masses, and chemical centers-of-mass through time. A more comprehensive plume stability evaluation (including a statistical evaluation of chemical concentration trends in individual monitor wells) will be provided in a separate report. Plume stability is the result of very slow groundwater velocities and attenuation by dilution. The dilution occurs primarily as the result of recharge on the agricultural fields (specifically on the fields of the Hunewill Ranch) and leakage from irrigation ditches (specifically the West Campbell Ditch), and dispersion within the groundwater plume. Consequently, the plume is not currently adversely affecting and is not expected to affect the use of groundwater by agricultural irrigation and municipal drinking water wells. In addition, the plume of mine-impacted groundwater does not discharge to surface water.

SECTION 1.0
INTRODUCTION

Atlantic Richfield Company (ARC) prepared this *Site-Wide Groundwater Operable Unit (OU-1) Remedial Investigation Report* (OU-1 RI Report) pursuant to Section 7.0 of the Scope of Work (SOW) attached to the Administrative Order for Remedial Investigation and Feasibility Study (RI/FS), CERCLA Docket No. 9-2007-0005 (2007 Order) for the Anaconda Copper Mine Site (Site). The 2007 Order (EPA 2007a) was issued to ARC by the U.S. Environmental Protection Agency - Region 9 (EPA) on January 12, 2007. Future work on the OU-1 RI/FS will proceed under oversight by the Nevada Division of Environmental Protection (NDEP) pursuant to the "Interim Administrative Settlement Agreement and Order on Consent for: (i) Remedial Design/ Remedial Action, (ii) Site-Wide Remedial Investigation/Feasibility Study, and (iii) Fluid Management" entered into with NDEP (the IAOC) and the attached Statement of Work for RI/FS.

The term "Site" refers to the area where copper mining activities historically occurred. The Site is located west and northwest of the City of Yerington (Figure 1-1). Figure 1-2 depicts the Study Area boundary for OU-1 and the boundaries for the seven other OUs at the Site that were identified in the 2007 Order. The eight OUs identified in the 2007 Order include:

- Site-Wide Groundwater (OU-1);
- Pit Lake (OU-2);
- Process Areas (OU-3);
- Evaporation Ponds and Sulfide Tailings (OU-4);
- Waste Rock Areas (OU-5);
- Oxide Tailings Areas (OU-6);
- Wabuska Drain (OU-7); and
- Arimetco Facilities (OU-8).

Since the 2007 Order (EPA 2007a), substantial Site characterization activities have resulted in a better understanding of the nature and extent of chemicals of interest (COIs) within the various Site OUs, and the past and/or ongoing impacts to OU-1. Consequently, the EPA approved a subdivision of OU-4 into OU-4a (Evaporation Ponds) and OU-4b (Sulfide Tailings), as well as the transfer of the southern portion of the Calcine Ditch from OU-3 to OU-4a.

The EPA-approved OU-4 subdivision and transfer of a portion of the Calcine Ditch to OU-4a was based on a recognition of: 1) the different types of mine-waste materials in the Evaporation Ponds and Sulfide Tailings; 2) the similarity of mine-waste materials in the Calcine Ditch and portions of the Evaporation Ponds; and 3) the differences in the presence and magnitude of COIs in groundwater underlying the Evaporation Ponds and Sulfide Tailings. This OU-1 RI Report retains the OU-based framework in the 2007 Order (updated to include the EPA-approved restructuring). However, ARC, EPA and NDEP recognize that significant closure efficiencies will likely result from integrating EPA-designated OUs into geographic-based closure management units.

The term "Study Area" refers to on-Site and off-Site areas in which OU-1 RI-related investigations have been conducted. The Study Area boundary is based on the OU-1 hydrogeologic conceptual site model (HCSM) that was described in the EPA-approved *Site-Wide Groundwater Operable Unit (OU-1) Remedial Investigation Work Plan - Revision 1* (Revised Groundwater RI Work Plan; Brown and Caldwell [BC] 2014a).

1.1 Purpose of Report

Consistent with the SOW attached to the 2007 Order (EPA 2007a) and EPA (1988) guidance, this OU-1 RI Report: 1) summarizes activities conducted to "characterize and monitor groundwater in the vicinity of the Site (study area to be determined), including on- and off-Site locations"; 2) describes the nature and extent of mine-related COIs in groundwater; and 3) integrates relevant aspects of other OUs that represent potential sources of chemical loading to groundwater or have the potential to influence groundwater flow conditions. Additionally, this OU-1 RI Report addresses the fifteen study elements specified in Section 7.0 of the SOW (EPA 2007a), which served as the principal bases for RI planning, data collection, and analysis.

Given the complexity of Site-Wide groundwater conditions, several phases of investigations have been approved by EPA and conducted by ARC since 2005. During this time period, ARC, EPA, and other stakeholders including the Yerington Piaute Tribe (YPT), NDEP, and Bureau of Land Management (BLM) have periodically held groundwater technical meetings to discuss field data collection activities, technical findings, and remaining data gaps relative to: 1) the 15 study elements specified in Section 7.0 of the SOW attached to the 2007 Order; and 2) the Data Quality Objectives (DQOs) established in the draft and final versions of the remedial investigation work plans for OU-1 (BC and Integral Consulting, Inc. 2007 and BC 2014a, respectively). Table 1-1 relates the 15 study elements specified in the 2007 SOW to the DQOs presented in the Revised Groundwater RI Work Plan (BC 2014a).

Table 1-1. Comparison of Study Elements Specified in the SOW to the 2007 Order to DQOs Presented in the Revised Groundwater RI Work Plan

DQO	DQO Title	SOW Study Element														
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	Discriminate Background and Mine-Impacted Groundwater		X									X			X	
2	Identify Potential Chemical Loading Sources to Groundwater		X									X		X		X
3	Determine Geochemical Mobilization/Attenuation Processes											X				
4	Characterize Chemical Distribution and Migration Pathways	X						X	X	X	X	X			X	X
5	Determine Aquifer Properties								X				X			
6	Determine Groundwater Flow and Chemical Transport Rates	X	X		X	X	X	X		X	X	X				
7	Assess Anthropogenic Influences on Groundwater and Surface Water/Groundwater Interactions	X	X	X			X									
8	Determine Pumpback Well System Efficiency	X														
9	Assess Human Health and Ecological Effects							X	X	X	X	X		X	X	

Numerous investigations and monitoring activities conducted by ARC and others provide substantial geologic, hydrogeologic, and water quality information relevant to OU-1. However, this OU-1 RI Report relies primarily on data obtained after 2005 to address the study elements specified in Section 7.0 of the SOW, characterize groundwater conditions, and refine the HCSM to support the OU-1 RI/FS. Data obtained after 2005 have been selected for these purposes because: 1) data collection was performed pursuant to EPA-approved quality assurance/quality control (QA/QC) planning documents and OU-1 specific work plans that were developed with input from other stakeholders including the YPT, NDEP, and BLM; 2) the spatial coverage and amount of data increased substantially after 2005; and 3) post-2005 sampling results better represent current conditions and potential risks at the Site, which is the proper focus of the RI and risk assessment.

The August 2014 dataset is emphasized in this OU-1 RI Report for the reasons previously cited and because a variety of data types were concurrently collected (e.g., groundwater level data, groundwater quality data, and hydrologic tracer data) and/or evaluated (e.g., geochemical speciation modeling to help asses COI transport). Consequently, the August 2014 dataset is particularly informative for characterizing spatial aspects of OU-1 groundwater conditions. Temporal aspects of OU-1 groundwater conditions are based on post-2005 data, which indicate that the August 2014 dataset is generally representative of post-2005 groundwater conditions.

Long-term monitoring of Site-wide groundwater conditions is conducted pursuant to the *Site-Wide Groundwater Monitoring Plan - Revision 2* (GMP; BC 2012a), which was prepared by ARC pursuant to Section 6.0 of the 2007 SOW. The development of the monitoring program and a description of the monitor well network are also provided in this OU-1 RI Report.

Potential human health risks will be addressed more comprehensively in a separate OU-1 Human Health Risk Assessment (HHRA) report. This OU-1 RI Report provides the basis for ARC to identify remedial action objectives (RAOs) and screen/evaluate remedial alternatives for OU-1, which will occur during the feasibility study (FS).

1.2 Site and Study Area Description

The Site and Study Area are located in the Mason Valley in Lyon County, Nevada. The Site boundary includes portions of Township 13 North, Range 25 East, Sections 4, 5, 8, 9, 16, 17, 20, and 21 (Mount Diablo Baseline and Meridian) on the Mason Valley and Yerington United States Geological Survey (USGS) 7.5 minute quadrangles. The Site covers approximately 3,017 acres (4.7 square miles) of land altered by copper mining and processing activities. Including the Site, the Study Area covers approximately 19,300 acres (30.2 square miles).

The Mason Valley Basin (Basin no. 108, as defined by the Nevada Division of Water Resources [NDWR]) is located within the larger Walker River Hydrographic Basin (no.9). Mason Valley covers about 510 square miles, and the valley floor occurs at an elevation between 4,300 and 4,700 feet above mean sea level (amsl). The principal agricultural activities in the valley include farming (hay, grain, and onions) and cattle ranching (Lopes and Allander 2009a, 2009b; Carroll et al. 2010). Irrigation water is provided by surface water diversions from the Walker River and from pumped groundwater. The Walker River flows northerly and northeasterly between the Site and the City of Yerington. The river is within a quarter-mile of the southern portion of the Site (Figure 1-1).

1.3 Groundwater Zone Designations

Groundwater zone designations based on elevation have been used in previous groundwater-related reports, as well as this OU-1 RI Report, to identify and group monitor wells with similar screen interval elevations in the alluvial aquifer, as follows:

- Shallow (S): screen intervals that straddle the water table, or are within 50 feet of the water table when a shallower well does not exist, typically >4,300 feet amsl
- Intermediate (I): 4,250 to 4,300 feet amsl
- Deep (D): <4,250 feet amsl; given the thickness of alluvium, the Deep zone is further subdivided as follows:
    - Deep 1 (D1): 4,200 to 4,250 feet amsl
    - Deep 2 (D2): 4,120 to 4,200 feet amsl
    - Deep 3 (D3): 4,000 to 4,120 feet amsl
    - Deep 4 (D4): 3,900 to 4,000 feet amsl
    - Deep 5 (D5): <3,900 feet amsl

Monitor wells with screen intervals in bedrock, regardless of elevation, are designated as bedrock ("B") wells. The groundwater zone designation is included as a suffix to the monitor well identification number (e.g., the "S" suffix in monitor well identification B/W-1S indicates that the screen for this well is positioned in the Shallow zone).

1.4 Report Organization

Consistent with EPA guidance (EPA 1988) and recommendations provided during groundwater technical meetings in 2015 and 2016, the content and organization of this OU-1 RI Report is presented in this section.

Section 2.0 summarizes the Site operation history. Section 3.0 details the investigations related to OU-1 and relevant Site-wide studies and evaluations. Section 4.0 describes the physical characteristics of the Study Area. Section 5.0 describes the background groundwater quality assessment. This assessment served as the basis for determining the extent of mine-impacted groundwater, identifying agriculturally-affected groundwater, and assessing the occurrence of naturally-occurring COIs in groundwater. Section 5.0 also discusses the primary sources of past and/or ongoing releases of mine-related COIs to groundwater. Section 6.0 describes the fate and transport of contaminants in Study Area groundwater. Section 7.0 summarizes the HCSM for OU-1. Section 8.0 discusses the risk evaluation process and status. Section 9.0 lists the references cited in this OU-1 RI Report.

Appendix A provides historical mining-related information including the *Final Historical Summary Report* (HSR; CH2M Hill 2010) and historic Anaconda water supply and use information. Appendix B provides the *Shallow Zone Data Summary Report - Revision 1* (BC 2010a), which refined the distributions of select COIs in Shallow zone groundwater north of the Site and helped guide subsequent monitor well installation efforts. Appendix C presents information on the groundwater monitor wells including lithologic logs, well construction information, and depth-specific (zonal) groundwater quality data obtained during borehole drilling and well installation.

Appendix D presents water level and groundwater quality information. Appendix E provides soil sampling data. Appendix F presents hydraulic conductivity information and analyses. Appendix G presents regional and local surface water data. Appendix H presents hydrologic tracer data and supplemental information. Appendix I presents the *Bedrock Groundwater Assessment Technical Memorandum* (BC 2015a). Appendix J provides various groundwater studies, evaluations, and reports that were conducted to fulfill certain study elements specified in Section 7.0 of the SOW attached to the 2007 Order (EPA 2007a) and have been previously submitted to the EPA. These include an evaluation of the effectiveness of the Pumpback Well System (PWS), a Pit Lake water balance, public information pertaining to agricultural water use, the groundwater flow model report, the *Geochemical Characterization Data Summary Report - Revision 2* (BC 2016a), Site-specific chemical distribution coefficients, and the *Background Groundwater Quality Assessment - Revision 3* (BC 2016b). Appendix K presents maps illustrating the distributions of select COIs (including pH, sulfate, dissolved uranium, alkalinity, nitrate, and dissolved arsenic) in groundwater. Appendix L presents maps illustrating groundwater temperatures.

SECTION 2.0
SITE HISTORY

The following summary of the operational history of the Site paraphrases and/or is derived from the HSR (CH2M Hill 2010), which is provided in Appendix A-1. Topics covered in detail in the HSR include: 1) Site chronology; 2) processing operations utilized by the various owners and operators; 3) historic mine Site water usage and quality information; 4) uses and releases of chemicals; and 5) current Site status since 2000 focusing on removal actions conducted by EPA.

The following discussion focuses on key historic mining practices, releases, and features relevant to the historic and/or current aspects of the HCSM for OU-1. This summary is not intended to comprehensively cover all the information provided in the HSR. Historic mining-related features are shown on Figure 1-2. Historic ore processing facilities located within the Process Areas (OU-3) are shown on Figure 2-1.

2.1 Mining and Processing Operations

Copper in the Yerington district was initially discovered in the late 1860s, with large-scale exploration of the porphyry copper system occurring in the early 1900s when the area was organized into a mining district by Nevada-Empire Copper Mining and Smelting Company. Mining and ore processing operations at the Site were conducted by various owners from 1953 to November 1999.

2.1.1 Anaconda Operations

The Anaconda Company (Anaconda) became involved in the Site when it entered into a lease agreement and acquired the claims in 1941. Anaconda purchased the property in 1951 and the mine began producing copper in 1953, producing approximately 1.7 billion pounds of copper during its operations. Anaconda divested itself of the Site on June 30, 1978. Anaconda mining operations generated approximately 360 million tons of ore, 15 million tons of overburden and waste rock (400 acres), 3,000 acres of tailings, and 1,377 acres of disposal ponds.

Mined materials included oxide ore, sulfide ore, low-grade dump-leach ore, low-grade sulfide ore, and alluvium and waste rock overburden. Several processes were required to extract copper from the ore, as discussed further below. Briefly, all oxide and sulfide ore were crushed prior to leaching or processing in the various plant facilities. Copper was extracted from oxide ore using a sulfuric acid leach solution. The vast majority of leaching was conducted in vat leach tanks. A leach dump was operated over a much shorter period (discussed below). Pregnant copper solutions from the tanks and dump were stored in large solution tanks. Copper extracted from the oxide ore was recovered from the acidic leach solutions in the precipitation plant by precipitating (i.e., cementing) the copper onto iron scraps. A concentration/flotation process was used to extract copper from the sulfide minerals.

Dump Oxide Ore Processing

Crushed oxide ore was bedded into vat leach tanks capable of holding 12,000 dry tons of ore and 800,000 gallons of sulfuric acid leach solution. Spent ore, known as oxide tailings or vat leach tailings (VLT), was excavated from the vat leach tanks and disposed in the Oxide Tailings. The vats typically operated on a 96-hour or 120-hour leaching cycle, with an additional 32- to 40-hour wash period, and 24 hours required to excavate and refill. The entire cycle required approximately 8 days. Thus, eight leach vats were installed and used to process ore.

Following the leaching process, the ore underwent three wash cycles. Acidic leach solutions were recirculated and pumped at a rate of 2,000 gallons per minute (gpm). Copper-enriched wash solutions were put into three of the four open solution storage tanks located between the vat leach tanks and precipitation plant. The three solution tanks used for storing pregnant copper solutions had a total storage capacity of 1.4 million gallons. The additional storage tank, referred to as the wash water sump, stored up to 845,000 gallons of wash water from the leaching circuit, which included slurry from the scrubber in the sulfuric acid plant. Copper was recovered from the leach solution in the precipitation plant, which consisted of the iron launders, solution sumps, an adjacent launder pump station, scrap iron storage, and trommel screens.

The iron launders consisted of 20 parallel launders that were filled with scrap iron used to precipitate (i.e., cement) copper from the sulfuric acid leach solution pumped out of the leach vats and temporarily stored in the solution tanks. The waste product from the precipitation plant was an iron-sulfate solution that was conveyed in unlined ditches (such as the Calcine Ditch) to lined and unlined evaporation ponds in the northern portion of the Site (as further discussed in Section 2.2). Pregnant copper solution from dump leaching activities (discussed below) was also sent to the precipitation plant, but was kept separate from the vat leach solutions. Historical information on flows and chemical concentrations of solutions in various stages of the cementation circuit are provided in Table 2-1. Following cementation, the copper cement product was washed and dried to reduce moisture content prior to shipment off-Site for final smelting (Skillings 1972).

Table 2-1. Average Assay Values of Solutions at Various Stages in the Cementation Circuit

	Flow (gpm)	Cu (g/L)	H_2SO_4 (g/L)	Fe (g/L)	Fe^{3+} (g/L)
Primary and Scavenger Launders					
New Solution	700	20.0	5.8	7.2	5.4
Recirculated Solution	900	3.5	2.4	23.6	0.5 [a]
Total Feed (new solution plus recirculated solution)	1,600	10.7	3.8	16.4	2.6
Discharge	1,600	3.8	2.5	23.2	Trace
Secondary Launders					
Recirculated Solution (feed)	900	3.5	2.4	23.6	0.5
Discharge	900	1.0	2.1	26.4	[b]
Stripping/Settling Launders					
Feed	700	1.0	2.1	26.4	- -
Discharge	700	0.5	2.0	28.1	- -

Notes:
[a] The recirculated solution in the primary launders is the same strength as the recirculated solution in the secondary launders.
[b] The discharge solution in the secondary launders is the same strength as the feed solution to the stripping bank (U.S. Bureau of Mines 1958).
Cu = copper; H_2SO_4 = sulfuric acid; Fe = iron; Fe^{3+} = ferric iron; gpm = gallons per minute, g/L = grams per liter

Dump Leaching

In February 1965, Anaconda began dump leaching low-grade oxide ore in the W-3 Waste Rock Area. Copper-enriched solutions were stored in the Dump Leach Surge Pond (Figure 2-1) prior to conveyance to the iron launders for copper recovery. Copper extraction by heap leaching was in in its infancy at the time and recovery from the W-3 Waste Rock Area was inefficient because there were large quantities of ore that never came into contact with the acid-bearing leach solutions. Due to poor copper recovery, Anaconda ceased dump leaching in 1968.

Sulfide Ore Processing

To process sulfide ore, a froth flotation system was constructed and began operating on September 25, 1961. Flotation separation was accomplished by mixing very finely ground ore (pulp) with water and a chemical "collector" (typically xanthates and aerofloats) to make sulfide minerals hydrophobic, and then sparging air and a surfactant chemical "frother" (typically pine oil) through the mixture to create froth. The collector attaches to the sulfide mineral making it hydrophobic and susceptible to attachment to the stabilized air bubbles in the froth mixture, which was skimmed off as copper concentrate. The concentrate was further beneficiated in a scavenger flotation circuit, dewatered and dried, and subsequently hauled by truck to the Wabuska railroad spur and transported to the Washoe Smelter in Anaconda, Montana (Skillings 1972). Excess pulp after the flotation separation was disposed in the Sulfide Tailings area as a slurry mixture. Operation of the concentrator required approximately 3,000 gpm of water.

Acid Plant

Sulfuric acid was produced at the Site in the fluosolids and acid plant from 1952 to 1978. Raw sulfur ore (predominantly native sulfur and sulfide minerals) was hauled by truck to the Site from the Leviathan Mine located in Alpine County, California until 1962. The fluosolids system roasted the sulfur ore to generate sulfur dioxide (SO_2) gas, which was converted to sulfuric acid (H_2SO_4) in the contact acid plant. In 1962, Anaconda ceased mining sulfur ore from the Leviathan Mine. Between 1962 and 1978, previously stockpiled sulfur ore was blended with liquid sulfur, which was purchased from several suppliers and hauled to the Site where it was used as feed to the Acid Plant to generate sulfuric acid.

The final product was a 93 percent (%) sulfuric acid solution that was used in the vat leach tanks and dump leach of oxide ores. Byproducts such as selenium, were generated during production of sulfuric acid (CH2M Hill 2010). Operation of the sulfuric acid plant was discontinued in 1978 and the plant was dismantled by Arimetco, Inc. (Arimetco) in 1992. For its leaching operations, Arimetco purchased liquid sulfuric acid from off-Site vendors and stored it in tanks at the Site. The Acid Plant and surrounding area has subsequently been buried under the Arimetco Phase III South Heap Leach Pad (HLP).

2.1.2 Post-Anaconda Operations

Subsequent operators and lessees used some of the buildings within the Process Areas for operational support, storage, and various light industrial activities; however, the Anaconda-constructed processing components remained inactive after 1978.

In 1982, Copper Tek Corp. operated the mine under the ownership of Don Tibbals, and leased the Site for reprocessing tailings and low-grade copper ore using heap leaching and solvent extraction/electrowinning (SX/EW) processes in the area to the south of the Process Areas. In 1988, Don Tibbals sold his interests (except for the Weed Heights community and certain other parcels) to Arimetco. Prior to the sale, Arimetco (operating under the name Arizona Metals Company) had leased a large portion of the mine Site from Don Tibbals. By 1989, Arimetco had also acquired 90% of Copper Tek.

2.1.3 Arimetco Operations

From 1989 to November 1999, Arimetco conducted the following SX/EW operations on the Site:

- Phase I/II HLP: operated from 1990 to 1996, plus five months in 1997;
- Phase III South HLP: operated from August 1992 to early 1997, plus a few months in 1998;
- Phase III 4X HLP: operated from August 1995 to 1999;
- Phase IV Slot HLP: operated from March 1996 to November 1998; and
- Phase IV VLT HLP: operated from August 1998 to November 1998.

The HLPs (Figure 1-2) were constructed over high-density polyethylene (HDPE) liners with leak detection systems. The HLPs were leached with a sulfuric acid solution and the acidic, copper-laden draindown fluids were collected in HDPE-lined perimeter ditches, routed to HDPE-lined collection ponds, and conveyed to the SX/EW Plant. The copper-laden acid solution was then stripped of copper in a solvent extraction circuit using a mixture of kerosene and an organic hydroxyamine-based chelating agent (tradename ACORGA) in three process vats (total of approximately 200,000 gallons).

In the SX circuit, the copper in the dump leach liquor was concentrated by the organic in exchange for hydrogen ions producing a strong acid that became the electrolyte for the EW circuit. In the EW circuit, the copper was electroplated to stainless-steel sheets to produce 99.999% fine copper and in the process, additional sulfuric acid was generated. It was this strong acid in the EW circuit that was used to exchange copper from the loaded organic chelating agent.

Arimetco recirculated the acid solution from the EW vats back into the HLPs, which currently continue to drain fluids to the present. The electrolyte circulated between the EW plant and the tail end of the SX plant (called raffinate). The kerosene and organic reagent were also recirculated within the SX/EW circuit, being loaded and stripped repeatedly.

In January 2000, Arimetco, on the verge of bankruptcy and unable to make payroll, abandoned operations at the Site. From 2000 to 2004, NDEP managed HLP drain-down fluids by re-circulation and evaporation. In 2005, ARC was required by EPA to assume responsibility for fluid management operations at the Site. Since 2006, EPA has conducted various RI/FS and closure-related activities associated with the Arimetco Facilities (OU-8).

Inactive Arimetco HLPs that continue to produce drain-down fluids include the Phase I/II HLP, two Phase III HLPs, the Phase IV Slot HLP, and the Phase IV VLT HLP (BC 2014b). HLP drain-down fluids are currently stored and conveyed in a network of ponds, ditches, and 25,000 feet of pipe, collectively referred to as the fluid management system (FMS). The HLPs and associated FMS components are briefly described below. Additional FMS details are provided in annual operation and maintenance (O&M) reports for the FMS (e.g., BC 2014b).

Phase I/II Heap Leach Pads

The Phase I/II HLP covers an area of approximately 14 acres (Phase II was extended to the west and north of Phase I). A solution ditch with eleven leak detection points was constructed around the HLP. A variable two- to ten-foot-thick layer of VLT was placed on a single 40-mil (0.04-inch-thick) HDPE liner. The solution ditch that surrounds the Phase I/II HLPs drained to the Phase I Pond.

Phase III Heap Leach Pads

The 46-acre Phase III South HLP and the 50-acre Phase III 4X HLP were constructed by Arimetco to leach low-grade oxide ores. A single 40-mil HDPE liner was installed by Arimetco to recover drain-down solution, and the drainage ditch was designed with a leak detection system over a second, 40-mil HDPE liner. The solution ditches surrounding the Phase III South HLP and the Phase III 4X HLP drained to the Phase III Bathtub Pond and to the Mega Pond, respectively.

Phase IV Slot Heap Leach Pad

The approximate 86-acre Phase IV Slot HLP was constructed by Arimetco on a pad excavated into the W-3 waste rock dump and an asphalt-lined area, and was expanded northward between 1993 and 1996 on a 40-mil HDPE liner over a secondary liner of compacted clay. This HLP is surrounded by a berm and double HDPE-lined collection ditch with leak detection between the membranes and seven leak detection monitoring points. Drain-down solutions flow to one of two pregnant leach solution (PLS) ponds.

Until late 2003, drain-down solutions were pumped by NDEP from the PLS ponds to the surface of the HLP for evaporation. In 2006, EPA relined the northern Phase IV Slot PLS Pond, and solutions from this pond were routinely conveyed to the FMS Evaporation Pond (also known as the EPA 4-Acre Pond) constructed by EPA in 2007.

Phase IV VLT Heap Leach Pad

The 54-acre Phase IV VLT HLP was constructed by Arimetco on the southern portion of the former finger evaporation ponds, and on native alluvial soils, north of the Oxide Tailings OU, and consists of oxide tailings, and run-of-mine and crushed ore from the MacArthur Mine. The Phase IV VLT HLP was constructed on a 40-mil HDPE liner overlying a secondary liner of compacted clay. The solution drainage ditch includes a leak detection system over a 40-mil HDPE liner designed with five leak detection points, and drains to the northeast corner of the HLP to a single PLS pond (5.04 million-gallon capacity).

Drain-down solutions from the Phase IV VLT HLP flow by gravity to the VLT Pond and, as needed to improve evaporation efficiency of the FMS, are pumped to one of two new FMS Evaporation Ponds (B and C) described below. EPA completed a VLT pond liner replacement project in October 2012 (BC 2014b).

2.2 Evaporation Ponds

From the Process Areas, spent process solutions resulting from the beneficiation of copper oxide and sulfide ores were conveyed in unlined trenches to the lined and unlined evaporation ponds, and ponds in the northern portion of the Site. The evaporation ponds in the northern portion of the Site are identified on Figure 1-2 as the Unlined Evaporation Pond (UEP), the Lined Evaporation Pond (LEP), and the Finger Ponds. The Sulfide Tailings were also used to dispose spent oxide ore process solutions prior to the mining of sulfide ores. A brief description of these ponds follows:

- <u>UEP</u>: consists of a large northern section (98 acres) and a much smaller southern section (4.1 acres) constructed on alluvial soils without a liner surrounded by berms constructed of VLT. The volume of pond sediments contained in the UEP is approximately 270,230 cubic yards based on average thicknesses of approximately 1.5 and five feet in the northern and southern sections, respectively.
- <u>LEP</u>: consists of three sections (North, Middle and South), which were lined with a relatively thin (0.5 to one-inch-thick) liner consisting of a mixture of asphalt tar and crushed gravel. The asphalt liner was placed over one to 2.5 feet of VLT materials. The LEP has a total combined area of approximately 101 acres. The thickness of the pond sediments averages three to six inches, with a maximum measured thickness of approximately 12 inches within the central, topographically lower portion of the LEP. The volume of pond sediments contained in the LEP is approximately 65,800 cubic yards.
- <u>Finger Ponds</u>: consist of four narrow “Finger Ponds” and one larger “Thumb Pond”. The four Finger Ponds (17.8 acres) were lined similar to the LEP without the VLT sub-base. The estimated volume of sediments within the Finger Ponds is 5,838 cubic yards based on an average thickness of four inches. The unlined Thumb Pond has elevated embankments along its north and east margins. The exposed portion of the Thumb Pond (i.e., not covered by the Arimetco Phase IV VLT HLP) covers about 69 acres and was capped in 2010 with VLT materials. The volume of pond sediments contained within the Thumb Pond is 95,000 cubic yards based on an average thickness of 3.5 feet.

In 1955, the flow rate to the evaporation ponds averaged approximately 2,000,000 gallons per day or 1,385 gpm and water quality characteristics of the fluid showed a free acid concentration of 1.0 g/L, total soluble salts concentration of 171 g/L, and total iron concentration of 37.5 g/L (Nesbitt 1955; Dalton 1998).

Infiltration of process solutions at these locations due to increased hydraulic heads associated with impounded fluids, likely raised groundwater elevations and created mounding effects that influenced groundwater gradients, flow directions and velocities, and groundwater quality. Due to the net evaporative character of the Site, significantly less flux (if any) of residual process-related chemicals to groundwater occurs at the Site at present relative to historic periods when the mine facilities were operational. The term "evaporation ponds" used in the following sections refers to the LEP and UEP.

2.3 Historical Mine Site Groundwater Pumping, Distribution and Use

Details of Anaconda's historical groundwater pumping, distribution, and water management at the Site are provided in Appendix A-2 and summarized below.

Mine Site Water

Gill (1951) conducted a groundwater investigation to support open pit mining, and reported that the groundwater table around the proposed open pit was approximately 4,350 to 4,380 feet amsl, with variable water levels a result of bedrock compartmentalization of groundwater. Gill (1951) also reported that most groundwater in the proposed open pit was recharged by the Walker River. Dewatering of the pit in advance of mining operations in the early 1950s resulted in a depressed water table.

Groundwater produced from the pit area wells and other supply wells was primarily used in the beneficiation of copper oxide and sulfide ores in the Process Areas. Pit dewatering ended in 1978. The resulting Pit Lake functions as a hydraulic sink that captures alluvial and bedrock groundwater, as discussed in Section 3.3.2.

Historical Groundwater Pumping and Water Management

The known locations of historic wells used for mining-related activities are shown on Figure 2-2. These wells include those that have been abandoned per the State of Nevada Administrative Codes (NAC) 534.420, 534.4365 or 534.4371 and others that have not been abandoned but are not currently in active use.

Groundwater pumped by Anaconda was used for four general purposes: 1) to depress the water level in the open pit to achieve safe working conditions for mining operations; 2) copper ore beneficiation activities in the Process Areas; 3) residential use at Weed Heights, commonly referred to as the “Townsite” in archived documents (Anaconda 1953, 1955, and 1957); and 4) ancillary operations at the Site (e.g., fire protection, dust control, drilling, blasting, and supply to shops).

Groundwater use was less during the period from 1952 through 1963 when only oxide ores were leached than in the period from 1963 through 1978 when the copper sulfide ore milling circuit was added to the existing copper oxide ore leaching operations, which resulted in an increased demand for groundwater. References in archived documents to the “Plant” generally refer to oxide leaching facilities prior to 1963, and combined copper oxide and copper sulfide ore beneficiation operations after 1963. Groundwater supplies were obtained from four geographic areas: open pit area wells; evaporation area wells; well WW-10 in the Process Areas; and off-Site area wells. Excess pumped water, from pit dewatering activities, was discharged to the Walker River.

Discharge of water to the Walker River peaked in 1953 at 2,373 acre-feet per year, which is equivalent to approximately 1,471 gpm, and generally declined through 1963. At this point, pumped water to the combined Townsite and Plant rose steadily until 1974 at which time it reached 11,388 acre-feet per year (7,058 gpm). There was a general decline in total water pumped during the last four years of Anaconda operations. The annual average pumping rate at the Site ranged from 1,658 gpm in 1978 (the final year of operations) to 7,119 gpm in 1974 (the peak year of water production).

Although the monthly water reports did not specify on-Site water use, some details of water distribution to operational areas are available for 1964 and the first half of 1978 (Table 2-2). In 1964, the Plant received 2,055 acre-feet (45% of total) and the sulfide milling circuit (Concentrator) received 1,511 acre-feet (33% of total).

Table 2-2. Water Distributed to Operational Areas During 1964 and 1978

Operational Area or Use	1964 (acre-feet)	1964 Percent of Total	Jan-Jun 1978 (acre-feet)	Jan-Jun 1978 % of Total
Townsite	455	9.9%	58	4.3%
Roads	51	1.1%	31	2.3%
Leach Vats	2,055	44.7%	271	20.2%
Precipitation Plant	---	---	15	1.1%
Sulfide Concentrator	1,511	32.9%	---	---
Acid Plant	481	10.5%	538	40.1%
Water Discharged to Walker River	46	1.0%	0	---
W-3 Waste Rock Dump	---	---	259	19.3%
Dust System	---	---	169	12.6%
Total	4,600	100%	1,340	100%

Open pit area wells were installed during the period 1952-1954 (WW-1 through WW-7) and in 1959 (WW-36) to dewater the pit, supply water to the Townsite, and supply water for copper oxide ore beneficiation. During July 1955, the combined flow from six of the open pit area wells was estimated to be 2,454 gpm, and the total demand was 2,553 gpm. The use of recycled process water during this period made up for the approximate 100 gpm difference. In 1966, combined demand at the Plant and Townsite was 2,600 gpm.

Evaporation area wells were installed during the period 1959-1961 (WW-8, WW-9 and WW-11) and in 1965 (WW-12C) to provide the required make-up water (i.e., approximately 1,000 gpm) for the Sulfide Concentrator, which began operation in 1963. Based on 1964 monthly water reports, evaporation area wells had a combined pumping rate that ranged from 442 to 1,390 gpm with an annual average rate of 690 gpm. Well WW-10 was installed in the Process Areas in 1960 to provide additional water for the copper oxide and copper sulfide ore beneficiation operations.

Per the well log on file with the NDWR, the well was drilled to a depth of 610 feet, and penetrated 200 feet of alluvial materials before reaching bedrock. At that time, the depth to groundwater was 100 feet below ground surface (bgs). The well casing was perforated from 105 to 505 feet bgs, resulting in about 95 feet of alluvial materials and 305 feet of bedrock that could yield groundwater. When tested for two hours at a rate of 595 gpm, WW-10 exhibited a drawdown of 81 feet (close to the alluvium-bedrock contact).

Historical pumping records for WW-10 are limited. Table 2-3 summarizes 1964 monthly water reports for well WW-10. The monthly pumping rate was calculated by dividing the monthly volume by the number of days in each month and the number of minutes in each day. The pumping rate ranged from 102 gpm in January 1964 to 254 gpm in October 1964, with an average annual rate of approximately 169 gpm for the 10 months with pumping data.

Table 2-3. 1964 Monthly Pumping Volumes and Rates for Mine-Water Supply Well WW-10

Month, 1964	Volume Pumped (cu ft)	Volume Pumped (gal)	Average Pumping Rate (gpm)
January	606,470	4,537,000	102
February	NA	NA	NA
March	NA	NA	NA
April	1,135,410	8,494,000	190
May	1,230,851	9,208,000	206
June	1,329,595	9,946,700	223
July	1,134,621	8,488,100	190
August	1,362,839	10,195,400	228
September	1,227,109	9,180,000	206
October	1,514,771	11,332,000	254
November	1,220,291	9,129,000	205
December	1,139,420	8,524,000	191
Annual Values	11,901,377	89,034,200	169

NA = not available; cu ft = cubic feet; gpm = gallons per minute; gal = gallons

Groundwater quality samples were obtained from WW-10 from August 1991 to June 2006. From August 1991 through 1994, at least three samples were collected during each year. From 1995 through June 2006, samples were collected quarterly. Not all parameters were monitored in each sampling event. Results for sulfate, uranium and arsenic are discussed below.

Concentrations of sulfate in the 49 samples collected from August 1991 to June 2006 ranged from 457 to 2,485 milligrams per liter (mg/L). Concentrations of uranium in the 10 samples collected from September 2003 to June 2006 ranged from 190 to 310 micrograms per liter (µg/L). From August 1991 to June 2006, 95% (i.e. 35 of the 37) reported arsenic results were less than or approximately equal to the laboratory analytical reporting limits. Laboratory reporting limits for arsenic were commonly higher (i.e., 25 µg/L) during the early part of the monitoring history and lower (as low as 4 µg/L) during the latter part of the monitoring history. In September and October 1991, arsenic concentrations were reportedly 1,040 and 3,475 µg/L, respectively. The arsenic results for these two sampling events are inconsistent with and three orders of magnitude greater than the results for the other 35 sampling events.

2.4 Pumpback Well System

The PWS and associated monitor wells were constructed under an Administrative Order on Consent issued by NDEP on October 1, 1985. ARC operated the PWS located along the northern margin of the Site to collect shallow groundwater beginning in March 1986 (Piedmont 2001). The initial PWS consisted of five extraction wells (PW-1 through PW-5; see Figure 3-3) and a clay-lined 23-acre evaporation pond for containment of extracted groundwater.

In 1998, six additional extraction wells (PW-6 through PW-11; see Figure 3-3) were installed and operated as part of the PWS. Other improvements to the PWS included partitioning the 23-acre evaporation pond into three cells and installing an HDPE liner on top of the clay liners in the middle and south cells to protect the clay liners from desiccation during the summer dry season. No HDPE liner was placed on the north cell.

The pumpback wells are approximately 40 to 60 feet deep and are spaced at intervals ranging from approximately 380 feet (PW-2 to PW-3) to 1,400 feet (PW-5 to PW-6). Prior to March 25, 2009, the PWS operated continuously (i.e., 24 hours per day, 7 days per week), with individual wells temporarily taken off-line for maintenance and repairs of pumps and related equipment. For example, in 2006, individual well production rates ranged from 0.5 to 16.7 gpm with a total combined pumping rate of 56.4 gpm. Approximately 29.7 million gallons (91.1 acre-feet) of groundwater were pumped from the Shallow zone in 2006 (Norwest Applied Hydrology 2007).

EPA approved the shutdown of the PWS on March 25, 2009 to allow for a characterization of groundwater conditions at the northern Site margin. Subsequently, the pumpback wells were used as part of an aquifer test to characterize hydraulic properties of the Shallow zone (ARC 2010). The test data were used to: 1) delineate the hydraulic capture zones of the PWS; and 2) assess the historical effectiveness of the PWS in limiting the off-Site migration of Shallow groundwater. The PWS evaluation is discussed in Section 3.3.1. Since completion of hydraulic testing, the PWS has been shut down and wells PW-1 to PW-11 have been monitored pursuant to the Groundwater Monitoring Plan (GMP) (BC 2012a).

2.5 Wabuska Drain

The Wabuska Drain is a 13.8-mile long unlined ditch that extends from the Site to the Walker River. The grade of the Wabuska Drain between the Site and the southern margin of the YPT Reservation is approximately 0.15% over 4.1 miles. The grade increases to about 0.16% along the 1.1-mile length within the YPT Reservation. From the northern margin of the YPT Reservation to its intersection with the Walker River, the average grade is approximately 0.04% (BC 2015b). Adjacent surrounding agricultural fields slope gently toward the Wabuska Drain, or connect to the drain through lateral ditches that feed into the drain by gravity flow. The drain was constructed in the late 1930s, when the regional groundwater table was higher, to intercept shallow groundwater to stabilize areas north of the Site adjacent to the tracks of the former Nevada Copper Belt Railroad and several farms. The Wabuska Drain alignment near the Site has changed over time (BC 2015b; CH2M Hill 2010), as shown on Figure 2-3. Portions of these former alignments are now buried beneath the Evaporation Ponds and the Hunewill Ranch agricultural fields.

Currently the drain functions as one of many irrigation return-flow ditches in the northern Mason Valley. These drains collect irrigation tail water and run-off from agricultural fields, and convey water to downgradient agricultural areas for further irrigation uses and/or discharge to the Walker River (CH2M Hill 2010).

Historically, the Wabuska Drain alignments near the Site intercepted shallow groundwater (CH2M Hill 2010). However, the various drain alignments near the Site no longer intercept shallow groundwater due to basin-wide groundwater level declines (Section 4.9). In the northern part of the Wabuska Drain, inputs also include intercepted shallow groundwater and deeper water associated with alluvial groundwater discharge and geothermal springs that coincide with a series of northwest trending faults referred to as the Wabuska lineament (Stewart 1988). Other potential past and/or current inputs include discharges from, or groundwater influenced by, the Thompson smelter and various geothermal power production activities.

Details regarding the Wabuska Drain are provided in the HSR (CH2M Hill 2010; Appendix A-1). Results of the ongoing RI for the Wabuska Drain will be reported separately. Available data indicate that concentrations of mine-related chemicals decrease with distance from the Site and depth in the soil profile (EPA 2007a, BC 2015b).

SECTION 3.0
GROUNDWATER INVESTIGATIONS AND RELATED STUDIES

Numerous investigations and monitoring activities conducted prior to 2005 have provided substantial geologic, hydrogeologic, and water quality information pertaining to OU-1. These pre-2005 activities were primarily associated with a limited number of monitor wells (having screens positioned across the water table) located around the northern Site margin. Sampling methods and the quality of laboratory analytical results prior to 2005 were not well documented.

Pre-2005 investigations and reports for the Site and surrounding area are summarized in Section 3.1. Post-2005 investigations and reports performed and/or prepared by ARC are summarized in Section 3.2. Pre-2005 data are used to address historical aspects of the HCSM because historical conditions (e.g., groundwater elevations and flow directions) were different from current conditions due to mine operations, agricultural activities, groundwater and surface water usage, and weather conditions (BC 2014a). Historical aspects of the HCSM are generally more qualitative relative to aspects of the HCSM developed using data collected after 2005 because the historical data are typically limited (especially with respect to spatial coverage) and data quality is often not well documented.

Since 2005, numerous investigations and monitoring activities have been conducted by ARC with EPA and stakeholder involvement, and the sampling methods and quality of the laboratory analytical results since 2005 have been well documented. A draft Quality Assurance Project Plan (QAPP) that included standard operating procedures (SOPs) for sampling and field data collection methods was prepared in 2003 to establish and implement strict QA/QC procedures and, subsequently, was periodically revised to result in the current *Quality Assurance Project Plan - Revision 5* (Environmental Standards, Inc. [ESI] and BC 2009). Other QA planning documents that were prepared pursuant to the 2007 Order included the: 1) *Data Management Plan for the Yerington Mine Site* (BC 2007a); 2) GMP (BC 2012a); and 3) EPA-approved work plans specific to OU-1.

3.1 Pre-2005 Investigations

Investigations and reports relevant to the OU-1 Study Area that were conducted prior to 2005 are provided below, generally listed in chronological order:

- Gill, D.K., 1951. Groundwater at the Yerington Mine, Lyon County, Nevada, a consultant report prepared for The Anaconda Company that describes the results of aquifer testing, and provides projections of groundwater inflows and dewatering rates for the open pit.
- Huxel, C.J., Jr. and E.E. Harris, 1969. Water Resources and Development in Mason Valley, Lyon and Mineral Counties, Nevada, 1948-1965, NDWR Bulletin No. 38 prepared in cooperation with the USGS. This is a comprehensive hydrologic study of the Mason Valley area including water budgets and effects of agriculture on surface water and groundwater quality and quantity.
- Seitz, H., A.S. Van Denburgh, and R.J. La Camera, 1982. Ground Water Quality Downgradient from Copper Ore Milling Wastes at Weed Heights, Lyon County, Nevada, USGS Open File Report 80-1217. This study presents hydrologic and geochemical data on the effects of mining on groundwater quality from several monitor wells, most of which are no longer operational.
- Applied Hydrology Associates (AHA), 1983. Evaluation of Water Quality and Solids Leaching Data, a consultant report prepared for Anaconda Minerals Company. This report includes surface water and solids leaching data in addition to groundwater sampling data that are compared to the data reported by Seitz et al. (1982).
- Anaconda Minerals Company, 1984. Water Quality Investigation and Mitigation Plan, Yerington Mine Site, Yerington, Nevada, a report prepared for NDEP that summarized additional field data and groundwater conditions north of the Site.
- Proffett, J.M., Jr., and J.H. Dilles, 1984. Geologic Map of the Yerington District, Nevada, Nevada Bureau of Mines and Geology, Map 77.
- Nork, W., 1989. MacArthur Project Hydrogeologic Investigation, Lyon County, Nevada, a consultant report prepared for MacArthur Mining and Processing Co. that describes the general hydrogeologic conditions associated with a proposed project to develop an open pit mine located to the northwest of the Site.
- Dalton, D., 1998. *Arimetco Yerington Mine and Process Facility Site Assessment of Groundwater Quality*, a consultant report prepared for Arimetco for submittal to NDEP in response to NDEP's Finding of Alleged Violation and Order of February 1997.
- Lewis, B., 2000. *Geophysical Survey Results of the Yerington Mine, Mason Valley, Nevada*, a BLM report on electro-magnetic and resistivity surveys north of the Site.
- Superfund Technical Assessment and Response Team (START), 2000 and 2001. *Expanded Site Inspection: Yerington Mine* and *Anaconda, Yerington Mine Site Emergency Response Assessment Final Report,* reports prepared for the EPA that describe Site conditions including groundwater quality.

- Piedmont Engineering, Inc., 2001. *Yerington Shallow Aquifer Data Evaluation Report*, consultant prepared for ARC. Interpretations of data presented in this report related to the nature and extent of mine-impacted groundwater.
- AHA and Norwest Applied Hydrology, 2000 through 2007. *Annual Monitoring and Operation Summary: Pumpback Well System, Yerington Nevada*, annual consultant reports prepared for ARC. These reports provide groundwater elevation and water quality data for the pumpback system and associated monitor wells. The reports also include pumping rates and time-concentration plots for select chemicals.
- Brown and Caldwell, 2002. *Installation of Two Monitor Wells at the Yerington Mine Site, Lyon County, Nevada.* This letter report described the drilling and well construction activities of two monitor wells, which was an interim action required by NDEP, EPA, and BLM.

3.2 Post-2005 Investigations

A generalized chronology of the phased, groundwater-related field investigations conducted since 2005 is provided in Figure 3-1. The following subsections describe the post-2005 investigations and related evaluations by media. Groundwater characterization activities largely involved monitor well installation. Monitor wells installation procedures are described in Section 3.2.1. After installation, initial sampling and testing for OU-1 characterization purposes, these wells were subsequently incorporated into the Site-Wide Groundwater Monitoring Program, which is described in Section 3.2.3.

3.2.1 Monitor Well Installations

Recognizing that groundwater characterization activities would largely involve monitor well installation, ARC and EPA adopted the following sequential approach to field data collection to maximize usable data and optimize the design of a monitor well network intended to serve the data needs for both OU-1 RI characterization and long-term Site-Wide groundwater monitoring.

- Borehole drilling using a roto-sonic core drilling rig and lithologic logging of continuous cores to identify coarse-grained or potentially transmissive intervals where chemicals could potentially migrate.
- Depth-specific (zonal) groundwater sample collection in the alluvial aquifer at nominal 20-foot intervals from the top of the water table to the target depth of each borehole using low-flow, minimal drawdown purging and sampling procedures approved by EPA.

- Collection of field measurements from zonal samples including pH, specific conductivity, temperature, dissolved oxygen (DO), oxidation-reduction potential (ORP), sulfate, alkalinity, and total and ferrous iron, using routinely-calibrated field meters and accuracy-checked water quality field test kits.
- Laboratory analyses of zonal samples for total and dissolved uranium, total and dissolved arsenic, total organic carbon (TOC), and uranium isotopes (^{234}U, ^{235}U, and ^{238}U).
- Based on the zonal groundwater sample results, construction of new monitor wells in various groundwater zones using methods and materials specified in EPA-approved SOPs and work plans, with EPA approval of well screen lengths and positions.
- Surveying of well location coordinates and reference point elevations, followed by measurement of groundwater elevations in all new and existing monitor wells.
- Hydraulic (slug) testing of monitor wells and analysis of hydraulic test data.
- Deployment of pressure transducers and data loggers in select monitor wells with EPA approval to collect groundwater elevation data at four-hour intervals and assess temporal water level fluctuations.
- Collection of hydrologic tracers from monitor wells.
- Incorporation of the new monitor wells into the GMP (BC 2012a), discussed below in Section 3.2.3.

In total, the groundwater RI characterization activities described above resulted in drilling 133 boreholes, logging approximately 33,000 linear feet of core, collecting and analyzing 624 zonal groundwater samples, installing 299 new monitor wells, and hydraulic (slug) testing 296 wells. Appendix C provides monitor well information including: 1) borehole lithologic information and well construction diagrams; 2) well construction and location information for the active monitor wells; 3) construction information for abandoned and inactive wells not used for routine groundwater monitoring; and 4) zonal groundwater sample results.

The various investigations involving monitor well installations are integrated into the discussion of the Site-Wide groundwater monitoring program in the following section. Appendix D provides OU-1/Site-Wide groundwater monitoring information including water level and chemical data, water-level hydrographs, charts illustrating temporal changes in vertical gradients at monitor well clusters, and charts illustrating temporal changes in chemical concentrations at monitor wells.

3.2.2 Shallow Zone Groundwater Investigation

The 2009 Shallow zone investigation is detailed in the *Shallow Zone Data Summary Report - Revision 1* (BC 2010a; Appendix B) and summarized below. The Shallow zone investigation was designed to improve the understanding of hydrogeologic and geochemical conditions in the Shallow zone of the alluvial aquifer to the north of the Site by refining the distributions of sulfate, uranium, uranium isotopes, dissolved metals, TOC and alkalinity in Shallow zone groundwater. This information was used to evaluate potential sources of chemicals in groundwater in this portion of the Study Area and identify portions of the Intermediate or Deep zones in the alluvial aquifer that would warrant the installation of monitor wells.

Shallow zone characterization activities during 2009 included:

- Direct push technology (DPT) with Geoprobe® equipment was used to obtain continuous, high-resolution electrical conductivity (EC) measurements of subsurface materials at 93 locations. EC profiling was initially conducted at four locations (OU1-DPT-18, OU1-DPT-40, OU1-DPT-16, and OU1-DPT-24) where lithologic logging and zonal sampling had been previously conducted during borehole drilling and well installation at the B/W-2, B/W-3, B/W-18, and USGS-13S/W32DC-D well clusters, respectively, and one location (OU1-DPT-13) where geophysical logging had been conducted in 1983 (W5AB-2). This comparison was intended to help correlate EC data with clays and/or elevated solute concentrations in groundwater. In addition, EC data were also used to make decisions regarding the number and depths of sampling intervals at each individual DPT location.
- Field parameters were measured in groundwater samples collected from the sampled intervals within the Shallow zone including pH, specific conductivity, temperature, sulfate and total alkalinity (alkalinity) using routinely-calibrated field meters and accuracy-checked water quality field test kits.
- DPT equipment was used to collect groundwater samples at each location from as many as three intervals within the Shallow zone, and samples were submitted to the analytical laboratory for chemical analyses including total and dissolved uranium, TOC, 28 metals, uranium isotopes, and sulfur and oxygen isotopes in dissolved sulfate at EPA-selected locations.
- DPT locations were surveyed by a registered Nevada surveyor.
- Upon completion of EC profiling and/or groundwater sample collection, all boreholes were abandoned in compliance with Nevada regulatory requirements.

In 2010, DPT equipment and identical sample collection methods were used at 10 additional locations to obtain groundwater samples for laboratory analysis (BC 2013a). EC profiling was not conducted during the 2010 investigation. Both the 2009 and 2010 DPT locations are shown on Figure 3-2. Chemical distributions in the Shallow zone of the alluvial aquifer are shown on figures provided in Appendix B and are described as follows:

- The highest concentrations of major ions and metals (e.g., aluminum, copper, iron, manganese, nickel, vanadium and zinc) and uranium in the Shallow zone were typically detected beneath the central portion of the UEP, and the south-central and north-central portions of the LEP. Low pH values occur beneath the LEP and UEP. Alkalinity was depressed or non-detectable beneath the UEP. Elevated alkalinity (e.g., >500 mg/L) occurred down-gradient of the Weed Heights sewage lagoons.
- The high chemical concentrations beneath the evaporation ponds decrease laterally by varying orders of magnitude because of past and current physical and chemical attenuation processes. West of the LEP, concentrations of sulfate, other mobile chemicals, and metals decrease rapidly with distance from the Site. To the east beneath the agricultural fields, chemical concentrations are generally lower than other locations beneath or near the Site. Localized occurrences of elevated concentrations of select constituents in groundwater samples were observed from sample locations on the agricultural fields and included: alkalinity, manganese, molybdenum, nickel, potassium, selenium, sodium, uranium, vanadium, and zinc.

  The distribution of dissolved (i.e., filtered) uranium in the Shallow zone is generally consistent with the distribution of many other Site chemicals in that: 1) the highest concentrations occur beneath the central portion of the UEP, and the south-central and north-central portions of the LEP; 2) elevated concentrations extend beyond the Site boundary along a northwest alignment from the Evaporation Ponds; and 3) elevated chemical concentrations beneath the Evaporation Ponds decrease laterally by varying orders of magnitude. However, there are important differences that suggest that alkalinity and calcium influence the mobility/attenuation of uranium. Uranium concentrations rapidly decrease laterally to the west, similar to other chemicals, but do not decrease as rapidly to the east beneath the irrigated agricultural fields. Elevated concentrations of uranium in DPT locations including OU1-DPT-41, OU1-DPT-42, OU1-DPT-46, OU1-DPT-49, OU1-DPT-61, and OU1-DPT-72 are roughly coincident with: 1) the areas of locally high concentrations of alkalinity (over 300 mg/L) in Shallow zone groundwater at the northwest and northern edge of the agricultural fields; and 2) high calcium concentrations to the northwest of the agricultural fields and general widespread distribution of calcium throughout the agricultural fields.

- The distribution of arsenic in Shallow zone groundwater differs from the distributions of the parameters and chemicals described above. The highest concentrations of arsenic were detected in Shallow zone groundwater at OU1-DPT-23 (up to 620 ug/L), OU1-DPT-28 (up to 580 ug/L), and other nearby locations, which are located approximately 3,000 to 3,500 feet north of the Evaporation Ponds. Beneath the Evaporation Ponds, arsenic concentrations were much lower and typically ranged from approximately 10 to 160 ug/L. In this area, the lowest arsenic concentrations in Shallow zone groundwater occur along a northwest trend from the Weed Heights sewage lagoons. To the west of the LEP, arsenic occurs in Shallow groundwater at concentrations at or slightly above 50 ug/L.

3.2.3 Site-Wide Groundwater Monitoring Program

Groundwater monitoring in the Study Area has evolved over time in response to regulatory requirements and incorporation of new wells installed during the OU-1 RI. Currently, long-term Site-Wide groundwater monitoring is conducted in accordance with the GMP (BC 2012a) and EPA-approved modifications listed in Table 3-1. Provided below is a summary of the: 1) development of the monitoring program; 2) current active monitor well network; 3) water level monitoring activities; and 4) groundwater quality monitoring activities.

Monitoring Program Development

Table 3-1 provides a chronological summary of groundwater characterization and monitoring activities at the Site and the evolution of the monitor well network over time.

Table 3-1. Chronology of Groundwater Characterization and Monitoring Activities

Date	Activity
1976-1982	The USGS conducted groundwater investigations north of the Site boundary, which culminated in a report entitled: *Ground-water quality down-gradient from copper-ore milling wastes at Weed Heights, Lyon County, Nevada* (Seitz et al. 1982).
1982-1985	1982 – An NDEP Order required groundwater investigations near the Sulfide Tailings and Evaporation Ponds, and initial groundwater monitoring. 1985 – An NDEP Order required construction of the PWS and performance of associated O&M and groundwater monitoring activities.
1997	An NDEP Order was issued that required Arimetco to conduct groundwater investigations and monitoring of the Site, requesting both a complete hydrogeological assessment for the Yerington Mine (including existing and projected Pit Lake conditions), and a facility assessment to identify all areas where constituent concentrations in groundwater exceed the drinking water standards or background.
1999	Implementation of a Geoprobe® investigation of Shallow zone alluvial aquifer conditions north of the Site, which consisted of collecting 29 samples from 18 locations (AHA 2000).
2002	Two groundwater monitor wells, MW-2002-1 (subsequently re-named B/W-2S) and MW-2002-2, were installed (BC 2002) under an interim action directed by NDEP.
2004	Several groundwater characterization boreholes were drilled to collect groundwater grab samples, and three groundwater monitor wells were installed in the Process Areas, pursuant to the *Final Draft Process*

Table 3-1. Chronology of Groundwater Characterization and Monitoring Activities

Date	Activity
	Areas Work Plan (BC 2003).
2005	Implementation of the *First-Step Hydrogeologic Framework Assessment* (HFA; BC 2005) under the Unilateral Administrative Order (UAO) issued by EPA for Initial Response Activities, EPA Docket No. 9-2005-0011, including the installation of the first phase of B/W wells.
2007-2008	Implementation of the Second-Step HFA (BC 2007b) included a second phase of well installations, and the preparation of OU-specific work plans that describe additional on-Site monitor well installations under the 2007 Order. ARC submitted the *Draft Site-Wide Groundwater Monitoring Plan* (BC 2007c).
2008	Monitor well identification numbers modified to include a suffix designating the groundwater zone in which the well screen is positioned, including the Shallow, Intermediate, Deep and bedrock zones.
2008	EPA approved the elimination of well MW-1S from the monitoring network due to an obstruction well.
2008	Collection of groundwater grab samples and groundwater levels beneath the Anaconda Evaporation Ponds pursuant to the *Anaconda Evaporation Ponds Removal Action Characterization Work Plan* (BC 2008a).
2009	-Shutdown of the pumpback wells on March 25, 2009 with EPA approval. -Implementation of activities pursuant to the *Pumpback Well System Characterization Work Plan* (ARC 2008) including: 1) installation of nine groundwater monitor wells north of the PWS and the LEP; and 2) pumpback well aquifer testing pursuant to the *PWS Characterization Work Plan Addendum - Revision 2* (ARC 2010), which was performed in 2010. - Implementation of activities pursuant to the *Shallow Alluvial Aquifer Characterization Work Plan for Northern Portion of the Yerington Mine Site* (BC 2008b). -EPA approved the QAPP - Revision 5 dated May 20, 2009 (ESI and BC 2009), which contains SOPs for groundwater monitoring. -Implementation of a separate Domestic Well Monitoring Plan (BC 2010b) as a revision to the QAPP per EPA direction. The Domestic Well Monitoring Plan and related Bottled Water Program are discussed further in Section 3.4. -ARC submitted the *Site-Wide Groundwater Monitoring Plan - Revision 1* (BC 2009a).
2010-2011	Installation of 123 wells per the *2010 Groundwater Monitoring Well Work Plan - Revision 2* (BC 2010c) and the *Agricultural Fields Characterization Work Plan - Revision 2* (BC 2010d).
2011	-Installation of 58 wells per the the *On-Site Monitor Well Installation Work Plan - Revision 1* (BC 2011a). -Aquifer testing of an agricultural well (WDW019) north of the Site, including a 96-well observation network, pursuant to the *Aquifer Test Work Plan - Revision 1* (BC 2011b).
2012	Submittal of the *Site-Wide Groundwater Monitoring Plan - Revision 2* (BC 2012a). Addition of new well YPT-MW-15I to the monitoring program in November 2012.
2013	-Installation of 58 monitor wells per the *Additional Monitor Well Work Plan - Revision 1* (BC 2013b). -Addition of five EPA Arimetco wells, nine YPT wells, and the one MacArthur mine well (MMW-2) to the monitoring program after the 4Q 2011 event. -EPA (2013a) approved of eliminating well USEPA2S from the active monitor well network. EPA (2013b) approves of abandoning well USEPA2S and eliminating the following five metals from the analyte list for wells having at least four quarters of data: lead, silver, thallium, tin, and titanium. EPA (2013b) also approved of reducing the sampling frequency of 118 wells from quarterly to semi-annually, with sampling to be conducted in the first and third quarters of subsequent years.
2014	-EPA (2013c) approved the abandonment of well B/W-14S and the well was abandoned in January 2014. -Well USEPA2S was abandoned in April 2014 and was moved from the inactive to abandoned well list. -ARC submitted the *Technical Memorandum: Site-Wide Groundwater Monitoring Optimization* (ARC 2014) proposing several modifications to the GMP (BC 2012a). -EPA approved of reducing the frequency of manual water level monitoring in wells installed before 2013 from monthly to quarterly, to coincide with the quarterly sampling events (EPA 2014a). EPA also approved reducing the frequency of collecting groundwater samples from wells installed before 2013 for nitrate analysis from quarterly to semi-annually, with sampling to be conducted in the first and third quarters of subsequent years (EPA 2014a).
2015	Installation of six additional monitor wells (B/W-63 cluster) in the third quarter of 2015 (3Q 2015), pursuant to the *Additional Monitor Well Work Plan - Revision 1* (BC 2013b). Initial water level monitoring and sampling of these six wells in 4Q 2015.

The network development detailed in Table 3-1 included the addition and elimination of monitor locations as summarized in Table 3-2.

Table 3-2. Inventory of Monitor Well and Piezometer Locations (2007 - 2015)

Date (Through)	Total (1)	Monitor Wells and/or Piezometers	Pumpback Wells
2007	87	76	11
2008	101	90	11
1Q 2009	110	99	11
2Q 2009	114(2)	103(2)	11
3Q 2009	114(2)	103(2)	11
4Q 2009	114(2)	103(2)	11
1Q 2010	114(2)	103(2)	11
2Q 2010	114(2)	103(2)	11
3Q 2010	114(2)	103(2)	11
4Q 2010	114(2)	103(2)	11
1Q 2011	237(3)	226(3)	11
2Q 2011	237(3)	226(3)	11
3Q 2011	237(3)	226(3)	11
4Q 2011	242(4)	231(4)	11
1Q 2012	309(5)	298(5)	11
2Q 2012	309(5)	298(5)	11
3Q 2012	309(5)	298(5)	11
4Q 2012	310(6)	299(6)	11
1Q 2013	309(7)	298(7)	11
2Q 2013	309(7)	298(7)	11
3Q 2013	309(7)	298(7)	11
4Q 2013	309(7)	298(7)	11
1Q 2014	308(8)	297(8)	11
2Q 2014	325(9)	314(9)	11
3Q 2014	354(10)	343(10)	11
4Q 2014	354(10)	343(10)	11
1Q 2015	354(10)	343(10)	11
2Q 2015	354(10)	343(10)	11
3Q 2015	360(11)	349(11)	11
4Q 2015	360(11)	349(11)	11

Notes:

1) Total does not include domestic/supply wells that were part of the network until 2010. Total does include the eleven pumpback wells.
2) Includes four Lyon County wells.
3) Includes four Lyon County wells and 123 wells installed in 2010/2011.
4) Includes four Lyon County wells, 123 wells installed in 2010/2011, and five EPA Arimetco wells (sampled in 3Q 2011 and added to the monitoring program after the 4Q 2011 event).

5) Includes four Lyon County wells, 123 wells installed in 2010/2011, 58 wells installed in 2011/2012, five EPA Arimetco wells, eight YPT wells (excluding YPT-MW-7), and one MacArthur mine well (MMW-2). Prior to 1Q 2012, these wells were or may have been sampled; however, sample collection methods were either inconsistent with EPA-approved sample collection methods or were not documented.
6) Includes four Lyon County wells, 123 wells installed in 2010/2011, 58 wells installed in 2011/2012, five EPA Arimetco wells, nine YPT wells (including new well YPT-MW-15I in November 2012), and one MacArthur mine well (MMW-2).
7) With EPA approval, well USEPA2S moved to inactive well list in March 2013, subsequently proposed for abandonment in August 2013, and abandoned in April 2014.
8) With EPA approval, well B/W-14S was abandoned in January 2014.
9) Includes 17 wells installed in 2013/2014 and first sampled in 2Q 2014.
10) Includes 29 wells installed in 2013/2014 and first sampled in 3Q 2014.
11) Includes six wells (B/W-63 cluster) installed in 3Q 2015 and first sampled in 4Q 2015.

Active Monitor Well Network

The active monitor well network included 360 wells at 170 locations: 133 wells in the Shallow zone, including 11 PWS wells formerly used for groundwater extraction (currently in shutdown mode); 55 wells in the Intermediate zone; 105 wells in the Deep zone; and 67 bedrock wells (Table 3-3 and Figure 3-3). Of the 360 monitor wells, seven are used only for water level measurements, and the remaining 353 are monitored for both water levels and water quality.

A generalized cross-section that depicts alluvial monitor well screen intervals and groundwater zone designations for active wells within the monitoring network is presented in Figure 3-4. A generalized cross-section that depicts bedrock monitor well screen intervals is presented in Figure 3-5. All monitor wells in the network were surveyed by a Nevada-registered surveyor. Project datum is Nevada State Plane West Zone coordinate system (NAD27).

Table 3-3. Well Construction Details for the Active Groundwater Monitoring Network

Well Name (1)	Completion Date	Groundwater Zone	Well Type	Well Screen Interval feet amsl
Pumpback Wells				
PW-1S	10/1/85	Shallow	Sampling	4335.02 - 4312.52
PW-2S	10/1/85	Shallow	Sampling	4335.73 - 4315.23
PW-3S	10/1/85	Shallow	Sampling	4333.88 - 4313.38
PW-4S	10/1/85	Shallow	Sampling	4331.48 - 4311.98
PW-5S	10/1/85	Shallow	Sampling	4334.23 - 4313.73
PW-6S	10/21/98	Shallow	Sampling	4340.11 - 4323.11
PW-7S	10/22/98	Shallow	Sampling	4339.32 - 4319.82
PW-8S	10/22/98	Shallow	Sampling	4336.63 - 4316.63
PW-9S	10/23/98	Shallow	Sampling	4337.38 - 4317.38
PW-10S	10/23/98	Shallow	Sampling	4338.46 - 4318.46
PW-11S	10/24/98	Shallow	Sampling	4339.68 - 4319.68

Table 3-3. Well Construction Details for the Active Groundwater Monitoring Network

Well Name (1)	Completion Date	Groundwater Zone	Well Type	Well Screen Interval
				feet amsl
Shallow Zone Monitor Wells				
B-2S	5/18/89	Shallow	Water Level	NR - NR
B-3S	5/18/89	Shallow	Water Level	NR - NR
B/W-1S	1/23/08	Shallow	Sampling	4334.71 - 4314.71
B/W-2S	6/13/02	Shallow	Sampling	4330.95 - 4320.95
B/W-3S	9/26/07	Shallow	Sampling	4332.50 - 4312.50
B/W-4S	1/21/08	Shallow	Sampling	4316.74 - 4296.74
B/W-5RS	11/16/07	Shallow	Sampling	4326.12 - 4306.12
B/W-6S	1/30/08	Shallow	Sampling	4326.78 - 4306.78
B/W-8S	10/9/07	Shallow	Sampling	4325.95 - 4305.95
B/W-9S	11/7/07	Shallow	Sampling	4331.77 - 4311.77
B/W-10S	1/23/08	Shallow	Sampling	4321.56 - 4301.56
B/W-11S	11/4/07	Shallow	Sampling	4330.42 - 4310.42
B/W-13S	7/13/05	Shallow	Sampling	4364.14 - 4344.14
B/W-15S	7/22/05	Shallow	Sampling	4348.48 - 4328.48
B/W-16S	10/7/07	Shallow	Sampling	4328.68 - 4308.68
B/W-18S	2/19/08	Shallow	Sampling	4333.87 - 4308.87
B/W-19S	1/9/08	Shallow	Sampling	4331.43 - 4311.43
B/W-20S	7/13/07	Shallow	Sampling	4377.44 - 4357.44
B/W-21S	7/24/07	Shallow	Sampling	4338.99 - 4318.99
B/W-22S	7/18/07	Shallow	Sampling	4309.55 - 4289.55
B/W-25S	1/31/08	Shallow	Sampling	4322.63 - 4302.63
B/W-27S	2/7/08	Shallow	Sampling	4338.98 - 4318.98
B/W-28S	1/15/08	Shallow	Sampling	4331.67 - 4311.67
B/W-29S	1/6/08	Shallow	Sampling	4314.97 - 4294.97
B/W-30S	10/25/10	Shallow	Sampling	4325.10 - 4305.10
B/W-31S1	12/8/10	Shallow	Sampling	4330.77 - 4315.77
B/W-31S2	12/8/10	Shallow	Sampling	4304.95 - 4294.95
B/W-32S	1/11/11	Shallow	Sampling	4328.60 - 4308.60
B/W-33S	8/4/10	Shallow	Sampling	4328.23 - 4308.23
B/W-34S	12/5/10	Shallow	Sampling	4337.68 - 4317.68
B/W-36S	8/11/10	Shallow	Sampling	4329.76 - 4319.76
B/W-37S	6/6/10	Shallow	Sampling	4331.62 - 4311.62
B/W-38RS	10/11/10	Shallow	Sampling	4320.17 - 4300.17
B/W-40S	1/10/11	Shallow	Sampling	4318.41 - 4298.41
B/W-41S	2/8/11	Shallow	Sampling	4324.54 - 4304.54
B/W-42S	11/9/10	Shallow	Sampling	4326.05 - 4306.05
B/W-43S	12/17/10	Shallow	Sampling	4323.75 - 4303.75
B/W-44S	9/24/10	Shallow	Sampling	4324.88 - 4304.88

Table 3-3. Well Construction Details for the Active Groundwater Monitoring Network

Well Name (1)	Completion Date	Groundwater Zone	Well Type	Well Screen Interval
				feet amsl
B/W-45S	1/17/11	Shallow	Sampling	4331.84 - 4311.84
B/W-46S	11/8/10	Shallow	Sampling	4327.09 - 4307.09
B/W-50S (2)	2/11/14	Shallow	Sampling	4337.83 - 4317.83
B/W-51S	8/25/10	Shallow	Sampling	4303.87 - 4293.87
B/W-52S	8/18/10	Shallow	Sampling	4329.90 - 4309.90
B/W-53S1	1/20/11	Shallow	Sampling	4310.26 - 4290.26
B/W-53S2	1/19/11	Shallow	Sampling	4265.87 - 4255.87
B/W-54S	8/20/10	Shallow	Sampling	4298.38 - 4288.38
B/W-55S	10/20/10	Shallow	Sampling	4327.27 - 4307.27
B/W-56S	3/13/12	Shallow	Sampling	4334.12 - 4314.12
B/W-57S	3/15/12	Shallow	Sampling	4325.36 - 4305.36
B/W-58S	3/14/12	Shallow	Sampling	4294.04 - 4284.04
B/W-59S (2)	11/20/13	Shallow	Sampling	4338.55 - 4318.55
B/W-60S	1/8/11	Shallow	Sampling	4342.73 - 4322.73
B/W-61S	8/27/10	Shallow	Sampling	4342.05 - 4322.05
B/W-62S	11/22/10	Shallow	Sampling	4333.94 - 4313.94
B/W-63S (3)	8/9/15	Shallow	Sampling	4325.73 - 4305.73
B/W-64S	12/6/10	Shallow	Sampling	4348.03 - 4328.03
B/W-65S	9/29/10	Shallow	Sampling	4325.29 - 4305.29
B/W-66S	12/5/10	Shallow	Sampling	4313.88 - 4293.88
B/W-67S	1/23/11	Shallow	Sampling	4329.26 - 4309.26
B/W-68S (2)	4/30/14	Shallow	Sampling	4325.57 - 4305.57
B/W-69S (2)	4/15/14	Shallow	Sampling	4319.18 - 4299.18
B/W-70S	10/20/11	Shallow	Sampling	4338.80 - 4318.80
B/W-71S	10/12/11	Shallow	Sampling	4342.25 - 4322.25
B/W-73S	9/10/11	Shallow	Sampling	4357.74 - 4337.74
B/W-74S	10/26/11	Shallow	Sampling	4342.98 - 4322.98
B/W-75S	12/20/11	Shallow	Sampling	4346.69 - 4326.69
B/W-76S	12/15/11	Shallow	Sampling	4335.33 - 4315.33
B/W-77S (2)	4/24/14	Shallow	Sampling	4320.30 - 4300.30
B/W-78S (2)	4/23/14	Shallow	Sampling	4329.30 - 4309.30
B/W-79S (2)	4/25/14	Shallow	Sampling	4335.29 - 4315.29
B/W-81S (2)	3/10/14	Shallow	Sampling	4308.10 - 4288.10
B/W-82RS (2)	11/3/13	Shallow	Sampling	4310.40 - 4290.40
B/W-83S (2)	2/5/14	Shallow	Sampling	4326.66 - 4306.66
D4BC-1S	10/1/85	Shallow	Sampling	4333.98 - 4313.98
D5AC-1S	5/6/84	Shallow	Sampling	4332.48 - 4327.48
FMS-05S (4)	10/20/13	Shallow	Sampling	4335.34 - 4315.34
FMS-06S (4)	11/6/13	Shallow	Sampling	4336.55 - 4316.55

Table 3-3. Well Construction Details for the Active Groundwater Monitoring Network

Well Name (1)	Completion Date	Groundwater Zone	Well Type	Well Screen Interval
				feet amsl
FMS-07S (4)	11/14/13	Shallow	Sampling	4337.75 - 4317.75
HLP-03S (4)	11/16/13	Shallow	Sampling	4341.79 - 4321.79
HLP-04S (4)	10/8/13	Shallow	Sampling	4340.55 - 4320.55
HLP-08S (4)	10/21/13	Shallow	Sampling	4331.83 - 4311.83
LC-MW-1S (5)	1/18/06	Shallow	Sampling	NR - 4303.80(6)
LC-MW-2S (5)	1/18/06	Shallow	Sampling	NR - 4313.90(6)
LC-MW-3S (5)	1/18/06	Shallow	Sampling	NR - 4323.70(6)
LC-MW-5S (5)	NR	Shallow	Sampling	NR - 4323.10(6)
LEP-MW-1S	2/26/09	Shallow	Sampling	4330.92 - 4320.92
LEP-MW-2S	2/27/09	Shallow	Sampling	4331.46 - 4321.46
LEP-MW-3S	2/28/09	Shallow	Sampling	4333.75 - 4323.75
LEP-MW-5S	3/2/09	Shallow	Sampling	4336.35 - 4326.35
LEP-MW-6S	3/2/09	Shallow	Sampling	4327.51 - 4317.51
LEP-MW-7S	3/3/09	Shallow	Sampling	4342.81 - 4332.81
MW2002-2S	6/14/02	Shallow	Sampling	4323.78 - 4313.78
MW-2S	12/13/92	Shallow	Sampling	4326.61 - 4311.61
MW-4S	12/10/92	Shallow	Sampling	4325.68 - 4310.68
MW-5S	10/20/95	Shallow	Sampling	4330.79 - 4315.79
MW-SXN	7/26/09	Shallow	Sampling	4355.39 - 4335.39
MW-SXS	8/28/09	Shallow	Sampling	4354.32 - 4334.32
PA-MW-1S	1/20/05	Shallow	Sampling	4347.32 - 4327.32
PA-MW-2S	1/21/05	Shallow	Sampling	4347.37 - 4327.37
PA-MW-3S1	1/19/05	Shallow	Sampling	4348.13 - 4328.13
PA-MW-3S2	11/19/11	Shallow	Sampling	4309.85 - 4299.85
PA-MW-4S	10/18/11	Shallow	Sampling	4348.09 - 4328.09
PA-MW-5S1	11/17/11	Shallow	Sampling	4344.01 - 4324.01
PA-MW-5S2	11/14/11	Shallow	Sampling	4311.16 - 4301.16
PA-MW-7S	10/25/11	Shallow	Sampling	4317.46 - 4297.46
PLMW-2S	8/3/11	Shallow	Sampling	4369.05 - 4349.05
PLMW-4S	10/31/11	Shallow	Sampling	4319.72 - 4289.72
PW10-P1	9/27/05	Shallow	Water Level	4339.10 - 4319.10
USGS-13S	6/10/76	Shallow	Sampling	4342.06 - 4332.06
USGS-2BS	6/8/76	Shallow	Sampling	4326.34 - 4324.44
UW-1S	10/1/85	Shallow	Sampling	4333.32 - 4313.32
W5AA-2S	10/26/83	Shallow	Water Level	4333.65 - 4313.65
W5AA-3S	10/24/98	Shallow	Sampling	4342.86 - 4332.86
W5AB-2S	10/1/83	Shallow	Sampling	4337.68 - 4322.68
W5AD-1S	5/2/82	Shallow	Water Level	4330.91 - 4325.91
W5BB-S	10/23/83	Shallow	Sampling	4337.12 - 4307.12

Table 3-3. Well Construction Details for the Active Groundwater Monitoring Network

Well Name [1]	**Completion Date**	**Groundwater Zone**	**Well Type**	**Well Screen Interval**
				feet amsl
W5DB-S	10/9/10	Shallow	Sampling	4345.06 - 4325.06
WRP-1S	6/19/07	Shallow	Water Level	4382.53 - 4372.53
WRP-2S	6/19/07	Shallow	Water Level	4382.29 - 4372.29
YPT-MW-6S	1/11/02	Shallow	Sampling	4320.21 - 4315.21
YPT-MW-8S	1/9/02	Shallow	Sampling	4322.26 - 4317.26
YPT-MW-11S	1/11/02	Shallow	Sampling	4317.43 - 4312.43
Intermediate Zone Monitor Wells				
B/W-2I	10/17/07	Intermediate	Sampling	4279.78 - 4259.78
B/W-3I	9/27/07	Intermediate	Sampling	4266.40 - 4246.40
B/W-4I	1/21/08	Intermediate	Sampling	4276.50 - 4256.50
B/W-5RI	11/16/07	Intermediate	Sampling	4278.65 - 4258.65
B/W-6I	9/26/05	Intermediate	Sampling	4259.84 - 4249.84
B/W-7I	8/14/05	Intermediate	Sampling	4304.69 - 4284.69
B/W-8I	8/21/05	Intermediate	Sampling	4284.16 - 4264.16
B/W-9I	11/7/07	Intermediate	Sampling	4281.19 - 4261.19
B/W-19I	1/11/08	Intermediate	Sampling	4281.40 - 4261.40
B/W-27I	8/17/10	Intermediate	Sampling	4274.77 - 4254.77
B/W-28I	1/17/08	Intermediate	Sampling	4277.23 - 4257.23
B/W-29I	12/19/07	Intermediate	Sampling	4288.07 - 4278.07
B/W-30I	10/25/10	Intermediate	Sampling	4267.63 - 4247.63
B/W-31I	12/7/10	Intermediate	Sampling	4287.82 - 4246.82
B/W-32I	1/10/11	Intermediate	Sampling	4286.67 - 4266.67
B/W-33I	8/3/10	Intermediate	Sampling	4265.02 - 4255.02
B/W-34I	12/5/10	Intermediate	Sampling	4303.85 - 4283.85
B/W-37I	8/10/10	Intermediate	Sampling	4296.85 - 4276.85
B/W-38RI	10/9/10	Intermediate	Sampling	4287.91 - 4267.91
B/W-41I	2/7/11	Intermediate	Sampling	4278.31 - 4268.31
B/W-42I	11/8/10	Intermediate	Sampling	4266.21 - 4246.21
B/W-46I	11/7/10	Intermediate	Sampling	4276.66 - 4256.66
B/W-51I	9/9/10	Intermediate	Sampling	4264.06 - 4244.06
B/W-52I	8/20/10	Intermediate	Sampling	4296.06 - 4276.06
B/W-54I	8/21/10	Intermediate	Sampling	4277.24 - 4267.24
B/W-57I	3/14/12	Intermediate	Sampling	4270.47 - 4250.47
B/W-63I (3)	8/9/15	Intermediate	Sampling	4285.58 - 4265.58
B/W-65I	9/29/10	Intermediate	Sampling	4285.30 - 4265.30
B/W-66I	12/5/10	Intermediate	Sampling	4268.85 - 4248.85
B/W-67I	1/22/11	Intermediate	Sampling	4289.41 - 4269.41
B/W-70I	10/22/11	Intermediate	Sampling	4288.59 - 4268.59
B/W-71I	10/11/11	Intermediate	Sampling	4281.11 - 4261.11

Table 3-3. Well Construction Details for the Active Groundwater Monitoring Network

Well Name (1)	Completion Date	Groundwater Zone	Well Type	Well Screen Interval
				feet amsl
B/W-74I1	10/20/11	Intermediate	Sampling	4307.69 - 4297.69
B/W-74I2	10/21/11	Intermediate	Sampling	4277.50 - 4257.50
B/W-76I	12/13/11	Intermediate	Sampling	4276.82 - 4256.82
B/W-82RI (2)	11/2/13	Intermediate	Sampling	4280.35 - 4270.35
HLP-03I (4)	11/5/13	Intermediate	Sampling	4300.00 - 4280.00
HLP-08I (4)	10/20/13	Intermediate	Sampling	4296.56 - 4276.56
LEP-MW-4I	3/1/09	Intermediate	Sampling	4266.95 - 4256.95
LEP-MW-8I	3/4/09	Intermediate	Sampling	4271.83 - 4261.83
LEP-MW-9I	3/6/09	Intermediate	Sampling	4258.17 - 4248.17
MW-4I	8/30/10	Intermediate	Sampling	4285.18 - 4265.18
MW-5I	1/23/11	Intermediate	Sampling	4269.38 - 4249.38
PA-MW-2I	9/8/11	Intermediate	Sampling	4296.59 - 4276.59
PA-MW-3I	11/18/11	Intermediate	Sampling	4281.86 - 4271.86
PA-MW-4I	10/17/11	Intermediate	Sampling	4273.89 - 4253.89
W4CB-1I	10/27/83	Intermediate	Sampling	4280.31 - 4265.31
W4CB-2I	10/28/83	Intermediate	Sampling	4307.74 - 4295.74
W5AA-1I	10/26/83	Intermediate	Sampling	4293.56 - 4278.56
W5AB-3I	9/19/97	Intermediate	Sampling	4308.70 - 4284.20
W5DB-I	10/10/10	Intermediate	Sampling	4287.77 - 4267.77
YPT-MW-9I	1/8/02	Intermediate	Sampling	4282.60 - 4272.60
YPT-MW-12I	1/10/02	Intermediate	Sampling	4280.36 - 4270.36
YPT-MW-13I	7/20/04	Intermediate	Sampling	4287.78 - 4262.78
YPT-MW-15I	10/5/12	Intermediate	Sampling	4275.21 - 4270.21
Deep Zone Monitor Wells				
B/W-1D1	11/5/07	Deep	Sampling	4229.76 - 4209.76
B/W-1D2	10/22/07	Deep	Sampling	4139.92 - 4119.92
B/W-1D3	11/5/05	Deep	Sampling	4028.63 - 4018.63
B/W-1D5	1/7/11	Deep	Sampling	3877.18 - 3867.18
B/W-2D1	9/10/05	Deep	Sampling	4224.01 - 4204.01
B/W-2D3	1/23/11	Deep	Sampling	4049.28 - 4029.28
B/W-2D4	1/21/11	Deep	Sampling	3938.99 - 3918.99
B/W-3D1	8/31/05	Deep	Sampling	4221.87 - 4201.87
B/W-4D1	8/26/05	Deep	Sampling	4228.07 - 4208.07
B/W-5RD1	11/16/07	Deep	Sampling	4241.21 - 4221.21
B/W-9D2	9/14/05	Deep	Sampling	4206.72 - 4186.72
B/W-10D1	8/5/05	Deep	Sampling	4241.10 - 4221.10
B/W-11D2	9/28/05	Deep	Sampling	4197.64 - 4177.64
B/W-18D1	2/19/08	Deep	Sampling	4232.79 - 4212.79
B/W-18D2	12/15/07	Deep	Sampling	4194.17 - 4174.17

Table 3-3. Well Construction Details for the Active Groundwater Monitoring Network

Well Name (1)	Completion Date	Groundwater Zone	Well Type	Well Screen Interval
				feet amsl
B/W-19D1	6/14/07	Deep	Sampling	4216.51 - 4196.51
B/W-25D1	2/1/08	Deep	Sampling	4249.71 - 4229.71
B/W-25D2	1/19/08	Deep	Sampling	4133.82 - 4113.82
B/W-27D2	2/6/08	Deep	Sampling	4124.99 - 4104.99
B/W-27D3	1/6/11	Deep	Sampling	4022.95 - 4002.95
B/W-27D4(2)	2/21/14	Deep	Sampling	3944.83 - 3924.83
B/W-27D5(2)	2/11/14	Deep	Sampling	3879.66 - 3859.66
B/W-28D1	6/28/07	Deep	Sampling	4221.83 - 4201.83
B/W-29D1	12/16/07	Deep	Sampling	4225.24 - 4215.24
B/W-29D3	9/25/07	Deep	Sampling	4050.12 - 4030.12
B/W-30D1	10/26/10	Deep	Sampling	4228.86 - 4208.86
B/W-31D2	11/7/10	Deep	Sampling	4199.84 - 4179.84
B/W-32D2	1/9/11	Deep	Sampling	4147.42 - 4127.42
B/W-32D5	10/24/10	Deep	Sampling	3886.73 - 3866.73
B/W-33D1	7/29/10	Deep	Sampling	4239.39 - 4229.39
B/W-34D1	12/4/10	Deep	Sampling	4257.96 - 4237.96
B/W-37D1	6/5/10	Deep	Sampling	4218.80 - 4198.80
B/W-38RD1	10/10/10	Deep	Sampling	4210.93 - 4190.93
B/W-40D1	1/20/11	Deep	Sampling	4222.20 - 4202.20
B/W-40D3	11/3/10	Deep	Sampling	4057.58 - 4037.58
B/W-41D2	2/7/11	Deep	Sampling	4198.22 - 4178.22
B/W-41D4	2/5/11	Deep	Sampling	4004.14 - 3984.14
B/W-42D1	10/25/10	Deep	Sampling	4210.91 - 4190.91
B/W-44D1	9/23/10	Deep	Sampling	4229.65 - 4209.65
B/W-44D2	9/22/10	Deep	Sampling	4152.72 - 4132.72
B/W-45D1	1/18/11	Deep	Sampling	4252.78 - 4232.78
B/W-45D2	11/20/10	Deep	Sampling	4209.84 - 4189.84
B/W-46D1	11/6/10	Deep	Sampling	4219.76 - 4199.76
B/W-50D1(2)	2/10/14	Deep	Sampling	4206.81 - 4186.81
B/W-50D2(2)	2/8/14	Deep	Sampling	4125.75 - 4105.75
B/W-50D3(2)	2/5/14	Deep	Sampling	4024.73 - 4014.73
B/W-52D2	8/17/10	Deep	Sampling	4177.59 - 4157.59
B/W-55D1	10/20/10	Deep	Sampling	4251.44 - 4241.44
B/W-55D2	10/13/10	Deep	Sampling	4171.59 - 4151.59
B/W-57D1	3/14/12	Deep	Sampling	4212.37 - 4192.37
B/W-57D4	3/13/12	Deep	Sampling	3940.67 - 3920.67
B/W-58D1	3/16/12	Deep	Sampling	4234.41 - 4214.41
B/W-58D3	3/25/12	Deep	Sampling	4054.51 - 4044.51
B/W-59D3(2)	11/19/13	Deep	Sampling	4126.65 - 4106.65

Table 3-3. Well Construction Details for the Active Groundwater Monitoring Network

Well Name (1)	Completion Date	Groundwater Zone	Well Type	Well Screen Interval
				feet amsl
B/W-60D1	12/17/10	Deep	Sampling	4247.69 - 4227.69
B/W-60D3	12/16/10	Deep	Sampling	4036.75 - 4016.75
B/W-60D5	12/7/10	Deep	Sampling	3881.82 - 3861.82
B/W-61D1	8/23/10	Deep	Sampling	4247.00 - 4227.00
B/W-61D3	8/29/10	Deep	Sampling	4036.94 - 4016.94
B/W-62D1	11/21/10	Deep	Sampling	4243.89 - 4223.89
B/W-62D2	11/20/10	Deep	Sampling	4173.88 - 4153.88
B/W-62D4	11/19/10	Deep	Sampling	3953.94 - 3933.94
B/W-62D5	1/6/11	Deep	Sampling	3833.92 - 3813.92
B/W-63D1(3)	8/8/15	Deep	Sampling	4240.50 - 4220.50
B/W-63D2(3)	8/7/15	Deep	Sampling	4170.83 - 4150.83
B/W-63D3(3)	8/5/15	Deep	Sampling	4015.78 - 3995.78
B/W-63D5(3)	7/29/15	Deep	Sampling	3900.65 - 3880.65
B/W-64D1	12/5/10	Deep	Sampling	4260.09 - 4240.09
B/W-64D2	12/3/10	Deep	Sampling	4175.77 - 4155.77
B/W-65D1	9/27/10	Deep	Sampling	4213.36 - 4193.36
B/W-65D5	9/23/10	Deep	Sampling	3750.51 - 3740.51
B/W-66D1	12/4/10	Deep	Sampling	4208.81 - 4188.81
B/W-66D5	12/2/10	Deep	Sampling	3761.03 - 3751.03
B/W-67D1	1/21/11	Deep	Sampling	4245.24 - 4225.24
B/W-67D3	1/13/11	Deep	Sampling	4125.04 - 4105.04
B/W-68D1(2)	4/29/14	Deep	Sampling	4240.74 - 4220.74
B/W-68D4(2)	4/28/14	Deep	Sampling	3964.32 - 3954.32
B/W-69D1(2)	4/14/14	Deep	Sampling	4259.33 - 4239.33
B/W-69D2(2)	4/13/14	Deep	Sampling	4194.30 - 4174.30
B/W-69D5(2)	4/9/14	Deep	Sampling	3782.33 - 3772.33
B/W-70D2	10/25/11	Deep	Sampling	4143.64 - 4123.64
B/W-71D1	10/5/11	Deep	Sampling	4222.09 - 4202.09
B/W-71D3	10/3/11	Deep	Sampling	4094.16 - 4074.16
B/W-74D1	11/20/11	Deep	Sampling	4247.72 - 4227.72
B/W-76D1	10/4/11	Deep	Sampling	4251.74 - 4231.74
B/W-81D1(2)	3/9/14	Deep	Sampling	4243.06 - 4223.06
B/W-81D2(2)	3/10/14	Deep	Sampling	4153.13 - 4133.13
B/W-83D1(2)	2/4/14	Deep	Sampling	4216.67 - 4196.67
B/W-83D3(2)	1/29/14	Deep	Sampling	4066.59 - 4046.59
HLP-08D1(4)	10/19/13	Deep	Sampling	4249.87 - 4229.87
HLP-08D2(4)	10/15/13	Deep	Sampling	4174.99 - 4154.99
LEP-MW-2D1	10/25/10	Deep	Sampling	4229.98 - 4209.98
LEP-MW-2D3	10/22/10	Deep	Sampling	4100.11 - 4080.11

Table 3-3. Well Construction Details for the Active Groundwater Monitoring Network

Well Name (1)	Completion Date	Groundwater Zone	Well Type	Well Screen Interval
				feet amsl
MW-5D2	1/12/11	Deep	Sampling	4194.22 - 4174.22
MW-5D3	1/18/11	Deep	Sampling	4119.72 - 4099.72
MW2002-2D1	7/12/07	Deep	Sampling	4249.75 - 4239.75
PA-MW-4D2	10/15/11	Deep	Sampling	4192.92 - 4172.92
W32DC-D1	10/25/83	Deep	Sampling	4240.41 - 4197.41
W4CB-2D1	9/15/10	Deep	Sampling	4240.56 - 4220.56
W4CB-2D3	9/14/10	Deep	Sampling	4065.76 - 4045.76
W4CB-2D4	11/8/10	Deep	Sampling	3965.54 - 3955.54
W5DB-D1	10/19/98	Deep	Sampling	4239.49 - 4211.49
W5DB-D3	11/17/10	Deep	Sampling	4091.93 - 4071.93
W5DB-D4	10/25/10	Deep	Sampling	4009.93 - 3989.93
YPT-MW-14D1	7/21/04	Deep	Sampling	4255.83 - 4235.83
Bedrock Monitor Wells				
B/W-1B	5/19/10	Bedrock	Sampling	3700.10 - 3690.10
B/W-2B	1/12/11	Bedrock	Sampling	3839.17 - 3819.17
B/W-6B	1/25/11	Bedrock	Sampling	4172.04 - 4152.04
B/W-11B	11/3/07	Bedrock	Sampling	4132.88 - 4122.88
B/W-12RB	12/6/11	Bedrock	Sampling	4382.05 - 4302.05
B/W-17B	10/30/11	Bedrock	Sampling	4385.06 - 4365.06
B/W-22B	5/8/10	Bedrock	Sampling	4261.26 - 4241.26
B/W-23B	8/8/07	Bedrock	Sampling	4340.26 - 4330.26
B/W-26RB	11/3/11	Bedrock	Sampling	4367.92 - 4347.92
B/W-27B (2)	11/12/13	Bedrock	Sampling	3800.16 - 3780.16
B/W-33B	7/26/10	Bedrock	Sampling	4167.48 - 4157.48
B/W-34B	12/1/10	Bedrock	Sampling	4203.76 - 4183.76
B/W-36B	6/17/10	Bedrock	Sampling	4271.60 - 4261.60
B/W-37B	5/27/10	Bedrock	Sampling	4166.84 - 4146.84
B/W-38RB	10/8/10	Bedrock	Sampling	4166.90 - 4146.90
B/W-39B	10/7/10	Bedrock	Sampling	4309.10 - 4299.10
B/W-44B	9/16/10	Bedrock	Sampling	4124.48 - 4104.48
B/W-51B	6/25/10	Bedrock	Sampling	4198.79 - 4188.79
B/W-53B	12/17/10	Bedrock	Sampling	4240.77 - 4220.77
B/W-54B	7/10/10	Bedrock	Sampling	4261.30 - 4251.30
B/W-58B	2/4/12	Bedrock	Sampling	4014.50 - 3994.50
B/W-61B	7/9/10	Bedrock	Sampling	3684.05 - 3664.05
B/W-62B	9/25/10	Bedrock	Sampling	3690.87 - 3670.87
B/W-64B	12/2/10	Bedrock	Sampling	4089.75 - 4069.75
B/W-70B	8/30/11	Bedrock	Sampling	4060.86 - 4040.86
B/W-71B	9/1/11	Bedrock	Sampling	3931.06 - 3911.06

Table 3-3. Well Construction Details for the Active Groundwater Monitoring Network

Well Name (1)	Completion Date	Groundwater Zone	Well Type	Well Screen Interval feet amsl
B/W-73B	9/7/11	Bedrock	Sampling	4307.60 - 4287.60
B/W-74B	9/21/11	Bedrock	Sampling	4207.18 - 4187.18
B/W-75B	1/7/12	Bedrock	Sampling	4266.82 - 4246.82
B/W-82RB (2)	11/1/13	Bedrock	Sampling	4235.38 - 4215.38
B/W-83B (2)	1/24/14	Bedrock	Sampling	3943.51 - 3913.51
HLP-01B (4)	9/20/13	Bedrock	Sampling	4333.97 - 4313.97
HLP-02B (4)	9/22/13	Bedrock	Sampling	4406.47 - 4386.27
HLP-03B (4)	10/18/13	Bedrock	Sampling	4236.98 - 4206.98
HLP-05B (4)	10/5/13	Bedrock	Sampling	4346.26 - 4306.26
HLP-06B (4)	10/1/13	Bedrock	Sampling	4338.55 - 4318.55
HLP-07B (4)	9/24/13	Bedrock	Sampling	4345.04 - 4325.04
HLP-08B (4)	10/8/14	Bedrock	Sampling	4117.44 - 4097.44
LEP-MW-2B	10/13/10	Bedrock	Sampling	4040.47 - 4020.47
MMW-2	12/6/92	Bedrock	Sampling	4246.34 - 4186.34
MW-4B	8/28/10	Bedrock	Sampling	4251.41 - 4231.41
MW-5B	1/7/11	Bedrock	Sampling	3984.29 - 3964.29
MW-H12	8/6/09	Bedrock	Sampling	4353.58 - 4323.58
MW-H4SN	8/11/09	Bedrock	Sampling	4371.56 - 4341.56
MW-H4SS	8/13/09	Bedrock	Sampling	4360.63 - 4330.63
PA-MW-1B	8/6/11	Bedrock	Sampling	4290.87 - 4270.87
PA-MW-2B	9/3/11	Bedrock	Sampling	4210.44 - 4190.44
PA-MW-3B	10/11/11	Bedrock	Sampling	4246.82 - 4226.82
PA-MW-4B	9/14/11	Bedrock	Sampling	4157.96 - 4137.96
PA-MW-5B	8/20/11	Bedrock	Sampling	4281.60 - 4261.60
PA-MW-7B	9/30/11	Bedrock	Sampling	4174.49 - 4154.49
PLMW-1B	9/29/11	Bedrock	Sampling	4218.23 - 4168.23
PLMW-2B	8/2/11	Bedrock	Sampling	4313.20 - 4293.20
PLMW-3RB	11/12/11	Bedrock	Sampling	4237.72 - 4197.72
PLMW-4B	10/20/11	Bedrock	Sampling	4094.72 - 4064.72
PLMW-5B	9/18/11	Bedrock	Sampling	4243.58 - 4203.58
W4CB-2B	7/9/10	Bedrock	Sampling	3844.55 - 3824.55
W5DB-B	9/26/10	Bedrock	Sampling	3781.04 - 3761.04
WRA3-1B	10/1/11	Bedrock	Sampling	4369.32 - 4339.32
WRA3-2B	10/19/11	Bedrock	Sampling	4322.60 - 4302.60
WRA3-3B	12/5/11	Bedrock	Sampling	4330.39 - 4310.39
WW-1B	NR	Bedrock	Sampling	4364.42 - 4344.42
WW-2B	NR	Bedrock	Sampling	4342.48 - 4322.48
WW-36B	4/15/69	Bedrock	Sampling	4305.78 - 4105.78
WW-40B	NR	Bedrock	Sampling	NR - NR

Table 3-3. Well Construction Details for the Active Groundwater Monitoring Network

Well Name [(1)]	Completion Date	Groundwater Zone	Well Type	Well Screen Interval feet amsl
WW-59B	11/20/72	Bedrock	Sampling	4280.04 - 3888.04
YPT-MW-10B	1/7/02	Bedrock	Sampling	4107.46 - 4097.46

Notes:

1) The names of 117 wells for which the sampling frequency has been reduced from quarterly to semi-annually are bold and italicized. Well names for older wells reflect revisions based on their alluvial aquifer zone designations.
2) New well added to the monitor well network and first sampled in 3Q 2014.
3) New well added to the monitor well network and first sampled in 4Q 2015.
4) New well added to the monitor well network and first sampled in 4Q 2014.
5) Lyon County well.
6) The bottom of screen elevations for the Lyon County wells are based on a 2009 survey conducted for ARC and the total depth of each well measured in the field by BC. The measured well depths are not consistent with the information on the well logs provided by Lyon County (see Appendix C-1 for the well logs).
7) NR = not recorded on well construction logs. amsl = above mean sea level

Water Level Monitoring

Routine water level monitoring was initiated in 2006, to evaluate seasonal and temporal changes in groundwater flow directions and hydraulic gradients, and aquifer responses to irrigation practices. Water level elevation monitoring was historically conducted monthly, and subsequently reduced to quarterly in 2014 for wells installed before 2013, in accordance with the *Technical Memorandum: Site-Wide Groundwater Monitoring Optimization* (ARC 2014).

As outlined in the GMP (BC 2012a), water levels are measured within a three-day (or shorter) period, for representative aquifer conditions throughout the monitoring network. Water level elevations are also measured electronically using pressure transducers/data loggers, at four-hour intervals at select monitor wells, and at one-hour intervals at the Pit Lake. Water level data from transducers are typically downloaded in conjunction with monthly water level measurements. Appendix D provides groundwater level data, hydrographs, and vertical gradient information.

Groundwater Quality Monitoring

Monitor wells comprising the active monitoring network are sampled on a quarterly or semi-annual frequency pursuant to the GMP (BC 2012a) using EPA-approved low-flow, minimal drawdown purging and sampling procedures, where applicable. Groundwater samples are analyzed for the constituents listed in Table 3-4 pursuant to the data requirements presented in the QAPP (ESI and BC 2009).

Table 3-4. Analyte List for Active Monitor Well and Surface Water Sampling

Parameter or Analyte	Total/ Dissolved (1)	Method (2)	Reporting Limit (2)	Units
Physical Parameters and Major Anions/Cations				
Alkalinity, Bicarbonate (as $CaCO_3$)	Total	SM 2320B	2.0	mg/L
Alkalinity, Carbonate (as $CaCO_3$)	Total	SM 2320B	2.0	mg/L
Alkalinity, Total (as $CaCO_3$)	Total	SM 2320B	2.0	mg/L
Chloride	Total	EPA 300.0	0.5	mg/L
Fluoride	Total	EPA 300.0	0.5	mg/L
Nitrate, as N	Total	EPA 300.0	0.1	mg/L
Nitrate (NO_3 + NO_2 as N)	Total	EPA 300.0	0.1	mg/L
Nitrite, as N	Total	EPA 300.0	0.1	mg/L
Sulfate	Total	EPA 300.0	0.5	mg/L
pH (Lab)	Total	SM 4500B	0.1	sun.
Total Dissolved Solids (TDS) (3)	Total (Lab Filtered) (3)	SM 2540C	10	mg/L
Total Organic Carbon (TOC)	Total	SM 5310B	1.0	mg/L
Metals				
Aluminum	Total + Dissolved	EPA 200.7	0.05	mg/L
Antimony	Total + Dissolved	EPA 200.8	2.0	µg/L
Arsenic	Total + Dissolved	EPA 200.8	1.0	µg/L
Barium	Total + Dissolved	EPA 200.8	1.0	µg/L
Beryllium	Total + Dissolved	EPA 200.8	0.5	µg/L
Boron	Total + Dissolved	EPA 200.7	50	µg/L
Cadmium	Total + Dissolved	EPA 200.8	1.0	µg/L
Calcium	Total + Dissolved	EPA 200.7	0.1	mg/L
Chromium	Total + Dissolved	EPA 200.8	2.0	µg/L
Cobalt	Total + Dissolved	EPA 200.8	1.0	µg/L
Copper	Total + Dissolved	EPA 200.8	1.0	µg/L
Iron	Total + Dissolved	EPA 200.7	0.04	mg/L
Lead	Total + Dissolved	EPA 200.8	1.0	µg/L
Lithium	Total + Dissolved	EPA 200.7	50	µg/L
Magnesium	Total + Dissolved	EPA 200.7	0.02	mg/L
Manganese	Total + Dissolved	EPA 200.8	1.0	µg/L
Mercury	Total + Dissolved	EPA 245.1	0.2	µg/L
Molybdenum	Total + Dissolved	EPA 200.8	2.0	µg/L
Nickel	Total + Dissolved	EPA 200.8	2.0	µg/L
Phosphorus	Total + Dissolved	EPA 200.7	0.04	mg/L
Potassium	Total + Dissolved	EPA 200.7	0.5	mg/L
Selenium	Total + Dissolved	EPA 200.8	0.6	µg/L
Silica	Total + Dissolved	EPA 200.7	0.05	mg/L
Silver	Total + Dissolved	EPA 200.8	1.0	µg/L
Sodium	Total + Dissolved	EPA 200.7	0.5	mg/L
Strontium	Total + Dissolved	EPA 200.7	0.02	mg/L
Thallium	Total + Dissolved	EPA 200.8	1.0	µg/L
Tin	Total + Dissolved	EPA 200.7	100	µg/L

Table 3-4. Analyte List for Active Monitor Well and Surface Water Sampling

Parameter or Analyte	Total/ Dissolved (1)	Method (2)	Reporting Limit (2)	Units
Titanium	Total + Dissolved	EPA 200.7	0.005	mg/L
Uranium, Total	Total + Dissolved	EPA 200.8	1.0	µg/L
Vanadium	Total + Dissolved	EPA 200.8	2.0	µg/L
Zinc	Total + Dissolved	EPA 200.8	10	µg/L
Radiochemicals				
Gross Alpha	Dissolved	EPA 900.0	1.0	pCi/L
Gross Beta	Dissolved	EPA 900.0	1.0	pCi/L
Radium-226	Dissolved	EPA 903.0	1.0	pCi/L
Radium-228	Dissolved	EPA 904.0	1.0	pCi/L
Thorium-228	Dissolved	HASL 300	1.0	pCi/L
Thorium-230	Dissolved	HASL 300	1.0	pCi/L

Notes:

1) Dissolved constituents are field-filtered with a new disposable 0.45-micron (µm) filter. Dissolved (filtered) metals collected quarterly. Total (unfiltered) metals collected in two non-consecutive quarters once a well is installed and/or initially included in the GMP (BC 2012a).
2) Except for lithium and selenium, EPA laboratory analytical methods and reporting limits are consistent with those provided in Revision 5 of the QAPP (ESI and BC 2009); alternative analytical methods identified in the QAPP may also be used. For lithium, the lab was unable to get reproducible results using EPA Method 200.8 (as indicated in QAPP); therefore, the lab has used EPA Method 200.7 for lithium, which has a higher reporting limit than indicated in the QAPP. For selenium, the reporting limit of 0.6 µg/L is lower than that indicated in the QAPP (2 µg/L).
3) The samples for TDS are filtered in the analytical laboratory with a new disposable 0.45 µm filter.
4) s.u. = pH standard units; mg/L = milligrams per liter; µg/L = micrograms per liter; pCi/L = picocuries per liter.

Appendix D provides groundwater quality data associated with the Site-Wide groundwater monitoring program and charts illustrating temporal changes in chemical concentrations.

Dissolved versus Total Metals

Beginning with the 3Q 2010 sampling event, samples from monitor wells at the Site have been periodically collected in two different quarters from each well and analyzed for both dissolved (0.45 µm-filtered) and total (unfiltered) metals to determine whether the two sampling methods produce comparable results. The results of the comparative statistical analysis of the available dissolved and total metals datasets have been periodically reported in previous quarterly and annual groundwater monitoring reports (GMRs). The most recent and final sampling for dissolved and total metals occurred during the 3Q 2014 and 1Q 2015 events for 29 off-Site wells that were installed in 2013/2014 and first sampled in 3Q 2014. The statistical comparison of the complete dissolved and total metals datasets is presented in the 2015 Annual GMR (BC 2016c).

Based on the statistical analyses, differences between dissolved and total metals concentrations in groundwater samples collected from monitor wells are non-existent or are too small to be meaningful. It is concluded that groundwater sampling both with and without filtering of samples produce equivalent datasets.

3.2.4 Soil Sampling and Testing

Pursuant to the *Agricultural Fields Characterization Work Plan - Revision 2* (BC 2010d), soil samples were collected from select borehole cores in the Shallow, Intermediate and Deep zones. The types of samples collected, and a brief description of the sampling objectives, are provided below.

- Soil samples were collected for analysis of grain size distribution to generate laboratory-determined Unified Soil Classification System (USCS) soil descriptions for comparison to USCS descriptions made in the field at the time of drilling.
- Non-redox preserved soil samples were collected for bulk chemical analyses to characterize chemical concentrations in soils.
- Redox-preserved soil samples were collected using EPA-specified procedures that preserve the subsurface oxidation state of the sediments, and archived at the Site for potential testing pursuant to the *Aquifer Solids Testing Work Plan - Revision 1* (BC 2010e).

Soil sampling information is provided in Appendix E and discussed briefly below.

Grain Size Analysis

A total of 37 samples of aquifer materials were obtained from 16 borehole locations for grain size distribution analyses by sieving of material larger than 75 µm (i.e., retained on a No. 200 sieve). Laboratory reports with the grain size distribution data are provided in Appendix E-1. Grain size distribution results were used to generate laboratory-derived USCS lithologic classifications for comparison to the field-derived USCS lithologic classifications based on visual inspection of core during drilling. As shown in Table 3-5, field USCS classifications were generally consistent with laboratory USCS classifications, especially with respect to finer-grained materials.

Table 3-5. Sample Locations for Grain Size Analysis

Borehole Name	Sample Interval (feet bgs)	USCS Classification (Field)	Percent Fines (Field)	USCS Classification (Laboratory)	Percent Fines (Laboratory)
B/W-2	378-384	SW	5	SM	12.7
B/W-2	442-454	SC	35	SC	26.4
B/W-32	21-27	SM	15	SM	18.7
B/W-32	411-414	SW-SM	10	SM	13.5
B/W-36	57-71	SM	30	SM	13.5
B/W-37	111-117	CL	80	CL	82.0
B/W-38R	140-143	GW	5	SW-SM	7.8
B/W-38R	208-212	SC	35	SC	25.7
B/W-38R	249-253	SM	30	SM	18.6
B/W-40	220.5-226	SM	15	SM	19.2
B/W-40	451-456	SP	5	SM	20.9
B/W-42	159-165	SM	15	SP-SM	5.9
B/W-51	64-69	SC	35	SC	15.0
B/W-54	46-52	CL	65	CL	63.1
B/W-54	52-61	SW	10	SW-SM	8.3
B/W-55	42-51	CH	95	CL	74.4
B/W-55	118-125	SM	20	CL	51.2
B/W-55	135-145	SW	5	SP	4.9
B/W-55	175-185	SP	5	SW	2.9
B/W-60	32-36	SM	35	SM	23.3
B/W-60	132.5-136	ML	60	CL	70.1
B/W-60	450-456	SM	25	SM	22.6
B/W-61	299-306	SP	10	SP-SM	7.7
B/W-64	27-31	SP	10	SP-SM	12.0
B/W-64	43-47	CL	75	CL	93.0
B/W-64	67-77	SW	10	SP-SM	12.0
B/W-64	177-185	SW	10	SW	5.0
B/W-66	59-64	CH	70	CL	66.1
B/W-66	65.5-68	SC	40	SC	23.0
B/W-66	89-93	SC	20	SC	48.7
B/W-67	27-32	SP	5	SM	28.5
B/W-67	38-55	CL	60	CL	64.0
B/W-67	142-146	SC	40	SC	31.8
LEP-MW-2	61-66	CL	50	SC	22.1
LEP-MW-2	212-217	CH	95	SC	34.4
LEP-MW-2	266-273	SW-SM	10	SM	12.8
LEP-MW-2	341-346	CL	50	SC	36.2

Notes: SW = Well Graded Sand or Well Graded Sand with Gravel (where gravel is more than 15%).
SP = Poorly Graded Sand or Poorly Graded Sand with Gravel (where gravel is more than 15%).
SW-SM = Well Graded Sand with Silt or Well Graded Sand with Silt and Gravel (where gravel is more than 15%).
SP-SM = Poorly Graded Sand with Silt or Poorly Graded Sand with Silt and Gravel (where gravel is more than 15%).
SC = Clayey Sand or Clayey Sand with Gravel (where gravel is more than 15%).
SM = Silty Sand or Silty Sand with Gravel (where gravel is more than 15%).
CL = Lean Clay, Lean Clay with Sand, Sandy Lean Clay or Sandy Lean Clay with Gravel (where gravel is more than 15%).
CH = Fat Clay, Fat Clay with Sand, Sandy Fat Clay or Sandy Fat Clay with Gravel (where gravel is more than 15%).
GW = Well Graded Gravel with Sand.

Solids Sampling for Bulk Chemistry

Samples of archived core were collected from select depths in boreholes B/W-1, B/W-31, B/W-32, B/W-42, B/W-46, B/W-61, B/W-62, B/W-65, B/W-66, B/W-67, and MW-5 and submitted to the laboratory for bulk chemical analysis of the parameters listed in Table 3-6. Sample collection methods conformed to SOP-11 of the QAPP. Concentrations of metal/metalloids (hereinafter referred to as metals) and radiochemicals in the solid soil samples were determined by microwave-assisted digestion using EPA Method 3051A (HNO_3). The locations, sample depths and laboratory results are summarized in Appendix E-2.

Table 3-6. Analyte List for Soil Samples

Parameter or Analyte	Method (1)	Reporting Limit (1)	Units (2)
Soil pH	EPA 9045C	0.1	s.u.
Total and Acid Soluble Sulfur	Method 9030B	0.4	mg/kg
Chloride	EPA 300.0	5	mg/kg
Nitrate (as N)	EPA 300.0	1.1	mg/kg
Sulfate	EPA 300.0 (4)	5.0	mg/kg
TOC, TC, TIC (3)	EPA LG601 (2)	1.0	mg/kg
Aluminum	EPA 6010B	10	mg/kg
Antimony	EPA 6020	1.0	mg/kg
Arsenic	EPA 6020	0.5	mg/kg
Barium	EPA 6020	0.5	mg/kg
Beryllium	EPA 6020	0.3	mg/kg
Boron	EPA 6010B	5.0	mg/kg
Cadmium	EPA 6020	0.5	mg/kg
Calcium	EPA 6010B	15	mg/kg
Chromium	EPA 6020	1.0	mg/kg
Cobalt	EPA 6020	0.5	mg/kg
Copper	EPA 6020	1.0	mg/kg
Iron	EPA 6010B	5.0	mg/kg
Lead	EPA 6020	0.5	mg/kg
Magnesium	EPA 6010B	10	mg/kg
Manganese	EPA 6020	0.5	mg/kg
Molybdenum	EPA 6020	1.0	mg/kg
Nickel	EPA 6020	1.0	mg/kg
Potassium	EPA 6010B	50	mg/kg
Selenium	EPA 6020	1.0	mg/kg
Sodium	EPA 6010B	50	mg/kg
Uranium, Total	EPA 6020	0.10	mg/kg
Vanadium	EPA 6020	1.0	mg/kg
Zinc	EPA 6020	10	mg/kg
Uranium-234, 235, 238	HASL 300 (U-02-RC)	1.0	pCi/g

Notes:

1) EPA laboratory analytical methods and reporting limits are consistent with those provided in QAPP (ESI and BC 2009); alternative analytical methods identified in the QAPP may also be used.
2) s.u. = standard units; mg/kg = milligrams per kilogram; pCi/g = picocuries per gram.
3) Total Organic Carbon (TOC), Total Carbon (TC), and Total Inorganic Carbon (TIC).
4) EPA Method LG601 (Dry Combustion, Infrared Detection) as described in EPA 2005.

Vertical profiling of chemical concentrations in soils beneath the agricultural fields was performed to help understand potential chemical loading to groundwater unrelated to mining. Other evaluations involving characterization of groundwater quality upgradient and downgradient of agricultural fields and the sulfur isotope signatures associated with gypsum, an agricultural fertilizer/soil amendment, proved more useful for evaluating groundwater impacts associated with agricultural activities (see Section 5.5).

Redox-Preserved Soil Sampling and Archiving

During the 2007 Second-Step HFA (BC 2008c) and 2010 field investigation (BC 2013a), soil samples were opportunistically collected using EPA-specified procedures that preserved the subsurface oxidation state of the sediments. Redox-preserved soil samples were collected at select borehole locations near the Evaporation Ponds (B/W-11, B/W-18, LEP-MW-9I, MW-5, and W4CB-2), the agricultural fields adjacent to the Site (B/W-61, B/W-65, and B/W-66), and at B/W-32 (i.e., at OU1-DPT-28, which was identified during the Shallow zone investigation in 2009).

The redox-preserved soil samples were archived at the Site for potential laboratory testing (BC 2010e) to evaluate geochemical processes that affect the release and/or attenuation of chemicals from/onto aquifer solids (in particular, chemical partitioning to various mineral fractions), and the mobility and transport of chemicals in groundwater at the Site. The disposition of archived, redox-preserved soil samples is described in Section 3.3.5, which addresses chemical transport evaluations.

3.2.5 Aquifer Hydraulic Properties Testing

The 2007 SOW (EPA 2007a) required "*Definition of aquifer properties (e.g., hydraulic conductivity, transmissivity, and storativity) by a program of aquifer testing to measure the hydraulic connection between areas and throughout the known extent of contamination*." In addition, characterization of aquifer hydraulic properties was identified as DQO #5 in the Revised Groundwater RI Work Plan (BC 2014a).

Hydraulic properties of the alluvial aquifer, as well as bedrock, are provided in Appendix F and have been estimated based on a variety of small- to large-scale test methods including:

- Slug testing of groundwater monitor wells;
- Analysis of steady-state drawdown data obtained during routine quarterly low-flow sampling of monitor wells;
- Constant-rate pumping tests of the eleven wells comprising the PWS during 2010;
- Slug testing of piezometers installed near the PWS that were used as observation wells during constant-rate pumping tests of the 11 wells comprising the PWS during 2010; and
- A constant-rate pumping test of agricultural well WDW019 using an observation network of 93 monitor wells, of which 61 exhibited pumping-related responses.

Small-scale test methods, such as slug testing, provide data that are useful for identifying spatial patterns related to geology, guiding characterization, and as a preliminary estimate of hydraulic conductivity. Because slug test data are available throughout the Study Area, this dataset is used to evaluate spatial patterns in hydraulic conductivity within the Study Area. Data from the pumping test at WDW019, the other large-scale pumping tests, and subsequent groundwater model development using a parameter estimation technique (Doherty 2009), have been used to develop representative field-scale estimates of hydraulic conductivity and, therefore, groundwater velocity.

3.2.6 Surface Water Characterization

The hydrology of the study area is dominated by groundwater recharge from surface water associated with agricultural irrigation (Carroll et al. 2010; Huxel and Harris 1969; Myers 2001). Therefore, understanding the flows in the Walker River and diversions for nearby agricultural activities is important for understanding and contextualizing the data collected in the Study Area. Both regional and local (i.e. Study Area) characterization activities were conducted.

To characterize regional surface water hydrology, daily stream flows for the Walker River are obtained at several gaging locations throughout the Mason Valley, both upstream and downstream of the Site. The data collected from the gaging stations are maintained by the USGS, often in cooperation with state and local agencies, and are available at the USGS website (http://waterdata.usgs.gov/nv/nwis/sw). Surface water quality in the Walker River is also routinely

monitored by various federal, state, and miscellaneous agencies/entities. Much of this data is assembled and made publicly-available through the EPA's STOrage and RETrieval (STORET) Data Warehouse. This dataset supplements the data collected by ARC.

To evaluate the quality of surface water used to irrigate the Hunewill Ranch agricultural fields next to the Site, samples were collected and analyzed from the West Campbell Ditch (SW-WCD-01) and the Walker River (SW-WR-01), pursuant to the *Agricultural Fields Characterization Work Plan - Revision 2* (BC 2010d). Sampling locations are shown on Figure 3-6. West Campbell Ditch receives its water directly from the Walker River. The Walker River monitoring point (SW-WR-01) is located less than 1,000 feet upstream of the diversion point for West Campbell Ditch. The monitoring location in West Campbell Ditch (SW-WCD-01) is located about three miles farther downstream from the diversion point. Potential temporal trends in surface water quality during non-irrigation and irrigation periods were addressed by collecting samples monthly at these locations for 12 months during 2010/2011.

Field parameters (temperature, pH, specific conductivity, DO, sulfate and turbidity) were measured at the time of sample collection, and samples were submitted for the analysis (total concentrations) of the parameters listed in Table 3-4. Surface water samples were collected using the direct-grab method described in SOP-18 in the QAPP. This surface water sample collection method is consistent with the method used by NDEP to collect samples at other surface water monitoring stations in the Mason Valley. Laboratory analyses were conducted in accordance with the QAPP. Surface water data are presented in Appendix G and summarized in Section 4.7.

3.2.7 Hydrologic Tracer Studies

Hydrologic tracer investigations were initiated to help characterize Study Area groundwater conditions, refine the HCSM, and identify background groundwater quality types (BC 2008c, 2012b, 2014a). A variety of hydrologic tracers were initially identified as having the potential to provide information on the origin, age, sources of dissolved constituents, and migration pathways of groundwater and surface water in the Study Area.

To evaluate the feasibility of using hydrologic tracers to support these objectives, samples were collected prior to 2010 from a select number of groundwater monitor wells and surface water features. Based on the apparent efficacy of using hydrologic tracers to assess Study Area groundwater conditions, additional EPA-approved hydrologic tracer sampling events were conducted. Over time, the hydrologic tracer sampling events evolved with changes primarily related to increases in the number of groundwater monitor wells that were sampled, opportunistic collection of standing rainwater samples, and elimination of select tracers considered less useful for characterizing groundwater conditions.

Table 3-7 provides a chronology of the various OU-1 hydrologic tracer sampling events.

Table 3-7. Chronology of Hydrologic Tracer Sampling Events

Date	Sampling Locations (1)	Hydrologic Tracers (2)	Information Source(s)
July/August 2008	Hydrologic tracer samples were collected from 47 of the 94 (50%) active groundwater monitor wells at the time that routine groundwater monitoring was conducted.	Uranium isotopes, sulfate isotopes, tritium, tritium/ helium, $\delta^{18}O/\delta^{2}H$ in water, and nitrate isotopes.	*Second-Step Hydrogeologic Framework Assessment Data Summary Report* (BC 2008c).
February 2011	Samples were collected from the Walker River and West Campbell Ditch, and from 127 of the 223 (57%) active groundwater monitor wells at the time of sampling.	Uranium isotopes, sulfate isotopes, tritium, tritium/ helium, $\delta^{18}O/\delta^{2}H$ in water, nitrate isotopes, CFCs, $\delta^{13}B$, and $\delta^{36}Cl$.	*Draft Site-Wide Groundwater Operable Unit (OU-1) Remedial Investigation Work Plan* (BC 2012b). Revised Groundwater RI Work Plan (BC 2014a).
May 2012	Samples were collected from: 1) three surface water locations (Pit Lake, Walker River and West Campbell Ditch); and 2) 279 of the 287 (97%) active groundwater monitor wells at the time of sampling.	Uranium isotopes, sulfate isotopes, tritium, tritium/ helium, CFCs, and SF_6.	Conclusions about the usefulness of specific hydrologic tracers collected in 2011 were noted in correspondence between ARC and EPA (2012a). With EPA approval (2012b), samples collected during May 2012 were not analyzed for stable isotopes in water or nitrate isotopes. May 2012 results were provided in the *Background Groundwater Quality Assessment - Revision 2* (BC 2015c).
July 2013	Collection of 14 standing rain water samples following a large precipitation event.	Uranium isotopes and sulfate isotopes.	July 2013 results provided in the *Background Groundwater Quality Assessment - Revision 2* (BC 2015c).
August 2014	Groundwater samples were collected from all (100%) of the new wells installed pursuant to the Additional Monitor Well Work Plan (BC 2013b) except well HLP-02B because it was dry. Also sampled were the four wells at the B/W-65 cluster, which were inaccessible in May 2012, and monitor well YPT-MW-15I, which was installed in October 2012. Five wells were resampled to evaluate the results reported in May 2012.	Uranium isotopes, sulfate isotopes, tritium, and tritium /helium.	August 2014 results provided in the *Background Groundwater Quality Assessment - Revision 2* (BC 2015c).

Notes:

1) Hydrologic tracer samples from monitor wells were collected in conjunction with routine groundwater monitoring events associated with the GMP (BC 2012a).
2) Uranium isotopes include ^{234}U, ^{235}U, and ^{238}U; Sulfate isotopes = $\delta^{34}S/\delta^{18}O$ in dissolved sulfate; Nitrate isotopes = $\delta^{15}N/\delta^{18}O$ in dissolved nitrate; $\delta^{13}B$ = boron isotopes in the water samples; $\delta^{36}Cl$ = chloride isotopes in the water samples; CFCs = chlorofluorocarbons; SF_6 = Sulfur Hexafluoride.

Hydrologic tracer samples were collected from monitor wells in conjunction with routine Site-Wide groundwater sampling events using low-flow, minimal drawdown sample collection procedures specified in the GMP (BC 2012a), as well as tracer-specific sampling protocols specified in SOP-17 of the QAPP (ESI and BC 2009). Surface water hydrologic tracer samples were collected using the direct-grab method described in SOP-18 of the QAPP. This surface water sample collection method is consistent with the method used by the NDEP to collect samples at other surface water monitoring stations in the Mason Valley. Table 3-8 presents the parameters, analytical methods, reporting limits, and accuracy and precision goals for the hydrologic tracer analyses.

Table 3-8. Analyte List for Hydrologic Tracer Samples

Parameter	Analytical Method	Analytical Precision (1)	Reporting Limit (2)	Matrix Spike Accuracy	Lab Control Sample Accuracy
Tritium (^{3}H)	wrd (^{3}He-ingrowth)	± 0.1 TU (3)	NA	NA	NA
Tritium/Helium (^{3}H/^{3}He)	Noble Gas MS	± 1%	NA	NA	NA
^{34}S in Sulfate	EA-IRMS (Combination to SO_2) USGS RSIL Lab Code 1951	± 0.5‰	NA	NA	NA
^{18}O in Sulfate	EA-IRMS (Combination to CO_2) USGS RSIL Lab Code 1951 (4)	± 0.5‰	NA	NA	NA
^{234}U, ^{235}U, ^{238}U	HASL-300 (U-02-RC) (5)	RPD<20% or RER<2	1 pCi/L	70-130%	75-125%
Total Uranium	EPA 200.8 ICP-MS	20%	0.1 µg/L	70-130%	80-120%
Chlorofluorocarbons (CFCs)	GC-ECD	0-2%	0.001×10^{-12} pmol/kg	NA	NA
Sulfur Hexafluoride (SF_6)	GC-ECD	1-3% (6)	0.01×10^{-15} fmol/kg	NA	NA

Notes:

1) Precision is the average standard deviation (1-sigma) in per mil units (‰). Precision limit applicable for matrix spike/matrix spike duplicate, laboratory duplicate, laboratory control sample/ laboratory control sample duplicate, or reference standard analyses.
2) The method detection limits presented are laboratory-derived limits.
3) TU = tritium unit; NA = not applicable; RPD = relative percent difference; RER = replicate error ratio; EA-IRMS = elemental analyzer-isotopic ratio mass spectrometer; ICP-MS = inductively coupled plasma mass spectroscopy; TIMS = thermal ionization mass spectrometer; GC-ECD = Gas Chromatography with Electron Capture Detection; % = percent
4) USGS Reston Stable Isotope Laboratory (RSIL) Lab Code 1951 (USGS 2006).
5) Method U-02-RC: see Isotopic Uranium in Biological and Environmental Materials for water samples as documented in HASL-300 (Rev. 1, February 2000) available at URL address: http://www.eml.st.dhs.gov/publications/procman/.
6) Wanninkhof et al. (1991); Law et al. (1994).
7) mg/L = milligrams per liter; µg/L = micrograms per liter; pmol/kg = picomoles per kilogram; fmol/kg = femtomole per kilogram; pCi/L = picocuries per liter.

Laboratory analytical results for hydrologic tracers achieved the completeness, accuracy and precision goals specified in relevant planning documents including the QAPP (ESI and BC 2009) and SOP-17. Hydrologic tracer information that relates directly to the groundwater recharge aspects of the HCSM and the background groundwater assessment was obtained in May 2012 and August 2014. These data are discussed in Section 5.0. Appendix H provides supplemental information about hydrologic tracer sampling and analysis including:

- A detailed discussion of the locations where hydrologic tracer samples were collected during May 2012, July 2013, and August 2014;
- Analytical results of hydrologic tracer samples of standing rain water impounded on mine waste features after a large rain event (average of 1.55 inches on-Site) on July 4, 2013;
- A detailed description of the sample collection procedures, analytical methods, laboratory precision goals for each hydrologic tracer, and QA/QC sample results;
- An evaluation and discussion of the limited usefulness of CFC and SF_6 data for estimating groundwater ages in the Study Area;
- A discussion of the principles and application of uranium isotopes to groundwater interpretation;
- A discussion of the principles of groundwater age estimation using data for tritium and tritium/helium in groundwater;
- A discussion of the additional sources of sulfate isotope data potentially relevant to groundwater conditions in the Study Area; and
- Electronic copies of the analytical results provided by the laboratory and laboratory-calculated apparent groundwater ages.

3.2.8 Bedrock Groundwater Characterization

Since 2005, phased field investigations associated with OU-1 have included characterization of both the alluvial and bedrock groundwater systems. The Revised Groundwater RI Work Plan (BC 2014a) presented available groundwater information through May 2012, and described an updated HCSM for the bedrock and alluvial groundwater systems. The Revised Groundwater RI Work Plan also outlined the approach for completing the bedrock groundwater study elements specified in the 2007 SOW. Bedrock characterization activities that were approved by EPA are described below in Table 3-9.

Table 3-9. Chronology of Bedrock Groundwater Characterization Activities

2004-2007	Bedrock characterization (including borehole drilling, lithologic logging, well installation, hydraulic testing, water level monitoring, and groundwater quality monitoring) conducted pursuant to the First-Step HFA Work Plan (BC 2005) and Second-Step HFA Work Plan (BC 2007b).
2007	Characterization of bedrock groundwater conditions is required under the Administrative Order for Remedial Investigation and Feasibility Study (RI/FS), CERCLA Docket No. 9-2007-0005 dated January 12, 2007.
2007-2011	Bedrock characterization (including borehole drilling, lithologic logging, well installation, hydraulic testing, water level monitoring, and groundwater quality monitoring) conducted pursuant to the *2010 Groundwater Monitor Well Work Plan - Revision 2* (BC 2010c), *Agricultural Fields Characterization Work Plan - Revision 2* (BC 2010d), *On-Site Monitor Well Installation Work Plan - Revision 1* (BC 2011a), and the *Addendum to the On-Site Monitor Well Installation Work Plan* (ARC 2011).
August 17, 2011	Groundwater technical meeting with EPA, ARC and stakeholders to discuss progress of the phased approach to groundwater RI activities, which resulted in concurrence to conduct initial bedrock characterization activities to support a more comprehensive assessment of bedrock groundwater conditions as part of the RI characterization.
September 29, 2011	EPA (2011a) provided comments on the *2010 Annual Site-Wide Groundwater Monitoring Report* dated April 15, 2011, and the First and Second Quarter (1Q and 2Q) 2011 Groundwater Monitoring Reports dated July 1, 2011 and August 26, 2011, respectively, that pertained to bedrock characterization.
January 5, 2012	ARC submitted the *Proposed Initial Bedrock Characterization Activities* (ARC 2012a).
April 12, 2012	EPA (2012c) provided comments on the *Proposed Initial Bedrock Characterization Activities* (ARC 2012a).
June 18, 2012	ARC submitted preliminary responses to EPA comments on the *Proposed Initial Bedrock Characterization Activities.*
August 28, 2012	Groundwater technical meeting with EPA, ARC and other stakeholders to resolve comments on the *Proposed Initial Bedrock Characterization Activities.*
October 11, 2012	Submittal of ARC final responses to EPA comments on the *Proposed Initial Bedrock Characterization Activities,* and submittal of the *Proposed Initial Bedrock Characterization Activities - Revision 1* (ARC 2012b).
October 22, 2012	EPA (2012d) approval of the *Proposed Initial Bedrock Characterization Activities - Revision 1,* included as Attachment D to the Revised Groundwater RI Work Plan (BC 2014a).
March 2013	ARC began implementation of the EPA-approved *Proposed Initial Bedrock Characterization Work Plan - Revision 1.*
November 20, 2013	ARC submitted the *Initial Bedrock Characterization Data Summery Report* (BC 2013c).
February 7, 2014	ARC submitted the *Site-Wide Groundwater Remedial Investigation Work Plan - Revision 1* (BC 2014a), which presented available groundwater information through May 2012, and described an updated HCSM for the bedrock and alluvial groundwater systems.
January 28, 2015	ARC submitted the *Bedrock Groundwater Assessment Technical Memorandum* (BC 2015a).
June 11, 2015	ARC submitted the *Additional Monitor Well Installation Data Summary Report* (BC 2015d) detailing installation and testing of bedrock and alluvial wells installed in 2013 and 2014.
July 31, 2016	EPA (2016a) approved the *Bedrock Groundwater Assessment Technical Memorandum* (BC 2015a).

After installation and testing of new bedrock monitor wells in late 2013 and 2014, and a technical meeting in May 2015 to discuss the full set of bedrock information, EPA (2015a) concluded that sufficient data had been collected to conclude that bedrock is not an important migration pathway

at the Site, and requested preparation of a technical memorandum to update the bedrock HCSM. The *Bedrock Groundwater Assessment Technical Memorandum* (BC 2015a) is provided in Appendix I and bedrock information is summarized in Section 4.9.

3.3 Site-Wide Groundwater Studies and Evaluations

Studies and evaluations relying on OU-1 RI data that were conducted to fulfill certain study elements specified in Section 7.0 of the SOW attached to the 2007 Order (EPA 2007a) are described below. Reports describing the approach, analysis, and results of these groundwater related studies and evaluations are provided in Appendix J.

3.3.1 Pumpback Well System Effectiveness

The effectiveness of the PWS in limiting the off-Site migration of mine-impacted groundwater was evaluated in accordance with the *Pumpback Well System Characterization Work Plan Addendum - Revision 2* (ARC 2010).

The 11 pumpback wells ceased pumping on March 25, 2009 and were subsequently hydraulically tested to generate information to support a capture zone analysis using an analytical element model. These activities provided a preliminary assessment sufficient to conclude that the PWS was only partially effective in capturing Shallow zone mine-impacted groundwater during its operational life. The PWS effectiveness evaluation is described in the *Summary of PWS Aquifer Testing* (BC 2010f), which is included as Appendix J-1.

3.3.2 Pit Lake Water Levels

The Pit Lake (OU-2), which is currently refilling with groundwater from bedrock and alluvial flow systems (BC 2014a), has been studied to better understand its influence on Site-wide groundwater conditions. Pit Lake studies related to OU-1 include routine monitoring of the Pit Lake water level elevation beginning in September 2007 and a water balance evaluation (Appendix J-2) to predict the future "steady-state" elevation of the Pit Lake.

Groundwater inflow, based on the lake water balance study, is estimated to be slightly greater than the current rate of evaporation. Thus, the lake level is slowly rising with time. The Pit Lake water balance and projection of the pit refilling curve (Figure 3-7) indicate that the lake is expected to reach a steady-state level, where water inflow and evaporation are balanced, prior to 2030. The steady-state Pit Lake elevation is estimated to be in the range of 4,249 to 4,253 feet amsl, with more recent data indicating that the steady-state elevation may fall within the lower end of this range. The steady-state Pit Lake elevation is approximately: 1) 100 feet lower than the pre-mining groundwater elevation range of 4,350 to 4,375 feet amsl reported by Gill (1951); 2) 140 feet lower than current groundwater levels in the alluvial aquifer adjacent to the Walker River just east of the Pit Lake; 3) 65 feet lower than the current groundwater levels beneath the Evaporation Ponds; and 4) 150 and 340 feet below the east and west pit rim elevations, respectively.

The steady-state Pit Lake level is projected to be lower than the pre-mining water level as the result of the significant evaporation that occurs from the Pit Lake surface. Consequently, the lake is and will continue to be a groundwater sink that creates a localized cone of depression (extending as far north as the Process Areas) with local groundwater flow toward the pit. Because the Pit Lake does not and will not in the future discharge into the Site-wide groundwater system, the Pit Lake is not a source of COIs to Site-Wide groundwater.

3.3.3 Groundwater Pumping and Surface Water Points of Diversion

Groundwater conditions in the Study Area are influenced by groundwater pumping and surface water diversion associated primarily with irrigation and, to a lesser extent, stock watering and mining/milling (BC 2014a; S.S. Papadopulos & Associates, Inc. [SSPA] 2014).

Publicly-available groundwater pumping and surface water diversion information applicable to the Study Area is provided in the *Revised Public Information for the Northern Portion of the Background Groundwater Study Area* (BC 2013d) included in Appendix J-3. That document also includes: well ownership, location and construction; underground and surface water rights and points of diversion (PODs); well pumping records from 1993 to 2010; sub-surface lithology and, as applicable, depth to bedrock; and groundwater elevations from the NDWR and the USGS.

PODs from an underground source (i.e., groundwater) for the wells with water rights within and adjacent to the Study Area are shown on Figure 3-8, along with diversion rates and annual duties. All agricultural wells within and near the Study Area are screened in the alluvial aquifer. Although well construction varies greatly, agricultural wells used to extract groundwater for crop irrigation are either screened beginning at or near the water table to the total depth of installation and/or have been installed with a permeable filter pack from above the water table surface to the total depth of installation. Annual pumping inventories (i.e., actual total amounts pumped each year) for wells in the Mason Valley from 1994 to 2003 and from 2004 to 2010 have been reported by Gallagher (2004) and Gallagher (2013), respectively.

Within the Study Area, there are 20 wells used for irrigation, four wells used for stock watering, one used for mining/milling, and one used for commercial purposes (Gallagher 2013). The 20 irrigation wells are currently permitted to irrigate a total of 5,509 acres using an annual duty of 15,788 acre-feet with a combined diversion rate of 46.36 cubic feet per second (cfs). Of the 36 active water rights, 26 allow for pumping to occur on a year-round basis, nine of the rights can only be pumped during the irrigation season, and one right can only be used in the winter.

The place of use (POU) of 37 surface water rights within and adjacent to the Study Area that are identified in the amended Walker River Decree (WRD), Case in Equity, C-125, filed April 24, 1940 (WRD C-125; WRD, 1940) are shown on Figure 3-9. This figure also shows the POUs of surface water rights approved by NDWR as either new appropriations or applications to change WRD rights. Additional information about the distribution and routing of surface water is included in the discussion of surface water hydrology in Section 4.7.

The POUs of flood waters permitted by NDWR Application 5528, Certificate 8859 are shown on Figure 3-10 by quarter-section. Application 5528 was filed by the Walker River Irrigation District (WRID) to divert flood waters from the Walker River for irrigation from May 1 to July 31 of each year. Application 5528 was certificated for 491.2 cfs, not to exceed 89,612 acre-feet per season (the total duty of water cannot exceed 4.0 acre-feet per acre per season from any and/or all sources). The lands irrigated under this Certificate during any one season cannot exceed 30,000 acres.

3.3.4 Groundwater Model Development

The 2007 SOW (EPA 2007a) specified that the OU-1 RI "extrapolate the future contaminant transport using a comprehensive groundwater flow and fate-and-transport model". In addition, determining groundwater flow and chemical transport rates was identified as DQO #6 in the Revised Groundwater RI Work Pan (BC 2014a).

The technical and programmatic framework to address quantitative numerical modeling of groundwater flow and chemical transport was developed during iterative technical discussions with the EPA, ARC, and other stakeholders, and documented in the Revised Groundwater RI Work Plan (BC 2014a). Table 3-10 summarizes the chronology of investigations, evaluations, communications, and documents related to groundwater flow modeling.

Table 3-10. Chronology of Groundwater Modeling Activities

2004-2007	Characterization of groundwater conditions in the Study Area pursuant to the First-Step HFA Work Plan (BC 2005) and Second-Step HFA Work Plan (BC 2007b).
2007	Characterization of bedrock groundwater conditions is required under the Administrative Order for Remedial Investigation and Feasibility Study (RI/FS), CERCLA Docket No. 9-2007-0005 dated January 12, 2007.
2007-2011	Characterization of groundwater conditions in the Study Area pursuant to the various work plans and related correspondence (BC 2008c, 2010c, 2010d, 2011a; ARC 2011).
May 16, 2011	Conference call with EPA, ARC and other stakeholders to discuss groundwater flow modeling.
August 17, 2011	Groundwater technical meeting with EPA, ARC and stakeholders to discuss the status of RI activities, which resulted in concurrence to conduct groundwater modeling to support a quantitative evaluation of groundwater flow and chemical transport.
June 4, 2012	Conference call with EPA, ARC and other stakeholders to discuss groundwater flow modeling activities, which resulted in a request by EPA that ARC submit a document describing key groundwater modeling deliverables and milestones, and a draft table of contents for a groundwater modeling work plan.
June 25, 2012	ARC submitted the *Groundwater Flow Modeling Deliverables* (ARC 2012c), which included: 1) a preliminary summary of key groundwater modeling deliverables and milestones; and 2) a draft table of contents for a groundwater flow model work plan.
July 11, 2012	EPA (2012e) provided comments on the *Groundwater Flow Modeling Deliverables* (ARC 2012c).
July 17, 2012	Groundwater technical meeting with EPA, ARC and stakeholders to discuss findings of the 2011 Monitor Well Installation investigation, and related RI activities, which resulted in an EPA request that ARC submit a document summarizing groundwater modeling objectives.
August 14, 2012	ARC submitted the *Objectives for Groundwater Modeling in the RI/FS Process, Yerington Mine Site* (SSPA 2012a).
August 29, 2012	Groundwater technical meeting with EPA, ARC, and other stakeholders to discuss the groundwater modeling objectives.
October 15, 2012	ARC submittal of the *Objectives for Groundwater Modeling in the RI/FS Process - Revision 1, Yerington Mine Site* (SSPA 2012b).
October 26, 2012	EPA (2012f) approval of the *Objectives for Groundwater Modeling in the RI/FS Process - Revision 1, Yerington Mine Site* (SSPA 2012b).

Table 3-10. Chronology of Groundwater Modeling Activities	
December 28, 2012	ARC submittal of the *Draft Groundwater Flow Model Work Plan for the Yerington Mine Site* (SSPA 2012c).
March 29, 2013	EPA (2013d) provided comments on the *Draft Groundwater Flow Model Work Plan for the Yerington Mine Site* (SSPA 2012c).
May 21, 2013	ARC submittal of the *Groundwater Flow Model Work Plan - Revision 1* (SSPA 2013) included as Attachment E to the Revised Groundwater RI Work Plan, along with responses to EPA comments on the *Draft Groundwater Flow Model Work Plan* (SSPA 2012c).
March 18, 2014	ARC submittal of the *Groundwater Flow Model Yerington Mine Site* (SSPA 2014). This report synthesized available hydrologic and geochemical information into a quantitative representation of the current and historic HCSM. The report also contained: 1) documentation of the study goals; 2) a discussion of the modeling strategy and assumptions; 3) details about model construction, calibration and validation; 4) a summary of model predictions; and 5) an analysis of the uncertainty associated with the model predictions.
October 28, 2014	EPA provided comments on the *Groundwater Flow Model Yerington Mine Site* (SSPA 2014).
February 3, 2015	ARC submits the *Flow Model "Supplemental" Materials* (SSPA 2015) in response to EPA comments.
May 18, 2015	EPA (2015b) provided comments on the *Flow Model "Supplemental" Materials* (SSPA 2015) and approved the *Groundwater Flow Model Yerington Mine Site* (SSPA 2014).

Based on review of the *Flow Model Supplemental Materials* (SSPA 2015), EPA (2015b) constrained the modeling objective and approved the groundwater flow model, noting that: "The primary goal foreseen for the Yerington groundwater model is to provide a management tool that can be used to evaluate possible remediation options. As such, its greatest value will be in allowing short-term comparisons of remedial designs and possible effectiveness of different remediation scenarios using a common tool and less so in predicting long-term migration of contaminants. It appears that this tool is adequate for that purpose".

The groundwater flow model is provided in Appendix J-4. The flow model domain, which encompasses an area of approximately 86 square miles, consists of that portion of the Mason Valley west of the Walker River and north of Mason that is underlain by saturated alluvium (Regional Domain). Nested within the model domain is the Study Area which encompasses an area of approximately 23 square miles that is bounded to the north by Campbell Lane, to the west by the Singatse Range, to the east by a north-south trending line located one mile east of Highway 95, and to the southeast by the Walker River (Local Domain). The Local Domain is nested within the Regional Domain so that appropriate boundary conditions along the northern and eastern boundaries of the overall model domain can be calculated. In addition, the model domain is subdivided to reflect two different sources of data, which may differ in data quality.

The vertical extent of the model domain extends from the ground surface to the alluvial/bedrock contact and into the portions of the bedrock groundwater system in hydrologic communication with the alluvial aquifer. The model domain extends laterally to include monitor well locations for identifying background groundwater quality and groundwater impacted by mining and other anthropogenic activities.

Since 2005, hydrogeologic data within the Local Domain have been and continue to be collected as part of the RI process, pursuant to EPA-approved planning documents and work plans. Thus, these data are high quality and there is a high degree of confidence in the data. Hydrogeologic data from outside the Local Domain but within the Regional Domain are from multiple sources and are of uncertain quality. Much of these data are from the USGS (e.g., water-level data) and the NDWR (e.g., well logs).

Temporal (e.g., seasonal, annual) variations in groundwater flow patterns and chemical concentrations continue to be assessed due to variability in hydrologic stresses on the groundwater system. Monitor wells installed for groundwater characterization purposes continue to be routinely monitored pursuant to the GMP (BC 2012a) to address temporal aspects of the study within the Local Domain. Within the Regional Domain, available water-level and surface water flow data from the USGS and NDWR will be used to assess temporal variations in groundwater conditions.

3.3.5 Chemical Transport Evaluations

The technical and programmatic framework for characterizing groundwater geochemical conditions and assessing geochemical processes that affect the release and subsequent mobility or attenuation of COIs during groundwater transport in the Study Area was presented as DQO #3 in Revised Groundwater RI Work Plan (BC 2014a).

Table 3-11 summarizes the chronology of investigations, evaluations, communications, and documents related to chemical transport evaluation.

Table 3-11. Chronology of Activities to Determine Geochemical Mobilization/Attenuation Processes	
2008	The Second-Step HFA Work Plan (BC 2007b) included collecting and archiving redox-preserved samples of saturated and unsaturated alluvium. EPA technical staff observed the redox-sample collection and archiving methods, and provided input on locations and depth intervals for collecting an initial set of samples. These initial samples were collected for use in a "methods development" phase of work intended to develop Site-specific testing procedures.
June 21, 2010	ARC submitted the *Draft Aquifer Solids Testing Work Plan* (BC 2010g).
September 13, 2010	EPA (2010a) provided comments on the *Draft Aquifer Solids Testing Work Plan* (BC 2010g).
September 21, 2010	ARC submitted the *Aquifer Solids Testing Work Plan - Revision 1* (BC 2010e), which was revised in response to EPA comments.
September 30, 2010	EPA (2010b) approved the *Aquifer Solids Testing Work Plan - Revision 1* (BC 2010e).
2011	ARC developed Site-specific procedures and methods to physically separate redox-preserved samples into solid and liquid fractions for subsequent characterization of total metals concentrations, mineralogy, and porewater chemistry.
February 28, 2012	EPA technical staff visited the testing laboratory (Hazen Research, Inc. in Golden, Colorado) and observed the Site-specific testing procedures.
August 17, 2012	ARC submittal of *SOP-23: Aquifer Solids Testing SOP - Redox-Preserved Sample Preparation and Testing* (BC 2012c).
September 26, 2012	EPA (2012g) transmitted comments on *SOP-23: Aquifer Solids Testing SOP- Redox-Preserved Sample Preparation and Testing* (BC 2012c).
October 15, 2012	ARC submittal of *SOP-23: Aquifer Solids Testing SOP - Redox-Preserved Sample Preparation and Testing - Revision 1* (BC 2012d).
October 22, 2012	EPA (2012d) approval of SOP-23 Revision 1, pending minor changes. These minor changes were incorporated into SOP-23 Revision 2*,* included as Appendix H-1 to the Revised Groundwater RI Work Plan (BC 2014a).
February 7, 2014	ARC submitted the Revised Groundwater RI Work Plan (BC 2014a), which included: 1) DQO #3 pertaining to geochemical attenuation/mobilization; 2) the thermodynamic data for Site-specific geochemical modeling; and 3) Site-specific distribution coefficients (a simple, lumped-parameter variable that describes either the relative affinity of the aquifer matrix for a particular ion or the mobility of the ion in a groundwater flow system) based on chemical concentrations in co-located aquifer sediment and groundwater samples.
October 9, 2014	EPA (2014b) approved the Revised Groundwater RI Work Plan including the thermodynamic data presented in Appendix H-4 for Site-specific geochemical modeling, and directed ARC to prepare a Groundwater Geochemical Characterization Data Summary Report.
December 30, 2014	ARC submitted the *Groundwater Geochemical Characterization Data Summary Report* (BC 2014c). As noted in ARC's transmittal letter, the document partially fulfilled the requirements for the geochemical characterization and ARC recommended additional refinements to the thermodynamic database for geochemical modeling.
April 27, 2015	ARC transmitted recommendations to EPA for refining the thermodynamic database to be used for geochemical modeling (via e-mail).
May 4, 2015	EPA approved ARC's recommendations on refining the thermodynamic database to be used for geochemical modeling (also via e-mail).
September 23, 2015	EPA, ARC and other stakeholders agreed during a conference call that geochemical characterization to be performed for the OU-1 RI should focus on geochemical modeling of: 1) controls on the fate and transport of key COIs anticipated to drive decision-making in the FS; and 2) other chemicals that may affect their mobility and transport in groundwater.
December 11, 2015	ARC submitted the *Groundwater Geochemical Characterization Data Summary Report – Revision 1* (BC 2015e).

Table 3-11. Chronology of Activities to Determine Geochemical Mobilization/Attenuation Processes

July 2016	EPA conditionally approved the document on July 31, 2016 (EPA 2016b) subject to minor editorial changes and revision of statements referencing COI concentrations and spatial extent relative to background chemical concentrations presented in the *Background Groundwater Quality Assessment - Revision 2* (BC 2015c). EPA recommended that a revised version of the report be included as an appendix to the OU-1 RI Report.

The *Groundwater Geochemical Characterization Data Summary Report - Revision 2* (BC 2016a) is provided in Appendix J-5. The chemical speciation model and approach to calculating Site-specific distribution coefficients is summarized below.

Chemical Speciation Model Development

The specific objectives of the *Groundwater Geochemical Characterization Data Summary Report - Revision 2* are as follows:

- Describe the occurrence and distributions of select chemicals in Study Area groundwater based on the comprehensive set of monitor well data obtained during August 2014; and
- Using the EPA-approved thermodynamic database developed for the Site and geochemical modeling, evaluate the aqueous geochemical speciation of select COIs and potential formation of solid mineral phases in Study Area groundwater to assess chemical mobility/attenuation.

The primary geochemical data inputs used to identify the geochemical processes controlling chemical transport consist of: 1) groundwater chemical data from monitor wells installed in the groundwater zones in the alluvial aquifer and bedrock; 2) field parameter measurements that characterize the pH and redox status of the groundwater system (because these affect the aqueous speciation of inorganic chemicals and formation of mineral phases); and 3) thermodynamic data describing chemical reactions for each of the important aqueous species, minerals comprising the aquifer solids, gases, and adsorbed species. The geochemical assessment primarily relied on groundwater information associated with the August 2014 groundwater monitoring event. Approximately 2% of the August 2014 dataset had speciated charge imbalances outside the acceptable range of ±10%, and groundwater data obtained in October 2014 were substituted for August 2014 data.

Geochemical modeling using the Site-specific thermodynamic database with PHREEQC version 3.1.5 was conducted to determine the chemical speciation of aqueous constituents and the saturation indices of solid mineral phases in equilibrium with the groundwater samples. The geochemical modeling did not involve adsorption to aquifer soil/sediments or organics in aquifer materials. Details regarding the development of the Site-specific thermodynamic database are provided in Appendix J-5 and key modifications are discussed briefly below.

The WATEQ4F database was used as the starting point for database development because its major-element data are consistent with the Nordstrom et al. (1990) data compilation, which is a reliable and internally-consistent data set. Subsequently, the WATEQ4F database was modified by replacing aqueous speciation and solid-phase solubility data for uranium, phosphate, vanadium, sulfide, arsenic and copper with new data that have been critically reviewed by federal agencies (e.g., compilations prepared by the Nuclear Energy Agency were the principal sources of the uranium data in the ARC database) or in the peer-reviewed literature (e.g., Dong and Brooks 2006). Uranyl species $Ca_2UO_2(CO_3)_3^0$, $CaUO_2(CO_3)_3^{-2}$, $Mg_2UO_2(CO_3)_3^0$ and $MgUO_2(CO_3)_3^{-2}$ are of particular importance in evaluating the mobility of uranium; therefore, the thermodynamic data for these constituents were added to the Site-specific database. Thermodynamic solubility data for schwertmannite (an oxyhydroxide sulfate mineral) reported by Bigham et al. (1996) and confirmed by Sánchez-España et al. (2011) were included in the database. In addition, thermodynamic solubility data reported by Bourrié et al. (1999) for three hydroxy-green rusts were included in the database.

PHREEQC is a geochemical software model distributed by the USGS. The model assumes equilibrium mass transfer and does not account for the kinetics of mineral precipitation and dissolution reactions using applicable reaction rate laws (Parkhurst and Appelo 1999; EPA 2007b). Chemical speciation modeling describes the distribution of chemical mass between aqueous and solid mineral phases, and hence, predicts the geochemical conditions under which various constituents might be sequestered by mineral precipitation or remain mobile in the groundwater flow system. Both chemical speciation and mineral precipitation are pertinent data for evaluating the mobility of constituents in the groundwater system.

Information generated from the geochemical assessment is incorporated into the discussion of contaminant fate and transport in Section 6.0, and will be used to guide the development of quantitative approaches to representing chemical transport in the numerical groundwater flow model (SSPA 2014) to evaluate various remedial alternatives during the FS. As noted by the EPA (2016b), decisions will be made during the FS regarding the most appropriate reactive transport modelling approach and whether it will be necessary and/or beneficial to integrate the models or how that can be accomplished to efficiently meet the technical needs of the OU-1 RI/FS without introducing unnecessary complexity to the modeling efforts.

Distribution Coefficients

The partition (distribution) coefficient (K_d) is a simple, lumped-parameter variable that is used to assess contaminant transport by describing either the relative affinity of the aquifer matrix for a particular ion or the mobility of the ion in a groundwater flow system (EPA 2007b; Freeze and Cherry 1979).

The initial approach to developing Site-specific distribution coefficients based on chemical concentrations in co-located groundwater and aquifer sediment samples was presented in the Revised Groundwater RI Work Plan (BC 2014a) and is reproduced in this OU-1 RI Report as Appendix J-6. The approach to developing the distribution coefficients is summarized below.

Distribution coefficients were calculated for a variety of chemicals in Site groundwater including aluminum, arsenic, barium, boron, calcium, chloride, chromium, cobalt, copper, fluoride, iron, lead, lithium, magnesium, manganese, molybdenum, nickel, nitrate, potassium, selenium, sodium, sulfate, uranium, vanadium, and zinc. Distribution coefficients were not calculated for parameters that were only infrequently detected in groundwater or are not likely to be the subject of FS transport modeling including alkalinity, antimony, beryllium, cadmium, mercury, phosphorous, silica, silver, strontium, thallium, tin, and titanium.

Site-specific distribution coefficients were calculated using data from a single set of soil samples that were collected during the borehole drilling for monitor well installation and two distinct sets of water quality data. Soil samples were analyzed for a variety of bulk chemical concentrations (analyses were performed on liquid extracts from treatment of the solid samples by microwave-assisted digestion using EPA Method 3051A).

The first set of water quality data used in K_d calculations was the zonal water quality data that were collected at the time of borehole drilling. As discussed in Section 3.2.1, zonal groundwater samples were analyzed only for sulfate, uranium and arsenic. These data were collected over small depth intervals, typically ranging from three to five feet. Co-located zonal groundwater and soil samples were collected at multiple depth intervals in 13 locations throughout the Site that included B/W-1, B/W-2, B/W-3, B/W-4, B/W-11, B/W-31, B/W-32, B/W-42, B/W-46, B/W-61, B/W-62, B/W-65, and B/W-66.

The second set of water quality data used in K_d calculations included groundwater quality data obtained during quarterly sampling events from 15 monitor wells typically having a screen interval length of 20 feet. Monitor well samples were analyzed for the broader set of constituents listed in Table 3-4. The soil sample data used in the calculations were selected such that the sample intervals were within the screened interval of the well. The wells considered in this portion of the analysis were B/W-2D1, B/W-3I, B/W-4I, B/W-4D1, B/W-11D2, B/W-31S1, B/W-31S2, B/W-32S, B/W-42S, B/W-46S, B/W-61S, B/W-62S, B/W-65S, B/W-66S, and B/W-67S. The quarterly groundwater quality results collected closest to the date of the zonal soil sample collection for each particular well were used to calculate K_d values to minimize potential effects from variability in groundwater concentrations over time.

The distribution coefficient is calculated as the ratio of the concentration of a chemical adsorbed onto the solid phase (commonly expressed as milligrams [mg] of chemical per kilogram [kg] of solid) to the dissolved concentration of the chemical in the water (mg of chemical per liter [L] of solution) at equilibrium (Freeze and Cherry 1979). Based on the formulation below, K_d values are expressed in units of L/kg.

$$K_d = \frac{C_{\text{adsorbed}}}{C_{\text{water}}}$$

where: $C_{adsorbed}$ = adsorbed chemical concentration (mg/kg)
C_{water} = dissolved chemical concentration in water (mg/L)

Initially, distribution coefficients were calculated using water chemical data and chemical concentrations in the aquifer sediment sample that were determined using EPA digestion Method 3051A. Because of the relatively aggressive digestion method, the aquifer sediment data represent the bulk (i.e., total) chemical concentration in the solid rather than the adsorbed chemical concentration. As recommended by EPA (1999), trace metals that are present in crystalline lattice sites of minerals present in soils do not participate in adsorption/desorption reactions and should not be included in the K_d calculation. Consequently, the original K_ds were revised for this OU-1 RI Report. To better estimate K_ds, the adsorbed amount of a chemical was estimated by subtracting the average chemical concentration in Sub-area A-1 soils (BC 2009b) from the bulk (i.e., total) chemical concentration in the individual aquifer sediment sample, as follows:

$$K_d = \frac{C_{\text{soil}} - C_{\text{bkgd}}}{C_{\text{water}}}$$

where: $C_{adsorbed} = C_{soil} - C_{bkgd}$
C_{soil} = bulk chemical concentration in the solid (mg/kg)
C_{bkgd} = average background chemical concentration in the solid (mg/kg)
C_{water} = dissolved chemical concentration in water (mg/L)

The revised Site-specific distribution coefficient values are presented in the contaminant fate and transport discussion in Section 6.0.

3.3.6 Background Groundwater Quality Assessment

Identifying background water types and defining the extent of mine-impacted groundwater was specified in the 2007 SOW (EPA 2007a) and identified as DQO #1 in the Revised Groundwater RI Work Plan (BC 2014a). The background groundwater quality assessment (BGQA) has been integrated into groundwater characterization activities performed in the Study Area since 2007.

Table 3-12 summarizes the chronology of the BGQA and other background-related orders, investigations and documents.

Table 3-12. Chronology of Activities Related to Establishing Background Groundwater Quality

2004-2008	Monitor wells B/W-13S, B/W-14S, B/W-15S, B/W-20S, and B/W-21S installed adjacent to Walker River and hydraulically up-gradient of the Site, pursuant to the First-Step HFA Work Plan (BC 2005) and the Second-Step HFA Work Plan (BC 2007b).
2007	Characterization of background groundwater quality is required under the Administrative Order for Remedial Investigation and Feasibility Study (RI/FS), CERCLA Docket No. 9-2007-0005 dated January 12, 2007.
2007-2011	Background characterization conducted pursuant to the *2010 Groundwater Monitor Well Installation Work Plan - Revision 2* (BC 2010c), *Agricultural Fields Characterization Work Plan - Revision 2* (BC 2010d), *On-Site Monitor Installation Work Plan - Revision 1* (BC 2011a), and the *Addendum to the On-Site Monitor Well Installation Work Plan* (ARC 2011).
August 17, 2011	Groundwater technical meeting with EPA, ARC and stakeholders to discuss progress of the phased approach to groundwater RI activities, which resulted in concurrence to accelerate background groundwater characterization activities and an EPA request for ARC to prepare and submit a BGQA. Also discussed were installation of additional well clusters (B/W-12R, B/W-17, and B/W-22R) in areas south and southwest of the Site, pursuant to the *On-Site Monitor Well Installation Work Plan* (BC 2011a), to support background groundwater characterization.
September 7, 2011	ARC submitted the *Addendum to the On-Site Monitor Well Installation Work Plan* (ARC 2011) proposing additional well clusters at B/W-12R, B/W-17, and B/W-26R to support background groundwater characterization.
September 28, 2011	ARC submitted the *Draft Background Groundwater Quality Assessment* (BC 2011c), which recommended the installation of three monitor well clusters (B/W-56, B/W-57 and B/W-58) located in the northern portion of the Study Area.
September 30, 2011	The *Addendum to the On-Site Monitor Well Installation Work Plan* (ARC 2011) was approved by EPA (2011b).
December 7, 2011	Via e-mail communication, ARC requests and receives EPA approval to install well clusters B/W-56, B/W-57, and B/W-58 proposed in the Draft BGQA during implementation of the *On-Site Monitor Well Installation Work Plan - Revision 1.*
February 7, 2012	EPA (2012a) provided comments on the Draft BGQA.
March 19, 2012	ARC (2012d) submitted a request to implement a comprehensive hydrologic tracer sampling event that was larger in scope than the sampling event proposed in the *On-Site Monitor Well Installation Work Plan - Revision 1* (BC 2011a) and to eliminate select hydrologic tracers. Hydrologic tracers are considered one line of evidence that may be useful for determining background groundwater quality.
April 18, 2012	ARC (2012e) submitted responses to EPA comments on the Draft BGQA.
April 27, 2012	EPA approved the comprehensive hydrologic tracer sampling event and request to eliminate select tracers (EPA 2012b).
May 2012	Comprehensive hydrologic tracer sampling event conducted concurrent with the 2Q 2012 quarterly groundwater monitoring event.
August 28, 2012	Groundwater technical meeting with EPA, ARC, and other stakeholders to clarify and resolve comments on the Draft BGQA.
November 19, 2012	Submittal of final ARC responses to EPA comments on the *Draft BGQA* and the *Background Groundwater Quality Assessment - Revision 1* as Attachment A to the *Draft Site-Wide Groundwater Operable Unit (OU-1) Remedial Investigation Work Plan* (BC 2012b).

Table 3-12. Chronology of Activities Related to Establishing Background Groundwater Quality

June 26, 2013	Submittal of the *Draft Additional Monitor Well Work Plan* (BC 2013e) as Attachment B to the *Draft Site-Wide Groundwater Operable Unit (OU-1) Remedial Investigation Work Plan* (BC 2012b), to address data gaps identified by ARC and EPA, including groundwater conditions in the north and northeastern portion of the Study Area. ARC recommended sampling of all wells proposed for hydrologic tracers to supplement data from the May 2012 hydrologic tracer sampling event.
July 29, 2013	EPA (2013e) provided comments on the *Draft Additional Monitor Well Work Plan*.
October 8, 2013	ARC submitted the *Additional Monitor Well Work Plan - Revision 1* (Additional Well Work Plan; BC 2013b). This work plan was also included as Attachment B to the Revised Groundwater RI Work Plan (BC 2014a). EPA (2014b) approved the Revised Groundwater RI Work Plan including Attachment B on October 9, 2014.
September 2013 to July 2014	Installation, development, and hydraulic testing of new wells installed pursuant the Additional Well Work Plan (BC 2013b).
August 2014	Hydrologic tracer sampling of new wells installed pursuant to the Additional Well Work Plan (BC 2013b).
May 2015	Receipt of hydrologic tracer laboratory analytical results for new wells installed pursuant to the Additional Well Work Plan (BC 2013b).
June 11, 2015	ARC submitted the *Additional Monitor Well Installation Data Summary Report* (BC 2015d).
July 2, 2015	ARC submitted the *BGQA – Revision 1 - Revision 2* (BC 2015c), which described: 1) the technical approach, scope, rationale and methods to establish background groundwater quality; and 2) multiple supporting lines of evidence for defining the extent of mine-impacted groundwater and identifying other anthropogenic groundwater impacts.
February 11, 2016	EPA (2016c) provided comments on the *Background Groundwater Quality Assessment - Revision 2*.
June 14, 2016	ARC (2016b) provided responses to EPA Comments on the *Background Groundwater Quality Assessment - Revision 2*.
June 29, 2016	EPA, ARC and other project stakeholders held a groundwater technical meeting to discuss the background assessment.
September 27, 2016	EPA (2016d) letter to ARC providing final direction on the background groundwater quality assessment including an attachment (EPA 2016e) dated September 2, 2016 and titled EPA Memorandum, Subject: Yerington Mine Site, Yerington Nevada (16-R09-003) Responses to ARC Responses to Comments on the Background Groundwater Quality Assessment - Revision 2.
November 11, 2016	ARC submitted the *Background Groundwater Quality Assessment - Revision 3* (BC 2016b).
February 16, 2017	EPA (2017) approved the *Background Groundwater Quality Assessment - Revision 3*.

The *Background Groundwater Quality Assessment - Revision 3* is provided in Appendix J-7 and the results of the background assessment are integrated into the discussion of the nature and extent of contamination in Section 5.0.

3.4 Former Domestic Well Monitoring and Bottled Water Programs

Water quality monitoring of domestic, commercial, and irrigation wells (collectively referred to as domestic wells) located near the Site has evolved over time.

Domestic well monitoring began in late 1983. Up through early 2009, domestic well monitoring activities were performed pursuant to:

- Paragraphs 15(e) and 15(f) of the Unilateral Administrative Order for Initial Response Activities, Docket No. 9-2005-0011 (2005 Order);
- Section 6.0 of the 2007 SOW; and
- The Administrative Order on Consent and Settlement Agreement for Removal Actions and Past Response Costs, Docket No. 09-2009-0010 (2009 Order).

In March 2009, EPA requested that ARC expand the domestic well monitoring program because of the EPA-approved shutdown of the PWS to evaluate OU-1 hydrogeologic conditions. The expanded domestic well monitoring program has been conducted pursuant to the *Domestic Well Monitoring Plan - Revision 3* (DWMP; BC 2010b), which was prepared as an addendum to the Site-Wide QAPP (ESI and BC 2009). Results of domestic well monitoring have been used to: 1) characterize the quality of groundwater used for drinking water or other domestic water supply purposes; 2) assess potential risk, if any, to human health and the environment by the use of groundwater extracted by domestic wells for drinking water or agricultural purposes; and 3) determine eligibility for receiving bottled water as part of an interim response action.

The Bottled Water Program was initiated in March 2004. Domestic well owners were deemed eligible to receive bottled water if uranium concentrations measured during domestic well monitoring exceeded 25 µg/L.

The number of wells/properties included in the DWMP and Bottled Water Program was substantially reduced in 2016 (ARC 2016a; EPA 2016f). As part of the settlement entered in the class action lawsuit *Roeder et al. v. Atlantic Richfield Company et al.*, D. Nev., Case No. 3-11-cv-00105-RCJ-WGC (“Roeder Settlement Agreement”), ARC provided funding to the City of Yerington to extend municipal water service to then-existing residences located within that part of the settlement class area that was also within the City’s projected future service area. Domestic well owners who connected to the City of Yerington’s municipal water system could elect to either abandon their well or apply for a state permit to authorize withdrawals of groundwater for outdoor use only (landscape watering). Each property owner who received a connection to the City Water System executed and recorded an environmental covenant either prohibiting future domestic use of groundwater altogether or limiting it to outdoor purposes.

Construction of the expanded water system began in the fall of 2014 and the construction of new mains and service connections was completed in June 2016. The first phase of well abandonments and system testing was completed as of August 1, 2016. The water system is functional, and domestic wells for all participating property owners have been abandoned or disconnected from the residences within the expansion area. A relatively small number of domestic wells located within the area of mine-impacted groundwater (see Figure 3-11) were not disconnected or converted to outdoor use only in 2016. ARC has been in communication with the owners of most of these wells, and disconnections for all but a few are scheduled to occur in 2017.

SECTION 4.0

PHYSICAL CHARACTERISTICS OF THE STUDY AREA

This section describes the physical characteristics of the Study Area including demographics, land use, climate, topography, geology and soils, hydrology and groundwater, ecological setting, and vegetation.

4.1 Demographics and Study Area Land Use

Lyon County, Nevada covers approximately 1,993 square miles, and its population in 2013 was 51,585 (U.S. Census Bureau 2015). Communities near the Site include Yerington (population 3,486), Weed Heights (population 500), and the YPT (approximate population 575). The regional population and industrial centers near the Site include Fernley (47 miles north), Fallon (59 miles northwest), Hawthorne (57 miles southeast), and Reno (85 miles northwest). Yerington's economic base is primarily agriculture.

Land use has included mine operations, ranching, agriculture, urban development, establishment of the YPT colony, BLM range land, and residential development. Mason Valley has long been the largest agricultural area in the Walker River basin and the most productive area in Nevada. In 2000, a total of 88,600 acres of irrigated land was mapped in the Walker River basin. Total irrigated land included 39,100 acres (44%) in Mason Valley (USGS 2009a).

4.2 Climate

Nevada is located on the leeward side (rain shadow) of the Sierra Nevada mountain range, which results in a dry climate. The climate in Lyon County is warm and arid. Snow melt is the primary natural source of streamflow and groundwater recharge in the Walker River Basin (USGS 2009b). The average annual precipitation in Yerington is approximately 5.1 inches, and average snowfall is 6.7 inches (Western Regional Climate Center [WRCC] 2015). The annual average precipitation rate is low relative to the regional pan evaporation rate of about 69 inches per year. The average monthly temperature for the period of record (March 1, 1894 through January 20, 2015) ranges from a maximum of 92.4 degrees Fahrenheit (°F) in July to a minimum of 17.8°F in January.

Tables 4-1 and 4-2 summarize monthly climate data for the City of Yerington weather station for the period from 1894 through 2015 (WRCC 2015). Table 4-1 summarizes monthly minimum and maximum temperatures, and monthly precipitation. Table 4-2 provides monthly average, maximum, and minimum precipitation values, and the one-day maximum rainfall event.

Table 4-1. Average Monthly Climate Data for the Yerington Weather Station #269229 (1894 - 2015)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Average Maximum. Temperature (°F) [1]	46.2	52.5	59.7	67.0	75.1	83.8	92.4	91.0	83.1	70.8	56.8	47.1	68.8
Average Minimum Temperature (°F) [1]	17.8	22.6	27.0	32.4	40.2	46.8	52.7	50.4	42.3	33.3	23.5	17.9	33.9
Average Total Precipitation[2]	0.57	0.53	0.42	0.41	0.63	0.46	0.26	0.25	0.24	0.35	0.42	0.52	5.06
Average Snow Fall [2]	1.9	1.2	1.0	0.4	0.1	0.0	0.0	0.0	0.0	0.1	0.8	1.2	6.7

Notes:

1) °F = Degrees Fahrenheit;
2) Precipitation values in inches

Table 4-2. Precipitation Data for the Yerington Weather Station #269229 (1894 - 2012)

Month	Mean	Maximum	Year	Minimum	Year	1-Day Maximum (Year)
January	0.57	3.67	1916	0.00	1915	1.40 (1943)
February	0.53	2.62	1962	0.00	1953	1.28 (1962)
March	0.42	1.83	1991	0.00	1914	0.98 (1941)
April	0.41	1.80	1990	0.00	1916	1.30 (1990)
May	0.63	3.04	1995	0.00	1916	1.90 (1939)
June	0.46	2.01	1997	0.00	1895	1.02 (1997)
July	0.26	2.00	2003	0.00	1916	1.75 (1984)
August	0.25	2.37	1983	0.00	1895	1.46 (1983)
September	0.24	2.15	1955	0.00	1920	2.02 (1955)
October	0.35	3.02	1993	0.00	1895	1.83 (1993)
November	0.42	2.39	1965	0.00	1894	1.04 (1974)
December	0.52	3.51	1955	0.00	1917	2.00 (1955)
Annual	5.06	10.58	1983	1.61	1947	2.02 (1955)

Notes:

1) Precipitation values presented in inches.
2) Most minimum values (11 of 12 months) of 0.00 inches were recorded prior to 1920.

Wind speed and direction at the Site vary on the local scale due, in part, to the heterogeneous natural topography (i.e., micro-climates) and modified topography due to surface mining operations. Meteorological data collected since 2002 indicate that wind direction is variable at the Site with no quadrant representing over 50% of the total measurements. However, when wind speeds are above 15 miles per hour, a predominant wind direction from southwest to northeast has been documented (BC, 2008c).

4.3 Topography

The Site is in Mason Valley, which is a north-south trending structural valley (graben) within the Basin and Range physiographic province filled with up to 1,000 feet of unconsolidated sediments. Mason Valley occupies a structural graben (i.e., down-dropped faulted basin) immediately east of the Singatse Range, Desert Mountains to the north, and the Wassuk Range to the east. Elevations in the Wassuk and Singatse Ranges reach 9,000 and 6,700 feet amsl, respectively (Huxel and Harris 1969). The valley ranges in width from about nine miles in the south to nearly 20 miles in the central part, and is about 40 miles long. The valley floor ranges from approximately 4,600 feet amsl in elevation at the south end to 4,290 feet amsl at the north end. The center of the Process Areas is at an elevation of approximately 4,450 feet amsl.

4.4 Ecological Setting

The Study Area is part of the Great Basin sagebrush-steppe ecosystem (Lopes and Allander 2009a). The Singatse Range to the west and the Mason Valley are dominated by a scrub brush community, except along the Walker River with s riparian community. These communities support resident and migrating birds, mammals, reptiles, amphibians and invertebrates. The Walker River flows within 0.25 mile of the southeastern end of the Site. Although riparian systems comprise an extremely small fraction of the Great Basin region, they are critical centers of biodiversity; more than 75% of the species in the region are strongly associated with riparian vegetation. The Study Area ecosystem has been impacted by anthropogenic activity, including mining, cattle ranching and agriculture. Site activities have resulted in the large piles of tailings and waste rock, which could be used as vantage points for predators surveying the surrounding area, and steep-sloped piles may potentially be used by nesting birds (e.g., swallows).

4.5 Vegetation

The terrestrial ecosystem in the Study Area not disturbed by anthropogenic activities supports an arid sagebrush-steppe vegetative community that is dominated by sagebrush and other low-lying woody vegetation, interspersed with a variety of forbs and grasses. The scrub brush community in the Study Area is predominately sparse greasewood, sagebrush, and rabbitbrush (Lopes and Allander 2009a). Livestock and wildlife preference for grasses contributes to the domination of vegetation in this system by sagebrush and other shrubs (Ricketts et al. 1999).

The riparian community along the Walker River supports a variety of trees, shrubs and grasses (USGS 2009b). Vegetation can be dense with large trees such as Freemont cottonwood, Russian olive, and invasive Tamarisk (Salt Cedar). Saltbush may be abundant where riverbank soil is saline. As previously stated, many areas on the Site have been disturbed to varying degrees by historical mining activities, but still retain areas of sandy soil interspersed with vegetation typical of the sagebrush-steppe vegetative mix of shrubs, forbs, and grasses. Mason Valley has long been the most agricultural part of the Walker River basin and remains one of the most productive agricultural areas in Nevada (Lopes and Allander 2009a). During the growing season, agricultural fields to the north may include onions, alfalfa, winter wheat and sorghum.

4.6 Regional and Site Geology

Mason Valley is a structural graben that has been filled with unconsolidated alluvial deposits derived by erosion of the emerging mountain horst blocks, and from materials transported into the valley by the East and West Walker Rivers (Huxel and Harris 1969). The alluvial apron and the valley floor are the two major land-forms comprising the lowland area. The mountain blocks, and bedrock beneath the basins, are primarily composed of granitic, metamorphic, and volcanic rocks of Precambrian to Tertiary age and, to a lesser extent, of consolidated to semi-consolidated sedimentary rocks of Paleozoic to Cenozoic age (Heath 1984; Proffett and Dilles 1984; Proffett 1977). Faults along the eastern margin of the Singatse Range are gently- to steeply-dipping normal faults that generally trend north-northeast (Figure 4-1) and dip to the east (Proffett and Dilles 1984; Proffett 1977). Faulting caused moderate to steeply westward tilting of the bedrock.

Unconsolidated deposits underlying the valley floor are collectively termed valley-fill deposits and, where saturated, constitute the valley-fill alluvial aquifer. Huxel and Harris (1969) reported that the valley-fill deposits include four stratigraphic units: 1) younger alluvium, including lacustrine deposits associated with Pleistocene Lake Lahontan (Reheis 1999); 2) younger alluvial fan deposits resulting from the uplift of mountain blocks; 3) older alluvium; and 4) older alluvial fan deposits.

Older and younger alluvial fan deposits are generally coarse-grained, poorly-sorted, and have relatively few inter-bedded clay lenses (Huxel and Harris 1969; Plume 1996; Mifflin 1988). The grain size of the valley-fill deposits generally decreases toward the center of Mason Valley (Huxel and Harris 1969; Plume 1996), and transitional facies have been identified in the Study Area (BC 2008c). Basin-scale variability in valley-fill deposits leads to variation in hydraulic properties of the alluvial aquifer, which is discussed in Section 4.9.6.

Bedrock and alluvial deposits in Mason Valley, and their associated hydrologic characteristics, are summarized in Table 4-3, which is reproduced from Huxel and Harris (1969). Lake Lahontan lacustrine deposits of Pleistocene age have been eroded or reworked by the Walker River as it meandered across Mason Valley. Lake Lahontan strandline units, consisting of beach, bar, and beach-ridge deposits, were formed for the most part on alluvial aprons between altitudes of 4,340 and 4,375 feet amsl (Huxel and Harris 1969). The occurrence of Lake Lahontan within Mason Valley had a relatively short life, and probably was less than 60 feet deep during much of its existence (Morrison 1964).

Table 4-3. Mason Valley Geologic Units: Lithologic and Hydrologic Characteristics (from Huxel and Harris, 1969)

Geologic Age		Geologic Unit		Thickness (feet)	Lithology	Hydrologic Characteristics
Quaternary	Pleistocene to Holocene	Valley Fill	Younger Alluvium	0-100±	Loose, well-sorted sand, gravel, cobbles, and boulders, with layers of silt or sandy clay. Comprises channel, flood-plain, and terrace deposits laid down by the Walker River and its major tributaries, plus strand-line and bottom deposits of Pleistocene Lake Lahontan. Bottom deposits consist of silt, fine sand, and clay.	Channel and flood-plain deposits are highly permeable and are good aquifers. Significant infiltration of surface waters, which recharges the alluvial-fill aquifer, occurs through the coarse deposits in the Holocene channels of the Walker River.
			Younger Fan Deposits	0-100±	Poorly-sorted gravelly clay, sandy clay, and fine sand with occasional stringers and lenses of sand and gravel. Locally, derived from erosion of older rocks and deposits in Mason Valley; generally equivalent to younger alluvium.	In general, younger and older fan deposits are of low permeability. However, stock watering and mining wells penetrating buried sand and gravel deposits yield small to moderate amounts of water. Properly constructed, large-diameter wells may yield up to several hundred gpm.
	Pleistocene		Older Fan Deposits	0-700±	Sandy- to gravelly-clay with abundant cobbles and boulders and occasional lenses of semi-consolidated to cemented sand and gravel. Locally-derived from erosion of consolidated rocks of the surrounding mountains. Equivalent in part to older alluvium.	
			Older Alluvium	0-500±	Similar in lithology to younger alluvium described above. Deposited by ancestral Walker River; underlies valley floor at depths greater than 100 feet. Not exposed at land surface.	Constitutes largest and most productive aquifer in the area, with tested transmissibility as high as 270,000 gallons per day/foot. Wells yield up to 3,000 gpm.
Tertiary	Miocene and Pliocene	Consolidated Rocks	Sedimentary Rocks	--	Sandstone, mudstone, shale, marl, diatomite, and limestone. Includes interbedded tuffaceous rocks, lava flows, and breccia.	Consolidated rocks generally have low permeability. However, where they are fractured or jointed, they yield small to moderate amounts of water to wells.
	Oligocene to Pliocene		Volcanic Rocks	--	Rhyolite flows and tuff, andesite and dacite lava flows, breccia, and agglomerate. Includes interbedded sedimentary rocks and, locally, thin basalt flows with interbeds and scoriaceous basalt breccia.	
Cretaceous			Granitic Rocks	--	Granodiorite, quartz monzonite, and granite porphyry.	
Permian to Jurassic			Metamorphic Rocks	--	Metamorphosed andesite, basalt, and rhyolite flows, tuff and breccia, metamorphosed limestone, lime shale, dolomite, and gypsum and volcanically-derived sedimentary rocks.	

Bedrock in the Study Area forms a U-shaped graben structure that reaches its lowest point beneath the north end of the Hunewill Ranch, at an elevation of approximately 3,600 feet amsl (700 feet bgs). The elevations of the alluvium-bedrock contact, shown in plan view on Figure 4-2, clearly depict this graben structure in the Study Area. From its lowest elevation, bedrock rises in elevation south toward the Site. The U-shaped graben ends at the open pit and the alluvial-bedrock contact is exposed on the pit walls. The bedrock exposed in the open pit is the host rock for the Yerington copper porphyry deposit. East and west of the Site, bedrock rises to mapped outcroppings associated with the Singatse Range (west) and Singatse Spur (east; this term refers to two adjacent bedrock outcrops located east of the Site called the Ground Hog Hills and McLeod Hills as shown on Figure 4-2. At the north end of the Study Area, bedrock outcrops occur in the Sunset Hills area. In the northeast portions of the Study Area (i.e., toward the Mason Butte bedrock outcrop), bedrock rises in elevation. Range-bounding faults in the Study Area include steeply-dipping and shallower-dipping normal faults (Proffett and Dilles 1984).

The unconsolidated alluvial deposits in the Study Area were derived primarily from erosion of the uplifted mountain block of the Singatse Range, with minor deposition of fluvial sediments in the Walker River flood-plain. In addition, lacustrine deposits derived from ancestral Lake Lahontan occur north of the Site (Reheis 1999). Uplift and erosion of the Singatse Range formed the east-dipping alluvial fan deposits, which include distal facies that extend into the transitional environment. Concurrent with the development of the alluvial fan, flat-lying fluvial sediments (e.g., sands and gravels) were deposited in the Walker River flood-plain. Flat-lying clay-rich deposits have been preserved in the transitional setting, and these deposits are interpreted to have formed within the ancestral Lake Lahontan depositional environment.

Regional metal mineralization and hydrothermal alteration occurs in portions of Mason Valley, and the Singatse Range in particular, in areas of localized porphyry and skarn copper deposits. The Yerington copper porphyry district is located within the productive Walker Lane mineralized belt in western Nevada (Tetra Tech 2010). The Walker Lane is a northwest-trending zone of active crustal movement (i.e., right-slip transcurrent faulting) that extends for more than 500 miles from Las Vegas, Nevada to beyond Honey Lake, California (Bell and Slemmons 1979).

In addition to the Yerington and MacArthur open pit mines along the eastern margin of the Singatse Range, other areas of mineralization include the Bluestone and Ann Mason mines, and the Bear deposit. Areas of known mineralization and ore deposits in the Mason Valley are shown on Figure 4-3. The Bear deposit is located beneath the Sulfide Tailings and Hunewill Ranch, in a structurally-uplifted segment of the Singatse Range. The Pumpkin Hollow copper skarn deposit, located across Mason Valley from the Site, occurs along the margin of the intrusive rocks that host the Yerington porphyry copper deposit.

4.7 Surface Water Hydrology

The Mason Valley Basin (Basin no. 108, as defined by the NDWR) is located within the larger Walker River Hydrographic Basin (no. 9). The Walker River Hydrographic Basin extends from the Sierra Nevada Mountain Range above Bridgeport, California and Topaz Lake to Walker Lake located north of Hawthorne, Nevada. Most streamflows in the basin originate as snowmelt in the Sierra Nevada, with headwaters at elevations of more than 12,000 feet amsl (Lopes and Allander 2009a, 2009b).

The Walker River originates in two distinct headwater areas in the Sierra Nevada that source the East and West Walker Rivers (Figure 3-6). The East Walker River is sourced above Bridgeport, California. Streamflows are regulated before flowing into the Mason Valley. The West Walker River is sourced above Topaz Lake, a reservoir located along the California-Nevada border, and passes through the town of Wellington, Nevada on its way to the Mason Valley. The confluence of the East and West Walker Rivers occurs in Mason Valley at a location approximately seven miles upstream (three miles directly south) of the Site. The main stem of the Walker River flows north past the Site at the City of Yerington, traverses the geothermal discharge area near the town of Wabuska, exits the north end of Mason Valley at Walker Gap approximately 4.5 miles east of the town of Wabuska, and then turns south and empties into Walker Lake (a terminal lake with no outlet).

4.7.1 Surface Water Flows

Mason Valley is the largest irrigated agricultural area within the Walker River Basin including irrigated areas along the West and East Forks, and the main stem, of the Walker River. Key documents providing information on stream flows and water budgets in the Mason Valley include Huxel and Harris (1969), Lopes and Allander (2009b), and Carroll et al. (2010).

Each of these three documents present information on streamflows and water budgets for different periods of time. Appendix G-1 presents surface water flow information for 1948 to 2001, a period longer than addressed in these three documents. Streamflow and water budget information from these three documents and Appendix G-1 are summarized in Table 4-4 and discussed below.

Table 4-4. Summary of Mason Valley Streamflow and Water Budget Information

	Huxel and Harris (1969)	**Lopes and Allander (2009b)**	**Carroll et al. (2010)**	**Flow Data Appendix G-1**
Period of Record	1948 - 1965	1971 - 2000	1996 - 2006	1948 - 2011
	18-year Average	30-year Average	11-year Average	48-year Average (1)
Stream Inflows (acre-feet) (2)	216,000	269,000	277,832	207,900
Stream Diversions (acre-feet)	140,000	117,000	139,643	NA
Stream Outflows (acre-feet) (3)	107,200	138,000	129,471	80,400
Total Stream Loss (acre-feet) (4)	109,300	131,000	148,361	127,500
Stream Loss as Percent of Inflow	50%	49%	62%	NA
Irrigated Area (acres)	30,000	38,964	38,721	NA
Surface Water Diversion Rate (ft/yr) (5)	3.6	3.4	3.8	NA
Groundwater Pumpage (acre-feet/yr)	4,000	40,000	77,423	NA
Groundwater Application Rate (ft/yr) (6)	0.1	1.0	2.0	NA
Crop Consumption Rate (ft/yr)	1.0	1.6 (7)	2.9 - 3.1	NA

Notes:

1) Excludes 1979 - 1994 because flow data were not collected during winter months (October through March).
2) Sum of streamflow at Hudson (East Walker River) and Strosnider Ditch (West Walker River) gages (USGS gages 10300000 and 10293500, respectively).
3) Streamflow at Wabuska gage (USGS gage 10301500).
4) Total Stream Loss = Stream Inflows - Stream Outflows.
5) Surface Water Diversion Rate = Total Stream Loss/Irrigated Area.
6) Groundwater Application Rate = Groundwater Pumpage/Irrigated Area.
7) Value of 1.6 ft/yr from Myers (2001) cited by Lopes and Allander (2009b).
8) ft/yr = feet per year; % = percent; NA = not available

Lopes and Allander (2009b) provide a surface water budget for Mason Valley based on data collected from 1971 to 2000. Combined average annual inflows to Mason Valley were estimated to be 269,000 acre-feet per year. The average annual outflow from Mason Valley was estimated to be 138,000 acre-feet per year. The average net annual diverted surface water in Mason Valley was estimated to be 117,000 acre-feet per year. Stream infiltration and riparian evapotranspiration was estimated to be 14,000 acre-feet per year (Lopes and Allander 2009b).

An analysis of Walker River streamflow data from 1948 to 2011 (Appendix G-1) indicates a median annual flow at the confluence of the East and West Walker Rivers of 207,900 acre-feet. The minimum recorded flow was 65,900 acre-feet per year, and the maximum recorded flow was 596,500 acre-feet per year. Outflows from the Mason Valley are recorded near Wabuska, north of the Study Area. The median annual outflow was 80,400 acre-feet. The minimum recorded outflow was 15,800 acre-feet per year. The maximum recorded out flow was 417,900 acre-feet per year. In all months of all years, combined flows at the confluence of the East and West Walker Rivers were greater than outflows from the Mason Valley, with greater differences observed in summer months compared to winter months. Differences between inflows and outflows are accounted for by seepage losses, evapotranspiration and diversions for crop irrigation.

The disposition and routing of surface water within the Mason Valley is complex. Detailed information is provided in appendices to the *Groundwater Flow Model Yerington Mine Site* (SSPA 2014).

4.7.2 Recharge to the Alluvial Aquifer

Percolation of surface water is the primary source of groundwater recharge to the alluvial aquifer in the Mason Valley, with mountain-front recharge contributing significantly less (Carroll et al. 2010; Huxel and Harris 1969; Myers 2001; SSPA 2014). The amount of recharge derived by infiltration from stream channels, ditches, and percolation from flooded agricultural fields varies from year to year, depending upon the volume of Walker River flow entering the basin, the amount of surface water diverted from the river for irrigation, and the amount of available groundwater storage.

Huxel and Harris (1969) estimated that the annual recharge from the sources listed above ranged from 30,000 to 100,000 acre-feet, with an average of about 70,000 acre-feet, for the period from 1948 to 1965. These estimates were calculated as inflows minus the sum of surface-water outflows and consumptive use by crops and pastures, and assumed that all stream flows not consumptively used for irrigation or flowing out of the valley recharged the valley-fill alluvial aquifer. Carroll et al. (2010) estimated that recharge from the sources listed above ranged from 60,400 to 99,400 acre-feet per year for the time period 1996 to 2006, and noted the consistency between their more recent estimates and those provided by Huxel and Harris (1969).

The groundwater flow model water budget (SSPA 2014) indicates that the alluvial aquifer is primarily recharged by downward percolation from irrigated fields (49%), leakage from irrigation ditches such as the West and East Campbell Ditches (29%), infiltration from the channel of the Walker River (20%), and infiltration through bedrock of precipitation that falls on surrounding mountain ranges and minor tributary surface flows in ephemeral drainages (2%). Recharge from precipitation falling directly on the valley floor is negligible based on work by Huxel and Harris (1969) and Lopes and Allander (2009a, 2009b), as well as data from stable isotope (i.e., oxygen/deuterium) analysis of precipitation and groundwater (BC 2014a; EPA 2012b).

4.7.3 Surface Water Quality

Surface water quality is discussed below with a focus on data at sample locations SW-WR-01 (Walker River) and SW-WCD-01 (West Campbell Ditch), and chemicals considered primary indicators of mine-impacted groundwater (i.e., sulfate and uranium). A detailed analysis of the surface water quality data is presented in Appendix G-2. Chemical concentrations in Walker River and West Campbell Ditch samples are similar with low total dissolved solids (TDS) (110 to 300 mg/L; average: 194 mg/L) and relatively low sulfate (7.7 to 54 mg/L; average: 29 mg/L) and dissolved uranium (3.7 to 19 µg/L; average 9.3 µg/L). Surface water pH is slightly alkaline (7.72 to 8.36 s.u.; average: 8.05 s.u.). Temporal trends indicate more elevated major ion (e.g., sulfate, calcium and chloride) values and trace metal (e.g., dissolved arsenic and dissolved uranium) values in samples at both locations during the winter months relative to the summer months. Overall, the STORET surface water quality data are similar to the surface water quality data collected by ARC.

Shallow alluvial groundwater near the Walker River and West Campbell Ditch exhibits similar chemical characteristics to surface water quality, which is the primary source of groundwater in Mason Valley (Carroll et al. 2010; Huxel and Harris 1969; Myers 2001; SSPA 2014). General ion chemistry in groundwater was found to be statistically similar to surface water for five of eight major ions. Calcium, chloride, and sulfate were found to be higher in groundwater than surface water. Dissolved metals in groundwater were found to be statistically similar to surface water for some parameters (14 of 27) but different for others (13 of 27). However, differences between surface water and Shallow alluvial groundwater in major ions and dissolved metals reflect changes in geochemical conditions in groundwater arising from the effects of residence time, presence (or absence) of dissolved atmospheric gasses, localized mineralization, and influences from land-surface features that alter groundwater quality as it recharges from surface water sources.

4.8 Mason Valley Regional Hydrogeology

Groundwater conditions in Mason Valley are based on: 1) general characteristics of groundwater flow for the Basin and Range province; 2) investigations specific to the Mason Valley and/or the Walker River Basin; and 3) groundwater data available from the USGS and/or NDWR. The general conceptual model for groundwater flow in the Basin and Range province (Heath 1984; Maurer et al. 2004) is movement of groundwater in unconsolidated sediments deposited within the basins that occur between uplifted mountain blocks comprised of consolidated bedrock.

The groundwater flow system in Mason Valley consists of: 1) a heterogeneous valley-fill alluvial aquifer system comprised of laterally-discontinuous confining units of clay or other low-permeability sediments, and unconfined (i.e., water table), semi-confined, and confined aquifers; and 2) a relatively impermeable bedrock flow system underlying and bounding the alluvial aquifer with limited primary permeability and groundwater flow focused along faults and fractures (Maurer et al. 2004; Thomas 1995; Tetra Tech 2010; Huxel and Harris 1969).

Groundwater in the alluvial aquifer within Mason Valley generally flows from south to north toward the topographically lowest part of the valley at the northern end of the valley (Figure 4-4).

Similar water-level patterns are depicted in Huxel and Harris (1969, Plate 2), Lopes and Allander (2009a, Plate 1), and Tetra Tech (2010, Figure 24-3). Locally, groundwater flow directions are affected by: 1) bedrock outcrops within and along the margins of the valley; 2) drawdown from pumped wells; and 3) irrigation activities on cultivated fields. The Walker River is generally a losing stream except in the far northeastern portion of the valley where it is generally a gaining stream. Water level elevations shown on Figure 4-4 are based on USGS monitor well data from October through December 2010 when agricultural pumping was limited or non-existent. Table 4-5 summarizes the USGS wells and water level data used to develop the water table (i.e., alluvial aquifer potentiometric surface) map shown on Figure 4-4.

Table 4-5. 2010 USGS Monitor Well Data for Mason Valley

USGS Site Number	Site Name	Latitude	Longitude	Surface Elev. (feet amsl)	Vertical Datum	Measurement Date	Depth to Water (feet)	Water Elev. NGVD29 (feet amsl)	Well Depth (feet bgs)	Boring Depth (feet bgs)	Number of Measurements
391655119330901	103 N16 E22 06ACD1 HIWAY 50	39.28200000	119.5524167	4352.1	NAVD88	10/13/10	55.4	4293.29	96	96	154
391729119294501	103 N17 E22 34DBDD1 EUREKA	39.29147220	119.4957500	4283.8	NAVD88	10/14/10	10.06	4270.35	35	35	101
391711119303301	103 N16 E22 04AAAD1 RA-4	39.28647220	119.5091667	4288.5	NAVD88	10/14/10	4.8	4280.30	14	14	69
391625119324801	103 N16 E22 07AAAA1 R-3	39.27352778	119.5468056	4303.9	NAVD88	10/14/10	9.07	4291.42	35	35	66
391605119331901	103 N16 E22 07ACCB1 R-2	39.26797220	119.5551389	4308.1	NAVD88	10/14/10	8.27	4296.41	30	30	64
384942119100801	108 N11 E25 10DBCD1	38.82802778	119.1703610	4565	NGVD29	11/23/10	98.14	4466.86	597	597	42
390715119095901	108 N15 E25 34ACDD1	39.12075170	119.1673767	4292	NGVD29	11/22/10	13.48	4278.52	370	370	41
390006119043901	108 N13 E26 09DBCC1	39.00158530	119.0784852	4396	NGVD29	11/24/10	60.37	4335.63	166	166	39
390011119060201	108 N13 E26 08CACA1	39.00297394	119.1015412	4367	NGVD29	11/24/10	21.88	4345.12	130	130	37
390127119030001	108 N13 E26 02BBCC1	39.02408569	119.0509851	4406	NGVD29	11/24/10	87.92	4318.08	203	203	36
390203119055101	108 N14 E26 32BDDD1	39.03408520	119.0984860	4352	NGVD29	11/30/10	13.56	4338.44	104	104	32
385903119073001	108 N13 E25 13DDDD1	38.98408457	119.1259859	4380	NGVD29	11/24/10	16.92	4363.08	280	280	32
390531119115901	108 N14 E25 08ADDC1	39.09186235	119.2007101	4320	NGVD29	11/22/10	30.73	4289.27	523	523	32
385720119085001	108 N13 E25 26DDCC1	38.95547285	119.1482085	4409	NGVD29	11/24/10	26.14	4382.86	160	NA	31
385255119090501	108 N12 E25 23DCC 1	38.88186075	119.1523750	4462	NGVD29	11/23/10	15.84	4446.16	325	325	31
385456119091901	108 N12 E25 11CACD1	38.91547224	119.1562641	4439	NGVD29	11/23/10	21.5	4417.50	245	245	31
390137119065402	108 N14 E26 31DCCC2	39.02686280	119.1159861	4357	NGVD29	11/30/10	13.44	4343.56	400	400	30
390558119094701	108 N14 E25 03DDDC1	39.09936270	119.1640431	4323	NGVD29	11/22/10	20.54	4302.46	85	258	30
390611119110301	108 N14 E25 04DACC1	39.10297367	119.1851545	4321	NGVD29	11/22/10	20.75	4300.25	451	451	30
385447119075901	108 N12 E25 12CDAA1	38.91297248	119.1340414	4476	NGVD29	11/23/10	59.94	4416.06	102	102	28
390004119103001	108 N13 E25 10CDB 1	39.00102868	119.1759868	4380	NGVD29	11/30/10	9.19	4370.81	328	328	27
390026119090401	108 N13 E25 11ACBD1	39.00714008	119.1520976	4370	NGVD29	11/24/10	13	4357.00	435	435	25
385717119080901	108 N13 E25 25CDDA2	38.95463960	119.1368194	4419	NGVD29	11/24/10	33.88	4385.12	106	106	21
385109119085601	108 N12 E25 35DCDD2	38.85241595	119.1498750	4505	NGVD29	11/22/10	35.38	4469.62	NA	NA	20

Table 4-5. 2010 USGS Monitor Well Data for Mason Valley

USGS Site Number	Site Name	Latitude	Longitude	Surface Elev. (feet amsl)	Vertical Datum	Measure-ment Date	Depth to Water (feet)	Water Elev. NGVD29 (feet amsl)	Well Depth (feet bgs)	Boring Depth (feet bgs)	Number of Measurements
385003119085201	108 N11 E25 11AACC1	38.83408240	119.1487638	4565	NGVD29	11/23/10	97.14	4467.86	256	256	19
390057119080001	108 N13 E25 01DBCC1	39.0157514	119.1343196	4365	NGVD29	11/19/10	19.96	4345.04	570	570	19
385047119080401	108 N11 E25 01ACCB1	38.84630495	119.1354302	4547	NGVD29	11/23/10	75.13	4471.87	526	526	18
385018119091101	108 N11 E25 02CDDD1	38.83813889	119.1538889	4544	NGVD29	11/23/10	73.59	4470.41	554	560	17
385718119101301	108 N13 E25 27DCCD2	38.95491700	119.1712645	4409	NGVD29	11/23/10	19	4390.00	440	440	17
390152119104401	108 N14 E25 34CBCA2	39.03102880	119.1798760	4362	NGVD29	11/30/10	25.56	4336.44	415	430	14
391741119150601	102 N17 E24 35DAAB1 OLD BUCKLANDS STATION	39.29472220	119.2516667	4203	NGVD29	10/12/10	16.23	4186.77	93	93	14
391610119115801	102 N16 E25 05DCCA1 USBLM	39.27464167	119.2004333	4219	NGVD29	10/12/10	70.24	4148.76	127	NA	12
391757119151801	102 N17 E24 35ACAA1 OLD WEEKS SIDING	39.29916667	119.3050000	4206	NGVD29	10/12/10	18.28	4187.72	23	23	11
392522119101901	102 N18 E25 15CBCA1 STUCCO	39.42288889	119.1718889	4213	NAVD88	10/12/10	57.72	4152.13	200	200	11
392546119121201	102 N18 E25 17BDAA TRAILER GRAVEYARD	39.42947220	119.2034167	4201	NAVD88	10/12/10	14.92	4182.94	170	170	11
392222119075101	103 N17 E25 01BAB1 E OF LAHONTAN	39.37283330	119.1307222	4202	NAVD88	10/12/10	61.18	4137.68	72	72	9
390416119112401	108 N14 E25 16DCCB1 CMPBLL SHALLOW	39.07097220	119.1900833	4336	NGVD29	11/22/10	20.14	4315.86	25	25	8
385249119221401	107 N12 E23 26ABAD1 85471	38.8803611	119.3706667	4729	NGVD29	11/18/10	13.76	4715.24	340	340	8
391727119190701	103 N17 E24 32CDBB1 BULL CANYON	39.29088889	119.3184722	4250.5	NAVD88	11/15/10	27.8	4219.363	41	41	8
391706119322601	103 N16 E22 05BACD1	39.28488889	119.5405556	4345	NAVD88	10/23/10	59.9	4281.691	182	182	8
391709119314001	103 N16 E22 04BBCB1 CARDELLI	39.28569444	119.5278333	4304.5	NAVD88	11/15/10	15.85	4285.244	39	39	2

Notes:

1) All groundwater elevation data downloaded from USGS website http://nwis.waterdata.usgs.gov/nv/nwis/gwlevels, accessed on August 15, 2011.
2) amsl = above mean sea level; bgs = below ground surface; NA = not available.

Hydraulic properties of the basin-fill sediments of Mason Valley vary both laterally and vertically because of variable depositional facies and environments observed in the valley. The transmissivity of the basin fill deposits was stated by Huxel and Harris (1969) to generally range from 6,700 ft^2/day to 27,000 ft^2/day. Based on an average basin-fill thickness of 500 feet, this is equivalent to average hydraulic conductivities in the range of 13 ft/day to 53 ft/day. Based on unspecified geotechnical investigations, Nork (1989) reported hydraulic conductivity values ranging from 0.35 to 0.50 feet per day (ft/day) for older alluvial fan deposits. Consolidated rocks beneath the unconsolidated basin-fill sediments and/or comprising the adjacent mountain ranges have low hydraulic conductivities, but may transmit water where fractures are open and interconnected (Lopes and Allander 2009a). Nork (1989) reported hydraulic conductivity values ranging from 0.23 to 1.5 ft/day for weathered intrusive rocks in the Mason Valley area.

Groundwater in Mason Valley is primarily recharged by downward percolation of surface water diverted from the Walker River to irrigation ditches and irrigated fields, downward percolation of groundwater applied to irrigated fields, and infiltration of surface water from the channel of the Walker River. To a lesser degree, valley-fill sediments are also recharged by mountain-front recharge (MFR), which includes a variety of hydrologic processes such as partitioning of precipitation and snowmelt into deep infiltration through bedrock (i.e., along faults and fractures), surface runoff, focused flow and subflow along mountain stream channels and alluvial fans, and diffuse movement of groundwater through the underlying mountain block (Wilson and Guan 2004; Huxel and Harris 1969; Myers 2001). Huxel and Harris (1969) considered recharge from direct precipitation on the valley floor to be negligible. Recharge from irrigation water and seasonal pumping of irrigation wells affects the vertical flow of groundwater in the alluvial aquifer (i.e., a seasonal increase in the downward vertical gradient in the alluvial aquifer).

Discharge from the Walker River Basin occurs as evapotranspiration from irrigated crops and natural vegetation (e.g., phreatophytes and wetland vegetation) as described by Heath (1984) and Carroll et al. (2010), and as direct evaporation from shallow groundwater (Huxel and Harris 1969; Lopes and Allander 2009a). Huxel and Harris (1969, Plate 2) identified an area of artesian

conditions (17 flowing wells) in the northern portion of Mason Valley where the alluvial aquifer thins and pinches out, and reported that groundwater in this area exhibited elevated specific conductance values (i.e., dissolved solids concentrations) due to evapoconcentration and possible effects of geothermal discharge associated with the Wabuska Lineament.

Lopes and Allander (2009a, 2009b) report that: 1) in 2008, no flowing wells were observed in the Wabuska area due to groundwater pumping; 2) water depths in this area were less than five feet, and efflorescent salts formed where groundwater evaporated from the shallow water table; and 3) pumping in Mason Valley since the early 1960s had caused groundwater levels to decline as much as 60 feet. The long-term decline in water levels is reflected in Site hydrographs for select monitor wells that cover the time period from 1985 to 2015, as shown on Figure 4-5. In addition to factors described above, the sharp decline in the 1980's in water levels in well UW-1S, located near the northern end of the Process Areas, is in part attributed to cessation of mining activities in 1978. Discharge of groundwater through bedrock from the Mason Valley Basin to other groundwater basins may occur, but is limited (Thomas 1995; Tetra Tech 2010).

4.9 Site and Study Area Local Hydrogeology

A generalized hydrogeologic south-north cross-section with a vertical exaggeration of 20V:1H is presented in Figure 4-7 (location shown on Figure 4-6). This cross-section (A-A') transects the Study Area and extends from well B/W-13S, which is the southernmost well in the Study Area, to a monitor well cluster, B/W-82R, which is located at the north end of the Study Area.

The south-north cross-section depicts: 1) the alluvial materials in the valley-fill alluvial aquifer within the Study Area; 2) the alluvial aquifer zone designations; 3) the occurrence of bedrock outcrops at the open pit and the north end of the Study Area; 4) the water table elevation in the alluvial aquifer in August 2015; 5) the depth of the open pit and the Pit Lake level in August 2015; and 6) the cone-of-depression associated with the open pit. The water table in the Shallow zone of the alluvial aquifer generally slopes toward the north on this cross-section, though the elevation of the water is relatively flat in much of the Site.

4.9.1 Depth to Groundwater

Contour maps of the depth to groundwater (i.e., depth to water table) below the ground surface in February 2015 and August 2015 are presented on Figures 4-8 and 4-9, respectively. February 2015 and August 2015 represent the non-irrigation and irrigation seasons, respectively. The depth to groundwater is typically less than 20 feet beneath irrigated areas such as the Hunewill Ranch and between monitor wells B/W-59S and B/W-68S. In areas beneath the Site, beneath the Sunset Hills neighborhood, and in the northern portions of the Study Area, the depth to groundwater is greater than 20 feet. To the west of the Site and beneath the Process Areas, the depth to groundwater exceeds 100 feet. Between February 2015 and August 2015, the depth to groundwater beneath irrigated portions of the Study Area as well as beneath the Evaporation Ponds uniformly increased by up to three feet (i.e., the water table declined) due to depletion of groundwater by agricultural pumping. Depth to groundwater fluctuations in other parts of the Study Area were minor.

4.9.2 Saturated Alluvial Thickness

The thickness of saturated alluvium in the Study Area in August 2015 is shown on Figure 4-10, which is similar in shape to the alluvium-bedrock contact map shown on Figure 4-2 (the similarity results from a relatively flat water table beneath the Study Area). On Figure 4-10, the line denoting the approximate lateral extent of saturated alluvium represents the zero-foot contour line (i.e., saturated alluvium does not occur outside of this contour line). Saturated alluvium is bounded to the west by the Singatse Range, to the northwest by the bedrock outcrops in the Sunset Hills area, to the northeast by the Mason Butte bedrock outcrop, to the east by the Singatse Spur, and to the south by the local bedrock high exposed within the open pit and, locally, by that portion of the Singatse Range located south of the Site. As shown on Figure 4-10, saturated alluvium is thickest (more than 700 feet) beneath the northern portion of the Hunewill Ranch.

4.9.3 Alluvial Groundwater

Potentiometric surface maps for the various alluvial aquifer zones in August 2015 are provided in Figure 4-11. Groundwater flow in August 2015 in the Study Area was generally to the north/northwest in the Shallow, Intermediate, and Deep 1 zones, and to the northeast in the Deep

2 through Deep 5 zones. Locally, the flow of groundwater in the Study Area is affected by: 1) the cone-of-depression around the Pit Lake, which is a hydraulic sink for alluvial and bedrock groundwater; 2) recharge sources such as the Walker River, the West Campbell Ditch and irrigation on the Hunewill Ranch; 3) bedrock in the Singatse Range to the west of the Site, which serves as a low flux boundary condition; 4) bedrock outcrops on the eastern margin of the Site (the Singatse Spur, comprised of the Ground Hog Hills and McLeod Hill), which impede groundwater flow from the West Campbell Ditch and the Walker River to the alluvium beneath the Site; 5) bedrock ridges north of the Site associated with the Sunset Hills and Mason Butte, which affect the direction of groundwater flow in the northeastern portions of the Study Area; and 6) drawdown from pumped wells (particularly in deeper zones of the alluvial aquifer).

As seen on the Shallow zone potentiometric surface map (Figure 4-11a), the Pit Lake is currently a hydraulic sink that is refilling with groundwater predominantly derived from alluvial groundwater recharged locally from the Walker River and, to a lesser extent, bedrock groundwater (Hershey 2002). As noted in Section 3.3.2, the lake is and will continue to be a groundwater sink due to the large amount of evaporation that occurs from the lake surface.

Saturated alluvium is in contact with the Pit Lake on the western margin of the open pit (Figure 4-11a). However, groundwater gradients in this area are toward the Pit Lake, and alluvial groundwater recharges the Pit Lake rather than the Pit Lake recharging the alluvial aquifer. On the eastern margin of the open pit, groundwater derived from seepage from the Walker River flows into the pit. Beneath the Process Areas, the Pit Lake cone-of-depression creates a groundwater divide in the Shallow zone (Figure 4-11a). Because of local bedrock elevations, only the Shallow, Intermediate, and a limited portion of the Deep 1 zones exist in this area (Figures 4-11 a through c, respectively).

North of the Site, recharge from the Walker River and its surface water diversions, as well as irrigation practices in the Study Area, are the primary influences on groundwater flow directions. In the Shallow, Intermediate, and Deep 1 zones, groundwater flow directions are away from, or parallel to, the Walker River and West Campbell Ditch (i.e., north/northwest), indicating recharge

of the alluvial aquifer from these features. In addition, groundwater mounding beneath irrigated areas is observed in these zones. As this recharged water percolates deeper into the Deep 2 through Deep 5 zones of the alluvial aquifer, the groundwater flow direction rotates to the northeast as relatively impermeable bedrock results in alluvial groundwater flow toward the trough in the alluvial-bedrock contact between the Sunset Hills and Mason Butte.

Irrigation practices on the Hunewill Ranch, located immediately north of the Site, locally affect groundwater flow conditions. Historically, irrigation practices on the Hunewill Ranch included seasonal diversion of surface water from the Walker River via the West Campbell Ditch and pumped groundwater, as necessary, from up to three wells. These three wells were located within 2,500 feet of the B/W-1 monitor well cluster and included Well Log No. 82983 (also referred to as WDW019), Well Log No. 26694, and Well Log No. 78925. Well WDW019 and other underground water rights points of diversion are shown on Figure 3-8. Groundwater pumping from the Hunewill Ranch wells to support agricultural irrigation ceased in September 2009. In 2011 and subsequent years, crops on the Hunewill Ranch were irrigated with surface water diverted from the Walker River and groundwater pumped from a nearby parcel located near the Walker River to the east. Additional information about these wells is provided in the *Aquifer Test Data Summary Report - Revision 1* (BC 2012e).

Potentiometric surface maps for the Shallow through Deep 2 zones (Figures 4-11a through 4-11d) have been outfitted with rose diagrams at select locations to illustrate seasonal changes in groundwater flow directions resulting from the historical and current irrigation practices on the Hunewill Ranch. Rose diagrams indicate the relative frequencies of groundwater flow directions over a period of time. Monthly groundwater flow directions were calculated by using water level measurements in sets of three monitoring wells to estimate the slope and direction of slope of a plane connecting the water levels in the three wells. This approach is commonly referred to as a "three-point problem" (EPA 2014c). Rose diagrams were generated for two time periods: 1) 2008 - 2009 to illustrate historical irrigation practices associated with operation of the Hunewill Ranch pumping wells; and 2) 2010 - 3Q 2015 to illustrate current irrigation practices.

Both historical and current irrigation practices for the Hunewill Ranch created a groundwater mound in the Shallow, Intermediate, and Deep 1 zones of the alluvial aquifer due to infiltration of applied irrigation water. Mounding was most pronounced beneath the Hunewill Ranch fields, and the mound extended beyond the edges of the fields including beneath the Wabuska Drain, which collects and diverts agricultural runoff. The rose diagrams for the Shallow, Intermediate, and Deep 1 zones (Figures 4-11a through 4-11c) indicate that, in both time periods, the mound beneath Wabuska Drain predominantly acted as a groundwater divide, directing recharged groundwater: 1) to the west/southwest beneath the Evaporation Ponds; and 2) to the east/northeast beneath the Hunewill Ranch. The rose diagrams also indicate that, in a small number of months, the groundwater divide was not present and groundwater flow directions were from the east beneath the Hunewill Ranch to the west beneath the Evaporation Ponds. This east-to-west flow predominantly occurred in winter months when irrigation was not occurring.

Historical irrigation practices for the Hunewill Ranch prior to 2010, which included seasonal groundwater pumping and surface application to the fields, created a cone-of-depression around WDW019 that was most pronounced in the Deep 1 through Deep 3 zones but was also manifested in the Shallow and Intermediate zones (BC 2014a). The cone-of-depression in the combined Deep 1 through Deep 3 zones extended beneath the Sulfide Tailings area and the Evaporation Ponds, and as far north as the Sunset Hills neighborhood. Figure 4-12 provides monthly water level hydrographs of Shallow and Deep monitor wells in the B/W-1 and B/W-27 well clusters (located beneath and adjacent to the Hunewill Ranch, respectively) that illustrate the hydraulic head drawdown during and after operation of the Hunewill Ranch pumping wells. Although agricultural pumping in the Study Area continues to affect hydraulic head in wells B/W-1D3 and B/W-27D2, hydraulic head drawdown in these wells was up to three times greater during operation of the Hunewill Ranch pumping wells than it has been in recent years.

The rose diagrams for the Deep 2 zone (Figure 4-11d) indicate that, under both historical and current irrigation practices, groundwater between the Site and the B/W-1 well cluster has been toward the northeast as the result of agricultural pumping, with occasional periods of northward groundwater flow corresponding with winter months when irrigation was not occurring. Beneath

the Evaporation Ponds, the rose diagrams indicate differing distributions of groundwater flow directions between historical and current irrigation practices. Groundwater flow directions in the Deep 2 zone beneath the Evaporation Ponds have been predominantly to the west/northwest in both time periods. However, the large cone of depression that was present during operation of the Hunewill Ranch pumping wells caused on-Site water beneath the Evaporation Ponds to occasionally flow east/northeast to off-Site areas beneath the Hunewill Ranch.

Figure 4-13 presents monthly vertical groundwater gradients in the alluvial aquifer at select locations. Vertical gradients were calculated as the difference in water levels between the shallowest and deepest alluvial monitoring wells in a cluster divided by the distance between the midpoints of the screened intervals of the wells. If a well was screened across the water table, then the water table elevation was used in place of the midpoint of the screened interval for that well. Monthly vertical gradients were calculated using water level measurements from 2013, which was the last full calendar year during which water levels in all active monitor wells were measured monthly. For wells installed after 2013 pursuant to the Additional Monitor Well Work Plan (BC 2013b), monthly vertical gradients were calculated using water level measurements from September 2014 through August 2015. Where available, monthly vertical gradients were also calculated using water level measurements from 2009 to illustrate groundwater conditions during operation of the Hunewill Ranch pumping wells.

Alluvial vertical gradients beneath the Process Areas are generally upward (PA-MW-4 well cluster), reflecting potential discharge of bedrock groundwater to alluvium as a potential source of groundwater to this portion of the Site (i.e., mountain-front recharge). Beneath the Evaporation Ponds (B/W-11 well cluster) and Hunewill Ranch (B/W-1 well cluster), alluvial vertical gradients are downward, with stronger vertical gradients corresponding to months when irrigation, and thus groundwater recharge and pumping, occurs. In addition, alluvial vertical gradients were even more strongly downward in these areas in 2009 when the Hunewill Ranch pumping wells were operating. In other irrigated areas (i.e., B/W-68 and B/W-81 well clusters), alluvial vertical gradients are also consistently downward, again with stronger vertical gradients in months when irrigation occurs.

Immediately northwest of the Site at the B/W-41 well cluster, vertical gradients are upward in the winter months, reflecting potential discharge of bedrock groundwater to alluvium (i.e., mountain-front recharge), and downward in the summer months, reflecting the influences of agricultural pumping. Downward vertical gradients at the B/W-41 well cluster are approximately two orders of magnitude smaller than the downward vertical gradients in irrigated areas, reflecting the greater distance of B/W-41 from irrigated areas. The B/W-28 well cluster (located in the Sunset Hills neighborhood) also exhibits seasonal changes in the direction of vertical gradients - upward vertical gradients occur in the winter (reflecting the non-irrigation season) and downward vertical gradients occur in the summer (reflecting the influences of agricultural pumping). In 2009, the effects of operation of the Hunewill Ranch pumping wells, in addition to other agricultural pumping in the Study Area, caused strongly downward vertical gradients that resulted in water levels in monitor well B/W-28S to decline below the bottom of the screened interval in August and September.

4.9.4 Groundwater Recharge

Recharge to the alluvial aquifer in the Mason Valley primarily occurs from surface water diverted from the Walker River within unlined irrigation ditches, infiltration of surface water and groundwater applied to irrigated fields, and infiltration of surface water from the channel of the Walker River. Recharge to the alluvial aquifer also occurs along the range front via a variety of hydrologic processes.

As indicated above, infiltration of surface water is the primary source of groundwater recharge to the alluvial aquifer in the Mason Valley, with MFR contributing significantly less (Carroll et al. 2010; Huxel and Harris 1969; Myers 2001; SSPA 2014). The annual amount of recharge derived by infiltration from stream channels, ditches, and agricultural fields is a function of Walker River flows, the volumes of surface water and groundwater used for irrigation, and water table depths within Mason Valley.

Hydrologic tracer data for tritium/helium (^{3}H/^{3}He) groundwater age estimates (Figure 4-14) and uranium isotopes (Figure 4-15) are consistent with the two principal recharge components of the HCSM: 1) seepage from the Walker River and irrigation ditches, and infiltration from irrigated fields on the east margins of the Study Area; and 2) MFR on the west side of the Study Area adjacent to the Singatse Range.

The use of groundwater uranium isotopes (and their relationship to tritium/helium groundwater age estimates) is briefly summarized as follows. In groundwater systems, ^{234}U is more environmentally mobile than ^{238}U due to physical recoil of the atom following alpha decay of ^{238}U, and the subsequent displacement of the ^{234}U atom to weaker binding sites within the crystalline lattice of the mineral in which it is contained. Thus, the two isotopes are released (weathered) at different rates, and the ^{234}U/^{238}U ratio is generally greater than unity in natural waters. Changes in the isotopic ratios (and uranium excess [Ue] values derived from the ratios) are assumed to be solely associated with transport/contact time between groundwater and aquifer solids. Consequently, high Ue values are associated with “long” periods of contact between groundwater and aquifer solids (i.e., “old” water) whereas low Ue values are associated with “short” periods of contact between groundwater and aquifer solids (i.e., “young” water). However, ^{234}U/^{238}U ratios in mine-impacted groundwater are also close to unity (resulting in low Ue values) because acidic process solutions leach both isotopes from ore material with equal effectiveness (Iles et al. 1995).

On the east side of the Study Area, Shallow zone alluvial groundwater directly recharged by surface water commonly exhibits younger, more modern age estimates and low Ue values. Low Ue values are also observed in mine-impacted Shallow zone groundwater beneath the Evaporation Ponds. In contrast, the older groundwater age estimates and highest Ue values commonly occur on the west side of the Study Area adjacent to the Singatse Range, in Deep alluvial groundwater, and in bedrock groundwater. An exception to the typical vertical distribution of higher Ue values and older groundwater age estimates is evident at the B/W-1 well cluster where younger groundwater age estimates and lower Ue values occur locally in the Deep groundwater zones.

This local pattern of Ue values and groundwater age estimates around the B/W-1 well cluster is consistent with the HSCM, which recognizes groundwater mixing due to agricultural pumping, especially former pumping at (which is located adjacent to the B/W-1 well cluster). Pumping at WDW019 has resulted in the migration of mine-impacted groundwater present beneath the Evaporation Ponds into the Intermediate and Deep zones of the alluvial aquifer beneath the Hunewill Ranch.

4.9.5 Alluvial Aquifer Hydraulic Property Data

Hydraulic conductivity values in alluvium from slug tests (Appendix F-1) range from 0.04 to 157 ft/day, with a median value of 6.8 ft/day. The 25th and 75th percentiles are 3.1 ft/day and 22.0 ft/day, respectively. Hydraulic conductivity values in alluvium calculated from an analysis of low-flow sampling data (Appendix F-2) range from 0.08 to 240 ft/day, with a median value of 18.4 ft/day. The 25th and 75th percentiles are 6.8 ft/day and 33.6 ft/day, respectively. Statistical analyses indicate that: 1) hydraulic conductivity values in each alluvial zone exhibit similar ranges, median values, and distributional shapes; and 2) hydraulic conductivity values throughout the alluvial aquifer are statistically equivalent in their distributions from zone to zone. Hydraulic conductivity estimates for the individual groundwater zone are provided in Table 4-6.

Table 4-6. Hydraulic Conductivity by Groundwater Zone (from Slug Test Data)

Zone	Median K (ft/day)	Standard Deviation (ft/day)	Count
Shallow	6	24	81
Intermediate	6	23	35
Deep 1	8	25	38
Deep 2	4	11	15
Deep 3	4	16	13
Deep 4	31	33	5
Deep 5	14	7	6
Bedrock	2	74	32

Notes: K = hydraulic conductivity.

Constant-rate testing of the eleven pumpback wells in 2010, which are screened in the Shallow zone (Appendix F-3), resulted in hydraulic conductivity estimates ranging from 0.9 to 47 ft/day (median of 9.4 ft/day). Slug testing of piezometers (33 in total, all screened in the Shallow zone) installed near the PWS, that were used as observation wells during constant-rate pumping tests of the 11 pumpback wells during 2010 (Appendix F-4), provided hydraulic conductivity estimates ranging from 1.1 to 83ft/day (median of 4.1 ft/day). Testing of five pumpback wells (PW-6, PW-7, PW-9, PW-10 and PW-11) in 2000 yielded hydraulic conductivity estimates that ranged from 6.4 to 33 ft/day, with a geometric mean of 16 ft/day, based on an assumed aquifer thickness of 50 feet (AHA 2000).

A constant-rate test of well WDW019, using an observation network of 93 monitor wells, resulted in estimated values for hydraulic conductivity and specific storage at 61 observation wells that exhibited pumping-related responses (Appendix F-5). Hydraulic conductivity values in alluvium derived from constant-rate pumping tests of WDW019 ranged from 4.9 to 1,200 ft/day, with a median value of 77 ft/day. The 25th and 75th percentiles are 38 ft/day and 195 ft/day, respectively. Five hydraulic conductivity values in bedrock ranged from 13.0 to 92 ft/day.

Specific storage values in alluvium from constant-rate pumping tests of WDW019 range from 1.45×10^{-8} to 1.46×10^{-3} $(\text{feet})^{-1}$, with a median value of 1.14×10^{-5} $(\text{feet})^{-1}$. The 25th and 75th percentiles are 5.16×10^{-6} $(\text{feet})^{-1}$ and 2.73×10^{-5} $(\text{feet})^{-1}$, respectively.

4.9.6 Spatial Variation in Hydraulic Conductivity

The spatial distributions of slug-test hydraulic conductivities in each alluvial groundwater zone are shown on Figure 4-16, and bedrock slug-test hydraulic conductivities are shown on Figure 4-17. Slug-test hydraulic conductivities represent the largest hydraulic conductivity dataset for evaluating spatial variation within the Study Area. To date, 295 measurements of hydraulic conductivity have been obtained using slug-test methods (Appendix F-1).

Although analysis of drawdown measurements during low-flow sampling of monitor wells has yielded more measurements of hydraulic conductivity than slug testing (318 measurements versus 295 measurements through August 2015), the approach has limitations that that do not capture the highest and lowest values of hydraulic conductivity in the Study Area. Due to the low flow rates used, measurable drawdown (i.e., drawdown exceeding 0.01 feet) does not occur during the sampling of many monitor wells that have sufficiently high hydraulic conductivities. In practice, hydraulic conductivities of greater than 100 ft/day cannot be determined with this method. Conversely, most monitor wells that have hydraulic conductivities less than 0.1 ft/day never achieve steady-state drawdown conditions during low-flow sampling (i.e., the water level in the monitor well continues to fall during the entire sampling period).

Spatial variation in slug-test hydraulic conductivities reflects the heterogeneous lithology of the alluvium underlying the Study Area. Alluvial slug-test hydraulic conductivities beneath the Site (i.e., beneath the Process Areas, Sulfide Tailings, and the Evaporation Ponds) are generally in the range of 1 to 10 ft/day, with some infrequent exceptions. To the west of the Site, along the margin of the Singatse Range, alluvial slug-test hydraulic conductivities extend into the range of 10 to 100 ft/day, with some locations still in the range of 1 to 10 ft/day. This trend continues north to towards the Sunset Hills. Beneath the Hunewill Ranch, alluvial aquifer slug-test hydraulic conductivity values generally range from 1 to 50 ft/day, with noted high conductivity exceptions at monitor wells B/W-60S, B/W-61S, and B/W-60D1.

Alluvial slug-test hydraulic conductivities near the Walker River (east of the Pit Lake) are generally higher than alluvial slug-test hydraulic conductivities beneath the Site, as evidenced by monitor wells B/W-13S, B/W-14S, B/W-15S, B/W-21S, and PLMW-2S. In this area, alluvial slug-test hydraulic conductivities are in the range of 10 to 50 ft/day. North of the Site and east of the West Campbell Ditch, alluvial slug-test hydraulic conductivities are also high, generally ranging from 10 to 100 ft/day or higher.

The spatial variability of alluvial slug-test hydraulic conductivity values reflects the varied depositional environments in Mason Valley, which are discussed in Section 4.8. The areas beneath the Site represent older fan deposits, which typically display lower permeability compared to the valley-fill sediments (i.e., younger and older alluvium). North of the Site, a transitional environment with higher permeability exists between the older fan deposits and the valley-fill sediments. Areas near the Walker River and generally to the east of West Campbell Ditch appear to represent valley-fill sediments, which exhibit the highest overall permeability. To the west of the Site, a narrow north-south trending band of higher permeability aquifer materials occurs along the flank of the Singatse Range, which represents coarser-grained alluvial fan materials eroded from the Singatse Range.

4.9.7 Bedrock Groundwater

The conceptual model of OU-1 bedrock groundwater flow conditions is based on regional and Site-specific information, including: 1) the lithologic and structural geology information presented in Proffett and Dilles (1984), and Proffett (1977); 2) a general understanding of bedrock groundwater flow in the Great Basin portion of the Basin-and-Range Physiographic Province; 3) hydrogeologic information obtained from drilling, lithologic logging, testing, and monitoring of 67 bedrock groundwater monitor wells located in the OU-1 Study Area (typically installed with 20-30 foot long screen intervals positioned in the upper 50 feet of bedrock); 4) evaluation of hydraulic head data in the bedrock and alluvial groundwater systems; 5) hydrologic tracer data for stable isotopes of oxygen and hydrogen in water ($^{18}O/^{2}H$), tritium/helium ($^{3}H/^{3}He$) groundwater age estimates, and uranium isotopes; and 6) bedrock monitor well chemical data.

As noted previously, the Site and surrounding Study Area are in a U-shaped graben structure on the western margin of Mason Valley. Within the Study Area, the depth to bedrock is highly variable and ranges from 0 to 750 feet bgs. Bedrock within the Mason Valley and Study Area is comprised of consolidated granitic, metamorphic, and volcanic rocks. The bedrock groundwater system consists of a fractured rock aquifer where water moves predominantly through fracture porosity, and matrix permeability is considered negligible. The fractures occupy only a small fraction of the bedrock.

Large-scale geologic structures (i.e., faults) result in structural compartmentalization of the bedrock groundwater system in the Study Area, with limited groundwater flow across and along faults that are commonly characterized as containing fine-grained, low-permeability fault gouge and brittle or plastic clay. The fractured rock aquifer exhibits high, three-dimensional (i.e., anisotropic) spatial variability in hydraulic conductivity (and hence groundwater flow rate). Hydraulic conductivity (K) values in bedrock monitor wells have been derived from slug tests performed after the wells were constructed, and from an analysis of low-flow sampling of bedrock monitor wells during groundwater monitoring activities (BC 2015a). Both methods yield comparable results. In addition, both methods provide estimates of hydraulic properties local to the test well and, consequently, are primarily used to assess the spatial distribution of bedrock hydraulic properties in the Study Area. Mapping of the hydraulic conductivity values indicate a high degree of spatial variability with significant changes (often greater than three orders of magnitude) over distances that are small relative to the size of the Study Area.

In bedrock, estimated conductivities range from approximately 0.002 to 334 feet/day, with the higher values measured in wells located near faults and the open pit (Figure 4-17). The 25th and 75th percentiles were 0.15 and 11.7 feet/day, respectively. The median bedrock slug-test K value was 1.7 feet/day. The lowest bedrock K values are up to two orders of magnitude lower than the lowest K values in alluvium in the Study Area. The minimum measured low-flow sampling K value in bedrock was 0.013 feet/day, and the maximum value was 67 feet/day. The 25th and 75th percentiles were 0.485 feet/day and 16.6 feet/day, respectively. The median bedrock low-flow sampling K value was 4.3 feet/day. Consistent with the slug-test data set, the lowest K values in bedrock are up to two orders of magnitude lower than the lowest K values in alluvium in the Study Area.

Similar water level responses in paired bedrock/alluvial monitor wells at any given location throughout the Study Area result from: 1) the interconnectivity between the bedrock and overlying alluvial groundwater flow systems (except locally around the B/W-1 well cluster where an aquitard separates the two flow systems); and 2) the transmission of stresses through the skeletal structure

of the aquifer solids. Seasonal fluctuations in bedrock groundwater levels (and vertical gradients between the bedrock and alluvial groundwater systems) due to agricultural pumping from the alluvial aquifer are observed beneath the Hunewill Ranch and Evaporation Ponds, and in the Sunset Hills area. Both the bedrock and alluvial groundwater systems exhibit similar long-term water level declines.

Vertical interconnection between bedrock and overlying alluvial groundwater is indicated by water level data (and the presence of locally-elevated concentrations of sulfate and uranium in bedrock groundwater that are sourced from overlying mine-impacted alluvial groundwater). Spatially, vertical gradients between bedrock and alluvium generally reflect the recharge components of the alluvial groundwater HCSM (BC 2014a), with downward vertical gradients east and north of the Site driven by recharge of surface water and irrigation water on crop fields, and upward vertical gradients in western portions of the Study Area driven by mountain-front recharge.

The largest vertical gradients between bedrock and alluvium occur: 1) within the Pit Lake cone of depression; and 2) beneath the Hunewill Ranch fields and Evaporation Ponds. In all other portions of the Study Area, vertical gradients between bedrock and alluvium are relatively small. Seasonal crop irrigation effects are observed near the Hunewill Ranch fields, Evaporation Ponds, and Sunset Hills, as represented by locations with both upward and downward vertical gradients.

Stable isotopes ($^{18}O/^{2}H$) in bedrock groundwater are generally more depleted with respect to Walker River surface water and alluvial groundwater (BC 2014a). The most depleted stable water isotope signatures in the bedrock groundwater are associated with the oldest apparent groundwater ages, as determined by $^{3}H/^{3}He$ age dating (Figure 4-18). The youngest groundwater ages are associated with the least depleted bedrock groundwater samples, which also overlap the region of cool season Walker River flows. Walker River samples display an evaporative fractionation signature, with less fractionated values occurring during periods of snowmelt runoff and more fractionated values occurring during periods of lower flows during the summer.

The greater degree of $^{18}O/^{2}H$ depletion of bedrock groundwater compared to the alluvial aquifer and Walker River surface water suggests different recharge processes. The depleted stable isotope signature indicates that bedrock groundwater is: 1) sourced from snowmelt recharged directly in the Singatse Range, which does not undergo the same evaporative fractionation as Walker River water, and/or fossil water recharged during the Pleistocene (a cooler and more humid climate than the current climate); and 2) older and of a different origin than surface water and alluvial groundwater. Bedrock groundwater ages are older than 1954, and essentially pre-date Site mining activities, occur throughout most the Study Area. Younger bedrock groundwater within and downgradient of the Singatse Spur, proximal to the Walker River, exhibits isotopic similarities between younger bedrock groundwater and cool season Walker River water.

Although groundwater ages exhibit some degree of spatial association, groundwater ages are not correlated with hydraulic conductivity. The widespread occurrence of older groundwater ages and localized occurrence of younger groundwater ages, irrespective of hydraulic conductivity, suggests slow and limited movement of bedrock groundwater. The spatial distribution of Ue values generally comports with the spatial distribution of $^{3}H/^{3}He$ groundwater ages. This pattern of widespread higher Ue values (i.e., “old” water) with localized areas of lower Ue values (i.e., “young” water), irrespective of hydraulic conductivity, again suggests slow/limited movement of bedrock groundwater.

In addition to a high degree of anisotropy in hydraulic characteristics and hydrologic tracer signatures, the bedrock groundwater system also exhibits three-dimensional (i.e., anisotropic) spatial variability in chemical concentrations. As noted in Brown and Caldwell (2014a) and discussed further in Section 5.0, concentrations of mine-related chemicals in groundwater are most elevated in the Shallow zone of the alluvial aquifer beneath the LEP, UEP, Finger Ponds, Phase IV VLT HLP, and Phase IV VLT Pond. COI concentrations decrease with vertical depth and horizontal distance from the Site sources, resulting in values in bedrock groundwater that are one to several orders of magnitude lower than the values in overlying alluvial groundwater.

In addition, areas of elevated COIs in bedrock groundwater are small in comparison to the alluvial aquifer, highly localized, and found mostly on-Site. The localized areas of elevated COI concentrations in bedrock groundwater indicate that bedrock fractures have limited hydraulic connectivity and transmissivity over horizontal distances relevant to the scale of the Study Area.

Collectively, the bedrock characterization information indicates: 1) a high degree of vertical hydraulic connection between the bedrock and alluvial groundwater systems; and 2) limited horizontal hydraulic connectivity and transmissivity of bedrock fractures, especially over horizontal distances that are relevant to the scale of the Site and the surrounding Study Area. Despite localized areas of relatively high hydraulic conductivity, bedrock groundwater flow velocities, average volumetric flow rates and chemical fluxes through the bedrock groundwater system are low.

SECTION 5.0

NATURE AND EXTENT OF GROUNDWATER CONTAMINATION

Identifying background groundwater quality and defining the extent of mine-impacted groundwater have been elements of the phased OU-1 groundwater characterization activities since 2005. This activity, referred to as the background assessment, was specifically identified as DQO #1 in both the draft and final versions of the remedial investigation work plans for OU-1 (BC and Integral Consulting, Inc. 2007 and BC 2014a, respectively).

5.1 Background Assessment Approach

The conventional approach to a background assessment described by EPA (2012a) involves obtaining groundwater chemical data from areas that were not impacted by Site sources to establish background chemical concentration ranges and background concentration limits (BCLs) for the COIs. Typically, the chemical concentration data are obtained from locations that are hydraulically upgradient or cross-gradient of Site sources. However, EPA and ARC recognized that there are constraints to relying solely on this conventional, statistical approach at the Site because locations where background wells can be installed hydraulically upgradient or cross-gradient of the Site sources do not fully account for all of the factors affecting groundwater quality downgradient of the Site, such as the following: 1) naturally-occurring variations in groundwater chemistry associated with geologic formations; 2) chemical inputs associated with application of agricultural fertilizers (e.g., nitrate and sulfate) and/or crop irrigation (e.g., uranium and sulfate); 3) increases in dissolved chemical concentrations associated with longer periods of contact between groundwater and aquifer sediments (i.e., longer groundwater residence times); and 4) spatial variations in groundwater flow conditions and the groundwater geochemical regime, which affect dissolved chemical concentrations.

Consequently, multiple lines of evidence are used to differentiate background groundwater quality from mine-impacted groundwater, including:

- Hydrogeologic Conceptual Site Model: The hydrogeologic information defines the current and plausible historic groundwater flow and chemical transport pathways, and related anthropogenic activities (including mining and agriculture). The HCSM: 1) incorporates observed temporal variations in groundwater flow conditions and chemical concentrations in groundwater based on an extensive Site-wide groundwater monitoring network, aquifer testing, and a groundwater flow model; and 2) constrains how chemical distributions in groundwater can be reasonably interpreted and related to mining and agricultural activities.
- Contoured Chemical Distributions: Chemical distributions outline distinct plumes of off-Site impacted groundwater that have physical continuity along plausible flow pathways linked to Site features that are known sources of groundwater impacts. Other areas where chemicals occur in groundwater at concentrations above Maximum Contaminant Levels (MCLs), such as the North Study Area (NSA; i.e., that portion of the Study Area located northeast of the West Campbell Ditch and north of Sunset Hills), are separate from and do not physically connect along groundwater flow pathways to the Site.
- Sulfur Isotope Signatures: Distinct sulfur isotope ($\delta^{34}S_{SO4}$) signatures associated with sulfate in the acidic process leach solutions are used to differentiate mine-impacted groundwater from groundwater that is unaffected by mining operations, and to delineate the extent of groundwater contamination associated with mining. Specifically, the extent of mine-impacted groundwater is constrained where the $\delta^{34}S_{SO4}$ value in alluvial groundwater downgradient of the Site exceeds the minimum background value of +4.93‰ at locations that are within predominant recharge areas to the alluvial aquifer. Such background areas of the alluvial aquifer are also consistent with contoured or numerically-modeled flow pathways from the Site.
- Conventional Approach: The conventional approach to defining background groundwater quality for the Site (EPA 2012a) relies on chemical data from the background monitor wells and EPA-recommended statistical procedures (EPA 2009) to calculate BCLs for COIs. BCLs are computed for each COI in three geographic recharge areas identified in the Study Area HCSM: 1) the Southeast Recharge Area (SERA) - representing recharge by infiltration and percolation of water associated with streams, ditches and agricultural fields; 2) the Southwest Recharge Area (SWRA) - representing mountain-front recharge; and 3) the NSA - representing groundwater lateral to the Site flowing into the NSA.

The BCLs are used for two purposes. BCLs for sulfate and dissolved uranium in the SERA and SWRA are used to confirm the extent of mine-impacted groundwater defined by $\delta^{34}S_{SO4}$ signatures. Sulfate and dissolved uranium are suitable chemicals for this purpose because these two chemicals are typically more mobile in groundwater relative to other indicators of mine-impacted groundwater such as iron and other metals (BC 2014a; EPA 2010d). BCLs are computed for other COIs, which can then be used to define areas within the extent of mine-impacted groundwater where chemical concentrations exceed background chemical concentrations.

Because the NSA BCLs characterize groundwater quality flowing into the NSA, they are not used to define the extent of mine-impacted groundwater but can instead be used to evaluate chemical loading to groundwater due to agricultural practices in this part of the Study Area. The steps identified in the BGQA - Revision 3 (BC 2016b) for performing the background groundwater assessment are illustrated on Figure 5-1 and summarized in Table 5-1.

Table 5-1. Site-Wide Background Groundwater Quality Assessment Approach

Step	Information Source(s)
Obtain and evaluate available OU-1 hydrogeologic and geochemical data with respect to data quality and relevance.	▪ Brown and Caldwell (BC 2014a) ▪ Brown and Caldwell (BC 2015e)
Refine the HCSM based on recent information obtained in 2013 and 2014 from existing wells and new wells installed pursuant to the Additional Well Work Plan (BC 2013b).	▪ Brown and Caldwell (BC 2015d) ▪ Brown and Caldwell (BC 2016b). Summarized below; see Section 3.0 in Appendix J-7 for details.
Define hydrogeologic areas that are considered representative of background conditions and/or other water quality types.	▪ Brown and Caldwell (BC 2016b). Summarized below; see Section 3.0 in Appendix J-7 for details.
Specify the types and quality of RI groundwater data selected as relevant and appropriate for the background assessment.	▪ Brown and Caldwell (BC 2016b). See Section 4.0 in Appendix J-7 for details.
Use hydrologic tracer results to refine the HCSM, especially as the results relate to the information inputs identified in DQO #1 for the background groundwater assessment. Use $\delta^{34}S_{SO4}$ signatures to differentiate mine-impacted groundwater from groundwater impacted by other anthropogenic activities.	▪ Brown and Caldwell (BC 2016b). Summarized below; see Section 6.0 in Appendix J-7 for details.
Establish quantitative background concentration ranges and calculate groundwater BCLs for each background area. Use sulfate and uranium BCLs to evaluate the extent of mine-impacted groundwater. Use BCLs for other COIs to define areas within the extent of mine-impacted groundwater where chemical concentrations exceed background chemical concentrations.	▪ Brown and Caldwell (BC 2016b). Summarized below; see Section 6.0 in Appendix J-7 for details.
Evaluate the consistency of the two approaches (i.e., $\delta^{34}S_{SO4}$ signatures tracers and BCLs) to identifying the extent of mine-impacted groundwater. Integrate the results of the two approaches along with other RI characterization information into a single boundary representing the extent of mine-impacted groundwater in each zone of the alluvial aquifer.	▪ Brown and Caldwell (BC 2016b). Summarized below; see Section 7.0 in Appendix J-7 for details.

Ultimately, the identification of the extent of mine-impacted groundwater in the Study Area integrates the three major elements of boundary delineation (i.e., $\delta^{34}S_{SO4}$ signatures, and BCLs for the two most mobile, aerially extensive, indicators of mine-impacted groundwater, sulfate and uranium), as well as other lines of evidence that include hydrogeologic information, chemical concentration data, and other hydrologic tracer data.

5.2 Contoured Chemical Distributions

The following sections discuss the distributions of select parameters and COIs in Study Area groundwater.

5.2.1 Alluvial Aquifer

To illustrate aspects of the HCSM discussed below, the distributions of six chemicals (pH, sulfate, uranium, alkalinity, nitrate, and arsenic) in groundwater during August 2014 are illustrated on cross sections (cross section locations shown on Figure 4-6) and plan view maps for the Shallow and Deep 3 groundwater zones (Figures 5-2 through 5-7). The distributions of the six chemicals in all the groundwater zones are shown on plan view maps in Appendix K. The distributions of the six chemicals have routinely been presented in various groundwater reports for the following reasons.

Historical operational information and groundwater quality data indicate that elevated acidity (i.e., low pH), sulfate, and uranium are indicator parameters for mine-impacted groundwater at the Site. Because sulfate and uranium, which are naturally-occurring in the Study Area, are more mobile in groundwater relative to other indicators of mine-impacted groundwater (e.g., iron), these mine-related chemicals have been used to preliminarily evaluate the extent of mine-impacted groundwater (BC 2014a). Alkalinity in groundwater is important because complexation of dissolved uranium with bicarbonate enhances its solubility and mobility in groundwater (EPA 2010d; BC 2014a).

Given their association with agricultural amendments and fertilizer, sulfate and nitrate in groundwater are also important indicators of agricultural-impacted groundwater (BC 2014a). Although arsenic is detected at locally high concentrations in both on-Site and off-Site locations, it occurs naturally in the Study Area (and throughout Nevada) and exhibits complex geochemical transport behavior, which limits its usefulness as an indicator of mine-impacted groundwater (EPA 2016e).

pH

The distributions of pH values in the Shallow and Deep 3 groundwater zones in August 2014 are shown on Figures 5-2a and 5-2b, respectively. The lowest pH values are observed in Shallow zone groundwater beneath the Evaporation Ponds and downgradient of the Phase IV VLT HLP and VLT Pond, and pH values increase laterally and vertically away from these structures by orders of magnitude.

Sulfate and Uranium

The distributions of sulfate and uranium in groundwater in August 2014 are illustrated on Figures 5-3 and 5-4, respectively. The most elevated concentrations of sulfate and uranium are also observed in Shallow zone groundwater beneath the Evaporation Ponds and downgradient of the Phase IV VLT HLP and VLT Pond, and concentrations decrease laterally and vertically away from these features by orders of magnitude.

In particular, elevated concentrations of sulfate and uranium in the alluvial aquifer occur in: 1) Shallow zone groundwater where sulfate (Figure 5-3a) and uranium (Figure 5-4a) distributions exhibit a northwest longitudinal orientation consistent with the northwest direction of groundwater flow across the Study Area; and 2) Deep zone alluvial groundwater where sulfate (Figure 5-3b) and uranium (Figure 5-4b) distributions exhibit a northeast longitudinal orientation from the northern portion of the Site to beneath the Hunewill Ranch toward former (e.g., WDW019) and existing agricultural wells used seasonally to extract groundwater for crop irrigation.

In addition, elevated concentrations of sulfate and uranium (as well as alkalinity and nitrate discussed below) occur in Shallow, Intermediate, and Deep 1 groundwater zones beneath agricultural fields in the NSA. Given the low concentrations of sulfate and uranium detected in all groundwater zones at well cluster B/W-27 (Figures 5-3d and 5-4d, respectively), elevated concentrations of these chemicals in groundwater beneath the agricultural fields located in the NSA are not physically connected along current and plausible historic groundwater flow paths back to known sources of mine-impacted groundwater beneath the Site. A more detailed discussion of data specific to the NSA is provided in Section 5.5.

Alkalinity

The distribution of alkalinity in groundwater in August 2014 is illustrated on Figure 5-5. The most elevated values of alkalinity occur beneath the Evaporation Ponds in the northern portion of the Site. In the Shallow zone beneath the UEP and downgradient of the Phase IV VLT HLP and VLT Pond, pH values are generally less than 4 s.u.. Similar to sulfate and uranium, elevated alkalinity occurs in: 1) Shallow zone groundwater where the distribution (Figure 5-5a) exhibits a northwest longitudinal orientation consistent with the northwest direction of groundwater flow across the Study Area; and 2) Deep zone alluvial groundwater where the distribution (Figure 5-5b) exhibits a northeast longitudinal orientation from the Evaporation Ponds, Phase IV VLT HLP and VLT Pond to beneath the Hunewill Ranch toward former (e.g., WDW019) and existing agricultural wells used seasonally to extract groundwater for crop irrigation. Alkalinity values above 200 mg/L occur beneath the Hunewill Ranch and other agricultural fields located in the northeastern portion of the Study Area.

Nitrate

The distribution of nitrate in groundwater in August 2014 is illustrated on Figure 5-6. The most elevated nitrate concentrations occur in groundwater beneath the Hunewill Ranch and other agricultural fields located in the northeast portion of the Study Area (Figure 5-6a). Beneath the Hunewill Ranch, nitrate concentrations in Shallow zone groundwater were as high as 42 mg/L during August 2014. Former groundwater extraction from high-capacity wells (especially WDW019) for irrigation of crops on the Hunewill Ranch has mobilized nitrate from the Shallow zone into the Intermediate and Deep zones of the alluvial aquifer system. Nitrate is subsequently transported in groundwater that flows northwest to the Sunset Hills area.

Nitrate concentrations in Shallow zone groundwater beneath the agricultural fields in the northeast Study Area were as high as 38 mg/L during August 2014 (Figure 5-6a). Groundwater extraction from high-capacity agricultural wells for crop irrigation on fields located in the northeastern portion of the Study Area has mobilized nitrate from the Shallow zone into the Intermediate and Deep zones of the alluvial aquifer system. Nitrate beneath these agricultural fields is subsequently transported in groundwater that flows north and northwest.

Nitrate concentrations in groundwater samples from the B/W-27 cluster have consistently been at low concentrations throughout their monitoring history. In August 2014, nitrate concentrations ranged from 0.13J to 0.88J mg/L. The nitrate data from the B/W-27 well cluster shows that the nitrate concentrations beneath the Hunewill Ranch and other agricultural fields in the northeast Study Area are physically separate. The horizontal and vertical patterns in nitrate concentrations in groundwater indicate that application of fertilizer on the agricultural fields has resulted in downward vertical migration of agricultural nitrate rather than horizontal transport of nitrate in the groundwater system. A more detailed discussion of data specific to the NSA is provided in Section 5.5.2.

Arsenic

The distribution of arsenic in alluvial groundwater in August 2014 (Figure 5-7) differs from the distributions observed for sulfate, nitrate, and alkalinity. The most elevated arsenic values occur in Shallow zone groundwater at off-Site wells B/W-77S (560 µg/L) and B/W-32S (420 µg/L), which are located approximately 2,500 feet north of the Evaporation Ponds (Figure 5-7a). Arsenic values decrease laterally and vertically from these two wells by at least an order of magnitude. In contrast to the elevated arsenic values at these two off-Site wells, the most elevated arsenic values in groundwater beneath the Site are approximately 3.5 times lower.

The most elevated arsenic concentrations in on-Site groundwater range from approximately 120 to 160 µg/L in Shallow zone wells MW-5S, FMS-06S, and MW-2S (Figure 5-7a). These three wells are located near the Thumb Pond and the Phase IV VLT HLP and VLT Pond. Historic process solutions discharged to the Thumb Pond were reported to contain 42 mg/L of arsenic (Seitz et al., 1982). Arsenic values in the range of 50 to 80 µg/L occur in the Shallow, Intermediate and Deep zones west and northwest of the Evaporation Ponds and below the Phase IV VLT HLP and VLT Pond.

In addition, data from zonal groundwater samples and monitor wells installed in the NSA indicate elevated concentrations of arsenic in Deep zone groundwater that inflows (i.e., recharges) the NSA and migrates beneath the agricultural fields. Groundwater arsenic concentrations in this portion of the Study Area increase as a function of depth in the alluvial aquifer (at a relatively uniform pH) as indicated best by the zonal groundwater sample data from wells B/W-56 and B/W-69 (Figure 5-8) where arsenic concentrations are as high as 83 ug/L. At other NSA monitoring locations (such as B/W-59, B/W-57 and B/W-68), chemical profiling did not extend as deep as the B/W-56 and B/W-69 locations. Nonetheless, arsenic concentrations at these three locations began increasing as a function of depth below 4,200 feet amsl. Had sampling been conducted to greater depths at these locations, elevated arsenic concentrations are expected since no known plausible hydrologic/geochemical explanation would limit arsenic enrichments strictly to those areas around B/W-56 and B/W-69.

Because profile locations B/W-56 and B/W-69 represents background (i.e., characterize groundwater inflows to the NSA), chemical concentrations at these locations represent naturally-occurring concentrations and are not related to advancement of mine-impacted groundwater from the south. Furthermore, the elevated arsenic concentrations at this depth are not associated with agricultural activity, which is shown in Section 5.5.2 to affect the Shallow, Intermediate and Deep1 zones in the NSA. Instead, these elevated arsenic concentrations appear to be associated with regional groundwater conditions in the Mason Valley, likely associated with deep bedrock discharge to the alluvial basin aquifer.

5.2.2 Bedrock Groundwater

Most of the bedrock wells have 20- to 30-foot long screens that are positioned in the upper 50 feet of the bedrock to straddle fractures that yield groundwater for monitoring purposes. The pH measurements and concentrations of sulfate, uranium, alkalinity, nitrate and arsenic in the bedrock groundwater system in August 2014 are shown on Figure 5-9. Most pH measurements in bedrock groundwater are near-neutral (i.e., approximately 7.0).

Sulfate and uranium were detected in bedrock groundwater during August 2014 at concentrations as high as 1,600 mg/L and 950J µg/L, respectively. For both chemicals, the most elevated concentrations were detected in bedrock groundwater within the mine Site, and somewhat lower concentrations were detected immediately west of the Evaporation Ponds below the VLT Pond. The most elevated sulfate concentrations in bedrock groundwater occurred beneath the Sulfide Tailings at well B/W-36B. Off-Site, sulfate was detected in bedrock groundwater at a concentration above 500 mg/L in well B/W-58B, which monitors groundwater emanating from the MacArthur Mine. The most elevated uranium concentrations in bedrock groundwater occurred at on-Site wells MW-5B and B/W-74B. Similarly, the most elevated alkalinity concentrations in bedrock groundwater occurred at on-Site wells MW-5B and B/W-74B (as well as MW-H4SN).

Nitrate concentrations were most elevated in bedrock groundwater at wells B/W-73B and HLP-06B, which are located to the west and southwest of the mine Site.

Elevated arsenic concentrations in bedrock groundwater occurred in three distinct areas. Elevated arsenic concentrations were detected in: 1) four wells (PA-MW-2B, PA-MW-4B, HLP-03B, and HLP-06B) located around the Phase III 4X HLP and nearby Calcine Ditch; 2) six wells (MW-4B, B/W-34B, B/W-6B, B/W-44B, LEP-MW-2B, and B/W-33B) located to the immediate west of the Evaporation Ponds in an area potentially influenced by MFR; and 3) in two wells (B/W-54B and YPT-MW-10B) located north of Sunset Hills.

5.3 Identification of Groundwater Impacts

5.3.1 Differentiating Groundwater Impacts Using Sulfur Isotopes

Sulfur Isotope Signature in Background Groundwater

The $\delta^{34}S_{SO4}$ signature used to differentiate mine-impacted groundwater from non-mine-impacted groundwater reflects the dominant background groundwater types in off-Site areas. Groundwater modeling (SSPA 2014) indicates that recharge to groundwater in the alluvial aquifer (98% of all recharge) in the Study Area results from irrigation field percolation (49%), leakage from irrigation ditches (29%), and seepage from the Walker River (20%).

Background wells associated with these water types include some, but not all, of the wells in the SERA and NSA recharge areas. Eight background wells that represent the dominant background groundwater types in off-Site areas, based on their locations in the groundwater flow field relative to the Walker River and agricultural features, include: B/W-15S, B/W-20S, B/W-21S, B/W-56S, B/W-59S, B/W-59D3, PLMW-2S and PLMW-2B. Values of $\delta^{34}S_{SO4}$ in groundwater samples from these wells range from +4.93 to +6.62‰.

Sulfur Isotope Signature in Mine-Impacted Groundwater

Sulfur isotopes in groundwater were used to differentiate the leading edge of mine-impacted groundwater from background groundwater or groundwater impacted by other anthropogenic activities within the Study Area because: 1) sulfur isotopes in dissolved sulfate can be used to infer groundwater movement because these isotopes are mobile tracers whose movement is not strongly retarded by the aquifer matrix in groundwater settings similar to the Study Area; and 2) early copper extraction operations at Yerington (during the 1950s and 1960s) primarily relied on sulfuric acid derived from sulfur ores (i.e., pyrite) from the Leviathan Mine in California (BC 2014a), which had a distinct sulfur isotopic signature (Taylor and Wheeler 1994). Sulfur sources with different (higher) isotopic signatures were used during later operations in the 1970s, 1980s, and 1990s. These different isotopic signatures may be used, along with chemical data and other information, to differentiate groundwater impacts associated with Anaconda and Arimetco operations.

Delineation of mine-impacted groundwater reasonably assumes that groundwater affected by the earliest operations at the Site has traveled the farthest downgradient distance in the alluvial aquifer. Therefore, the isotopic signature for sulfur sources used during the 1950s and 1960s serves as a potentially reliable tool for characterizing the leading edge of the plume and for differentiating mine-impacted water at the leading edge of the plume from background conditions. The median value reported by Taylor and Wheeler (1994) for $\delta^{34}S_{SO4}$ in aqueous samples collected from seeps and adit discharge at the Leviathan Mine is -17.6‰ (Table 5-5 in Appendix J-7).

Distinct $\delta^{34}S_{SO4}$ signatures associated with sulfate in the sulfuric acid process leach solutions used during early Site operations (most evident in groundwater at well W5DB-D3) and groundwater from the background monitor wells are used to evaluate the extent of mine-impacted groundwater. This approach conceptualizes initial infiltration of acidic process leach solutions exhibiting a diagnostic $\delta^{34}S_{SO4}$ signature of approximately -17‰ into originally un-impacted groundwater beneath the Evaporation Ponds.

The conceptual approach assumes a simplified aquifer geometry and flow configuration that account for mixing of a conservative (i.e., geochemically unreactive) tracer within the aquifer. Again, the isotope signature for the sulfur source used during the earliest processing operations at the Site would be representative of any mine-impacted water first entering the alluvial aquifer and now present at the leading, downgradient edge of the plume. The leading edge of mine-impacted groundwater is identified as locations where the $\delta^{34}S_{SO4}$ signature in groundwater associated with mining impacts cannot be differentiated from the $\delta^{34}S_{SO4}$ signature in background groundwater.

Quantitatively, mine-impacted groundwater can no longer be differentiated from background groundwater when the $\delta^{34}S_{SO4}$ value at a given location falls within the background $\delta^{34}S_{SO4}$ range (i.e., exceeds the minimum background value of +4.93‰). Higher isotope signatures measured inside the leading edge of the plume may be indicative of mixing with groundwater, subsequent sulfur releases derived from sources having a different isotopic signature, or some combination of these two processes.

Lateral and vertical patterns in $\delta^{34}S_{SO4}$ groundwater data are illustrated on Figure 5-10. The distinctly negative $\delta^{34}S_{SO4}$ signature of -17.6‰ associated with sulfate in the sulfuric acid process leach solutions used for copper recovery at Yerington is evident in Deep zone alluvial groundwater beneath the Evaporation Ponds, especially at well W5DB-D3, which has a strongly negative $\delta^{34}S_{SO4}$ signature of -17.12‰.

The low $\delta^{34}S_{SO4}$ values in Deep zone alluvial groundwater beneath the Evaporation Ponds also extend off-Site toward the Hunewill Ranch, particularly in the Deep 3, Deep 4, and Deep 5 zones. The region of low $\delta^{34}S_{SO4}$ values beneath the Evaporation Ponds is displayed on cross section A-A' (Figure 5-10c), centered around the W5DB well cluster. The low values of $\delta^{34}S_{SO4}$ that extend off-Site toward the Hunewill Ranch are visible on cross section B-B' (Figure 5-10d).

5.3.2 Differentiating Groundwater Impacts Using BCLs

A conventional approach to a BGQA emphasizes the groundwater flow regime to identify wells that are located hydraulically up-gradient and/or cross-gradient to sources of chemical loading to groundwater, as noted by the EPA (2012a) in comments on the Draft BGQA (BC 2011c). A background assessment may also consider groundwater recharge sources, the different geologic materials through which groundwater flows, and the residence time because these factors are recognized to naturally affect groundwater composition (BC 2014a; Hem 1985; Freeze and Cherry 1979). Key HCSM elements that are relevant to identifying background monitor wells include:

- Groundwater Flow Direction: Groundwater in the alluvial aquifer within the Study Area generally flows to the northwest, with flow directions locally affected by a variety of factors discussed previously in Section 4.0.
- Recharge Sources: The alluvial aquifer within the Study Area is primarily recharged by infiltration and percolation of water associated with stream channels, ditches, and irrigated agricultural fields located to the east of the mine Site. Limited recharge to the alluvial aquifer also occurs as mountain-front recharge to the west of the Site.
- Chemical Loading Sources: The northern portion of the Site (including the Evaporation Ponds, the Phase IV VLT HLP and the VLT Pond) is considered the primary source of chemicals that migrate off-Site. The most elevated acidity and chemical concentrations are observed in Shallow zone groundwater beneath this area, and concentrations decrease laterally away from this area by orders of magnitude. Furthermore, other Site sources are located hydraulically upgradient of the northern portion of the Site.

Based on these considerations, background monitor wells for the Study Area are categorized by geographic recharge area and described below.

- SERA: This background groundwater quality type is represented by seven monitor wells (B/W-15S, B/W-20S, B/W-21S, PLMW-2S, PLMW-2B, WRA3-1B and WRA3-2B) that are located up-gradient of the mine Site and near the Walker River. Data from these wells represent recharge of groundwater having a short residence time in the flow system.

- NSA: This background groundwater quality type is represented by three monitor wells (B/W-56S, B/W-59S and B/W-59D3) that are located upgradient of the NSA and represent both Shallow and Deep zone alluvial groundwater quality.
- SWRA: This background groundwater quality type is represented by six monitor wells (B/W-12RB, B/W-13S, B/W-23B, B/W-26RB, PLMW-3RB, and PLMW-4B) that are located up-gradient and west/southwest of the Site and, thus, represent mountain-front recharge.

The BCL for each COI for each background water quality type was calculated as the 95% upper tolerance limit (UTL) with 95% confidence, consistent with the sampling and statistical comparison strategy recommended in EPA guidance (EPA 1992). The 95% UTL is the numerical value below which 95% of the background data are expected to fall, with 95% confidence. That is, one can be 95% sure that 95% of data in the background population fall below this value. The upper bound of this interval is the 95/95 UTL.

The 95/95 UTL is calculated from a sample dataset and depends on the distribution, central tendency, and variability of the dataset, as well as sample size (EPA 2009). The statistical test used to calculate the 95/95 UTL also depends on the distribution of the dataset, the sample size, and the percentage of non-detects present. The ProUCL software program (version 5.0.00) (EPA 2013f) was used to perform statistical calculations of the 95/95 UTL. ProUCL evaluates a dataset to determine the likely form (or forms) of the distribution, calculates UTLs using numerous appropriate statistical methods, and provides a recommendation as to which method is most appropriate for a particular dataset.

Distributional testing in ProUCL is performed using the Shapiro-Wilk (S-W) test for normality on the untransformed data, the log-transformed data, and the gamma-transformed data. The S-W test may conclude that the data set conforms to multiple parametric distributions. In this case, the distribution with the highest probability of association (calculated p-value from the S-W test) is selected as the underlying parametric distribution. When an insufficient sample size or insufficient number of detected results existed to statistically calculate a 95/95 UTL, the maximum value of the dataset was selected, as is common practice in selecting upper threshold values in the absence

of adequate sample sizes (EPA 2009). For datasets with 100% non-detects, the lowest detection limit in the dataset was selected as the BCL. The calculated 95/95 UTLs for each constituent and background water quality type are provided in Table 5-2.

Table 5-2. Summary of Calculated Background Concentration Limits

Chemical	Units	Groundwater Standard	SERA	NSA Inflows	SWRA
pH (field)	s.u.	6.5-8.5	7.96	7.65	8.35
Alkalinity, Bicarbonate (as $CaCO_3$)	mg/L	--	180	160	210
Alkalinity, Carbonate (as $CaCO_3$)	mg/L	--	2	2	2
Alkalinity, Hydroxide (as $CaCO_3$)	mg/L	--	2	2	2
Alkalinity, Total (as $CaCO_3$)	mg/L	--	180	160	210
Total Dissolved Solids	mg/L	500	570	304	561
Total Organic Carbon (TOC)	mg/L	--	1.8	1.5	1.8
Calcium	mg/L	--	71	38	72
Magnesium	mg/L	--	13	11	16
Potassium	mg/L	--	5	7	5
Sodium	mg/L	--	96	51	130
Chloride	mg/L	250	59	17	72
Fluoride	mg/L	2	1	0.9	1.5
Sulfate	mg/L	250	160	57	180
Nitrate (as N)	mg/L	10	1.5	0.1	0.8
Nitrite (as N)	mg/L	1	0.1	0.2	0.4
Nitrate-Nitrite (as N)	mg/L	--	1.5	0.3	0.8
Aluminum	mg/L	0.2	0.04	0.03	0.05
Antimony	µg/L	6	0.41	0.31	0.96
Arsenic	µg/L	10	12	38	20
Barium	µg/L	2,000	50	141	41
Beryllium	µg/L	4	0.17	0.25	0.25
Boron	µg/L	--	680	410	920
Cadmium	µg/L	5	0.11	0.25	0.17
Chromium	µg/L	100	0.9	1.0	1.8
Cobalt	µg/L	--	1.5	1.4	2
Copper	µg/L	1,300	0.9	0.9	4.3
Iron	mg/L	0.3	0.1	0.3	1.4
Lead	µg/L	15	0.28	0.20	0.2
Lithium	µg/L	--	65	49	44
Manganese	µg/L	50	870	2,825	303
Mercury	µg/L	2	0.35	0.10	1.1
Molybdenum	µg/L	--	18	20	140
Nickel	µg/L	--	1.1	1.6	19
Phosphorus	mg/L	--	0.16	0.91	0.12
Selenium	µg/L	50	1.1	0.5	20
Silica	mg/L	--	44	40	55
Silver	µg/L	100	0.12	0.14	0.36
Strontium	mg/L	--	0.74	0.4	0.47

Table 5-2. Summary of Calculated Background Concentration Limits

Chemical	Units	Groundwater Standard	SERA	NSA Inflows	SWRA
Thallium	µg/L	2	0.2	0.2	0.2
Tin	µg/L	--	14	12	30
Titanium	mg/L	--	0.002	0.002	0.002
Uranium	µg/L	30	20	10	27
Vanadium	µg/L	--	8	5	16
Zinc	µg/L	5,000	6	4	120
Gross Alpha	pCi/L	15	12.2	6.7	21.3
Gross Beta	pCi/L	--	10.8	10.0	11.9
Radium-226	pCi/L	5 (combined 226 + 228)	0.8	1.0	1
Radium-228	pCi/L	5 (combined 226 + 228)	1	0.9	1.5
Thorium-228	pCi/L	--	0.5	0.4	0.5
Thorium-230	pCi/L	--	0.4	0.4	0.7

Notes:

1) SERA = Southeast Recharge Area; NSA = North Study Area; SWRA = Southwest Recharge Area
2) s.u. = standard units; µg/L = milligrams per liter; µg/L = micrograms per liter; pCi/L = picocuries per liter

5.3.3 Comparison of Methods

The extent of mine-impacted groundwater based on sulfate and uranium BCLs is generally similar to the extent of mine-impacted groundwater based on $\delta^{34}S_{SO4}$ signatures. Furthermore, the extent of mine-impacted groundwater in each zone of the alluvial aquifer varies in ways that are consistent with flow directions, chemical distributions, and other hydrologic tracer data presented in the HCSM. Differences in the spatial extent of mine-impacted groundwater delineated by the two background assessment approaches are considered minor and likely associated with local variations in transport behavior and locally variable evapoconcentration and chemical loading processes.

5.4 Extent of Mine-Impacted Groundwater

The extent of mine-impacted groundwater presented in this OU-1 RI Report reflects the outcome of discussions during a groundwater technical meeting on June 29, 2016 and EPA’s subsequent direction to conservatively establish the extent of mine-impacted groundwater because “is in the best interest of the overall progress for completing the OU-1 Groundwater Remedial Investigation Report” (EPA 2016e).

EPA (2016e) noted that professional judgement is an inherent component of estimating the extent of mine-impacted groundwater in this complex setting, and that tools used in the background assessment to estimate the area of mine-impacted groundwater may not fully account for the range of chemical concentrations that occur naturally in groundwater within the Study Area. However, as noted during previous submittals (e.g., ARC 2016b) and during groundwater technical meetings, further refinements to the mine-impacted groundwater boundary may be warranted based on additional evaluations of monitoring data and other new information to better account for naturally-occurring chemical concentrations in Study Area groundwater.

As previously described, the identification of the extent of mine-impacted groundwater in the Study Area integrates the three major elements of boundary delineation (i.e., $\delta^{34}S_{SO4}$ signatures, and BCLs for the two most mobile, aerially extensive, indicators of mine-impacted groundwater, sulfate and uranium), as well as other lines of evidence that include hydrogeologic information, chemical concentration data, and other hydrologic tracer data. Also, the boundary delineating mine-impacted groundwater from unimpacted groundwater is conceptualized as a zone on a plan view map rather than a distinct line due to many factors including the size of the Study Area, age and complexity of the contaminant releases, occurrence and variability of naturally-occurring chemical concentrations, and complexities of subsurface contaminant transport and fate.

The extent of mine-impacted alluvial groundwater is shown on Figure 5-11, and can be generally described as follows, recognizing that mine-impacted groundwater is spatially more extensive in the Shallow, Intermediate and Deep 1 zones of the alluvial aquifer relative to the Deep 2 through Deep 5 zones. The northernmost extent of mine-impacted groundwater in the Shallow, Intermediate and Deep 1 zones of the alluvial aquifer is located near the Sunset Hills between well clusters B/W-10 and B/W-52. The eastern extent of mine-impacted groundwater in the Shallow, Intermediate and Deep 1 zones of the alluvial aquifer is approximately located near or beneath the West Campbell Ditch alignment. To the west of the Site, mine-impacted groundwater extends almost to the western extent of saturated alluvium between unimpacted wells/clusters B/W-16S and B/W-40, and impacted well clusters B/W-33, B/W-6 and B/W-22.

Mine-impacted groundwater in the deeper zones does not extend as far north as the upper three zones. In the Deep 2 through Deep 5 zones, the maximum northern extent of mine-impacted groundwater is near the northern end of the Hunewill Ranch fields. The eastern extent of mine-impacted groundwater in the Deep 2 through Deep 5 zones of the alluvial aquifer is located between well clusters B/W-27 and B/W-50. Particularly on the east, the area of mine-impacted groundwater in the Deep 3 through Deep 5 zones reflect the former influence of seasonal groundwater extraction for crop irrigation from agricultural wells (e.g., WDW019, located adjacent to the B/W-1 well cluster). To the west of the Site, mine-impacted groundwater in the Deep 3 through Deep 5 zones extends almost to the western extent of saturated alluvium.

Based on the background assessment methodology, the plume of mine-impacted groundwater in the various zones of the alluvial aquifer does not discharge to surface water. Estimates of the volume of mine-impacted groundwater and masses of sulfate and uranium in each groundwater zone are provided in Table 5-3.

Table 5-3. Estimated Volume and Masses of Sulfate and Uranium in Mine-Impacted Alluvial Groundwater

Zone	Zone Thickness (feet)	Volume of Mine-Impacted Alluvial Groundwater (acre-feet)	Sulfate Mass (tons)	Uranium Mass (tons)
Shallow	35	45,899	140,116	11.1
Intermediate	50	65,905	96,501	9.9
Deep 1	50	62,238	52,346	5.3
Deep 2	80	64,611	80,610	20.7
Deep 3	120	48,032	79,397	22.5
Deep 4	100	35,669	23,414	12.8
Deep 5	200	62,973	25,374	16.5
Total		**385,327**	**497,758**	**98.8**

The estimates in Table 5-3 are based on the thickness of each groundwater zone within the plume of mine-impacted groundwater shown on Figure 5-11 and the areas/average concentrations within the chemical concentration contouring. The volume of mine-impacted groundwater and masses of sulfate and uranium are large, and the following two analyses provide insights to FS considerations about aquifer cleanup.

Simple Analysis

In this simple analysis, PWS performance monitoring information and a simplifying assumption regarding chemical removal from aquifer sediments are used to estimate the time frame for aquifer cleanup.

From the early 2000s to March 25, 2009, the PWS operated continuously (i.e., 24 hours per day, 7 days per week), except during periods when individual wells were temporarily taken off line for maintenance and repairs of pumps and related equipment. The average pumping rate from the PWS from 1999 through 2008 was about 52 gpm. During this 10-year time period, approximately 800 acre-feet of water and approximately 5,000 tons of sulfate (average sulfate concentration in the pumped water of approximately 4,000 mg/L) were removed from the Shallow zone.

If it is assumed that three times the volume of mine-impacted Shallow zone groundwater (which is 45,899 acre-feet) must be removed to achieve aquifer cleanup, then at least 137,697 acre-feet of water would need to be removed from the Shallow zone. (This volume is about 172 times the volume of water removed by the PWS over the 10-year period). This volume does not address aquifer cleanup in the deeper zones of the alluvial aquifer or ongoing chemical loading to groundwater from impacted sediments and vadose zone soils, and dissolving sulfate or other minerals. Recognizing that the total volume of mine-impacted groundwater in the aquifer is 385,327 acre-feet, approximately 285 years of pumping at 2,500 gpm would be required to potentially achieve aquifer cleanup assuming that a volume of only three times the contaminated volume of mine-impacted groundwater would need to be removed. In reality, this estimate likely underestimates the actual time to cleanup.

Groundwater Modeling

In this analysis, the “batch flush” model (EPA 1988; Zheng et al. 1991) is used to estimate the minimum time (with an efficient extraction system) to restore groundwater quality to 500 mg/L sulfate. In this approach, the number of pore volumes (PV) of water that must be circulated through the contaminated zone having an initial concentration (Ci) to achieve cleanup to the specified standard (Cs) is calculated from the relationship:

$$PV = -R \ln Cs/Ci$$

In this relationship, R is the retardation coefficient for the target constituent. Based on this modeling approach, groundwater restoration to 500 mg/L sulfate would require approximately 100 years at a pumping rate of 2,300 gpm.

5.5 Sources of Impacted Groundwater

OU-1 RI characterization activities indicate that the past and/or ongoing major sources of COIs to Study Area groundwater include:

- Mine waste facilities, which have been grouped into the various Site OUs for individual RI/FS investigations;
- Agriculture activities that contribute COIs or affect the release of naturally occurring COIs in geologic materials (BC 2014a, 2016b); and
- Geologic materials containing naturally-occurring COIs (BC 2009a, 2014a, 2016b).

Section 7.0 of the 2007 SOW notes that the groundwater OU underlies all other OUs identified at the Site, and recommends that relevant elements of the other OUs be integrated with the OU-1 RI. Consistent with the SOW, this OU-1 RI Report discusses relevant source-related information for the other Site OUs that represent past or ongoing sources of chemical loading to groundwater (Section 5.5.1). In addition, the other major non-mining sources of COIs to groundwater are discussed in Sections 5.5.2 and 5.5.3.

5.5.1 Mine Waste Facilities

The major past and/or ongoing sources of COIs to groundwater include: 1) OU-4a, the Evaporation Ponds (BC 2014a); OU-8, the Arimetco Facilities (CH2M Hill 2010, 2011a, 2011b); and 3) OU-3, the Process Areas (BC 2014a). Concentrations of COIs in groundwater beneath OU-4b (Sulfide Tailings) are generally at least 10 times lower than COI concentrations in groundwater beneath OU-4a. Furthermore, OU-4b is located hydraulically upgradient or cross-gradient of OU-4a, and groundwater beneath OU-4b flows toward the higher COI concentrations under OU-4a.

Evaporation Ponds (OU-4a)

OU-4a RI field activities and characterization data are presented in reports by BC (e.g., 2009a, 2017a). OU-1 RI information that is particularly relevant to OU-4a includes the following: 1) the most elevated concentrations of mine-related chemicals occur in groundwater in this area; 2) concentrations of mine-related chemicals in groundwater beneath OU-4a are 100 or more times greater than chemical concentrations in groundwater beneath other OUs (Figures 5-2 to 5-7); and 3) the depth to water beneath OU-4a (i.e., vadose zone thickness) is generally smaller than the depth to water beneath other OUs. The depth to water beneath OU-4a ranges from approximately 20 to 40 feet bgs, except beneath the southern portion of the Calcine Ditch where the depth to water is up to approximately 70 feet bgs (Figures 4-8 and 4-9).

The summary below focuses on the magnitude and distribution of COIs in OU-4a mine waste materials and vadose zone soils, extent of contamination based on a comparison of OU-4a data to applicable soil BCLs, and the potential for vadose zone transport and chemical loading to groundwater based on vadose zone modeling and soil moisture probe data obtained during 2016. The highest COI concentrations in OU-4a mine waste materials are most commonly associated with pond sediments and calcines, which are typically located at depths ranging from approximately 0-3 feet bgs. Relative to the overlying pond sediments and calcines, the underlying alluvial soils generally exhibit lower concentrations of COIs.

Based on Site background soil concentrations presented in Table 5-3 of the *Background Soils Data Summary Report - Revision 1* (BC 2009b) for Sub-area A-1, located directly west of the Evaporation Pond and Calcine Ditch areas, approximate maximum depths of soil exceeding applicable BCLs within OU-4a include: 1) 17 to 20 feet bgs beneath the LEP; 2) 15 to 20 feet bgs beneath the UEP; 3) 47 to 52 feet bgs beneath the Finger Ponds; 4) 38 to 43 feet bgs beneath the Thumb Pond; and 5) 45 to 50 feet bgs at the north end of the Calcine Ditch and 75 to 80 feet bgs at the south end of the Calcine Ditch. These approximate maximum depths of alluvial soil contamination beneath the ponds and Calcine Ditch are primarily based on uranium, arsenic, selenium, iron, and copper.

Vadose zone model simulations were performed using the variably-saturated modeling code SVFlux™ to understand the potential for transport and chemical loading to groundwater beneath OU-4a. Vadose zone model results are summarized below (values presented in meters, input and output unit of measurement in the SVFlux™ modeling code):

- The LEP 'wet' areas simulation indicated a fairly constant downward net flux of soil water toward the water table. The cumulative flux at the deepest flux line in the profile was approximately 0.16 meters after 5 years of simulation.
- LEP 'dry' (non-ponded) areas showed a small downward net flux of water, approximately 0.013 meters after 15 years of simulation. Because the same soil moisture conditions for the 'wet' areas simulation was used for the 'dry' areas simulation, and because the soil moisture conditions for the 'dry' areas of the LEP are more likely to be similar to the conditions observed in the UEP, the numerical simulation likely over-predicted downward flux to the water table.
- The UEP simulation indicated a continuous upward net flux of water. The cumulative flux at the deepest flux line in the model was approximately 1.8 meters for 15 years of simulation (approximately 0.12 meters per year when averaged over the 15-year simulation period). For the 10-year period following the equilibration of the model, the cumulative flux was approximately 1.5 meters (approximately 0.15 meters per year).
- The Thumb Pond simulation indicated a very small upward net flux of water. The cumulative flux rate was approximately 4.0E-04 meters after 15 years of simulation (approximately 2.7E-05 meters per year when averaged over the simulation period). The simulation indicated both upward and downward flux of soil water in the upper portion of the profile, and a relatively constant upward flux in the deeper portion of the profile.
- The vadose zone simulation for the Finger Evaporation Ponds (FEPs) indicated a small downward flux of soil water during the 15-year simulation period, with a cumulative flux rate at the deepest flux line in the profile of approximately 0.043 meters after 15 years (approximately 2.9E-03 meters per year when averaged over the simulation period).

Integration of these estimated flux rates over the Pond acreages result in the following annual estimated volumes of soil water that could potentially flux to groundwater:

- Approximately 0.31 acre-feet per year (ac-ft/yr) for the LEP 'dry' areas, based on an estimated flux rate of 0.0012 m/yr and an area of 79.5 acres, equivalent to 0.19 gallons per minute (gpm);
- Approximately 1.13 ac-ft/yr for the LEP 'wet' areas, based on an estimated flux rate of 0.016 m/yr and an area of 21.5 acres, equivalent to 0.70 gpm; and

- Approximately 0.15 ac-ft/yr for FEP 1-4, based on an estimated flux rate of 0.0026 m/yr and an area of 17.8 acres, equivalent to 0.09 gpm.

Vadose zone modeling results indicated that: 1) the Thumb Pond and UEP exhibit an upward vertical flux of soil moisture to the atmosphere (i.e., no cumulative flux of soil moisture toward groundwater); and 2) the 'wet' areas of the LEP and FEPs 1-4 exhibit a cumulative downward flux of soil moisture toward the water table. Model results for the dry (peripheral) portions of the LEP indicate: 1) a net evaporative flux to the atmosphere; and 2) a downward flux of soil moisture during the latter third of the simulation period, resulting from wetter climate conditions.

Soil moisture data provide additional insights to the potential for transport and chemical loading to groundwater. Soil moisture has been monitored continuously since August 2016 and is ongoing. As part of the 2015–2016 field activities, soil moisture probes and porous cup lysimeters were installed at four locations. Further description of the installed equipment and the installation process is provided in the *Phase 1 Evaporation Ponds Characterization Data Summary Report* (BC 2017b). The monitoring locations are located at EP-VZC-2 (Thumb Pond), EP-VZC-3 (northern edge of the UEP), EP-VZC-6 (near the southern portion of the UEP and next to the Calcine Ditch), and EP-VZC-8 (northern edge of the LEP). Each location has soil moisture probes at three or four depth intervals, depending on the thickness of the vadose zone.

During the initial soil moisture monitoring period, a significant precipitation event occurred between January 4 and January 13, 2017, when 2.35 inches of precipitation fell over the 10-day period (WRCC 2017).

Soil moisture probe readings for EP-VZC-2 at the Thumb Pond, with the shallowest monitoring interval of 10 feet bgs, did not register any changes in vadose zone soil moisture at all monitored depths during and after the 10-day precipitation event. Soil moisture readings at EP-VZC-6, located near the southern tip of the UEP, registered moisture content increases in the shallow probes (2 and 6 feet bgs), but not at any greater depth during and following the January 2017 event. Soil moisture readings at EP-VZC-3, located in the northern portion of the UEP, registered a response to the January 2017 storm event at only the shallowest probe depth (1.5 feet bgs), but not

at the two deeper probes (5 and 15 feet bgs). Similarly, soil moisture readings at EP-VZC-8, located at the northern end of the LEP, registered a response to the January 2017 storm event at only the shallowest probe (3 feet bgs), but not at the two deeper probe depths (10 and 20 feet bgs).

In summary, there were no observable changes in soil moisture at depths greater than 6 feet bgs resulting from this significant precipitation event. At most locations, soil moisture data at the shallowest monitoring intervals (1.5 to 3 feet bgs) illustrate an abrupt increase in soil moisture immediately following the January 4-13 storm event. At some stations, soil moisture at 5 feet and 6 feet bgs also experienced changes following the January precipitation event, but were less pronounced than soil moisture changes at shallower intervals. Based upon these data, there does not appear to be evidence indicating moisture changes in deeper probes that result from an infiltration front moving vertically through the vadose zone.

Future data collection and evaluation may provide additional insight into the: 1) potential advancement of the wetting front to depths of 10 feet bgs and deeper; 2) effects of underlying native clay-rich alluvial layers on potential advancement of the wetting front and pore water chemistry; and 3) potential migration of chemicals within and between vadose zone materials based on lysimeter data from multiple points in time. However, the existing information suggests that: 1) the groundwater impacts beneath OU-4a are the result of past mining operations and fluid management; and 2) chemical loading to the groundwater system under current climatic conditions is very limited, based on vadose zone modeling and soil moisture probe data.

Arimetco Facilities (OU-8)

OU-8 components located throughout the Site include five HLPs (Phase I/II, Phase III South, Phase III 4X, Phase IV Slot, and Phase IV VLT), the FMS (which stores and conveys drain-down solution via a network of ponds, ditches, and 25,000 feet of pipe), and the SX/EW Plant.

RI activities characterized the nature and extent of radiochemicals, metals, and physical properties of the OU-8 HLPs and their associated ponds and ditches. Sources of contamination include:

- Leachable metals (aluminum, copper, iron, and manganese and, to a lesser extent, arsenic, beryllium, cadmium, chromium, cobalt mercury, and nickel) and other COIs on the surface and within the HLPs;
- Acidic draindown solutions containing COIs entrained within the HLPs;
- Acidic drain-down solutions containing COIs stored at the base of the HLPs or contained within their associated ponds and ditches; and
- Historic spills and releases containing COIs.

The OU-8 RI/FS determined that the areas affected by Arimetco operations include the footprints of each HLP and their associated drain-down FMS components, the SX/EW Plant, and historical spill areas (CH2M Hill 2011b). The environmental release or migration pathways of drain-down fluids are infiltration into the subsurface from unlined areas, through tears/breaches in liner systems and FMS components, and through tears/breaches due to potential settling/structural failure of the HLP liner systems (Ecology and Environment, Inc. 2013).

On the basis of groundwater monitoring results, these impacts are thought to extend vertically down to OU-1 groundwater (CH2M Hill 2011b). Furthermore, the OU-8 FS (CH2M Hill 2011b) also notes that additional characterization efforts are needed to fully determine the nature and extent of contamination in: 1) in OU-8 surface and subsurface soil due to releases of drain-down fluids from the Arimetco Facilities; and 2) OU-1 groundwater that may be attributed to OU-8 releases.

Numerous spills of process solution in connection with past Arimetco operations have been recorded, and all of the recorded spills report limited to no confirmation sampling data or post-remedial efforts (CH2M Hill 2010, 2011b). As noted by CH2M Hill (2011b), the spill report documentation in the HSR (CH2M Hill 2010) only generally describes the location and type of materials spilled, along with the estimated quantity of each spill and general response action that was taken. In some instances, these records appear to underestimate the overall quantity of materials spilled. On the basis of the existing spill reports and the suspected quantities of fluids released to the environment, further investigations may be required (CH2M Hill 2011b).

Process Areas (OU-3)

The OU-3 RI has involved extensive characterization to determine the vertical extent of impacted soils beneath known source areas and above known areas of impacted groundwater in the underlying alluvial aquifer (e.g., BC 2011a, 2014e). OU-3 RI activities have included: 1) soils and groundwater characterization in 2004-2005; 2) a variety of radiometric surveys; 3) groundwater monitor well installations in 2005; 4) sub-surface utility and dry well investigations during the period 2010-2013; 5) step-out (vertical and horizontal) soil characterization activities during the period 2013-2014; and 6) sampling and analysis of standing water in select locations during the 2013-2014 field program.

During the RI, a total of 3,385 samples of vadose zone alluvial soils were collected and analyzed from metals (57,764 analyses) and radiochemicals (9,172 analyses). Analytical results are discussed in the context of exceedances relative to the EPA Industrial regional screening level (RSL), a background level, and the maximum depth below ground surface that such exceedances occurred. A total of 198 metals exceedances, primarily arsenic and chromium, occurred in near-surface soils to approximately 15 feet bgs in every sub-area of OU-3. Metals exceedances also occurred at depths to 80 feet bgs at three primary waste solution conveyance ditches (Overflow, East Solution and Calcine Ditches) and the Acid Plant Pond. Fifty-one radiochemical exceedances, primarily for radium-226 and -228, occurred in shallow soils to depths of up to five feet bgs throughout OU-3. Three exceedances occurred in the southern Calcine Ditch (now included in OU-4a) to a depth of 20 feet.

COI concentrations in OU-3 groundwater are highest beneath the Precipitation Plant (Sub-area 5 on Figure 2-1), and are typically 10 times less than the concentrations in groundwater beneath OU-4a (Figures 5-2 to 5-7). The depth to groundwater beneath OU-3 ranges from 90 to more than 120 feet bgs (Figures 4-8 and 4-9). Vadose zone alluvial materials beneath OU-3 do not differ substantially from the vadose zone alluvial materials beneath OU-4a. Thus, to the extent that insights from the OU-4a vadose zone modeling results and soil moisture profiling are applicable to OU-3, groundwater impacts beneath OU-3 appear to be the result of past mining operations and fluid management rather than post-mining ambient Site climate conditions.

5.5.2 Agriculture

Agricultural influences on Study Area groundwater were identified and quantified during the background assessment and are summarized below.

Benson and Spencer (1983) noted that "agricultural practices strongly influence the concentration of uranium in Walker River and its East and West Forks. Irrigation practices induce significant losses of fluid through evaporation and evapotranspiration processes. This results in artificial increases in concentrations of uranium and other elements." Percolation of crop irrigation water through soils increases alkalinity in soil moisture, which has been shown at other sites (Jurgens et al. 2010; Brown et al. 2007) to solubilize and desorb naturally-occurring uranium from sediments resulting in elevated uranium concentrations in Shallow zone groundwater. Application of agricultural amendments and fertilizer on crop fields contributes sulfate, calcium, nitrate and other COIs to groundwater (Benson and Spencer 1983; BC 2014a, 2016b). Nitrate originating primarily from surface-applied fertilizers also plays a role in uranium solubilization leading to uranium mobilization (Nolan and Weber 2015).

Groundwater data from the NSA show that agricultural activities contribute sulfate, uranium, nitrate, alkalinity, and other COIs to groundwater. The NSA refers to the portion of the groundwater Study Area located northeast of West Campbell Ditch and north of the Sunset Hills. Monitor wells and well clusters located in the NSA include B/W-10(S, D1), B/W-50(S, D1, D2, D3), B/W-53(S1, S2, B), B/W-54(S, I, B), B/W-55(S, D1, D2), B/W-56S, B/W-57(S, I, D1, D4), B/W-58(S, D1, D3, B), B/W-59(S, D3), B/W-68(S, D1, D4), B/W-69(S, D1, D2, D5), B/W-81(S, D1, D2), B/W-82R(S, I, B), YPT-MW-(8S, 9I, 10B), YPT-MW-(11S, 12I), YPT-MW-(13I, 14D1) and MMW-2. Groundwater flow data and chemical distributions from monitor wells and clusters B/W-56, B/W-57, B/W-59, B/W-68, B/W-69, and B/W-81 discussed below illustrate the effects of agricultural practices on groundwater quality near agricultural fields in the northeastern part of the Study Area. The locations of these wells are shown on Figure 3-3 and potentiometric surface maps for the alluvial aquifer (Figures 4-11a through g) indicate that groundwater in the NSA flows to the north and northwest.

Groundwater near these wells in the NSA is recharged by infiltration from the East Campbell Ditch and irrigation on a series of agricultural fields (BC 2014a; SSPA 2014). During drilling and installation of monitor wells, zonal groundwater samples were collected to profile vertical chemical gradients in the alluvial aquifer upgradient and downgradient of the fields. Chemical profiles for sulfate, uranium, alkalinity, and arsenic in groundwater are provided on Figure 5-12 for B/W-59, B/W-68, and B/W-69, and on Figure 5-13 for B/W-56, B/W-57, and B/W-81. The wells are grouped in this manner to illustrate changes in groundwater chemistry along two parallel flow paths beneath the agricultural fields.

Except for arsenic, chemical concentrations in alluvial groundwater in the Shallow through Deep 2 zones (i.e., above 4,120 feet amsl) increase along the flow path beneath the agricultural fields (i.e., from B/W-59 and B/W-56 upgradient of the agricultural fields to B/W-68 and B/W-57 immediately downgradient of the agricultural fields). B/W-69 and B/W-81, located farther along their respective flow paths, also exhibit elevated values above 4,120 feet amsl, although the values are not as high as in B/W-68 and B/W-57 immediately downgradient of the agricultural fields. From B/W-56 to B/W-57, sulfate values exhibit more than a four-fold increase from about 30 mg/L at B/W-56 to a maximum of 137 mg/L at B/W-57. Uranium values exhibit more than a ten-fold increase from about 2 µg/L at B/W-56 to a maximum of 73 µg/L at B/W-57. Alkalinity exhibits a 2.5-fold increase from about 100 mg/L at B/W-56 to a maximum of 257 mg/L at B/W-57. From B/W-59 to B/W-68, sulfate values exhibit a two-fold increase from about 75 mg/L at B/W-59 to a maximum of 140 mg/L at B/W-68. Uranium values exhibit almost a two-fold increase from about 25 µg/L at B/W-59 to a maximum of 44 µg/L at B/W-68. Alkalinity exhibits a 20% increase from about 190 mg/L at B/W-59 to a maximum of 235 mg/L at B/W-68.

Arsenic exhibits increasing concentrations with depth at all locations, with the greatest increases observed in the Deep 3 through Deep 5 zones (i.e., below 4,120 feet amsl). Arsenic values generally increase from about 5 µg/L in the Shallow zone to approximately 80 µg/L in the Deep 5 zone. Arsenic values decrease along the flow path beneath the agricultural fields (the highest values are observed in B/W-59 and B/W-56, and the lowest values are observed in B/W-69 and B/W-81).

Data from well clusters B/W-59, B/W-68, B/W69, B/W-56, B/W-57 and B/W-81 indicate that concentrations of other constituents in addition to sulfate, uranium and alkalinity also increase in groundwater above 4,120 feet amsl along the flow path beneath the agricultural fields (Table 5-4). These constituents include TDS, calcium, chloride, magnesium, potassium, nitrate, and strontium. The average horizontal groundwater flow gradient in Shallow zone groundwater beneath the agricultural fields is approximately 0.002 feet/foot. Vertical (downward) groundwater flow gradients beneath the agricultural fields range between 0.02 feet/foot when agricultural pumping is not occurring and 0.1 feet/foot during pumping periods (calculated using water levels in B/W-57S and B/W-57D4).

Increasing alkalinity and calcium concentrations are important controls on mobilization of naturally-occurring uranium from aquifer solids (Bernhard et al. 2001). The correlation between increasing concentrations of alkalinity and calcium associated with agricultural activities, and increasing uranium concentrations as groundwater flows beneath agricultural fields in the NSA is discussed in Section 6.2.2.

Table 5-4. Concentrations of Constituents that Increase Beneath the Agricultural Fields in the North Study Area

Constituent	Units	Average Concentration in Monitor Well (May 2012 - October 2014)				
		B/W-59S	B/W-68S	B/W-68D1	B/W-69S	B/W-69D1 & B/W-69D2
Sulfate	mg/L	48	110	79	125	79
Uranium	µg/L	9	30	41	29	30
Alkalinity, bicarbonate (as $CaCO_3$)	mg/L	140	260	230	275	188
Total Dissolved Solids (TDS)	mg/L	260	530	440	540	400
Calcium	mg/L	31	49	76	78	64
Chloride	mg/L	16	20	20	25	20
Magnesium	mg/L	9	12	19	20	15
Potassium	mg/L	4	5	6	6	6
Nitrate (as N)	mg/L	0.06	5.0	2.9	1.2	0.9
Strontium	mg/L	0.3	0.5	0.6	0.7	0.6

Constituent	Units	Average Concentration in Monitor Well (May 2012 - October 2014)				
		B/W-56S	B/W-57S	B/W-57I & B/W-57D1	B/W-81S	B/W-81D1 & B/W-81D2
Sulfate	mg/L	41	62	142	70	62
Uranium	µg/L	4	11	75	4	36
Alkalinity, bicarbonate (as $CaCO_3$)	mg/L	140	174	293	160	213
Total Dissolved Solids (TDS)	mg/L	254	345	620	350	370
Calcium	mg/L	31	41	103	50	64
Chloride	mg/L	15	18	32	21	20
Magnesium	mg/L	8	11	25	13	15
Potassium	mg/L	5	3	9	5	7
Nitrate (as N)	mg/L	0.08	1.3	1.4	1.4	0.7
Strontium	mg/L	0.3	0.4	0.9	0.4	0.6

Notes: mg/L = milligrams per liter; µg/L = micrograms per liter

5.5.3 Naturally-Occurring Sources

Sulfate, uranium, arsenic, and other COIs occur naturally in groundwater in Mason Valley because of groundwater contact with naturally-mineralized and/or hydrothermally-altered bedrock associated with copper deposits and/or alluvial sediments derived from mineralized bedrock (BC 2014a, 2016b).

As noted in Section 5.4, the extent of mine-impacted groundwater was conservatively estimated under EPA direction because it "is in the best interest of the overall progress for completing the OU-1 Groundwater Remedial Investigation Report" and that the tools used in the background assessment to estimate the area of mine-impacted groundwater may not account for the full range of chemical concentrations that occur naturally in Study Area groundwater (EPA 2016c).

Extensive evidence of naturally-occurring sulfate, uranium, arsenic and other COIs in Mason Valley groundwater includes detectable concentrations of these chemicals in: 1) surface water, which is the primary component of alluvial aquifer recharge, at sampling points located upstream of the Site (Benson and Spencer 1983; BC 2014a); 2) groundwater and geothermal water in the discharge area at the northern end of Mason Valley (Benson and Leach 1979); 3) groundwater samples from Yerington municipal water supply wells that are located hydraulically upgradient and/or cross-gradient of the Site; 4) groundwater samples from monitor wells installed by ARC that are located hydraulically upgradient and/or cross-gradient of the Site (BC 2016b), with concentrations of sulfate and uranium occasionally above MCLs; 5) groundwater from private wells sampled by the USGS located hydraulically upgradient and/or cross-gradient of the Site, with concentrations of sulfate, uranium and arsenic occasionally above MCLs (Benson and Spencer 1983); and 6) groundwater samples from monitor wells installed by ARC that are located outside of the plume of mine-impacted groundwater in the NSA (BC 2016b), with concentrations of uranium as high as 100 µg/L or more.

Further evidence of naturally-occurring COIs in groundwater near the Site occurs in the SWRA where elevated arsenic, and possibly other COIs, appears to be associated with MFR hydrologic processes. These MFR processes include: 1) subsurface water transmitted along fractures and

faults (especially oblique range-front faults such as the Sales Fault) in arsenic-bearing volcanic and granitic bedrock that connect subsurface water in the mountain block and the basin aquifer; and 2) contributions of water at the mountain front from surface stream runoff and shallow subsurface water transmitted in stream bed sediments. Elevated arsenic in SWRA groundwater is associated with low concentrations of sulfate and uranium (the two primary indicators of mine-impacted groundwater), and hydrologic tracer data yield groundwater age estimates that pre-date mining (BC 2016b; EPA 2016b). Collectively, this information indicates that elevated arsenic and possibly other COIs in groundwater in this part of the Study Area are not associated with mining activities. Instead, elevated arsenic in this part of the Study Area is likely naturally-occurring. Elevated arsenic values have been associated with MFR, geothermal groundwater, and stagnant groundwater systems (Smedley and Kinniburgh 2001), and these characteristics apply to the sub-geothermal groundwater present in all groundwater zones to the west of the Site. The elevated temperature of groundwater to the west of the Site and adjacent to the Singatse Range, where MFR hydrologic processes predominate, are shown on figures provided in Appendix L.

SECTION 6.0
CONTAMINANT FATE AND TRANSPORT

The medium of concern in the OU-1 Study Area is groundwater and the mine-related COIs include acidity (i.e., low pH), TDS, major ions including sulfate, metals, and radiochemicals including uranium. The physical transport mechanisms and geochemical attenuation/mobilization processes that affect the movement of COIs in Study Area groundwater are discussed below.

6.1 Contaminant Transport

Transport mechanisms are physical processes controlling the movement of COIs from points of origin through the groundwater system. In the Study Area, COIs are (were) sourced to groundwater from Site sources and/or agricultural practices, and occur naturally in groundwater in Mason Valley because of groundwater contact with naturally-mineralized and/or hydrothermally-altered bedrock associated with copper deposits and/or alluvial sediments derived from mineralized bedrock.

The dominant solute transport mechanisms for COIs in groundwater are advection and dispersion. Advective transport is the migration of the COI with the groundwater. Groundwater moves from areas of recharge (i.e., high hydraulic head) to areas of discharge (i.e., low hydraulic head) and groundwater velocities are determined by solving the groundwater flow equation, which is a function of hydraulic conductivity, hydraulic gradient, and porosity. Groundwater levels in monitor wells provide hydraulic head and groundwater flow velocity information. Hydrodynamic dispersion describes the spread of COIs around an average groundwater flow path, beyond the region they would normally occupy due to advection alone. Hydrodynamic dispersion is the sum of two processes: mechanical dispersion and molecular diffusion. Mechanical dispersion results from mixing that occurs because of local variations in groundwater velocity and the aquifer's matrix. Molecular diffusion results from variations in solute concentrations within the groundwater system.

The primary influences on groundwater movement in the Study Area are subsurface lithology and structure, and local groundwater pumpage and irrigation associated with agriculture. Agricultural activities influence groundwater flow rates and directions, chemical migration pathways and transport rates, and contribute chemicals to groundwater via leaching of soil amendments and subsequent transport through the vadose zone to groundwater. Irrigation practices near the mine Site, including groundwater extraction using high-capacity wells and conveyance/irrigation of both water from the Walker River and groundwater, alter groundwater flow rates and directions during the irrigation season due to the alteration of the natural recharge/discharge rates and locations. These alterations in groundwater flow affect contaminant transport rates and directions.

6.2 Geochemical Attenuation/Mobilization Processes

Geochemical processes that affect the release and subsequent mobility/attenuation of mine-related COIs such as sulfate, uranium and metals during groundwater transport in the Study Area have been evaluated (BC 2016b; Appendix J-7) using: 1) Study Area groundwater data from August 2014 including field parameter measurements (i.e., pH, ORP and DO) and chemical concentrations; 2) the EPA-approved thermodynamic database developed for geochemical modeling Site geochemical attenuation/mobilization processes; and 3) correlations between common groundwater chemicals that affect uranium mobility.

6.2.1 Groundwater Geochemical Conditions and Chemical Speciation

Geochemical oxidation/reduction (redox) conditions within alluvial aquifer groundwater are variable; however, certain general trends and patterns are observed. In general, oxic conditions (i.e., DO > 1 mg/L and higher Eh values) occur in Shallow zone groundwater and suboxic to anoxic conditions (i.e., DO < 1 mg/L and lower Eh values) occur in Intermediate and Deep groundwater zones (Figure 6-1). Exceptions to this general pattern include the following: 1) in Shallow zone groundwater beneath much of the Site and off-Site to the north of the Evaporation Ponds, anoxic (rather than oxic) conditions occur; 2) in Deep groundwater zones beneath the Hunewill Ranch, oxic (rather than anoxic) conditions occur; and 3) on the west side of the Study Area adjacent to the Singatse Range, oxic conditions occur in the Shallow zone, as well as all deeper zones in this part of the Study Area.

Dissolved iron and the iron-system mineralogy, of all the metals present in groundwater, provide the most important constraints on pH, redox, and other metal solubilities in Study Area groundwater (BC 2016b; Appendix J-5). Ferric hydroxide solids in the aquifer sediments can adsorb significant concentrations of dissolved metals and metalloids such as uranium and arsenic, attenuating transport of these constituents. The importance of iron mineralogy and its widespread influence on the Study Area fluid chemistry are illustrated with two Eh-pH diagrams (Figures 6-2 and 6-3). The mineral stability fields in each diagram were constructed for groundwater pH values below, and above, 5.5 respectively, using chemical data from discrete groundwater populations. The individual samples were then plotted on each diagram. The populations were selected from similar chemical environments (samples from two or more unrelated populations are scattered and often obscure the trends).

Groundwater samples from two populations with strong mining impact (pH values below 5.5; Figure 6-2) clearly plot along the K-jarosite and schwertmannite phase boundaries and triple points. Sample alignment near and along the aqueous-mineral boundaries demonstrates the important role these minerals play in dominating and buffering the acidic groundwater at relatively oxidizing Eh levels, as noted above. Also shown on the figure is the specific sample from which the phase boundaries in the figure were computed.

Groundwater samples from two off-Site and more alkaline populations (pH values above 5.5; Figure 6-3) are aligned along the aqueous Fe^{2+} - $Fe(OH)_3(a)$ phase boundary. The mineral $Fe(OH)_3(a)$ is an important adsorptive phase that limits/attenuates the concentrations of other groundwater metals.

As noted previously, the strong alignment demonstrates the impact of the ferric hydroxide phase upon the groundwater redox and pH. The phase boundaries for this diagram were computed from the cluster centroid composition. Based on the groundwater redox conditions and geochemical modeling (BC 2016a; Appendix J-5), chemicals in Study Area groundwater exhibit the following:

- The dominant aqueous redox states determined in virtually all August 2014 groundwater samples were As(V), Fe(II), Mn(II) Se(IV) and U(VI). Vanadium was present in the V(V) redox state in all August 2014 groundwater samples from the Intermediate, Deep and bedrock wells. In Shallow zone groundwater, the V(IV) redox state predominated below a pH of about 5 and the V(V) redox state predominated above a pH of 5.
- Sulfur dissolved in Study Area groundwater is present as sulfate (a negatively-charged ion) and gypsum saturation is observed only in groundwater samples with sulfate concentrations exceeding approximately 1,500 mg/L.
- In the absence of sulfate reduction or gypsum precipitation, the negatively-charged sulfate ion is minimally attenuated in groundwater systems by adsorption. Consequently, in Study Area groundwater with sulfate concentrations less than approximately 1,500 mg/L, sulfate can be expected to be transported as a conservative constituent.
- U(VI) is the dominant oxidation state of dissolved uranium in all August 2014 groundwater samples. Differences in the aqueous speciation of uranium are related to the pH and availability of cations in solution, not redox conditions. Dissolved uranium in Study Area groundwater is predominantly present in complexes with sulfate, carbonate and/or calcium that form neutral or negatively-charged ions (e.g., $Ca_2UO_2(CO_3)_3^0$, $CaUO_2(CO_3)_3^{-2}$, $UO_2(SO_4)_2^{-2}$, and UO_2SO_4) (Figure 6-4). Samples with dominant calcium-uranyl-carbonate ligands reflect oxidizing, carbonate-rich groundwater conditions. Samples with dominant uranyl-sulfate ligands reflect oxidizing conditions with no detectable amounts of alkalinity and pH <5.
- Formation of neutral or negatively-charged aqueous uranium species has been shown to limit uranium adsorption and increase uranium mobility (Fox et al. 2006; Stewart et al. 2010). Since limited uranium adsorption onto hydrous ferric hydroxide solids and soils is expected in neutral to slightly alkaline groundwater (Hsi and Langmuir 1985; Echevarria et al. 2001), uranium attenuation during groundwater transport in off-Site portions of the Study Area can be assumed to be negligible as a conservative first approximation.
- As(V) arsenate is the dominant oxidation state for all August 2014 groundwater samples indicating oxic groundwater conditions, and arsenic speciation is dominated by the negatively-charged $H_2AsO_4^-$ and $HAsO_4^{-2}$ species. Geochemical modeling indicates the potential for precipitation of several arsenic mineral phases including scorodite and barium arsenate.
- Arsenate adsorption on sediments tends to decrease with increasing pH because of competition for adsorption sites between the negatively-charged arsenate aqueous species and OH^- or bicarbonate (Sø et al. 2008; Stachowicz et al. 2007).
- Geochemical modeling predicts the potential for jarosite mineral precipitation primarily in the Shallow zone under the LEP, UEP, Thumb Pond, and Phase IV HLP (Figure 6-5). Uranium and other metals associated with predicted jarosite mineral phases and aquifer sediments beneath these features potentially represent a persistent source of chemicals to groundwater.

- The spatial distributions of elevated concentrations of mobile parameters such as sulfate and uranium are significantly more extensive than the spatial distributions of acidity (as indicated by pH) and metals. The limited spatial extent of low pH values and elevated metal concentrations indicates that geochemical attenuation processes in Study Area groundwater reduces acidity and limits the mobility of metals relative to the more mobile chemicals such as sulfate and uranium. Elevated metal concentrations in groundwater correlate strongly with low pH.

6.2.2 Controls on Uranium Mobility in North Study Area Groundwater

As noted previously in Section 5.5.2, the concentrations of numerous COIs in groundwater increase along groundwater flowpaths beneath agricultural fields in the NSA. The correlation between increasing concentrations of alkalinity and calcium associated with agricultural activities, and increasing uranium concentrations as groundwater flows beneath agricultural fields in the NSA is shown on Figure 6-6. Increasing alkalinity and calcium concentrations are important controls on the formation of uranium species that have a low tendency to bind to aquifer solids (Bernhard et al. 2001) and, thus, uranium is mobilized from aquifer solids to adjacent groundwater as alkalinity and calcium concentrations increase. In addition, the observed correlation between increasing concentrations of alkalinity, calcium and uranium is consistent with the previously-noted geochemical modeling predictions of uranium speciation in Study Area groundwater.

The upper panel in Figure 6-6 displays data for all the alluvial monitor wells in the NSA that are located near agricultural fields. The lower panel in Figure 6-6 displays a subset of the data presented in the upper panel. Specifically, this lower panel displays data along a groundwater flow path from wells upgradient of the NSA agricultural fields (i.e., wells B/W-56 and B/W-59) to wells/well clusters located downgradient of the NSA agricultural fields (i.e., well cluster B/W-57 and well YPT-MW-12I). In wells located upgradient of the NSA, uranium concentrations are less than 12 µg/L. However, as groundwater flows beneath the NSA agricultural fields and concentrations of alkalinity and calcium increase, naturally-occurring uranium attached to aquifer solids is released. At well B/W-57I, elevated uranium concentrations range from approximately 48 to 72 µg/L and at well B/W-57D1 elevated uranium concentrations range from 73 to 110 µg/L.

Well YPT-MW-12I is located hydraulically downgradient of well cluster B/W-57, which provides additional information about chemical loading to alluvial groundwater associated with agricultural activities in the NSA. The influence of agricultural activities on chemical concentrations in YPT-MW-12I is shown on Figure 6-7. Although concentrations of uranium in groundwater at YPT-MW-12I have increased recently (upper panel), the trends in chemical concentrations in groundwater at this well are consistent with geochemical projections based on the control that calcium and alkalinity have on uranium mobility, and are not related to the Site.

As indicated in the lower panel, sulfate concentrations in well YPT-MW-12I are greater than 71 mg/L and exhibit seasonal variability, with elevated concentrations occurring in February of each year. Plume advancement cannot account for the magnitude of sulfate concentrations or seasonality observed in this well because sulfate concentrations are lower in wells to the southwest that demarcate the leading edge of mine-impacted groundwater (i.e., well clusters B/W-10, B/W-52, and B/W-55). Instead, the concentrations of sulfate in well YPT-MW-12I can only be accounted for by sulfate concentrations in upgradient wells B/W-57I and B/W-57D1, which are impacted by agricultural activities.

6.2.3 Site-Specific Distribution Coefficients

As groundwater migrates within the Study Area, certain geochemical reactions occur between the COIs in groundwater and the alluvial aquifer sediments. These reactions determine the relative rates at which chemicals migrate with respect to the advective front of groundwater. The primary process associated with the attenuation of inorganic COIs, particularly metals, in groundwater is adsorption onto the surfaces of minerals or organic material in the aquifer sediments.

The Site-specific distribution coefficient (K_d) discussed in Section 3.3.5 may be used to quantify adsorption reactions between COIs in groundwater and the alluvial aquifer sediments during groundwater flow and chemical transport simulations. It should be noted that the distribution coefficient is a bulk measurement and provides only indirect information on the type of adsorption interactions taking place on the alluvial aquifer sediments. Summary statistics for the revised K_d values calculated using zonal groundwater sample data are shown in Table 6-1.

Table 6-1. Summary Statistics for Zonal Sample K_d Values

Analyte	Distribution Coefficient Statistics (L/kg)				
	Minimum	Maximum	Mean	Geometric Mean	Median
Sulfate	0.05	0.62	0.18	0.15	0.16
Uranium	0.42	289	49	17	33
Arsenic	108	6,412	1,763	957	800

Notes: L/kg = liters per kilogram

K_d values less than 1 L/kg, as is the case for sulfate, indicate little if any partitioning of this negatively-charged ion from the dissolved (i.e., liquid) phase to the solids phase. The uranium K_d values are higher than K_d values for sulfate, indicating some tendency for uranium adsorption on aquifer sediments. Dissolved uranium in Study Area groundwater is predominantly present in neutral or negatively-charged complexes (Figure 6-4), which has been shown to limit uranium adsorption (Fox et al. 2006; Stewart et al. 2010). However, limited uranium adsorption onto hydrous ferric hydroxide solids and soils is expected in neutral to slightly alkaline groundwater (Hsi and Langmuir 1985; Echevarria et al. 2001; Li and Kaplan 2012), and likely explains the higher uranium K_d values.

K_d values for arsenic are substantially greater than 1 L/kg. These high K_d values reflect much higher concentrations of those chemicals in the solid phase versus the dissolved phase, which indicates a strong tendency for arsenic to partition from the dissolved to the solid phase.

Summary statistics for the K_d values calculated for the 25 chemicals and compounds using monitor well groundwater samples are shown in Table 6-2.

Table 6-2. Summary Statistics for Monitor Well K_d Values

Analyte	Distribution Coefficient Statistics [(1)]				
	Minimum	Maximum	Mean	Geometric Mean	Median
Aluminum	10,850	214,670	88,830	64,851	98,350
Arsenic	18.4	1,311	461.2	277.2	421
Boron	0.40	9.26	4.39	3.15	3.36
Barium	93.8	6,676	1,937	959	1,000
Calcium	0.38	20.6	7.62	3.47	4.74
Chloride	0.07	1.56	0.22	0.18	0.17
Cobalt	192.3	4,643	2,462	1,869	2625
Chromium	316	1,182	689	626	579
Copper	83.3	13,684	4,645	2,662	3,333
Fluoride	1.56	17.2	4.52	3.73	3.26
Iron	8.6	541,880	22,112	146,061	242,733
Potassium	5.1	292.4	109.0	72.7	97.5
Lithium	46.0	379.3	126.6	116.1	113.8
Magnesium	0.34	76.8	26.2	12.5	23.5
Manganese	56.8	3,838	795	351	291
Molybdenum	0.14	2,130	176.9	21.0	63.1
Sodium	0.21	1.3	0.78	0.64	0.88
Nickel	300	1,736	1,142	1030	1,200
Nitrate	0.03	4.0	0.30	0.16	0.15
Lead	1,000	48,100	14,983	8,355	9,600
Selenium	35.9	9,180	3,084	1,202	2154
Sulfate	0.03	1.04	0.186	0.15	0.17
Uranium	1.0	238.2	41.7	20.2	25.6
Vanadium	43.5	4,717	1,115	673	917
Zinc [(2)]	1,385	1,385	1,385	1,385	1,385

Notes:
1) L/kg = liters per kilogram.
2) For zinc, only one set of co-located sediment and water samples were available for calculating a K_d.

The majority of the K_d values calculated using the monitor well groundwater samples are greater than 1 L/kg. Chloride, nitrate, and sulfate (negatively charged ions in groundwater) and sodium were the only chemicals where the K_d values were consistently less than 1 L/kg. Boron, calcium and fluoride had K_d values in the range of 1 to 10 L/kg. All other chemicals and compounds had K_d values ranging from 10 L/kg up to approximately 500,000 L/kg.

The values at the high end of the range are influenced by the presence of non-detects in the data for the groundwater concentrations. In particular, groundwater concentrations for aluminum, iron and lead were almost universally below the detection limits. However, the concentrations in the soil samples for those same chemicals were nearly all above the detection limit. In these cases, the groundwater concentrations used to calculate K_d values typically represented the reporting limit for that particular chemical. Given that, the K_d values can be thought of as upper bounds for that particular chemical and indicate very little mobility in groundwater.

The variability between the K_d values for the same chemical or compound was, in general, consistent. Only a few chemicals had K_d values with variabilities of more than one order of magnitude. Typically, the wider-ranging K_d variabilities were expressed for those chemicals with non-detect results that were incorporated into the calculation.

Statistical parameters characterizing the uranium K_d values derived from zonal and monitor well groundwater sample data are similar. Uranium K_d values based on monitor well data vary by approximately two orders of magnitude. A correlation of uranium K_d values with Site geochemical data shows that uranium adsorption varies as a function of changes in pH and concentrations of alkalinity, calcium and magnesium. Consequently, use of a constant K_d approach to simulate uranium adsorption during predictive transport modeling may not accurately represent actual adsorption processes.

Instead, a surface complexation model (SCM), such as the general composite approach described by Davis et al. (2009), may be more suitable for modeling adsorption processes during transport at the Site because it can describe changes in adsorption reactions at mineral surfaces as chemical conditions and aqueous speciation(s) change. However, in off-Site portions of the Study Area where aqueous concentrations are lower and hydrous ferric hydroxide solid concentrations are more sporadic, it may be appropriate to assume negligible uranium attenuation during groundwater transport as a conservative first-order approximation.

6.3 Mine-Impacted Groundwater Plume Dynamics

Summarized below are the initial evaluations of mine-impacted groundwater plume dynamics that have been presented in previous reports (BC 2014f, 2015f) and/or discussed with EPA, NDEP and other stakeholders during groundwater technical meetings in 2015 and 2016. The results of these initial evaluations will be provided in a separate report, along with: 1) a statistical evaluation of chemical concentration trends in individual monitor wells, as requested by EPA; and 2) flow model predictions of future changes in plume dimensions and chemical concentrations.

Multiple approaches consisting of center-of-mass calculations and trend evaluations of the total masses and average concentrations of sulfate and uranium have been used to evaluate the dynamics of the plume of mine-impacted groundwater.

Methods

This evaluation was conducted using the Monitoring and Remediation Optimization System (MAROS) software that was developed by the U.S. Airforce Center for Environmental Excellence (AFCEE 2006). MAROS uses the Delaunay Triangulation/Voronoi Diagrams method (George and Borouchaki 1998) to partition the interpolation area into polygon-shaped sub-regions associated with each monitor well. The chemical concentration in an entire sub-region is represented by the concentration in the associated monitor well in a given sampling event. MAROS then calculates the location of the center-of-mass of the interpolated chemical distribution.

MAROS software allows for efficient and consistent computation of large groundwater datasets and depictions of the chemical center-of-mass over time, as well as providing output for computation of changes in chemical mass and average chemical concentration over time. However, the MAROS computation method uses polygon-shaped sub-areas that do not fully encompass the curvilinear area of mine-impacted groundwater. Consequently, although the MAROS output is consistently computed over time, the computed volumes (and derived chemical masses and average concentrations) are underestimated relative to the method used in Section 5.4 to estimate plume statistics.

Center-of-Mass Evaluation

The center-of-mass of plumes of the mine-related constituents sulfate and uranium and the total chemical mass in these plumes were evaluated over the three-year period 2012 through 2015 to assist in the evaluation of plume dynamics. The center-of-mass analysis requires a consistent set of data over time to make meaningful inferences about plume movement. Therefore, only wells that were monitored in every quarter from 1Q 2012 through 1Q 2016 were included in the analysis. Centers-of-mass for sulfate and uranium were calculated for the Shallow, Intermediate, Deep 1, Deep 2, Deep 3, and combined Deep 4 and 5 zones of the alluvial aquifer. The Deep 4 and 5 zones of the alluvial aquifer were combined due to the limited number of monitor wells in these zones.

In the evaluation, monitor well B/W-27D3a was included in the list of Deep 2 zone wells and monitor well B/W-41D4 was included in the list of Deep 3 zone wells to address areas within each zone that were lacking adequate spatial coverage. Monitor wells in the B/W-65 well cluster, located in the middle of an agricultural field, were not included in the analysis because the wells have been sampled sporadically due to lack of access during the irrigation season.

Prior to interpolation, chemical data from the 261 monitor wells were reviewed using time-concentration plots to screen for potential outliers. When outliers were identified for a particular sampling event, the value of the data point was replaced with the average value of the previous and subsequent sampling events. The number of outliers identified represents less than 0.2 percent of the data used in the analysis.

The calculated centers-of-mass for sulfate and uranium are located beneath the Evaporation Ponds (Figure 6-8), with the following exceptions:

- The uranium center-of-mass in the Deep 1 zone is located beneath the Hunewill Ranch (about 3,000 feet northwest of the monitor well B/W-25D1). This is consistent with the presence of collocated elevated concentrations of uranium and alkalinity beneath the agricultural fields in the Deep 1 zone compared to areas beneath the Site.
- The uranium center-of-mass in the Deep 4/5 zone is located beneath the Hunewill Ranch within a few hundred feet of the Site boundary.

From February 2012 to February 2016, the centers-of-mass for the sulfate and uranium plumes exhibit very little relative movement, an indication of stable plume behavior.

Total Mass and Average Concentrations

Over the 3-year monitoring period from February 2012 to February 2015, the masses of sulfate and uranium in each of the groundwater zones remained relatively stable, with typically less than five percent variation between the initial and more recent monitoring events (Figure 6-9). Also, clear trends (either increasing or decreasing) are not evident, with the exception of decreasing sulfate trends observed in the Shallow zone and decreasing sulfate and uranium trends in combined Deep 4 and Deep 5 zones. During the monitoring period, the calculated mass of sulfate in the Shallow zone decreased from about 97,000 to 85,000 tons (i.e., 12%) and the mass of sulfate in the Deep 4/5 zones decreased from about 13,000 to 10,000 tons (i.e., 25%). The mass of uranium in the combined Deep 4 and Deep 5 zones decreased from about 5.2 to 3.7 tons (i.e., 29%).

Because the various alluvial groundwater zones have different thicknesses and volumes, the total chemical masses in each individual zone are not directly comparable. For example, the Intermediate zone contains the smallest sulfate mass because it is the thinnest groundwater zone. Consequently, changes in average concentrations over time in the various groundwater zones are a more appropriate comparison. Changes over time in average concentrations of sulfate and uranium in the alluvial aquifer groundwater zones are also shown on Figure 6-9.

Clear trends (either increasing or decreasing) are not evident, with the exception of decreasing average sulfate concentrations in the Shallow zone and decreasing sulfate and uranium concentrations in the combined Deep 4 and 5 zones. During the monitoring period, the average concentration of sulfate in the Shallow zone decreased from 1,518 mg/L to 1,330 mg/L (i.e., 12%) and the average concentration of sulfate in the Deep 4/5 zones decreased from 90 mg/L to 67 mg/L (i.e., 25%). The concentration of uranium in the Deep 4/5 zone decreased from 35 to 25 ug/L (i.e., 29%).

The decrease in sulfate mass and average concentration in the Shallow zone is interpreted as dilution effects from irrigation practices in the agricultural fields north of the mine boundary. The cause of the observed decrease in calculated average uranium concentrations in the combined Deep 4 and Deep 5 zones is likely due to dilution and dispersion. The calculated decrease in total sulfate and uranium mass is likely an apparent effect due to the fewer data points for calculating chemical mass.

The results of these evaluations indicate that, in general, the plume of mine-impacted groundwater is stable. The plume stability is the result of very slow groundwater velocities and attenuation by dilution. The dilution occurs primarily as the result of recharge on the agricultural fields (specifically on the fields of the Hunewill Ranch) and leakage from irrigation ditches (specifically the West Campbell Ditch), and dispersion within the groundwater plume.

SECTION 7.0

HYDROGEOLOGIC CONCEPTUAL SITE MODEL

The Site is a former copper mine located in the west-central portion of the Mason Valley, a Basin-and-Range-type graben filled with up to 1,000 feet of unconsolidated valley-fill deposits of Tertiary and Quaternary age lying unconformably on a weathered surface of hydrothermally-altered Tertiary volcanic and Mesozoic intrusive bedrock. The valley is bordered to the west by the Singatse Range, to the east by the Wassuk Range, and to the north by the Desert Mountains. Regional metals mineralization and hydrothermal alteration associated with localized porphyry and skarn copper deposits occur in the Singatse Range and nearby portions of the Mason Valley.

The unconsolidated valley fill deposits were derived primarily from erosion of the uplifted mountain blocks and from deposition in the floodplain of the Walker River. In addition, lacustrine deposits derived from ancestral Lake Lahonton occur north of the Site. Depositional processes have resulted in a complex interbedded sequence of alluvial sediments.

Historically, regional groundwater flow patterns in the Mason Valley prior to Anaconda/Arimetco mining operations were similar to current conditions with groundwater moving generally from south to north, and discharging to surface seeps and geothermal springs in the northern portion of the basin. Locally, though, current flow patterns have been significantly altered from historical patterns by agricultural activities. The alluvial aquifer in the Mason Valley is very productive and groundwater is currently pumped extensively for irrigation (Carroll et al. 2010; SSPA 2014).

The alluvial aquifer is primarily recharged by downward percolation from irrigated fields (49%), leakage from irrigation ditches (29%), infiltration from the channel of the Walker River (20%), and MFR (2%), consisting of infiltration through bedrock of precipitation that falls on surrounding mountain ranges and minor tributary surface flows in ephemeral drainages (SSPA 2014). Recharge from precipitation falling directly on the valley floor is negligible (Huxel and Harris 1969; Lopes and Allander 2009a, 2009b).

Within the Study Area, the alluvial sediments are up to 700 feet thick and comprise a single aquifer. The alluvial aquifer is subdivided into a Shallow, an Intermediate and a Deep zone (which is further subdivided into Deep zones 1 through 5). These groundwater zone designations are based on elevation and used only to identify and group monitor wells with similar screen intervals at the same relative depth in the aquifer. Clay layers or other low-permeability sediments are laterally discontinuous resulting in unconfined or semi-confined alluvial aquifer groundwater conditions.

Alluvial groundwater near the Site generally flows to the northwest, but flow directions are locally affected by bedrock outcrops within and along the margins of the valley, drawdown from pumped wells (particularly in deeper zones of the alluvial aquifer), and recharge sources including the Walker River, the West Campbell Ditch and irrigation on the Hunewill Ranch and other agricultural fields. Groundwater in the alluvial aquifer moves relatively slowly, with flow velocities estimated to be less than 100 feet per year (BC 2014a).

Anthropogenic activities within the Study Area, especially agricultural activities, influence groundwater flow rates and directions, chemical migration pathways and transport rates, and contribute chemicals to groundwater via evapoconcentration and leaching of soil amendments and naturally-occurring chemicals in alluvial sediments, and subsequent transport through the vadose zone to groundwater. Irrigation practices near the mine Site, including groundwater extraction using high-capacity wells and conveyance/irrigation of both water from the Walker River and groundwater, alter groundwater flow rates and directions during the irrigation season due to the alteration of the natural recharge/discharge rates and locations. Agricultural pumping seasonally results in strong downward vertical gradients that are often 10 to 100 times greater than horizontal gradients.

Past and/or ongoing sources of COIs to Study Area groundwater include: 1) the mine waste facilities, which have been grouped into the various Site OUs; 2) naturally-occurring chemicals; and 3) agriculture. The major past and/or ongoing mine-related sources of COIs to groundwater include: 1) OU-4a, the Evaporation Ponds (BC 2014a, 2014d); OU-8, the Arimetco Facilities (CH2M Hill 2010, 2011a, 2011b); and 3) OU-3, the Process Areas (BC 2014a, 2014e).

Mine-related COIs include acidity (i.e., low pH) and elevated concentrations of TDS, major ions including sulfate, metals, and radiochemicals including uranium. Concentrations of mine-related chemicals in groundwater are most elevated in the Shallow zone of the alluvial aquifer beneath OU-4a features that include the LEP, UEP, Finger Ponds, Phase IV VLT HLP, Phase IV VLT Pond, and the Calcine Ditch. Chemical concentrations in groundwater decrease with vertical depth and horizontal distance from these facilities.

Hydraulic assessments and chemical distributions indicate that the PWS was only partially effective in capturing Shallow zone mine-impacted groundwater during its operational life from 1989 to 2009, when it was shut down with EPA approval.

Geochemical evaluations of groundwater quality data (BC 2016a) indicate that sulfate and dissolved uranium form neutral or negatively-charged aqueous ionic species in groundwater throughout Study Area (except beneath the Evaporation Ponds) and, thus, undergo very limited (if any) geochemical attenuation due to mineral precipitation or adsorption to aquifer materials during groundwater transport. Dissolved uranium in Study Area groundwater is predominantly present in complexes with carbonate plus or minus calcium, which reflect oxidizing, carbonate-rich groundwater conditions. Locally, dissolved uranium is also complexed with sulfate in Shallow zone groundwater beneath the Evaporation Ponds where pH is less than 5 and sulfate concentrations exceed 1,500 mg/L.

The spatial distributions of elevated concentrations of mobile parameters such as sulfate and uranium are significantly more extensive than the spatial distributions of acidity (as indicated by pH) and metals. The significantly more limited spatial extent of low pH values and elevated metal concentrations indicates that geochemical attenuation processes in Study Area groundwater reduce acidity and limit the mobility of metals relative to the more mobile chemicals such as sulfate and uranium (EPA 2007b; BC 2016a, 2016b). Elevated metal concentrations in groundwater correlate strongly with low pH.

Geochemical evaluations of groundwater quality data (BC 2016a) also indicate the likely precipitation of solid mineral phases (e.g., jarosite) primarily in the Shallow zone beneath the LEP, UEP, Thumb Pond and Phase IV HLP. These mineral phases likely represent a potential, ongoing source of COIs to groundwater.

Sulfate, uranium, and arsenic (and other COIs) occur naturally in groundwater in Mason Valley because of groundwater contact with naturally-mineralized and/or hydrothermally-altered bedrock associated with copper deposits and/or alluvial sediments derived from mineralized bedrock (BC 2014a, 2016b). To the west of the Site where sulfate and uranium concentrations are low, elevated concentrations of arsenic are associated with MFR and elevated groundwater temperatures. In addition, sulfate, uranium, and other COIs are sourced to groundwater due to agricultural activities (BC 2016b; EPA 2016c). The assessment of background groundwater quality conservatively established the maximum extent of mine-impacted groundwater and identified an area of groundwater in the northern part of the Study Area (i.e., the NSA) that has been impacted by agricultural activities rather than mining activities.

The extent of mine-impacted groundwater has been defined using sulfate, dissolved uranium, and sulfur isotopes in sulfate because these parameters are more mobile in groundwater relative to other mine-related COIs such as metals (EPA 2007b) and, thus, have traveled the farthest downgradient distance in the alluvial aquifer (BC 2016b). The extent of mine-impacted groundwater in the Study Area can be generally described as follows, recognizing that mine-impacted groundwater is spatially more extensive in the Shallow, Intermediate and Deep 1 zones of the alluvial aquifer relative to the Deep 2 through Deep 5 zones. The northernmost extent of mine-impacted groundwater in the Shallow, Intermediate and Deep 1 zones of the alluvial aquifer is located near the Sunset Hills between well clusters B/W-10 and B/W-52. The eastern extent of mine-impacted groundwater in the Shallow, Intermediate and Deep 1 zones of the alluvial aquifer is approximately located near or beneath the West Campbell Ditch alignment. To the west of the Site, mine-impacted groundwater extends almost to the western extent of saturated alluvium between unimpacted wells/clusters B/W-16S and B/W-40, and impacted well clusters B/W-33, B/W-6 and B/W-22.

Mine-impacted groundwater in the deeper zones does not extend as far north as the upper three zones. In the Deep 2 through Deep 5 zones, the maximum northern extent of mine-impacted groundwater is near the northern end of the Hunewill Ranch fields. The eastern extent of mine-impacted groundwater in the Deep 2 through Deep 5 zones of the alluvial aquifer is located between well clusters B/W-27 and B/W-50. On the east, the area of mine-impacted groundwater in the Deep 3 through Deep 5 zones reflects the former influence of seasonal groundwater extraction for crop irrigation from agricultural wells (e.g., WDW019, located adjacent to the B/W-1 well cluster). To the west of the Site, mine-impacted groundwater in the Deep 3 through Deep 5 zones extends almost to the western extent of saturated alluvium.

The estimated volume of mine-impacted groundwater (i.e., the portion of the downgradient aquifer where sulfate and uranium exceed background concentrations) is 385,327 acre-feet, and contains an estimated 0.5 million tons of sulfate and 100 tons of dissolved uranium. Irrigation wells and municipal wells are located outside of the plume of mine-impacted groundwater (Figure 3-13). In addition, the plume of mine-impacted groundwater does not discharge to surface water.

The plume of mine-impacted groundwater appears stable based on evaluations of changes in the estimated volume of contaminated groundwater, sulfate/uranium masses, and chemical centers-of-mass through time. Plume stability is the result of very slow groundwater velocities and attenuation by dilution. The dilution occurs primarily as the result of recharge on the agricultural fields (specifically on the fields of the Hunewill Ranch) and leakage from irrigation ditches (specifically the West Campbell Ditch), and dispersion within the groundwater plume.

Groundwater quality in the NSA has been impacted by agricultural activities rather than mining activities (BC 2016b) based on multiple lines of evidence including groundwater flow patterns, chemical distributions, groundwater age estimates, hydrologic tracers, and sulfur isotopes. These agricultural practices have resulted in concentrations of sulfate and uranium that are elevated above background values and/or MCLs and/or exhibit increasing trends.

Monitor well data from the NSA indicate that concentrations of nitrate, sulfate, calcium, uranium, and alkalinity in alluvial groundwater in the Shallow through Deep 2 zones increase along the flow path beneath the agricultural fields. Increases in nitrate are associated with organic fertilizer application on crop fields. Increases in sulfate and calcium concentrations are associated with application of gypsum ($CaSO_4$) as a soil amendment on crop fields, which dissolve in irrigation water that percolates down to the water table. Increases in uranium concentrations are associated with crop irrigation. Percolation of irrigation water through soils increases alkalinity in the soil moisture, which mobilizes and desorbs naturally-occurring uranium from sediments (as soluble complexes with sulfate, carbonate plus or minus calcium) resulting in elevated uranium concentrations in groundwater (Jurgens et al. 2010; Brown et al. 2007). Alluvial sediments in Mason Valley contain naturally-occurring uranium (BC 2009b). The impact of agriculture activities on uranium mobility in NSA groundwater within or near irrigated land is illustrated by the strong correlation between uranium, alkalinity and calcium. Increases in alkalinity and calcium are associated with increases in uranium concentrations that can exceed 100 µg/L.

SECTION 8.0
RISK EVALUATION

In a groundwater technical meeting held on June 30, 2016 attended by ARC, EPA and other stakeholders, EPA directed ARC to proceed with preparation and submittal of this OU-1 RI Report without including the risk evaluation. The risk evaluation is ongoing and will proceed on a separate but parallel path from this document. Potential human health risks are generally described herein, but will be addressed more comprehensively in a separate OU-1 HHRA report.

This OU-1 RI Report, in conjunction with the OU-1 HHRA, will provide the basis for ARC to identify RAOs and potential remedies for OU-1, which would occur during future FS scoping discussions.

SECTION 9.0
REFERENCES

Air Force Center for Environmental Excellence (AFCEE), 2006. Monitoring and Remediation Optimization System (MAROS), User's Guide, March 2006.

Anaconda Mining Company, 1958. Engineering Drawing WHE-201, Tailing Disposal Sulphide Plant - Tailings Pond General Arrangement. March 24.

Anaconda Mining Company, 1966. Engineering Drawing YG-20, Water Supply & Distribution - Daily Water Balance Diagram. Prepared July 15, 1953. Revised July 28.

Anaconda Mining Company, 1967. Engineering Drawing WHN-1208, Sulphide Plant Quantitative Flow Diagram. Prepared May 19, 1966. Revised January 9.

Anaconda Minerals Company, 1984. Water Quality Investigation and Mitigation Plan. Yerington Mine.

Applied Hydrology Associates, 1983. Evaluation of Water Quality and Solids Leaching Data. Yerington Mine. Prepared for Atlantic Richfield Company.

Applied Hydrology Associates (also Norwest Applied Hydrology), 2000-2007. 2000-2007 Annual Monitoring and Operation Summary reports, Prepared for Atlantic Richfield Company.

Atlantic Richfield Company, 2008. Pumpback Well System Characterization Work Plan. Yerington Mine Site, Lyon County, Nevada.

Atlantic Richfield Company, 2010. Pumpback Well System Characterization Work Plan Addendum - Revision 2. Yerington Mine Site, Lyon County, Nevada. February 17.

Atlantic Richfield Company, 2011. Addendum to the On-Site Monitor Well Installation Work Plan. Yerington Mine Site, Lyon County, Nevada. September 7.

Atlantic Richfield Company, 2012a. Proposed Initial Bedrock Characterization Activities, Yerington Mine Site, Lyon County, Nevada. January 5.

Atlantic Richfield Company, 2012b. Proposed Initial Bedrock Characterization Activities - Revision 1, Yerington Mine Site, Lyon County, Nevada. October 11.

Atlantic Richfield Company, 2012c. Groundwater Flow Modeling Deliverables, Yerington Mine Site, Lyon County, Yerington, Nevada. June 25.

Atlantic Richfield Company, 2012d. Comprehensive Hydrologic Tracer Sampling Event and Request to Eliminate Select Tracers, Yerington Mine Site, Lyon County, Nevada. March 19.

Atlantic Richfield Company, 2012e. Preliminary Responses to February 7, 2012 EPA Comments on the 2011 Background Groundwater Quality Assessment, Yerington Mine Site dated September 28, 2011; Administrative Order on Consent, EPA Region 9 CERCLA Docket No. 9-2007-0005. April 18.

Atlantic Richfield Company, 2014. Technical Memorandum: Site-Wide Groundwater Monitoring Optimization, Yerington Mine Site, Lyon County, Nevada. April 14.

Atlantic Richfield Company, 2016a. Letter to D. Seter, Subject: Yerington Mine Site, Lyon County Nevada, Site ID #09GU, Request to Modify Domestic Well Monitoring Program and Bottled Water Program. September 1.

Atlantic Richfield Company, 2016b. Responses to EPA Comments dated February 11, 2016 on the Background Groundwater Quality Assessment - Revision 2 dated July 2, 2015; Administrative Order on Consent, EPA Region 9 CERCLA Docket No. 9-2007-0005. June 14.

Bell, E.J. and D.B. Slemmons, 1979. Recent crustal movements in the central Sierra Nevada-Walker Lane region of California-Nevada--Part II, The Pyramid Lake right-slip fault zone segment of the Walker Lane: Tectonophysics, v. 52, p. 571-583.

Benson, L.V. and D. L. Leach, 1979. Uranium Transport in the Walker River Basin, California and Nevada. Journal of Geochemical Exploration, vol. 11, p. 227-248.

Benson, L.V. and R.J. Spencer, 1983. A Hydrochemical Reconnaissance Study of the Walker River Basin, California and Nevada. USGS Open-File Report 83-740.

Bernhard, G., G. Geipel, T. Reich, V. Brendler, S. Amayri, and H. Nitsche, 2001. Uranyl(VI) carbonate complex formation: Validation of the $Ca_2UO_2(CO_3)_3$ (aq) species. Radiochimica Acta, 89:511-518.

Bigham, J.M., U. Schwertmann, S.J. Traina, R.L. Winland, and M. Wolf, 1996. Schwertmannite and the chemical modeling of iron in acid sulfate waters. Geochimica et Cosmochimica Acta, Vol. 60, pp. 2111-2121.

Bourrié, G., F. Trolard, J.M. Génin, A. Jaffrezic, V. Maître, and M. Abdelmoula, 1999. Iron control by equilibria between hydroxy-green rusts and solutions in hydromorphic soils. Geochimica et Cosmochimica Acta, Vol. 63, pp. 3417-3427.

Brown, C.J., B.C. Jurgens, B.G. Katz, M.K. Landon, and S.E. Eberts, 2007. Arsenic and Uranium in Four Aquifer Settings: Occurrence, Distribution, and Mechanisms for Transport to

Supply Wells. NGWA Naturally Occurring Contaminants Conference: Arsenic, Radium, Radon, Uranium. March 22-23.

Brown and Caldwell, 2002. Installation of Two Monitor Wells at the Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company.

Brown and Caldwell, 2003. Final Draft Process Areas Work Plan. Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. December 15.

Brown and Caldwell, 2005. First-Step Hydrogeologic Framework Assessment Work Plan North of the Anaconda Mine Site. Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. April 22.

Brown and Caldwell, 2007a. Data Management Plan for the Yerington Mine Site, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. April 24.

Brown and Caldwell, 2007b. Second-Step Hydrogeologic Framework Assessment Work Plan, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. February 28.

Brown and Caldwell, 2007c. Draft Site-Wide Groundwater Monitoring Plan, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. August 8.

Brown and Caldwell, 2008, Anaconda Evaporation Ponds Removal Action Characterization Work Plan, Yerington Mine Site. Prepared for Atlantic Richfield Company. September 15.

Brown and Caldwell, 2008a. Anaconda Evaporation Ponds Removal Action Characterization Work Plan, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. September 15.

Brown and Caldwell, 2008b. Shallow Alluvial Aquifer Characterization Work Plan for the Northern Portion of the Yerington Mine Site, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. December 30.

Brown and Caldwell, 2008c. Second-Step Hydrogeologic Framework Assessment Data Summary Report, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. October 15.

Brown and Caldwell, 2009, Evaporation Ponds Removal Action Characterization Data Summary Report. June 12.

Brown and Caldwell, 2009a. Site-Wide Groundwater Monitoring Plan - Revision 1, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. December 15.

Brown and Caldwell, 2009b. Background Soils Data Summary Report - Revision 1, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. March 9.

Brown and Caldwell, 2010a. Shallow Zone Characterization Data Summary Report - Revision 1, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. January 29.

Brown and Caldwell, 2010b. Addendum to the Site-Wide Quality Assurance Project Plan, Domestic Well Monitoring Plan - Revision 3, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. July 1.

Brown and Caldwell, 2010c. 2010 Groundwater Monitor Well Work Plan - Revision 2, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. July 22.

Brown and Caldwell, 2010d. Agricultural Fields Characterization Work Plan - Revision 2, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. July 20.

Brown and Caldwell, 2010e. Aquifer Solids Testing Work Plan - Revision 1, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. September 21.

Brown and Caldwell, 2010f. Summary of PWS Aquifer Testing, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. September 24.

Brown and Caldwell, 2010g. Draft Aquifer Solids Testing Work Plan, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. June 21.

Brown and Caldwell, 2011a. On-Site Monitor Well Installation Work Plan - Revision 1, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. August 29.

Brown and Caldwell, 2011b. Aquifer Solids Testing Work Plan - Revision 1, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. September 21.

Brown and Caldwell, 2011c. Draft Background Groundwater Quality Assessment, Site-Wide Groundwater Operable Unit, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. September 28.

Brown and Caldwell, 2012a. Site-Wide Groundwater Monitoring Plan - Revision 2, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. July 19.

Brown and Caldwell, 2012b. Draft Site-Wide Groundwater Operable Unit (OU-1) Remedial Investigation Work Plan, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. November 19.

Brown and Caldwell, 2012c. SOP-23 Aquifer Solids Testing SOP - Redox-Preserved Sample Preparation and Testing, Yerington Mine Site, Hazen Research, Inc. Laboratory Facility, Golden, CO. Prepared for Atlantic Richfield Company. August 17.

Brown and Caldwell, 2012d. SOP-23 Aquifer Solids Testing SOP - Redox-Preserved Sample Preparation and Testing - Revision 1, Yerington Mine Site, Hazen Research, Inc. Laboratory Facility, Golden, CO. Prepared for Atlantic Richfield Company. October 15.

Brown and Caldwell, 2012e. Aquifer Test Data Summary Report - Revision 1, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. December 13.

Brown and Caldwell, 2013a. 2010 Monitor Well Installation and Agricultural Fields Characterization Data Summary Report - Revision 1. Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. January 18.

Brown and Caldwell, 2013b. Additional Monitor Well Work Plan - Revision 1, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. October 8.

Brown and Caldwell, 2013c. Initial Bedrock Characterization Data Summary Report, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. November 20.

Brown and Caldwell, 2013d. Revised Public Information for the Northern Portion of the Background Groundwater Study Area, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. August 5.

Brown and Caldwell, 2013e. Draft Additional Monitor Well Work Plan, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. June 26.

Brown and Caldwell, 2014a. Site-Wide Groundwater Operable Unit (OU-1) Remedial Investigation Work Plan - Revision 1, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. February 7.

Brown and Caldwell, 2014b. 2013 Annual Operations and Maintenance Report for the Arimetco Fluid Management System, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. June 9.

Brown and Caldwell, 2014c. Groundwater Geochemical Characterization Data Summary Report, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. December 30.

Brown and Caldwell, 2014d. Phase 1 Field Sampling and Analysis Plan Anaconda Evaporation Ponds, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. July 31.

Brown and Caldwell, 2014e. OU-3 Step-out Soils Characterization Data Summary Report, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. December 12.

Brown and Caldwell, 2014f. 2013 Annual Groundwater Monitoring Report, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. May 12.

Brown and Caldwell, 2015a. Bedrock Groundwater Assessment Technical Memorandum, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. January 28.

Brown and Caldwell, 2015b. Draft Wabuska Drain (OU-7) Remedial Investigation Work Plan - Conceptual Site Model and Data Quality Objectives, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. July 14.

Brown and Caldwell, 2015c. Background Groundwater Quality Assessment - Revision 2, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. July 2.

Brown and Caldwell, 2015d. Additional Monitor Well Installation Data Summary Report, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. June 11.

Brown and Caldwell, 2015e. Groundwater Geochemical Characterization Data Summary Report - Revision 1, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. December 11.

Brown and Caldwell, 2015f. Technical Memorandum: Draft Initial Screening of Remedial Alternatives, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. December 2.

Brown and Caldwell, 2016a. Groundwater Geochemical Characterization Data Summary Report - Revision 2, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company.

Brown and Caldwell, 2016b. Background Groundwater Quality Assessment - Revision 3, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. November 11.

Brown and Caldwell, 2016c. 2015 Annual Groundwater Monitoring Report, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. May 16.

BC, 2017. Technical Memorandum: Phase 1 Evaporation Ponds Characterization Data Summary Report. Prepared for Atlantic Richfield Company, March 16

Brown and Caldwell, 2017a. Technical Memorandum: Wabuska Drain (OU-7) Field Sampling and Analysis Plan Data Summary Report and Conceptual Site Model Update. Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. January 3

Brown and Caldwell, 2017b. Technical Memorandum: Phase 1 Evaporation Ponds Characterization Data Summary Report. Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. January 20.

Brown and Caldwell and Integral Consulting, Inc., 2007. Draft Remedial Investigation Work Plan for Site-Wide Groundwater Operable Unit 1, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. November 16.

Carroll, R.W.H., G. Pohll, D. McGraw, C. Garner, A. Knust, D. Boyle, T. Minor, S. Bassett, and K. Pohlmann, 2010. Mason Valley Groundwater Model: Linking Surface Water and Groundwater in the Walker River Basin, Nevada. Journal of American Water Resources Association.

CH2M Hill, 2010. Final Historical Summary Report, Anaconda-Yerington Mine Site, Yerington, Nevada. October.

CH2M Hill, 2011a. Final Supplemental Remedial Investigation Report Arimetco Facilities Operable Unit 8, Anaconda-Yerington Copper Mine. Yerington, Nevada. October.

CH2M Hill, 2011b. Feasibility Study for Arimetco Facilities Operable Unit 8 Heap Leach Pads and Drain-down Fluids, Anaconda-Yerington Copper Mine. Yerington, Nevada. July.

Dalton, D., 1998. Arimetco Yerington Mine and Process Facility Site Assessment of Groundwater Quality, Yerington, Nevada. Prepared for Arimetco, Inc. July.

Davis, J.A., S.P. Hyun, P.M. Fox, and K.F. Hayes, 2009. A surface complexation modeling approach for Uranium (VI) transport in groundwater. Abstracts of the International Mine Water Conference, Proceedings. October.

Doherty, J., 2009. PEST - Model-Independent Parameter Estimation & Uncertainty Analysis, Version 12.2. Watermark Computing. Brisbane, Australia.

Dong, W. and S.C. Brooks, 2006. Determination of the formation constants of ternary complexes of uranyl and carbonate with alkaline earth metals (Mg^{2+}, Ca^{2+}, Sr^{2+}, and Ba^{2+}) using anion exchange method. Environmental Science and Technology Vol. 40, pp. 4689–4695.

Echevarria, G., M.I. Sheppard, and J.L. Morel, 2001. Effect of pH on the sorption of uranium in soils. Journal of Environmental Radioactivity, Vol. 53, pp. 257-264.

Ecology and Environment, Inc., 2013. Technical Memorandum and Report of START Activities, Arimetco Pond Design and Perimeter Ditch Repair Field Observations and Operation and

Maintenance Recommendations, Yerington, Nevada. Prepared for the Atlantic Richfield Company. April 29.

Environmental Standards, Inc. and Brown and Caldwell, 2009. Quality Assurance Project Plan Yerington Mine Site, Revision 5. Prepared for Atlantic Richfield Company. May 20.

EPA, 1988. Interim Final Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA. EPA/540/G-89/004.

EPA, 1992. Guidance for Data Usability for Risk Assessment. (Part B). Final. Office of Emergency and Remedial Response. Washington D.C.

EPA, 1999. Understanding Variation in Partition Coefficient, Kd, Values. Volume I: The k_d Model, Methods of Measurement, and Application of Chemical Reaction Codes. EPA 402-R-99-004A.

EPA, 2005. Standard Operating Procedure for Analysis of Total Organic Carbon in Sediments (Dry Combustion, Infrared Detection). Method LG601. Revision 04. March.

EPA, 2007a. Administrative Order for the Remedial Investigation and Feasibility Study. In the matter of Anaconda / Yerington Mine Site, Yerington, Lyon County, Nevada. Atlantic Richfield, Respondent. U.S. EPA Region 9, Docket No. 9-2007-0005. Proceeding under Section 106(a) of CERCLA, as amended, 42 USC § 9606(a). Including Attachment A: Scope of Work for the Remedial Investigations / Feasibility Studies Continued Response Action. January 12, 2007.

EPA, 2007b. Monitored Natural Attenuation of Inorganic Constituents in Ground Water, Volume 1 Technical Basis for Assessment. EPA/600/R-07-139.

EPA, 2008. A Systematic Approach to Evaluation of Capture Zones at Pump and Treat Systems, Final Project Report. EPA 600/R-8/003.

EPA, 2009. Statistical Analysis of Groundwater Monitoring Data at RCRA Facilities, Unified Guidance. EPA/530/R-09-007.

EPA, 2010a. Letter from EPA to Atlantic Richfield Company RE: Comments on the Draft Aquifer Solids Testing Work Plan. September 13.

EPA, 2010b. Letter from EPA to Atlantic Richfield Company RE: Aquifer Solids Testing Work Plan - Revision 1. September 30.

EPA, 2010d. Monitored Natural Attenuation of Inorganic Constituents in Ground Water, Volume 3, Assessment for Radionuclides Including Tritium, Radon, Strontium, Technetium, Uranium, Iodine, Radium, Thorium, Cesium, and Plutonium-Americium. EPA/600/R-10/039.

EPA, 2011a. Letter from EPA to Atlantic Richfield Company RE: Comments on the 2010 Annual Groundwater Monitoring Report (April 15, 2011), the First Quarter 2011 Groundwater Monitoring Report (July 1, 2011), and the Second Quarter 2011 Groundwater Monitoring Report (August 26, 2011) for the Anaconda Mine Site. September 29.

EPA, 2011b. Letter from EPA to Atlantic Richfield Company RE: Approval of the Addendum to the On-Site Monitor Well Installation Work Plan. September 30.

EPA, 2012a. Letter from EPA to Atlantic Richfield Company RE: Comments on the Draft Background Groundwater Quality Assessment, Yerington Mine Site, Nevada. February 7.

EPA, 2012b. Letter from EPA to Atlantic Richfield Company RE: Comprehensive Hydrologic Tracer Sampling Event and Request to Eliminate Select Tracers, Yerington Mine Site, Nevada. April 27.

EPA, 2012c. Letter from EPA to Atlantic Richfield Company RE: Comments on the Proposed Initial Bedrock Characterization Activities for the Anaconda Mine Site. April 12.

EPA, 2012d. Letter from EPA to Atlantic Richfield Company. October 22.

EPA, 2012e. Letter from EPA to Atlantic Richfield Company RE: Groundwater Flow Modeling Deliverables Anaconda Mine Site, Nevada. July 11.

EPA, 2012f. Letter from EPA to Atlantic Richfield Company. October 26.

EPA, 2012g. Letter from EPA to Atlantic Richfield Company RE: Comments on SOP-23 Aquifer Solids Testing - Redox-Preserved Sample Preservation and Testing Dated August 14, 2012. September 26.

EPA, 2013a. Letter from EPA to Atlantic Richfield Company RE: Comments on 2011 Annual Groundwater Monitoring Report, Anaconda Yerington Mine Site. March 27.

EPA, 2013b. Letter from EPA to Atlantic Richfield Company RE: Comments on 2012 Annual Groundwater Monitoring Report, Anaconda Yerington Mine Site. August 1.

EPA, 2013c. Letter from EPA to Atlantic Richfield Company RE: EPA Approval to Abandon Well B/W-14S, Anaconda Yerington Mine Site. November 22.

EPA, 2013d. Letter from EPA to Atlantic Richfield Company RE: Comments on the Draft Groundwater Flow Model Work Plan, Anaconda Yerington Mine Site. March 29.

EPA, 2013e. Letter from EPA to Atlantic Richfield Company RE: Comments on the Draft Additional Monitor Well Work Plan, Anaconda Yerington Mine Site. July 29.

EPA, 2013f. Statistical Software ProUCL 5.0.00 for Environmental Applications for Data Sets with and without Nondetect Observations.

EPA, 2014a. Letter from EPA to Atlantic Richfield Company RE: EPA Approval of Site-Wide Groundwater Monitoring Optimization, Anaconda Yerington Mine Site. June 26.

EPA, 2014b. Letter from EPA to Atlantic Richfield Company RE: Anaconda Yerington Mine Site OU1, Approval of Site-Wide Groundwater RI Work Plan Revision 1. October 9.

EPA, 2014c. 3PE: A Tool for Estimating Groundwater Flow Vectors. EPA 600/R-14/273.

EPA, 2015a. Letter from EPA to Atlantic Richfield Company RE: Anaconda Yerington Mine Site OU-1 Request for Bedrock Characterization DSR in Place of Work Plan. May 18.

EPA, 2015b. Letter from EPA to Atlantic Richfield Company RE: Approval of Groundwater Flow Model Report and Supplemental Materials, Anaconda Yerington Mine Site OU-1.

EPA, 2016a. Letter from EPA to Atlantic Richfield Company RE: Anaconda Copper Mine Site OU-1 Approval of Bedrock Groundwater Assessment Technical Memorandum. July 31.

EPA, 2016b. Letter from EPA to the Atlantic Richfield Company RE: Anaconda Yerington Mine Site OU-1, Approval of Geochemical Characterization DSR with Conditions. July.

EPA, 2016c. Letter from EPA to Atlantic Richfield Company RE: Anaconda Mine Site, Comments on the Background Groundwater Quality Assessment - Revision 2 dated July 2, 2015. February 11.

EPA, 2016d. Letter from EPA to Atlantic Richfield Company RE: Anaconda Copper Mine OU-1, Background Groundwater Quality Assessment. September 27.

EPA, 2016e. Memorandum from Dr. R. Ford (USEPA Land Remediation & Pollution Control Division) and Mr. S. Acree (USEPA Applied Research and Technical Support Branch) to Mr. D. Seter (USEPA Region 9), Subject: Yerington Mine Site, Yerington Nevada (16-R09-003) Responses to ARC Responses to Comments on the Background Groundwater Quality Assessment - Revision 2. September 2.

EPA, 2016f. Letter from EPA to Atlantic Richfield Company RE: Anaconda Copper Mine, Domestic Well Monitoring Program (DWMP) and Bottled Water Program (BWP). October 25.

EPA, 2017. Letter to the Atlantic Richfield Company RE: Anaconda Copper Mine Site OU-1, OU-1 Background Water Quality Assessment - Revision 3. February 16.

Fox, P.M., J.A. Davis, and J.M. Zachara, 2006. The effect of calcium on aqueous uranium(VI) speciation and adsorption to ferrihydrite and quartz. Geochimica et Cosmochimica Acta, Vol. 70, pp. 1379-1387.

Freeze, R.A. and J.A. Cherry, 1979. Groundwater. Prentice-Hall, Upper Saddle River, NJ.

Gallagher, T. K., 2004. Estimated Annual Ground-Water Pumpage 1994 - 2003, Smith Valley and Mason Valley, Lyon County, Nevada, Nevada Department of Conservation and Natural Resources, Division of Water Resources.

Gallagher, T. K., 2013. Estimated Annual Ground-Water Pumpage 2004 - 2010, Smith Valley and Mason Valley, Lyon County, Nevada, Nevada Department of Conservation and Natural Resources, Division of Water Resources.

George, P. L. and H. Borouchaki, 1998, Delaunay Triangulation and Meshing Application to Finite Elements, Paris, Hermes.

Gill, D. K., 1951. Groundwater at the Yerington Mine, Lyon County, Nevada. Report prepared for the Anaconda Mining Company. March.

Heath, R.C., 1984. Ground-Water Regions of the United States. U.S. Geological Survey (USGS) Water-Supply Paper 2242.

Hem, J., 1985. Study and Interpretation of the Chemical Characteristics of Natural Water. 3rd Ed. U.S. Geological Survey (USGS) Water-Supply Paper 2254.

Hershey, R.L., 2002. Hydrology and water quality of the Yerington Pit Lake, In: Geological Society of Nevada 2002 Spring Field Trip Guidebook Special Publication No. 35, Jurassic Magmatism and Metal Deposits in Western Nevada, Yerington Mine District, Humboldt Mafic Complex, June 15-16, 2003, Ed. Bob Thomas, pp. 93-98.

Hsi, C. K. D., and D. Langmuir, 1985. Adsorption of uranyl onto ferric oxyhydroxides: application to the surface complexation site-binding model. Geochimica et Cosmochimica Acta, Vol. 49, pp. 1931-1941.

Huxel, C.J., and E.E. Harris, 1969. Water resources and development in Mason Valley, Lyon and Mineral Counties, Nevada, 1948-65. State of Nevada Department of Conservation and Natural Resources, Division of Water Resources, Water Resources Bulletin No. 38.

Jurgens, B.C., M.S. Fram, K. Belitz, K.R. Burow, and M.K. Landon, 2010. Effects of Groundwater Development on Uranium: Central Valley, California, USA. Ground Water. Vol. 48, pp. 913-928.

Lewis, B., 2000. Geophysical Survey Results of the Yerington Mine, Mason Valley, Nevada, Prepared by the U.S. Bureau of Land Management - National Science and Technology Center. August.

Li, D., and D. I. Kaplan, 2012. Sorption coefficients and molecular mechanisms of Pu, U, Np, Am and Tc to Fe (hydr)oxides: A review. Journal of Hazardous Materials. Vol. 243, pp. 1-18.

Lopes, T.J., and K.K. Allander, 2009a. Hydrologic Setting and Conceptual Hydrologic Model of the Walker River Basin, West-Central Nevada. USGS Scientific Investigations Report 2009-5155.

Lopes, T.J., and K.K. Allander, 2009b. Water Budgets of the Walker River Basin and Walker Lake, California and Nevada. USGS Scientific Investigations Report 2009-5157.

Maurer, D.K., T.J. Lopes, R.L. Medina, and J.L. Smith, 2004. Hydrogeology and Hydrologic Landscapes of Nevada. USGS Scientific Investigations Report 2004-5131.

Mifflin, M.D., 1988. Region 5, Great Basin. In Hydrogeology, the Geology of North America, DNAG volume, vol. 0-2; ed. W. Back, J.S. Rosenshein, and P.R. Seaber, 60-78. Boulder, Colorado: Geological Society of America.

Morrison, R.B., 1964. Lake Lahontan: Geology of the southern Carson Desert. U.S. Geological Survey (USGS) Professional Paper 401.

Myers, T., 2001. Hydrogeology of the Basin Fill Aquifer in Mason Valley, Nevada: Effects of Water Rights Transferred. Prepared for the U.S. Bureau of Land Management, Carson City Field Office, Carson City, NV. Public Resources Associates, Inc., Reno, Nevada.

Nesbitt, M., 1955. Memorandum to A. J. Gould, Plant Superintendent, Anaconda Company. July 27.

Nevada Department of Conservation and Natural Resources, Division of Water Resources, 2013a, NDWR-Water Rights Database Advanced Search (Special Hydrographic Abstract), http://water.nv.gov/data/hydrographic/ June 4, 2013.

Nevada Department of Conservation and Natural Resources, Division of Water Resources, 2013b, Well Log Database Query Tool, http://water.nv.gov/data/welllog/ June 5, 2013.

Nevada Department of Conservation and Natural Resources, Division of Water Resources, 2013c, Water Level Data, http://water.nv.gov/data/waterlevel/ June 27, 2013.

Nevada Division of Water Resources, 2015. Memorandum titled “Curtailment Order in Mason and Smith Valley”. Department of Conservation and Natural Resources, Division of Water Resources. February 3.

Nolan, J., and K.A. Weber, 2015. Natural Uranium Contamination in Major U.S. Aquifers Linked to Nitrate. Environ. Sci. Technol. Lett., Vol. 2, pp. 215-220.

Nordstrom, K., L.N. Plummer, D. Langmuir, and E. Busenburg, 1990. Revised Chemical Equilibrium Data for Major Water-Mineral Reactions and Their Limitations, in "Chemical Modeling of Aqueous Systems II," Chapter 31, pp. 398-413.

Nork, W.E., 1989. MacArthur Project Hydrogeologic Investigation Lyon County, Nevada. Prepared for MacArthur Mining and Processing Company, Inc. August 14.

Norwest Applied Hydrology, 2007. Pumpback Well System 2006 Operations and Monitoring Summary, Yerington Mine Site. Prepared for Atlantic Richfield Company. April 30.

Parkhurst, D.L., and C.A.J. Appelo, 1999. User's Guide to PHREEQC (Version 2) - A Computer Program for Speciation, Batch-Reaction, One-Dimensional Transport, and Inverse Geochemical Calculations. Water-Resources Investigations Report 99-4259, U.S. Geological Survey, Denver, Colorado.

Piedmont Engineering Inc., 2001. Yerington Shallow Aquifer Data Evaluation Report. Prepared for ARCO Environmental Remediation L.L.C.

Plume, R.W., 1996. Hydrogeologic framework of the Great Basin region of Nevada, Utah, and adjacent states. USGS Professional Paper 1409-B.

Proffett, J.M., 1977. Cenozoic geology of the Yerington District, Nevada, and implications for the nature and origin of Basin and Range faulting. Geologic Society of America Bulletin, Vol. 88, pp. 247-266.

Proffett, J.M., Jr., and J.H. Dilles, 1984. Geologic Map of the Yerington District, Nevada. Nevada Bureau of Mines and Geology, Map 77.

Reheis, M., 1999. Extent of Pleistocene Lakes in the Western Great Basin. USGS Miscellaneous Field Studies Map MF-2323.

Ricketts, T.H., E. Dinerstein, D.M. Olson, and C.J. Loucks, 1999. Terrestrial ecoregions of North America: a conservation assessment. Island Press, Washington, D.C.

Sánchez-España, J. I. Yusta, and M. Diez-Ercilla, 2011. Schwertmannite and hydrobasaluminite: A re-evaluation of their solubility and control on the iron and aluminum concentration in acidic Pit Lakes. Applied Geochemistry, Vol. 26, pp.1752-1774.

Seitz, H.R., A.S. Van Denburgh, and R.J. La Carma, 1982. Ground-Water Quality Down-gradient from Copper-One Milling Wastes at Weed Heights, Lyon County, Nevada. USGS Open-File Report 80-1217.

Skillings Jr., D.N., 1972. Yerington Copper Mine. Skillings Mining review. Vol. 61, No. 21.

Smedley, P.L. and D.G. Kinniburgh, 2001. A review of the source, behavior and distribution of arsenic in natural waters. Applied geochemistry, Vol. 17, pp. 517-568

Sø, H.U., D. Postma, R. Jakobsen, and F. Larsen, 2008. Sorption and desorption of arsenate and arsenite on calcite. Geochimica et Cosmochimica Acta, Vol. 72, pp. 5871-5884.

S.S. Papadopulos & Associates, Inc., 2012a. Objectives for Groundwater Modeling in the RI/FS Process, Yerington Mine Site. Prepared for Atlantic Richfield Company. August 14.

S.S. Papadopulos & Associates, Inc., 2012b. Objectives for Groundwater Modeling in the RI/FS Process - Revision 1, Yerington Mine Site. Prepared for Atlantic Richfield Company. October 15.

S.S. Papadopulos & Associates, Inc., 2012c. Draft Groundwater Flow Model, Work Plan for the Yerington Mine Site. Lyon County, Nevada. Prepared for Atlantic Richfield Company. December 28.

S.S. Papadopulos & Associates, Inc., 2013. Groundwater Flow Model Work Plan for the Yerington Mine Site - Revision 1, Lyon County, Nevada. Prepared for Atlantic Richfield Company. May 21.

S.S. Papadopulos & Associates, Inc., 2014. Groundwater Flow Model, Yerington Mine Site, Nevada. Prepared for Atlantic Richfield Company. March 18.

S.S. Papadopulos & Associates, Inc., 2015. Flow Model Supplemental Materials, Yerington Mine Site, Nevada. Prepared for Atlantic Richfield Company. March 18.

Stachowicz, M., T. Hiemstra, and W.H. van Riemsdijk, 2007. Arsenic-bicarbonate interaction on goethite particles. Environmental Science and Technology, Vol. 41, pp. 5620-5625.

Stewart, J.H., 1988. Tectonics of the Walker Lane belt, western Great Basin: Mesozoic and Cenozoic deformation in a zone of shear. In Ernst, W.G., Metamorphism and crustal evolution of the western United States, Rubey volume VII: Prentice Hall, Englewood Cliffs, N.J.

Stewart, B.D., M.A. Mayes, and S. Fendorf, 2010. Impact of uranyl-calcium-carbonate complexes on uranium(VI) adsorption to synthetic and natural sediments. Environmental Science and Technology, Vol. 44, pp. 928-934.

Superfund Technical Assessment Response Team (START), 2000. Anaconda Copper Company, Yerington Mine Site, Expanded Site Inspection, Yerington, Lyon County, Nevada. Prepared by Ecology & Environment Incorporated. December.

Superfund Technical Assessment Response Team (START), 2001. Anaconda Copper Company, Yerington Mine Site, Emergency Response Assessment, Yerington, Lyon County, Nevada. Prepared by Ecology & Environment Incorporated. June.

Taylor, B.E., and M.C. Wheeler, 1994. Sulfur- and Oxygen-Isotope Geochemistry of Acid Mine Drainage in the Western United States. Chptr. 30. Environmental Geochemistry of Sulfide Oxidation. Eds. C.W. Alpers and D.W. Blowes.

Tetra Tech, 2010. Preliminary Economic Assessment Update Pumpkin Hollow Copper Project, Lyon County, Nevada. Prepared for Nevada Copper Corp. January 13.

Thomas, J.M., 1995. Water Budget and Salinity of Walker Lake, Western Nevada. USGS Fact Sheet FS-115-98.

U.S. Bureau of Mines, 1958. Methods and Operations at the Yerington Copper Mine and Plant of the Anaconda Company, Weed Heights, Nev., by M. Claire Smith; Information Circular 7848, Department of the Interior.

U.S. Census Bureau, 2015. State and County Quickfacts. Available at: http://www.census.gov/quickfacts/table/PST045215/32019.

U.S. Geological Survey, 2006. Determination of the Delta ($^{34}S/^{32}S$) of Sulfate in Water, RSIL Lab Code 1951. Techniques and Methods of the Reston Stable Isotope Laboratory, Chapter 10.

U.S. Geological Survey, 2008. $^{3}H/^{3}He$ Sampling. The Reston Chlorofluorocarbon Laboratory. http://water.usgs.gov/lab/3h3he/sampling/.

U.S. Geological Society, 2009a. Hydrologic Setting and Conceptual Hydrologic Model of the Walker River Basin, West-Central Nevada. U.S. Department of Interior, USGS, Scientific Investigations Report 2009-5155.

U.S. Geological Society, 2009b. Water Budgets of the Walker River Basin and Walker Lake, California and Nevada. U.S. Department of Interior, USGS, Scientific Investigations Report 2009-5157.

U.S. Geological Survey, 2013. National Water Information System, USGS Groundwater for Nevada: Water Levels, http://nwis.waterdata.usgs.gov /nv/nwis/gwlevels June 27.

Walker River Decree C-125, 1936 amended 1940. United States vs. Walker River Irrigation District, Docket C-125, District Court of the United States - District of Nevada.

Wanninkhof, R., J.R. Ledwell, and A. J. Watson, 1991. Analysis of sulfur hexafluoride in seawater. J. Geophys. Res - Oceans 96(C5), pp. 8733-8740.

Wilson, J.L., and H. Guan, 2004. Mountain-Block Hydrology and Mountain-Front Recharge. In: Groundwater Recharge in a Desert Environment: The Southwestern United States, edited by F.M. Phillips, J. Hogan, and B. Scanlon. AGU, Washington, DC.

WRCC, 2015. Yerington, Nevada (269229): Period NCDC 1894-2015 Monthly Normals. Western Regional Climate Center. http://www.wrcc.dri.edu/cgi-bin/cliMAIN.pl?nv9229.

Western Regional Climate Center (WRCC). 2017. Yerington, Nevada (269229) Period of Record Monthly Climate Summary, 1/1/1914 to 12/31/2005. http://www.wrcc.dri.edu/cgi-bin/cliMAIN.pl?nvyeri.

Zheng, C., G.D. Bennett, and C.B. Andrews, 1991. Analysis of Ground-Water Remedial Alternatives at a Superfund Site. Ground Water. Vol. 29, No. 6., pp. 838-848.

REMEDIAL INVESTIGATION REPORT
SITE-WIDE GROUNDWATER OPERABLE UNIT (OU-1)

ANACONDA COPPER MINE SITE
LYON COUNTY, NEVADA

OCTOBER 20, 2017

PREPARED FOR:
Atlantic Richfield Company
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LIST OF ACRONYMS AND ABREVIATIONS

AFCEE	Air Force Center for Environmental Excellence
AHA	Applied Hydrology Associates
Anaconda	Anaconda Companya
ARC	Atlantic Richfield Company
BC	Brown and Caldwell
BCL	Background Concentration Limit
BGQA	Background Groundwater Quality Assessment
BLM	Bureau of Land Management
CFC	Chlorofluorocarbon
COI	Chemical of Interest
DO	Dissolved Oxygen
DPT	Direct Push Technology
DSR	Data Summary Report
DQO	Data Quality Objective
DWMP	Domestic Well Monitoring Program
EA-IRMS	Elemental Analyzer-Isotopic Ratio Mass Spectrometer
EC	Electrical Conductivity
EPA	U.S. Environmental Protection Agency
ESI	Environmental Standards, Inc.
FEP	Finger Evaporation Ponds
FMS	Fluid Management System
FS	Feasibility Study
GC-ECD	Gas Chromatography with Electron Capture Detection
GMP	Groundwater Monitoring Plan
GMR	Groundwater Monitoring Report
HCSM	Hydrogeologic Conceptual Site Model
HDPE	High-Density Polyethylene
HFA	Hydrogeologic Framework Assessment
HLP	Heap Leach Pad
HHRA	Human Health Risk Assessment
HSR	Historical Summary Report
IAOC	Interim Administrative Settlement Agreement and Order on Consent
ICP-MS	Inductively Coupled Plasma Mass Spectroscopy
J	Estimated Concentration
K	Hydraulic Conductivity
Kd	Partition (or Distribution) Coefficient
LEP	Lined Evaporation Pond
MAROS	Monitoring and Remediation Optimization System
MCL	Maximum Contaminant Level
MFR	Mountain Front Recharge
NA	Not Applicable/Not Available
NAC	Nevada Administrative Code
NDEP	Nevada Division of Environmental Protection
NDWR	Nevada Division of Water Resources
NR	Not Recorded
NSA	North Study Area
NS	No Sample
O&M	Operation and Maintenance
ORP	Oxidation-Reduction Potential
OU	Operable Unit
PLS	Pregnant Leach Solution
POD	Point of Diversion
POU	Place of Use
PV	Pore Volume
PWS	Pumpback Well System
Q	Quarter
QA/QC	Quality Assurance/Quality Control
QAPP	Quality Assurance Project Plan
R	Retardation Coefficient
RAO	Remedial Action Objective
RER	Replicate Error Ratio
RI/FS	Remedial Investigation and Feasibility Study
RPD	Relative Percent Difference
RSIL	USGS Reston Stable Isotope Laboratory
RSL	Regional Screening Level
SCM	Surface Complexation Model
SERA	Southeast Recharge Area
SOP	Standard Operating Procedure
SOW	Scope of Work
SSPA	S.S. Papadopulos & Associates, Inc.
START	Superfund Technical Assessment and Response Team
STORET	STOrage and RETrieval
SWRA	Southwest Recharge Area
TC	Total Carbon
SX/EW	Solvent Extraction /Electrowinning
TIC	Total Inorganic Carbon
TDS	Total Dissolved Solids
TIMS	Thermal Ionization Mass Spectrometer
TOC	Total Organic Carbon
TU	Tritium Unit
U	Chemical not detected at the indicated sample detection limit
UAO	Unilateral Administrative Order
Ue	Uranium Excess
UEP	Unlined Evaporation Pond
UJ	Chemical not detected at the indicated estimated sample detection limit
USCS	Unified Soil Classification System
USGS	United States Geological Survey
UTL	Upper Tolerance Limit
VLT	Vat Leach Tailings
WRCC	Western Regional Climate Center

LIST OF ACRONYMS AND ABREVIATIONS - CONTINUED

WRD	Walker River Decree
WRID	Walker River Irrigation District
YPT	Yerington Paiute Tribe

%	percent
‰	per mil
amsl	above mean sea level
bgs	below ground surface
cu ft	cubic feet
cfs	cubic feet per second
°F	degrees Fahrenheit
°C	degrees Celsius or Centigrade
ft	foot/feet
ft/day	feet per day
ft/yr	feet per year
fmol/kg	femtomole per kilogram
gal	gallons
g/L	grams per liter
gpd	gallons per day
gpm	gallons per minute
L	liter
L/kg	liters per kilogram
µg	microgram
µm	micron or micrometer
mg	milligram
pCi/g	picocuries per gram
pCi/L	picocuries per liter
pCi	picocurie
pmol/kg	picomoles per kilogram
s.u.	standard units (pH)

MINERALS, CHEMICAL FORMULAS, AND ABBREVIATIONS

Barium Arsenate	$Ba_3(AsO_4)_2$
Ferric oxide	$Fe(OH)_3(a)$
Gypsum	$CaSO_4$
Hydroxy-green rust	$Fe_3(OH)_7(s)$ and $Fe_2(OH)_5(s)$
Jarosite (ss)	$(K_{0.77}Na_{0.03}H_{0.2})Fe_3(SO_4)_2(OH)_6(s)$
K-jarosite	$KFe_3(SO_4)_2(OH)_6(s)$
Na-jarosite	$NaFe_3(SO_4)_2(OH)_6(s)$
Schwertmannite	$Fe_8O_8(OH)_{4.8}(SO_4)_{1.6}(s)$
Scorodite	$FeAsO_4(s)$

(a)	Amorphous
(aq)	Aqueous
(s)	Solid
(ss)	Solid Solution

$\delta^{13}B$	Boron isotopes in water samples
$\delta^{36}Cl$	Chloride isotopes in water samples
$\delta^{34}S_{SO4}$	Sulfur isotopes in dissolved sulfate
$\delta^{34}O_{SO4}$	Oxygen isotopes in dissolved sulfate
$\delta^{15}N_{NO3}$	Nitrogen isotopes in dissolved nitrate
$\delta^{18}O_{NO3}$	Oxygen isotopes in dissolved nitrate

Nitric Acid	HNO_3
Sulfuric Acid	H_2SO_4
Sulfur Hexafluoride	SF_6
Sulfur Dioxide	SO_2

EXECUTIVE SUMMARY

This *Site-Wide Groundwater Operable Unit (OU-1) Remedial Investigation Report* (OU-1 RI Report) has been prepared by Atlantic Richfield Company (ARC) pursuant to Section 7.0 of the Scope of Work (SOW) attached to the Administrative Order for Remedial Investigation and Feasibility Study (RI/FS), CERCLA Docket No. 9-2007-0005 (2007 Order) for the Anaconda Copper Mine Site (Site). The 2007 Order (EPA 2007a) was issued to ARC by the U.S. Environmental Protection Agency - Region 9 (EPA) on January 12, 2007. Future work on the OU-1 RI/FS will proceed under oversight by the Nevada Division of Environmental Protection (NDEP) pursuant to the "Interim Administrative Settlement Agreement and Order on Consent for: (i) Remedial Design/Remedial Action, (ii) Site-Wide Remedial Investigation/Feasibility Study, and (iii) Fluid Management" entered into with NDEP (the IAOC) and the attached Statement of Work for RI/FS.

The term "Site" refers to the area where copper mining and ore processing activities historically occurred. The term "Study Area" in this document refers to a larger area encompassing both on-Site and off-Site areas in which OU-1 RI-related investigations have been conducted. The Site is a former copper mine that is located west and northwest of the City of Yerington. The 2007 Order identified eight OUs at the Site, which include:

- Site-Wide Groundwater (OU-1);
- Pit Lake (OU-2);
- Process Areas (OU-3);
- Evaporation Ponds (OU-4a) and Sulfide Tailings (OU-4b);
- Waste Rock Areas (OU-5);
- Oxide Tailings Areas (OU-6);
- Wabuska Drain (OU-7); and
- Arimetco Facilities (OU-8).

Consistent with the SOW attached to the 2007 Order (EPA 2007a) and general RI report objectives established by EPA (EPA 1988), this OU-1 RI Report:

- Summarizes activities conducted to characterize and monitor groundwater (including on- and off-Site locations), establish background groundwater quality, and determine the nature, extent, and transport of mine-related chemicals of interest (COIs) in groundwater;
- Integrates relevant historical operations and aspects of other OUs that represent potential sources of chemical loading to groundwater or have the potential to influence groundwater flow conditions;
- Describes the program for long-term monitoring of Site-wide groundwater conditions;
- Summarizes the domestic well monitoring program, which characterized the quality of groundwater used for drinking water or other domestic water supply purposes and determined eligibility for receiving bottled water as part of an interim response action; and
- Describes the process for completing the human health risk assessment, which is being addressed in a separate OU-1 Human Health Risk Assessment (HHRA) report, per EPA direction during a groundwater technical meeting held on June 30, 2016 attended by ARC, EPA, the NDEP, the Yerington Paiute Tribe (YPT), and other stakeholders.

The information provided in this OU-1 RI Report is considered sufficient to characterize the groundwater system, define the nature and extent of mine-related groundwater contamination, perform a risk assessment, and conduct a feasibility study. Numerous investigations and monitoring activities conducted by ARC and others provide substantial geologic, hydrogeologic, and water quality information relevant to OU-1. However, this OU-1 RI Report relies primarily on data obtained after 2005 to address the study elements specified in Section 7.0 of the SOW, characterize groundwater conditions, and refine the hydrogeologic conceptual site model (HCSM) to support the OU-1 RI/FS. Data obtained after 2005 have been selected for these purposes because: 1) data collection was performed pursuant to EPA-approved quality assurance/quality control (QA/QC) planning documents and OU-1 specific work plans that were developed with input from other stakeholders including the NDEP, YPT, and the Bureau of Land Management (BLM); 2) the spatial coverage and amount of data increased substantially after 2005; and 3) post-2005 sampling results better represent current conditions and potential risks at the Site, which is the proper focus of the RI and risk assessment.

The dataset obtained during August 2014 is emphasized in this OU-1 RI Report for the reasons previously cited, and because a variety of data types were concurrently collected (e.g., groundwater level data, groundwater quality data, and hydrologic tracer data) and/or evaluated (e.g., geochemical speciation modeling to help assess COI transport). Consequently, the August 2014 dataset is particularly useful for characterizing spatial aspects of OU-1 groundwater conditions.

Recognizing that groundwater characterization activities would largely involve monitor well installation, ARC and EPA adopted a multi-step sequential approach to field data collection to maximize usable data and optimize the design of a monitor well network intended to serve the data needs for both OU-1 RI characterization and long-term Site-Wide groundwater monitoring. In total, the groundwater RI characterization activities resulted in drilling 133 boreholes, logging approximately 33,000 linear feet of core, collecting and analyzing 624 zonal groundwater samples, installing 299 new monitor wells, and hydraulic (slug) testing of 296 wells.

After installation and development, new monitor wells were incorporated along with select existing monitor wells into the Site-Wide Groundwater Monitoring Program. Within the Study Area, the alluvial aquifer is up to 700 feet thick and is subdivided into Shallow, Intermediate and Deep zones (Deep zones 1 through 5). Underlying the alluvial aquifer is a bedrock groundwater flow system. The current monitor well network includes 360 wells at 170 locations: 133 wells in the Shallow zone, including 11 Pumpback Well System (PWS) wells formerly used for groundwater extraction that are currently inactive; 55 wells in the Intermediate zone; 105 wells in the Deep zone; and 67 bedrock wells. Of the 360 monitor wells, seven are used only for water level measurements, and the remaining 353 are monitored for both water levels and water quality.

The Site and Study Area are in the Mason Valley, a north-south trending structural valley (graben) in the Basin and Range Province that is filled with up to 1,000 feet of unconsolidated alluvial sediments. The valley is bordered to the west by the Singatse Range, to the east by the Wassuk Range, and to the north by the Desert Mountains. Regional metals mineralization and hydrothermal alteration associated with localized porphyry and skarn copper deposits occur throughout the Singatse Range and nearby portions of the Mason Valley.

Depositional processes have resulted in a complex sequence of laterally-discontinuous, heterogeneous, unconsolidated alluvial sediments that exhibit spatially-variable hydraulic properties (Brown and Caldwell [BC] 2014a). Clay layers or other low-permeability sediments are laterally discontinuous resulting in unconfined or semi-confined alluvial aquifer groundwater conditions. Based on groundwater flow model results (S.S. Papadopulos & Associates, Inc. [SSPA] 2014), the alluvial aquifer is primarily recharged by downward percolation of water from irrigated fields (49 percent [%]), leakage from irrigation ditches (29%), infiltration from the channel of the Walker River (20%), and mountain front recharge (2%) resulting from infiltration through bedrock of precipitation that falls on surrounding mountain ranges and minor tributary surface flows in ephemeral drainages. Recharge from precipitation falling directly on the valley floor is negligible (Huxel and Harris 1969; Lopes and Allander 2009a, 2009b).

The alluvial aquifer in the Mason Valley yields significant quantities of groundwater and the groundwater resource is pumped extensively for irrigation (Carroll et al. 2010; SSPA 2014). Alluvial groundwater near the Site generally flows to the northwest, but flow directions are locally affected by bedrock outcrops within and along the margins of the valley, drawdown from pumped wells (particularly in deeper zones of the alluvial aquifer), and recharge sources such as the Walker River, the West Campbell Ditch, and irrigation on the Hunewill Ranch and other agricultural fields. Groundwater in the alluvial aquifer moves relatively slowly, with flow velocities estimated to be less than 100 feet per year (BC 2014a). Agricultural pumping seasonally results in strong downward vertical gradients that are often 10 to 100 times greater than horizontal gradients.

Historic mining and copper ore beneficiation activities involved the use of sulfuric acid (H_2SO_4). The major past and/or ongoing sources of COIs to groundwater include: 1) OU-4a, the Evaporation Ponds (BC 2014a, 2014d); 2) OU-8, the Arimetco Facilities (CH2M Hill 2010, 2011a, 2011b); and 3) OU-3, the Process Areas (BC 2014a, 2014e). Concentrations of COIs in groundwater beneath OU-4b (Sulfide Tailings) are generally at least 10 to 100 times lower than COI concentrations in groundwater beneath OU-4a. Furthermore, OU-4b is located hydraulically upgradient or cross-gradient of OU-4a, and groundwater beneath OU-4b flows toward the higher COI concentrations under OU-4a.

The Pit Lake (OU-2), which was studied as part of the OU-1 RI (BC 2014a), is not a source of COIs to Site-wide groundwater because the lake elevation is lower than the surrounding potentiometric surface and the pre-mining groundwater level. The Pit Lake surface is projected to reach a steady-state level, where water inflow and evaporation are balanced, prior to 2030. The steady-state Pit Lake elevation is estimated to be in the range of 4,249 to 4,253 feet above mean sea level, and is projected to remain lower than the surrounding potentiometric surface even after reaching steady-state conditions. Consequently, the lake is and will continue to be a groundwater sink that does not discharge into the Site-wide groundwater system.

Results of the ongoing RI for the Wabuska Drain (OU-7) will be reported separately. Available data indicate that concentrations of mine-related chemicals decrease with distance from the Site and depth in the soil profile (EPA 2007, BC 2015b).

Mine-related COIs include acidity (i.e., low pH), total dissolved solids (TDS), major ions including sulfate, metals/metalloids (hereinafter referred to as metals), and radiochemicals including uranium (BC 2014a). Concentrations of mine-related chemicals in groundwater are most elevated in the Shallow zone of the alluvial aquifer beneath OU-4a features that include the Lined Evaporation Pond (LEP), Unlined Evaporation Pond (UEP), Finger Ponds, Phase IV Vat Leach Tailings (VLT) Heap Leach Pad (HLP), Phase IV VLT Pond, and the northern end of the Calcine Ditch. Chemical concentrations in groundwater generally decrease with vertical depth and horizontal distance from these facilities. To the extent localized downgradient increases in chemical concentrations are observed, they result from non-mine-related factors.

Hydraulic assessments and chemical distributions indicate that the PWS was only partially effective in capturing Shallow zone mine-impacted groundwater during its operational life from 1989 to 2009 (BC 2010), when it was shut down with EPA approval.

Geochemical evaluations of groundwater quality data (BC 2016a) indicate that sulfate and dissolved uranium form neutral or negatively-charged aqueous ionic complexes in groundwater throughout the Study Area (except beneath the Evaporation Ponds) and, thus, undergo very limited (if any) geochemical attenuation due to mineral precipitation or adsorption to aquifer materials during groundwater transport. Dissolved uranium in Study Area groundwater is predominantly present in complexes with carbonate plus or minus calcium, which reflect oxidizing, carbonate-rich groundwater conditions. Locally, dissolved uranium is also complexed with sulfate in Shallow zone groundwater beneath the Evaporation Ponds where pH is less than 5 and sulfate concentrations exceed 1,500 milligrams per liter (mg/L).

The spatial distributions of elevated concentrations of mobile parameters such as sulfate and uranium are significantly more extensive than the spatial distributions of acidity (as indicated by pH) and metals. The limited spatial extent of low pH values and elevated metal concentrations indicates that geochemical attenuation processes in Study Area groundwater limit the mobility of acidity and metals relative to the more mobile chemicals such as sulfate and uranium (EPA 2007b; BC 2016a, 2016b). Elevated metal concentrations in groundwater correlate strongly with low pH. Geochemical evaluations of groundwater quality data (BC 2016a) also indicate the likely precipitation of solid mineral phases (e.g., jarosite) primarily in the Shallow zone beneath the LEP, UEP, Thumb Pond, and Phase IV HLP. These mineral phases likely represent a potential ongoing source of COIs to groundwater.

Sulfate, uranium and arsenic (and other COIs) occur naturally in groundwater in Mason Valley because of groundwater contact with naturally-mineralized and/or hydrothermally-altered bedrock associated with copper deposits and/or alluvial sediments derived from mineralized bedrock (BC 2009a, 2014b). These regional groundwater conditions, unrelated to mining, affect COI concentrations at two key locations within the OU-1 groundwater Study Area. To the west of the Site and adjacent to the Singatse Range, naturally-occurring arsenic, other COIs, and elevated groundwater temperatures in alluvial aquifer groundwater are associated with subsurface water transmitted along fractures and faults (especially oblique range-front faults such as the Sales Fault).

These faults occur in arsenic-bearing volcanic and granitic bedrock formations that provide conduits for bedrock groundwater to discharge into the overlying alluvial aquifer. In the North Study Area (NSA), which refers to the portion of the OU-1 groundwater Study Area located northeast of West Campbell Ditch and north of the Sunset Hills, naturally-occurring arsenic concentrations as high as 83 micrograms per liter (µg/L) occurs in Deep zone groundwater. The elevated arsenic in this portion of the Study Area is likely related to bedrock discharge to the alluvial aquifer and is not related to agricultural activities that source COIs to the Shallow through Deep 2 zones of the alluvial groundwater, as discussed further below.

Groundwater quality in the NSA is influenced by agricultural activities but not by mining activities (BC 2016b). Multiple lines of evidence (including groundwater flow patterns, chemical distributions, groundwater age estimates, hydrologic tracers, and sulfur isotopes) confirm that groundwater in the NSA has been affected by agricultural practices and not by mining activities, resulting in concentrations of sulfate and uranium that are elevated above background values and/or Maximum Contaminant Levels (MCLs) or exhibit increasing trends.

Monitor well data from the NSA indicate that concentrations of nitrate, sulfate, calcium, uranium, and alkalinity in alluvial groundwater in the Shallow through Deep 2 zones increase along the flow path beneath the agricultural fields. Increases in nitrate are associated with fertilizer application on crop fields. Increases in sulfate and calcium concentrations are associated with application of gypsum ($CaSO_4$) as a soil amendment on crop fields, which dissolves in irrigation water that percolates down to the water table. Increases in uranium concentrations are associated with crop irrigation. Percolation of irrigation water through soils increases alkalinity in the soil moisture, which mobilizes and desorbs naturally-occurring uranium from sediments (as soluble complexes with sulfate, carbonate plus or minus calcium) resulting in elevated uranium concentrations in groundwater (Jurgens et al. 2010; Brown et al. 2007).

Alluvial sediments in the Mason Valley contain naturally-occurring uranium (BC 2009b). The impact of agricultural activities on uranium mobility in NSA groundwater within or near irrigated land is illustrated by the strong correlation between uranium, alkalinity and calcium. Increases in alkalinity and calcium are associated with increases in uranium concentrations that can exceed 100 µg/L. Evaporation of irrigation water derived from surface water and groundwater sources also serves to increase chemical concentrations in water that infiltrates and percolates to the water table.

The extent of mine-impacted groundwater has been defined using sulfate, dissolved uranium, and sulfur isotopes in sulfate because these parameters undergo very limited (if any) geochemical attenuation during groundwater transport and, thus, have traveled the farthest downgradient distance in the alluvial aquifer (BC 2016b). As noted by EPA (2016c), the background assessment conservatively over-estimated the area of mine-impacted groundwater and may not fully account for the range of chemical concentrations that occur naturally in groundwater within the Study Area. Portions of the aquifer where sulfate and uranium exceed background concentrations include: 1) all groundwater zones beneath portions of the Site; 2) Shallow zone groundwater extending north/northwest to the Sunset Hills located approximately three miles north of the Site boundary; and 3) deeper groundwater beneath the Site and extending northeast beneath portions of the Hunewill Ranch. The estimated volume of mine-impacted groundwater (i.e., the portion of the downgradient aquifer where sulfate and uranium exceed background concentrations) is 385,327 acre-feet, and contains an estimated 500,000 tons of sulfate and 100 tons of dissolved uranium.

Bedrock characterization information indicates: 1) a high degree of fracture heterogeneity and vertical hydraulic connection between the bedrock and alluvial groundwater systems; and 2) limited horizontal hydraulic connectivity and transmissivity of bedrock fractures, especially over horizontal distances that are relevant to the scale of the Site and the surrounding Study Area. In addition to a high degree of three-dimensional (i.e., anisotropic) variability in hydraulic characteristics and hydrologic tracer signatures, the bedrock groundwater system also exhibits high, three-dimensional spatial variability in chemical concentrations.

Concentrations of mine-related chemicals in the alluvial aquifer are most elevated in the Shallow zone beneath OU-4a, as noted previously. COI concentrations generally decrease with vertical depth and horizontal distance from the Site sources, resulting in values in bedrock groundwater that are 10 to over 1,000 times lower than the values in overlying alluvial groundwater. In addition, areas of elevated mine-related COIs in bedrock groundwater are small in comparison to the alluvial aquifer, highly localized, and found mostly on-Site.

The localized areas of elevated mine-related COIs in bedrock groundwater indicate that bedrock fractures have limited hydraulic connectivity and transmissivity over horizontal distances relevant to the scale of the Study Area. Despite localized areas of relatively high hydraulic conductivity, bedrock groundwater flow velocities, average volumetric flow rates and chemical fluxes through the bedrock groundwater system are low, and the bedrock groundwater system is not considered to be an important migration pathway at the Site (EPA 2015a). It is however an important source for elevated concentrations of arsenic, originating from bedrock and transported with mountain front recharge over much longer timescales.

Water quality monitoring of domestic, commercial, and irrigation wells (collectively referred to as domestic wells) located near the Site began in late 1983 and evolved over time. Results of domestic well monitoring have been used to: 1) characterize the quality of groundwater used for drinking water or other domestic uses; 2) assess potential risk, if any, to human health and the environment from the use of domestic well water for drinking water or agricultural purposes; and 3) determine eligibility for receiving bottled water as part of an interim response action.

The number of wells/properties included in the domestic well monitoring program (BC 2010) and receiving bottled water was substantially reduced in 2016 (ARC 2016a; EPA 2016f). As part of a settlement entered in the class action lawsuit *Roeder et al. v. Atlantic Richfield Company et al.*, D. Nev., Case No. 3-11-cv-00105-RCJ-WGC ("Roeder Settlement Agreement") ARC provided funding to the City of Yerington to extend municipal water service to then-existing residences located within that part of the settlement class area that was also within the City's projected future service area.

Domestic well owners who connected to the City of Yerington's municipal water system could elect to either abandon their well or apply for a state permit to authorize withdrawals of groundwater for outdoor use only (landscape watering). Each property owner who received a connection to the City Water System executed and recorded an environmental covenant either prohibiting future domestic use of groundwater altogether or limiting it to outdoor purposes. Construction of the expanded water system began in the fall of 2014, and the construction of new mains and service connections was completed in June 2016.

The first phase of well abandonments and system testing was completed as of August 1, 2016. The water system is functional, and domestic wells for all participating property owners have been abandoned or disconnected from the residences within the expansion area. A relatively small number of domestic wells located within the area of mine-impacted groundwater were not disconnected or converted to outdoor use in 2016. ARC has been in communication with the owners of most of these wells, and disconnections for all but a few are scheduled to occur in 2017.

There are no irrigation wells or municipal drinking water wells located within the plume of mine-impacted groundwater that was delineated during the background assessment.

The plume of mine-impacted groundwater is generally stable based on evaluations of changes in the estimated volume of contaminated groundwater, sulfate and uranium masses, and chemical centers-of-mass through time. A more comprehensive plume stability evaluation (including a statistical evaluation of chemical concentration trends in individual monitor wells) will be provided in a separate report. Plume stability is the result of very slow groundwater velocities and attenuation by dilution. The dilution occurs primarily as the result of recharge on the agricultural fields (specifically on the fields of the Hunewill Ranch) and leakage from irrigation ditches (specifically the West Campbell Ditch), and dispersion within the groundwater plume. Consequently, the plume is not currently adversely affecting and is not expected to affect the use of groundwater by agricultural irrigation and municipal drinking water wells. In addition, the plume of mine-impacted groundwater does not discharge to surface water.

SECTION 1.0
INTRODUCTION

Atlantic Richfield Company (ARC) prepared this *Site-Wide Groundwater Operable Unit (OU-1) Remedial Investigation Report* (OU-1 RI Report) pursuant to Section 7.0 of the Scope of Work (SOW) attached to the Administrative Order for Remedial Investigation and Feasibility Study (RI/FS), CERCLA Docket No. 9-2007-0005 (2007 Order) for the Anaconda Copper Mine Site (Site). The 2007 Order (EPA 2007a) was issued to ARC by the U.S. Environmental Protection Agency - Region 9 (EPA) on January 12, 2007. Future work on the OU-1 RI/FS will proceed under oversight by the Nevada Division of Environmental Protection (NDEP) pursuant to the "Interim Administrative Settlement Agreement and Order on Consent for: (i) Remedial Design/ Remedial Action, (ii) Site-Wide Remedial Investigation/Feasibility Study, and (iii) Fluid Management" entered into with NDEP (the IAOC) and the attached Statement of Work for RI/FS.

The term "Site" refers to the area where copper mining activities historically occurred. The Site is located west and northwest of the City of Yerington (Figure 1-1). Figure 1-2 depicts the Study Area boundary for OU-1 and the boundaries for the seven other OUs at the Site that were identified in the 2007 Order. The eight OUs identified in the 2007 Order include:

- Site-Wide Groundwater (OU-1);
- Pit Lake (OU-2);
- Process Areas (OU-3);
- Evaporation Ponds and Sulfide Tailings (OU-4);
- Waste Rock Areas (OU-5);
- Oxide Tailings Areas (OU-6);
- Wabuska Drain (OU-7); and
- Arimetco Facilities (OU-8).

Since the 2007 Order (EPA 2007a), substantial Site characterization activities have resulted in a better understanding of the nature and extent of chemicals of interest (COIs) within the various Site OUs, and the past and/or ongoing impacts to OU-1. Consequently, the EPA approved a subdivision of OU-4 into OU-4a (Evaporation Ponds) and OU-4b (Sulfide Tailings), as well as the transfer of the southern portion of the Calcine Ditch from OU-3 to OU-4a.

The EPA-approved OU-4 subdivision and transfer of a portion of the Calcine Ditch to OU-4a was based on a recognition of: 1) the different types of mine-waste materials in the Evaporation Ponds and Sulfide Tailings; 2) the similarity of mine-waste materials in the Calcine Ditch and portions of the Evaporation Ponds; and 3) the differences in the presence and magnitude of COIs in groundwater underlying the Evaporation Ponds and Sulfide Tailings. This OU-1 RI Report retains the OU-based framework in the 2007 Order (updated to include the EPA-approved restructuring). However, ARC, EPA and NDEP recognize that significant closure efficiencies will likely result from integrating EPA-designated OUs into geographic-based closure management units.

The term "Study Area" refers to on-Site and off-Site areas in which OU-1 RI-related investigations have been conducted. The Study Area boundary is based on the OU-1 hydrogeologic conceptual site model (HCSM) that was described in the EPA-approved *Site-Wide Groundwater Operable Unit (OU-1) Remedial Investigation Work Plan - Revision 1* (Revised Groundwater RI Work Plan; Brown and Caldwell [BC] 2014a).

1.1 Purpose of Report

Consistent with the SOW attached to the 2007 Order (EPA 2007a) and EPA (1988) guidance, this OU-1 RI Report: 1) summarizes activities conducted to "characterize and monitor groundwater in the vicinity of the Site (study area to be determined), including on- and off-Site locations"; 2) describes the nature and extent of mine-related COIs in groundwater; and 3) integrates relevant aspects of other OUs that represent potential sources of chemical loading to groundwater or have the potential to influence groundwater flow conditions. Additionally, this OU-1 RI Report addresses the fifteen study elements specified in Section 7.0 of the SOW (EPA 2007a), which served as the principal bases for RI planning, data collection, and analysis.

Given the complexity of Site-Wide groundwater conditions, several phases of investigations have been approved by EPA and conducted by ARC since 2005. During this time period, ARC, EPA, and other stakeholders including the Yerington Piaute Tribe (YPT), NDEP, and Bureau of Land Management (BLM) have periodically held groundwater technical meetings to discuss field data collection activities, technical findings, and remaining data gaps relative to: 1) the 15 study elements specified in Section 7.0 of the SOW attached to the 2007 Order; and 2) the Data Quality Objectives (DQOs) established in the draft and final versions of the remedial investigation work plans for OU-1 (BC and Integral Consulting, Inc. 2007 and BC 2014a, respectively). Table 1-1 relates the 15 study elements specified in the 2007 SOW to the DQOs presented in the Revised Groundwater RI Work Plan (BC 2014a).

Table 1-1. Comparison of Study Elements Specified in the SOW to the 2007 Order to DQOs Presented in the Revised Groundwater RI Work Plan

DQO	DQO Title	SOW Study Element														
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	Discriminate Background and Mine-Impacted Groundwater		X									X			X	
2	Identify Potential Chemical Loading Sources to Groundwater		X									X		X		X
3	Determine Geochemical Mobilization/Attenuation Processes											X				
4	Characterize Chemical Distribution and Migration Pathways	X						X	X	X	X	X			X	X
5	Determine Aquifer Properties								X				X			
6	Determine Groundwater Flow and Chemical Transport Rates	X	X		X	X	X	X		X	X	X				
7	Assess Anthropogenic Influences on Groundwater and Surface Water/Groundwater Interactions	X	X	X			X									
8	Determine Pumpback Well System Efficiency	X														
9	Assess Human Health and Ecological Effects							X	X	X	X	X		X	X	

Numerous investigations and monitoring activities conducted by ARC and others provide substantial geologic, hydrogeologic, and water quality information relevant to OU-1. However, this OU-1 RI Report relies primarily on data obtained after 2005 to address the study elements specified in Section 7.0 of the SOW, characterize groundwater conditions, and refine the HCSM to support the OU-1 RI/FS. Data obtained after 2005 have been selected for these purposes because: 1) data collection was performed pursuant to EPA-approved quality assurance/quality control (QA/QC) planning documents and OU-1 specific work plans that were developed with input from other stakeholders including the YPT, NDEP, and BLM; 2) the spatial coverage and amount of data increased substantially after 2005; and 3) post-2005 sampling results better represent current conditions and potential risks at the Site, which is the proper focus of the RI and risk assessment.

The August 2014 dataset is emphasized in this OU-1 RI Report for the reasons previously cited and because a variety of data types were concurrently collected (e.g., groundwater level data, groundwater quality data, and hydrologic tracer data) and/or evaluated (e.g., geochemical speciation modeling to help asses COI transport). Consequently, the August 2014 dataset is particularly informative for characterizing spatial aspects of OU-1 groundwater conditions. Temporal aspects of OU-1 groundwater conditions are based on post-2005 data, which indicate that the August 2014 dataset is generally representative of post-2005 groundwater conditions.

Long-term monitoring of Site-wide groundwater conditions is conducted pursuant to the *Site-Wide Groundwater Monitoring Plan - Revision 2* (GMP; BC 2012a), which was prepared by ARC pursuant to Section 6.0 of the 2007 SOW. The development of the monitoring program and a description of the monitor well network are also provided in this OU-1 RI Report.

Potential human health risks will be addressed more comprehensively in a separate OU-1 Human Health Risk Assessment (HHRA) report. This OU-1 RI Report provides the basis for ARC to identify remedial action objectives (RAOs) and screen/evaluate remedial alternatives for OU-1, which will occur during the feasibility study (FS).

1.2 Site and Study Area Description

The Site and Study Area are located in the Mason Valley in Lyon County, Nevada. The Site boundary includes portions of Township 13 North, Range 25 East, Sections 4, 5, 8, 9, 16, 17, 20, and 21 (Mount Diablo Baseline and Meridian) on the Mason Valley and Yerington United States Geological Survey (USGS) 7.5 minute quadrangles. The Site covers approximately 3,017 acres (4.7 square miles) of land altered by copper mining and processing activities. Including the Site, the Study Area covers approximately 19,300 acres (30.2 square miles).

The Mason Valley Basin (Basin no. 108, as defined by the Nevada Division of Water Resources [NDWR]) is located within the larger Walker River Hydrographic Basin (no.9). Mason Valley covers about 510 square miles, and the valley floor occurs at an elevation between 4,300 and 4,700 feet above mean sea level (amsl). The principal agricultural activities in the valley include farming (hay, grain, and onions) and cattle ranching (Lopes and Allander 2009a, 2009b; Carroll et al. 2010). Irrigation water is provided by surface water diversions from the Walker River and from pumped groundwater. The Walker River flows northerly and northeasterly between the Site and the City of Yerington. The river is within a quarter-mile of the southern portion of the Site (Figure 1-1).

1.3 Groundwater Zone Designations

Groundwater zone designations based on elevation have been used in previous groundwater-related reports, as well as this OU-1 RI Report, to identify and group monitor wells with similar screen interval elevations in the alluvial aquifer, as follows:

- Shallow (S): screen intervals that straddle the water table, or are within 50 feet of the water table when a shallower well does not exist, typically >4,300 feet amsl
- Intermediate (I): 4,250 to 4,300 feet amsl
- Deep (D): <4,250 feet amsl; given the thickness of alluvium, the Deep zone is further subdivided as follows:
    - Deep 1 (D1): 4,200 to 4,250 feet amsl
    - Deep 2 (D2): 4,120 to 4,200 feet amsl
    - Deep 3 (D3): 4,000 to 4,120 feet amsl
    - Deep 4 (D4): 3,900 to 4,000 feet amsl
    - Deep 5 (D5): <3,900 feet amsl

Monitor wells with screen intervals in bedrock, regardless of elevation, are designated as bedrock ("B") wells. The groundwater zone designation is included as a suffix to the monitor well identification number (e.g., the "S" suffix in monitor well identification B/W-1S indicates that the screen for this well is positioned in the Shallow zone).

1.4 Report Organization

Consistent with EPA guidance (EPA 1988) and recommendations provided during groundwater technical meetings in 2015 and 2016, the content and organization of this OU-1 RI Report is presented in this section.

Section 2.0 summarizes the Site operation history. Section 3.0 details the investigations related to OU-1 and relevant Site-wide studies and evaluations. Section 4.0 describes the physical characteristics of the Study Area. Section 5.0 describes the background groundwater quality assessment. This assessment served as the basis for determining the extent of mine-impacted groundwater, identifying agriculturally-affected groundwater, and assessing the occurrence of naturally-occurring COIs in groundwater. Section 5.0 also discusses the primary sources of past and/or ongoing releases of mine-related COIs to groundwater. Section 6.0 describes the fate and transport of contaminants in Study Area groundwater. Section 7.0 summarizes the HCSM for OU-1. Section 8.0 discusses the risk evaluation process and status. Section 9.0 lists the references cited in this OU-1 RI Report.

Appendix A provides historical mining-related information including the *Final Historical Summary Report* (HSR; CH2M Hill 2010) and historic Anaconda water supply and use information. Appendix B provides the *Shallow Zone Data Summary Report - Revision 1* (BC 2010a), which refined the distributions of select COIs in Shallow zone groundwater north of the Site and helped guide subsequent monitor well installation efforts. Appendix C presents information on the groundwater monitor wells including lithologic logs, well construction information, and depth-specific (zonal) groundwater quality data obtained during borehole drilling and well installation.

Appendix D presents water level and groundwater quality information. Appendix E provides soil sampling data. Appendix F presents hydraulic conductivity information and analyses. Appendix G presents regional and local surface water data. Appendix H presents hydrologic tracer data and supplemental information. Appendix I presents the *Bedrock Groundwater Assessment Technical Memorandum* (BC 2015a). Appendix J provides various groundwater studies, evaluations, and reports that were conducted to fulfill certain study elements specified in Section 7.0 of the SOW attached to the 2007 Order (EPA 2007a) and have been previously submitted to the EPA. These include an evaluation of the effectiveness of the Pumpback Well System (PWS), a Pit Lake water balance, public information pertaining to agricultural water use, the groundwater flow model report, the *Geochemical Characterization Data Summary Report - Revision 2* (BC 2016a), Site-specific chemical distribution coefficients, and the *Background Groundwater Quality Assessment - Revision 3* (BC 2016b). Appendix K presents maps illustrating the distributions of select COIs (including pH, sulfate, dissolved uranium, alkalinity, nitrate, and dissolved arsenic) in groundwater. Appendix L presents maps illustrating groundwater temperatures.

SECTION 2.0
SITE HISTORY

The following summary of the operational history of the Site paraphrases and/or is derived from the HSR (CH2M Hill 2010), which is provided in Appendix A-1. Topics covered in detail in the HSR include: 1) Site chronology; 2) processing operations utilized by the various owners and operators; 3) historic mine Site water usage and quality information; 4) uses and releases of chemicals; and 5) current Site status since 2000 focusing on removal actions conducted by EPA.

The following discussion focuses on key historic mining practices, releases, and features relevant to the historic and/or current aspects of the HCSM for OU-1. This summary is not intended to comprehensively cover all the information provided in the HSR. Historic mining-related features are shown on Figure 1-2. Historic ore processing facilities located within the Process Areas (OU-3) are shown on Figure 2-1.

2.1 Mining and Processing Operations

Copper in the Yerington district was initially discovered in the late 1860s, with large-scale exploration of the porphyry copper system occurring in the early 1900s when the area was organized into a mining district by Nevada-Empire Copper Mining and Smelting Company. Mining and ore processing operations at the Site were conducted by various owners from 1953 to November 1999.

2.1.1 Anaconda Operations

The Anaconda Company (Anaconda) became involved in the Site when it entered into a lease agreement and acquired the claims in 1941. Anaconda purchased the property in 1951 and the mine began producing copper in 1953, producing approximately 1.7 billion pounds of copper during its operations. Anaconda divested itself of the Site on June 30, 1978. Anaconda mining operations generated approximately 360 million tons of ore, 15 million tons of overburden and waste rock (400 acres), 3,000 acres of tailings, and 1,377 acres of disposal ponds.

Mined materials included oxide ore, sulfide ore, low-grade dump-leach ore, low-grade sulfide ore, and alluvium and waste rock overburden. Several processes were required to extract copper from the ore, as discussed further below. Briefly, all oxide and sulfide ore were crushed prior to leaching or processing in the various plant facilities. Copper was extracted from oxide ore using a sulfuric acid leach solution. The vast majority of leaching was conducted in vat leach tanks. A leach dump was operated over a much shorter period (discussed below). Pregnant copper solutions from the tanks and dump were stored in large solution tanks. Copper extracted from the oxide ore was recovered from the acidic leach solutions in the precipitation plant by precipitating (i.e., cementing) the copper onto iron scraps. A concentration/flotation process was used to extract copper from the sulfide minerals.

Dump Oxide Ore Processing

Crushed oxide ore was bedded into vat leach tanks capable of holding 12,000 dry tons of ore and 800,000 gallons of sulfuric acid leach solution. Spent ore, known as oxide tailings or vat leach tailings (VLT), was excavated from the vat leach tanks and disposed in the Oxide Tailings. The vats typically operated on a 96-hour or 120-hour leaching cycle, with an additional 32- to 40-hour wash period, and 24 hours required to excavate and refill. The entire cycle required approximately 8 days. Thus, eight leach vats were installed and used to process ore.

Following the leaching process, the ore underwent three wash cycles. Acidic leach solutions were recirculated and pumped at a rate of 2,000 gallons per minute (gpm). Copper-enriched wash solutions were put into three of the four open solution storage tanks located between the vat leach tanks and precipitation plant. The three solution tanks used for storing pregnant copper solutions had a total storage capacity of 1.4 million gallons. The additional storage tank, referred to as the wash water sump, stored up to 845,000 gallons of wash water from the leaching circuit, which included slurry from the scrubber in the sulfuric acid plant. Copper was recovered from the leach solution in the precipitation plant, which consisted of the iron launders, solution sumps, an adjacent launder pump station, scrap iron storage, and trommel screens.

The iron launders consisted of 20 parallel launders that were filled with scrap iron used to precipitate (i.e., cement) copper from the sulfuric acid leach solution pumped out of the leach vats and temporarily stored in the solution tanks. The waste product from the precipitation plant was an iron-sulfate solution that was conveyed in unlined ditches (such as the Calcine Ditch) to lined and unlined evaporation ponds in the northern portion of the Site (as further discussed in Section 2.2). Pregnant copper solution from dump leaching activities (discussed below) was also sent to the precipitation plant, but was kept separate from the vat leach solutions. Historical information on flows and chemical concentrations of solutions in various stages of the cementation circuit are provided in Table 2-1. Following cementation, the copper cement product was washed and dried to reduce moisture content prior to shipment off-Site for final smelting (Skillings 1972).

Table 2-1. Average Assay Values of Solutions at Various Stages in the Cementation Circuit

	Flow (gpm)	Cu (g/L)	H_2SO_4 (g/L)	Fe (g/L)	Fe^{3+} (g/L)
Primary and Scavenger Launders					
New Solution	700	20.0	5.8	7.2	5.4
Recirculated Solution	900	3.5	2.4	23.6	0.5 [a]
Total Feed (new solution plus recirculated solution)	1,600	10.7	3.8	16.4	2.6
Discharge	1,600	3.8	2.5	23.2	Trace
Secondary Launders					
Recirculated Solution (feed)	900	3.5	2.4	23.6	0.5
Discharge	900	1.0	2.1	26.4	[b]
Stripping/Settling Launders					
Feed	700	1.0	2.1	26.4	- -
Discharge	700	0.5	2.0	28.1	- -

Notes:
[a] The recirculated solution in the primary launders is the same strength as the recirculated solution in the secondary launders.
[b] The discharge solution in the secondary launders is the same strength as the feed solution to the stripping bank (U.S. Bureau of Mines 1958).
Cu = copper; H_2SO_4 = sulfuric acid; Fe = iron; Fe^{3+} = ferric iron; gpm = gallons per minute, g/L = grams per liter

Dump Leaching

In February 1965, Anaconda began dump leaching low-grade oxide ore in the W-3 Waste Rock Area. Copper-enriched solutions were stored in the Dump Leach Surge Pond (Figure 2-1) prior to conveyance to the iron launders for copper recovery. Copper extraction by heap leaching was in in its infancy at the time and recovery from the W-3 Waste Rock Area was inefficient because there were large quantities of ore that never came into contact with the acid-bearing leach solutions. Due to poor copper recovery, Anaconda ceased dump leaching in 1968.

Sulfide Ore Processing

To process sulfide ore, a froth flotation system was constructed and began operating on September 25, 1961. Flotation separation was accomplished by mixing very finely ground ore (pulp) with water and a chemical "collector" (typically xanthates and aerofloats) to make sulfide minerals hydrophobic, and then sparging air and a surfactant chemical "frother" (typically pine oil) through the mixture to create froth. The collector attaches to the sulfide mineral making it hydrophobic and susceptible to attachment to the stabilized air bubbles in the froth mixture, which was skimmed off as copper concentrate. The concentrate was further beneficiated in a scavenger flotation circuit, dewatered and dried, and subsequently hauled by truck to the Wabuska railroad spur and transported to the Washoe Smelter in Anaconda, Montana (Skillings 1972). Excess pulp after the flotation separation was disposed in the Sulfide Tailings area as a slurry mixture. Operation of the concentrator required approximately 3,000 gpm of water.

Acid Plant

Sulfuric acid was produced at the Site in the fluosolids and acid plant from 1952 to 1978. Raw sulfur ore (predominantly native sulfur and sulfide minerals) was hauled by truck to the Site from the Leviathan Mine located in Alpine County, California until 1962. The fluosolids system roasted the sulfur ore to generate sulfur dioxide (SO_2) gas, which was converted to sulfuric acid (H_2SO_4) in the contact acid plant. In 1962, Anaconda ceased mining sulfur ore from the Leviathan Mine. Between 1962 and 1978, previously stockpiled sulfur ore was blended with liquid sulfur, which was purchased from several suppliers and hauled to the Site where it was used as feed to the Acid Plant to generate sulfuric acid.

The final product was a 93 percent (%) sulfuric acid solution that was used in the vat leach tanks and dump leach of oxide ores. Byproducts such as selenium, were generated during production of sulfuric acid (CH2M Hill 2010). Operation of the sulfuric acid plant was discontinued in 1978 and the plant was dismantled by Arimetco, Inc. (Arimetco) in 1992. For its leaching operations, Arimetco purchased liquid sulfuric acid from off-Site vendors and stored it in tanks at the Site. The Acid Plant and surrounding area has subsequently been buried under the Arimetco Phase III South Heap Leach Pad (HLP).

2.1.2 Post-Anaconda Operations

Subsequent operators and lessees used some of the buildings within the Process Areas for operational support, storage, and various light industrial activities; however, the Anaconda-constructed processing components remained inactive after 1978.

In 1982, Copper Tek Corp. operated the mine under the ownership of Don Tibbals, and leased the Site for reprocessing tailings and low-grade copper ore using heap leaching and solvent extraction/electrowinning (SX/EW) processes in the area to the south of the Process Areas. In 1988, Don Tibbals sold his interests (except for the Weed Heights community and certain other parcels) to Arimetco. Prior to the sale, Arimetco (operating under the name Arizona Metals Company) had leased a large portion of the mine Site from Don Tibbals. By 1989, Arimetco had also acquired 90% of Copper Tek.

2.1.3 Arimetco Operations

From 1989 to November 1999, Arimetco conducted the following SX/EW operations on the Site:

- Phase I/II HLP: operated from 1990 to 1996, plus five months in 1997;
- Phase III South HLP: operated from August 1992 to early 1997, plus a few months in 1998;
- Phase III 4X HLP: operated from August 1995 to 1999;
- Phase IV Slot HLP: operated from March 1996 to November 1998; and
- Phase IV VLT HLP: operated from August 1998 to November 1998.

The HLPs (Figure 1-2) were constructed over high-density polyethylene (HDPE) liners with leak detection systems. The HLPs were leached with a sulfuric acid solution and the acidic, copper-laden draindown fluids were collected in HDPE-lined perimeter ditches, routed to HDPE-lined collection ponds, and conveyed to the SX/EW Plant. The copper-laden acid solution was then stripped of copper in a solvent extraction circuit using a mixture of kerosene and an organic hydroxyamine-based chelating agent (tradename ACORGA) in three process vats (total of approximately 200,000 gallons).

In the SX circuit, the copper in the dump leach liquor was concentrated by the organic in exchange for hydrogen ions producing a strong acid that became the electrolyte for the EW circuit. In the EW circuit, the copper was electroplated to stainless-steel sheets to produce 99.999% fine copper and in the process, additional sulfuric acid was generated. It was this strong acid in the EW circuit that was used to exchange copper from the loaded organic chelating agent.

Arimetco recirculated the acid solution from the EW vats back into the HLPs, which currently continue to drain fluids to the present. The electrolyte circulated between the EW plant and the tail end of the SX plant (called raffinate). The kerosene and organic reagent were also recirculated within the SX/EW circuit, being loaded and stripped repeatedly.

In January 2000, Arimetco, on the verge of bankruptcy and unable to make payroll, abandoned operations at the Site. From 2000 to 2004, NDEP managed HLP drain-down fluids by re-circulation and evaporation. In 2005, ARC was required by EPA to assume responsibility for fluid management operations at the Site. Since 2006, EPA has conducted various RI/FS and closure-related activities associated with the Arimetco Facilities (OU-8).

Inactive Arimetco HLPs that continue to produce drain-down fluids include the Phase I/II HLP, two Phase III HLPs, the Phase IV Slot HLP, and the Phase IV VLT HLP (BC 2014b). HLP drain-down fluids are currently stored and conveyed in a network of ponds, ditches, and 25,000 feet of pipe, collectively referred to as the fluid management system (FMS). The HLPs and associated FMS components are briefly described below. Additional FMS details are provided in annual operation and maintenance (O&M) reports for the FMS (e.g., BC 2014b).

Phase I/II Heap Leach Pads

The Phase I/II HLP covers an area of approximately 14 acres (Phase II was extended to the west and north of Phase I). A solution ditch with eleven leak detection points was constructed around the HLP. A variable two- to ten-foot-thick layer of VLT was placed on a single 40-mil (0.04-inch-thick) HDPE liner. The solution ditch that surrounds the Phase I/II HLPs drained to the Phase I Pond.

Phase III Heap Leach Pads

The 46-acre Phase III South HLP and the 50-acre Phase III 4X HLP were constructed by Arimetco to leach low-grade oxide ores. A single 40-mil HDPE liner was installed by Arimetco to recover drain-down solution, and the drainage ditch was designed with a leak detection system over a second, 40-mil HDPE liner. The solution ditches surrounding the Phase III South HLP and the Phase III 4X HLP drained to the Phase III Bathtub Pond and to the Mega Pond, respectively.

Phase IV Slot Heap Leach Pad

The approximate 86-acre Phase IV Slot HLP was constructed by Arimetco on a pad excavated into the W-3 waste rock dump and an asphalt-lined area, and was expanded northward between 1993 and 1996 on a 40-mil HDPE liner over a secondary liner of compacted clay. This HLP is surrounded by a berm and double HDPE-lined collection ditch with leak detection between the membranes and seven leak detection monitoring points. Drain-down solutions flow to one of two pregnant leach solution (PLS) ponds.

Until late 2003, drain-down solutions were pumped by NDEP from the PLS ponds to the surface of the HLP for evaporation. In 2006, EPA relined the northern Phase IV Slot PLS Pond, and solutions from this pond were routinely conveyed to the FMS Evaporation Pond (also known as the EPA 4-Acre Pond) constructed by EPA in 2007.

Phase IV VLT Heap Leach Pad

The 54-acre Phase IV VLT HLP was constructed by Arimetco on the southern portion of the former finger evaporation ponds, and on native alluvial soils, north of the Oxide Tailings OU, and consists of oxide tailings, and run-of-mine and crushed ore from the MacArthur Mine. The Phase IV VLT HLP was constructed on a 40-mil HDPE liner overlying a secondary liner of compacted clay. The solution drainage ditch includes a leak detection system over a 40-mil HDPE liner designed with five leak detection points, and drains to the northeast corner of the HLP to a single PLS pond (5.04 million-gallon capacity).

Drain-down solutions from the Phase IV VLT HLP flow by gravity to the VLT Pond and, as needed to improve evaporation efficiency of the FMS, are pumped to one of two new FMS Evaporation Ponds (B and C) described below. EPA completed a VLT pond liner replacement project in October 2012 (BC 2014b).

2.2 Evaporation Ponds

From the Process Areas, spent process solutions resulting from the beneficiation of copper oxide and sulfide ores were conveyed in unlined trenches to the lined and unlined evaporation ponds, and ponds in the northern portion of the Site. The evaporation ponds in the northern portion of the Site are identified on Figure 1-2 as the Unlined Evaporation Pond (UEP), the Lined Evaporation Pond (LEP), and the Finger Ponds. The Sulfide Tailings were also used to dispose spent oxide ore process solutions prior to the mining of sulfide ores. A brief description of these ponds follows:

- UEP: consists of a large northern section (98 acres) and a much smaller southern section (4.1 acres) constructed on alluvial soils without a liner surrounded by berms constructed of VLT. The volume of pond sediments contained in the UEP is approximately 270,230 cubic yards based on average thicknesses of approximately 1.5 and five feet in the northern and southern sections, respectively.
- LEP: consists of three sections (North, Middle and South), which were lined with a relatively thin (0.5 to one-inch-thick) liner consisting of a mixture of asphalt tar and crushed gravel. The asphalt liner was placed over one to 2.5 feet of VLT materials. The LEP has a total combined area of approximately 101 acres. The thickness of the pond sediments averages three to six inches, with a maximum measured thickness of approximately 12 inches within the central, topographically lower portion of the LEP. The volume of pond sediments contained in the LEP is approximately 65,800 cubic yards.
- Finger Ponds: consist of four narrow “Finger Ponds” and one larger “Thumb Pond”. The four Finger Ponds (17.8 acres) were lined similar to the LEP without the VLT sub-base. The estimated volume of sediments within the Finger Ponds is 5,838 cubic yards based on an average thickness of four inches. The unlined Thumb Pond has elevated embankments along its north and east margins. The exposed portion of the Thumb Pond (i.e., not covered by the Arimetco Phase IV VLT HLP) covers about 69 acres and was capped in 2010 with VLT materials. The volume of pond sediments contained within the Thumb Pond is 95,000 cubic yards based on an average thickness of 3.5 feet.

In 1955, the flow rate to the evaporation ponds averaged approximately 2,000,000 gallons per day or 1,385 gpm and water quality characteristics of the fluid showed a free acid concentration of 1.0 g/L, total soluble salts concentration of 171 g/L, and total iron concentration of 37.5 g/L (Nesbitt 1955; Dalton 1998).

Infiltration of process solutions at these locations due to increased hydraulic heads associated with impounded fluids, likely raised groundwater elevations and created mounding effects that influenced groundwater gradients, flow directions and velocities, and groundwater quality. Due to the net evaporative character of the Site, significantly less flux (if any) of residual process-related chemicals to groundwater occurs at the Site at present relative to historic periods when the mine facilities were operational. The term "evaporation ponds" used in the following sections refers to the LEP and UEP.

2.3 Historical Mine Site Groundwater Pumping, Distribution and Use

Details of Anaconda's historical groundwater pumping, distribution, and water management at the Site are provided in Appendix A-2 and summarized below.

Mine Site Water

Gill (1951) conducted a groundwater investigation to support open pit mining, and reported that the groundwater table around the proposed open pit was approximately 4,350 to 4,380 feet amsl, with variable water levels a result of bedrock compartmentalization of groundwater. Gill (1951) also reported that most groundwater in the proposed open pit was recharged by the Walker River. Dewatering of the pit in advance of mining operations in the early 1950s resulted in a depressed water table.

Groundwater produced from the pit area wells and other supply wells was primarily used in the beneficiation of copper oxide and sulfide ores in the Process Areas. Pit dewatering ended in 1978. The resulting Pit Lake functions as a hydraulic sink that captures alluvial and bedrock groundwater, as discussed in Section 3.3.2.

Historical Groundwater Pumping and Water Management

The known locations of historic wells used for mining-related activities are shown on Figure 2-2. These wells include those that have been abandoned per the State of Nevada Administrative Codes (NAC) 534.420, 534.4365 or 534.4371 and others that have not been abandoned but are not currently in active use.

Groundwater pumped by Anaconda was used for four general purposes: 1) to depress the water level in the open pit to achieve safe working conditions for mining operations; 2) copper ore beneficiation activities in the Process Areas; 3) residential use at Weed Heights, commonly referred to as the “Townsite” in archived documents (Anaconda 1953, 1955, and 1957); and 4) ancillary operations at the Site (e.g., fire protection, dust control, drilling, blasting, and supply to shops).

Groundwater use was less during the period from 1952 through 1963 when only oxide ores were leached than in the period from 1963 through 1978 when the copper sulfide ore milling circuit was added to the existing copper oxide ore leaching operations, which resulted in an increased demand for groundwater. References in archived documents to the “Plant” generally refer to oxide leaching facilities prior to 1963, and combined copper oxide and copper sulfide ore beneficiation operations after 1963. Groundwater supplies were obtained from four geographic areas: open pit area wells; evaporation area wells; well WW-10 in the Process Areas; and off-Site area wells. Excess pumped water, from pit dewatering activities, was discharged to the Walker River.

Discharge of water to the Walker River peaked in 1953 at 2,373 acre-feet per year, which is equivalent to approximately 1,471 gpm, and generally declined through 1963. At this point, pumped water to the combined Townsite and Plant rose steadily until 1974 at which time it reached 11,388 acre-feet per year (7,058 gpm). There was a general decline in total water pumped during the last four years of Anaconda operations. The annual average pumping rate at the Site ranged from 1,658 gpm in 1978 (the final year of operations) to 7,119 gpm in 1974 (the peak year of water production).

Although the monthly water reports did not specify on-Site water use, some details of water distribution to operational areas are available for 1964 and the first half of 1978 (Table 2-2). In 1964, the Plant received 2,055 acre-feet (45% of total) and the sulfide milling circuit (Concentrator) received 1,511 acre-feet (33% of total).

Table 2-2. Water Distributed to Operational Areas During 1964 and 1978

Operational Area or Use	1964 (acre-feet)	1964 Percent of Total	Jan-Jun 1978 (acre-feet)	Jan-Jun 1978 % of Total
Townsite	455	9.9%	58	4.3%
Roads	51	1.1%	31	2.3%
Leach Vats	2,055	44.7%	271	20.2%
Precipitation Plant	---	---	15	1.1%
Sulfide Concentrator	1,511	32.9%	---	---
Acid Plant	481	10.5%	538	40.1%
Water Discharged to Walker River	46	1.0%	0	---
W-3 Waste Rock Dump	---	---	259	19.3%
Dust System	---	---	169	12.6%
Total	4,600	100%	1,340	100%

Open pit area wells were installed during the period 1952-1954 (WW-1 through WW-7) and in 1959 (WW-36) to dewater the pit, supply water to the Townsite, and supply water for copper oxide ore beneficiation. During July 1955, the combined flow from six of the open pit area wells was estimated to be 2,454 gpm, and the total demand was 2,553 gpm. The use of recycled process water during this period made up for the approximate 100 gpm difference. In 1966, combined demand at the Plant and Townsite was 2,600 gpm.

Evaporation area wells were installed during the period 1959-1961 (WW-8, WW-9 and WW-11) and in 1965 (WW-12C) to provide the required make-up water (i.e., approximately 1,000 gpm) for the Sulfide Concentrator, which began operation in 1963. Based on 1964 monthly water reports, evaporation area wells had a combined pumping rate that ranged from 442 to 1,390 gpm with an annual average rate of 690 gpm. Well WW-10 was installed in the Process Areas in 1960 to provide additional water for the copper oxide and copper sulfide ore beneficiation operations.

Per the well log on file with the NDWR, the well was drilled to a depth of 610 feet, and penetrated 200 feet of alluvial materials before reaching bedrock. At that time, the depth to groundwater was 100 feet below ground surface (bgs). The well casing was perforated from 105 to 505 feet bgs, resulting in about 95 feet of alluvial materials and 305 feet of bedrock that could yield groundwater. When tested for two hours at a rate of 595 gpm, WW-10 exhibited a drawdown of 81 feet (close to the alluvium-bedrock contact).

Historical pumping records for WW-10 are limited. Table 2-3 summarizes 1964 monthly water reports for well WW-10. The monthly pumping rate was calculated by dividing the monthly volume by the number of days in each month and the number of minutes in each day. The pumping rate ranged from 102 gpm in January 1964 to 254 gpm in October 1964, with an average annual rate of approximately 169 gpm for the 10 months with pumping data.

Table 2-3. 1964 Monthly Pumping Volumes and Rates for Mine-Water Supply Well WW-10

Month, 1964	Volume Pumped (cu ft)	Volume Pumped (gal)	Average Pumping Rate (gpm)
January	606,470	4,537,000	102
February	NA	NA	NA
March	NA	NA	NA
April	1,135,410	8,494,000	190
May	1,230,851	9,208,000	206
June	1,329,595	9,946,700	223
July	1,134,621	8,488,100	190
August	1,362,839	10,195,400	228
September	1,227,109	9,180,000	206
October	1,514,771	11,332,000	254
November	1,220,291	9,129,000	205
December	1,139,420	8,524,000	191
Annual Values	11,901,377	89,034,200	169

NA = not available; cu ft = cubic feet; gpm = gallons per minute; gal = gallons

Groundwater quality samples were obtained from WW-10 from August 1991 to June 2006. From August 1991 through 1994, at least three samples were collected during each year. From 1995 through June 2006, samples were collected quarterly. Not all parameters were monitored in each sampling event. Results for sulfate, uranium and arsenic are discussed below.

Concentrations of sulfate in the 49 samples collected from August 1991 to June 2006 ranged from 457 to 2,485 milligrams per liter (mg/L). Concentrations of uranium in the 10 samples collected from September 2003 to June 2006 ranged from 190 to 310 micrograms per liter (µg/L). From August 1991 to June 2006, 95% (i.e. 35 of the 37) reported arsenic results were less than or approximately equal to the laboratory analytical reporting limits. Laboratory reporting limits for arsenic were commonly higher (i.e., 25 µg/L) during the early part of the monitoring history and lower (as low as 4 µg/L) during the latter part of the monitoring history. In September and October 1991, arsenic concentrations were reportedly 1,040 and 3,475 µg/L, respectively. The arsenic results for these two sampling events are inconsistent with and three orders of magnitude greater than the results for the other 35 sampling events.

2.4 Pumpback Well System

The PWS and associated monitor wells were constructed under an Administrative Order on Consent issued by NDEP on October 1, 1985. ARC operated the PWS located along the northern margin of the Site to collect shallow groundwater beginning in March 1986 (Piedmont 2001). The initial PWS consisted of five extraction wells (PW-1 through PW-5; see Figure 3-3) and a clay-lined 23-acre evaporation pond for containment of extracted groundwater.

In 1998, six additional extraction wells (PW-6 through PW-11; see Figure 3-3) were installed and operated as part of the PWS. Other improvements to the PWS included partitioning the 23-acre evaporation pond into three cells and installing an HDPE liner on top of the clay liners in the middle and south cells to protect the clay liners from desiccation during the summer dry season. No HDPE liner was placed on the north cell.

The pumpback wells are approximately 40 to 60 feet deep and are spaced at intervals ranging from approximately 380 feet (PW-2 to PW-3) to 1,400 feet (PW-5 to PW-6). Prior to March 25, 2009, the PWS operated continuously (i.e., 24 hours per day, 7 days per week), with individual wells temporarily taken off-line for maintenance and repairs of pumps and related equipment. For example, in 2006, individual well production rates ranged from 0.5 to 16.7 gpm with a total combined pumping rate of 56.4 gpm. Approximately 29.7 million gallons (91.1 acre-feet) of groundwater were pumped from the Shallow zone in 2006 (Norwest Applied Hydrology 2007).

EPA approved the shutdown of the PWS on March 25, 2009 to allow for a characterization of groundwater conditions at the northern Site margin. Subsequently, the pumpback wells were used as part of an aquifer test to characterize hydraulic properties of the Shallow zone (ARC 2010). The test data were used to: 1) delineate the hydraulic capture zones of the PWS; and 2) assess the historical effectiveness of the PWS in limiting the off-Site migration of Shallow groundwater. The PWS evaluation is discussed in Section 3.3.1. Since completion of hydraulic testing, the PWS has been shut down and wells PW-1 to PW-11 have been monitored pursuant to the Groundwater Monitoring Plan (GMP) (BC 2012a).

2.5 Wabuska Drain

The Wabuska Drain is a 13.8-mile long unlined ditch that extends from the Site to the Walker River. The grade of the Wabuska Drain between the Site and the southern margin of the YPT Reservation is approximately 0.15% over 4.1 miles. The grade increases to about 0.16% along the 1.1-mile length within the YPT Reservation. From the northern margin of the YPT Reservation to its intersection with the Walker River, the average grade is approximately 0.04% (BC 2015b). Adjacent surrounding agricultural fields slope gently toward the Wabuska Drain, or connect to the drain through lateral ditches that feed into the drain by gravity flow. The drain was constructed in the late 1930s, when the regional groundwater table was higher, to intercept shallow groundwater to stabilize areas north of the Site adjacent to the tracks of the former Nevada Copper Belt Railroad and several farms. The Wabuska Drain alignment near the Site has changed over time (BC 2015b; CH2M Hill 2010), as shown on Figure 2-3. Portions of these former alignments are now buried beneath the Evaporation Ponds and the Hunewill Ranch agricultural fields.

Currently the drain functions as one of many irrigation return-flow ditches in the northern Mason Valley. These drains collect irrigation tail water and run-off from agricultural fields, and convey water to downgradient agricultural areas for further irrigation uses and/or discharge to the Walker River (CH2M Hill 2010).

Historically, the Wabuska Drain alignments near the Site intercepted shallow groundwater (CH2M Hill 2010). However, the various drain alignments near the Site no longer intercept shallow groundwater due to basin-wide groundwater level declines (Section 4.9). In the northern part of the Wabuska Drain, inputs also include intercepted shallow groundwater and deeper water associated with alluvial groundwater discharge and geothermal springs that coincide with a series of northwest trending faults referred to as the Wabuska lineament (Stewart 1988). Other potential past and/or current inputs include discharges from, or groundwater influenced by, the Thompson smelter and various geothermal power production activities.

Details regarding the Wabuska Drain are provided in the HSR (CH2M Hill 2010; Appendix A-1). Results of the ongoing RI for the Wabuska Drain will be reported separately. Available data indicate that concentrations of mine-related chemicals decrease with distance from the Site and depth in the soil profile (EPA 2007a, BC 2015b).

SECTION 3.0
GROUNDWATER INVESTIGATIONS AND RELATED STUDIES

Numerous investigations and monitoring activities conducted prior to 2005 have provided substantial geologic, hydrogeologic, and water quality information pertaining to OU-1. These pre-2005 activities were primarily associated with a limited number of monitor wells (having screens positioned across the water table) located around the northern Site margin. Sampling methods and the quality of laboratory analytical results prior to 2005 were not well documented.

Pre-2005 investigations and reports for the Site and surrounding area are summarized in Section 3.1. Post-2005 investigations and reports performed and/or prepared by ARC are summarized in Section 3.2. Pre-2005 data are used to address historical aspects of the HCSM because historical conditions (e.g., groundwater elevations and flow directions) were different from current conditions due to mine operations, agricultural activities, groundwater and surface water usage, and weather conditions (BC 2014a). Historical aspects of the HCSM are generally more qualitative relative to aspects of the HCSM developed using data collected after 2005 because the historical data are typically limited (especially with respect to spatial coverage) and data quality is often not well documented.

Since 2005, numerous investigations and monitoring activities have been conducted by ARC with EPA and stakeholder involvement, and the sampling methods and quality of the laboratory analytical results since 2005 have been well documented. A draft Quality Assurance Project Plan (QAPP) that included standard operating procedures (SOPs) for sampling and field data collection methods was prepared in 2003 to establish and implement strict QA/QC procedures and, subsequently, was periodically revised to result in the current *Quality Assurance Project Plan - Revision 5* (Environmental Standards, Inc. [ESI] and BC 2009). Other QA planning documents that were prepared pursuant to the 2007 Order included the: 1) *Data Management Plan for the Yerington Mine Site* (BC 2007a); 2) GMP (BC 2012a); and 3) EPA-approved work plans specific to OU-1.

3.1 Pre-2005 Investigations

Investigations and reports relevant to the OU-1 Study Area that were conducted prior to 2005 are provided below, generally listed in chronological order:

- Gill, D.K., 1951. Groundwater at the Yerington Mine, Lyon County, Nevada, a consultant report prepared for The Anaconda Company that describes the results of aquifer testing, and provides projections of groundwater inflows and dewatering rates for the open pit.
- Huxel, C.J., Jr. and E.E. Harris, 1969. Water Resources and Development in Mason Valley, Lyon and Mineral Counties, Nevada, 1948-1965, NDWR Bulletin No. 38 prepared in cooperation with the USGS. This is a comprehensive hydrologic study of the Mason Valley area including water budgets and effects of agriculture on surface water and groundwater quality and quantity.
- Seitz, H., A.S. Van Denburgh, and R.J. La Camera, 1982. Ground Water Quality Downgradient from Copper Ore Milling Wastes at Weed Heights, Lyon County, Nevada, USGS Open File Report 80-1217. This study presents hydrologic and geochemical data on the effects of mining on groundwater quality from several monitor wells, most of which are no longer operational.
- Applied Hydrology Associates (AHA), 1983. Evaluation of Water Quality and Solids Leaching Data, a consultant report prepared for Anaconda Minerals Company. This report includes surface water and solids leaching data in addition to groundwater sampling data that are compared to the data reported by Seitz et al. (1982).
- Anaconda Minerals Company, 1984. Water Quality Investigation and Mitigation Plan, Yerington Mine Site, Yerington, Nevada, a report prepared for NDEP that summarized additional field data and groundwater conditions north of the Site.
- Proffett, J.M., Jr., and J.H. Dilles, 1984. Geologic Map of the Yerington District, Nevada, Nevada Bureau of Mines and Geology, Map 77.
- Nork, W., 1989. MacArthur Project Hydrogeologic Investigation, Lyon County, Nevada, a consultant report prepared for MacArthur Mining and Processing Co. that describes the general hydrogeologic conditions associated with a proposed project to develop an open pit mine located to the northwest of the Site.
- Dalton, D., 1998. *Arimetco Yerington Mine and Process Facility Site Assessment of Groundwater Quality*, a consultant report prepared for Arimetco for submittal to NDEP in response to NDEP's Finding of Alleged Violation and Order of February 1997.
- Lewis, B., 2000. *Geophysical Survey Results of the Yerington Mine, Mason Valley, Nevada*, a BLM report on electro-magnetic and resistivity surveys north of the Site.
- Superfund Technical Assessment and Response Team (START), 2000 and 2001. *Expanded Site Inspection: Yerington Mine* and *Anaconda, Yerington Mine Site Emergency Response Assessment Final Report,* reports prepared for the EPA that describe Site conditions including groundwater quality.

- Piedmont Engineering, Inc., 2001. *Yerington Shallow Aquifer Data Evaluation Report*, consultant prepared for ARC. Interpretations of data presented in this report related to the nature and extent of mine-impacted groundwater.
- AHA and Norwest Applied Hydrology, 2000 through 2007. *Annual Monitoring and Operation Summary: Pumpback Well System, Yerington Nevada*, annual consultant reports prepared for ARC. These reports provide groundwater elevation and water quality data for the pumpback system and associated monitor wells. The reports also include pumping rates and time-concentration plots for select chemicals.
- Brown and Caldwell, 2002. *Installation of Two Monitor Wells at the Yerington Mine Site, Lyon County, Nevada.* This letter report described the drilling and well construction activities of two monitor wells, which was an interim action required by NDEP, EPA, and BLM.

3.2 Post-2005 Investigations

A generalized chronology of the phased, groundwater-related field investigations conducted since 2005 is provided in Figure 3-1. The following subsections describe the post-2005 investigations and related evaluations by media. Groundwater characterization activities largely involved monitor well installation. Monitor wells installation procedures are described in Section 3.2.1. After installation, initial sampling and testing for OU-1 characterization purposes, these wells were subsequently incorporated into the Site-Wide Groundwater Monitoring Program, which is described in Section 3.2.3.

3.2.1 Monitor Well Installations

Recognizing that groundwater characterization activities would largely involve monitor well installation, ARC and EPA adopted the following sequential approach to field data collection to maximize usable data and optimize the design of a monitor well network intended to serve the data needs for both OU-1 RI characterization and long-term Site-Wide groundwater monitoring.

- Borehole drilling using a roto-sonic core drilling rig and lithologic logging of continuous cores to identify coarse-grained or potentially transmissive intervals where chemicals could potentially migrate.
- Depth-specific (zonal) groundwater sample collection in the alluvial aquifer at nominal 20-foot intervals from the top of the water table to the target depth of each borehole using low-flow, minimal drawdown purging and sampling procedures approved by EPA.

- Collection of field measurements from zonal samples including pH, specific conductivity, temperature, dissolved oxygen (DO), oxidation-reduction potential (ORP), sulfate, alkalinity, and total and ferrous iron, using routinely-calibrated field meters and accuracy-checked water quality field test kits.
- Laboratory analyses of zonal samples for total and dissolved uranium, total and dissolved arsenic, total organic carbon (TOC), and uranium isotopes (^{234}U, ^{235}U, and ^{238}U).
- Based on the zonal groundwater sample results, construction of new monitor wells in various groundwater zones using methods and materials specified in EPA-approved SOPs and work plans, with EPA approval of well screen lengths and positions.
- Surveying of well location coordinates and reference point elevations, followed by measurement of groundwater elevations in all new and existing monitor wells.
- Hydraulic (slug) testing of monitor wells and analysis of hydraulic test data.
- Deployment of pressure transducers and data loggers in select monitor wells with EPA approval to collect groundwater elevation data at four-hour intervals and assess temporal water level fluctuations.
- Collection of hydrologic tracers from monitor wells.
- Incorporation of the new monitor wells into the GMP (BC 2012a), discussed below in Section 3.2.3.

In total, the groundwater RI characterization activities described above resulted in drilling 133 boreholes, logging approximately 33,000 linear feet of core, collecting and analyzing 624 zonal groundwater samples, installing 299 new monitor wells, and hydraulic (slug) testing 296 wells. Appendix C provides monitor well information including: 1) borehole lithologic information and well construction diagrams; 2) well construction and location information for the active monitor wells; 3) construction information for abandoned and inactive wells not used for routine groundwater monitoring; and 4) zonal groundwater sample results.

The various investigations involving monitor well installations are integrated into the discussion of the Site-Wide groundwater monitoring program in the following section. Appendix D provides OU-1/Site-Wide groundwater monitoring information including water level and chemical data, water-level hydrographs, charts illustrating temporal changes in vertical gradients at monitor well clusters, and charts illustrating temporal changes in chemical concentrations at monitor wells.

3.2.2 Shallow Zone Groundwater Investigation

The 2009 Shallow zone investigation is detailed in the *Shallow Zone Data Summary Report - Revision 1* (BC 2010a; Appendix B) and summarized below. The Shallow zone investigation was designed to improve the understanding of hydrogeologic and geochemical conditions in the Shallow zone of the alluvial aquifer to the north of the Site by refining the distributions of sulfate, uranium, uranium isotopes, dissolved metals, TOC and alkalinity in Shallow zone groundwater. This information was used to evaluate potential sources of chemicals in groundwater in this portion of the Study Area and identify portions of the Intermediate or Deep zones in the alluvial aquifer that would warrant the installation of monitor wells.

Shallow zone characterization activities during 2009 included:

- Direct push technology (DPT) with Geoprobe® equipment was used to obtain continuous, high-resolution electrical conductivity (EC) measurements of subsurface materials at 93 locations. EC profiling was initially conducted at four locations (OU1-DPT-18, OU1-DPT-40, OU1-DPT-16, and OU1-DPT-24) where lithologic logging and zonal sampling had been previously conducted during borehole drilling and well installation at the B/W-2, B/W-3, B/W-18, and USGS-13S/W32DC-D well clusters, respectively, and one location (OU1-DPT-13) where geophysical logging had been conducted in 1983 (W5AB-2). This comparison was intended to help correlate EC data with clays and/or elevated solute concentrations in groundwater. In addition, EC data were also used to make decisions regarding the number and depths of sampling intervals at each individual DPT location.
- Field parameters were measured in groundwater samples collected from the sampled intervals within the Shallow zone including pH, specific conductivity, temperature, sulfate and total alkalinity (alkalinity) using routinely-calibrated field meters and accuracy-checked water quality field test kits.
- DPT equipment was used to collect groundwater samples at each location from as many as three intervals within the Shallow zone, and samples were submitted to the analytical laboratory for chemical analyses including total and dissolved uranium, TOC, 28 metals, uranium isotopes, and sulfur and oxygen isotopes in dissolved sulfate at EPA-selected locations.
- DPT locations were surveyed by a registered Nevada surveyor.
- Upon completion of EC profiling and/or groundwater sample collection, all boreholes were abandoned in compliance with Nevada regulatory requirements.

In 2010, DPT equipment and identical sample collection methods were used at 10 additional locations to obtain groundwater samples for laboratory analysis (BC 2013a). EC profiling was not conducted during the 2010 investigation. Both the 2009 and 2010 DPT locations are shown on Figure 3-2. Chemical distributions in the Shallow zone of the alluvial aquifer are shown on figures provided in Appendix B and are described as follows:

- The highest concentrations of major ions and metals (e.g., aluminum, copper, iron, manganese, nickel, vanadium and zinc) and uranium in the Shallow zone were typically detected beneath the central portion of the UEP, and the south-central and north-central portions of the LEP. Low pH values occur beneath the LEP and UEP. Alkalinity was depressed or non-detectable beneath the UEP. Elevated alkalinity (e.g., >500 mg/L) occurred down-gradient of the Weed Heights sewage lagoons.
- The high chemical concentrations beneath the evaporation ponds decrease laterally by varying orders of magnitude because of past and current physical and chemical attenuation processes. West of the LEP, concentrations of sulfate, other mobile chemicals, and metals decrease rapidly with distance from the Site. To the east beneath the agricultural fields, chemical concentrations are generally lower than other locations beneath or near the Site. Localized occurrences of elevated concentrations of select constituents in groundwater samples were observed from sample locations on the agricultural fields and included: alkalinity, manganese, molybdenum, nickel, potassium, selenium, sodium, uranium, vanadium, and zinc.

  The distribution of dissolved (i.e., filtered) uranium in the Shallow zone is generally consistent with the distribution of many other Site chemicals in that: 1) the highest concentrations occur beneath the central portion of the UEP, and the south-central and north-central portions of the LEP; 2) elevated concentrations extend beyond the Site boundary along a northwest alignment from the Evaporation Ponds; and 3) elevated chemical concentrations beneath the Evaporation Ponds decrease laterally by varying orders of magnitude. However, there are important differences that suggest that alkalinity and calcium influence the mobility/attenuation of uranium. Uranium concentrations rapidly decrease laterally to the west, similar to other chemicals, but do not decrease as rapidly to the east beneath the irrigated agricultural fields. Elevated concentrations of uranium in DPT locations including OU1-DPT-41, OU1-DPT-42, OU1-DPT-46, OU1-DPT-49, OU1-DPT-61, and OU1-DPT-72 are roughly coincident with: 1) the areas of locally high concentrations of alkalinity (over 300 mg/L) in Shallow zone groundwater at the northwest and northern edge of the agricultural fields; and 2) high calcium concentrations to the northwest of the agricultural fields and general widespread distribution of calcium throughout the agricultural fields.

- The distribution of arsenic in Shallow zone groundwater differs from the distributions of the parameters and chemicals described above. The highest concentrations of arsenic were detected in Shallow zone groundwater at OU1-DPT-23 (up to 620 ug/L), OU1-DPT-28 (up to 580 ug/L), and other nearby locations, which are located approximately 3,000 to 3,500 feet north of the Evaporation Ponds. Beneath the Evaporation Ponds, arsenic concentrations were much lower and typically ranged from approximately 10 to 160 ug/L. In this area, the lowest arsenic concentrations in Shallow zone groundwater occur along a northwest trend from the Weed Heights sewage lagoons. To the west of the LEP, arsenic occurs in Shallow groundwater at concentrations at or slightly above 50 ug/L.

3.2.3 Site-Wide Groundwater Monitoring Program

Groundwater monitoring in the Study Area has evolved over time in response to regulatory requirements and incorporation of new wells installed during the OU-1 RI. Currently, long-term Site-Wide groundwater monitoring is conducted in accordance with the GMP (BC 2012a) and EPA-approved modifications listed in Table 3-1. Provided below is a summary of the: 1) development of the monitoring program; 2) current active monitor well network; 3) water level monitoring activities; and 4) groundwater quality monitoring activities.

Monitoring Program Development

Table 3-1 provides a chronological summary of groundwater characterization and monitoring activities at the Site and the evolution of the monitor well network over time.

Table 3-1. Chronology of Groundwater Characterization and Monitoring Activities

Date	Activity
1976-1982	The USGS conducted groundwater investigations north of the Site boundary, which culminated in a report entitled: *Ground-water quality down-gradient from copper-ore milling wastes at Weed Heights, Lyon County, Nevada* (Seitz et al. 1982).
1982-1985	1982 – An NDEP Order required groundwater investigations near the Sulfide Tailings and Evaporation Ponds, and initial groundwater monitoring. 1985 – An NDEP Order required construction of the PWS and performance of associated O&M and groundwater monitoring activities.
1997	An NDEP Order was issued that required Arimetco to conduct groundwater investigations and monitoring of the Site, requesting both a complete hydrogeological assessment for the Yerington Mine (including existing and projected Pit Lake conditions), and a facility assessment to identify all areas where constituent concentrations in groundwater exceed the drinking water standards or background.
1999	Implementation of a Geoprobe® investigation of Shallow zone alluvial aquifer conditions north of the Site, which consisted of collecting 29 samples from 18 locations (AHA 2000).
2002	Two groundwater monitor wells, MW-2002-1 (subsequently re-named B/W-2S) and MW-2002-2, were installed (BC 2002) under an interim action directed by NDEP.
2004	Several groundwater characterization boreholes were drilled to collect groundwater grab samples, and three groundwater monitor wells were installed in the Process Areas, pursuant to the *Final Draft Process*

Table 3-1. Chronology of Groundwater Characterization and Monitoring Activities

Date	Activity
	Areas Work Plan (BC 2003).
2005	Implementation of the *First-Step Hydrogeologic Framework Assessment* (HFA; BC 2005) under the Unilateral Administrative Order (UAO) issued by EPA for Initial Response Activities, EPA Docket No. 9-2005-0011, including the installation of the first phase of B/W wells.
2007-2008	Implementation of the Second-Step HFA (BC 2007b) included a second phase of well installations, and the preparation of OU-specific work plans that describe additional on-Site monitor well installations under the 2007 Order. ARC submitted the *Draft Site-Wide Groundwater Monitoring Plan* (BC 2007c).
2008	Monitor well identification numbers modified to include a suffix designating the groundwater zone in which the well screen is positioned, including the Shallow, Intermediate, Deep and bedrock zones.
2008	EPA approved the elimination of well MW-1S from the monitoring network due to an obstruction well.
2008	Collection of groundwater grab samples and groundwater levels beneath the Anaconda Evaporation Ponds pursuant to the *Anaconda Evaporation Ponds Removal Action Characterization Work Plan* (BC 2008a).
2009	-Shutdown of the pumpback wells on March 25, 2009 with EPA approval. -Implementation of activities pursuant to the *Pumpback Well System Characterization Work Plan* (ARC 2008) including: 1) installation of nine groundwater monitor wells north of the PWS and the LEP; and 2) pumpback well aquifer testing pursuant to the *PWS Characterization Work Plan Addendum - Revision 2* (ARC 2010), which was performed in 2010. - Implementation of activities pursuant to the *Shallow Alluvial Aquifer Characterization Work Plan for Northern Portion of the Yerington Mine Site* (BC 2008b). -EPA approved the QAPP - Revision 5 dated May 20, 2009 (ESI and BC 2009), which contains SOPs for groundwater monitoring. -Implementation of a separate Domestic Well Monitoring Plan (BC 2010b) as a revision to the QAPP per EPA direction. The Domestic Well Monitoring Plan and related Bottled Water Program are discussed further in Section 3.4. -ARC submitted the *Site-Wide Groundwater Monitoring Plan - Revision 1* (BC 2009a).
2010-2011	Installation of 123 wells per the *2010 Groundwater Monitoring Well Work Plan - Revision 2* (BC 2010c) and the *Agricultural Fields Characterization Work Plan - Revision 2* (BC 2010d).
2011	-Installation of 58 wells per the the *On-Site Monitor Well Installation Work Plan - Revision 1* (BC 2011a). -Aquifer testing of an agricultural well (WDW019) north of the Site, including a 96-well observation network, pursuant to the *Aquifer Test Work Plan - Revision 1* (BC 2011b).
2012	Submittal of the *Site-Wide Groundwater Monitoring Plan - Revision 2* (BC 2012a). Addition of new well YPT-MW-15I to the monitoring program in November 2012.
2013	-Installation of 58 monitor wells per the *Additional Monitor Well Work Plan - Revision 1* (BC 2013b). -Addition of five EPA Arimetco wells, nine YPT wells, and the one MacArthur mine well (MMW-2) to the monitoring program after the 4Q 2011 event. -EPA (2013a) approved of eliminating well USEPA2S from the active monitor well network. EPA (2013b) approves of abandoning well USEPA2S and eliminating the following five metals from the analyte list for wells having at least four quarters of data: lead, silver, thallium, tin, and titanium. EPA (2013b) also approved of reducing the sampling frequency of 118 wells from quarterly to semi-annually, with sampling to be conducted in the first and third quarters of subsequent years.
2014	-EPA (2013c) approved the abandonment of well B/W-14S and the well was abandoned in January 2014. -Well USEPA2S was abandoned in April 2014 and was moved from the inactive to abandoned well list. -ARC submitted the *Technical Memorandum: Site-Wide Groundwater Monitoring Optimization* (ARC 2014) proposing several modifications to the GMP (BC 2012a). -EPA approved of reducing the frequency of manual water level monitoring in wells installed before 2013 from monthly to quarterly, to coincide with the quarterly sampling events (EPA 2014a). EPA also approved reducing the frequency of collecting groundwater samples from wells installed before 2013 for nitrate analysis from quarterly to semi-annually, with sampling to be conducted in the first and third quarters of subsequent years (EPA 2014a).
2015	Installation of six additional monitor wells (B/W-63 cluster) in the third quarter of 2015 (3Q 2015), pursuant to the *Additional Monitor Well Work Plan - Revision 1* (BC 2013b). Initial water level monitoring and sampling of these six wells in 4Q 2015.

The network development detailed in Table 3-1 included the addition and elimination of monitor locations as summarized in Table 3-2.

Table 3-2. Inventory of Monitor Well and Piezometer Locations (2007 - 2015)

Date (Through)	Total (1)	Monitor Wells and/or Piezometers	Pumpback Wells
2007	87	76	11
2008	101	90	11
1Q 2009	110	99	11
2Q 2009	114(2)	103(2)	11
3Q 2009	114(2)	103(2)	11
4Q 2009	114(2)	103(2)	11
1Q 2010	114(2)	103(2)	11
2Q 2010	114(2)	103(2)	11
3Q 2010	114(2)	103(2)	11
4Q 2010	114(2)	103(2)	11
1Q 2011	237(3)	226(3)	11
2Q 2011	237(3)	226(3)	11
3Q 2011	237(3)	226(3)	11
4Q 2011	242(4)	231(4)	11
1Q 2012	309(5)	298(5)	11
2Q 2012	309(5)	298(5)	11
3Q 2012	309(5)	298(5)	11
4Q 2012	310(6)	299(6)	11
1Q 2013	309(7)	298(7)	11
2Q 2013	309(7)	298(7)	11
3Q 2013	309(7)	298(7)	11
4Q 2013	309(7)	298(7)	11
1Q 2014	308(8)	297(8)	11
2Q 2014	325(9)	314(9)	11
3Q 2014	354(10)	343(10)	11
4Q 2014	354(10)	343(10)	11
1Q 2015	354(10)	343(10)	11
2Q 2015	354(10)	343(10)	11
3Q 2015	360(11)	349(11)	11
4Q 2015	360(11)	349(11)	11

Notes:

1) Total does not include domestic/supply wells that were part of the network until 2010. Total does include the eleven pumpback wells.
2) Includes four Lyon County wells.
3) Includes four Lyon County wells and 123 wells installed in 2010/2011.
4) Includes four Lyon County wells, 123 wells installed in 2010/2011, and five EPA Arimetco wells (sampled in 3Q 2011 and added to the monitoring program after the 4Q 2011 event).

5) Includes four Lyon County wells, 123 wells installed in 2010/2011, 58 wells installed in 2011/2012, five EPA Arimetco wells, eight YPT wells (excluding YPT-MW-7), and one MacArthur mine well (MMW-2). Prior to 1Q 2012, these wells were or may have been sampled; however, sample collection methods were either inconsistent with EPA-approved sample collection methods or were not documented.
6) Includes four Lyon County wells, 123 wells installed in 2010/2011, 58 wells installed in 2011/2012, five EPA Arimetco wells, nine YPT wells (including new well YPT-MW-15I in November 2012), and one MacArthur mine well (MMW-2).
7) With EPA approval, well USEPA2S moved to inactive well list in March 2013, subsequently proposed for abandonment in August 2013, and abandoned in April 2014.
8) With EPA approval, well B/W-14S was abandoned in January 2014.
9) Includes 17 wells installed in 2013/2014 and first sampled in 2Q 2014.
10) Includes 29 wells installed in 2013/2014 and first sampled in 3Q 2014.
11) Includes six wells (B/W-63 cluster) installed in 3Q 2015 and first sampled in 4Q 2015.

Active Monitor Well Network

The active monitor well network included 360 wells at 170 locations: 133 wells in the Shallow zone, including 11 PWS wells formerly used for groundwater extraction (currently in shutdown mode); 55 wells in the Intermediate zone; 105 wells in the Deep zone; and 67 bedrock wells (Table 3-3 and Figure 3-3). Of the 360 monitor wells, seven are used only for water level measurements, and the remaining 353 are monitored for both water levels and water quality.

A generalized cross-section that depicts alluvial monitor well screen intervals and groundwater zone designations for active wells within the monitoring network is presented in Figure 3-4. A generalized cross-section that depicts bedrock monitor well screen intervals is presented in Figure 3-5. All monitor wells in the network were surveyed by a Nevada-registered surveyor. Project datum is Nevada State Plane West Zone coordinate system (NAD27).

Table 3-3. Well Construction Details for the Active Groundwater Monitoring Network

Well Name (1)	Completion Date	Groundwater Zone	Well Type	Well Screen Interval
				feet amsl
Pumpback Wells				
PW-1S	10/1/85	Shallow	Sampling	4335.02 - 4312.52
PW-2S	10/1/85	Shallow	Sampling	4335.73 - 4315.23
PW-3S	10/1/85	Shallow	Sampling	4333.88 - 4313.38
PW-4S	10/1/85	Shallow	Sampling	4331.48 - 4311.98
PW-5S	10/1/85	Shallow	Sampling	4334.23 - 4313.73
PW-6S	10/21/98	Shallow	Sampling	4340.11 - 4323.11
PW-7S	10/22/98	Shallow	Sampling	4339.32 - 4319.82
PW-8S	10/22/98	Shallow	Sampling	4336.63 - 4316.63
PW-9S	10/23/98	Shallow	Sampling	4337.38 - 4317.38
PW-10S	10/23/98	Shallow	Sampling	4338.46 - 4318.46
PW-11S	10/24/98	Shallow	Sampling	4339.68 - 4319.68

Table 3-3. Well Construction Details for the Active Groundwater Monitoring Network

Well Name (1)	Completion Date	Groundwater Zone	Well Type	Well Screen Interval
				feet amsl
Shallow Zone Monitor Wells				
B-2S	5/18/89	Shallow	Water Level	NR - NR
B-3S	5/18/89	Shallow	Water Level	NR - NR
B/W-1S	1/23/08	Shallow	Sampling	4334.71 - 4314.71
B/W-2S	6/13/02	Shallow	Sampling	4330.95 - 4320.95
B/W-3S	9/26/07	Shallow	Sampling	4332.50 - 4312.50
B/W-4S	1/21/08	Shallow	Sampling	4316.74 - 4296.74
B/W-5RS	11/16/07	Shallow	Sampling	4326.12 - 4306.12
B/W-6S	1/30/08	Shallow	Sampling	4326.78 - 4306.78
B/W-8S	10/9/07	Shallow	Sampling	4325.95 - 4305.95
B/W-9S	11/7/07	Shallow	Sampling	4331.77 - 4311.77
B/W-10S	1/23/08	Shallow	Sampling	4321.56 - 4301.56
B/W-11S	11/4/07	Shallow	Sampling	4330.42 - 4310.42
B/W-13S	7/13/05	Shallow	Sampling	4364.14 - 4344.14
B/W-15S	7/22/05	Shallow	Sampling	4348.48 - 4328.48
B/W-16S	10/7/07	Shallow	Sampling	4328.68 - 4308.68
B/W-18S	2/19/08	Shallow	Sampling	4333.87 - 4308.87
B/W-19S	1/9/08	Shallow	Sampling	4331.43 - 4311.43
B/W-20S	7/13/07	Shallow	Sampling	4377.44 - 4357.44
B/W-21S	7/24/07	Shallow	Sampling	4338.99 - 4318.99
B/W-22S	7/18/07	Shallow	Sampling	4309.55 - 4289.55
B/W-25S	1/31/08	Shallow	Sampling	4322.63 - 4302.63
B/W-27S	2/7/08	Shallow	Sampling	4338.98 - 4318.98
B/W-28S	1/15/08	Shallow	Sampling	4331.67 - 4311.67
B/W-29S	1/6/08	Shallow	Sampling	4314.97 - 4294.97
B/W-30S	10/25/10	Shallow	Sampling	4325.10 - 4305.10
B/W-31S1	12/8/10	Shallow	Sampling	4330.77 - 4315.77
B/W-31S2	12/8/10	Shallow	Sampling	4304.95 - 4294.95
B/W-32S	1/11/11	Shallow	Sampling	4328.60 - 4308.60
B/W-33S	8/4/10	Shallow	Sampling	4328.23 - 4308.23
B/W-34S	12/5/10	Shallow	Sampling	4337.68 - 4317.68
B/W-36S	8/11/10	Shallow	Sampling	4329.76 - 4319.76
B/W-37S	6/6/10	Shallow	Sampling	4331.62 - 4311.62
B/W-38RS	10/11/10	Shallow	Sampling	4320.17 - 4300.17
B/W-40S	1/10/11	Shallow	Sampling	4318.41 - 4298.41
B/W-41S	2/8/11	Shallow	Sampling	4324.54 - 4304.54
B/W-42S	11/9/10	Shallow	Sampling	4326.05 - 4306.05
B/W-43S	12/17/10	Shallow	Sampling	4323.75 - 4303.75
B/W-44S	9/24/10	Shallow	Sampling	4324.88 - 4304.88

Table 3-3. Well Construction Details for the Active Groundwater Monitoring Network

Well Name (1)	Completion Date	Groundwater Zone	Well Type	Well Screen Interval
				feet amsl
B/W-45S	1/17/11	Shallow	Sampling	4331.84 - 4311.84
B/W-46S	11/8/10	Shallow	Sampling	4327.09 - 4307.09
B/W-50S (2)	2/11/14	Shallow	Sampling	4337.83 - 4317.83
B/W-51S	8/25/10	Shallow	Sampling	4303.87 - 4293.87
B/W-52S	8/18/10	Shallow	Sampling	4329.90 - 4309.90
B/W-53S1	1/20/11	Shallow	Sampling	4310.26 - 4290.26
B/W-53S2	1/19/11	Shallow	Sampling	4265.87 - 4255.87
B/W-54S	8/20/10	Shallow	Sampling	4298.38 - 4288.38
B/W-55S	10/20/10	Shallow	Sampling	4327.27 - 4307.27
B/W-56S	3/13/12	Shallow	Sampling	4334.12 - 4314.12
B/W-57S	3/15/12	Shallow	Sampling	4325.36 - 4305.36
B/W-58S	3/14/12	Shallow	Sampling	4294.04 - 4284.04
B/W-59S (2)	11/20/13	Shallow	Sampling	4338.55 - 4318.55
B/W-60S	1/8/11	Shallow	Sampling	4342.73 - 4322.73
B/W-61S	8/27/10	Shallow	Sampling	4342.05 - 4322.05
B/W-62S	11/22/10	Shallow	Sampling	4333.94 - 4313.94
B/W-63S (3)	8/9/15	Shallow	Sampling	4325.73 - 4305.73
B/W-64S	12/6/10	Shallow	Sampling	4348.03 - 4328.03
B/W-65S	9/29/10	Shallow	Sampling	4325.29 - 4305.29
B/W-66S	12/5/10	Shallow	Sampling	4313.88 - 4293.88
B/W-67S	1/23/11	Shallow	Sampling	4329.26 - 4309.26
B/W-68S (2)	4/30/14	Shallow	Sampling	4325.57 - 4305.57
B/W-69S (2)	4/15/14	Shallow	Sampling	4319.18 - 4299.18
B/W-70S	10/20/11	Shallow	Sampling	4338.80 - 4318.80
B/W-71S	10/12/11	Shallow	Sampling	4342.25 - 4322.25
B/W-73S	9/10/11	Shallow	Sampling	4357.74 - 4337.74
B/W-74S	10/26/11	Shallow	Sampling	4342.98 - 4322.98
B/W-75S	12/20/11	Shallow	Sampling	4346.69 - 4326.69
B/W-76S	12/15/11	Shallow	Sampling	4335.33 - 4315.33
B/W-77S (2)	4/24/14	Shallow	Sampling	4320.30 - 4300.30
B/W-78S (2)	4/23/14	Shallow	Sampling	4329.30 - 4309.30
B/W-79S (2)	4/25/14	Shallow	Sampling	4335.29 - 4315.29
B/W-81S (2)	3/10/14	Shallow	Sampling	4308.10 - 4288.10
B/W-82RS (2)	11/3/13	Shallow	Sampling	4310.40 - 4290.40
B/W-83S (2)	2/5/14	Shallow	Sampling	4326.66 - 4306.66
D4BC-1S	10/1/85	Shallow	Sampling	4333.98 - 4313.98
D5AC-1S	5/6/84	Shallow	Sampling	4332.48 - 4327.48
FMS-05S (4)	10/20/13	Shallow	Sampling	4335.34 - 4315.34
FMS-06S (4)	11/6/13	Shallow	Sampling	4336.55 - 4316.55

Table 3-3. Well Construction Details for the Active Groundwater Monitoring Network

Well Name (1)	Completion Date	Groundwater Zone	Well Type	Well Screen Interval
				feet amsl
FMS-07S (4)	11/14/13	Shallow	Sampling	4337.75 - 4317.75
HLP-03S (4)	11/16/13	Shallow	Sampling	4341.79 - 4321.79
HLP-04S (4)	10/8/13	Shallow	Sampling	4340.55 - 4320.55
HLP-08S (4)	10/21/13	Shallow	Sampling	4331.83 - 4311.83
***LC-MW-1S* (5)**	1/18/06	Shallow	Sampling	NR - 4303.80(6)
***LC-MW-2S* (5)**	1/18/06	Shallow	Sampling	NR - 4313.90(6)
LC-MW-3S (5)	1/18/06	Shallow	Sampling	NR - 4323.70(6)
***LC-MW-5S* (5)**	NR	Shallow	Sampling	NR - 4323.10(6)
LEP-MW-1S	2/26/09	Shallow	Sampling	4330.92 - 4320.92
LEP-MW-2S	2/27/09	Shallow	Sampling	4331.46 - 4321.46
LEP-MW-3S	2/28/09	Shallow	Sampling	4333.75 - 4323.75
LEP-MW-5S	3/2/09	Shallow	Sampling	4336.35 - 4326.35
LEP-MW-6S	3/2/09	Shallow	Sampling	4327.51 - 4317.51
LEP-MW-7S	3/3/09	Shallow	Sampling	4342.81 - 4332.81
MW2002-2S	6/14/02	Shallow	Sampling	4323.78 - 4313.78
MW-2S	12/13/92	Shallow	Sampling	4326.61 - 4311.61
MW-4S	12/10/92	Shallow	Sampling	4325.68 - 4310.68
MW-5S	10/20/95	Shallow	Sampling	4330.79 - 4315.79
MW-SXN	7/26/09	Shallow	Sampling	4355.39 - 4335.39
MW-SXS	8/28/09	Shallow	Sampling	4354.32 - 4334.32
PA-MW-1S	1/20/05	Shallow	Sampling	4347.32 - 4327.32
PA-MW-2S	1/21/05	Shallow	Sampling	4347.37 - 4327.37
PA-MW-3S1	1/19/05	Shallow	Sampling	4348.13 - 4328.13
PA-MW-3S2	11/19/11	Shallow	Sampling	4309.85 - 4299.85
PA-MW-4S	10/18/11	Shallow	Sampling	4348.09 - 4328.09
PA-MW-5S1	11/17/11	Shallow	Sampling	4344.01 - 4324.01
PA-MW-5S2	11/14/11	Shallow	Sampling	4311.16 - 4301.16
PA-MW-7S	10/25/11	Shallow	Sampling	4317.46 - 4297.46
PLMW-2S	8/3/11	Shallow	Sampling	4369.05 - 4349.05
PLMW-4S	10/31/11	Shallow	Sampling	4319.72 - 4289.72
PW10-P1	9/27/05	Shallow	Water Level	4339.10 - 4319.10
USGS-13S	6/10/76	Shallow	Sampling	4342.06 - 4332.06
USGS-2BS	6/8/76	Shallow	Sampling	4326.34 - 4324.44
UW-1S	10/1/85	Shallow	Sampling	4333.32 - 4313.32
W5AA-2S	10/26/83	Shallow	Water Level	4333.65 - 4313.65
W5AA-3S	10/24/98	Shallow	Sampling	4342.86 - 4332.86
W5AB-2S	10/1/83	Shallow	Sampling	4337.68 - 4322.68
W5AD-1S	5/2/82	Shallow	Water Level	4330.91 - 4325.91
W5BB-S	10/23/83	Shallow	Sampling	4337.12 - 4307.12

Table 3-3. Well Construction Details for the Active Groundwater Monitoring Network

Well Name (1)	Completion Date	Groundwater Zone	Well Type	Well Screen Interval feet amsl
W5DB-S	10/9/10	Shallow	Sampling	4345.06 - 4325.06
WRP-1S	6/19/07	Shallow	Water Level	4382.53 - 4372.53
WRP-2S	6/19/07	Shallow	Water Level	4382.29 - 4372.29
YPT-MW-6S	1/11/02	Shallow	Sampling	4320.21 - 4315.21
YPT-MW-8S	1/9/02	Shallow	Sampling	4322.26 - 4317.26
YPT-MW-11S	1/11/02	Shallow	Sampling	4317.43 - 4312.43
Intermediate Zone Monitor Wells				
B/W-2I	10/17/07	Intermediate	Sampling	4279.78 - 4259.78
B/W-3I	9/27/07	Intermediate	Sampling	4266.40 - 4246.40
B/W-4I	1/21/08	Intermediate	Sampling	4276.50 - 4256.50
B/W-5RI	11/16/07	Intermediate	Sampling	4278.65 - 4258.65
B/W-6I	9/26/05	Intermediate	Sampling	4259.84 - 4249.84
B/W-7I	8/14/05	Intermediate	Sampling	4304.69 - 4284.69
B/W-8I	8/21/05	Intermediate	Sampling	4284.16 - 4264.16
B/W-9I	11/7/07	Intermediate	Sampling	4281.19 - 4261.19
B/W-19I	1/11/08	Intermediate	Sampling	4281.40 - 4261.40
B/W-27I	8/17/10	Intermediate	Sampling	4274.77 - 4254.77
B/W-28I	1/17/08	Intermediate	Sampling	4277.23 - 4257.23
B/W-29I	12/19/07	Intermediate	Sampling	4288.07 - 4278.07
B/W-30I	10/25/10	Intermediate	Sampling	4267.63 - 4247.63
B/W-31I	12/7/10	Intermediate	Sampling	4287.82 - 4246.82
B/W-32I	1/10/11	Intermediate	Sampling	4286.67 - 4266.67
B/W-33I	8/3/10	Intermediate	Sampling	4265.02 - 4255.02
B/W-34I	12/5/10	Intermediate	Sampling	4303.85 - 4283.85
B/W-37I	8/10/10	Intermediate	Sampling	4296.85 - 4276.85
B/W-38RI	10/9/10	Intermediate	Sampling	4287.91 - 4267.91
B/W-41I	2/7/11	Intermediate	Sampling	4278.31 - 4268.31
B/W-42I	11/8/10	Intermediate	Sampling	4266.21 - 4246.21
B/W-46I	11/7/10	Intermediate	Sampling	4276.66 - 4256.66
B/W-51I	9/9/10	Intermediate	Sampling	4264.06 - 4244.06
B/W-52I	8/20/10	Intermediate	Sampling	4296.06 - 4276.06
B/W-54I	8/21/10	Intermediate	Sampling	4277.24 - 4267.24
B/W-57I	3/14/12	Intermediate	Sampling	4270.47 - 4250.47
B/W-63I (3)	8/9/15	Intermediate	Sampling	4285.58 - 4265.58
B/W-65I	9/29/10	Intermediate	Sampling	4285.30 - 4265.30
B/W-66I	12/5/10	Intermediate	Sampling	4268.85 - 4248.85
B/W-67I	1/22/11	Intermediate	Sampling	4289.41 - 4269.41
B/W-70I	10/22/11	Intermediate	Sampling	4288.59 - 4268.59
B/W-71I	10/11/11	Intermediate	Sampling	4281.11 - 4261.11

Table 3-3. Well Construction Details for the Active Groundwater Monitoring Network

Well Name (1)	Completion Date	Groundwater Zone	Well Type	Well Screen Interval feet amsl
B/W-74I1	10/20/11	Intermediate	Sampling	4307.69 - 4297.69
B/W-74I2	10/21/11	Intermediate	Sampling	4277.50 - 4257.50
B/W-76I	12/13/11	Intermediate	Sampling	4276.82 - 4256.82
B/W-82RI (2)	11/2/13	Intermediate	Sampling	4280.35 - 4270.35
HLP-03I (4)	11/5/13	Intermediate	Sampling	4300.00 - 4280.00
HLP-08I (4)	10/20/13	Intermediate	Sampling	4296.56 - 4276.56
LEP-MW-4I	3/1/09	Intermediate	Sampling	4266.95 - 4256.95
LEP-MW-8I	3/4/09	Intermediate	Sampling	4271.83 - 4261.83
LEP-MW-9I	3/6/09	Intermediate	Sampling	4258.17 - 4248.17
MW-4I	8/30/10	Intermediate	Sampling	4285.18 - 4265.18
MW-5I	1/23/11	Intermediate	Sampling	4269.38 - 4249.38
PA-MW-2I	9/8/11	Intermediate	Sampling	4296.59 - 4276.59
PA-MW-3I	11/18/11	Intermediate	Sampling	4281.86 - 4271.86
PA-MW-4I	10/17/11	Intermediate	Sampling	4273.89 - 4253.89
W4CB-1I	10/27/83	Intermediate	Sampling	4280.31 - 4265.31
W4CB-2I	10/28/83	Intermediate	Sampling	4307.74 - 4295.74
W5AA-1I	10/26/83	Intermediate	Sampling	4293.56 - 4278.56
W5AB-3I	9/19/97	Intermediate	Sampling	4308.70 - 4284.20
W5DB-I	10/10/10	Intermediate	Sampling	4287.77 - 4267.77
YPT-MW-9I	1/8/02	Intermediate	Sampling	4282.60 - 4272.60
YPT-MW-12I	1/10/02	Intermediate	Sampling	4280.36 - 4270.36
YPT-MW-13I	7/20/04	Intermediate	Sampling	4287.78 - 4262.78
YPT-MW-15I	10/5/12	Intermediate	Sampling	4275.21 - 4270.21
Deep Zone Monitor Wells				
B/W-1D1	11/5/07	Deep	Sampling	4229.76 - 4209.76
B/W-1D2	10/22/07	Deep	Sampling	4139.92 - 4119.92
B/W-1D3	11/5/05	Deep	Sampling	4028.63 - 4018.63
B/W-1D5	1/7/11	Deep	Sampling	3877.18 - 3867.18
B/W-2D1	9/10/05	Deep	Sampling	4224.01 - 4204.01
B/W-2D3	1/23/11	Deep	Sampling	4049.28 - 4029.28
B/W-2D4	1/21/11	Deep	Sampling	3938.99 - 3918.99
B/W-3D1	8/31/05	Deep	Sampling	4221.87 - 4201.87
B/W-4D1	8/26/05	Deep	Sampling	4228.07 - 4208.07
B/W-5RD1	11/16/07	Deep	Sampling	4241.21 - 4221.21
B/W-9D2	9/14/05	Deep	Sampling	4206.72 - 4186.72
B/W-10D1	8/5/05	Deep	Sampling	4241.10 - 4221.10
B/W-11D2	9/28/05	Deep	Sampling	4197.64 - 4177.64
B/W-18D1	2/19/08	Deep	Sampling	4232.79 - 4212.79
B/W-18D2	12/15/07	Deep	Sampling	4194.17 - 4174.17

Table 3-3. Well Construction Details for the Active Groundwater Monitoring Network

Well Name (1)	Completion Date	Groundwater Zone	Well Type	Well Screen Interval
				feet amsl
B/W-19D1	6/14/07	Deep	Sampling	4216.51 - 4196.51
B/W-25D1	2/1/08	Deep	Sampling	4249.71 - 4229.71
B/W-25D2	1/19/08	Deep	Sampling	4133.82 - 4113.82
B/W-27D2	2/6/08	Deep	Sampling	4124.99 - 4104.99
B/W-27D3	1/6/11	Deep	Sampling	4022.95 - 4002.95
B/W-27D4(2)	2/21/14	Deep	Sampling	3944.83 - 3924.83
B/W-27D5(2)	2/11/14	Deep	Sampling	3879.66 - 3859.66
B/W-28D1	6/28/07	Deep	Sampling	4221.83 - 4201.83
B/W-29D1	12/16/07	Deep	Sampling	4225.24 - 4215.24
B/W-29D3	9/25/07	Deep	Sampling	4050.12 - 4030.12
B/W-30D1	10/26/10	Deep	Sampling	4228.86 - 4208.86
B/W-31D2	11/7/10	Deep	Sampling	4199.84 - 4179.84
B/W-32D2	1/9/11	Deep	Sampling	4147.42 - 4127.42
B/W-32D5	10/24/10	Deep	Sampling	3886.73 - 3866.73
B/W-33D1	7/29/10	Deep	Sampling	4239.39 - 4229.39
B/W-34D1	12/4/10	Deep	Sampling	4257.96 - 4237.96
B/W-37D1	6/5/10	Deep	Sampling	4218.80 - 4198.80
B/W-38RD1	10/10/10	Deep	Sampling	4210.93 - 4190.93
B/W-40D1	1/20/11	Deep	Sampling	4222.20 - 4202.20
B/W-40D3	11/3/10	Deep	Sampling	4057.58 - 4037.58
B/W-41D2	2/7/11	Deep	Sampling	4198.22 - 4178.22
B/W-41D4	2/5/11	Deep	Sampling	4004.14 - 3984.14
B/W-42D1	10/25/10	Deep	Sampling	4210.91 - 4190.91
B/W-44D1	9/23/10	Deep	Sampling	4229.65 - 4209.65
B/W-44D2	9/22/10	Deep	Sampling	4152.72 - 4132.72
B/W-45D1	1/18/11	Deep	Sampling	4252.78 - 4232.78
B/W-45D2	11/20/10	Deep	Sampling	4209.84 - 4189.84
B/W-46D1	11/6/10	Deep	Sampling	4219.76 - 4199.76
B/W-50D1(2)	2/10/14	Deep	Sampling	4206.81 - 4186.81
B/W-50D2(2)	2/8/14	Deep	Sampling	4125.75 - 4105.75
B/W-50D3(2)	2/5/14	Deep	Sampling	4024.73 - 4014.73
B/W-52D2	8/17/10	Deep	Sampling	4177.59 - 4157.59
B/W-55D1	10/20/10	Deep	Sampling	4251.44 - 4241.44
B/W-55D2	10/13/10	Deep	Sampling	4171.59 - 4151.59
B/W-57D1	3/14/12	Deep	Sampling	4212.37 - 4192.37
B/W-57D4	3/13/12	Deep	Sampling	3940.67 - 3920.67
B/W-58D1	3/16/12	Deep	Sampling	4234.41 - 4214.41
B/W-58D3	3/25/12	Deep	Sampling	4054.51 - 4044.51
B/W-59D3(2)	11/19/13	Deep	Sampling	4126.65 - 4106.65

Table 3-3. Well Construction Details for the Active Groundwater Monitoring Network

Well Name (1)	Completion Date	Groundwater Zone	Well Type	Well Screen Interval
				feet amsl
B/W-60D1	12/17/10	Deep	Sampling	4247.69 - 4227.69
B/W-60D3	12/16/10	Deep	Sampling	4036.75 - 4016.75
B/W-60D5	12/7/10	Deep	Sampling	3881.82 - 3861.82
B/W-61D1	8/23/10	Deep	Sampling	4247.00 - 4227.00
B/W-61D3	8/29/10	Deep	Sampling	4036.94 - 4016.94
B/W-62D1	11/21/10	Deep	Sampling	4243.89 - 4223.89
B/W-62D2	11/20/10	Deep	Sampling	4173.88 - 4153.88
B/W-62D4	11/19/10	Deep	Sampling	3953.94 - 3933.94
B/W-62D5	1/6/11	Deep	Sampling	3833.92 - 3813.92
B/W-63D1(3)	8/8/15	Deep	Sampling	4240.50 - 4220.50
B/W-63D2(3)	8/7/15	Deep	Sampling	4170.83 - 4150.83
B/W-63D3(3)	8/5/15	Deep	Sampling	4015.78 - 3995.78
B/W-63D5(3)	7/29/15	Deep	Sampling	3900.65 - 3880.65
B/W-64D1	12/5/10	Deep	Sampling	4260.09 - 4240.09
B/W-64D2	12/3/10	Deep	Sampling	4175.77 - 4155.77
B/W-65D1	9/27/10	Deep	Sampling	4213.36 - 4193.36
B/W-65D5	9/23/10	Deep	Sampling	3750.51 - 3740.51
B/W-66D1	12/4/10	Deep	Sampling	4208.81 - 4188.81
B/W-66D5	12/2/10	Deep	Sampling	3761.03 - 3751.03
B/W-67D1	1/21/11	Deep	Sampling	4245.24 - 4225.24
B/W-67D3	1/13/11	Deep	Sampling	4125.04 - 4105.04
B/W-68D1(2)	4/29/14	Deep	Sampling	4240.74 - 4220.74
B/W-68D4(2)	4/28/14	Deep	Sampling	3964.32 - 3954.32
B/W-69D1(2)	4/14/14	Deep	Sampling	4259.33 - 4239.33
B/W-69D2(2)	4/13/14	Deep	Sampling	4194.30 - 4174.30
B/W-69D5(2)	4/9/14	Deep	Sampling	3782.33 - 3772.33
B/W-70D2	10/25/11	Deep	Sampling	4143.64 - 4123.64
B/W-71D1	10/5/11	Deep	Sampling	4222.09 - 4202.09
B/W-71D3	10/3/11	Deep	Sampling	4094.16 - 4074.16
B/W-74D1	11/20/11	Deep	Sampling	4247.72 - 4227.72
B/W-76D1	10/4/11	Deep	Sampling	4251.74 - 4231.74
B/W-81D1(2)	3/9/14	Deep	Sampling	4243.06 - 4223.06
B/W-81D2(2)	3/10/14	Deep	Sampling	4153.13 - 4133.13
B/W-83D1(2)	2/4/14	Deep	Sampling	4216.67 - 4196.67
B/W-83D3(2)	1/29/14	Deep	Sampling	4066.59 - 4046.59
HLP-08D1(4)	10/19/13	Deep	Sampling	4249.87 - 4229.87
HLP-08D2(4)	10/15/13	Deep	Sampling	4174.99 - 4154.99
LEP-MW-2D1	10/25/10	Deep	Sampling	4229.98 - 4209.98
LEP-MW-2D3	10/22/10	Deep	Sampling	4100.11 - 4080.11

Table 3-3. Well Construction Details for the Active Groundwater Monitoring Network

Well Name (1)	Completion Date	Groundwater Zone	Well Type	Well Screen Interval
				feet amsl
MW-5D2	1/12/11	Deep	Sampling	4194.22 - 4174.22
MW-5D3	1/18/11	Deep	Sampling	4119.72 - 4099.72
MW2002-2D1	7/12/07	Deep	Sampling	4249.75 - 4239.75
PA-MW-4D2	10/15/11	Deep	Sampling	4192.92 - 4172.92
W32DC-D1	10/25/83	Deep	Sampling	4240.41 - 4197.41
W4CB-2D1	9/15/10	Deep	Sampling	4240.56 - 4220.56
W4CB-2D3	9/14/10	Deep	Sampling	4065.76 - 4045.76
W4CB-2D4	11/8/10	Deep	Sampling	3965.54 - 3955.54
W5DB-D1	10/19/98	Deep	Sampling	4239.49 - 4211.49
W5DB-D3	11/17/10	Deep	Sampling	4091.93 - 4071.93
W5DB-D4	10/25/10	Deep	Sampling	4009.93 - 3989.93
YPT-MW-14D1	7/21/04	Deep	Sampling	4255.83 - 4235.83
Bedrock Monitor Wells				
B/W-1B	5/19/10	Bedrock	Sampling	3700.10 - 3690.10
B/W-2B	1/12/11	Bedrock	Sampling	3839.17 - 3819.17
B/W-6B	1/25/11	Bedrock	Sampling	4172.04 - 4152.04
B/W-11B	11/3/07	Bedrock	Sampling	4132.88 - 4122.88
B/W-12RB	12/6/11	Bedrock	Sampling	4382.05 - 4302.05
B/W-17B	10/30/11	Bedrock	Sampling	4385.06 - 4365.06
B/W-22B	5/8/10	Bedrock	Sampling	4261.26 - 4241.26
B/W-23B	8/8/07	Bedrock	Sampling	4340.26 - 4330.26
B/W-26RB	11/3/11	Bedrock	Sampling	4367.92 - 4347.92
B/W-27B (2)	11/12/13	Bedrock	Sampling	3800.16 - 3780.16
B/W-33B	7/26/10	Bedrock	Sampling	4167.48 - 4157.48
B/W-34B	12/1/10	Bedrock	Sampling	4203.76 - 4183.76
B/W-36B	6/17/10	Bedrock	Sampling	4271.60 - 4261.60
B/W-37B	5/27/10	Bedrock	Sampling	4166.84 - 4146.84
B/W-38RB	10/8/10	Bedrock	Sampling	4166.90 - 4146.90
B/W-39B	10/7/10	Bedrock	Sampling	4309.10 - 4299.10
B/W-44B	9/16/10	Bedrock	Sampling	4124.48 - 4104.48
B/W-51B	6/25/10	Bedrock	Sampling	4198.79 - 4188.79
B/W-53B	12/17/10	Bedrock	Sampling	4240.77 - 4220.77
B/W-54B	7/10/10	Bedrock	Sampling	4261.30 - 4251.30
B/W-58B	2/4/12	Bedrock	Sampling	4014.50 - 3994.50
B/W-61B	7/9/10	Bedrock	Sampling	3684.05 - 3664.05
B/W-62B	9/25/10	Bedrock	Sampling	3690.87 - 3670.87
B/W-64B	12/2/10	Bedrock	Sampling	4089.75 - 4069.75
B/W-70B	8/30/11	Bedrock	Sampling	4060.86 - 4040.86
B/W-71B	9/1/11	Bedrock	Sampling	3931.06 - 3911.06

Table 3-3. Well Construction Details for the Active Groundwater Monitoring Network

Well Name (1)	Completion Date	Groundwater Zone	Well Type	Well Screen Interval
				feet amsl
B/W-73B	9/7/11	Bedrock	Sampling	4307.60 - 4287.60
B/W-74B	9/21/11	Bedrock	Sampling	4207.18 - 4187.18
B/W-75B	1/7/12	Bedrock	Sampling	4266.82 - 4246.82
B/W-82RB (2)	11/1/13	Bedrock	Sampling	4235.38 - 4215.38
B/W-83B (2)	1/24/14	Bedrock	Sampling	3943.51 - 3913.51
HLP-01B (4)	9/20/13	Bedrock	Sampling	4333.97 - 4313.97
HLP-02B (4)	9/22/13	Bedrock	Sampling	4406.47 - 4386.27
HLP-03B (4)	10/18/13	Bedrock	Sampling	4236.98 - 4206.98
HLP-05B (4)	10/5/13	Bedrock	Sampling	4346.26 - 4306.26
HLP-06B (4)	10/1/13	Bedrock	Sampling	4338.55 - 4318.55
HLP-07B (4)	9/24/13	Bedrock	Sampling	4345.04 - 4325.04
HLP-08B (4)	10/8/14	Bedrock	Sampling	4117.44 - 4097.44
LEP-MW-2B	10/13/10	Bedrock	Sampling	4040.47 - 4020.47
MMW-2	12/6/92	Bedrock	Sampling	4246.34 - 4186.34
MW-4B	8/28/10	Bedrock	Sampling	4251.41 - 4231.41
MW-5B	1/7/11	Bedrock	Sampling	3984.29 - 3964.29
MW-H12	8/6/09	Bedrock	Sampling	4353.58 - 4323.58
MW-H4SN	8/11/09	Bedrock	Sampling	4371.56 - 4341.56
MW-H4SS	8/13/09	Bedrock	Sampling	4360.63 - 4330.63
PA-MW-1B	8/6/11	Bedrock	Sampling	4290.87 - 4270.87
PA-MW-2B	9/3/11	Bedrock	Sampling	4210.44 - 4190.44
PA-MW-3B	10/11/11	Bedrock	Sampling	4246.82 - 4226.82
PA-MW-4B	9/14/11	Bedrock	Sampling	4157.96 - 4137.96
PA-MW-5B	8/20/11	Bedrock	Sampling	4281.60 - 4261.60
PA-MW-7B	9/30/11	Bedrock	Sampling	4174.49 - 4154.49
PLMW-1B	9/29/11	Bedrock	Sampling	4218.23 - 4168.23
PLMW-2B	8/2/11	Bedrock	Sampling	4313.20 - 4293.20
PLMW-3RB	11/12/11	Bedrock	Sampling	4237.72 - 4197.72
PLMW-4B	10/20/11	Bedrock	Sampling	4094.72 - 4064.72
PLMW-5B	9/18/11	Bedrock	Sampling	4243.58 - 4203.58
W4CB-2B	7/9/10	Bedrock	Sampling	3844.55 - 3824.55
W5DB-B	9/26/10	Bedrock	Sampling	3781.04 - 3761.04
WRA3-1B	10/1/11	Bedrock	Sampling	4369.32 - 4339.32
WRA3-2B	10/19/11	Bedrock	Sampling	4322.60 - 4302.60
WRA3-3B	12/5/11	Bedrock	Sampling	4330.39 - 4310.39
WW-1B	NR	Bedrock	Sampling	4364.42 - 4344.42
WW-2B	NR	Bedrock	Sampling	4342.48 - 4322.48
WW-36B	4/15/69	Bedrock	Sampling	4305.78 - 4105.78
WW-40B	NR	Bedrock	Sampling	NR - NR

Table 3-3. Well Construction Details for the Active Groundwater Monitoring Network

Well Name (1)	Completion Date	Groundwater Zone	Well Type	Well Screen Interval feet amsl
WW-59B	11/20/72	Bedrock	Sampling	4280.04 - 3888.04
YPT-MW-10B	1/7/02	Bedrock	Sampling	4107.46 - 4097.46

Notes:
1) The names of 117 wells for which the sampling frequency has been reduced from quarterly to semi-annually are bold and italicized. Well names for older wells reflect revisions based on their alluvial aquifer zone designations.
2) New well added to the monitor well network and first sampled in 3Q 2014.
3) New well added to the monitor well network and first sampled in 4Q 2015.
4) New well added to the monitor well network and first sampled in 4Q 2014.
5) Lyon County well.
6) The bottom of screen elevations for the Lyon County wells are based on a 2009 survey conducted for ARC and the total depth of each well measured in the field by BC. The measured well depths are not consistent with the information on the well logs provided by Lyon County (see Appendix C-1 for the well logs).
7) NR = not recorded on well construction logs. amsl = above mean sea level

Water Level Monitoring

Routine water level monitoring was initiated in 2006, to evaluate seasonal and temporal changes in groundwater flow directions and hydraulic gradients, and aquifer responses to irrigation practices. Water level elevation monitoring was historically conducted monthly, and subsequently reduced to quarterly in 2014 for wells installed before 2013, in accordance with the *Technical Memorandum: Site-Wide Groundwater Monitoring Optimization* (ARC 2014).

As outlined in the GMP (BC 2012a), water levels are measured within a three-day (or shorter) period, for representative aquifer conditions throughout the monitoring network. Water level elevations are also measured electronically using pressure transducers/data loggers, at four-hour intervals at select monitor wells, and at one-hour intervals at the Pit Lake. Water level data from transducers are typically downloaded in conjunction with monthly water level measurements. Appendix D provides groundwater level data, hydrographs, and vertical gradient information.

Groundwater Quality Monitoring

Monitor wells comprising the active monitoring network are sampled on a quarterly or semi-annual frequency pursuant to the GMP (BC 2012a) using EPA-approved low-flow, minimal drawdown purging and sampling procedures, where applicable. Groundwater samples are analyzed for the constituents listed in Table 3-4 pursuant to the data requirements presented in the QAPP (ESI and BC 2009).

Table 3-4. Analyte List for Active Monitor Well and Surface Water Sampling

Parameter or Analyte	Total/ Dissolved (1)	Method (2)	Reporting Limit (2)	Units
Physical Parameters and Major Anions/Cations				
Alkalinity, Bicarbonate (as $CaCO_3$)	Total	SM 2320B	2.0	mg/L
Alkalinity, Carbonate (as $CaCO_3$)	Total	SM 2320B	2.0	mg/L
Alkalinity, Total (as $CaCO_3$)	Total	SM 2320B	2.0	mg/L
Chloride	Total	EPA 300.0	0.5	mg/L
Fluoride	Total	EPA 300.0	0.5	mg/L
Nitrate, as N	Total	EPA 300.0	0.1	mg/L
Nitrate (NO_3 + NO_2 as N)	Total	EPA 300.0	0.1	mg/L
Nitrite, as N	Total	EPA 300.0	0.1	mg/L
Sulfate	Total	EPA 300.0	0.5	mg/L
pH (Lab)	Total	SM 4500B	0.1	sun.
Total Dissolved Solids (TDS) (3)	Total (Lab Filtered) (3)	SM 2540C	10	mg/L
Total Organic Carbon (TOC)	Total	SM 5310B	1.0	mg/L
Metals				
Aluminum	Total + Dissolved	EPA 200.7	0.05	mg/L
Antimony	Total + Dissolved	EPA 200.8	2.0	µg/L
Arsenic	Total + Dissolved	EPA 200.8	1.0	µg/L
Barium	Total + Dissolved	EPA 200.8	1.0	µg/L
Beryllium	Total + Dissolved	EPA 200.8	0.5	µg/L
Boron	Total + Dissolved	EPA 200.7	50	µg/L
Cadmium	Total + Dissolved	EPA 200.8	1.0	µg/L
Calcium	Total + Dissolved	EPA 200.7	0.1	mg/L
Chromium	Total + Dissolved	EPA 200.8	2.0	µg/L
Cobalt	Total + Dissolved	EPA 200.8	1.0	µg/L
Copper	Total + Dissolved	EPA 200.8	1.0	µg/L
Iron	Total + Dissolved	EPA 200.7	0.04	mg/L
Lead	Total + Dissolved	EPA 200.8	1.0	µg/L
Lithium	Total + Dissolved	EPA 200.7	50	µg/L
Magnesium	Total + Dissolved	EPA 200.7	0.02	mg/L
Manganese	Total + Dissolved	EPA 200.8	1.0	µg/L
Mercury	Total + Dissolved	EPA 245.1	0.2	µg/L
Molybdenum	Total + Dissolved	EPA 200.8	2.0	µg/L
Nickel	Total + Dissolved	EPA 200.8	2.0	µg/L
Phosphorus	Total + Dissolved	EPA 200.7	0.04	mg/L
Potassium	Total + Dissolved	EPA 200.7	0.5	mg/L
Selenium	Total + Dissolved	EPA 200.8	0.6	µg/L
Silica	Total + Dissolved	EPA 200.7	0.05	mg/L
Silver	Total + Dissolved	EPA 200.8	1.0	µg/L
Sodium	Total + Dissolved	EPA 200.7	0.5	mg/L
Strontium	Total + Dissolved	EPA 200.7	0.02	mg/L
Thallium	Total + Dissolved	EPA 200.8	1.0	µg/L
Tin	Total + Dissolved	EPA 200.7	100	µg/L

Table 3-4. Analyte List for Active Monitor Well and Surface Water Sampling

Parameter or Analyte	Total/ Dissolved (1)	Method (2)	Reporting Limit (2)	Units
Titanium	Total + Dissolved	EPA 200.7	0.005	mg/L
Uranium, Total	Total + Dissolved	EPA 200.8	1.0	µg/L
Vanadium	Total + Dissolved	EPA 200.8	2.0	µg/L
Zinc	Total + Dissolved	EPA 200.8	10	µg/L
Radiochemicals				
Gross Alpha	Dissolved	EPA 900.0	1.0	pCi/L
Gross Beta	Dissolved	EPA 900.0	1.0	pCi/L
Radium-226	Dissolved	EPA 903.0	1.0	pCi/L
Radium-228	Dissolved	EPA 904.0	1.0	pCi/L
Thorium-228	Dissolved	HASL 300	1.0	pCi/L
Thorium-230	Dissolved	HASL 300	1.0	pCi/L

Notes:

1) Dissolved constituents are field-filtered with a new disposable 0.45-micron (µm) filter. Dissolved (filtered) metals collected quarterly. Total (unfiltered) metals collected in two non-consecutive quarters once a well is installed and/or initially included in the GMP (BC 2012a).
2) Except for lithium and selenium, EPA laboratory analytical methods and reporting limits are consistent with those provided in Revision 5 of the QAPP (ESI and BC 2009); alternative analytical methods identified in the QAPP may also be used. For lithium, the lab was unable to get reproducible results using EPA Method 200.8 (as indicated in QAPP); therefore, the lab has used EPA Method 200.7 for lithium, which has a higher reporting limit than indicated in the QAPP. For selenium, the reporting limit of 0.6 µg/L is lower than that indicated in the QAPP (2 µg/L).
3) The samples for TDS are filtered in the analytical laboratory with a new disposable 0.45 µm filter.
4) s.u. = pH standard units; mg/L = milligrams per liter; µg/L = micrograms per liter; pCi/L = picocuries per liter.

Appendix D provides groundwater quality data associated with the Site-Wide groundwater monitoring program and charts illustrating temporal changes in chemical concentrations.

Dissolved versus Total Metals

Beginning with the 3Q 2010 sampling event, samples from monitor wells at the Site have been periodically collected in two different quarters from each well and analyzed for both dissolved (0.45 µm-filtered) and total (unfiltered) metals to determine whether the two sampling methods produce comparable results. The results of the comparative statistical analysis of the available dissolved and total metals datasets have been periodically reported in previous quarterly and annual groundwater monitoring reports (GMRs). The most recent and final sampling for dissolved and total metals occurred during the 3Q 2014 and 1Q 2015 events for 29 off-Site wells that were installed in 2013/2014 and first sampled in 3Q 2014. The statistical comparison of the complete dissolved and total metals datasets is presented in the 2015 Annual GMR (BC 2016c).

Based on the statistical analyses, differences between dissolved and total metals concentrations in groundwater samples collected from monitor wells are non-existent or are too small to be meaningful. It is concluded that groundwater sampling both with and without filtering of samples produce equivalent datasets.

3.2.4 Soil Sampling and Testing

Pursuant to the *Agricultural Fields Characterization Work Plan - Revision 2* (BC 2010d), soil samples were collected from select borehole cores in the Shallow, Intermediate and Deep zones. The types of samples collected, and a brief description of the sampling objectives, are provided below.

- Soil samples were collected for analysis of grain size distribution to generate laboratory-determined Unified Soil Classification System (USCS) soil descriptions for comparison to USCS descriptions made in the field at the time of drilling.
- Non-redox preserved soil samples were collected for bulk chemical analyses to characterize chemical concentrations in soils.
- Redox-preserved soil samples were collected using EPA-specified procedures that preserve the subsurface oxidation state of the sediments, and archived at the Site for potential testing pursuant to the *Aquifer Solids Testing Work Plan - Revision 1* (BC 2010e).

Soil sampling information is provided in Appendix E and discussed briefly below.

Grain Size Analysis

A total of 37 samples of aquifer materials were obtained from 16 borehole locations for grain size distribution analyses by sieving of material larger than 75 µm (i.e., retained on a No. 200 sieve). Laboratory reports with the grain size distribution data are provided in Appendix E-1. Grain size distribution results were used to generate laboratory-derived USCS lithologic classifications for comparison to the field-derived USCS lithologic classifications based on visual inspection of core during drilling. As shown in Table 3-5, field USCS classifications were generally consistent with laboratory USCS classifications, especially with respect to finer-grained materials.

Table 3-5. Sample Locations for Grain Size Analysis

Borehole Name	Sample Interval (feet bgs)	USCS Classification (Field)	Percent Fines (Field)	USCS Classification (Laboratory)	Percent Fines (Laboratory)
B/W-2	378-384	SW	5	SM	12.7
B/W-2	442-454	SC	35	SC	26.4
B/W-32	21-27	SM	15	SM	18.7
B/W-32	411-414	SW-SM	10	SM	13.5
B/W-36	57-71	SM	30	SM	13.5
B/W-37	111-117	CL	80	CL	82.0
B/W-38R	140-143	GW	5	SW-SM	7.8
B/W-38R	208-212	SC	35	SC	25.7
B/W-38R	249-253	SM	30	SM	18.6
B/W-40	220.5-226	SM	15	SM	19.2
B/W-40	451-456	SP	5	SM	20.9
B/W-42	159-165	SM	15	SP-SM	5.9
B/W-51	64-69	SC	35	SC	15.0
B/W-54	46-52	CL	65	CL	63.1
B/W-54	52-61	SW	10	SW-SM	8.3
B/W-55	42-51	CH	95	CL	74.4
B/W-55	118-125	SM	20	CL	51.2
B/W-55	135-145	SW	5	SP	4.9
B/W-55	175-185	SP	5	SW	2.9
B/W-60	32-36	SM	35	SM	23.3
B/W-60	132.5-136	ML	60	CL	70.1
B/W-60	450-456	SM	25	SM	22.6
B/W-61	299-306	SP	10	SP-SM	7.7
B/W-64	27-31	SP	10	SP-SM	12.0
B/W-64	43-47	CL	75	CL	93.0
B/W-64	67-77	SW	10	SP-SM	12.0
B/W-64	177-185	SW	10	SW	5.0
B/W-66	59-64	CH	70	CL	66.1
B/W-66	65.5-68	SC	40	SC	23.0
B/W-66	89-93	SC	20	SC	48.7
B/W-67	27-32	SP	5	SM	28.5
B/W-67	38-55	CL	60	CL	64.0
B/W-67	142-146	SC	40	SC	31.8
LEP-MW-2	61-66	CL	50	SC	22.1
LEP-MW-2	212-217	CH	95	SC	34.4
LEP-MW-2	266-273	SW-SM	10	SM	12.8
LEP-MW-2	341-346	CL	50	SC	36.2

Notes: SW = Well Graded Sand or Well Graded Sand with Gravel (where gravel is more than 15%).
SP = Poorly Graded Sand or Poorly Graded Sand with Gravel (where gravel is more than 15%).
SW-SM = Well Graded Sand with Silt or Well Graded Sand with Silt and Gravel (where gravel is more than 15%).
SP-SM = Poorly Graded Sand with Silt or Poorly Graded Sand with Silt and Gravel (where gravel is more than 15%).
SC = Clayey Sand or Clayey Sand with Gravel (where gravel is more than 15%).
SM = Silty Sand or Silty Sand with Gravel (where gravel is more than 15%).
CL = Lean Clay, Lean Clay with Sand, Sandy Lean Clay or Sandy Lean Clay with Gravel (where gravel is more than 15%).
CH = Fat Clay, Fat Clay with Sand, Sandy Fat Clay or Sandy Fat Clay with Gravel (where gravel is more than 15%).
GW = Well Graded Gravel with Sand.

Solids Sampling for Bulk Chemistry

Samples of archived core were collected from select depths in boreholes B/W-1, B/W-31, B/W-32, B/W-42, B/W-46, B/W-61, B/W-62, B/W-65, B/W-66, B/W-67, and MW-5 and submitted to the laboratory for bulk chemical analysis of the parameters listed in Table 3-6. Sample collection methods conformed to SOP-11 of the QAPP. Concentrations of metal/metalloids (hereinafter referred to as metals) and radiochemicals in the solid soil samples were determined by microwave-assisted digestion using EPA Method 3051A (HNO_3). The locations, sample depths and laboratory results are summarized in Appendix E-2.

Table 3-6. Analyte List for Soil Samples

Parameter or Analyte	Method (1)	Reporting Limit (1)	Units (2)
Soil pH	EPA 9045C	0.1	s.u.
Total and Acid Soluble Sulfur	Method 9030B	0.4	mg/kg
Chloride	EPA 300.0	5	mg/kg
Nitrate (as N)	EPA 300.0	1.1	mg/kg
Sulfate	EPA 300.0 (4)	5.0	mg/kg
TOC, TC, TIC (3)	EPA LG601 (2)	1.0	mg/kg
Aluminum	EPA 6010B	10	mg/kg
Antimony	EPA 6020	1.0	mg/kg
Arsenic	EPA 6020	0.5	mg/kg
Barium	EPA 6020	0.5	mg/kg
Beryllium	EPA 6020	0.3	mg/kg
Boron	EPA 6010B	5.0	mg/kg
Cadmium	EPA 6020	0.5	mg/kg
Calcium	EPA 6010B	15	mg/kg
Chromium	EPA 6020	1.0	mg/kg
Cobalt	EPA 6020	0.5	mg/kg
Copper	EPA 6020	1.0	mg/kg
Iron	EPA 6010B	5.0	mg/kg
Lead	EPA 6020	0.5	mg/kg
Magnesium	EPA 6010B	10	mg/kg
Manganese	EPA 6020	0.5	mg/kg
Molybdenum	EPA 6020	1.0	mg/kg
Nickel	EPA 6020	1.0	mg/kg
Potassium	EPA 6010B	50	mg/kg
Selenium	EPA 6020	1.0	mg/kg
Sodium	EPA 6010B	50	mg/kg
Uranium, Total	EPA 6020	0.10	mg/kg
Vanadium	EPA 6020	1.0	mg/kg
Zinc	EPA 6020	10	mg/kg
Uranium-234, 235, 238	HASL 300 (U-02-RC)	1.0	pCi/g

Notes:

1) EPA laboratory analytical methods and reporting limits are consistent with those provided in QAPP (ESI and BC 2009); alternative analytical methods identified in the QAPP may also be used.
2) s.u. = standard units; mg/kg = milligrams per kilogram; pCi/g = picocuries per gram.
3) Total Organic Carbon (TOC), Total Carbon (TC), and Total Inorganic Carbon (TIC).
4) EPA Method LG601 (Dry Combustion, Infrared Detection) as described in EPA 2005.

Vertical profiling of chemical concentrations in soils beneath the agricultural fields was performed to help understand potential chemical loading to groundwater unrelated to mining. Other evaluations involving characterization of groundwater quality upgradient and downgradient of agricultural fields and the sulfur isotope signatures associated with gypsum, an agricultural fertilizer/soil amendment, proved more useful for evaluating groundwater impacts associated with agricultural activities (see Section 5.5).

Redox-Preserved Soil Sampling and Archiving

During the 2007 Second-Step HFA (BC 2008c) and 2010 field investigation (BC 2013a), soil samples were opportunistically collected using EPA-specified procedures that preserved the subsurface oxidation state of the sediments. Redox-preserved soil samples were collected at select borehole locations near the Evaporation Ponds (B/W-11, B/W-18, LEP-MW-9I, MW-5, and W4CB-2), the agricultural fields adjacent to the Site (B/W-61, B/W-65, and B/W-66), and at B/W-32 (i.e., at OU1-DPT-28, which was identified during the Shallow zone investigation in 2009).

The redox-preserved soil samples were archived at the Site for potential laboratory testing (BC 2010e) to evaluate geochemical processes that affect the release and/or attenuation of chemicals from/onto aquifer solids (in particular, chemical partitioning to various mineral fractions), and the mobility and transport of chemicals in groundwater at the Site. The disposition of archived, redox-preserved soil samples is described in Section 3.3.5, which addresses chemical transport evaluations.

3.2.5 Aquifer Hydraulic Properties Testing

The 2007 SOW (EPA 2007a) required "*Definition of aquifer properties (e.g., hydraulic conductivity, transmissivity, and storativity) by a program of aquifer testing to measure the hydraulic connection between areas and throughout the known extent of contamination*." In addition, characterization of aquifer hydraulic properties was identified as DQO #5 in the Revised Groundwater RI Work Plan (BC 2014a).

Hydraulic properties of the alluvial aquifer, as well as bedrock, are provided in Appendix F and have been estimated based on a variety of small- to large-scale test methods including:

- Slug testing of groundwater monitor wells;
- Analysis of steady-state drawdown data obtained during routine quarterly low-flow sampling of monitor wells;
- Constant-rate pumping tests of the eleven wells comprising the PWS during 2010;
- Slug testing of piezometers installed near the PWS that were used as observation wells during constant-rate pumping tests of the 11 wells comprising the PWS during 2010; and
- A constant-rate pumping test of agricultural well WDW019 using an observation network of 93 monitor wells, of which 61 exhibited pumping-related responses.

Small-scale test methods, such as slug testing, provide data that are useful for identifying spatial patterns related to geology, guiding characterization, and as a preliminary estimate of hydraulic conductivity. Because slug test data are available throughout the Study Area, this dataset is used to evaluate spatial patterns in hydraulic conductivity within the Study Area. Data from the pumping test at WDW019, the other large-scale pumping tests, and subsequent groundwater model development using a parameter estimation technique (Doherty 2009), have been used to develop representative field-scale estimates of hydraulic conductivity and, therefore, groundwater velocity.

3.2.6 Surface Water Characterization

The hydrology of the study area is dominated by groundwater recharge from surface water associated with agricultural irrigation (Carroll et al. 2010; Huxel and Harris 1969; Myers 2001). Therefore, understanding the flows in the Walker River and diversions for nearby agricultural activities is important for understanding and contextualizing the data collected in the Study Area. Both regional and local (i.e. Study Area) characterization activities were conducted.

To characterize regional surface water hydrology, daily stream flows for the Walker River are obtained at several gaging locations throughout the Mason Valley, both upstream and downstream of the Site. The data collected from the gaging stations are maintained by the USGS, often in cooperation with state and local agencies, and are available at the USGS website (http://waterdata.usgs.gov/nv/nwis/sw). Surface water quality in the Walker River is also routinely

monitored by various federal, state, and miscellaneous agencies/entities. Much of this data is assembled and made publicly-available through the EPA's STOrage and RETrieval (STORET) Data Warehouse. This dataset supplements the data collected by ARC.

To evaluate the quality of surface water used to irrigate the Hunewill Ranch agricultural fields next to the Site, samples were collected and analyzed from the West Campbell Ditch (SW-WCD-01) and the Walker River (SW-WR-01), pursuant to the *Agricultural Fields Characterization Work Plan - Revision 2* (BC 2010d). Sampling locations are shown on Figure 3-6. West Campbell Ditch receives its water directly from the Walker River. The Walker River monitoring point (SW-WR-01) is located less than 1,000 feet upstream of the diversion point for West Campbell Ditch. The monitoring location in West Campbell Ditch (SW-WCD-01) is located about three miles farther downstream from the diversion point. Potential temporal trends in surface water quality during non-irrigation and irrigation periods were addressed by collecting samples monthly at these locations for 12 months during 2010/2011.

Field parameters (temperature, pH, specific conductivity, DO, sulfate and turbidity) were measured at the time of sample collection, and samples were submitted for the analysis (total concentrations) of the parameters listed in Table 3-4. Surface water samples were collected using the direct-grab method described in SOP-18 in the QAPP. This surface water sample collection method is consistent with the method used by NDEP to collect samples at other surface water monitoring stations in the Mason Valley. Laboratory analyses were conducted in accordance with the QAPP. Surface water data are presented in Appendix G and summarized in Section 4.7.

3.2.7 Hydrologic Tracer Studies

Hydrologic tracer investigations were initiated to help characterize Study Area groundwater conditions, refine the HCSM, and identify background groundwater quality types (BC 2008c, 2012b, 2014a). A variety of hydrologic tracers were initially identified as having the potential to provide information on the origin, age, sources of dissolved constituents, and migration pathways of groundwater and surface water in the Study Area.

To evaluate the feasibility of using hydrologic tracers to support these objectives, samples were collected prior to 2010 from a select number of groundwater monitor wells and surface water features. Based on the apparent efficacy of using hydrologic tracers to assess Study Area groundwater conditions, additional EPA-approved hydrologic tracer sampling events were conducted. Over time, the hydrologic tracer sampling events evolved with changes primarily related to increases in the number of groundwater monitor wells that were sampled, opportunistic collection of standing rainwater samples, and elimination of select tracers considered less useful for characterizing groundwater conditions.

Table 3-7 provides a chronology of the various OU-1 hydrologic tracer sampling events.

Table 3-7. Chronology of Hydrologic Tracer Sampling Events

Date	Sampling Locations (1)	Hydrologic Tracers (2)	Information Source(s)
July/August 2008	Hydrologic tracer samples were collected from 47 of the 94 (50%) active groundwater monitor wells at the time that routine groundwater monitoring was conducted.	Uranium isotopes, sulfate isotopes, tritium, tritium/helium, $\delta^{18}O/\delta^{2}H$ in water, and nitrate isotopes.	*Second-Step Hydrogeologic Framework Assessment Data Summary Report* (BC 2008c).
February 2011	Samples were collected from the Walker River and West Campbell Ditch, and from 127 of the 223 (57%) active groundwater monitor wells at the time of sampling.	Uranium isotopes, sulfate isotopes, tritium, tritium/helium, $\delta^{18}O/\delta^{2}H$ in water, nitrate isotopes, CFCs, $\delta^{13}B$, and $\delta^{36}Cl$.	*Draft Site-Wide Groundwater Operable Unit (OU-1) Remedial Investigation Work Plan* (BC 2012b). Revised Groundwater RI Work Plan (BC 2014a).
May 2012	Samples were collected from: 1) three surface water locations (Pit Lake, Walker River and West Campbell Ditch); and 2) 279 of the 287 (97%) active groundwater monitor wells at the time of sampling.	Uranium isotopes, sulfate isotopes, tritium, tritium/helium, CFCs, and SF_6.	Conclusions about the usefulness of specific hydrologic tracers collected in 2011 were noted in correspondence between ARC and EPA (2012a). With EPA approval (2012b), samples collected during May 2012 were not analyzed for stable isotopes in water or nitrate isotopes. May 2012 results were provided in the *Background Groundwater Quality Assessment - Revision 2* (BC 2015c).
July 2013	Collection of 14 standing rain water samples following a large precipitation event.	Uranium isotopes and sulfate isotopes.	July 2013 results provided in the *Background Groundwater Quality Assessment - Revision 2* (BC 2015c).
August 2014	Groundwater samples were collected from all (100%) of the new wells installed pursuant to the Additional Monitor Well Work Plan (BC 2013b) except well HLP-02B because it was dry. Also sampled were the four wells at the B/W-65 cluster, which were inaccessible in May 2012, and monitor well YPT-MW-15I, which was installed in October 2012. Five wells were resampled to evaluate the results reported in May 2012.	Uranium isotopes, sulfate isotopes, tritium, and tritium /helium.	August 2014 results provided in the *Background Groundwater Quality Assessment - Revision 2* (BC 2015c).

Notes:

1) Hydrologic tracer samples from monitor wells were collected in conjunction with routine groundwater monitoring events associated with the GMP (BC 2012a).
2) Uranium isotopes include ^{234}U, ^{235}U, and ^{238}U; Sulfate isotopes = $\delta^{34}S/\delta^{18}O$ in dissolved sulfate; Nitrate isotopes = $\delta^{15}N/\delta^{18}O$ in dissolved nitrate; $\delta^{13}B$ = boron isotopes in the water samples; $\delta^{36}Cl$ = chloride isotopes in the water samples; CFCs = chlorofluorocarbons; SF_6 = Sulfur Hexafluoride.

Hydrologic tracer samples were collected from monitor wells in conjunction with routine Site-Wide groundwater sampling events using low-flow, minimal drawdown sample collection procedures specified in the GMP (BC 2012a), as well as tracer-specific sampling protocols specified in SOP-17 of the QAPP (ESI and BC 2009). Surface water hydrologic tracer samples were collected using the direct-grab method described in SOP-18 of the QAPP. This surface water sample collection method is consistent with the method used by the NDEP to collect samples at other surface water monitoring stations in the Mason Valley. Table 3-8 presents the parameters, analytical methods, reporting limits, and accuracy and precision goals for the hydrologic tracer analyses.

Table 3-8. Analyte List for Hydrologic Tracer Samples

Parameter	Analytical Method	Analytical Precision (1)	Reporting Limit (2)	Matrix Spike Accuracy	Lab Control Sample Accuracy
Tritium (^{3}H)	wrd (^{3}He-ingrowth)	± 0.1 TU (3)	NA	NA	NA
Tritium/Helium (^{3}H/^{3}He)	Noble Gas MS	± 1%	NA	NA	NA
^{34}S in Sulfate	EA-IRMS (Combination to SO_2) USGS RSIL Lab Code 1951	± 0.5‰	NA	NA	NA
^{18}O in Sulfate	EA-IRMS (Combination to CO_2) USGS RSIL Lab Code 1951 (4)	± 0.5‰	NA	NA	NA
^{234}U, ^{235}U, ^{238}U	HASL-300 (U-02-RC) (5)	RPD<20% or RER<2	1 pCi/L	70-130%	75-125%
Total Uranium	EPA 200.8 ICP-MS	20%	0.1 µg/L	70-130%	80-120%
Chlorofluorocarbons (CFCs)	GC-ECD	0-2%	0.001×10^{-12} pmol/kg	NA	NA
Sulfur Hexafluoride (SF_6)	GC-ECD	1-3% (6)	0.01×10^{-15} fmol/kg	NA	NA

Notes:

1) Precision is the average standard deviation (1-sigma) in per mil units (‰). Precision limit applicable for matrix spike/matrix spike duplicate, laboratory duplicate, laboratory control sample/ laboratory control sample duplicate, or reference standard analyses.
2) The method detection limits presented are laboratory-derived limits.
3) TU = tritium unit; NA = not applicable; RPD = relative percent difference; RER = replicate error ratio; EA-IRMS = elemental analyzer-isotopic ratio mass spectrometer; ICP-MS = inductively coupled plasma mass spectroscopy; TIMS = thermal ionization mass spectrometer; GC-ECD = Gas Chromatography with Electron Capture Detection; % = percent
4) USGS Reston Stable Isotope Laboratory (RSIL) Lab Code 1951 (USGS 2006).
5) Method U-02-RC: see Isotopic Uranium in Biological and Environmental Materials for water samples as documented in HASL-300 (Rev. 1, February 2000) available at URL address: http://www.eml.st.dhs.gov/publications/procman/.
6) Wanninkhof et al. (1991); Law et al. (1994).
7) mg/L = milligrams per liter; µg/L = micrograms per liter; pmol/kg = picomoles per kilogram; fmol/kg = femtomole per kilogram; pCi/L = picocuries per liter.

Laboratory analytical results for hydrologic tracers achieved the completeness, accuracy and precision goals specified in relevant planning documents including the QAPP (ESI and BC 2009) and SOP-17. Hydrologic tracer information that relates directly to the groundwater recharge aspects of the HCSM and the background groundwater assessment was obtained in May 2012 and August 2014. These data are discussed in Section 5.0. Appendix H provides supplemental information about hydrologic tracer sampling and analysis including:

- A detailed discussion of the locations where hydrologic tracer samples were collected during May 2012, July 2013, and August 2014;
- Analytical results of hydrologic tracer samples of standing rain water impounded on mine waste features after a large rain event (average of 1.55 inches on-Site) on July 4, 2013;
- A detailed description of the sample collection procedures, analytical methods, laboratory precision goals for each hydrologic tracer, and QA/QC sample results;
- An evaluation and discussion of the limited usefulness of CFC and SF_6 data for estimating groundwater ages in the Study Area;
- A discussion of the principles and application of uranium isotopes to groundwater interpretation;
- A discussion of the principles of groundwater age estimation using data for tritium and tritium/helium in groundwater;
- A discussion of the additional sources of sulfate isotope data potentially relevant to groundwater conditions in the Study Area; and
- Electronic copies of the analytical results provided by the laboratory and laboratory-calculated apparent groundwater ages.

3.2.8 Bedrock Groundwater Characterization

Since 2005, phased field investigations associated with OU-1 have included characterization of both the alluvial and bedrock groundwater systems. The Revised Groundwater RI Work Plan (BC 2014a) presented available groundwater information through May 2012, and described an updated HCSM for the bedrock and alluvial groundwater systems. The Revised Groundwater RI Work Plan also outlined the approach for completing the bedrock groundwater study elements specified in the 2007 SOW. Bedrock characterization activities that were approved by EPA are described below in Table 3-9.

Table 3-9. Chronology of Bedrock Groundwater Characterization Activities

2004-2007	Bedrock characterization (including borehole drilling, lithologic logging, well installation, hydraulic testing, water level monitoring, and groundwater quality monitoring) conducted pursuant to the First-Step HFA Work Plan (BC 2005) and Second-Step HFA Work Plan (BC 2007b).
2007	Characterization of bedrock groundwater conditions is required under the Administrative Order for Remedial Investigation and Feasibility Study (RI/FS), CERCLA Docket No. 9-2007-0005 dated January 12, 2007.
2007-2011	Bedrock characterization (including borehole drilling, lithologic logging, well installation, hydraulic testing, water level monitoring, and groundwater quality monitoring) conducted pursuant to the *2010 Groundwater Monitor Well Work Plan - Revision 2* (BC 2010c), *Agricultural Fields Characterization Work Plan - Revision 2* (BC 2010d), *On-Site Monitor Well Installation Work Plan - Revision 1* (BC 2011a), and the *Addendum to the On-Site Monitor Well Installation Work Plan* (ARC 2011).
August 17, 2011	Groundwater technical meeting with EPA, ARC and stakeholders to discuss progress of the phased approach to groundwater RI activities, which resulted in concurrence to conduct initial bedrock characterization activities to support a more comprehensive assessment of bedrock groundwater conditions as part of the RI characterization.
September 29, 2011	EPA (2011a) provided comments on the *2010 Annual Site-Wide Groundwater Monitoring Report* dated April 15, 2011, and the First and Second Quarter (1Q and 2Q) 2011 Groundwater Monitoring Reports dated July 1, 2011 and August 26, 2011, respectively, that pertained to bedrock characterization.
January 5, 2012	ARC submitted the *Proposed Initial Bedrock Characterization Activities* (ARC 2012a).
April 12, 2012	EPA (2012c) provided comments on the *Proposed Initial Bedrock Characterization Activities* (ARC 2012a).
June 18, 2012	ARC submitted preliminary responses to EPA comments on the *Proposed Initial Bedrock Characterization Activities.*
August 28, 2012	Groundwater technical meeting with EPA, ARC and other stakeholders to resolve comments on the *Proposed Initial Bedrock Characterization Activities.*
October 11, 2012	Submittal of ARC final responses to EPA comments on the *Proposed Initial Bedrock Characterization Activities,* and submittal of the *Proposed Initial Bedrock Characterization Activities - Revision 1* (ARC 2012b).
October 22, 2012	EPA (2012d) approval of the *Proposed Initial Bedrock Characterization Activities - Revision 1,* included as Attachment D to the Revised Groundwater RI Work Plan (BC 2014a).
March 2013	ARC began implementation of the EPA-approved *Proposed Initial Bedrock Characterization Work Plan - Revision 1.*
November 20, 2013	ARC submitted the *Initial Bedrock Characterization Data Summery Report* (BC 2013c).
February 7, 2014	ARC submitted the *Site-Wide Groundwater Remedial Investigation Work Plan - Revision 1* (BC 2014a), which presented available groundwater information through May 2012, and described an updated HCSM for the bedrock and alluvial groundwater systems.
January 28, 2015	ARC submitted the *Bedrock Groundwater Assessment Technical Memorandum* (BC 2015a).
June 11, 2015	ARC submitted the *Additional Monitor Well Installation Data Summary Report* (BC 2015d) detailing installation and testing of bedrock and alluvial wells installed in 2013 and 2014.
July 31, 2016	EPA (2016a) approved the *Bedrock Groundwater Assessment Technical Memorandum* (BC 2015a).

After installation and testing of new bedrock monitor wells in late 2013 and 2014, and a technical meeting in May 2015 to discuss the full set of bedrock information, EPA (2015a) concluded that sufficient data had been collected to conclude that bedrock is not an important migration pathway

at the Site, and requested preparation of a technical memorandum to update the bedrock HCSM. The *Bedrock Groundwater Assessment Technical Memorandum* (BC 2015a) is provided in Appendix I and bedrock information is summarized in Section 4.9.

3.3 Site-Wide Groundwater Studies and Evaluations

Studies and evaluations relying on OU-1 RI data that were conducted to fulfill certain study elements specified in Section 7.0 of the SOW attached to the 2007 Order (EPA 2007a) are described below. Reports describing the approach, analysis, and results of these groundwater related studies and evaluations are provided in Appendix J.

3.3.1 Pumpback Well System Effectiveness

The effectiveness of the PWS in limiting the off-Site migration of mine-impacted groundwater was evaluated in accordance with the *Pumpback Well System Characterization Work Plan Addendum - Revision 2* (ARC 2010).

The 11 pumpback wells ceased pumping on March 25, 2009 and were subsequently hydraulically tested to generate information to support a capture zone analysis using an analytical element model. These activities provided a preliminary assessment sufficient to conclude that the PWS was only partially effective in capturing Shallow zone mine-impacted groundwater during its operational life. The PWS effectiveness evaluation is described in the *Summary of PWS Aquifer Testing* (BC 2010f), which is included as Appendix J-1.

3.3.2 Pit Lake Water Levels

The Pit Lake (OU-2), which is currently refilling with groundwater from bedrock and alluvial flow systems (BC 2014a), has been studied to better understand its influence on Site-wide groundwater conditions. Pit Lake studies related to OU-1 include routine monitoring of the Pit Lake water level elevation beginning in September 2007 and a water balance evaluation (Appendix J-2) to predict the future “steady-state” elevation of the Pit Lake.

Groundwater inflow, based on the lake water balance study, is estimated to be slightly greater than the current rate of evaporation. Thus, the lake level is slowly rising with time. The Pit Lake water balance and projection of the pit refilling curve (Figure 3-7) indicate that the lake is expected to reach a steady-state level, where water inflow and evaporation are balanced, prior to 2030. The steady-state Pit Lake elevation is estimated to be in the range of 4,249 to 4,253 feet amsl, with more recent data indicating that the steady-state elevation may fall within the lower end of this range. The steady-state Pit Lake elevation is approximately: 1) 100 feet lower than the pre-mining groundwater elevation range of 4,350 to 4,375 feet amsl reported by Gill (1951); 2) 140 feet lower than current groundwater levels in the alluvial aquifer adjacent to the Walker River just east of the Pit Lake; 3) 65 feet lower than the current groundwater levels beneath the Evaporation Ponds; and 4) 150 and 340 feet below the east and west pit rim elevations, respectively.

The steady-state Pit Lake level is projected to be lower than the pre-mining water level as the result of the significant evaporation that occurs from the Pit Lake surface. Consequently, the lake is and will continue to be a groundwater sink that creates a localized cone of depression (extending as far north as the Process Areas) with local groundwater flow toward the pit. Because the Pit Lake does not and will not in the future discharge into the Site-wide groundwater system, the Pit Lake is not a source of COIs to Site-Wide groundwater.

3.3.3 Groundwater Pumping and Surface Water Points of Diversion

Groundwater conditions in the Study Area are influenced by groundwater pumping and surface water diversion associated primarily with irrigation and, to a lesser extent, stock watering and mining/milling (BC 2014a; S.S. Papadopulos & Associates, Inc. [SSPA] 2014).

Publicly-available groundwater pumping and surface water diversion information applicable to the Study Area is provided in the *Revised Public Information for the Northern Portion of the Background Groundwater Study Area* (BC 2013d) included in Appendix J-3. That document also includes: well ownership, location and construction; underground and surface water rights and points of diversion (PODs); well pumping records from 1993 to 2010; sub-surface lithology and, as applicable, depth to bedrock; and groundwater elevations from the NDWR and the USGS.

PODs from an underground source (i.e., groundwater) for the wells with water rights within and adjacent to the Study Area are shown on Figure 3-8, along with diversion rates and annual duties. All agricultural wells within and near the Study Area are screened in the alluvial aquifer. Although well construction varies greatly, agricultural wells used to extract groundwater for crop irrigation are either screened beginning at or near the water table to the total depth of installation and/or have been installed with a permeable filter pack from above the water table surface to the total depth of installation. Annual pumping inventories (i.e., actual total amounts pumped each year) for wells in the Mason Valley from 1994 to 2003 and from 2004 to 2010 have been reported by Gallagher (2004) and Gallagher (2013), respectively.

Within the Study Area, there are 20 wells used for irrigation, four wells used for stock watering, one used for mining/milling, and one used for commercial purposes (Gallagher 2013). The 20 irrigation wells are currently permitted to irrigate a total of 5,509 acres using an annual duty of 15,788 acre-feet with a combined diversion rate of 46.36 cubic feet per second (cfs). Of the 36 active water rights, 26 allow for pumping to occur on a year-round basis, nine of the rights can only be pumped during the irrigation season, and one right can only be used in the winter.

The place of use (POU) of 37 surface water rights within and adjacent to the Study Area that are identified in the amended Walker River Decree (WRD), Case in Equity, C-125, filed April 24, 1940 (WRD C-125; WRD, 1940) are shown on Figure 3-9. This figure also shows the POUs of surface water rights approved by NDWR as either new appropriations or applications to change WRD rights. Additional information about the distribution and routing of surface water is included in the discussion of surface water hydrology in Section 4.7.

The POUs of flood waters permitted by NDWR Application 5528, Certificate 8859 are shown on Figure 3-10 by quarter-section. Application 5528 was filed by the Walker River Irrigation District (WRID) to divert flood waters from the Walker River for irrigation from May 1 to July 31 of each year. Application 5528 was certificated for 491.2 cfs, not to exceed 89,612 acre-feet per season (the total duty of water cannot exceed 4.0 acre-feet per acre per season from any and/or all sources). The lands irrigated under this Certificate during any one season cannot exceed 30,000 acres.

3.3.4 Groundwater Model Development

The 2007 SOW (EPA 2007a) specified that the OU-1 RI "extrapolate the future contaminant transport using a comprehensive groundwater flow and fate-and-transport model". In addition, determining groundwater flow and chemical transport rates was identified as DQO #6 in the Revised Groundwater RI Work Pan (BC 2014a).

The technical and programmatic framework to address quantitative numerical modeling of groundwater flow and chemical transport was developed during iterative technical discussions with the EPA, ARC, and other stakeholders, and documented in the Revised Groundwater RI Work Plan (BC 2014a). Table 3-10 summarizes the chronology of investigations, evaluations, communications, and documents related to groundwater flow modeling.

Table 3-10. Chronology of Groundwater Modeling Activities

2004-2007	Characterization of groundwater conditions in the Study Area pursuant to the First-Step HFA Work Plan (BC 2005) and Second-Step HFA Work Plan (BC 2007b).
2007	Characterization of bedrock groundwater conditions is required under the Administrative Order for Remedial Investigation and Feasibility Study (RI/FS), CERCLA Docket No. 9-2007-0005 dated January 12, 2007.
2007-2011	Characterization of groundwater conditions in the Study Area pursuant to the various work plans and related correspondence (BC 2008c, 2010c, 2010d, 2011a; ARC 2011).
May 16, 2011	Conference call with EPA, ARC and other stakeholders to discuss groundwater flow modeling.
August 17, 2011	Groundwater technical meeting with EPA, ARC and stakeholders to discuss the status of RI activities, which resulted in concurrence to conduct groundwater modeling to support a quantitative evaluation of groundwater flow and chemical transport.
June 4, 2012	Conference call with EPA, ARC and other stakeholders to discuss groundwater flow modeling activities, which resulted in a request by EPA that ARC submit a document describing key groundwater modeling deliverables and milestones, and a draft table of contents for a groundwater modeling work plan.
June 25, 2012	ARC submitted the *Groundwater Flow Modeling Deliverables* (ARC 2012c), which included: 1) a preliminary summary of key groundwater modeling deliverables and milestones; and 2) a draft table of contents for a groundwater flow model work plan.
July 11, 2012	EPA (2012e) provided comments on the *Groundwater Flow Modeling Deliverables* (ARC 2012c).
July 17, 2012	Groundwater technical meeting with EPA, ARC and stakeholders to discuss findings of the 2011 Monitor Well Installation investigation, and related RI activities, which resulted in an EPA request that ARC submit a document summarizing groundwater modeling objectives.
August 14, 2012	ARC submitted the *Objectives for Groundwater Modeling in the RI/FS Process, Yerington Mine Site* (SSPA 2012a).
August 29, 2012	Groundwater technical meeting with EPA, ARC, and other stakeholders to discuss the groundwater modeling objectives.
October 15, 2012	ARC submittal of the *Objectives for Groundwater Modeling in the RI/FS Process - Revision 1, Yerington Mine Site* (SSPA 2012b).
October 26, 2012	EPA (2012f) approval of the *Objectives for Groundwater Modeling in the RI/FS Process - Revision 1, Yerington Mine Site* (SSPA 2012b).

Table 3-10. Chronology of Groundwater Modeling Activities

December 28, 2012	ARC submittal of the *Draft Groundwater Flow Model Work Plan for the Yerington Mine Site* (SSPA 2012c).
March 29, 2013	EPA (2013d) provided comments on the *Draft Groundwater Flow Model Work Plan for the Yerington Mine Site* (SSPA 2012c).
May 21, 2013	ARC submittal of the *Groundwater Flow Model Work Plan - Revision 1* (SSPA 2013) included as Attachment E to the Revised Groundwater RI Work Plan, along with responses to EPA comments on the *Draft Groundwater Flow Model Work Plan* (SSPA 2012c).
March 18, 2014	ARC submittal of the *Groundwater Flow Model Yerington Mine Site* (SSPA 2014). This report synthesized available hydrologic and geochemical information into a quantitative representation of the current and historic HCSM. The report also contained: 1) documentation of the study goals; 2) a discussion of the modeling strategy and assumptions; 3) details about model construction, calibration and validation; 4) a summary of model predictions; and 5) an analysis of the uncertainty associated with the model predictions.
October 28, 2014	EPA provided comments on the *Groundwater Flow Model Yerington Mine Site* (SSPA 2014).
February 3, 2015	ARC submits the *Flow Model "Supplemental" Materials* (SSPA 2015) in response to EPA comments.
May 18, 2015	EPA (2015b) provided comments on the *Flow Model "Supplemental" Materials* (SSPA 2015) and approved the *Groundwater Flow Model Yerington Mine Site* (SSPA 2014).

Based on review of the *Flow Model Supplemental Materials* (SSPA 2015), EPA (2015b) constrained the modeling objective and approved the groundwater flow model, noting that: "The primary goal foreseen for the Yerington groundwater model is to provide a management tool that can be used to evaluate possible remediation options. As such, its greatest value will be in allowing short-term comparisons of remedial designs and possible effectiveness of different remediation scenarios using a common tool and less so in predicting long-term migration of contaminants. It appears that this tool is adequate for that purpose".

The groundwater flow model is provided in Appendix J-4. The flow model domain, which encompasses an area of approximately 86 square miles, consists of that portion of the Mason Valley west of the Walker River and north of Mason that is underlain by saturated alluvium (Regional Domain). Nested within the model domain is the Study Area which encompasses an area of approximately 23 square miles that is bounded to the north by Campbell Lane, to the west by the Singatse Range, to the east by a north-south trending line located one mile east of Highway 95, and to the southeast by the Walker River (Local Domain). The Local Domain is nested within the Regional Domain so that appropriate boundary conditions along the northern and eastern boundaries of the overall model domain can be calculated. In addition, the model domain is subdivided to reflect two different sources of data, which may differ in data quality.

The vertical extent of the model domain extends from the ground surface to the alluvial/bedrock contact and into the portions of the bedrock groundwater system in hydrologic communication with the alluvial aquifer. The model domain extends laterally to include monitor well locations for identifying background groundwater quality and groundwater impacted by mining and other anthropogenic activities.

Since 2005, hydrogeologic data within the Local Domain have been and continue to be collected as part of the RI process, pursuant to EPA-approved planning documents and work plans. Thus, these data are high quality and there is a high degree of confidence in the data. Hydrogeologic data from outside the Local Domain but within the Regional Domain are from multiple sources and are of uncertain quality. Much of these data are from the USGS (e.g., water-level data) and the NDWR (e.g., well logs).

Temporal (e.g., seasonal, annual) variations in groundwater flow patterns and chemical concentrations continue to be assessed due to variability in hydrologic stresses on the groundwater system. Monitor wells installed for groundwater characterization purposes continue to be routinely monitored pursuant to the GMP (BC 2012a) to address temporal aspects of the study within the Local Domain. Within the Regional Domain, available water-level and surface water flow data from the USGS and NDWR will be used to assess temporal variations in groundwater conditions.

3.3.5 Chemical Transport Evaluations

The technical and programmatic framework for characterizing groundwater geochemical conditions and assessing geochemical processes that affect the release and subsequent mobility or attenuation of COIs during groundwater transport in the Study Area was presented as DQO #3 in Revised Groundwater RI Work Plan (BC 2014a).

Table 3-11 summarizes the chronology of investigations, evaluations, communications, and documents related to chemical transport evaluation.

Table 3-11. Chronology of Activities to Determine Geochemical Mobilization/Attenuation Processes

2008	The Second-Step HFA Work Plan (BC 2007b) included collecting and archiving redox-preserved samples of saturated and unsaturated alluvium. EPA technical staff observed the redox-sample collection and archiving methods, and provided input on locations and depth intervals for collecting an initial set of samples. These initial samples were collected for use in a "methods development" phase of work intended to develop Site-specific testing procedures.
June 21, 2010	ARC submitted the *Draft Aquifer Solids Testing Work Plan* (BC 2010g).
September 13, 2010	EPA (2010a) provided comments on the *Draft Aquifer Solids Testing Work Plan* (BC 2010g).
September 21, 2010	ARC submitted the *Aquifer Solids Testing Work Plan - Revision 1* (BC 2010e), which was revised in response to EPA comments.
September 30, 2010	EPA (2010b) approved the *Aquifer Solids Testing Work Plan - Revision 1* (BC 2010e).
2011	ARC developed Site-specific procedures and methods to physically separate redox-preserved samples into solid and liquid fractions for subsequent characterization of total metals concentrations, mineralogy, and porewater chemistry.
February 28, 2012	EPA technical staff visited the testing laboratory (Hazen Research, Inc. in Golden, Colorado) and observed the Site-specific testing procedures.
August 17, 2012	ARC submittal of *SOP-23: Aquifer Solids Testing SOP - Redox-Preserved Sample Preparation and Testing* (BC 2012c).
September 26, 2012	EPA (2012g) transmitted comments on *SOP-23: Aquifer Solids Testing SOP- Redox-Preserved Sample Preparation and Testing* (BC 2012c).
October 15, 2012	ARC submittal of *SOP-23: Aquifer Solids Testing SOP - Redox-Preserved Sample Preparation and Testing - Revision 1* (BC 2012d).
October 22, 2012	EPA (2012d) approval of SOP-23 Revision 1, pending minor changes. These minor changes were incorporated into SOP-23 Revision 2*,* included as Appendix H-1 to the Revised Groundwater RI Work Plan (BC 2014a).
February 7, 2014	ARC submitted the Revised Groundwater RI Work Plan (BC 2014a), which included: 1) DQO #3 pertaining to geochemical attenuation/mobilization; 2) the thermodynamic data for Site-specific geochemical modeling; and 3) Site-specific distribution coefficients (a simple, lumped-parameter variable that describes either the relative affinity of the aquifer matrix for a particular ion or the mobility of the ion in a groundwater flow system) based on chemical concentrations in co-located aquifer sediment and groundwater samples.
October 9, 2014	EPA (2014b) approved the Revised Groundwater RI Work Plan including the thermodynamic data presented in Appendix H-4 for Site-specific geochemical modeling, and directed ARC to prepare a Groundwater Geochemical Characterization Data Summary Report.
December 30, 2014	ARC submitted the *Groundwater Geochemical Characterization Data Summary Report* (BC 2014c). As noted in ARC's transmittal letter, the document partially fulfilled the requirements for the geochemical characterization and ARC recommended additional refinements to the thermodynamic database for geochemical modeling.
April 27, 2015	ARC transmitted recommendations to EPA for refining the thermodynamic database to be used for geochemical modeling (via e-mail).
May 4, 2015	EPA approved ARC's recommendations on refining the thermodynamic database to be used for geochemical modeling (also via e-mail).
September 23, 2015	EPA, ARC and other stakeholders agreed during a conference call that geochemical characterization to be performed for the OU-1 RI should focus on geochemical modeling of: 1) controls on the fate and transport of key COIs anticipated to drive decision-making in the FS; and 2) other chemicals that may affect their mobility and transport in groundwater.
December 11, 2015	ARC submitted the *Groundwater Geochemical Characterization Data Summary Report – Revision 1* (BC 2015e).

Table 3-11. Chronology of Activities to Determine Geochemical Mobilization/Attenuation Processes

July 2016	EPA conditionally approved the document on July 31, 2016 (EPA 2016b) subject to minor editorial changes and revision of statements referencing COI concentrations and spatial extent relative to background chemical concentrations presented in the *Background Groundwater Quality Assessment - Revision 2* (BC 2015c). EPA recommended that a revised version of the report be included as an appendix to the OU-1 RI Report.

The *Groundwater Geochemical Characterization Data Summary Report - Revision 2* (BC 2016a) is provided in Appendix J-5. The chemical speciation model and approach to calculating Site-specific distribution coefficients is summarized below.

Chemical Speciation Model Development

The specific objectives of the *Groundwater Geochemical Characterization Data Summary Report - Revision 2* are as follows:

- Describe the occurrence and distributions of select chemicals in Study Area groundwater based on the comprehensive set of monitor well data obtained during August 2014; and
- Using the EPA-approved thermodynamic database developed for the Site and geochemical modeling, evaluate the aqueous geochemical speciation of select COIs and potential formation of solid mineral phases in Study Area groundwater to assess chemical mobility/attenuation.

The primary geochemical data inputs used to identify the geochemical processes controlling chemical transport consist of: 1) groundwater chemical data from monitor wells installed in the groundwater zones in the alluvial aquifer and bedrock; 2) field parameter measurements that characterize the pH and redox status of the groundwater system (because these affect the aqueous speciation of inorganic chemicals and formation of mineral phases); and 3) thermodynamic data describing chemical reactions for each of the important aqueous species, minerals comprising the aquifer solids, gases, and adsorbed species. The geochemical assessment primarily relied on groundwater information associated with the August 2014 groundwater monitoring event. Approximately 2% of the August 2014 dataset had speciated charge imbalances outside the acceptable range of ±10%, and groundwater data obtained in October 2014 were substituted for August 2014 data.

Geochemical modeling using the Site-specific thermodynamic database with PHREEQC version 3.1.5 was conducted to determine the chemical speciation of aqueous constituents and the saturation indices of solid mineral phases in equilibrium with the groundwater samples. The geochemical modeling did not involve adsorption to aquifer soil/sediments or organics in aquifer materials. Details regarding the development of the Site-specific thermodynamic database are provided in Appendix J-5 and key modifications are discussed briefly below.

The WATEQ4F database was used as the starting point for database development because its major-element data are consistent with the Nordstrom et al. (1990) data compilation, which is a reliable and internally-consistent data set. Subsequently, the WATEQ4F database was modified by replacing aqueous speciation and solid-phase solubility data for uranium, phosphate, vanadium, sulfide, arsenic and copper with new data that have been critically reviewed by federal agencies (e.g., compilations prepared by the Nuclear Energy Agency were the principal sources of the uranium data in the ARC database) or in the peer-reviewed literature (e.g., Dong and Brooks 2006). Uranyl species $Ca_2UO_2(CO_3)_3^0$, $CaUO_2(CO_3)_3^{-2}$, $Mg_2UO_2(CO_3)_3^0$ and $MgUO_2(CO_3)_3^{-2}$ are of particular importance in evaluating the mobility of uranium; therefore, the thermodynamic data for these constituents were added to the Site-specific database. Thermodynamic solubility data for schwertmannite (an oxyhydroxide sulfate mineral) reported by Bigham et al. (1996) and confirmed by Sánchez-España et al. (2011) were included in the database. In addition, thermodynamic solubility data reported by Bourrié et al. (1999) for three hydroxy-green rusts were included in the database.

PHREEQC is a geochemical software model distributed by the USGS. The model assumes equilibrium mass transfer and does not account for the kinetics of mineral precipitation and dissolution reactions using applicable reaction rate laws (Parkhurst and Appelo 1999; EPA 2007b). Chemical speciation modeling describes the distribution of chemical mass between aqueous and solid mineral phases, and hence, predicts the geochemical conditions under which various constituents might be sequestered by mineral precipitation or remain mobile in the groundwater flow system. Both chemical speciation and mineral precipitation are pertinent data for evaluating the mobility of constituents in the groundwater system.

Information generated from the geochemical assessment is incorporated into the discussion of contaminant fate and transport in Section 6.0, and will be used to guide the development of quantitative approaches to representing chemical transport in the numerical groundwater flow model (SSPA 2014) to evaluate various remedial alternatives during the FS. As noted by the EPA (2016b), decisions will be made during the FS regarding the most appropriate reactive transport modelling approach and whether it will be necessary and/or beneficial to integrate the models or how that can be accomplished to efficiently meet the technical needs of the OU-1 RI/FS without introducing unnecessary complexity to the modeling efforts.

Distribution Coefficients

The partition (distribution) coefficient (K_d) is a simple, lumped-parameter variable that is used to assess contaminant transport by describing either the relative affinity of the aquifer matrix for a particular ion or the mobility of the ion in a groundwater flow system (EPA 2007b; Freeze and Cherry 1979).

The initial approach to developing Site-specific distribution coefficients based on chemical concentrations in co-located groundwater and aquifer sediment samples was presented in the Revised Groundwater RI Work Plan (BC 2014a) and is reproduced in this OU-1 RI Report as Appendix J-6. The approach to developing the distribution coefficients is summarized below.

Distribution coefficients were calculated for a variety of chemicals in Site groundwater including aluminum, arsenic, barium, boron, calcium, chloride, chromium, cobalt, copper, fluoride, iron, lead, lithium, magnesium, manganese, molybdenum, nickel, nitrate, potassium, selenium, sodium, sulfate, uranium, vanadium, and zinc. Distribution coefficients were not calculated for parameters that were only infrequently detected in groundwater or are not likely to be the subject of FS transport modeling including alkalinity, antimony, beryllium, cadmium, mercury, phosphorous, silica, silver, strontium, thallium, tin, and titanium.

Site-specific distribution coefficients were calculated using data from a single set of soil samples that were collected during the borehole drilling for monitor well installation and two distinct sets of water quality data. Soil samples were analyzed for a variety of bulk chemical concentrations (analyses were performed on liquid extracts from treatment of the solid samples by microwave-assisted digestion using EPA Method 3051A).

The first set of water quality data used in K_d calculations was the zonal water quality data that were collected at the time of borehole drilling. As discussed in Section 3.2.1, zonal groundwater samples were analyzed only for sulfate, uranium and arsenic. These data were collected over small depth intervals, typically ranging from three to five feet. Co-located zonal groundwater and soil samples were collected at multiple depth intervals in 13 locations throughout the Site that included B/W-1, B/W-2, B/W-3, B/W-4, B/W-11, B/W-31, B/W-32, B/W-42, B/W-46, B/W-61, B/W-62, B/W-65, and B/W-66.

The second set of water quality data used in K_d calculations included groundwater quality data obtained during quarterly sampling events from 15 monitor wells typically having a screen interval length of 20 feet. Monitor well samples were analyzed for the broader set of constituents listed in Table 3-4. The soil sample data used in the calculations were selected such that the sample intervals were within the screened interval of the well. The wells considered in this portion of the analysis were B/W-2D1, B/W-3I, B/W-4I, B/W-4D1, B/W-11D2, B/W-31S1, B/W-31S2, B/W-32S, B/W-42S, B/W-46S, B/W-61S, B/W-62S, B/W-65S, B/W-66S, and B/W-67S. The quarterly groundwater quality results collected closest to the date of the zonal soil sample collection for each particular well were used to calculate K_d values to minimize potential effects from variability in groundwater concentrations over time.

The distribution coefficient is calculated as the ratio of the concentration of a chemical adsorbed onto the solid phase (commonly expressed as milligrams [mg] of chemical per kilogram [kg] of solid) to the dissolved concentration of the chemical in the water (mg of chemical per liter [L] of solution) at equilibrium (Freeze and Cherry 1979). Based on the formulation below, K_d values are expressed in units of L/kg.

$$K_d = \frac{C_{adsorbed}}{C_{water}}$$

where: $C_{adsorbed}$ = adsorbed chemical concentration (mg/kg)
C_{water} = dissolved chemical concentration in water (mg/L)

Initially, distribution coefficients were calculated using water chemical data and chemical concentrations in the aquifer sediment sample that were determined using EPA digestion Method 3051A. Because of the relatively aggressive digestion method, the aquifer sediment data represent the bulk (i.e., total) chemical concentration in the solid rather than the adsorbed chemical concentration. As recommended by EPA (1999), trace metals that are present in crystalline lattice sites of minerals present in soils do not participate in adsorption/desorption reactions and should not be included in the K_d calculation. Consequently, the original K_ds were revised for this OU-1 RI Report. To better estimate K_ds, the adsorbed amount of a chemical was estimated by subtracting the average chemical concentration in Sub-area A-1 soils (BC 2009b) from the bulk (i.e., total) chemical concentration in the individual aquifer sediment sample, as follows:

$$K_d = \frac{C_{soil} - C_{bkgd}}{C_{water}}$$

where: $C_{adsorbed} = C_{soil} - C_{bkgd}$
C_{soil} = bulk chemical concentration in the solid (mg/kg)
C_{bkgd} = average background chemical concentration in the solid (mg/kg)
C_{water} = dissolved chemical concentration in water (mg/L)

The revised Site-specific distribution coefficient values are presented in the contaminant fate and transport discussion in Section 6.0.

3.3.6 Background Groundwater Quality Assessment

Identifying background water types and defining the extent of mine-impacted groundwater was specified in the 2007 SOW (EPA 2007a) and identified as DQO #1 in the Revised Groundwater RI Work Plan (BC 2014a). The background groundwater quality assessment (BGQA) has been integrated into groundwater characterization activities performed in the Study Area since 2007.

Table 3-12 summarizes the chronology of the BGQA and other background-related orders, investigations and documents.

Table 3-12. Chronology of Activities Related to Establishing Background Groundwater Quality

2004-2008	Monitor wells B/W-13S, B/W-14S, B/W-15S, B/W-20S, and B/W-21S installed adjacent to Walker River and hydraulically up-gradient of the Site, pursuant to the First-Step HFA Work Plan (BC 2005) and the Second-Step HFA Work Plan (BC 2007b).
2007	Characterization of background groundwater quality is required under the Administrative Order for Remedial Investigation and Feasibility Study (RI/FS), CERCLA Docket No. 9-2007-0005 dated January 12, 2007.
2007-2011	Background characterization conducted pursuant to the *2010 Groundwater Monitor Well Installation Work Plan - Revision 2* (BC 2010c), *Agricultural Fields Characterization Work Plan - Revision 2* (BC 2010d), *On-Site Monitor Installation Work Plan - Revision 1* (BC 2011a), and the *Addendum to the On-Site Monitor Well Installation Work Plan* (ARC 2011).
August 17, 2011	Groundwater technical meeting with EPA, ARC and stakeholders to discuss progress of the phased approach to groundwater RI activities, which resulted in concurrence to accelerate background groundwater characterization activities and an EPA request for ARC to prepare and submit a BGQA. Also discussed were installation of additional well clusters (B/W-12R, B/W-17, and B/W-22R) in areas south and southwest of the Site, pursuant to the *On-Site Monitor Well Installation Work Plan* (BC 2011a), to support background groundwater characterization.
September 7, 2011	ARC submitted the *Addendum to the On-Site Monitor Well Installation Work Plan* (ARC 2011) proposing additional well clusters at B/W-12R, B/W-17, and B/W-26R to support background groundwater characterization.
September 28, 2011	ARC submitted the *Draft Background Groundwater Quality Assessment* (BC 2011c), which recommended the installation of three monitor well clusters (B/W-56, B/W-57 and B/W-58) located in the northern portion of the Study Area.
September 30, 2011	The *Addendum to the On-Site Monitor Well Installation Work Plan* (ARC 2011) was approved by EPA (2011b).
December 7, 2011	Via e-mail communication, ARC requests and receives EPA approval to install well clusters B/W-56, B/W-57, and B/W-58 proposed in the Draft BGQA during implementation of the *On-Site Monitor Well Installation Work Plan - Revision 1*.
February 7, 2012	EPA (2012a) provided comments on the Draft BGQA.
March 19, 2012	ARC (2012d) submitted a request to implement a comprehensive hydrologic tracer sampling event that was larger in scope than the sampling event proposed in the *On-Site Monitor Well Installation Work Plan - Revision 1* (BC 2011a) and to eliminate select hydrologic tracers. Hydrologic tracers are considered one line of evidence that may be useful for determining background groundwater quality.
April 18, 2012	ARC (2012e) submitted responses to EPA comments on the Draft BGQA.
April 27, 2012	EPA approved the comprehensive hydrologic tracer sampling event and request to eliminate select tracers (EPA 2012b).
May 2012	Comprehensive hydrologic tracer sampling event conducted concurrent with the 2Q 2012 quarterly groundwater monitoring event.
August 28, 2012	Groundwater technical meeting with EPA, ARC, and other stakeholders to clarify and resolve comments on the Draft BGQA.
November 19, 2012	Submittal of final ARC responses to EPA comments on the *Draft BGQA* and the *Background Groundwater Quality Assessment - Revision 1* as Attachment A to the *Draft Site-Wide Groundwater Operable Unit (OU-1) Remedial Investigation Work Plan* (BC 2012b).

Table 3-12. Chronology of Activities Related to Establishing Background Groundwater Quality

June 26, 2013	Submittal of the *Draft Additional Monitor Well Work Plan* (BC 2013e) as Attachment B to the *Draft Site-Wide Groundwater Operable Unit (OU-1) Remedial Investigation Work Plan* (BC 2012b), to address data gaps identified by ARC and EPA, including groundwater conditions in the north and northeastern portion of the Study Area. ARC recommended sampling of all wells proposed for hydrologic tracers to supplement data from the May 2012 hydrologic tracer sampling event.
July 29, 2013	EPA (2013e) provided comments on the *Draft Additional Monitor Well Work Plan*.
October 8, 2013	ARC submitted the *Additional Monitor Well Work Plan - Revision 1* (Additional Well Work Plan; BC 2013b). This work plan was also included as Attachment B to the Revised Groundwater RI Work Plan (BC 2014a). EPA (2014b) approved the Revised Groundwater RI Work Plan including Attachment B on October 9, 2014.
September 2013 to July 2014	Installation, development, and hydraulic testing of new wells installed pursuant the Additional Well Work Plan (BC 2013b).
August 2014	Hydrologic tracer sampling of new wells installed pursuant to the Additional Well Work Plan (BC 2013b).
May 2015	Receipt of hydrologic tracer laboratory analytical results for new wells installed pursuant to the Additional Well Work Plan (BC 2013b).
June 11, 2015	ARC submitted the *Additional Monitor Well Installation Data Summary Report* (BC 2015d).
July 2, 2015	ARC submitted the *BGQA – Revision 1 - Revision 2* (BC 2015c), which described: 1) the technical approach, scope, rationale and methods to establish background groundwater quality; and 2) multiple supporting lines of evidence for defining the extent of mine-impacted groundwater and identifying other anthropogenic groundwater impacts.
February 11, 2016	EPA (2016c) provided comments on the *Background Groundwater Quality Assessment - Revision 2*.
June 14, 2016	ARC (2016b) provided responses to EPA Comments on the *Background Groundwater Quality Assessment - Revision 2*.
June 29, 2016	EPA, ARC and other project stakeholders held a groundwater technical meeting to discuss the background assessment.
September 27, 2016	EPA (2016d) letter to ARC providing final direction on the background groundwater quality assessment including an attachment (EPA 2016e) dated September 2, 2016 and titled EPA Memorandum, Subject: Yerington Mine Site, Yerington Nevada (16-R09-003) Responses to ARC Responses to Comments on the Background Groundwater Quality Assessment - Revision 2.
November 11, 2016	ARC submitted the *Background Groundwater Quality Assessment - Revision 3* (BC 2016b).
February 16, 2017	EPA (2017) approved the *Background Groundwater Quality Assessment - Revision 3*.

The *Background Groundwater Quality Assessment - Revision 3* is provided in Appendix J-7 and the results of the background assessment are integrated into the discussion of the nature and extent of contamination in Section 5.0.

3.4 Former Domestic Well Monitoring and Bottled Water Programs

Water quality monitoring of domestic, commercial, and irrigation wells (collectively referred to as domestic wells) located near the Site has evolved over time.

Domestic well monitoring began in late 1983. Up through early 2009, domestic well monitoring activities were performed pursuant to:

- Paragraphs 15(e) and 15(f) of the Unilateral Administrative Order for Initial Response Activities, Docket No. 9-2005-0011 (2005 Order);
- Section 6.0 of the 2007 SOW; and
- The Administrative Order on Consent and Settlement Agreement for Removal Actions and Past Response Costs, Docket No. 09-2009-0010 (2009 Order).

In March 2009, EPA requested that ARC expand the domestic well monitoring program because of the EPA-approved shutdown of the PWS to evaluate OU-1 hydrogeologic conditions. The expanded domestic well monitoring program has been conducted pursuant to the *Domestic Well Monitoring Plan - Revision 3* (DWMP; BC 2010b), which was prepared as an addendum to the Site-Wide QAPP (ESI and BC 2009). Results of domestic well monitoring have been used to: 1) characterize the quality of groundwater used for drinking water or other domestic water supply purposes; 2) assess potential risk, if any, to human health and the environment by the use of groundwater extracted by domestic wells for drinking water or agricultural purposes; and 3) determine eligibility for receiving bottled water as part of an interim response action.

The Bottled Water Program was initiated in March 2004. Domestic well owners were deemed eligible to receive bottled water if uranium concentrations measured during domestic well monitoring exceeded 25 µg/L.

The number of wells/properties included in the DWMP and Bottled Water Program was substantially reduced in 2016 (ARC 2016a; EPA 2016f). As part of the settlement entered in the class action lawsuit *Roeder et al. v. Atlantic Richfield Company et al.*, D. Nev., Case No. 3-11-cv-00105-RCJ-WGC ("Roeder Settlement Agreement"), ARC provided funding to the City of Yerington to extend municipal water service to then-existing residences located within that part of the settlement class area that was also within the City's projected future service area. Domestic well owners who connected to the City of Yerington's municipal water system could elect to either abandon their well or apply for a state permit to authorize withdrawals of groundwater for outdoor use only (landscape watering). Each property owner who received a connection to the City Water System executed and recorded an environmental covenant either prohibiting future domestic use of groundwater altogether or limiting it to outdoor purposes.

Construction of the expanded water system began in the fall of 2014 and the construction of new mains and service connections was completed in June 2016. The first phase of well abandonments and system testing was completed as of August 1, 2016. The water system is functional, and domestic wells for all participating property owners have been abandoned or disconnected from the residences within the expansion area. A relatively small number of domestic wells located within the area of mine-impacted groundwater (see Figure 3-11) were not disconnected or converted to outdoor use only in 2016. ARC has been in communication with the owners of most of these wells, and disconnections for all but a few are scheduled to occur in 2017.

SECTION 4.0

PHYSICAL CHARACTERISTICS OF THE STUDY AREA

This section describes the physical characteristics of the Study Area including demographics, land use, climate, topography, geology and soils, hydrology and groundwater, ecological setting, and vegetation.

4.1 Demographics and Study Area Land Use

Lyon County, Nevada covers approximately 1,993 square miles, and its population in 2013 was 51,585 (U.S. Census Bureau 2015). Communities near the Site include Yerington (population 3,486), Weed Heights (population 500), and the YPT (approximate population 575). The regional population and industrial centers near the Site include Fernley (47 miles north), Fallon (59 miles northwest), Hawthorne (57 miles southeast), and Reno (85 miles northwest). Yerington's economic base is primarily agriculture.

Land use has included mine operations, ranching, agriculture, urban development, establishment of the YPT colony, BLM range land, and residential development. Mason Valley has long been the largest agricultural area in the Walker River basin and the most productive area in Nevada. In 2000, a total of 88,600 acres of irrigated land was mapped in the Walker River basin. Total irrigated land included 39,100 acres (44%) in Mason Valley (USGS 2009a).

4.2 Climate

Nevada is located on the leeward side (rain shadow) of the Sierra Nevada mountain range, which results in a dry climate. The climate in Lyon County is warm and arid. Snow melt is the primary natural source of streamflow and groundwater recharge in the Walker River Basin (USGS 2009b). The average annual precipitation in Yerington is approximately 5.1 inches, and average snowfall is 6.7 inches (Western Regional Climate Center [WRCC] 2015). The annual average precipitation rate is low relative to the regional pan evaporation rate of about 69 inches per year. The average monthly temperature for the period of record (March 1, 1894 through January 20, 2015) ranges from a maximum of 92.4 degrees Fahrenheit (°F) in July to a minimum of 17.8°F in January.

Tables 4-1 and 4-2 summarize monthly climate data for the City of Yerington weather station for the period from 1894 through 2015 (WRCC 2015). Table 4-1 summarizes monthly minimum and maximum temperatures, and monthly precipitation. Table 4-2 provides monthly average, maximum, and minimum precipitation values, and the one-day maximum rainfall event.

Table 4-1. Average Monthly Climate Data for the Yerington Weather Station #269229 (1894 - 2015)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Average Maximum. Temperature (°F) [1]	46.2	52.5	59.7	67.0	75.1	83.8	92.4	91.0	83.1	70.8	56.8	47.1	68.8
Average Minimum Temperature (°F) [1]	17.8	22.6	27.0	32.4	40.2	46.8	52.7	50.4	42.3	33.3	23.5	17.9	33.9
Average Total Precipitation[2]	0.57	0.53	0.42	0.41	0.63	0.46	0.26	0.25	0.24	0.35	0.42	0.52	5.06
Average Snow Fall [2]	1.9	1.2	1.0	0.4	0.1	0.0	0.0	0.0	0.0	0.1	0.8	1.2	6.7

Notes:
1) °F = Degrees Fahrenheit;
2) Precipitation values in inches

Table 4-2. Precipitation Data for the Yerington Weather Station #269229 (1894 - 2012)

Month	Mean	Maximum	Year	Minimum	Year	1-Day Maximum (Year)
January	0.57	3.67	1916	0.00	1915	1.40 (1943)
February	0.53	2.62	1962	0.00	1953	1.28 (1962)
March	0.42	1.83	1991	0.00	1914	0.98 (1941)
April	0.41	1.80	1990	0.00	1916	1.30 (1990)
May	0.63	3.04	1995	0.00	1916	1.90 (1939)
June	0.46	2.01	1997	0.00	1895	1.02 (1997)
July	0.26	2.00	2003	0.00	1916	1.75 (1984)
August	0.25	2.37	1983	0.00	1895	1.46 (1983)
September	0.24	2.15	1955	0.00	1920	2.02 (1955)
October	0.35	3.02	1993	0.00	1895	1.83 (1993)
November	0.42	2.39	1965	0.00	1894	1.04 (1974)
December	0.52	3.51	1955	0.00	1917	2.00 (1955)
Annual	5.06	10.58	1983	1.61	1947	2.02 (1955)

Notes:

1) Precipitation values presented in inches.
2) Most minimum values (11 of 12 months) of 0.00 inches were recorded prior to 1920.

Wind speed and direction at the Site vary on the local scale due, in part, to the heterogeneous natural topography (i.e., micro-climates) and modified topography due to surface mining operations. Meteorological data collected since 2002 indicate that wind direction is variable at the Site with no quadrant representing over 50% of the total measurements. However, when wind speeds are above 15 miles per hour, a predominant wind direction from southwest to northeast has been documented (BC, 2008c).

4.3 Topography

The Site is in Mason Valley, which is a north-south trending structural valley (graben) within the Basin and Range physiographic province filled with up to 1,000 feet of unconsolidated sediments. Mason Valley occupies a structural graben (i.e., down-dropped faulted basin) immediately east of the Singatse Range, Desert Mountains to the north, and the Wassuk Range to the east. Elevations in the Wassuk and Singatse Ranges reach 9,000 and 6,700 feet amsl, respectively (Huxel and Harris 1969). The valley ranges in width from about nine miles in the south to nearly 20 miles in the central part, and is about 40 miles long. The valley floor ranges from approximately 4,600 feet amsl in elevation at the south end to 4,290 feet amsl at the north end. The center of the Process Areas is at an elevation of approximately 4,450 feet amsl.

4.4 Ecological Setting

The Study Area is part of the Great Basin sagebrush-steppe ecosystem (Lopes and Allander 2009a). The Singatse Range to the west and the Mason Valley are dominated by a scrub brush community, except along the Walker River with s riparian community. These communities support resident and migrating birds, mammals, reptiles, amphibians and invertebrates. The Walker River flows within 0.25 mile of the southeastern end of the Site. Although riparian systems comprise an extremely small fraction of the Great Basin region, they are critical centers of biodiversity; more than 75% of the species in the region are strongly associated with riparian vegetation. The Study Area ecosystem has been impacted by anthropogenic activity, including mining, cattle ranching and agriculture. Site activities have resulted in the large piles of tailings and waste rock, which could be used as vantage points for predators surveying the surrounding area, and steep-sloped piles may potentially be used by nesting birds (e.g., swallows).

4.5 Vegetation

The terrestrial ecosystem in the Study Area not disturbed by anthropogenic activities supports an arid sagebrush-steppe vegetative community that is dominated by sagebrush and other low-lying woody vegetation, interspersed with a variety of forbs and grasses. The scrub brush community in the Study Area is predominately sparse greasewood, sagebrush, and rabbitbrush (Lopes and Allander 2009a). Livestock and wildlife preference for grasses contributes to the domination of vegetation in this system by sagebrush and other shrubs (Ricketts et al. 1999).

The riparian community along the Walker River supports a variety of trees, shrubs and grasses (USGS 2009b). Vegetation can be dense with large trees such as Freemont cottonwood, Russian olive, and invasive Tamarisk (Salt Cedar). Saltbush may be abundant where riverbank soil is saline. As previously stated, many areas on the Site have been disturbed to varying degrees by historical mining activities, but still retain areas of sandy soil interspersed with vegetation typical of the sagebrush-steppe vegetative mix of shrubs, forbs, and grasses. Mason Valley has long been the most agricultural part of the Walker River basin and remains one of the most productive agricultural areas in Nevada (Lopes and Allander 2009a). During the growing season, agricultural fields to the north may include onions, alfalfa, winter wheat and sorghum.

4.6 Regional and Site Geology

Mason Valley is a structural graben that has been filled with unconsolidated alluvial deposits derived by erosion of the emerging mountain horst blocks, and from materials transported into the valley by the East and West Walker Rivers (Huxel and Harris 1969). The alluvial apron and the valley floor are the two major land-forms comprising the lowland area. The mountain blocks, and bedrock beneath the basins, are primarily composed of granitic, metamorphic, and volcanic rocks of Precambrian to Tertiary age and, to a lesser extent, of consolidated to semi-consolidated sedimentary rocks of Paleozoic to Cenozoic age (Heath 1984; Proffett and Dilles 1984; Proffett 1977). Faults along the eastern margin of the Singatse Range are gently- to steeply-dipping normal faults that generally trend north-northeast (Figure 4-1) and dip to the east (Proffett and Dilles 1984; Proffett 1977). Faulting caused moderate to steeply westward tilting of the bedrock.

Unconsolidated deposits underlying the valley floor are collectively termed valley-fill deposits and, where saturated, constitute the valley-fill alluvial aquifer. Huxel and Harris (1969) reported that the valley-fill deposits include four stratigraphic units: 1) younger alluvium, including lacustrine deposits associated with Pleistocene Lake Lahontan (Reheis 1999); 2) younger alluvial fan deposits resulting from the uplift of mountain blocks; 3) older alluvium; and 4) older alluvial fan deposits.

Older and younger alluvial fan deposits are generally coarse-grained, poorly-sorted, and have relatively few inter-bedded clay lenses (Huxel and Harris 1969; Plume 1996; Mifflin 1988). The grain size of the valley-fill deposits generally decreases toward the center of Mason Valley (Huxel and Harris 1969; Plume 1996), and transitional facies have been identified in the Study Area (BC 2008c). Basin-scale variability in valley-fill deposits leads to variation in hydraulic properties of the alluvial aquifer, which is discussed in Section 4.9.6.

Bedrock and alluvial deposits in Mason Valley, and their associated hydrologic characteristics, are summarized in Table 4-3, which is reproduced from Huxel and Harris (1969). Lake Lahontan lacustrine deposits of Pleistocene age have been eroded or reworked by the Walker River as it meandered across Mason Valley. Lake Lahontan strandline units, consisting of beach, bar, and beach-ridge deposits, were formed for the most part on alluvial aprons between altitudes of 4,340 and 4,375 feet amsl (Huxel and Harris 1969). The occurrence of Lake Lahontan within Mason Valley had a relatively short life, and probably was less than 60 feet deep during much of its existence (Morrison 1964).

Table 4-3. Mason Valley Geologic Units: Lithologic and Hydrologic Characteristics (from Huxel and Harris, 1969)

Geologic Age		Geologic Unit		Thickness (feet)	Lithology	Hydrologic Characteristics
Quaternary	Pleistocene to Holocene	Valley Fill	Younger Alluvium	0-100±	Loose, well-sorted sand, gravel, cobbles, and boulders, with layers of silt or sandy clay. Comprises channel, flood-plain, and terrace deposits laid down by the Walker River and its major tributaries, plus strand-line and bottom deposits of Pleistocene Lake Lahontan. Bottom deposits consist of silt, fine sand, and clay.	Channel and flood-plain deposits are highly permeable and are good aquifers. Significant infiltration of surface waters, which recharges the alluvial-fill aquifer, occurs through the coarse deposits in the Holocene channels of the Walker River.
			Younger Fan Deposits	0-100±	Poorly-sorted gravelly clay, sandy clay, and fine sand with occasional stringers and lenses of sand and gravel. Locally, derived from erosion of older rocks and deposits in Mason Valley; generally equivalent to younger alluvium.	In general, younger and older fan deposits are of low permeability. However, stock watering and mining wells penetrating buried sand and gravel deposits yield small to moderate amounts of water. Properly constructed, large-diameter wells may yield up to several hundred gpm.
	Pleistocene		Older Fan Deposits	0-700±	Sandy- to gravelly-clay with abundant cobbles and boulders and occasional lenses of semi-consolidated to cemented sand and gravel. Locally-derived from erosion of consolidated rocks of the surrounding mountains. Equivalent in part to older alluvium.	
			Older Alluvium	0-500±	Similar in lithology to younger alluvium described above. Deposited by ancestral Walker River; underlies valley floor at depths greater than 100 feet. Not exposed at land surface.	Constitutes largest and most productive aquifer in the area, with tested transmissibility as high as 270,000 gallons per day/foot. Wells yield up to 3,000 gpm.
Tertiary	Miocene and Pliocene	Consolidated Rocks	Sedimentary Rocks	--	Sandstone, mudstone, shale, marl, diatomite, and limestone. Includes interbedded tuffaceous rocks, lava flows, and breccia.	Consolidated rocks generally have low permeability. However, where they are fractured or jointed, they yield small to moderate amounts of water to wells.
	Oligocene to Pliocene		Volcanic Rocks	--	Rhyolite flows and tuff, andesite and dacite lava flows, breccia, and agglomerate. Includes interbedded sedimentary rocks and, locally, thin basalt flows with interbeds and scoriaceous basalt breccia.	
Cretaceous			Granitic Rocks	--	Granodiorite, quartz monzonite, and granite porphyry.	
Permian to Jurassic			Metamorphic Rocks	--	Metamorphosed andesite, basalt, and rhyolite flows, tuff and breccia, metamorphosed limestone, lime shale, dolomite, and gypsum and volcanically-derived sedimentary rocks.	

Bedrock in the Study Area forms a U-shaped graben structure that reaches its lowest point beneath the north end of the Hunewill Ranch, at an elevation of approximately 3,600 feet amsl (700 feet bgs). The elevations of the alluvium-bedrock contact, shown in plan view on Figure 4-2, clearly depict this graben structure in the Study Area. From its lowest elevation, bedrock rises in elevation south toward the Site. The U-shaped graben ends at the open pit and the alluvial-bedrock contact is exposed on the pit walls. The bedrock exposed in the open pit is the host rock for the Yerington copper porphyry deposit. East and west of the Site, bedrock rises to mapped outcroppings associated with the Singatse Range (west) and Singatse Spur (east; this term refers to two adjacent bedrock outcrops located east of the Site called the Ground Hog Hills and McLeod Hills as shown on Figure 4-2. At the north end of the Study Area, bedrock outcrops occur in the Sunset Hills area. In the northeast portions of the Study Area (i.e., toward the Mason Butte bedrock outcrop), bedrock rises in elevation. Range-bounding faults in the Study Area include steeply-dipping and shallower-dipping normal faults (Proffett and Dilles 1984).

The unconsolidated alluvial deposits in the Study Area were derived primarily from erosion of the uplifted mountain block of the Singatse Range, with minor deposition of fluvial sediments in the Walker River flood-plain. In addition, lacustrine deposits derived from ancestral Lake Lahontan occur north of the Site (Reheis 1999). Uplift and erosion of the Singatse Range formed the east-dipping alluvial fan deposits, which include distal facies that extend into the transitional environment. Concurrent with the development of the alluvial fan, flat-lying fluvial sediments (e.g., sands and gravels) were deposited in the Walker River flood-plain. Flat-lying clay-rich deposits have been preserved in the transitional setting, and these deposits are interpreted to have formed within the ancestral Lake Lahontan depositional environment.

Regional metal mineralization and hydrothermal alteration occurs in portions of Mason Valley, and the Singatse Range in particular, in areas of localized porphyry and skarn copper deposits. The Yerington copper porphyry district is located within the productive Walker Lane mineralized belt in western Nevada (Tetra Tech 2010). The Walker Lane is a northwest-trending zone of active crustal movement (i.e., right-slip transcurrent faulting) that extends for more than 500 miles from Las Vegas, Nevada to beyond Honey Lake, California (Bell and Slemmons 1979).

In addition to the Yerington and MacArthur open pit mines along the eastern margin of the Singatse Range, other areas of mineralization include the Bluestone and Ann Mason mines, and the Bear deposit. Areas of known mineralization and ore deposits in the Mason Valley are shown on Figure 4-3. The Bear deposit is located beneath the Sulfide Tailings and Hunewill Ranch, in a structurally-uplifted segment of the Singatse Range. The Pumpkin Hollow copper skarn deposit, located across Mason Valley from the Site, occurs along the margin of the intrusive rocks that host the Yerington porphyry copper deposit.

4.7 Surface Water Hydrology

The Mason Valley Basin (Basin no. 108, as defined by the NDWR) is located within the larger Walker River Hydrographic Basin (no. 9). The Walker River Hydrographic Basin extends from the Sierra Nevada Mountain Range above Bridgeport, California and Topaz Lake to Walker Lake located north of Hawthorne, Nevada. Most streamflows in the basin originate as snowmelt in the Sierra Nevada, with headwaters at elevations of more than 12,000 feet amsl (Lopes and Allander 2009a, 2009b).

The Walker River originates in two distinct headwater areas in the Sierra Nevada that source the East and West Walker Rivers (Figure 3-6). The East Walker River is sourced above Bridgeport, California. Streamflows are regulated before flowing into the Mason Valley. The West Walker River is sourced above Topaz Lake, a reservoir located along the California-Nevada border, and passes through the town of Wellington, Nevada on its way to the Mason Valley. The confluence of the East and West Walker Rivers occurs in Mason Valley at a location approximately seven miles upstream (three miles directly south) of the Site. The main stem of the Walker River flows north past the Site at the City of Yerington, traverses the geothermal discharge area near the town of Wabuska, exits the north end of Mason Valley at Walker Gap approximately 4.5 miles east of the town of Wabuska, and then turns south and empties into Walker Lake (a terminal lake with no outlet).

4.7.1 Surface Water Flows

Mason Valley is the largest irrigated agricultural area within the Walker River Basin including irrigated areas along the West and East Forks, and the main stem, of the Walker River. Key documents providing information on stream flows and water budgets in the Mason Valley include Huxel and Harris (1969), Lopes and Allander (2009b), and Carroll et al. (2010).

Each of these three documents present information on streamflows and water budgets for different periods of time. Appendix G-1 presents surface water flow information for 1948 to 2001, a period longer than addressed in these three documents. Streamflow and water budget information from these three documents and Appendix G-1 are summarized in Table 4-4 and discussed below.

Table 4-4. Summary of Mason Valley Streamflow and Water Budget Information

	Huxel and Harris (1969)	Lopes and Allander (2009b)	Carroll et al. (2010)	Flow Data Appendix G-1
Period of Record	1948 - 1965	1971 - 2000	1996 - 2006	1948 - 2011
	18-year Average	30-year Average	11-year Average	48-year Average (1)
Stream Inflows (acre-feet) (2)	216,000	269,000	277,832	207,900
Stream Diversions (acre-feet)	140,000	117,000	139,643	NA
Stream Outflows (acre-feet) (3)	107,200	138,000	129,471	80,400
Total Stream Loss (acre-feet) (4)	109,300	131,000	148,361	127,500
Stream Loss as Percent of Inflow	50%	49%	62%	NA
Irrigated Area (acres)	30,000	38,964	38,721	NA
Surface Water Diversion Rate (ft/yr) (5)	3.6	3.4	3.8	NA
Groundwater Pumpage (acre-feet/yr)	4,000	40,000	77,423	NA
Groundwater Application Rate (ft/yr) (6)	0.1	1.0	2.0	NA
Crop Consumption Rate (ft/yr)	1.0	1.6 (7)	2.9 - 3.1	NA

Notes:

1) Excludes 1979 - 1994 because flow data were not collected during winter months (October through March).
2) Sum of streamflow at Hudson (East Walker River) and Strosnider Ditch (West Walker River) gages (USGS gages 10300000 and 10293500, respectively).
3) Streamflow at Wabuska gage (USGS gage 10301500).
4) Total Stream Loss = Stream Inflows - Stream Outflows.
5) Surface Water Diversion Rate = Total Stream Loss/Irrigated Area.
6) Groundwater Application Rate = Groundwater Pumpage/Irrigated Area.
7) Value of 1.6 ft/yr from Myers (2001) cited by Lopes and Allander (2009b).
8) ft/yr = feet per year; % = percent; NA = not available

Lopes and Allander (2009b) provide a surface water budget for Mason Valley based on data collected from 1971 to 2000. Combined average annual inflows to Mason Valley were estimated to be 269,000 acre-feet per year. The average annual outflow from Mason Valley was estimated to be 138,000 acre-feet per year. The average net annual diverted surface water in Mason Valley was estimated to be 117,000 acre-feet per year. Stream infiltration and riparian evapotranspiration was estimated to be 14,000 acre-feet per year (Lopes and Allander 2009b).

An analysis of Walker River streamflow data from 1948 to 2011 (Appendix G-1) indicates a median annual flow at the confluence of the East and West Walker Rivers of 207,900 acre-feet. The minimum recorded flow was 65,900 acre-feet per year, and the maximum recorded flow was 596,500 acre-feet per year. Outflows from the Mason Valley are recorded near Wabuska, north of the Study Area. The median annual outflow was 80,400 acre-feet. The minimum recorded outflow was 15,800 acre-feet per year. The maximum recorded out flow was 417,900 acre-feet per year. In all months of all years, combined flows at the confluence of the East and West Walker Rivers were greater than outflows from the Mason Valley, with greater differences observed in summer months compared to winter months. Differences between inflows and outflows are accounted for by seepage losses, evapotranspiration and diversions for crop irrigation.

The disposition and routing of surface water within the Mason Valley is complex. Detailed information is provided in appendices to the *Groundwater Flow Model Yerington Mine Site* (SSPA 2014).

4.7.2 Recharge to the Alluvial Aquifer

Percolation of surface water is the primary source of groundwater recharge to the alluvial aquifer in the Mason Valley, with mountain-front recharge contributing significantly less (Carroll et al. 2010; Huxel and Harris 1969; Myers 2001; SSPA 2014). The amount of recharge derived by infiltration from stream channels, ditches, and percolation from flooded agricultural fields varies from year to year, depending upon the volume of Walker River flow entering the basin, the amount of surface water diverted from the river for irrigation, and the amount of available groundwater storage.

Huxel and Harris (1969) estimated that the annual recharge from the sources listed above ranged from 30,000 to 100,000 acre-feet, with an average of about 70,000 acre-feet, for the period from 1948 to 1965. These estimates were calculated as inflows minus the sum of surface-water outflows and consumptive use by crops and pastures, and assumed that all stream flows not consumptively used for irrigation or flowing out of the valley recharged the valley-fill alluvial aquifer. Carroll et al. (2010) estimated that recharge from the sources listed above ranged from 60,400 to 99,400 acre-feet per year for the time period 1996 to 2006, and noted the consistency between their more recent estimates and those provided by Huxel and Harris (1969).

The groundwater flow model water budget (SSPA 2014) indicates that the alluvial aquifer is primarily recharged by downward percolation from irrigated fields (49%), leakage from irrigation ditches such as the West and East Campbell Ditches (29%), infiltration from the channel of the Walker River (20%), and infiltration through bedrock of precipitation that falls on surrounding mountain ranges and minor tributary surface flows in ephemeral drainages (2%). Recharge from precipitation falling directly on the valley floor is negligible based on work by Huxel and Harris (1969) and Lopes and Allander (2009a, 2009b), as well as data from stable isotope (i.e., oxygen/deuterium) analysis of precipitation and groundwater (BC 2014a; EPA 2012b).

4.7.3 Surface Water Quality

Surface water quality is discussed below with a focus on data at sample locations SW-WR-01 (Walker River) and SW-WCD-01 (West Campbell Ditch), and chemicals considered primary indicators of mine-impacted groundwater (i.e., sulfate and uranium). A detailed analysis of the surface water quality data is presented in Appendix G-2. Chemical concentrations in Walker River and West Campbell Ditch samples are similar with low total dissolved solids (TDS) (110 to 300 mg/L; average: 194 mg/L) and relatively low sulfate (7.7 to 54 mg/L; average: 29 mg/L) and dissolved uranium (3.7 to 19 µg/L; average 9.3 µg/L). Surface water pH is slightly alkaline (7.72 to 8.36 s.u.; average: 8.05 s.u.). Temporal trends indicate more elevated major ion (e.g., sulfate, calcium and chloride) values and trace metal (e.g., dissolved arsenic and dissolved uranium) values in samples at both locations during the winter months relative to the summer months. Overall, the STORET surface water quality data are similar to the surface water quality data collected by ARC.

Shallow alluvial groundwater near the Walker River and West Campbell Ditch exhibits similar chemical characteristics to surface water quality, which is the primary source of groundwater in Mason Valley (Carroll et al. 2010; Huxel and Harris 1969; Myers 2001; SSPA 2014). General ion chemistry in groundwater was found to be statistically similar to surface water for five of eight major ions. Calcium, chloride, and sulfate were found to be higher in groundwater than surface water. Dissolved metals in groundwater were found to be statistically similar to surface water for some parameters (14 of 27) but different for others (13 of 27). However, differences between surface water and Shallow alluvial groundwater in major ions and dissolved metals reflect changes in geochemical conditions in groundwater arising from the effects of residence time, presence (or absence) of dissolved atmospheric gasses, localized mineralization, and influences from land-surface features that alter groundwater quality as it recharges from surface water sources.

4.8 Mason Valley Regional Hydrogeology

Groundwater conditions in Mason Valley are based on: 1) general characteristics of groundwater flow for the Basin and Range province; 2) investigations specific to the Mason Valley and/or the Walker River Basin; and 3) groundwater data available from the USGS and/or NDWR. The general conceptual model for groundwater flow in the Basin and Range province (Heath 1984; Maurer et al. 2004) is movement of groundwater in unconsolidated sediments deposited within the basins that occur between uplifted mountain blocks comprised of consolidated bedrock.

The groundwater flow system in Mason Valley consists of: 1) a heterogeneous valley-fill alluvial aquifer system comprised of laterally-discontinuous confining units of clay or other low-permeability sediments, and unconfined (i.e., water table), semi-confined, and confined aquifers; and 2) a relatively impermeable bedrock flow system underlying and bounding the alluvial aquifer with limited primary permeability and groundwater flow focused along faults and fractures (Maurer et al. 2004; Thomas 1995; Tetra Tech 2010; Huxel and Harris 1969).

Groundwater in the alluvial aquifer within Mason Valley generally flows from south to north toward the topographically lowest part of the valley at the northern end of the valley (Figure 4-4).

Similar water-level patterns are depicted in Huxel and Harris (1969, Plate 2), Lopes and Allander (2009a, Plate 1), and Tetra Tech (2010, Figure 24-3). Locally, groundwater flow directions are affected by: 1) bedrock outcrops within and along the margins of the valley; 2) drawdown from pumped wells; and 3) irrigation activities on cultivated fields. The Walker River is generally a losing stream except in the far northeastern portion of the valley where it is generally a gaining stream. Water level elevations shown on Figure 4-4 are based on USGS monitor well data from October through December 2010 when agricultural pumping was limited or non-existent. Table 4-5 summarizes the USGS wells and water level data used to develop the water table (i.e., alluvial aquifer potentiometric surface) map shown on Figure 4-4.

Table 4-5. 2010 USGS Monitor Well Data for Mason Valley

USGS Site Number	Site Name	Latitude	Longitude	Surface Elev. (feet amsl)	Vertical Datum	Measure-ment Date	Depth to Water (feet)	Water Elev. NGVD29 (feet amsl)	Well Depth (feet bgs)	Boring Depth (feet bgs)	Number of Measurements
391655119330901	103 N16 E22 06ACD1 HIWAY 50	39.28200000	119.5524167	4352.1	NAVD88	10/13/10	55.4	4293.29	96	96	154
391729119294501	103 N17 E22 34DBDD1 EUREKA	39.29147220	119.4957500	4283.8	NAVD88	10/14/10	10.06	4270.35	35	35	101
391711119303301	103 N16 E22 04AAAD1 RA-4	39.28647220	119.5091667	4288.5	NAVD88	10/14/10	4.8	4280.30	14	14	69
391625119324801	103 N16 E22 07AAAA1 R-3	39.27352778	119.5468056	4303.9	NAVD88	10/14/10	9.07	4291.42	35	35	66
391605119331901	103 N16 E22 07ACCB1 R-2	39.26797220	119.5551389	4308.1	NAVD88	10/14/10	8.27	4296.41	30	30	64
384942119100801	108 N11 E25 10DBCD1	38.82802778	119.1703610	4565	NGVD29	11/23/10	98.14	4466.86	597	597	42
390715119095901	108 N15 E25 34ACDD1	39.12075170	119.1673767	4292	NGVD29	11/22/10	13.48	4278.52	370	370	41
390006119043901	108 N13 E26 09DBCC1	39.00158530	119.0784852	4396	NGVD29	11/24/10	60.37	4335.63	166	166	39
390011119060201	108 N13 E26 08CACA1	39.00297394	119.1015412	4367	NGVD29	11/24/10	21.88	4345.12	130	130	37
390127119030001	108 N13 E26 02BBCC1	39.02408569	119.0509851	4406	NGVD29	11/24/10	87.92	4318.08	203	203	36
390203119055101	108 N14 E26 32BDDD1	39.03408520	119.0984860	4352	NGVD29	11/30/10	13.56	4338.44	104	104	32
385903119073001	108 N13 E25 13DDDD1	38.98408457	119.1259859	4380	NGVD29	11/24/10	16.92	4363.08	280	280	32
390531119115901	108 N14 E25 08ADDC1	39.09186235	119.2007101	4320	NGVD29	11/22/10	30.73	4289.27	523	523	32
385720119085001	108 N13 E25 26DDCC1	38.95547285	119.1482085	4409	NGVD29	11/24/10	26.14	4382.86	160	NA	31
385255119090501	108 N12 E25 23DCC 1	38.88186075	119.1523750	4462	NGVD29	11/23/10	15.84	4446.16	325	325	31
385456119091901	108 N12 E25 11CACD1	38.91547224	119.1562641	4439	NGVD29	11/23/10	21.5	4417.50	245	245	31
390137119065402	108 N14 E26 31DCCC2	39.02686280	119.1159861	4357	NGVD29	11/30/10	13.44	4343.56	400	400	30
390558119094701	108 N14 E25 03DDDC1	39.09936270	119.1640431	4323	NGVD29	11/22/10	20.54	4302.46	85	258	30
390611119110301	108 N14 E25 04DACC1	39.10297367	119.1851545	4321	NGVD29	11/22/10	20.75	4300.25	451	451	30
385447119075901	108 N12 E25 12CDAA1	38.91297248	119.1340414	4476	NGVD29	11/23/10	59.94	4416.06	102	102	28
390004119103001	108 N13 E25 10CDB 1	39.00102868	119.1759868	4380	NGVD29	11/30/10	9.19	4370.81	328	328	27
390026119090401	108 N13 E25 11ACBD1	39.00714008	119.1520976	4370	NGVD29	11/24/10	13	4357.00	435	435	25
385717119080901	108 N13 E25 25CDDA2	38.95463960	119.1368194	4419	NGVD29	11/24/10	33.88	4385.12	106	106	21
385109119085601	108 N12 E25 35DCDD2	38.85241595	119.1498750	4505	NGVD29	11/22/10	35.38	4469.62	NA	NA	20

Table 4-5. 2010 USGS Monitor Well Data for Mason Valley

USGS Site Number	Site Name	Latitude	Longitude	Surface Elev. (feet amsl)	Vertical Datum	Measure-ment Date	Depth to Water (feet)	Water Elev. NGVD29 (feet amsl)	Well Depth (feet bgs)	Boring Depth (feet bgs)	Number of Measurements
385003119085201	108 N11 E25 11AACC1	38.83408240	119.1487638	4565	NGVD29	11/23/10	97.14	4467.86	256	256	19
390057119080001	108 N13 E25 01DBCC1	39.0157514	119.1343196	4365	NGVD29	11/19/10	19.96	4345.04	570	570	19
385047119080401	108 N11 E25 01ACCB1	38.84630495	119.1354302	4547	NGVD29	11/23/10	75.13	4471.87	526	526	18
385018119091101	108 N11 E25 02CDDD1	38.83813889	119.1538889	4544	NGVD29	11/23/10	73.59	4470.41	554	560	17
385718119101301	108 N13 E25 27DCCD2	38.95491700	119.1712645	4409	NGVD29	11/23/10	19	4390.00	440	440	17
390152119104401	108 N14 E25 34CBCA2	39.03102880	119.1798760	4362	NGVD29	11/30/10	25.56	4336.44	415	430	14
391741119150601	102 N17 E24 35DAAB1 OLD BUCKLANDS STATION	39.29472220	119.2516667	4203	NGVD29	10/12/10	16.23	4186.77	93	93	14
391610119115801	102 N16 E25 05DCCA1 USBLM	39.27464167	119.2004333	4219	NGVD29	10/12/10	70.24	4148.76	127	NA	12
391757119151801	102 N17 E24 35ACAA1 OLD WEEKS SIDING	39.29916667	119.3050000	4206	NGVD29	10/12/10	18.28	4187.72	23	23	11
392522119101901	102 N18 E25 15CBCA1 STUCCO	39.42288889	119.1718889	4213	NAVD88	10/12/10	57.72	4152.13	200	200	11
392546119121201	102 N18 E25 17BDAA TRAILER GRAVEYARD	39.42947220	119.2034167	4201	NAVD88	10/12/10	14.92	4182.94	170	170	11
392222119075101	103 N17 E25 01BAB1 E OF LAHONTAN	39.37283330	119.1307222	4202	NAVD88	10/12/10	61.18	4137.68	72	72	9
390416119112401	108 N14 E25 16DCCB1 CMPBLL SHALLOW	39.07097220	119.1900833	4336	NGVD29	11/22/10	20.14	4315.86	25	25	8
385249119221401	107 N12 E23 26ABAD1 85471	38.8803611	119.3706667	4729	NGVD29	11/18/10	13.76	4715.24	340	340	8
391727119190701	103 N17 E24 32CDBB1 BULL CANYON	39.29088889	119.3184722	4250.5	NAVD88	11/15/10	27.8	4219.363	41	41	8
391706119322601	103 N16 E22 05BACD1	39.28488889	119.5405556	4345	NAVD88	10/23/10	59.9	4281.691	182	182	8
391709119314001	103 N16 E22 04BBCB1 CARDELLI	39.28569444	119.5278333	4304.5	NAVD88	11/15/10	15.85	4285.244	39	39	2

Notes:

1) All groundwater elevation data downloaded from USGS website http://nwis.waterdata.usgs.gov/nv/nwis/gwlevels, accessed on August 15, 2011.
2) amsl = above mean sea level; bgs = below ground surface; NA = not available.

Hydraulic properties of the basin-fill sediments of Mason Valley vary both laterally and vertically because of variable depositional facies and environments observed in the valley. The transmissivity of the basin fill deposits was stated by Huxel and Harris (1969) to generally range from 6,700 ft^2/day to 27,000 ft^2/day. Based on an average basin-fill thickness of 500 feet, this is equivalent to average hydraulic conductivities in the range of 13 ft/day to 53 ft/day. Based on unspecified geotechnical investigations, Nork (1989) reported hydraulic conductivity values ranging from 0.35 to 0.50 feet per day (ft/day) for older alluvial fan deposits. Consolidated rocks beneath the unconsolidated basin-fill sediments and/or comprising the adjacent mountain ranges have low hydraulic conductivities, but may transmit water where fractures are open and interconnected (Lopes and Allander 2009a). Nork (1989) reported hydraulic conductivity values ranging from 0.23 to 1.5 ft/day for weathered intrusive rocks in the Mason Valley area.

Groundwater in Mason Valley is primarily recharged by downward percolation of surface water diverted from the Walker River to irrigation ditches and irrigated fields, downward percolation of groundwater applied to irrigated fields, and infiltration of surface water from the channel of the Walker River. To a lesser degree, valley-fill sediments are also recharged by mountain-front recharge (MFR), which includes a variety of hydrologic processes such as partitioning of precipitation and snowmelt into deep infiltration through bedrock (i.e., along faults and fractures), surface runoff, focused flow and subflow along mountain stream channels and alluvial fans, and diffuse movement of groundwater through the underlying mountain block (Wilson and Guan 2004; Huxel and Harris 1969; Myers 2001). Huxel and Harris (1969) considered recharge from direct precipitation on the valley floor to be negligible. Recharge from irrigation water and seasonal pumping of irrigation wells affects the vertical flow of groundwater in the alluvial aquifer (i.e., a seasonal increase in the downward vertical gradient in the alluvial aquifer).

Discharge from the Walker River Basin occurs as evapotranspiration from irrigated crops and natural vegetation (e.g., phreatophytes and wetland vegetation) as described by Heath (1984) and Carroll et al. (2010), and as direct evaporation from shallow groundwater (Huxel and Harris 1969; Lopes and Allander 2009a). Huxel and Harris (1969, Plate 2) identified an area of artesian

conditions (17 flowing wells) in the northern portion of Mason Valley where the alluvial aquifer thins and pinches out, and reported that groundwater in this area exhibited elevated specific conductance values (i.e., dissolved solids concentrations) due to evapoconcentration and possible effects of geothermal discharge associated with the Wabuska Lineament.

Lopes and Allander (2009a, 2009b) report that: 1) in 2008, no flowing wells were observed in the Wabuska area due to groundwater pumping; 2) water depths in this area were less than five feet, and efflorescent salts formed where groundwater evaporated from the shallow water table; and 3) pumping in Mason Valley since the early 1960s had caused groundwater levels to decline as much as 60 feet. The long-term decline in water levels is reflected in Site hydrographs for select monitor wells that cover the time period from 1985 to 2015, as shown on Figure 4-5. In addition to factors described above, the sharp decline in the 1980's in water levels in well UW-1S, located near the northern end of the Process Areas, is in part attributed to cessation of mining activities in 1978. Discharge of groundwater through bedrock from the Mason Valley Basin to other groundwater basins may occur, but is limited (Thomas 1995; Tetra Tech 2010).

4.9 Site and Study Area Local Hydrogeology

A generalized hydrogeologic south-north cross-section with a vertical exaggeration of 20V:1H is presented in Figure 4-7 (location shown on Figure 4-6). This cross-section (A-A') transects the Study Area and extends from well B/W-13S, which is the southernmost well in the Study Area, to a monitor well cluster, B/W-82R, which is located at the north end of the Study Area.

The south-north cross-section depicts: 1) the alluvial materials in the valley-fill alluvial aquifer within the Study Area; 2) the alluvial aquifer zone designations; 3) the occurrence of bedrock outcrops at the open pit and the north end of the Study Area; 4) the water table elevation in the alluvial aquifer in August 2015; 5) the depth of the open pit and the Pit Lake level in August 2015; and 6) the cone-of-depression associated with the open pit. The water table in the Shallow zone of the alluvial aquifer generally slopes toward the north on this cross-section, though the elevation of the water is relatively flat in much of the Site.

4.9.1 Depth to Groundwater

Contour maps of the depth to groundwater (i.e., depth to water table) below the ground surface in February 2015 and August 2015 are presented on Figures 4-8 and 4-9, respectively. February 2015 and August 2015 represent the non-irrigation and irrigation seasons, respectively. The depth to groundwater is typically less than 20 feet beneath irrigated areas such as the Hunewill Ranch and between monitor wells B/W-59S and B/W-68S. In areas beneath the Site, beneath the Sunset Hills neighborhood, and in the northern portions of the Study Area, the depth to groundwater is greater than 20 feet. To the west of the Site and beneath the Process Areas, the depth to groundwater exceeds 100 feet. Between February 2015 and August 2015, the depth to groundwater beneath irrigated portions of the Study Area as well as beneath the Evaporation Ponds uniformly increased by up to three feet (i.e., the water table declined) due to depletion of groundwater by agricultural pumping. Depth to groundwater fluctuations in other parts of the Study Area were minor.

4.9.2 Saturated Alluvial Thickness

The thickness of saturated alluvium in the Study Area in August 2015 is shown on Figure 4-10, which is similar in shape to the alluvium-bedrock contact map shown on Figure 4-2 (the similarity results from a relatively flat water table beneath the Study Area). On Figure 4-10, the line denoting the approximate lateral extent of saturated alluvium represents the zero-foot contour line (i.e., saturated alluvium does not occur outside of this contour line). Saturated alluvium is bounded to the west by the Singatse Range, to the northwest by the bedrock outcrops in the Sunset Hills area, to the northeast by the Mason Butte bedrock outcrop, to the east by the Singatse Spur, and to the south by the local bedrock high exposed within the open pit and, locally, by that portion of the Singatse Range located south of the Site. As shown on Figure 4-10, saturated alluvium is thickest (more than 700 feet) beneath the northern portion of the Hunewill Ranch.

4.9.3 Alluvial Groundwater

Potentiometric surface maps for the various alluvial aquifer zones in August 2015 are provided in Figure 4-11. Groundwater flow in August 2015 in the Study Area was generally to the north/northwest in the Shallow, Intermediate, and Deep 1 zones, and to the northeast in the Deep

2 through Deep 5 zones. Locally, the flow of groundwater in the Study Area is affected by: 1) the cone-of-depression around the Pit Lake, which is a hydraulic sink for alluvial and bedrock groundwater; 2) recharge sources such as the Walker River, the West Campbell Ditch and irrigation on the Hunewill Ranch; 3) bedrock in the Singatse Range to the west of the Site, which serves as a low flux boundary condition; 4) bedrock outcrops on the eastern margin of the Site (the Singatse Spur, comprised of the Ground Hog Hills and McLeod Hill), which impede groundwater flow from the West Campbell Ditch and the Walker River to the alluvium beneath the Site; 5) bedrock ridges north of the Site associated with the Sunset Hills and Mason Butte, which affect the direction of groundwater flow in the northeastern portions of the Study Area; and 6) drawdown from pumped wells (particularly in deeper zones of the alluvial aquifer).

As seen on the Shallow zone potentiometric surface map (Figure 4-11a), the Pit Lake is currently a hydraulic sink that is refilling with groundwater predominantly derived from alluvial groundwater recharged locally from the Walker River and, to a lesser extent, bedrock groundwater (Hershey 2002). As noted in Section 3.3.2, the lake is and will continue to be a groundwater sink due to the large amount of evaporation that occurs from the lake surface.

Saturated alluvium is in contact with the Pit Lake on the western margin of the open pit (Figure 4-11a). However, groundwater gradients in this area are toward the Pit Lake, and alluvial groundwater recharges the Pit Lake rather than the Pit Lake recharging the alluvial aquifer. On the eastern margin of the open pit, groundwater derived from seepage from the Walker River flows into the pit. Beneath the Process Areas, the Pit Lake cone-of-depression creates a groundwater divide in the Shallow zone (Figure 4-11a). Because of local bedrock elevations, only the Shallow, Intermediate, and a limited portion of the Deep 1 zones exist in this area (Figures 4-11 a through c, respectively).

North of the Site, recharge from the Walker River and its surface water diversions, as well as irrigation practices in the Study Area, are the primary influences on groundwater flow directions. In the Shallow, Intermediate, and Deep 1 zones, groundwater flow directions are away from, or parallel to, the Walker River and West Campbell Ditch (i.e., north/northwest), indicating recharge

of the alluvial aquifer from these features. In addition, groundwater mounding beneath irrigated areas is observed in these zones. As this recharged water percolates deeper into the Deep 2 through Deep 5 zones of the alluvial aquifer, the groundwater flow direction rotates to the northeast as relatively impermeable bedrock results in alluvial groundwater flow toward the trough in the alluvial-bedrock contact between the Sunset Hills and Mason Butte.

Irrigation practices on the Hunewill Ranch, located immediately north of the Site, locally affect groundwater flow conditions. Historically, irrigation practices on the Hunewill Ranch included seasonal diversion of surface water from the Walker River via the West Campbell Ditch and pumped groundwater, as necessary, from up to three wells. These three wells were located within 2,500 feet of the B/W-1 monitor well cluster and included Well Log No. 82983 (also referred to as WDW019), Well Log No. 26694, and Well Log No. 78925. Well WDW019 and other underground water rights points of diversion are shown on Figure 3-8. Groundwater pumping from the Hunewill Ranch wells to support agricultural irrigation ceased in September 2009. In 2011 and subsequent years, crops on the Hunewill Ranch were irrigated with surface water diverted from the Walker River and groundwater pumped from a nearby parcel located near the Walker River to the east. Additional information about these wells is provided in the *Aquifer Test Data Summary Report - Revision 1* (BC 2012e).

Potentiometric surface maps for the Shallow through Deep 2 zones (Figures 4-11a through 4-11d) have been outfitted with rose diagrams at select locations to illustrate seasonal changes in groundwater flow directions resulting from the historical and current irrigation practices on the Hunewill Ranch. Rose diagrams indicate the relative frequencies of groundwater flow directions over a period of time. Monthly groundwater flow directions were calculated by using water level measurements in sets of three monitoring wells to estimate the slope and direction of slope of a plane connecting the water levels in the three wells. This approach is commonly referred to as a "three-point problem" (EPA 2014c). Rose diagrams were generated for two time periods: 1) 2008 - 2009 to illustrate historical irrigation practices associated with operation of the Hunewill Ranch pumping wells; and 2) 2010 - 3Q 2015 to illustrate current irrigation practices.

Both historical and current irrigation practices for the Hunewill Ranch created a groundwater mound in the Shallow, Intermediate, and Deep 1 zones of the alluvial aquifer due to infiltration of applied irrigation water. Mounding was most pronounced beneath the Hunewill Ranch fields, and the mound extended beyond the edges of the fields including beneath the Wabuska Drain, which collects and diverts agricultural runoff. The rose diagrams for the Shallow, Intermediate, and Deep 1 zones (Figures 4-11a through 4-11c) indicate that, in both time periods, the mound beneath Wabuska Drain predominantly acted as a groundwater divide, directing recharged groundwater: 1) to the west/southwest beneath the Evaporation Ponds; and 2) to the east/northeast beneath the Hunewill Ranch. The rose diagrams also indicate that, in a small number of months, the groundwater divide was not present and groundwater flow directions were from the east beneath the Hunewill Ranch to the west beneath the Evaporation Ponds. This east-to-west flow predominantly occurred in winter months when irrigation was not occurring.

Historical irrigation practices for the Hunewill Ranch prior to 2010, which included seasonal groundwater pumping and surface application to the fields, created a cone-of-depression around WDW019 that was most pronounced in the Deep 1 through Deep 3 zones but was also manifested in the Shallow and Intermediate zones (BC 2014a). The cone-of-depression in the combined Deep 1 through Deep 3 zones extended beneath the Sulfide Tailings area and the Evaporation Ponds, and as far north as the Sunset Hills neighborhood. Figure 4-12 provides monthly water level hydrographs of Shallow and Deep monitor wells in the B/W-1 and B/W-27 well clusters (located beneath and adjacent to the Hunewill Ranch, respectively) that illustrate the hydraulic head drawdown during and after operation of the Hunewill Ranch pumping wells. Although agricultural pumping in the Study Area continues to affect hydraulic head in wells B/W-1D3 and B/W-27D2, hydraulic head drawdown in these wells was up to three times greater during operation of the Hunewill Ranch pumping wells than it has been in recent years.

The rose diagrams for the Deep 2 zone (Figure 4-11d) indicate that, under both historical and current irrigation practices, groundwater between the Site and the B/W-1 well cluster has been toward the northeast as the result of agricultural pumping, with occasional periods of northward groundwater flow corresponding with winter months when irrigation was not occurring. Beneath

the Evaporation Ponds, the rose diagrams indicate differing distributions of groundwater flow directions between historical and current irrigation practices. Groundwater flow directions in the Deep 2 zone beneath the Evaporation Ponds have been predominantly to the west/northwest in both time periods. However, the large cone of depression that was present during operation of the Hunewill Ranch pumping wells caused on-Site water beneath the Evaporation Ponds to occasionally flow east/northeast to off-Site areas beneath the Hunewill Ranch.

Figure 4-13 presents monthly vertical groundwater gradients in the alluvial aquifer at select locations. Vertical gradients were calculated as the difference in water levels between the shallowest and deepest alluvial monitoring wells in a cluster divided by the distance between the midpoints of the screened intervals of the wells. If a well was screened across the water table, then the water table elevation was used in place of the midpoint of the screened interval for that well. Monthly vertical gradients were calculated using water level measurements from 2013, which was the last full calendar year during which water levels in all active monitor wells were measured monthly. For wells installed after 2013 pursuant to the Additional Monitor Well Work Plan (BC 2013b), monthly vertical gradients were calculated using water level measurements from September 2014 through August 2015. Where available, monthly vertical gradients were also calculated using water level measurements from 2009 to illustrate groundwater conditions during operation of the Hunewill Ranch pumping wells.

Alluvial vertical gradients beneath the Process Areas are generally upward (PA-MW-4 well cluster), reflecting potential discharge of bedrock groundwater to alluvium as a potential source of groundwater to this portion of the Site (i.e., mountain-front recharge). Beneath the Evaporation Ponds (B/W-11 well cluster) and Hunewill Ranch (B/W-1 well cluster), alluvial vertical gradients are downward, with stronger vertical gradients corresponding to months when irrigation, and thus groundwater recharge and pumping, occurs. In addition, alluvial vertical gradients were even more strongly downward in these areas in 2009 when the Hunewill Ranch pumping wells were operating. In other irrigated areas (i.e., B/W-68 and B/W-81 well clusters), alluvial vertical gradients are also consistently downward, again with stronger vertical gradients in months when irrigation occurs.

Immediately northwest of the Site at the B/W-41 well cluster, vertical gradients are upward in the winter months, reflecting potential discharge of bedrock groundwater to alluvium (i.e., mountain-front recharge), and downward in the summer months, reflecting the influences of agricultural pumping. Downward vertical gradients at the B/W-41 well cluster are approximately two orders of magnitude smaller than the downward vertical gradients in irrigated areas, reflecting the greater distance of B/W-41 from irrigated areas. The B/W-28 well cluster (located in the Sunset Hills neighborhood) also exhibits seasonal changes in the direction of vertical gradients - upward vertical gradients occur in the winter (reflecting the non-irrigation season) and downward vertical gradients occur in the summer (reflecting the influences of agricultural pumping). In 2009, the effects of operation of the Hunewill Ranch pumping wells, in addition to other agricultural pumping in the Study Area, caused strongly downward vertical gradients that resulted in water levels in monitor well B/W-28S to decline below the bottom of the screened interval in August and September.

4.9.4 Groundwater Recharge

Recharge to the alluvial aquifer in the Mason Valley primarily occurs from surface water diverted from the Walker River within unlined irrigation ditches, infiltration of surface water and groundwater applied to irrigated fields, and infiltration of surface water from the channel of the Walker River. Recharge to the alluvial aquifer also occurs along the range front via a variety of hydrologic processes.

As indicated above, infiltration of surface water is the primary source of groundwater recharge to the alluvial aquifer in the Mason Valley, with MFR contributing significantly less (Carroll et al. 2010; Huxel and Harris 1969; Myers 2001; SSPA 2014). The annual amount of recharge derived by infiltration from stream channels, ditches, and agricultural fields is a function of Walker River flows, the volumes of surface water and groundwater used for irrigation, and water table depths within Mason Valley.

Hydrologic tracer data for tritium/helium ($^{3}H/^{3}He$) groundwater age estimates (Figure 4-14) and uranium isotopes (Figure 4-15) are consistent with the two principal recharge components of the HCSM: 1) seepage from the Walker River and irrigation ditches, and infiltration from irrigated fields on the east margins of the Study Area; and 2) MFR on the west side of the Study Area adjacent to the Singatse Range.

The use of groundwater uranium isotopes (and their relationship to tritium/helium groundwater age estimates) is briefly summarized as follows. In groundwater systems, ^{234}U is more environmentally mobile than ^{238}U due to physical recoil of the atom following alpha decay of ^{238}U, and the subsequent displacement of the ^{234}U atom to weaker binding sites within the crystalline lattice of the mineral in which it is contained. Thus, the two isotopes are released (weathered) at different rates, and the $^{234}U/^{238}U$ ratio is generally greater than unity in natural waters. Changes in the isotopic ratios (and uranium excess [Ue] values derived from the ratios) are assumed to be solely associated with transport/contact time between groundwater and aquifer solids. Consequently, high Ue values are associated with "long" periods of contact between groundwater and aquifer solids (i.e., "old" water) whereas low Ue values are associated with "short" periods of contact between groundwater and aquifer solids (i.e., "young" water). However, $^{234}U/^{238}U$ ratios in mine-impacted groundwater are also close to unity (resulting in low Ue values) because acidic process solutions leach both isotopes from ore material with equal effectiveness (Iles et al. 1995).

On the east side of the Study Area, Shallow zone alluvial groundwater directly recharged by surface water commonly exhibits younger, more modern age estimates and low Ue values. Low Ue values are also observed in mine-impacted Shallow zone groundwater beneath the Evaporation Ponds. In contrast, the older groundwater age estimates and highest Ue values commonly occur on the west side of the Study Area adjacent to the Singatse Range, in Deep alluvial groundwater, and in bedrock groundwater. An exception to the typical vertical distribution of higher Ue values and older groundwater age estimates is evident at the B/W-1 well cluster where younger groundwater age estimates and lower Ue values occur locally in the Deep groundwater zones.

This local pattern of Ue values and groundwater age estimates around the B/W-1 well cluster is consistent with the HSCM, which recognizes groundwater mixing due to agricultural pumping, especially former pumping at (which is located adjacent to the B/W-1 well cluster). Pumping at WDW019 has resulted in the migration of mine-impacted groundwater present beneath the Evaporation Ponds into the Intermediate and Deep zones of the alluvial aquifer beneath the Hunewill Ranch.

4.9.5 Alluvial Aquifer Hydraulic Property Data

Hydraulic conductivity values in alluvium from slug tests (Appendix F-1) range from 0.04 to 157 ft/day, with a median value of 6.8 ft/day. The 25th and 75th percentiles are 3.1 ft/day and 22.0 ft/day, respectively. Hydraulic conductivity values in alluvium calculated from an analysis of low-flow sampling data (Appendix F-2) range from 0.08 to 240 ft/day, with a median value of 18.4 ft/day. The 25th and 75th percentiles are 6.8 ft/day and 33.6 ft/day, respectively. Statistical analyses indicate that: 1) hydraulic conductivity values in each alluvial zone exhibit similar ranges, median values, and distributional shapes; and 2) hydraulic conductivity values throughout the alluvial aquifer are statistically equivalent in their distributions from zone to zone. Hydraulic conductivity estimates for the individual groundwater zone are provided in Table 4-6.

Table 4-6. Hydraulic Conductivity by Groundwater Zone (from Slug Test Data)

Zone	Median K (ft/day)	Standard Deviation (ft/day)	Count
Shallow	6	24	81
Intermediate	6	23	35
Deep 1	8	25	38
Deep 2	4	11	15
Deep 3	4	16	13
Deep 4	31	33	5
Deep 5	14	7	6
Bedrock	2	74	32

Notes: K = hydraulic conductivity.

Constant-rate testing of the eleven pumpback wells in 2010, which are screened in the Shallow zone (Appendix F-3), resulted in hydraulic conductivity estimates ranging from 0.9 to 47 ft/day (median of 9.4 ft/day). Slug testing of piezometers (33 in total, all screened in the Shallow zone) installed near the PWS, that were used as observation wells during constant-rate pumping tests of the 11 pumpback wells during 2010 (Appendix F-4), provided hydraulic conductivity estimates ranging from 1.1 to 83ft/day (median of 4.1 ft/day). Testing of five pumpback wells (PW-6, PW-7, PW-9, PW-10 and PW-11) in 2000 yielded hydraulic conductivity estimates that ranged from 6.4 to 33 ft/day, with a geometric mean of 16 ft/day, based on an assumed aquifer thickness of 50 feet (AHA 2000).

A constant-rate test of well WDW019, using an observation network of 93 monitor wells, resulted in estimated values for hydraulic conductivity and specific storage at 61 observation wells that exhibited pumping-related responses (Appendix F-5). Hydraulic conductivity values in alluvium derived from constant-rate pumping tests of WDW019 ranged from 4.9 to 1,200 ft/day, with a median value of 77 ft/day. The 25th and 75th percentiles are 38 ft/day and 195 ft/day, respectively. Five hydraulic conductivity values in bedrock ranged from 13.0 to 92 ft/day.

Specific storage values in alluvium from constant-rate pumping tests of WDW019 range from 1.45 x 10^{-8} to 1.46 x 10^{-3} $(\text{feet})^{-1}$, with a median value of 1.14 x 10^{-5} $(\text{feet})^{-1}$. The 25th and 75th percentiles are 5.16 x 10^{-6} $(\text{feet})^{-1}$ and 2.73 x 10^{-5} $(\text{feet})^{-1}$, respectively.

4.9.6 Spatial Variation in Hydraulic Conductivity

The spatial distributions of slug-test hydraulic conductivities in each alluvial groundwater zone are shown on Figure 4-16, and bedrock slug-test hydraulic conductivities are shown on Figure 4-17. Slug-test hydraulic conductivities represent the largest hydraulic conductivity dataset for evaluating spatial variation within the Study Area. To date, 295 measurements of hydraulic conductivity have been obtained using slug-test methods (Appendix F-1).

Although analysis of drawdown measurements during low-flow sampling of monitor wells has yielded more measurements of hydraulic conductivity than slug testing (318 measurements versus 295 measurements through August 2015), the approach has limitations that that do not capture the highest and lowest values of hydraulic conductivity in the Study Area. Due to the low flow rates used, measurable drawdown (i.e., drawdown exceeding 0.01 feet) does not occur during the sampling of many monitor wells that have sufficiently high hydraulic conductivities. In practice, hydraulic conductivities of greater than 100 ft/day cannot be determined with this method. Conversely, most monitor wells that have hydraulic conductivities less than 0.1 ft/day never achieve steady-state drawdown conditions during low-flow sampling (i.e., the water level in the monitor well continues to fall during the entire sampling period).

Spatial variation in slug-test hydraulic conductivities reflects the heterogeneous lithology of the alluvium underlying the Study Area. Alluvial slug-test hydraulic conductivities beneath the Site (i.e., beneath the Process Areas, Sulfide Tailings, and the Evaporation Ponds) are generally in the range of 1 to 10 ft/day, with some infrequent exceptions. To the west of the Site, along the margin of the Singatse Range, alluvial slug-test hydraulic conductivities extend into the range of 10 to 100 ft/day, with some locations still in the range of 1 to 10 ft/day. This trend continues north to towards the Sunset Hills. Beneath the Hunewill Ranch, alluvial aquifer slug-test hydraulic conductivity values generally range from 1 to 50 ft/day, with noted high conductivity exceptions at monitor wells B/W-60S, B/W-61S, and B/W-60D1.

Alluvial slug-test hydraulic conductivities near the Walker River (east of the Pit Lake) are generally higher than alluvial slug-test hydraulic conductivities beneath the Site, as evidenced by monitor wells B/W-13S, B/W-14S, B/W-15S, B/W-21S, and PLMW-2S. In this area, alluvial slug-test hydraulic conductivities are in the range of 10 to 50 ft/day. North of the Site and east of the West Campbell Ditch, alluvial slug-test hydraulic conductivities are also high, generally ranging from 10 to 100 ft/day or higher.

The spatial variability of alluvial slug-test hydraulic conductivity values reflects the varied depositional environments in Mason Valley, which are discussed in Section 4.8. The areas beneath the Site represent older fan deposits, which typically display lower permeability compared to the valley-fill sediments (i.e., younger and older alluvium). North of the Site, a transitional environment with higher permeability exists between the older fan deposits and the valley-fill sediments. Areas near the Walker River and generally to the east of West Campbell Ditch appear to represent valley-fill sediments, which exhibit the highest overall permeability. To the west of the Site, a narrow north-south trending band of higher permeability aquifer materials occurs along the flank of the Singatse Range, which represents coarser-grained alluvial fan materials eroded from the Singatse Range.

4.9.7 Bedrock Groundwater

The conceptual model of OU-1 bedrock groundwater flow conditions is based on regional and Site-specific information, including: 1) the lithologic and structural geology information presented in Proffett and Dilles (1984), and Proffett (1977); 2) a general understanding of bedrock groundwater flow in the Great Basin portion of the Basin-and-Range Physiographic Province; 3) hydrogeologic information obtained from drilling, lithologic logging, testing, and monitoring of 67 bedrock groundwater monitor wells located in the OU-1 Study Area (typically installed with 20-30 foot long screen intervals positioned in the upper 50 feet of bedrock); 4) evaluation of hydraulic head data in the bedrock and alluvial groundwater systems; 5) hydrologic tracer data for stable isotopes of oxygen and hydrogen in water ($^{18}O/^{2}H$), tritium/helium ($^{3}H/^{3}He$) groundwater age estimates, and uranium isotopes; and 6) bedrock monitor well chemical data.

As noted previously, the Site and surrounding Study Area are in a U-shaped graben structure on the western margin of Mason Valley. Within the Study Area, the depth to bedrock is highly variable and ranges from 0 to 750 feet bgs. Bedrock within the Mason Valley and Study Area is comprised of consolidated granitic, metamorphic, and volcanic rocks. The bedrock groundwater system consists of a fractured rock aquifer where water moves predominantly through fracture porosity, and matrix permeability is considered negligible. The fractures occupy only a small fraction of the bedrock.

Large-scale geologic structures (i.e., faults) result in structural compartmentalization of the bedrock groundwater system in the Study Area, with limited groundwater flow across and along faults that are commonly characterized as containing fine-grained, low-permeability fault gouge and brittle or plastic clay. The fractured rock aquifer exhibits high, three-dimensional (i.e., anisotropic) spatial variability in hydraulic conductivity (and hence groundwater flow rate). Hydraulic conductivity (K) values in bedrock monitor wells have been derived from slug tests performed after the wells were constructed, and from an analysis of low-flow sampling of bedrock monitor wells during groundwater monitoring activities (BC 2015a). Both methods yield comparable results. In addition, both methods provide estimates of hydraulic properties local to the test well and, consequently, are primarily used to assess the spatial distribution of bedrock hydraulic properties in the Study Area. Mapping of the hydraulic conductivity values indicate a high degree of spatial variability with significant changes (often greater than three orders of magnitude) over distances that are small relative to the size of the Study Area.

In bedrock, estimated conductivities range from approximately 0.002 to 334 feet/day, with the higher values measured in wells located near faults and the open pit (Figure 4-17). The 25th and 75th percentiles were 0.15 and 11.7 feet/day, respectively. The median bedrock slug-test K value was 1.7 feet/day. The lowest bedrock K values are up to two orders of magnitude lower than the lowest K values in alluvium in the Study Area. The minimum measured low-flow sampling K value in bedrock was 0.013 feet/day, and the maximum value was 67 feet/day. The 25th and 75th percentiles were 0.485 feet/day and 16.6 feet/day, respectively. The median bedrock low-flow sampling K value was 4.3 feet/day. Consistent with the slug-test data set, the lowest K values in bedrock are up to two orders of magnitude lower than the lowest K values in alluvium in the Study Area.

Similar water level responses in paired bedrock/alluvial monitor wells at any given location throughout the Study Area result from: 1) the interconnectivity between the bedrock and overlying alluvial groundwater flow systems (except locally around the B/W-1 well cluster where an aquitard separates the two flow systems); and 2) the transmission of stresses through the skeletal structure

of the aquifer solids. Seasonal fluctuations in bedrock groundwater levels (and vertical gradients between the bedrock and alluvial groundwater systems) due to agricultural pumping from the alluvial aquifer are observed beneath the Hunewill Ranch and Evaporation Ponds, and in the Sunset Hills area. Both the bedrock and alluvial groundwater systems exhibit similar long-term water level declines.

Vertical interconnection between bedrock and overlying alluvial groundwater is indicated by water level data (and the presence of locally-elevated concentrations of sulfate and uranium in bedrock groundwater that are sourced from overlying mine-impacted alluvial groundwater). Spatially, vertical gradients between bedrock and alluvium generally reflect the recharge components of the alluvial groundwater HCSM (BC 2014a), with downward vertical gradients east and north of the Site driven by recharge of surface water and irrigation water on crop fields, and upward vertical gradients in western portions of the Study Area driven by mountain-front recharge.

The largest vertical gradients between bedrock and alluvium occur: 1) within the Pit Lake cone of depression; and 2) beneath the Hunewill Ranch fields and Evaporation Ponds. In all other portions of the Study Area, vertical gradients between bedrock and alluvium are relatively small. Seasonal crop irrigation effects are observed near the Hunewill Ranch fields, Evaporation Ponds, and Sunset Hills, as represented by locations with both upward and downward vertical gradients.

Stable isotopes ($^{18}O/^{2}H$) in bedrock groundwater are generally more depleted with respect to Walker River surface water and alluvial groundwater (BC 2014a). The most depleted stable water isotope signatures in the bedrock groundwater are associated with the oldest apparent groundwater ages, as determined by $^{3}H/^{3}He$ age dating (Figure 4-18). The youngest groundwater ages are associated with the least depleted bedrock groundwater samples, which also overlap the region of cool season Walker River flows. Walker River samples display an evaporative fractionation signature, with less fractionated values occurring during periods of snowmelt runoff and more fractionated values occurring during periods of lower flows during the summer.

The greater degree of $^{18}O/^{2}H$ depletion of bedrock groundwater compared to the alluvial aquifer and Walker River surface water suggests different recharge processes. The depleted stable isotope signature indicates that bedrock groundwater is: 1) sourced from snowmelt recharged directly in the Singatse Range, which does not undergo the same evaporative fractionation as Walker River water, and/or fossil water recharged during the Pleistocene (a cooler and more humid climate than the current climate); and 2) older and of a different origin than surface water and alluvial groundwater. Bedrock groundwater ages are older than 1954, and essentially pre-date Site mining activities, occur throughout most the Study Area. Younger bedrock groundwater within and downgradient of the Singatse Spur, proximal to the Walker River, exhibits isotopic similarities between younger bedrock groundwater and cool season Walker River water.

Although groundwater ages exhibit some degree of spatial association, groundwater ages are not correlated with hydraulic conductivity. The widespread occurrence of older groundwater ages and localized occurrence of younger groundwater ages, irrespective of hydraulic conductivity, suggests slow and limited movement of bedrock groundwater. The spatial distribution of Ue values generally comports with the spatial distribution of $^{3}H/^{3}He$ groundwater ages. This pattern of widespread higher Ue values (i.e., "old" water) with localized areas of lower Ue values (i.e., "young" water), irrespective of hydraulic conductivity, again suggests slow/limited movement of bedrock groundwater.

In addition to a high degree of anisotropy in hydraulic characteristics and hydrologic tracer signatures, the bedrock groundwater system also exhibits three-dimensional (i.e., anisotropic) spatial variability in chemical concentrations. As noted in Brown and Caldwell (2014a) and discussed further in Section 5.0, concentrations of mine-related chemicals in groundwater are most elevated in the Shallow zone of the alluvial aquifer beneath the LEP, UEP, Finger Ponds, Phase IV VLT HLP, and Phase IV VLT Pond. COI concentrations decrease with vertical depth and horizontal distance from the Site sources, resulting in values in bedrock groundwater that are one to several orders of magnitude lower than the values in overlying alluvial groundwater.

In addition, areas of elevated COIs in bedrock groundwater are small in comparison to the alluvial aquifer, highly localized, and found mostly on-Site. The localized areas of elevated COI concentrations in bedrock groundwater indicate that bedrock fractures have limited hydraulic connectivity and transmissivity over horizontal distances relevant to the scale of the Study Area.

Collectively, the bedrock characterization information indicates: 1) a high degree of vertical hydraulic connection between the bedrock and alluvial groundwater systems; and 2) limited horizontal hydraulic connectivity and transmissivity of bedrock fractures, especially over horizontal distances that are relevant to the scale of the Site and the surrounding Study Area. Despite localized areas of relatively high hydraulic conductivity, bedrock groundwater flow velocities, average volumetric flow rates and chemical fluxes through the bedrock groundwater system are low.

SECTION 5.0
NATURE AND EXTENT OF GROUNDWATER CONTAMINATION

Identifying background groundwater quality and defining the extent of mine-impacted groundwater have been elements of the phased OU-1 groundwater characterization activities since 2005. This activity, referred to as the background assessment, was specifically identified as DQO #1 in both the draft and final versions of the remedial investigation work plans for OU-1 (BC and Integral Consulting, Inc. 2007 and BC 2014a, respectively).

5.1 Background Assessment Approach

The conventional approach to a background assessment described by EPA (2012a) involves obtaining groundwater chemical data from areas that were not impacted by Site sources to establish background chemical concentration ranges and background concentration limits (BCLs) for the COIs. Typically, the chemical concentration data are obtained from locations that are hydraulically upgradient or cross-gradient of Site sources. However, EPA and ARC recognized that there are constraints to relying solely on this conventional, statistical approach at the Site because locations where background wells can be installed hydraulically upgradient or cross-gradient of the Site sources do not fully account for all of the factors affecting groundwater quality downgradient of the Site, such as the following: 1) naturally-occurring variations in groundwater chemistry associated with geologic formations; 2) chemical inputs associated with application of agricultural fertilizers (e.g., nitrate and sulfate) and/or crop irrigation (e.g., uranium and sulfate); 3) increases in dissolved chemical concentrations associated with longer periods of contact between groundwater and aquifer sediments (i.e., longer groundwater residence times); and 4) spatial variations in groundwater flow conditions and the groundwater geochemical regime, which affect dissolved chemical concentrations.

Consequently, multiple lines of evidence are used to differentiate background groundwater quality from mine-impacted groundwater, including:

- Hydrogeologic Conceptual Site Model: The hydrogeologic information defines the current and plausible historic groundwater flow and chemical transport pathways, and related anthropogenic activities (including mining and agriculture). The HCSM: 1) incorporates observed temporal variations in groundwater flow conditions and chemical concentrations in groundwater based on an extensive Site-wide groundwater monitoring network, aquifer testing, and a groundwater flow model; and 2) constrains how chemical distributions in groundwater can be reasonably interpreted and related to mining and agricultural activities.
- Contoured Chemical Distributions: Chemical distributions outline distinct plumes of off-Site impacted groundwater that have physical continuity along plausible flow pathways linked to Site features that are known sources of groundwater impacts. Other areas where chemicals occur in groundwater at concentrations above Maximum Contaminant Levels (MCLs), such as the North Study Area (NSA; i.e., that portion of the Study Area located northeast of the West Campbell Ditch and north of Sunset Hills), are separate from and do not physically connect along groundwater flow pathways to the Site.
- Sulfur Isotope Signatures: Distinct sulfur isotope ($\delta^{34}S_{SO4}$) signatures associated with sulfate in the acidic process leach solutions are used to differentiate mine-impacted groundwater from groundwater that is unaffected by mining operations, and to delineate the extent of groundwater contamination associated with mining. Specifically, the extent of mine-impacted groundwater is constrained where the $\delta^{34}S_{SO4}$ value in alluvial groundwater downgradient of the Site exceeds the minimum background value of +4.93‰ at locations that are within predominant recharge areas to the alluvial aquifer. Such background areas of the alluvial aquifer are also consistent with contoured or numerically-modeled flow pathways from the Site.
- Conventional Approach: The conventional approach to defining background groundwater quality for the Site (EPA 2012a) relies on chemical data from the background monitor wells and EPA-recommended statistical procedures (EPA 2009) to calculate BCLs for COIs. BCLs are computed for each COI in three geographic recharge areas identified in the Study Area HCSM: 1) the Southeast Recharge Area (SERA) - representing recharge by infiltration and percolation of water associated with streams, ditches and agricultural fields; 2) the Southwest Recharge Area (SWRA) - representing mountain-front recharge; and 3) the NSA - representing groundwater lateral to the Site flowing into the NSA.

The BCLs are used for two purposes. BCLs for sulfate and dissolved uranium in the SERA and SWRA are used to confirm the extent of mine-impacted groundwater defined by $\delta^{34}S_{SO4}$ signatures. Sulfate and dissolved uranium are suitable chemicals for this purpose because these two chemicals are typically more mobile in groundwater relative to other indicators of mine-impacted groundwater such as iron and other metals (BC 2014a; EPA 2010d). BCLs are computed for other COIs, which can then be used to define areas within the extent of mine-impacted groundwater where chemical concentrations exceed background chemical concentrations.

Because the NSA BCLs characterize groundwater quality flowing into the NSA, they are not used to define the extent of mine-impacted groundwater but can instead be used to evaluate chemical loading to groundwater due to agricultural practices in this part of the Study Area. The steps identified in the BGQA - Revision 3 (BC 2016b) for performing the background groundwater assessment are illustrated on Figure 5-1 and summarized in Table 5-1.

Table 5-1. Site-Wide Background Groundwater Quality Assessment Approach

Step	Information Source(s)
Obtain and evaluate available OU-1 hydrogeologic and geochemical data with respect to data quality and relevance.	▪ Brown and Caldwell (BC 2014a) ▪ Brown and Caldwell (BC 2015e)
Refine the HCSM based on recent information obtained in 2013 and 2014 from existing wells and new wells installed pursuant to the Additional Well Work Plan (BC 2013b).	▪ Brown and Caldwell (BC 2015d) ▪ Brown and Caldwell (BC 2016b). Summarized below; see Section 3.0 in Appendix J-7 for details.
Define hydrogeologic areas that are considered representative of background conditions and/or other water quality types.	▪ Brown and Caldwell (BC 2016b). Summarized below; see Section 3.0 in Appendix J-7 for details.
Specify the types and quality of RI groundwater data selected as relevant and appropriate for the background assessment.	▪ Brown and Caldwell (BC 2016b). See Section 4.0 in Appendix J-7 for details.
Use hydrologic tracer results to refine the HCSM, especially as the results relate to the information inputs identified in DQO #1 for the background groundwater assessment. Use $\delta^{34}S_{SO4}$ signatures to differentiate mine-impacted groundwater from groundwater impacted by other anthropogenic activities.	▪ Brown and Caldwell (BC 2016b). Summarized below; see Section 6.0 in Appendix J-7 for details.
Establish quantitative background concentration ranges and calculate groundwater BCLs for each background area. Use sulfate and uranium BCLs to evaluate the extent of mine-impacted groundwater. Use BCLs for other COIs to define areas within the extent of mine-impacted groundwater where chemical concentrations exceed background chemical concentrations.	▪ Brown and Caldwell (BC 2016b). Summarized below; see Section 6.0 in Appendix J-7 for details.
Evaluate the consistency of the two approaches (i.e., $\delta^{34}S_{SO4}$ signatures tracers and BCLs) to identifying the extent of mine-impacted groundwater. Integrate the results of the two approaches along with other RI characterization information into a single boundary representing the extent of mine-impacted groundwater in each zone of the alluvial aquifer.	▪ Brown and Caldwell (BC 2016b). Summarized below; see Section 7.0 in Appendix J-7 for details.

Ultimately, the identification of the extent of mine-impacted groundwater in the Study Area integrates the three major elements of boundary delineation (i.e., $\delta^{34}S_{SO4}$ signatures, and BCLs for the two most mobile, aerially extensive, indicators of mine-impacted groundwater, sulfate and uranium), as well as other lines of evidence that include hydrogeologic information, chemical concentration data, and other hydrologic tracer data.

5.2 Contoured Chemical Distributions

The following sections discuss the distributions of select parameters and COIs in Study Area groundwater.

5.2.1 Alluvial Aquifer

To illustrate aspects of the HCSM discussed below, the distributions of six chemicals (pH, sulfate, uranium, alkalinity, nitrate, and arsenic) in groundwater during August 2014 are illustrated on cross sections (cross section locations shown on Figure 4-6) and plan view maps for the Shallow and Deep 3 groundwater zones (Figures 5-2 through 5-7). The distributions of the six chemicals in all the groundwater zones are shown on plan view maps in Appendix K. The distributions of the six chemicals have routinely been presented in various groundwater reports for the following reasons.

Historical operational information and groundwater quality data indicate that elevated acidity (i.e., low pH), sulfate, and uranium are indicator parameters for mine-impacted groundwater at the Site. Because sulfate and uranium, which are naturally-occurring in the Study Area, are more mobile in groundwater relative to other indicators of mine-impacted groundwater (e.g., iron), these mine-related chemicals have been used to preliminarily evaluate the extent of mine-impacted groundwater (BC 2014a). Alkalinity in groundwater is important because complexation of dissolved uranium with bicarbonate enhances its solubility and mobility in groundwater (EPA 2010d; BC 2014a).

Given their association with agricultural amendments and fertilizer, sulfate and nitrate in groundwater are also important indicators of agricultural-impacted groundwater (BC 2014a). Although arsenic is detected at locally high concentrations in both on-Site and off-Site locations, it occurs naturally in the Study Area (and throughout Nevada) and exhibits complex geochemical transport behavior, which limits its usefulness as an indicator of mine-impacted groundwater (EPA 2016e).

pH

The distributions of pH values in the Shallow and Deep 3 groundwater zones in August 2014 are shown on Figures 5-2a and 5-2b, respectively. The lowest pH values are observed in Shallow zone groundwater beneath the Evaporation Ponds and downgradient of the Phase IV VLT HLP and VLT Pond, and pH values increase laterally and vertically away from these structures by orders of magnitude.

Sulfate and Uranium

The distributions of sulfate and uranium in groundwater in August 2014 are illustrated on Figures 5-3 and 5-4, respectively. The most elevated concentrations of sulfate and uranium are also observed in Shallow zone groundwater beneath the Evaporation Ponds and downgradient of the Phase IV VLT HLP and VLT Pond, and concentrations decrease laterally and vertically away from these features by orders of magnitude.

In particular, elevated concentrations of sulfate and uranium in the alluvial aquifer occur in: 1) Shallow zone groundwater where sulfate (Figure 5-3a) and uranium (Figure 5-4a) distributions exhibit a northwest longitudinal orientation consistent with the northwest direction of groundwater flow across the Study Area; and 2) Deep zone alluvial groundwater where sulfate (Figure 5-3b) and uranium (Figure 5-4b) distributions exhibit a northeast longitudinal orientation from the northern portion of the Site to beneath the Hunewill Ranch toward former (e.g., WDW019) and existing agricultural wells used seasonally to extract groundwater for crop irrigation.

In addition, elevated concentrations of sulfate and uranium (as well as alkalinity and nitrate discussed below) occur in Shallow, Intermediate, and Deep 1 groundwater zones beneath agricultural fields in the NSA. Given the low concentrations of sulfate and uranium detected in all groundwater zones at well cluster B/W-27 (Figures 5-3d and 5-4d, respectively), elevated concentrations of these chemicals in groundwater beneath the agricultural fields located in the NSA are not physically connected along current and plausible historic groundwater flow paths back to known sources of mine-impacted groundwater beneath the Site. A more detailed discussion of data specific to the NSA is provided in Section 5.5.

Alkalinity

The distribution of alkalinity in groundwater in August 2014 is illustrated on Figure 5-5. The most elevated values of alkalinity occur beneath the Evaporation Ponds in the northern portion of the Site. In the Shallow zone beneath the UEP and downgradient of the Phase IV VLT HLP and VLT Pond, pH values are generally less than 4 s.u.. Similar to sulfate and uranium, elevated alkalinity occurs in: 1) Shallow zone groundwater where the distribution (Figure 5-5a) exhibits a northwest longitudinal orientation consistent with the northwest direction of groundwater flow across the Study Area; and 2) Deep zone alluvial groundwater where the distribution (Figure 5-5b) exhibits a northeast longitudinal orientation from the Evaporation Ponds, Phase IV VLT HLP and VLT Pond to beneath the Hunewill Ranch toward former (e.g., WDW019) and existing agricultural wells used seasonally to extract groundwater for crop irrigation. Alkalinity values above 200 mg/L occur beneath the Hunewill Ranch and other agricultural fields located in the northeastern portion of the Study Area.

Nitrate

The distribution of nitrate in groundwater in August 2014 is illustrated on Figure 5-6. The most elevated nitrate concentrations occur in groundwater beneath the Hunewill Ranch and other agricultural fields located in the northeast portion of the Study Area (Figure 5-6a). Beneath the Hunewill Ranch, nitrate concentrations in Shallow zone groundwater were as high as 42 mg/L during August 2014. Former groundwater extraction from high-capacity wells (especially WDW019) for irrigation of crops on the Hunewill Ranch has mobilized nitrate from the Shallow zone into the Intermediate and Deep zones of the alluvial aquifer system. Nitrate is subsequently transported in groundwater that flows northwest to the Sunset Hills area.

Nitrate concentrations in Shallow zone groundwater beneath the agricultural fields in the northeast Study Area were as high as 38 mg/L during August 2014 (Figure 5-6a). Groundwater extraction from high-capacity agricultural wells for crop irrigation on fields located in the northeastern portion of the Study Area has mobilized nitrate from the Shallow zone into the Intermediate and Deep zones of the alluvial aquifer system. Nitrate beneath these agricultural fields is subsequently transported in groundwater that flows north and northwest.

Nitrate concentrations in groundwater samples from the B/W-27 cluster have consistently been at low concentrations throughout their monitoring history. In August 2014, nitrate concentrations ranged from 0.13J to 0.88J mg/L. The nitrate data from the B/W-27 well cluster shows that the nitrate concentrations beneath the Hunewill Ranch and other agricultural fields in the northeast Study Area are physically separate. The horizontal and vertical patterns in nitrate concentrations in groundwater indicate that application of fertilizer on the agricultural fields has resulted in downward vertical migration of agricultural nitrate rather than horizontal transport of nitrate in the groundwater system. A more detailed discussion of data specific to the NSA is provided in Section 5.5.2.

Arsenic

The distribution of arsenic in alluvial groundwater in August 2014 (Figure 5-7) differs from the distributions observed for sulfate, nitrate, and alkalinity. The most elevated arsenic values occur in Shallow zone groundwater at off-Site wells B/W-77S (560 µg/L) and B/W-32S (420 µg/L), which are located approximately 2,500 feet north of the Evaporation Ponds (Figure 5-7a). Arsenic values decrease laterally and vertically from these two wells by at least an order of magnitude. In contrast to the elevated arsenic values at these two off-Site wells, the most elevated arsenic values in groundwater beneath the Site are approximately 3.5 times lower.

The most elevated arsenic concentrations in on-Site groundwater range from approximately 120 to 160 µg/L in Shallow zone wells MW-5S, FMS-06S, and MW-2S (Figure 5-7a). These three wells are located near the Thumb Pond and the Phase IV VLT HLP and VLT Pond. Historic process solutions discharged to the Thumb Pond were reported to contain 42 mg/L of arsenic (Seitz et al., 1982). Arsenic values in the range of 50 to 80 µg/L occur in the Shallow, Intermediate and Deep zones west and northwest of the Evaporation Ponds and below the Phase IV VLT HLP and VLT Pond.

In addition, data from zonal groundwater samples and monitor wells installed in the NSA indicate elevated concentrations of arsenic in Deep zone groundwater that inflows (i.e., recharges) the NSA and migrates beneath the agricultural fields. Groundwater arsenic concentrations in this portion of the Study Area increase as a function of depth in the alluvial aquifer (at a relatively uniform pH) as indicated best by the zonal groundwater sample data from wells B/W-56 and B/W-69 (Figure 5-8) where arsenic concentrations are as high as 83 ug/L. At other NSA monitoring locations (such as B/W-59, B/W-57 and B/W-68), chemical profiling did not extend as deep as the B/W-56 and B/W-69 locations. Nonetheless, arsenic concentrations at these three locations began increasing as a function of depth below 4,200 feet amsl. Had sampling been conducted to greater depths at these locations, elevated arsenic concentrations are expected since no known plausible hydrologic/geochemical explanation would limit arsenic enrichments strictly to those areas around B/W-56 and B/W-69.

Because profile locations B/W-56 and B/W-69 represents background (i.e., characterize groundwater inflows to the NSA), chemical concentrations at these locations represent naturally-occurring concentrations and are not related to advancement of mine-impacted groundwater from the south. Furthermore, the elevated arsenic concentrations at this depth are not associated with agricultural activity, which is shown in Section 5.5.2 to affect the Shallow, Intermediate and Deep1 zones in the NSA. Instead, these elevated arsenic concentrations appear to be associated with regional groundwater conditions in the Mason Valley, likely associated with deep bedrock discharge to the alluvial basin aquifer.

5.2.2 Bedrock Groundwater

Most of the bedrock wells have 20- to 30-foot long screens that are positioned in the upper 50 feet of the bedrock to straddle fractures that yield groundwater for monitoring purposes. The pH measurements and concentrations of sulfate, uranium, alkalinity, nitrate and arsenic in the bedrock groundwater system in August 2014 are shown on Figure 5-9. Most pH measurements in bedrock groundwater are near-neutral (i.e., approximately 7.0).

Sulfate and uranium were detected in bedrock groundwater during August 2014 at concentrations as high as 1,600 mg/L and 950J µg/L, respectively. For both chemicals, the most elevated concentrations were detected in bedrock groundwater within the mine Site, and somewhat lower concentrations were detected immediately west of the Evaporation Ponds below the VLT Pond. The most elevated sulfate concentrations in bedrock groundwater occurred beneath the Sulfide Tailings at well B/W-36B. Off-Site, sulfate was detected in bedrock groundwater at a concentration above 500 mg/L in well B/W-58B, which monitors groundwater emanating from the MacArthur Mine. The most elevated uranium concentrations in bedrock groundwater occurred at on-Site wells MW-5B and B/W-74B. Similarly, the most elevated alkalinity concentrations in bedrock groundwater occurred at on-Site wells MW-5B and B/W-74B (as well as MW-H4SN).

Nitrate concentrations were most elevated in bedrock groundwater at wells B/W-73B and HLP-06B, which are located to the west and southwest of the mine Site.

Elevated arsenic concentrations in bedrock groundwater occurred in three distinct areas. Elevated arsenic concentrations were detected in: 1) four wells (PA-MW-2B, PA-MW-4B, HLP-03B, and HLP-06B) located around the Phase III 4X HLP and nearby Calcine Ditch; 2) six wells (MW-4B, B/W-34B, B/W-6B, B/W-44B, LEP-MW-2B, and B/W-33B) located to the immediate west of the Evaporation Ponds in an area potentially influenced by MFR; and 3) in two wells (B/W-54B and YPT-MW-10B) located north of Sunset Hills.

5.3 Identification of Groundwater Impacts

5.3.1 Differentiating Groundwater Impacts Using Sulfur Isotopes

Sulfur Isotope Signature in Background Groundwater

The $\delta^{34}S_{SO4}$ signature used to differentiate mine-impacted groundwater from non-mine-impacted groundwater reflects the dominant background groundwater types in off-Site areas. Groundwater modeling (SSPA 2014) indicates that recharge to groundwater in the alluvial aquifer (98% of all recharge) in the Study Area results from irrigation field percolation (49%), leakage from irrigation ditches (29%), and seepage from the Walker River (20%).

Background wells associated with these water types include some, but not all, of the wells in the SERA and NSA recharge areas. Eight background wells that represent the dominant background groundwater types in off-Site areas, based on their locations in the groundwater flow field relative to the Walker River and agricultural features, include: B/W-15S, B/W-20S, B/W-21S, B/W-56S, B/W-59S, B/W-59D3, PLMW-2S and PLMW-2B. Values of $\delta^{34}S_{SO4}$ in groundwater samples from these wells range from +4.93 to +6.62‰.

<u>Sulfur Isotope Signature in Mine-Impacted Groundwater</u>

Sulfur isotopes in groundwater were used to differentiate the leading edge of mine-impacted groundwater from background groundwater or groundwater impacted by other anthropogenic activities within the Study Area because: 1) sulfur isotopes in dissolved sulfate can be used to infer groundwater movement because these isotopes are mobile tracers whose movement is not strongly retarded by the aquifer matrix in groundwater settings similar to the Study Area; and 2) early copper extraction operations at Yerington (during the 1950s and 1960s) primarily relied on sulfuric acid derived from sulfur ores (i.e., pyrite) from the Leviathan Mine in California (BC 2014a), which had a distinct sulfur isotopic signature (Taylor and Wheeler 1994). Sulfur sources with different (higher) isotopic signatures were used during later operations in the 1970s, 1980s, and 1990s. These different isotopic signatures may be used, along with chemical data and other information, to differentiate groundwater impacts associated with Anaconda and Arimetco operations.

Delineation of mine-impacted groundwater reasonably assumes that groundwater affected by the earliest operations at the Site has traveled the farthest downgradient distance in the alluvial aquifer. Therefore, the isotopic signature for sulfur sources used during the 1950s and 1960s serves as a potentially reliable tool for characterizing the leading edge of the plume and for differentiating mine-impacted water at the leading edge of the plume from background conditions. The median value reported by Taylor and Wheeler (1994) for $\delta^{34}S_{SO4}$ in aqueous samples collected from seeps and adit discharge at the Leviathan Mine is -17.6‰ (Table 5-5 in Appendix J-7).

Distinct $\delta^{34}S_{SO4}$ signatures associated with sulfate in the sulfuric acid process leach solutions used during early Site operations (most evident in groundwater at well W5DB-D3) and groundwater from the background monitor wells are used to evaluate the extent of mine-impacted groundwater. This approach conceptualizes initial infiltration of acidic process leach solutions exhibiting a diagnostic $\delta^{34}S_{SO4}$ signature of approximately -17‰ into originally un-impacted groundwater beneath the Evaporation Ponds.

The conceptual approach assumes a simplified aquifer geometry and flow configuration that account for mixing of a conservative (i.e., geochemically unreactive) tracer within the aquifer. Again, the isotope signature for the sulfur source used during the earliest processing operations at the Site would be representative of any mine-impacted water first entering the alluvial aquifer and now present at the leading, downgradient edge of the plume. The leading edge of mine-impacted groundwater is identified as locations where the $\delta^{34}S_{SO4}$ signature in groundwater associated with mining impacts cannot be differentiated from the $\delta^{34}S_{SO4}$ signature in background groundwater.

Quantitatively, mine-impacted groundwater can no longer be differentiated from background groundwater when the $\delta^{34}S_{SO4}$ value at a given location falls within the background $\delta^{34}S_{SO4}$ range (i.e., exceeds the minimum background value of +4.93‰). Higher isotope signatures measured inside the leading edge of the plume may be indicative of mixing with groundwater, subsequent sulfur releases derived from sources having a different isotopic signature, or some combination of these two processes.

Lateral and vertical patterns in $\delta^{34}S_{SO4}$ groundwater data are illustrated on Figure 5-10. The distinctly negative $\delta^{34}S_{SO4}$ signature of -17.6‰ associated with sulfate in the sulfuric acid process leach solutions used for copper recovery at Yerington is evident in Deep zone alluvial groundwater beneath the Evaporation Ponds, especially at well W5DB-D3, which has a strongly negative $\delta^{34}S_{SO4}$ signature of -17.12‰.

The low $\delta^{34}S_{SO4}$ values in Deep zone alluvial groundwater beneath the Evaporation Ponds also extend off-Site toward the Hunewill Ranch, particularly in the Deep 3, Deep 4, and Deep 5 zones. The region of low $\delta^{34}S_{SO4}$ values beneath the Evaporation Ponds is displayed on cross section A-A' (Figure 5-10c), centered around the W5DB well cluster. The low values of $\delta^{34}S_{SO4}$ that extend off-Site toward the Hunewill Ranch are visible on cross section B-B' (Figure 5-10d).

5.3.2 Differentiating Groundwater Impacts Using BCLs

A conventional approach to a BGQA emphasizes the groundwater flow regime to identify wells that are located hydraulically up-gradient and/or cross-gradient to sources of chemical loading to groundwater, as noted by the EPA (2012a) in comments on the Draft BGQA (BC 2011c). A background assessment may also consider groundwater recharge sources, the different geologic materials through which groundwater flows, and the residence time because these factors are recognized to naturally affect groundwater composition (BC 2014a; Hem 1985; Freeze and Cherry 1979). Key HCSM elements that are relevant to identifying background monitor wells include:

- Groundwater Flow Direction: Groundwater in the alluvial aquifer within the Study Area generally flows to the northwest, with flow directions locally affected by a variety of factors discussed previously in Section 4.0.
- Recharge Sources: The alluvial aquifer within the Study Area is primarily recharged by infiltration and percolation of water associated with stream channels, ditches, and irrigated agricultural fields located to the east of the mine Site. Limited recharge to the alluvial aquifer also occurs as mountain-front recharge to the west of the Site.
- Chemical Loading Sources: The northern portion of the Site (including the Evaporation Ponds, the Phase IV VLT HLP and the VLT Pond) is considered the primary source of chemicals that migrate off-Site. The most elevated acidity and chemical concentrations are observed in Shallow zone groundwater beneath this area, and concentrations decrease laterally away from this area by orders of magnitude. Furthermore, other Site sources are located hydraulically upgradient of the northern portion of the Site.

Based on these considerations, background monitor wells for the Study Area are categorized by geographic recharge area and described below.

- SERA: This background groundwater quality type is represented by seven monitor wells (B/W-15S, B/W-20S, B/W-21S, PLMW-2S, PLMW-2B, WRA3-1B and WRA3-2B) that are located up-gradient of the mine Site and near the Walker River. Data from these wells represent recharge of groundwater having a short residence time in the flow system.

- NSA: This background groundwater quality type is represented by three monitor wells (B/W-56S, B/W-59S and B/W-59D3) that are located upgradient of the NSA and represent both Shallow and Deep zone alluvial groundwater quality.
- SWRA: This background groundwater quality type is represented by six monitor wells (B/W-12RB, B/W-13S, B/W-23B, B/W-26RB, PLMW-3RB, and PLMW-4B) that are located up-gradient and west/southwest of the Site and, thus, represent mountain-front recharge.

The BCL for each COI for each background water quality type was calculated as the 95% upper tolerance limit (UTL) with 95% confidence, consistent with the sampling and statistical comparison strategy recommended in EPA guidance (EPA 1992). The 95% UTL is the numerical value below which 95% of the background data are expected to fall, with 95% confidence. That is, one can be 95% sure that 95% of data in the background population fall below this value. The upper bound of this interval is the 95/95 UTL.

The 95/95 UTL is calculated from a sample dataset and depends on the distribution, central tendency, and variability of the dataset, as well as sample size (EPA 2009). The statistical test used to calculate the 95/95 UTL also depends on the distribution of the dataset, the sample size, and the percentage of non-detects present. The ProUCL software program (version 5.0.00) (EPA 2013f) was used to perform statistical calculations of the 95/95 UTL. ProUCL evaluates a dataset to determine the likely form (or forms) of the distribution, calculates UTLs using numerous appropriate statistical methods, and provides a recommendation as to which method is most appropriate for a particular dataset.

Distributional testing in ProUCL is performed using the Shapiro-Wilk (S-W) test for normality on the untransformed data, the log-transformed data, and the gamma-transformed data. The S-W test may conclude that the data set conforms to multiple parametric distributions. In this case, the distribution with the highest probability of association (calculated p-value from the S-W test) is selected as the underlying parametric distribution. When an insufficient sample size or insufficient number of detected results existed to statistically calculate a 95/95 UTL, the maximum value of the dataset was selected, as is common practice in selecting upper threshold values in the absence

of adequate sample sizes (EPA 2009). For datasets with 100% non-detects, the lowest detection limit in the dataset was selected as the BCL. The calculated 95/95 UTLs for each constituent and background water quality type are provided in Table 5-2.

Table 5-2. Summary of Calculated Background Concentration Limits

Chemical	Units	Groundwater Standard	SERA	NSA Inflows	SWRA
pH (field)	s.u.	6.5-8.5	7.96	7.65	8.35
Alkalinity, Bicarbonate (as $CaCO_3$)	mg/L	--	180	160	210
Alkalinity, Carbonate (as $CaCO_3$)	mg/L	--	2	2	2
Alkalinity, Hydroxide (as $CaCO_3$)	mg/L	--	2	2	2
Alkalinity, Total (as $CaCO_3$)	mg/L	--	180	160	210
Total Dissolved Solids	mg/L	500	570	304	561
Total Organic Carbon (TOC)	mg/L	--	1.8	1.5	1.8
Calcium	mg/L	--	71	38	72
Magnesium	mg/L	--	13	11	16
Potassium	mg/L	--	5	7	5
Sodium	mg/L	--	96	51	130
Chloride	mg/L	250	59	17	72
Fluoride	mg/L	2	1	0.9	1.5
Sulfate	mg/L	250	160	57	180
Nitrate (as N)	mg/L	10	1.5	0.1	0.8
Nitrite (as N)	mg/L	1	0.1	0.2	0.4
Nitrate-Nitrite (as N)	mg/L	--	1.5	0.3	0.8
Aluminum	mg/L	0.2	0.04	0.03	0.05
Antimony	µg/L	6	0.41	0.31	0.96
Arsenic	µg/L	10	12	38	20
Barium	µg/L	2,000	50	141	41
Beryllium	µg/L	4	0.17	0.25	0.25
Boron	µg/L	--	680	410	920
Cadmium	µg/L	5	0.11	0.25	0.17
Chromium	µg/L	100	0.9	1.0	1.8
Cobalt	µg/L	--	1.5	1.4	2
Copper	µg/L	1,300	0.9	0.9	4.3
Iron	mg/L	0.3	0.1	0.3	1.4
Lead	µg/L	15	0.28	0.20	0.2
Lithium	µg/L	--	65	49	44
Manganese	µg/L	50	870	2,825	303
Mercury	µg/L	2	0.35	0.10	1.1
Molybdenum	µg/L	--	18	20	140
Nickel	µg/L	--	1.1	1.6	19
Phosphorus	mg/L	--	0.16	0.91	0.12
Selenium	µg/L	50	1.1	0.5	20
Silica	mg/L	--	44	40	55
Silver	µg/L	100	0.12	0.14	0.36
Strontium	mg/L	--	0.74	0.4	0.47

Table 5-2. Summary of Calculated Background Concentration Limits

Chemical	Units	Groundwater Standard	SERA	NSA Inflows	SWRA
Thallium	µg/L	2	0.2	0.2	0.2
Tin	µg/L	--	14	12	30
Titanium	mg/L	--	0.002	0.002	0.002
Uranium	µg/L	30	20	10	27
Vanadium	µg/L	--	8	5	16
Zinc	µg/L	5,000	6	4	120
Gross Alpha	pCi/L	15	12.2	6.7	21.3
Gross Beta	pCi/L	--	10.8	10.0	11.9
Radium-226	pCi/L	5 (combined 226 + 228)	0.8	1.0	1
Radium-228	pCi/L	5 (combined 226 + 228)	1	0.9	1.5
Thorium-228	pCi/L	--	0.5	0.4	0.5
Thorium-230	pCi/L	--	0.4	0.4	0.7

Notes:

1) SERA = Southeast Recharge Area; NSA = North Study Area; SWRA = Southwest Recharge Area
2) s.u. = standard units; µg/L = milligrams per liter; µg/L = micrograms per liter; pCi/L = picocuries per liter

5.3.3 Comparison of Methods

The extent of mine-impacted groundwater based on sulfate and uranium BCLs is generally similar to the extent of mine-impacted groundwater based on $\delta^{34}S_{SO4}$ signatures. Furthermore, the extent of mine-impacted groundwater in each zone of the alluvial aquifer varies in ways that are consistent with flow directions, chemical distributions, and other hydrologic tracer data presented in the HCSM. Differences in the spatial extent of mine-impacted groundwater delineated by the two background assessment approaches are considered minor and likely associated with local variations in transport behavior and locally variable evapoconcentration and chemical loading processes.

5.4 Extent of Mine-Impacted Groundwater

The extent of mine-impacted groundwater presented in this OU-1 RI Report reflects the outcome of discussions during a groundwater technical meeting on June 29, 2016 and EPA's subsequent direction to conservatively establish the extent of mine-impacted groundwater because "is in the best interest of the overall progress for completing the OU-1 Groundwater Remedial Investigation Report" (EPA 2016e).

EPA (2016e) noted that professional judgement is an inherent component of estimating the extent of mine-impacted groundwater in this complex setting, and that tools used in the background assessment to estimate the area of mine-impacted groundwater may not fully account for the range of chemical concentrations that occur naturally in groundwater within the Study Area. However, as noted during previous submittals (e.g., ARC 2016b) and during groundwater technical meetings, further refinements to the mine-impacted groundwater boundary may be warranted based on additional evaluations of monitoring data and other new information to better account for naturally-occurring chemical concentrations in Study Area groundwater.

As previously described, the identification of the extent of mine-impacted groundwater in the Study Area integrates the three major elements of boundary delineation (i.e., $\delta^{34}S_{SO4}$ signatures, and BCLs for the two most mobile, aerially extensive, indicators of mine-impacted groundwater, sulfate and uranium), as well as other lines of evidence that include hydrogeologic information, chemical concentration data, and other hydrologic tracer data. Also, the boundary delineating mine-impacted groundwater from unimpacted groundwater is conceptualized as a zone on a plan view map rather than a distinct line due to many factors including the size of the Study Area, age and complexity of the contaminant releases, occurrence and variability of naturally-occurring chemical concentrations, and complexities of subsurface contaminant transport and fate.

The extent of mine-impacted alluvial groundwater is shown on Figure 5-11, and can be generally described as follows, recognizing that mine-impacted groundwater is spatially more extensive in the Shallow, Intermediate and Deep 1 zones of the alluvial aquifer relative to the Deep 2 through Deep 5 zones. The northernmost extent of mine-impacted groundwater in the Shallow, Intermediate and Deep 1 zones of the alluvial aquifer is located near the Sunset Hills between well clusters B/W-10 and B/W-52. The eastern extent of mine-impacted groundwater in the Shallow, Intermediate and Deep 1 zones of the alluvial aquifer is approximately located near or beneath the West Campbell Ditch alignment. To the west of the Site, mine-impacted groundwater extends almost to the western extent of saturated alluvium between unimpacted wells/clusters B/W-16S and B/W-40, and impacted well clusters B/W-33, B/W-6 and B/W-22.

Mine-impacted groundwater in the deeper zones does not extend as far north as the upper three zones. In the Deep 2 through Deep 5 zones, the maximum northern extent of mine-impacted groundwater is near the northern end of the Hunewill Ranch fields. The eastern extent of mine-impacted groundwater in the Deep 2 through Deep 5 zones of the alluvial aquifer is located between well clusters B/W-27 and B/W-50. Particularly on the east, the area of mine-impacted groundwater in the Deep 3 through Deep 5 zones reflect the former influence of seasonal groundwater extraction for crop irrigation from agricultural wells (e.g., WDW019, located adjacent to the B/W-1 well cluster). To the west of the Site, mine-impacted groundwater in the Deep 3 through Deep 5 zones extends almost to the western extent of saturated alluvium.

Based on the background assessment methodology, the plume of mine-impacted groundwater in the various zones of the alluvial aquifer does not discharge to surface water. Estimates of the volume of mine-impacted groundwater and masses of sulfate and uranium in each groundwater zone are provided in Table 5-3.

Table 5-3. Estimated Volume and Masses of Sulfate and Uranium in Mine-Impacted Alluvial Groundwater

Zone	Zone Thickness (feet)	Volume of Mine-Impacted Alluvial Groundwater (acre-feet)	Sulfate Mass (tons)	Uranium Mass (tons)
Shallow	35	45,899	140,116	11.1
Intermediate	50	65,905	96,501	9.9
Deep 1	50	62,238	52,346	5.3
Deep 2	80	64,611	80,610	20.7
Deep 3	120	48,032	79,397	22.5
Deep 4	100	35,669	23,414	12.8
Deep 5	200	62,973	25,374	16.5
Total		**385,327**	**497,758**	**98.8**

The estimates in Table 5-3 are based on the thickness of each groundwater zone within the plume of mine-impacted groundwater shown on Figure 5-11 and the areas/average concentrations within the chemical concentration contouring. The volume of mine-impacted groundwater and masses of sulfate and uranium are large, and the following two analyses provide insights to FS considerations about aquifer cleanup.

Simple Analysis

In this simple analysis, PWS performance monitoring information and a simplifying assumption regarding chemical removal from aquifer sediments are used to estimate the time frame for aquifer cleanup.

From the early 2000s to March 25, 2009, the PWS operated continuously (i.e., 24 hours per day, 7 days per week), except during periods when individual wells were temporarily taken off line for maintenance and repairs of pumps and related equipment. The average pumping rate from the PWS from 1999 through 2008 was about 52 gpm. During this 10-year time period, approximately 800 acre-feet of water and approximately 5,000 tons of sulfate (average sulfate concentration in the pumped water of approximately 4,000 mg/L) were removed from the Shallow zone.

If it is assumed that three times the volume of mine-impacted Shallow zone groundwater (which is 45,899 acre-feet) must be removed to achieve aquifer cleanup, then at least 137,697 acre-feet of water would need to be removed from the Shallow zone. (This volume is about 172 times the volume of water removed by the PWS over the 10-year period). This volume does not address aquifer cleanup in the deeper zones of the alluvial aquifer or ongoing chemical loading to groundwater from impacted sediments and vadose zone soils, and dissolving sulfate or other minerals. Recognizing that the total volume of mine-impacted groundwater in the aquifer is 385,327 acre-feet, approximately 285 years of pumping at 2,500 gpm would be required to potentially achieve aquifer cleanup assuming that a volume of only three times the contaminated volume of mine-impacted groundwater would need to be removed. In reality, this estimate likely underestimates the actual time to cleanup.

Groundwater Modeling

In this analysis, the "batch flush" model (EPA 1988; Zheng et al. 1991) is used to estimate the minimum time (with an efficient extraction system) to restore groundwater quality to 500 mg/L sulfate. In this approach, the number of pore volumes (PV) of water that must be circulated through the contaminated zone having an initial concentration (Ci) to achieve cleanup to the specified standard (Cs) is calculated from the relationship:

$$\mathrm{PV} = -\mathrm{R}\ln \mathrm{Cs}/\mathrm{Ci}$$

In this relationship, R is the retardation coefficient for the target constituent. Based on this modeling approach, groundwater restoration to 500 mg/L sulfate would require approximately 100 years at a pumping rate of 2,300 gpm.

5.5 Sources of Impacted Groundwater

OU-1 RI characterization activities indicate that the past and/or ongoing major sources of COIs to Study Area groundwater include:

- Mine waste facilities, which have been grouped into the various Site OUs for individual RI/FS investigations;
- Agriculture activities that contribute COIs or affect the release of naturally occurring COIs in geologic materials (BC 2014a, 2016b); and
- Geologic materials containing naturally-occurring COIs (BC 2009a, 2014a, 2016b).

Section 7.0 of the 2007 SOW notes that the groundwater OU underlies all other OUs identified at the Site, and recommends that relevant elements of the other OUs be integrated with the OU-1 RI. Consistent with the SOW, this OU-1 RI Report discusses relevant source-related information for the other Site OUs that represent past or ongoing sources of chemical loading to groundwater (Section 5.5.1). In addition, the other major non-mining sources of COIs to groundwater are discussed in Sections 5.5.2 and 5.5.3.

5.5.1 Mine Waste Facilities

The major past and/or ongoing sources of COIs to groundwater include: 1) OU-4a, the Evaporation Ponds (BC 2014a); OU-8, the Arimetco Facilities (CH2M Hill 2010, 2011a, 2011b); and 3) OU-3, the Process Areas (BC 2014a). Concentrations of COIs in groundwater beneath OU-4b (Sulfide Tailings) are generally at least 10 times lower than COI concentrations in groundwater beneath OU-4a. Furthermore, OU-4b is located hydraulically upgradient or cross-gradient of OU-4a, and groundwater beneath OU-4b flows toward the higher COI concentrations under OU-4a.

Evaporation Ponds (OU-4a)

OU-4a RI field activities and characterization data are presented in reports by BC (e.g., 2009a, 2017a). OU-1 RI information that is particularly relevant to OU-4a includes the following: 1) the most elevated concentrations of mine-related chemicals occur in groundwater in this area; 2) concentrations of mine-related chemicals in groundwater beneath OU-4a are 100 or more times greater than chemical concentrations in groundwater beneath other OUs (Figures 5-2 to 5-7); and 3) the depth to water beneath OU-4a (i.e., vadose zone thickness) is generally smaller than the depth to water beneath other OUs. The depth to water beneath OU-4a ranges from approximately 20 to 40 feet bgs, except beneath the southern portion of the Calcine Ditch where the depth to water is up to approximately 70 feet bgs (Figures 4-8 and 4-9).

The summary below focuses on the magnitude and distribution of COIs in OU-4a mine waste materials and vadose zone soils, extent of contamination based on a comparison of OU-4a data to applicable soil BCLs, and the potential for vadose zone transport and chemical loading to groundwater based on vadose zone modeling and soil moisture probe data obtained during 2016. The highest COI concentrations in OU-4a mine waste materials are most commonly associated with pond sediments and calcines, which are typically located at depths ranging from approximately 0-3 feet bgs. Relative to the overlying pond sediments and calcines, the underlying alluvial soils generally exhibit lower concentrations of COIs.

Based on Site background soil concentrations presented in Table 5-3 of the *Background Soils Data Summary Report - Revision 1* (BC 2009b) for Sub-area A-1, located directly west of the Evaporation Pond and Calcine Ditch areas, approximate maximum depths of soil exceeding applicable BCLs within OU-4a include: 1) 17 to 20 feet bgs beneath the LEP; 2) 15 to 20 feet bgs beneath the UEP; 3) 47 to 52 feet bgs beneath the Finger Ponds; 4) 38 to 43 feet bgs beneath the Thumb Pond; and 5) 45 to 50 feet bgs at the north end of the Calcine Ditch and 75 to 80 feet bgs at the south end of the Calcine Ditch. These approximate maximum depths of alluvial soil contamination beneath the ponds and Calcine Ditch are primarily based on uranium, arsenic, selenium, iron, and copper.

Vadose zone model simulations were performed using the variably-saturated modeling code SVFlux™ to understand the potential for transport and chemical loading to groundwater beneath OU-4a. Vadose zone model results are summarized below (values presented in meters, input and output unit of measurement in the SVFlux™ modeling code):

- The LEP 'wet' areas simulation indicated a fairly constant downward net flux of soil water toward the water table. The cumulative flux at the deepest flux line in the profile was approximately 0.16 meters after 5 years of simulation.
- LEP 'dry' (non-ponded) areas showed a small downward net flux of water, approximately 0.013 meters after 15 years of simulation. Because the same soil moisture conditions for the 'wet' areas simulation was used for the 'dry' areas simulation, and because the soil moisture conditions for the 'dry' areas of the LEP are more likely to be similar to the conditions observed in the UEP, the numerical simulation likely over-predicted downward flux to the water table.
- The UEP simulation indicated a continuous upward net flux of water. The cumulative flux at the deepest flux line in the model was approximately 1.8 meters for 15 years of simulation (approximately 0.12 meters per year when averaged over the 15-year simulation period). For the 10-year period following the equilibration of the model, the cumulative flux was approximately 1.5 meters (approximately 0.15 meters per year).
- The Thumb Pond simulation indicated a very small upward net flux of water. The cumulative flux rate was approximately 4.0E-04 meters after 15 years of simulation (approximately 2.7E-05 meters per year when averaged over the simulation period). The simulation indicated both upward and downward flux of soil water in the upper portion of the profile, and a relatively constant upward flux in the deeper portion of the profile.
- The vadose zone simulation for the Finger Evaporation Ponds (FEPs) indicated a small downward flux of soil water during the 15-year simulation period, with a cumulative flux rate at the deepest flux line in the profile of approximately 0.043 meters after 15 years (approximately 2.9E-03 meters per year when averaged over the simulation period).

Integration of these estimated flux rates over the Pond acreages result in the following annual estimated volumes of soil water that could potentially flux to groundwater:

- Approximately 0.31 acre-feet per year (ac-ft/yr) for the LEP 'dry' areas, based on an estimated flux rate of 0.0012 m/yr and an area of 79.5 acres, equivalent to 0.19 gallons per minute (gpm);
- Approximately 1.13 ac-ft/yr for the LEP 'wet' areas, based on an estimated flux rate of 0.016 m/yr and an area of 21.5 acres, equivalent to 0.70 gpm; and

- Approximately 0.15 ac-ft/yr for FEP 1-4, based on an estimated flux rate of 0.0026 m/yr and an area of 17.8 acres, equivalent to 0.09 gpm.

Vadose zone modeling results indicated that: 1) the Thumb Pond and UEP exhibit an upward vertical flux of soil moisture to the atmosphere (i.e., no cumulative flux of soil moisture toward groundwater); and 2) the 'wet' areas of the LEP and FEPs 1-4 exhibit a cumulative downward flux of soil moisture toward the water table. Model results for the dry (peripheral) portions of the LEP indicate: 1) a net evaporative flux to the atmosphere; and 2) a downward flux of soil moisture during the latter third of the simulation period, resulting from wetter climate conditions.

Soil moisture data provide additional insights to the potential for transport and chemical loading to groundwater. Soil moisture has been monitored continuously since August 2016 and is ongoing. As part of the 2015–2016 field activities, soil moisture probes and porous cup lysimeters were installed at four locations. Further description of the installed equipment and the installation process is provided in the *Phase 1 Evaporation Ponds Characterization Data Summary Report* (BC 2017b). The monitoring locations are located at EP-VZC-2 (Thumb Pond), EP-VZC-3 (northern edge of the UEP), EP-VZC-6 (near the southern portion of the UEP and next to the Calcine Ditch), and EP-VZC-8 (northern edge of the LEP). Each location has soil moisture probes at three or four depth intervals, depending on the thickness of the vadose zone.

During the initial soil moisture monitoring period, a significant precipitation event occurred between January 4 and January 13, 2017, when 2.35 inches of precipitation fell over the 10-day period (WRCC 2017).

Soil moisture probe readings for EP-VZC-2 at the Thumb Pond, with the shallowest monitoring interval of 10 feet bgs, did not register any changes in vadose zone soil moisture at all monitored depths during and after the 10-day precipitation event. Soil moisture readings at EP-VZC-6, located near the southern tip of the UEP, registered moisture content increases in the shallow probes (2 and 6 feet bgs), but not at any greater depth during and following the January 2017 event. Soil moisture readings at EP-VZC-3, located in the northern portion of the UEP, registered a response to the January 2017 storm event at only the shallowest probe depth (1.5 feet bgs), but not

at the two deeper probes (5 and 15 feet bgs). Similarly, soil moisture readings at EP-VZC-8, located at the northern end of the LEP, registered a response to the January 2017 storm event at only the shallowest probe (3 feet bgs), but not at the two deeper probe depths (10 and 20 feet bgs).

In summary, there were no observable changes in soil moisture at depths greater than 6 feet bgs resulting from this significant precipitation event. At most locations, soil moisture data at the shallowest monitoring intervals (1.5 to 3 feet bgs) illustrate an abrupt increase in soil moisture immediately following the January 4-13 storm event. At some stations, soil moisture at 5 feet and 6 feet bgs also experienced changes following the January precipitation event, but were less pronounced than soil moisture changes at shallower intervals. Based upon these data, there does not appear to be evidence indicating moisture changes in deeper probes that result from an infiltration front moving vertically through the vadose zone.

Future data collection and evaluation may provide additional insight into the: 1) potential advancement of the wetting front to depths of 10 feet bgs and deeper; 2) effects of underlying native clay-rich alluvial layers on potential advancement of the wetting front and pore water chemistry; and 3) potential migration of chemicals within and between vadose zone materials based on lysimeter data from multiple points in time. However, the existing information suggests that: 1) the groundwater impacts beneath OU-4a are the result of past mining operations and fluid management; and 2) chemical loading to the groundwater system under current climatic conditions is very limited, based on vadose zone modeling and soil moisture probe data.

Arimetco Facilities (OU-8)

OU-8 components located throughout the Site include five HLPs (Phase I/II, Phase III South, Phase III 4X, Phase IV Slot, and Phase IV VLT), the FMS (which stores and conveys drain-down solution via a network of ponds, ditches, and 25,000 feet of pipe), and the SX/EW Plant.

RI activities characterized the nature and extent of radiochemicals, metals, and physical properties of the OU-8 HLPs and their associated ponds and ditches. Sources of contamination include:

- Leachable metals (aluminum, copper, iron, and manganese and, to a lesser extent, arsenic, beryllium, cadmium, chromium, cobalt mercury, and nickel) and other COIs on the surface and within the HLPs;
- Acidic draindown solutions containing COIs entrained within the HLPs;
- Acidic drain-down solutions containing COIs stored at the base of the HLPs or contained within their associated ponds and ditches; and
- Historic spills and releases containing COIs.

The OU-8 RI/FS determined that the areas affected by Arimetco operations include the footprints of each HLP and their associated drain-down FMS components, the SX/EW Plant, and historical spill areas (CH2M Hill 2011b). The environmental release or migration pathways of drain-down fluids are infiltration into the subsurface from unlined areas, through tears/breaches in liner systems and FMS components, and through tears/breaches due to potential settling/structural failure of the HLP liner systems (Ecology and Environment, Inc. 2013).

On the basis of groundwater monitoring results, these impacts are thought to extend vertically down to OU-1 groundwater (CH2M Hill 2011b). Furthermore, the OU-8 FS (CH2M Hill 2011b) also notes that additional characterization efforts are needed to fully determine the nature and extent of contamination in: 1) in OU-8 surface and subsurface soil due to releases of drain-down fluids from the Arimetco Facilities; and 2) OU-1 groundwater that may be attributed to OU-8 releases.

Numerous spills of process solution in connection with past Arimetco operations have been recorded, and all of the recorded spills report limited to no confirmation sampling data or post-remedial efforts (CH2M Hill 2010, 2011b). As noted by CH2M Hill (2011b), the spill report documentation in the HSR (CH2M Hill 2010) only generally describes the location and type of materials spilled, along with the estimated quantity of each spill and general response action that was taken. In some instances, these records appear to underestimate the overall quantity of materials spilled. On the basis of the existing spill reports and the suspected quantities of fluids released to the environment, further investigations may be required (CH2M Hill 2011b).

Process Areas (OU-3)

The OU-3 RI has involved extensive characterization to determine the vertical extent of impacted soils beneath known source areas and above known areas of impacted groundwater in the underlying alluvial aquifer (e.g., BC 2011a, 2014e). OU-3 RI activities have included: 1) soils and groundwater characterization in 2004-2005; 2) a variety of radiometric surveys; 3) groundwater monitor well installations in 2005; 4) sub-surface utility and dry well investigations during the period 2010-2013; 5) step-out (vertical and horizontal) soil characterization activities during the period 2013-2014; and 6) sampling and analysis of standing water in select locations during the 2013-2014 field program.

During the RI, a total of 3,385 samples of vadose zone alluvial soils were collected and analyzed from metals (57,764 analyses) and radiochemicals (9,172 analyses). Analytical results are discussed in the context of exceedances relative to the EPA Industrial regional screening level (RSL), a background level, and the maximum depth below ground surface that such exceedances occurred. A total of 198 metals exceedances, primarily arsenic and chromium, occurred in near-surface soils to approximately 15 feet bgs in every sub-area of OU-3. Metals exceedances also occurred at depths to 80 feet bgs at three primary waste solution conveyance ditches (Overflow, East Solution and Calcine Ditches) and the Acid Plant Pond. Fifty-one radiochemical exceedances, primarily for radium-226 and -228, occurred in shallow soils to depths of up to five feet bgs throughout OU-3. Three exceedances occurred in the southern Calcine Ditch (now included in OU-4a) to a depth of 20 feet.

COI concentrations in OU-3 groundwater are highest beneath the Precipitation Plant (Sub-area 5 on Figure 2-1), and are typically 10 times less than the concentrations in groundwater beneath OU-4a (Figures 5-2 to 5-7). The depth to groundwater beneath OU-3 ranges from 90 to more than 120 feet bgs (Figures 4-8 and 4-9). Vadose zone alluvial materials beneath OU-3 do not differ substantially from the vadose zone alluvial materials beneath OU-4a. Thus, to the extent that insights from the OU-4a vadose zone modeling results and soil moisture profiling are applicable to OU-3, groundwater impacts beneath OU-3 appear to be the result of past mining operations and fluid management rather than post-mining ambient Site climate conditions.

5.5.2 Agriculture

Agricultural influences on Study Area groundwater were identified and quantified during the background assessment and are summarized below.

Benson and Spencer (1983) noted that "agricultural practices strongly influence the concentration of uranium in Walker River and its East and West Forks. Irrigation practices induce significant losses of fluid through evaporation and evapotranspiration processes. This results in artificial increases in concentrations of uranium and other elements." Percolation of crop irrigation water through soils increases alkalinity in soil moisture, which has been shown at other sites (Jurgens et al. 2010; Brown et al. 2007) to solubilize and desorb naturally-occurring uranium from sediments resulting in elevated uranium concentrations in Shallow zone groundwater. Application of agricultural amendments and fertilizer on crop fields contributes sulfate, calcium, nitrate and other COIs to groundwater (Benson and Spencer 1983; BC 2014a, 2016b). Nitrate originating primarily from surface-applied fertilizers also plays a role in uranium solubilization leading to uranium mobilization (Nolan and Weber 2015).

Groundwater data from the NSA show that agricultural activities contribute sulfate, uranium, nitrate, alkalinity, and other COIs to groundwater. The NSA refers to the portion of the groundwater Study Area located northeast of West Campbell Ditch and north of the Sunset Hills. Monitor wells and well clusters located in the NSA include B/W-10(S, D1), B/W-50(S, D1, D2, D3), B/W-53(S1, S2, B), B/W-54(S, I, B), B/W-55(S, D1, D2), B/W-56S, B/W-57(S, I, D1, D4), B/W-58(S, D1, D3, B), B/W-59(S, D3), B/W-68(S, D1, D4), B/W-69(S, D1, D2, D5), B/W-81(S, D1, D2), B/W-82R(S, I, B), YPT-MW-(8S, 9I, 10B), YPT-MW-(11S, 12I), YPT-MW-(13I, 14D1) and MMW-2. Groundwater flow data and chemical distributions from monitor wells and clusters B/W-56, B/W-57, B/W-59, B/W-68, B/W-69, and B/W-81 discussed below illustrate the effects of agricultural practices on groundwater quality near agricultural fields in the northeastern part of the Study Area. The locations of these wells are shown on Figure 3-3 and potentiometric surface maps for the alluvial aquifer (Figures 4-11a through g) indicate that groundwater in the NSA flows to the north and northwest.

Groundwater near these wells in the NSA is recharged by infiltration from the East Campbell Ditch and irrigation on a series of agricultural fields (BC 2014a; SSPA 2014). During drilling and installation of monitor wells, zonal groundwater samples were collected to profile vertical chemical gradients in the alluvial aquifer upgradient and downgradient of the fields. Chemical profiles for sulfate, uranium, alkalinity, and arsenic in groundwater are provided on Figure 5-12 for B/W-59, B/W-68, and B/W-69, and on Figure 5-13 for B/W-56, B/W-57, and B/W-81. The wells are grouped in this manner to illustrate changes in groundwater chemistry along two parallel flow paths beneath the agricultural fields.

Except for arsenic, chemical concentrations in alluvial groundwater in the Shallow through Deep 2 zones (i.e., above 4,120 feet amsl) increase along the flow path beneath the agricultural fields (i.e., from B/W-59 and B/W-56 upgradient of the agricultural fields to B/W-68 and B/W-57 immediately downgradient of the agricultural fields). B/W-69 and B/W-81, located farther along their respective flow paths, also exhibit elevated values above 4,120 feet amsl, although the values are not as high as in B/W-68 and B/W-57 immediately downgradient of the agricultural fields. From B/W-56 to B/W-57, sulfate values exhibit more than a four-fold increase from about 30 mg/L at B/W-56 to a maximum of 137 mg/L at B/W-57. Uranium values exhibit more than a ten-fold increase from about 2 µg/L at B/W-56 to a maximum of 73 µg/L at B/W-57. Alkalinity exhibits a 2.5-fold increase from about 100 mg/L at B/W-56 to a maximum of 257 mg/L at B/W-57. From B/W-59 to B/W-68, sulfate values exhibit a two-fold increase from about 75 mg/L at B/W-59 to a maximum of 140 mg/L at B/W-68. Uranium values exhibit almost a two-fold increase from about 25 µg/L at B/W-59 to a maximum of 44 µg/L at B/W-68. Alkalinity exhibits a 20% increase from about 190 mg/L at B/W-59 to a maximum of 235 mg/L at B/W-68.

Arsenic exhibits increasing concentrations with depth at all locations, with the greatest increases observed in the Deep 3 through Deep 5 zones (i.e., below 4,120 feet amsl). Arsenic values generally increase from about 5 µg/L in the Shallow zone to approximately 80 µg/L in the Deep 5 zone. Arsenic values decrease along the flow path beneath the agricultural fields (the highest values are observed in B/W-59 and B/W-56, and the lowest values are observed in B/W-69 and B/W-81).

Data from well clusters B/W-59, B/W-68, B/W69, B/W-56, B/W-57 and B/W-81 indicate that concentrations of other constituents in addition to sulfate, uranium and alkalinity also increase in groundwater above 4,120 feet amsl along the flow path beneath the agricultural fields (Table 5-4). These constituents include TDS, calcium, chloride, magnesium, potassium, nitrate, and strontium. The average horizontal groundwater flow gradient in Shallow zone groundwater beneath the agricultural fields is approximately 0.002 feet/foot. Vertical (downward) groundwater flow gradients beneath the agricultural fields range between 0.02 feet/foot when agricultural pumping is not occurring and 0.1 feet/foot during pumping periods (calculated using water levels in B/W-57S and B/W-57D4).

Increasing alkalinity and calcium concentrations are important controls on mobilization of naturally-occurring uranium from aquifer solids (Bernhard et al. 2001). The correlation between increasing concentrations of alkalinity and calcium associated with agricultural activities, and increasing uranium concentrations as groundwater flows beneath agricultural fields in the NSA is discussed in Section 6.2.2.

Table 5-4. Concentrations of Constituents that Increase Beneath the Agricultural Fields in the North Study Area

Constituent	Units	Average Concentration in Monitor Well (May 2012 - October 2014)				
		B/W-59S	B/W-68S	B/W-68D1	B/W-69S	B/W-69D1 & B/W-69D2
Sulfate	mg/L	48	110	79	125	79
Uranium	µg/L	9	30	41	29	30
Alkalinity, bicarbonate (as $CaCO_3$)	mg/L	140	260	230	275	188
Total Dissolved Solids (TDS)	mg/L	260	530	440	540	400
Calcium	mg/L	31	49	76	78	64
Chloride	mg/L	16	20	20	25	20
Magnesium	mg/L	9	12	19	20	15
Potassium	mg/L	4	5	6	6	6
Nitrate (as N)	mg/L	0.06	5.0	2.9	1.2	0.9
Strontium	mg/L	0.3	0.5	0.6	0.7	0.6
Constituent	**Units**	**Average Concentration in Monitor Well (May 2012 - October 2014)**				
		B/W-56S	**B/W-57S**	**B/W-57I & B/W-57D1**	**B/W-81S**	**B/W-81D1 & B/W-81D2**
Sulfate	mg/L	41	62	142	70	62
Uranium	µg/L	4	11	75	4	36
Alkalinity, bicarbonate (as $CaCO_3$)	mg/L	140	174	293	160	213
Total Dissolved Solids (TDS)	mg/L	254	345	620	350	370
Calcium	mg/L	31	41	103	50	64
Chloride	mg/L	15	18	32	21	20
Magnesium	mg/L	8	11	25	13	15
Potassium	mg/L	5	3	9	5	7
Nitrate (as N)	mg/L	0.08	1.3	1.4	1.4	0.7
Strontium	mg/L	0.3	0.4	0.9	0.4	0.6

Notes: mg/L = milligrams per liter; µg/L = micrograms per liter

5.5.3 Naturally-Occurring Sources

Sulfate, uranium, arsenic, and other COIs occur naturally in groundwater in Mason Valley because of groundwater contact with naturally-mineralized and/or hydrothermally-altered bedrock associated with copper deposits and/or alluvial sediments derived from mineralized bedrock (BC 2014a, 2016b).

As noted in Section 5.4, the extent of mine-impacted groundwater was conservatively estimated under EPA direction because it "is in the best interest of the overall progress for completing the OU-1 Groundwater Remedial Investigation Report" and that the tools used in the background assessment to estimate the area of mine-impacted groundwater may not account for the full range of chemical concentrations that occur naturally in Study Area groundwater (EPA 2016c).

Extensive evidence of naturally-occurring sulfate, uranium, arsenic and other COIs in Mason Valley groundwater includes detectable concentrations of these chemicals in: 1) surface water, which is the primary component of alluvial aquifer recharge, at sampling points located upstream of the Site (Benson and Spencer 1983; BC 2014a); 2) groundwater and geothermal water in the discharge area at the northern end of Mason Valley (Benson and Leach 1979); 3) groundwater samples from Yerington municipal water supply wells that are located hydraulically upgradient and/or cross-gradient of the Site; 4) groundwater samples from monitor wells installed by ARC that are located hydraulically upgradient and/or cross-gradient of the Site (BC 2016b), with concentrations of sulfate and uranium occasionally above MCLs; 5) groundwater from private wells sampled by the USGS located hydraulically upgradient and/or cross-gradient of the Site, with concentrations of sulfate, uranium and arsenic occasionally above MCLs (Benson and Spencer 1983); and 6) groundwater samples from monitor wells installed by ARC that are located outside of the plume of mine-impacted groundwater in the NSA (BC 2016b), with concentrations of uranium as high as 100 µg/L or more.

Further evidence of naturally-occurring COIs in groundwater near the Site occurs in the SWRA where elevated arsenic, and possibly other COIs, appears to be associated with MFR hydrologic processes. These MFR processes include: 1) subsurface water transmitted along fractures and

faults (especially oblique range-front faults such as the Sales Fault) in arsenic-bearing volcanic and granitic bedrock that connect subsurface water in the mountain block and the basin aquifer; and 2) contributions of water at the mountain front from surface stream runoff and shallow subsurface water transmitted in stream bed sediments. Elevated arsenic in SWRA groundwater is associated with low concentrations of sulfate and uranium (the two primary indicators of mine-impacted groundwater), and hydrologic tracer data yield groundwater age estimates that pre-date mining (BC 2016b; EPA 2016b). Collectively, this information indicates that elevated arsenic and possibly other COIs in groundwater in this part of the Study Area are not associated with mining activities. Instead, elevated arsenic in this part of the Study Area is likely naturally-occurring. Elevated arsenic values have been associated with MFR, geothermal groundwater, and stagnant groundwater systems (Smedley and Kinniburgh 2001), and these characteristics apply to the sub-geothermal groundwater present in all groundwater zones to the west of the Site. The elevated temperature of groundwater to the west of the Site and adjacent to the Singatse Range, where MFR hydrologic processes predominate, are shown on figures provided in Appendix L.

SECTION 6.0
CONTAMINANT FATE AND TRANSPORT

The medium of concern in the OU-1 Study Area is groundwater and the mine-related COIs include acidity (i.e., low pH), TDS, major ions including sulfate, metals, and radiochemicals including uranium. The physical transport mechanisms and geochemical attenuation/mobilization processes that affect the movement of COIs in Study Area groundwater are discussed below.

6.1 Contaminant Transport

Transport mechanisms are physical processes controlling the movement of COIs from points of origin through the groundwater system. In the Study Area, COIs are (were) sourced to groundwater from Site sources and/or agricultural practices, and occur naturally in groundwater in Mason Valley because of groundwater contact with naturally-mineralized and/or hydrothermally-altered bedrock associated with copper deposits and/or alluvial sediments derived from mineralized bedrock.

The dominant solute transport mechanisms for COIs in groundwater are advection and dispersion. Advective transport is the migration of the COI with the groundwater. Groundwater moves from areas of recharge (i.e., high hydraulic head) to areas of discharge (i.e., low hydraulic head) and groundwater velocities are determined by solving the groundwater flow equation, which is a function of hydraulic conductivity, hydraulic gradient, and porosity. Groundwater levels in monitor wells provide hydraulic head and groundwater flow velocity information. Hydrodynamic dispersion describes the spread of COIs around an average groundwater flow path, beyond the region they would normally occupy due to advection alone. Hydrodynamic dispersion is the sum of two processes: mechanical dispersion and molecular diffusion. Mechanical dispersion results from mixing that occurs because of local variations in groundwater velocity and the aquifer's matrix. Molecular diffusion results from variations in solute concentrations within the groundwater system.

The primary influences on groundwater movement in the Study Area are subsurface lithology and structure, and local groundwater pumpage and irrigation associated with agriculture. Agricultural activities influence groundwater flow rates and directions, chemical migration pathways and transport rates, and contribute chemicals to groundwater via leaching of soil amendments and subsequent transport through the vadose zone to groundwater. Irrigation practices near the mine Site, including groundwater extraction using high-capacity wells and conveyance/irrigation of both water from the Walker River and groundwater, alter groundwater flow rates and directions during the irrigation season due to the alteration of the natural recharge/discharge rates and locations. These alterations in groundwater flow affect contaminant transport rates and directions.

6.2 Geochemical Attenuation/Mobilization Processes

Geochemical processes that affect the release and subsequent mobility/attenuation of mine-related COIs such as sulfate, uranium and metals during groundwater transport in the Study Area have been evaluated (BC 2016b; Appendix J-7) using: 1) Study Area groundwater data from August 2014 including field parameter measurements (i.e., pH, ORP and DO) and chemical concentrations; 2) the EPA-approved thermodynamic database developed for geochemical modeling Site geochemical attenuation/mobilization processes; and 3) correlations between common groundwater chemicals that affect uranium mobility.

6.2.1 Groundwater Geochemical Conditions and Chemical Speciation

Geochemical oxidation/reduction (redox) conditions within alluvial aquifer groundwater are variable; however, certain general trends and patterns are observed. In general, oxic conditions (i.e., DO > 1 mg/L and higher Eh values) occur in Shallow zone groundwater and suboxic to anoxic conditions (i.e., DO < 1 mg/L and lower Eh values) occur in Intermediate and Deep groundwater zones (Figure 6-1). Exceptions to this general pattern include the following: 1) in Shallow zone groundwater beneath much of the Site and off-Site to the north of the Evaporation Ponds, anoxic (rather than oxic) conditions occur; 2) in Deep groundwater zones beneath the Hunewill Ranch, oxic (rather than anoxic) conditions occur; and 3) on the west side of the Study Area adjacent to the Singatse Range, oxic conditions occur in the Shallow zone, as well as all deeper zones in this part of the Study Area.

Dissolved iron and the iron-system mineralogy, of all the metals present in groundwater, provide the most important constraints on pH, redox, and other metal solubilities in Study Area groundwater (BC 2016b; Appendix J-5). Ferric hydroxide solids in the aquifer sediments can adsorb significant concentrations of dissolved metals and metalloids such as uranium and arsenic, attenuating transport of these constituents. The importance of iron mineralogy and its widespread influence on the Study Area fluid chemistry are illustrated with two Eh-pH diagrams (Figures 6-2 and 6-3). The mineral stability fields in each diagram were constructed for groundwater pH values below, and above, 5.5 respectively, using chemical data from discrete groundwater populations. The individual samples were then plotted on each diagram. The populations were selected from similar chemical environments (samples from two or more unrelated populations are scattered and often obscure the trends).

Groundwater samples from two populations with strong mining impact (pH values below 5.5; Figure 6-2) clearly plot along the K-jarosite and schwertmannite phase boundaries and triple points. Sample alignment near and along the aqueous-mineral boundaries demonstrates the important role these minerals play in dominating and buffering the acidic groundwater at relatively oxidizing Eh levels, as noted above. Also shown on the figure is the specific sample from which the phase boundaries in the figure were computed.

Groundwater samples from two off-Site and more alkaline populations (pH values above 5.5; Figure 6-3) are aligned along the aqueous Fe^{2+} - $Fe(OH)_3(a)$ phase boundary. The mineral $Fe(OH)_3(a)$ is an important adsorptive phase that limits/attenuates the concentrations of other groundwater metals.

As noted previously, the strong alignment demonstrates the impact of the ferric hydroxide phase upon the groundwater redox and pH. The phase boundaries for this diagram were computed from the cluster centroid composition. Based on the groundwater redox conditions and geochemical modeling (BC 2016a; Appendix J-5), chemicals in Study Area groundwater exhibit the following:

- The dominant aqueous redox states determined in virtually all August 2014 groundwater samples were As(V), Fe(II), Mn(II) Se(IV) and U(VI). Vanadium was present in the V(V) redox state in all August 2014 groundwater samples from the Intermediate, Deep and bedrock wells. In Shallow zone groundwater, the V(IV) redox state predominated below a pH of about 5 and the V(V) redox state predominated above a pH of 5.
- Sulfur dissolved in Study Area groundwater is present as sulfate (a negatively-charged ion) and gypsum saturation is observed only in groundwater samples with sulfate concentrations exceeding approximately 1,500 mg/L.
- In the absence of sulfate reduction or gypsum precipitation, the negatively-charged sulfate ion is minimally attenuated in groundwater systems by adsorption. Consequently, in Study Area groundwater with sulfate concentrations less than approximately 1,500 mg/L, sulfate can be expected to be transported as a conservative constituent.
- U(VI) is the dominant oxidation state of dissolved uranium in all August 2014 groundwater samples. Differences in the aqueous speciation of uranium are related to the pH and availability of cations in solution, not redox conditions. Dissolved uranium in Study Area groundwater is predominantly present in complexes with sulfate, carbonate and/or calcium that form neutral or negatively-charged ions (e.g., $Ca_2UO_2(CO_3)_3^0$, $CaUO_2(CO_3)_3^{-2}$, $UO_2(SO_4)_2^{-2}$, and UO_2SO_4) (Figure 6-4). Samples with dominant calcium-uranyl-carbonate ligands reflect oxidizing, carbonate-rich groundwater conditions. Samples with dominant uranyl-sulfate ligands reflect oxidizing conditions with no detectable amounts of alkalinity and pH <5.
- Formation of neutral or negatively-charged aqueous uranium species has been shown to limit uranium adsorption and increase uranium mobility (Fox et al. 2006; Stewart et al. 2010). Since limited uranium adsorption onto hydrous ferric hydroxide solids and soils is expected in neutral to slightly alkaline groundwater (Hsi and Langmuir 1985; Echevarria et al. 2001), uranium attenuation during groundwater transport in off-Site portions of the Study Area can be assumed to be negligible as a conservative first approximation.
- As(V) arsenate is the dominant oxidation state for all August 2014 groundwater samples indicating oxic groundwater conditions, and arsenic speciation is dominated by the negatively-charged $H_2AsO_4^-$ and $HAsO_4^{-2}$ species. Geochemical modeling indicates the potential for precipitation of several arsenic mineral phases including scorodite and barium arsenate.
- Arsenate adsorption on sediments tends to decrease with increasing pH because of competition for adsorption sites between the negatively-charged arsenate aqueous species and OH^- or bicarbonate (Sø et al. 2008; Stachowicz et al. 2007).
- Geochemical modeling predicts the potential for jarosite mineral precipitation primarily in the Shallow zone under the LEP, UEP, Thumb Pond, and Phase IV HLP (Figure 6-5). Uranium and other metals associated with predicted jarosite mineral phases and aquifer sediments beneath these features potentially represent a persistent source of chemicals to groundwater.

- The spatial distributions of elevated concentrations of mobile parameters such as sulfate and uranium are significantly more extensive than the spatial distributions of acidity (as indicated by pH) and metals. The limited spatial extent of low pH values and elevated metal concentrations indicates that geochemical attenuation processes in Study Area groundwater reduces acidity and limits the mobility of metals relative to the more mobile chemicals such as sulfate and uranium. Elevated metal concentrations in groundwater correlate strongly with low pH.

6.2.2 Controls on Uranium Mobility in North Study Area Groundwater

As noted previously in Section 5.5.2, the concentrations of numerous COIs in groundwater increase along groundwater flowpaths beneath agricultural fields in the NSA. The correlation between increasing concentrations of alkalinity and calcium associated with agricultural activities, and increasing uranium concentrations as groundwater flows beneath agricultural fields in the NSA is shown on Figure 6-6. Increasing alkalinity and calcium concentrations are important controls on the formation of uranium species that have a low tendency to bind to aquifer solids (Bernhard et al. 2001) and, thus, uranium is mobilized from aquifer solids to adjacent groundwater as alkalinity and calcium concentrations increase. In addition, the observed correlation between increasing concentrations of alkalinity, calcium and uranium is consistent with the previously-noted geochemical modeling predictions of uranium speciation in Study Area groundwater.

The upper panel in Figure 6-6 displays data for all the alluvial monitor wells in the NSA that are located near agricultural fields. The lower panel in Figure 6-6 displays a subset of the data presented in the upper panel. Specifically, this lower panel displays data along a groundwater flow path from wells upgradient of the NSA agricultural fields (i.e., wells B/W-56 and B/W-59) to wells/well clusters located downgradient of the NSA agricultural fields (i.e., well cluster B/W-57 and well YPT-MW-12I). In wells located upgradient of the NSA, uranium concentrations are less than 12 μg/L. However, as groundwater flows beneath the NSA agricultural fields and concentrations of alkalinity and calcium increase, naturally-occurring uranium attached to aquifer solids is released. At well B/W-57I, elevated uranium concentrations range from approximately 48 to 72 μg/L and at well B/W-57D1 elevated uranium concentrations range from 73 to 110 μg/L.

Well YPT-MW-12I is located hydraulically downgradient of well cluster B/W-57, which provides additional information about chemical loading to alluvial groundwater associated with agricultural activities in the NSA. The influence of agricultural activities on chemical concentrations in YPT-MW-12I is shown on Figure 6-7. Although concentrations of uranium in groundwater at YPT-MW-12I have increased recently (upper panel), the trends in chemical concentrations in groundwater at this well are consistent with geochemical projections based on the control that calcium and alkalinity have on uranium mobility, and are not related to the Site.

As indicated in the lower panel, sulfate concentrations in well YPT-MW-12I are greater than 71 mg/L and exhibit seasonal variability, with elevated concentrations occurring in February of each year. Plume advancement cannot account for the magnitude of sulfate concentrations or seasonality observed in this well because sulfate concentrations are lower in wells to the southwest that demarcate the leading edge of mine-impacted groundwater (i.e., well clusters B/W-10, B/W-52, and B/W-55). Instead, the concentrations of sulfate in well YPT-MW-12I can only be accounted for by sulfate concentrations in upgradient wells B/W-57I and B/W-57D1, which are impacted by agricultural activities.

6.2.3 Site-Specific Distribution Coefficients

As groundwater migrates within the Study Area, certain geochemical reactions occur between the COIs in groundwater and the alluvial aquifer sediments. These reactions determine the relative rates at which chemicals migrate with respect to the advective front of groundwater. The primary process associated with the attenuation of inorganic COIs, particularly metals, in groundwater is adsorption onto the surfaces of minerals or organic material in the aquifer sediments.

The Site-specific distribution coefficient (K_d) discussed in Section 3.3.5 may be used to quantify adsorption reactions between COIs in groundwater and the alluvial aquifer sediments during groundwater flow and chemical transport simulations. It should be noted that the distribution coefficient is a bulk measurement and provides only indirect information on the type of adsorption interactions taking place on the alluvial aquifer sediments. Summary statistics for the revised K_d values calculated using zonal groundwater sample data are shown in Table 6-1.

Table 6-1. Summary Statistics for Zonal Sample K_d Values

Analyte	Distribution Coefficient Statistics (L/kg)				
	Minimum	Maximum	Mean	Geometric Mean	Median
Sulfate	0.05	0.62	0.18	0.15	0.16
Uranium	0.42	289	49	17	33
Arsenic	108	6,412	1,763	957	800

Notes: L/kg = liters per kilogram

K_d values less than 1 L/kg, as is the case for sulfate, indicate little if any partitioning of this negatively-charged ion from the dissolved (i.e., liquid) phase to the solids phase. The uranium K_d values are higher than K_d values for sulfate, indicating some tendency for uranium adsorption on aquifer sediments. Dissolved uranium in Study Area groundwater is predominantly present in neutral or negatively-charged complexes (Figure 6-4), which has been shown to limit uranium adsorption (Fox et al. 2006; Stewart et al. 2010). However, limited uranium adsorption onto hydrous ferric hydroxide solids and soils is expected in neutral to slightly alkaline groundwater (Hsi and Langmuir 1985; Echevarria et al. 2001; Li and Kaplan 2012), and likely explains the higher uranium K_d values.

K_d values for arsenic are substantially greater than 1 L/kg. These high K_d values reflect much higher concentrations of those chemicals in the solid phase versus the dissolved phase, which indicates a strong tendency for arsenic to partition from the dissolved to the solid phase.

Summary statistics for the K_d values calculated for the 25 chemicals and compounds using monitor well groundwater samples are shown in Table 6-2.

Table 6-2. Summary Statistics for Monitor Well K_d Values

Analyte	Distribution Coefficient Statistics (1)				
	Minimum	Maximum	Mean	Geometric Mean	Median
Aluminum	10,850	214,670	88,830	64,851	98,350
Arsenic	18.4	1,311	461.2	277.2	421
Boron	0.40	9.26	4.39	3.15	3.36
Barium	93.8	6,676	1,937	959	1,000
Calcium	0.38	20.6	7.62	3.47	4.74
Chloride	0.07	1.56	0.22	0.18	0.17
Cobalt	192.3	4,643	2,462	1,869	2625
Chromium	316	1,182	689	626	579
Copper	83.3	13,684	4,645	2,662	3,333
Fluoride	1.56	17.2	4.52	3.73	3.26
Iron	8.6	541,880	22,112	146,061	242,733
Potassium	5.1	292.4	109.0	72.7	97.5
Lithium	46.0	379.3	126.6	116.1	113.8
Magnesium	0.34	76.8	26.2	12.5	23.5
Manganese	56.8	3,838	795	351	291
Molybdenum	0.14	2,130	176.9	21.0	63.1
Sodium	0.21	1.3	0.78	0.64	0.88
Nickel	300	1,736	1,142	1030	1,200
Nitrate	0.03	4.0	0.30	0.16	0.15
Lead	1,000	48,100	14,983	8,355	9,600
Selenium	35.9	9,180	3,084	1,202	2154
Sulfate	0.03	1.04	0.186	0.15	0.17
Uranium	1.0	238.2	41.7	20.2	25.6
Vanadium	43.5	4,717	1,115	673	917
Zinc (2)	1,385	1,385	1,385	1,385	1,385

Notes:

1) L/kg = liters per kilogram.
2) For zinc, only one set of co-located sediment and water samples were available for calculating a K_d.

The majority of the K_d values calculated using the monitor well groundwater samples are greater than 1 L/kg. Chloride, nitrate, and sulfate (negatively charged ions in groundwater) and sodium were the only chemicals where the K_d values were consistently less than 1 L/kg. Boron, calcium and fluoride had K_d values in the range of 1 to 10 L/kg. All other chemicals and compounds had K_d values ranging from 10 L/kg up to approximately 500,000 L/kg.

The values at the high end of the range are influenced by the presence of non-detects in the data for the groundwater concentrations. In particular, groundwater concentrations for aluminum, iron and lead were almost universally below the detection limits. However, the concentrations in the soil samples for those same chemicals were nearly all above the detection limit. In these cases, the groundwater concentrations used to calculate K_d values typically represented the reporting limit for that particular chemical. Given that, the K_d values can be thought of as upper bounds for that particular chemical and indicate very little mobility in groundwater.

The variability between the K_d values for the same chemical or compound was, in general, consistent. Only a few chemicals had K_d values with variabilities of more than one order of magnitude. Typically, the wider-ranging K_d variabilities were expressed for those chemicals with non-detect results that were incorporated into the calculation.

Statistical parameters characterizing the uranium K_d values derived from zonal and monitor well groundwater sample data are similar. Uranium K_d values based on monitor well data vary by approximately two orders of magnitude. A correlation of uranium K_d values with Site geochemical data shows that uranium adsorption varies as a function of changes in pH and concentrations of alkalinity, calcium and magnesium. Consequently, use of a constant K_d approach to simulate uranium adsorption during predictive transport modeling may not accurately represent actual adsorption processes.

Instead, a surface complexation model (SCM), such as the general composite approach described by Davis et al. (2009), may be more suitable for modeling adsorption processes during transport at the Site because it can describe changes in adsorption reactions at mineral surfaces as chemical conditions and aqueous speciation(s) change. However, in off-Site portions of the Study Area where aqueous concentrations are lower and hydrous ferric hydroxide solid concentrations are more sporadic, it may be appropriate to assume negligible uranium attenuation during groundwater transport as a conservative first-order approximation.

6.3 Mine-Impacted Groundwater Plume Dynamics

Summarized below are the initial evaluations of mine-impacted groundwater plume dynamics that have been presented in previous reports (BC 2014f, 2015f) and/or discussed with EPA, NDEP and other stakeholders during groundwater technical meetings in 2015 and 2016. The results of these initial evaluations will be provided in a separate report, along with: 1) a statistical evaluation of chemical concentration trends in individual monitor wells, as requested by EPA; and 2) flow model predictions of future changes in plume dimensions and chemical concentrations.

Multiple approaches consisting of center-of-mass calculations and trend evaluations of the total masses and average concentrations of sulfate and uranium have been used to evaluate the dynamics of the plume of mine-impacted groundwater.

<u>Methods</u>

This evaluation was conducted using the Monitoring and Remediation Optimization System (MAROS) software that was developed by the U.S. Airforce Center for Environmental Excellence (AFCEE 2006). MAROS uses the Delaunay Triangulation/Voronoi Diagrams method (George and Borouchaki 1998) to partition the interpolation area into polygon-shaped sub-regions associated with each monitor well. The chemical concentration in an entire sub-region is represented by the concentration in the associated monitor well in a given sampling event. MAROS then calculates the location of the center-of-mass of the interpolated chemical distribution.

MAROS software allows for efficient and consistent computation of large groundwater datasets and depictions of the chemical center-of-mass over time, as well as providing output for computation of changes in chemical mass and average chemical concentration over time. However, the MAROS computation method uses polygon-shaped sub-areas that do not fully encompass the curvilinear area of mine-impacted groundwater. Consequently, although the MAROS output is consistently computed over time, the computed volumes (and derived chemical masses and average concentrations) are underestimated relative to the method used in Section 5.4 to estimate plume statistics.

Center-of-Mass Evaluation

The center-of-mass of plumes of the mine-related constituents sulfate and uranium and the total chemical mass in these plumes were evaluated over the three-year period 2012 through 2015 to assist in the evaluation of plume dynamics. The center-of-mass analysis requires a consistent set of data over time to make meaningful inferences about plume movement. Therefore, only wells that were monitored in every quarter from 1Q 2012 through 1Q 2016 were included in the analysis. Centers-of-mass for sulfate and uranium were calculated for the Shallow, Intermediate, Deep 1, Deep 2, Deep 3, and combined Deep 4 and 5 zones of the alluvial aquifer. The Deep 4 and 5 zones of the alluvial aquifer were combined due to the limited number of monitor wells in these zones.

In the evaluation, monitor well B/W-27D3a was included in the list of Deep 2 zone wells and monitor well B/W-41D4 was included in the list of Deep 3 zone wells to address areas within each zone that were lacking adequate spatial coverage. Monitor wells in the B/W-65 well cluster, located in the middle of an agricultural field, were not included in the analysis because the wells have been sampled sporadically due to lack of access during the irrigation season.

Prior to interpolation, chemical data from the 261 monitor wells were reviewed using time-concentration plots to screen for potential outliers. When outliers were identified for a particular sampling event, the value of the data point was replaced with the average value of the previous and subsequent sampling events. The number of outliers identified represents less than 0.2 percent of the data used in the analysis.

The calculated centers-of-mass for sulfate and uranium are located beneath the Evaporation Ponds (Figure 6-8), with the following exceptions:

- The uranium center-of-mass in the Deep 1 zone is located beneath the Hunewill Ranch (about 3,000 feet northwest of the monitor well B/W-25D1). This is consistent with the presence of collocated elevated concentrations of uranium and alkalinity beneath the agricultural fields in the Deep 1 zone compared to areas beneath the Site.
- The uranium center-of-mass in the Deep 4/5 zone is located beneath the Hunewill Ranch within a few hundred feet of the Site boundary.

From February 2012 to February 2016, the centers-of-mass for the sulfate and uranium plumes exhibit very little relative movement, an indication of stable plume behavior.

Total Mass and Average Concentrations

Over the 3-year monitoring period from February 2012 to February 2015, the masses of sulfate and uranium in each of the groundwater zones remained relatively stable, with typically less than five percent variation between the initial and more recent monitoring events (Figure 6-9). Also, clear trends (either increasing or decreasing) are not evident, with the exception of decreasing sulfate trends observed in the Shallow zone and decreasing sulfate and uranium trends in combined Deep 4 and Deep 5 zones. During the monitoring period, the calculated mass of sulfate in the Shallow zone decreased from about 97,000 to 85,000 tons (i.e., 12%) and the mass of sulfate in the Deep 4/5 zones decreased from about 13,000 to 10,000 tons (i.e., 25%). The mass of uranium in the combined Deep 4 and Deep 5 zones decreased from about 5.2 to 3.7 tons (i.e., 29%).

Because the various alluvial groundwater zones have different thicknesses and volumes, the total chemical masses in each individual zone are not directly comparable. For example, the Intermediate zone contains the smallest sulfate mass because it is the thinnest groundwater zone. Consequently, changes in average concentrations over time in the various groundwater zones are a more appropriate comparison. Changes over time in average concentrations of sulfate and uranium in the alluvial aquifer groundwater zones are also shown on Figure 6-9.

Clear trends (either increasing or decreasing) are not evident, with the exception of decreasing average sulfate concentrations in the Shallow zone and decreasing sulfate and uranium concentrations in the combined Deep 4 and 5 zones. During the monitoring period, the average concentration of sulfate in the Shallow zone decreased from 1,518 mg/L to 1,330 mg/L (i.e., 12%) and the average concentration of sulfate in the Deep 4/5 zones decreased from 90 mg/L to 67 mg/L (i.e., 25%). The concentration of uranium in the Deep 4/5 zone decreased from 35 to 25 ug/L (i.e., 29%).

The decrease in sulfate mass and average concentration in the Shallow zone is interpreted as dilution effects from irrigation practices in the agricultural fields north of the mine boundary. The cause of the observed decrease in calculated average uranium concentrations in the combined Deep 4 and Deep 5 zones is likely due to dilution and dispersion. The calculated decrease in total sulfate and uranium mass is likely an apparent effect due to the fewer data points for calculating chemical mass.

The results of these evaluations indicate that, in general, the plume of mine-impacted groundwater is stable. The plume stability is the result of very slow groundwater velocities and attenuation by dilution. The dilution occurs primarily as the result of recharge on the agricultural fields (specifically on the fields of the Hunewill Ranch) and leakage from irrigation ditches (specifically the West Campbell Ditch), and dispersion within the groundwater plume.

SECTION 7.0

HYDROGEOLOGIC CONCEPTUAL SITE MODEL

The Site is a former copper mine located in the west-central portion of the Mason Valley, a Basin-and-Range-type graben filled with up to 1,000 feet of unconsolidated valley-fill deposits of Tertiary and Quaternary age lying unconformably on a weathered surface of hydrothermally-altered Tertiary volcanic and Mesozoic intrusive bedrock. The valley is bordered to the west by the Singatse Range, to the east by the Wassuk Range, and to the north by the Desert Mountains. Regional metals mineralization and hydrothermal alteration associated with localized porphyry and skarn copper deposits occur in the Singatse Range and nearby portions of the Mason Valley.

The unconsolidated valley fill deposits were derived primarily from erosion of the uplifted mountain blocks and from deposition in the floodplain of the Walker River. In addition, lacustrine deposits derived from ancestral Lake Lahonton occur north of the Site. Depositional processes have resulted in a complex interbedded sequence of alluvial sediments.

Historically, regional groundwater flow patterns in the Mason Valley prior to Anaconda/Arimetco mining operations were similar to current conditions with groundwater moving generally from south to north, and discharging to surface seeps and geothermal springs in the northern portion of the basin. Locally, though, current flow patterns have been significantly altered from historical patterns by agricultural activities. The alluvial aquifer in the Mason Valley is very productive and groundwater is currently pumped extensively for irrigation (Carroll et al. 2010; SSPA 2014).

The alluvial aquifer is primarily recharged by downward percolation from irrigated fields (49%), leakage from irrigation ditches (29%), infiltration from the channel of the Walker River (20%), and MFR (2%), consisting of infiltration through bedrock of precipitation that falls on surrounding mountain ranges and minor tributary surface flows in ephemeral drainages (SSPA 2014). Recharge from precipitation falling directly on the valley floor is negligible (Huxel and Harris 1969; Lopes and Allander 2009a, 2009b).

Within the Study Area, the alluvial sediments are up to 700 feet thick and comprise a single aquifer. The alluvial aquifer is subdivided into a Shallow, an Intermediate and a Deep zone (which is further subdivided into Deep zones 1 through 5). These groundwater zone designations are based on elevation and used only to identify and group monitor wells with similar screen intervals at the same relative depth in the aquifer. Clay layers or other low-permeability sediments are laterally discontinuous resulting in unconfined or semi-confined alluvial aquifer groundwater conditions.

Alluvial groundwater near the Site generally flows to the northwest, but flow directions are locally affected by bedrock outcrops within and along the margins of the valley, drawdown from pumped wells (particularly in deeper zones of the alluvial aquifer), and recharge sources including the Walker River, the West Campbell Ditch and irrigation on the Hunewill Ranch and other agricultural fields. Groundwater in the alluvial aquifer moves relatively slowly, with flow velocities estimated to be less than 100 feet per year (BC 2014a).

Anthropogenic activities within the Study Area, especially agricultural activities, influence groundwater flow rates and directions, chemical migration pathways and transport rates, and contribute chemicals to groundwater via evapoconcentration and leaching of soil amendments and naturally-occurring chemicals in alluvial sediments, and subsequent transport through the vadose zone to groundwater. Irrigation practices near the mine Site, including groundwater extraction using high-capacity wells and conveyance/irrigation of both water from the Walker River and groundwater, alter groundwater flow rates and directions during the irrigation season due to the alteration of the natural recharge/discharge rates and locations. Agricultural pumping seasonally results in strong downward vertical gradients that are often 10 to 100 times greater than horizontal gradients.

Past and/or ongoing sources of COIs to Study Area groundwater include: 1) the mine waste facilities, which have been grouped into the various Site OUs; 2) naturally-occurring chemicals; and 3) agriculture. The major past and/or ongoing mine-related sources of COIs to groundwater include: 1) OU-4a, the Evaporation Ponds (BC 2014a, 2014d); OU-8, the Arimetco Facilities (CH2M Hill 2010, 2011a, 2011b); and 3) OU-3, the Process Areas (BC 2014a, 2014e).

Mine-related COIs include acidity (i.e., low pH) and elevated concentrations of TDS, major ions including sulfate, metals, and radiochemicals including uranium. Concentrations of mine-related chemicals in groundwater are most elevated in the Shallow zone of the alluvial aquifer beneath OU-4a features that include the LEP, UEP, Finger Ponds, Phase IV VLT HLP, Phase IV VLT Pond, and the Calcine Ditch. Chemical concentrations in groundwater decrease with vertical depth and horizontal distance from these facilities.

Hydraulic assessments and chemical distributions indicate that the PWS was only partially effective in capturing Shallow zone mine-impacted groundwater during its operational life from 1989 to 2009, when it was shut down with EPA approval.

Geochemical evaluations of groundwater quality data (BC 2016a) indicate that sulfate and dissolved uranium form neutral or negatively-charged aqueous ionic species in groundwater throughout Study Area (except beneath the Evaporation Ponds) and, thus, undergo very limited (if any) geochemical attenuation due to mineral precipitation or adsorption to aquifer materials during groundwater transport. Dissolved uranium in Study Area groundwater is predominantly present in complexes with carbonate plus or minus calcium, which reflect oxidizing, carbonate-rich groundwater conditions. Locally, dissolved uranium is also complexed with sulfate in Shallow zone groundwater beneath the Evaporation Ponds where pH is less than 5 and sulfate concentrations exceed 1,500 mg/L.

The spatial distributions of elevated concentrations of mobile parameters such as sulfate and uranium are significantly more extensive than the spatial distributions of acidity (as indicated by pH) and metals. The significantly more limited spatial extent of low pH values and elevated metal concentrations indicates that geochemical attenuation processes in Study Area groundwater reduce acidity and limit the mobility of metals relative to the more mobile chemicals such as sulfate and uranium (EPA 2007b; BC 2016a, 2016b). Elevated metal concentrations in groundwater correlate strongly with low pH.

Geochemical evaluations of groundwater quality data (BC 2016a) also indicate the likely precipitation of solid mineral phases (e.g., jarosite) primarily in the Shallow zone beneath the LEP, UEP, Thumb Pond and Phase IV HLP. These mineral phases likely represent a potential, ongoing source of COIs to groundwater.

Sulfate, uranium, and arsenic (and other COIs) occur naturally in groundwater in Mason Valley because of groundwater contact with naturally-mineralized and/or hydrothermally-altered bedrock associated with copper deposits and/or alluvial sediments derived from mineralized bedrock (BC 2014a, 2016b). To the west of the Site where sulfate and uranium concentrations are low, elevated concentrations of arsenic are associated with MFR and elevated groundwater temperatures. In addition, sulfate, uranium, and other COIs are sourced to groundwater due to agricultural activities (BC 2016b; EPA 2016c). The assessment of background groundwater quality conservatively established the maximum extent of mine-impacted groundwater and identified an area of groundwater in the northern part of the Study Area (i.e., the NSA) that has been impacted by agricultural activities rather than mining activities.

The extent of mine-impacted groundwater has been defined using sulfate, dissolved uranium, and sulfur isotopes in sulfate because these parameters are more mobile in groundwater relative to other mine-related COIs such as metals (EPA 2007b) and, thus, have traveled the farthest downgradient distance in the alluvial aquifer (BC 2016b). The extent of mine-impacted groundwater in the Study Area can be generally described as follows, recognizing that mine-impacted groundwater is spatially more extensive in the Shallow, Intermediate and Deep 1 zones of the alluvial aquifer relative to the Deep 2 through Deep 5 zones. The northernmost extent of mine-impacted groundwater in the Shallow, Intermediate and Deep 1 zones of the alluvial aquifer is located near the Sunset Hills between well clusters B/W-10 and B/W-52. The eastern extent of mine-impacted groundwater in the Shallow, Intermediate and Deep 1 zones of the alluvial aquifer is approximately located near or beneath the West Campbell Ditch alignment. To the west of the Site, mine-impacted groundwater extends almost to the western extent of saturated alluvium between unimpacted wells/clusters B/W-16S and B/W-40, and impacted well clusters B/W-33, B/W-6 and B/W-22.

Mine-impacted groundwater in the deeper zones does not extend as far north as the upper three zones. In the Deep 2 through Deep 5 zones, the maximum northern extent of mine-impacted groundwater is near the northern end of the Hunewill Ranch fields. The eastern extent of mine-impacted groundwater in the Deep 2 through Deep 5 zones of the alluvial aquifer is located between well clusters B/W-27 and B/W-50. On the east, the area of mine-impacted groundwater in the Deep 3 through Deep 5 zones reflects the former influence of seasonal groundwater extraction for crop irrigation from agricultural wells (e.g., WDW019, located adjacent to the B/W-1 well cluster). To the west of the Site, mine-impacted groundwater in the Deep 3 through Deep 5 zones extends almost to the western extent of saturated alluvium.

The estimated volume of mine-impacted groundwater (i.e., the portion of the downgradient aquifer where sulfate and uranium exceed background concentrations) is 385,327 acre-feet, and contains an estimated 0.5 million tons of sulfate and 100 tons of dissolved uranium. Irrigation wells and municipal wells are located outside of the plume of mine-impacted groundwater (Figure 3-13). In addition, the plume of mine-impacted groundwater does not discharge to surface water.

The plume of mine-impacted groundwater appears stable based on evaluations of changes in the estimated volume of contaminated groundwater, sulfate/uranium masses, and chemical centers-of-mass through time. Plume stability is the result of very slow groundwater velocities and attenuation by dilution. The dilution occurs primarily as the result of recharge on the agricultural fields (specifically on the fields of the Hunewill Ranch) and leakage from irrigation ditches (specifically the West Campbell Ditch), and dispersion within the groundwater plume.

Groundwater quality in the NSA has been impacted by agricultural activities rather than mining activities (BC 2016b) based on multiple lines of evidence including groundwater flow patterns, chemical distributions, groundwater age estimates, hydrologic tracers, and sulfur isotopes. These agricultural practices have resulted in concentrations of sulfate and uranium that are elevated above background values and/or MCLs and/or exhibit increasing trends.

Monitor well data from the NSA indicate that concentrations of nitrate, sulfate, calcium, uranium, and alkalinity in alluvial groundwater in the Shallow through Deep 2 zones increase along the flow path beneath the agricultural fields. Increases in nitrate are associated with organic fertilizer application on crop fields. Increases in sulfate and calcium concentrations are associated with application of gypsum ($CaSO_4$) as a soil amendment on crop fields, which dissolve in irrigation water that percolates down to the water table. Increases in uranium concentrations are associated with crop irrigation. Percolation of irrigation water through soils increases alkalinity in the soil moisture, which mobilizes and desorbs naturally-occurring uranium from sediments (as soluble complexes with sulfate, carbonate plus or minus calcium) resulting in elevated uranium concentrations in groundwater (Jurgens et al. 2010; Brown et al. 2007). Alluvial sediments in Mason Valley contain naturally-occurring uranium (BC 2009b). The impact of agriculture activities on uranium mobility in NSA groundwater within or near irrigated land is illustrated by the strong correlation between uranium, alkalinity and calcium. Increases in alkalinity and calcium are associated with increases in uranium concentrations that can exceed 100 µg/L.

SECTION 8.0
RISK EVALUATION

In a groundwater technical meeting held on June 30, 2016 attended by ARC, EPA and other stakeholders, EPA directed ARC to proceed with preparation and submittal of this OU-1 RI Report without including the risk evaluation. The risk evaluation is ongoing and will proceed on a separate but parallel path from this document. Potential human health risks are generally described herein, but will be addressed more comprehensively in a separate OU-1 HHRA report.

This OU-1 RI Report, in conjunction with the OU-1 HHRA, will provide the basis for ARC to identify RAOs and potential remedies for OU-1, which would occur during future FS scoping discussions.

SECTION 9.0

REFERENCES

Air Force Center for Environmental Excellence (AFCEE), 2006. Monitoring and Remediation Optimization System (MAROS), User's Guide, March 2006.

Anaconda Mining Company, 1958. Engineering Drawing WHE-201, Tailing Disposal Sulphide Plant - Tailings Pond General Arrangement. March 24.

Anaconda Mining Company, 1966. Engineering Drawing YG-20, Water Supply & Distribution - Daily Water Balance Diagram. Prepared July 15, 1953. Revised July 28.

Anaconda Mining Company, 1967. Engineering Drawing WHN-1208, Sulphide Plant Quantitative Flow Diagram. Prepared May 19, 1966. Revised January 9.

Anaconda Minerals Company, 1984. Water Quality Investigation and Mitigation Plan. Yerington Mine.

Applied Hydrology Associates, 1983. Evaluation of Water Quality and Solids Leaching Data. Yerington Mine. Prepared for Atlantic Richfield Company.

Applied Hydrology Associates (also Norwest Applied Hydrology), 2000-2007. 2000-2007 Annual Monitoring and Operation Summary reports, Prepared for Atlantic Richfield Company.

Atlantic Richfield Company, 2008. Pumpback Well System Characterization Work Plan. Yerington Mine Site, Lyon County, Nevada.

Atlantic Richfield Company, 2010. Pumpback Well System Characterization Work Plan Addendum - Revision 2. Yerington Mine Site, Lyon County, Nevada. February 17.

Atlantic Richfield Company, 2011. Addendum to the On-Site Monitor Well Installation Work Plan. Yerington Mine Site, Lyon County, Nevada. September 7.

Atlantic Richfield Company, 2012a. Proposed Initial Bedrock Characterization Activities, Yerington Mine Site, Lyon County, Nevada. January 5.

Atlantic Richfield Company, 2012b. Proposed Initial Bedrock Characterization Activities - Revision 1, Yerington Mine Site, Lyon County, Nevada. October 11.

Atlantic Richfield Company, 2012c. Groundwater Flow Modeling Deliverables, Yerington Mine Site, Lyon County, Yerington, Nevada. June 25.

Atlantic Richfield Company, 2012d. Comprehensive Hydrologic Tracer Sampling Event and Request to Eliminate Select Tracers, Yerington Mine Site, Lyon County, Nevada. March 19.

Atlantic Richfield Company, 2012e. Preliminary Responses to February 7, 2012 EPA Comments on the 2011 Background Groundwater Quality Assessment, Yerington Mine Site dated September 28, 2011; Administrative Order on Consent, EPA Region 9 CERCLA Docket No. 9-2007-0005. April 18.

Atlantic Richfield Company, 2014. Technical Memorandum: Site-Wide Groundwater Monitoring Optimization, Yerington Mine Site, Lyon County, Nevada. April 14.

Atlantic Richfield Company, 2016a. Letter to D. Seter, Subject: Yerington Mine Site, Lyon County Nevada, Site ID #09GU, Request to Modify Domestic Well Monitoring Program and Bottled Water Program. September 1.

Atlantic Richfield Company, 2016b. Responses to EPA Comments dated February 11, 2016 on the Background Groundwater Quality Assessment - Revision 2 dated July 2, 2015; Administrative Order on Consent, EPA Region 9 CERCLA Docket No. 9-2007-0005. June 14.

Bell, E.J. and D.B. Slemmons, 1979. Recent crustal movements in the central Sierra Nevada-Walker Lane region of California-Nevada--Part II, The Pyramid Lake right-slip fault zone segment of the Walker Lane: Tectonophysics, v. 52, p. 571-583.

Benson, L.V. and D. L. Leach, 1979. Uranium Transport in the Walker River Basin, California and Nevada. Journal of Geochemical Exploration, vol. 11, p. 227-248.

Benson, L.V. and R.J. Spencer, 1983. A Hydrochemical Reconnaissance Study of the Walker River Basin, California and Nevada. USGS Open-File Report 83-740.

Bernhard, G., G. Geipel, T. Reich, V. Brendler, S. Amayri, and H. Nitsche, 2001. Uranyl(VI) carbonate complex formation: Validation of the $Ca_2UO_2(CO_3)_3$ (aq) species. Radiochimica Acta, 89:511-518.

Bigham, J.M., U. Schwertmann, S.J. Traina, R.L. Winland, and M. Wolf, 1996. Schwertmannite and the chemical modeling of iron in acid sulfate waters. Geochimica et Cosmochimica Acta, Vol. 60, pp. 2111-2121.

Bourrié, G., F. Trolard, J.M. Génin, A. Jaffrezic, V. Maître, and M. Abdelmoula, 1999. Iron control by equilibria between hydroxy-green rusts and solutions in hydromorphic soils. Geochimica et Cosmochimica Acta, Vol. 63, pp. 3417-3427.

Brown, C.J., B.C. Jurgens, B.G. Katz, M.K. Landon, and S.E. Eberts, 2007. Arsenic and Uranium in Four Aquifer Settings: Occurrence, Distribution, and Mechanisms for Transport to

Supply Wells. NGWA Naturally Occurring Contaminants Conference: Arsenic, Radium, Radon, Uranium. March 22-23.

Brown and Caldwell, 2002. Installation of Two Monitor Wells at the Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company.

Brown and Caldwell, 2003. Final Draft Process Areas Work Plan. Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. December 15.

Brown and Caldwell, 2005. First-Step Hydrogeologic Framework Assessment Work Plan North of the Anaconda Mine Site. Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. April 22.

Brown and Caldwell, 2007a. Data Management Plan for the Yerington Mine Site, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. April 24.

Brown and Caldwell, 2007b. Second-Step Hydrogeologic Framework Assessment Work Plan, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. February 28.

Brown and Caldwell, 2007c. Draft Site-Wide Groundwater Monitoring Plan, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. August 8.

Brown and Caldwell, 2008, Anaconda Evaporation Ponds Removal Action Characterization Work Plan, Yerington Mine Site. Prepared for Atlantic Richfield Company. September 15.

Brown and Caldwell, 2008a. Anaconda Evaporation Ponds Removal Action Characterization Work Plan, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. September 15.

Brown and Caldwell, 2008b. Shallow Alluvial Aquifer Characterization Work Plan for the Northern Portion of the Yerington Mine Site, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. December 30.

Brown and Caldwell, 2008c. Second-Step Hydrogeologic Framework Assessment Data Summary Report, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. October 15.

Brown and Caldwell, 2009, Evaporation Ponds Removal Action Characterization Data Summary Report. June 12.

Brown and Caldwell, 2009a. Site-Wide Groundwater Monitoring Plan - Revision 1, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. December 15.

Brown and Caldwell, 2009b. Background Soils Data Summary Report - Revision 1, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. March 9.

Brown and Caldwell, 2010a. Shallow Zone Characterization Data Summary Report - Revision 1, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. January 29.

Brown and Caldwell, 2010b. Addendum to the Site-Wide Quality Assurance Project Plan, Domestic Well Monitoring Plan - Revision 3, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. July 1.

Brown and Caldwell, 2010c. 2010 Groundwater Monitor Well Work Plan - Revision 2, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. July 22.

Brown and Caldwell, 2010d. Agricultural Fields Characterization Work Plan - Revision 2, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. July 20.

Brown and Caldwell, 2010e. Aquifer Solids Testing Work Plan - Revision 1, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. September 21.

Brown and Caldwell, 2010f. Summary of PWS Aquifer Testing, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. September 24.

Brown and Caldwell, 2010g. Draft Aquifer Solids Testing Work Plan, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. June 21.

Brown and Caldwell, 2011a. On-Site Monitor Well Installation Work Plan - Revision 1, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. August 29.

Brown and Caldwell, 2011b. Aquifer Solids Testing Work Plan - Revision 1, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. September 21.

Brown and Caldwell, 2011c. Draft Background Groundwater Quality Assessment, Site-Wide Groundwater Operable Unit, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. September 28.

Brown and Caldwell, 2012a. Site-Wide Groundwater Monitoring Plan - Revision 2, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. July 19.

Brown and Caldwell, 2012b. Draft Site-Wide Groundwater Operable Unit (OU-1) Remedial Investigation Work Plan, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. November 19.

Brown and Caldwell, 2012c. SOP-23 Aquifer Solids Testing SOP - Redox-Preserved Sample Preparation and Testing, Yerington Mine Site, Hazen Research, Inc. Laboratory Facility, Golden, CO. Prepared for Atlantic Richfield Company. August 17.

Brown and Caldwell, 2012d. SOP-23 Aquifer Solids Testing SOP - Redox-Preserved Sample Preparation and Testing - Revision 1, Yerington Mine Site, Hazen Research, Inc. Laboratory Facility, Golden, CO. Prepared for Atlantic Richfield Company. October 15.

Brown and Caldwell, 2012e. Aquifer Test Data Summary Report - Revision 1, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. December 13.

Brown and Caldwell, 2013a. 2010 Monitor Well Installation and Agricultural Fields Characterization Data Summary Report - Revision 1. Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. January 18.

Brown and Caldwell, 2013b. Additional Monitor Well Work Plan - Revision 1, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. October 8.

Brown and Caldwell, 2013c. Initial Bedrock Characterization Data Summary Report, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. November 20.

Brown and Caldwell, 2013d. Revised Public Information for the Northern Portion of the Background Groundwater Study Area, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. August 5.

Brown and Caldwell, 2013e. Draft Additional Monitor Well Work Plan, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. June 26.

Brown and Caldwell, 2014a. Site-Wide Groundwater Operable Unit (OU-1) Remedial Investigation Work Plan - Revision 1, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. February 7.

Brown and Caldwell, 2014b. 2013 Annual Operations and Maintenance Report for the Arimetco Fluid Management System, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. June 9.

Brown and Caldwell, 2014c. Groundwater Geochemical Characterization Data Summary Report, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. December 30.

Brown and Caldwell, 2014d. Phase 1 Field Sampling and Analysis Plan Anaconda Evaporation Ponds, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. July 31.

Brown and Caldwell, 2014e. OU-3 Step-out Soils Characterization Data Summary Report, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. December 12.

Brown and Caldwell, 2014f. 2013 Annual Groundwater Monitoring Report, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. May 12.

Brown and Caldwell, 2015a. Bedrock Groundwater Assessment Technical Memorandum, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. January 28.

Brown and Caldwell, 2015b. Draft Wabuska Drain (OU-7) Remedial Investigation Work Plan - Conceptual Site Model and Data Quality Objectives, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. July 14.

Brown and Caldwell, 2015c. Background Groundwater Quality Assessment - Revision 2, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. July 2.

Brown and Caldwell, 2015d. Additional Monitor Well Installation Data Summary Report, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. June 11.

Brown and Caldwell, 2015e. Groundwater Geochemical Characterization Data Summary Report - Revision 1, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. December 11.

Brown and Caldwell, 2015f. Technical Memorandum: Draft Initial Screening of Remedial Alternatives, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. December 2.

Brown and Caldwell, 2016a. Groundwater Geochemical Characterization Data Summary Report - Revision 2, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company.

Brown and Caldwell, 2016b. Background Groundwater Quality Assessment - Revision 3, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. November 11.

Brown and Caldwell, 2016c. 2015 Annual Groundwater Monitoring Report, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. May 16.

BC, 2017. Technical Memorandum: Phase 1 Evaporation Ponds Characterization Data Summary Report. Prepared for Atlantic Richfield Company, March 16

Brown and Caldwell, 2017a. Technical Memorandum: Wabuska Drain (OU-7) Field Sampling and Analysis Plan Data Summary Report and Conceptual Site Model Update. Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. January 3

Brown and Caldwell, 2017b. Technical Memorandum: Phase 1 Evaporation Ponds Characterization Data Summary Report. Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. January 20.

Brown and Caldwell and Integral Consulting, Inc., 2007. Draft Remedial Investigation Work Plan for Site-Wide Groundwater Operable Unit 1, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. November 16.

Carroll, R.W.H., G. Pohll, D. McGraw, C. Garner, A. Knust, D. Boyle, T. Minor, S. Bassett, and K. Pohlmann, 2010. Mason Valley Groundwater Model: Linking Surface Water and Groundwater in the Walker River Basin, Nevada. Journal of American Water Resources Association.

CH2M Hill, 2010. Final Historical Summary Report, Anaconda-Yerington Mine Site, Yerington, Nevada. October.

CH2M Hill, 2011a. Final Supplemental Remedial Investigation Report Arimetco Facilities Operable Unit 8, Anaconda-Yerington Copper Mine. Yerington, Nevada. October.

CH2M Hill, 2011b. Feasibility Study for Arimetco Facilities Operable Unit 8 Heap Leach Pads and Drain-down Fluids, Anaconda-Yerington Copper Mine. Yerington, Nevada. July.

Dalton, D., 1998. Arimetco Yerington Mine and Process Facility Site Assessment of Groundwater Quality, Yerington, Nevada. Prepared for Arimetco, Inc. July.

Davis, J.A., S.P. Hyun, P.M. Fox, and K.F. Hayes, 2009. A surface complexation modeling approach for Uranium (VI) transport in groundwater. Abstracts of the International Mine Water Conference, Proceedings. October.

Doherty, J., 2009. PEST - Model-Independent Parameter Estimation & Uncertainty Analysis, Version 12.2. Watermark Computing. Brisbane, Australia.

Dong, W. and S.C. Brooks, 2006. Determination of the formation constants of ternary complexes of uranyl and carbonate with alkaline earth metals (Mg^{2+}, Ca^{2+}, Sr^{2+}, and Ba^{2+}) using anion exchange method. Environmental Science and Technology Vol. 40, pp. 4689–4695.

Echevarria, G., M.I. Sheppard, and J.L. Morel, 2001. Effect of pH on the sorption of uranium in soils. Journal of Environmental Radioactivity, Vol. 53, pp. 257-264.

Ecology and Environment, Inc., 2013. Technical Memorandum and Report of START Activities, Arimetco Pond Design and Perimeter Ditch Repair Field Observations and Operation and

Maintenance Recommendations, Yerington, Nevada. Prepared for the Atlantic Richfield Company. April 29.

Environmental Standards, Inc. and Brown and Caldwell, 2009. Quality Assurance Project Plan Yerington Mine Site, Revision 5. Prepared for Atlantic Richfield Company. May 20.

EPA, 1988. Interim Final Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA. EPA/540/G-89/004.

EPA, 1992. Guidance for Data Usability for Risk Assessment. (Part B). Final. Office of Emergency and Remedial Response. Washington D.C.

EPA, 1999. Understanding Variation in Partition Coefficient, Kd, Values. Volume I: The k_d Model, Methods of Measurement, and Application of Chemical Reaction Codes. EPA 402-R-99-004A.

EPA, 2005. Standard Operating Procedure for Analysis of Total Organic Carbon in Sediments (Dry Combustion, Infrared Detection). Method LG601. Revision 04. March.

EPA, 2007a. Administrative Order for the Remedial Investigation and Feasibility Study. In the matter of Anaconda / Yerington Mine Site, Yerington, Lyon County, Nevada. Atlantic Richfield, Respondent. U.S. EPA Region 9, Docket No. 9-2007-0005. Proceeding under Section 106(a) of CERCLA, as amended, 42 USC § 9606(a). Including Attachment A: Scope of Work for the Remedial Investigations / Feasibility Studies Continued Response Action. January 12, 2007.

EPA, 2007b. Monitored Natural Attenuation of Inorganic Constituents in Ground Water, Volume 1 Technical Basis for Assessment. EPA/600/R-07-139.

EPA, 2008. A Systematic Approach to Evaluation of Capture Zones at Pump and Treat Systems, Final Project Report. EPA 600/R-8/003.

EPA, 2009. Statistical Analysis of Groundwater Monitoring Data at RCRA Facilities, Unified Guidance. EPA/530/R-09-007.

EPA, 2010a. Letter from EPA to Atlantic Richfield Company RE: Comments on the Draft Aquifer Solids Testing Work Plan. September 13.

EPA, 2010b. Letter from EPA to Atlantic Richfield Company RE: Aquifer Solids Testing Work Plan - Revision 1. September 30.

EPA, 2010d. Monitored Natural Attenuation of Inorganic Constituents in Ground Water, Volume 3, Assessment for Radionuclides Including Tritium, Radon, Strontium, Technetium, Uranium, Iodine, Radium, Thorium, Cesium, and Plutonium-Americium. EPA/600/R-10/039.

EPA, 2011a. Letter from EPA to Atlantic Richfield Company RE: Comments on the 2010 Annual Groundwater Monitoring Report (April 15, 2011), the First Quarter 2011 Groundwater Monitoring Report (July 1, 2011), and the Second Quarter 2011 Groundwater Monitoring Report (August 26, 2011) for the Anaconda Mine Site. September 29.

EPA, 2011b. Letter from EPA to Atlantic Richfield Company RE: Approval of the Addendum to the On-Site Monitor Well Installation Work Plan. September 30.

EPA, 2012a. Letter from EPA to Atlantic Richfield Company RE: Comments on the Draft Background Groundwater Quality Assessment, Yerington Mine Site, Nevada. February 7.

EPA, 2012b. Letter from EPA to Atlantic Richfield Company RE: Comprehensive Hydrologic Tracer Sampling Event and Request to Eliminate Select Tracers, Yerington Mine Site, Nevada. April 27.

EPA, 2012c. Letter from EPA to Atlantic Richfield Company RE: Comments on the Proposed Initial Bedrock Characterization Activities for the Anaconda Mine Site. April 12.

EPA, 2012d. Letter from EPA to Atlantic Richfield Company. October 22.

EPA, 2012e. Letter from EPA to Atlantic Richfield Company RE: Groundwater Flow Modeling Deliverables Anaconda Mine Site, Nevada. July 11.

EPA, 2012f. Letter from EPA to Atlantic Richfield Company. October 26.

EPA, 2012g. Letter from EPA to Atlantic Richfield Company RE: Comments on SOP-23 Aquifer Solids Testing - Redox-Preserved Sample Preservation and Testing Dated August 14, 2012. September 26.

EPA, 2013a. Letter from EPA to Atlantic Richfield Company RE: Comments on 2011 Annual Groundwater Monitoring Report, Anaconda Yerington Mine Site. March 27.

EPA, 2013b. Letter from EPA to Atlantic Richfield Company RE: Comments on 2012 Annual Groundwater Monitoring Report, Anaconda Yerington Mine Site. August 1.

EPA, 2013c. Letter from EPA to Atlantic Richfield Company RE: EPA Approval to Abandon Well B/W-14S, Anaconda Yerington Mine Site. November 22.

EPA, 2013d. Letter from EPA to Atlantic Richfield Company RE: Comments on the Draft Groundwater Flow Model Work Plan, Anaconda Yerington Mine Site. March 29.

EPA, 2013e. Letter from EPA to Atlantic Richfield Company RE: Comments on the Draft Additional Monitor Well Work Plan, Anaconda Yerington Mine Site. July 29.

EPA, 2013f. Statistical Software ProUCL 5.0.00 for Environmental Applications for Data Sets with and without Nondetect Observations.

EPA, 2014a. Letter from EPA to Atlantic Richfield Company RE: EPA Approval of Site-Wide Groundwater Monitoring Optimization, Anaconda Yerington Mine Site. June 26.

EPA, 2014b. Letter from EPA to Atlantic Richfield Company RE: Anaconda Yerington Mine Site OU1, Approval of Site-Wide Groundwater RI Work Plan Revision 1. October 9.

EPA, 2014c. 3PE: A Tool for Estimating Groundwater Flow Vectors. EPA 600/R-14/273.

EPA, 2015a. Letter from EPA to Atlantic Richfield Company RE: Anaconda Yerington Mine Site OU-1 Request for Bedrock Characterization DSR in Place of Work Plan. May 18.

EPA, 2015b. Letter from EPA to Atlantic Richfield Company RE: Approval of Groundwater Flow Model Report and Supplemental Materials, Anaconda Yerington Mine Site OU-1.

EPA, 2016a. Letter from EPA to Atlantic Richfield Company RE: Anaconda Copper Mine Site OU-1 Approval of Bedrock Groundwater Assessment Technical Memorandum. July 31.

EPA, 2016b. Letter from EPA to the Atlantic Richfield Company RE: Anaconda Yerington Mine Site OU-1, Approval of Geochemical Characterization DSR with Conditions. July.

EPA, 2016c. Letter from EPA to Atlantic Richfield Company RE: Anaconda Mine Site, Comments on the Background Groundwater Quality Assessment - Revision 2 dated July 2, 2015. February 11.

EPA, 2016d. Letter from EPA to Atlantic Richfield Company RE: Anaconda Copper Mine OU-1, Background Groundwater Quality Assessment. September 27.

EPA, 2016e. Memorandum from Dr. R. Ford (USEPA Land Remediation & Pollution Control Division) and Mr. S. Acree (USEPA Applied Research and Technical Support Branch) to Mr. D. Seter (USEPA Region 9), Subject: Yerington Mine Site, Yerington Nevada (16-R09-003) Responses to ARC Responses to Comments on the Background Groundwater Quality Assessment - Revision 2. September 2.

EPA, 2016f. Letter from EPA to Atlantic Richfield Company RE: Anaconda Copper Mine, Domestic Well Monitoring Program (DWMP) and Bottled Water Program (BWP). October 25.

EPA, 2017. Letter to the Atlantic Richfield Company RE: Anaconda Copper Mine Site OU-1, OU-1 Background Water Quality Assessment - Revision 3. February 16.

Fox, P.M., J.A. Davis, and J.M. Zachara, 2006. The effect of calcium on aqueous uranium(VI) speciation and adsorption to ferrihydrite and quartz. Geochimica et Cosmochimica Acta, Vol. 70, pp. 1379-1387.

Freeze, R.A. and J.A. Cherry, 1979. Groundwater. Prentice-Hall, Upper Saddle River, NJ.

Gallagher, T. K., 2004. Estimated Annual Ground-Water Pumpage 1994 - 2003, Smith Valley and Mason Valley, Lyon County, Nevada, Nevada Department of Conservation and Natural Resources, Division of Water Resources.

Gallagher, T. K., 2013. Estimated Annual Ground-Water Pumpage 2004 - 2010, Smith Valley and Mason Valley, Lyon County, Nevada, Nevada Department of Conservation and Natural Resources, Division of Water Resources.

George, P. L. and H. Borouchaki, 1998, Delaunay Triangulation and Meshing Application to Finite Elements, Paris, Hermes.

Gill, D. K., 1951. Groundwater at the Yerington Mine, Lyon County, Nevada. Report prepared for the Anaconda Mining Company. March.

Heath, R.C., 1984. Ground-Water Regions of the United States. U.S. Geological Survey (USGS) Water-Supply Paper 2242.

Hem, J., 1985. Study and Interpretation of the Chemical Characteristics of Natural Water. 3rd Ed. U.S. Geological Survey (USGS) Water-Supply Paper 2254.

Hershey, R.L., 2002. Hydrology and water quality of the Yerington Pit Lake, In: Geological Society of Nevada 2002 Spring Field Trip Guidebook Special Publication No. 35, Jurassic Magmatism and Metal Deposits in Western Nevada, Yerington Mine District, Humboldt Mafic Complex, June 15-16, 2003, Ed. Bob Thomas, pp. 93-98.

Hsi, C. K. D., and D. Langmuir, 1985. Adsorption of uranyl onto ferric oxyhydroxides: application to the surface complexation site-binding model. Geochimica et Cosmochimica Acta, Vol. 49, pp. 1931-1941.

Huxel, C.J., and E.E. Harris, 1969. Water resources and development in Mason Valley, Lyon and Mineral Counties, Nevada, 1948-65. State of Nevada Department of Conservation and Natural Resources, Division of Water Resources, Water Resources Bulletin No. 38.

Jurgens, B.C., M.S. Fram, K. Belitz, K.R. Burow, and M.K. Landon, 2010. Effects of Groundwater Development on Uranium: Central Valley, California, USA. Ground Water. Vol. 48, pp. 913-928.

Lewis, B., 2000. Geophysical Survey Results of the Yerington Mine, Mason Valley, Nevada, Prepared by the U.S. Bureau of Land Management - National Science and Technology Center. August.

Li, D., and D. I. Kaplan, 2012. Sorption coefficients and molecular mechanisms of Pu, U, Np, Am and Tc to Fe (hydr)oxides: A review. Journal of Hazardous Materials. Vol. 243, pp. 1-18.

Lopes, T.J., and K.K. Allander, 2009a. Hydrologic Setting and Conceptual Hydrologic Model of the Walker River Basin, West-Central Nevada. USGS Scientific Investigations Report 2009-5155.

Lopes, T.J., and K.K. Allander, 2009b. Water Budgets of the Walker River Basin and Walker Lake, California and Nevada. USGS Scientific Investigations Report 2009-5157.

Maurer, D.K., T.J. Lopes, R.L. Medina, and J.L. Smith, 2004. Hydrogeology and Hydrologic Landscapes of Nevada. USGS Scientific Investigations Report 2004-5131.

Mifflin, M.D., 1988. Region 5, Great Basin. In Hydrogeology, the Geology of North America, DNAG volume, vol. 0-2; ed. W. Back, J.S. Rosenshein, and P.R. Seaber, 60-78. Boulder, Colorado: Geological Society of America.

Morrison, R.B., 1964. Lake Lahontan: Geology of the southern Carson Desert. U.S. Geological Survey (USGS) Professional Paper 401.

Myers, T., 2001. Hydrogeology of the Basin Fill Aquifer in Mason Valley, Nevada: Effects of Water Rights Transferred. Prepared for the U.S. Bureau of Land Management, Carson City Field Office, Carson City, NV. Public Resources Associates, Inc., Reno, Nevada.

Nesbitt, M., 1955. Memorandum to A. J. Gould, Plant Superintendent, Anaconda Company. July 27.

Nevada Department of Conservation and Natural Resources, Division of Water Resources, 2013a, NDWR-Water Rights Database Advanced Search (Special Hydrographic Abstract), http://water.nv.gov/data/hydrographic/ June 4, 2013.

Nevada Department of Conservation and Natural Resources, Division of Water Resources, 2013b, Well Log Database Query Tool, http://water.nv.gov/data/welllog/ June 5, 2013.

Nevada Department of Conservation and Natural Resources, Division of Water Resources, 2013c, Water Level Data, http://water.nv.gov/data/waterlevel/ June 27, 2013.

Nevada Division of Water Resources, 2015. Memorandum titled “Curtailment Order in Mason and Smith Valley”. Department of Conservation and Natural Resources, Division of Water Resources. February 3.

Nolan, J., and K.A. Weber, 2015. Natural Uranium Contamination in Major U.S. Aquifers Linked to Nitrate. Environ. Sci. Technol. Lett., Vol. 2, pp. 215-220.

Nordstrom, K., L.N. Plummer, D. Langmuir, and E. Busenburg, 1990. Revised Chemical Equilibrium Data for Major Water-Mineral Reactions and Their Limitations, in “Chemical Modeling of Aqueous Systems II,” Chapter 31, pp. 398-413.

Nork, W.E., 1989. MacArthur Project Hydrogeologic Investigation Lyon County, Nevada. Prepared for MacArthur Mining and Processing Company, Inc. August 14.

Norwest Applied Hydrology, 2007. Pumpback Well System 2006 Operations and Monitoring Summary, Yerington Mine Site. Prepared for Atlantic Richfield Company. April 30.

Parkhurst, D.L., and C.A.J. Appelo, 1999. User’s Guide to PHREEQC (Version 2) - A Computer Program for Speciation, Batch-Reaction, One-Dimensional Transport, and Inverse Geochemical Calculations. Water-Resources Investigations Report 99-4259, U.S. Geological Survey, Denver, Colorado.

Piedmont Engineering Inc., 2001. Yerington Shallow Aquifer Data Evaluation Report. Prepared for ARCO Environmental Remediation L.L.C.

Plume, R.W., 1996. Hydrogeologic framework of the Great Basin region of Nevada, Utah, and adjacent states. USGS Professional Paper 1409-B.

Proffett, J.M., 1977. Cenozoic geology of the Yerington District, Nevada, and implications for the nature and origin of Basin and Range faulting. Geologic Society of America Bulletin, Vol. 88, pp. 247-266.

Proffett, J.M., Jr., and J.H. Dilles, 1984. Geologic Map of the Yerington District, Nevada. Nevada Bureau of Mines and Geology, Map 77.

Reheis, M., 1999. Extent of Pleistocene Lakes in the Western Great Basin. USGS Miscellaneous Field Studies Map MF-2323.

Ricketts, T.H., E. Dinerstein, D.M. Olson, and C.J. Loucks, 1999. Terrestrial ecoregions of North America: a conservation assessment. Island Press, Washington, D.C.

Sánchez-España, J. I. Yusta, and M. Diez-Ercilla, 2011. Schwertmannite and hydrobasaluminite: A re-evaluation of their solubility and control on the iron and aluminum concentration in acidic Pit Lakes. Applied Geochemistry, Vol. 26, pp.1752-1774.

Seitz, H.R., A.S. Van Denburgh, and R.J. La Carma, 1982. Ground-Water Quality Down-gradient from Copper-One Milling Wastes at Weed Heights, Lyon County, Nevada. USGS Open-File Report 80-1217.

Skillings Jr., D.N., 1972. Yerington Copper Mine. Skillings Mining review. Vol. 61, No. 21.

Smedley, P.L. and D.G. Kinniburgh, 2001. A review of the source, behavior and distribution of arsenic in natural waters. Applied geochemistry, Vol. 17, pp. 517-568

Sø, H.U., D. Postma, R. Jakobsen, and F. Larsen, 2008. Sorption and desorption of arsenate and arsenite on calcite. Geochimica et Cosmochimica Acta, Vol. 72, pp. 5871-5884.

S.S. Papadopulos & Associates, Inc., 2012a. Objectives for Groundwater Modeling in the RI/FS Process, Yerington Mine Site. Prepared for Atlantic Richfield Company. August 14.

S.S. Papadopulos & Associates, Inc., 2012b. Objectives for Groundwater Modeling in the RI/FS Process - Revision 1, Yerington Mine Site. Prepared for Atlantic Richfield Company. October 15.

S.S. Papadopulos & Associates, Inc., 2012c. Draft Groundwater Flow Model, Work Plan for the Yerington Mine Site. Lyon County, Nevada. Prepared for Atlantic Richfield Company. December 28.

S.S. Papadopulos & Associates, Inc., 2013. Groundwater Flow Model Work Plan for the Yerington Mine Site - Revision 1, Lyon County, Nevada. Prepared for Atlantic Richfield Company. May 21.

S.S. Papadopulos & Associates, Inc., 2014. Groundwater Flow Model, Yerington Mine Site, Nevada. Prepared for Atlantic Richfield Company. March 18.

S.S. Papadopulos & Associates, Inc., 2015. Flow Model Supplemental Materials, Yerington Mine Site, Nevada. Prepared for Atlantic Richfield Company. March 18.

Stachowicz, M., T. Hiemstra, and W.H. van Riemsdijk, 2007. Arsenic-bicarbonate interaction on goethite particles. Environmental Science and Technology, Vol. 41, pp. 5620-5625.

Stewart, J.H., 1988. Tectonics of the Walker Lane belt, western Great Basin: Mesozoic and Cenozoic deformation in a zone of shear. In Ernst, W.G., Metamorphism and crustal evolution of the western United States, Rubey volume VII: Prentice Hall, Englewood Cliffs, N.J.

Stewart, B.D., M.A. Mayes, and S. Fendorf, 2010. Impact of uranyl-calcium-carbonate complexes on uranium(VI) adsorption to synthetic and natural sediments. Environmental Science and Technology, Vol. 44, pp. 928-934.

Superfund Technical Assessment Response Team (START), 2000. Anaconda Copper Company, Yerington Mine Site, Expanded Site Inspection, Yerington, Lyon County, Nevada. Prepared by Ecology & Environment Incorporated. December.

Superfund Technical Assessment Response Team (START), 2001. Anaconda Copper Company, Yerington Mine Site, Emergency Response Assessment, Yerington, Lyon County, Nevada. Prepared by Ecology & Environment Incorporated. June.

Taylor, B.E., and M.C. Wheeler, 1994. Sulfur- and Oxygen-Isotope Geochemistry of Acid Mine Drainage in the Western United States. Chptr. 30. Environmental Geochemistry of Sulfide Oxidation. Eds. C.W. Alpers and D.W. Blowes.

Tetra Tech, 2010. Preliminary Economic Assessment Update Pumpkin Hollow Copper Project, Lyon County, Nevada. Prepared for Nevada Copper Corp. January 13.

Thomas, J.M., 1995. Water Budget and Salinity of Walker Lake, Western Nevada. USGS Fact Sheet FS-115-98.

U.S. Bureau of Mines, 1958. Methods and Operations at the Yerington Copper Mine and Plant of the Anaconda Company, Weed Heights, Nev., by M. Claire Smith; Information Circular 7848, Department of the Interior.

U.S. Census Bureau, 2015. State and County Quickfacts. Available at: http://www.census.gov/quickfacts/table/PST045215/32019.

U.S. Geological Survey, 2006. Determination of the Delta ($^{34}S/^{32}S$) of Sulfate in Water, RSIL Lab Code 1951. Techniques and Methods of the Reston Stable Isotope Laboratory, Chapter 10.

U.S. Geological Survey, 2008. $^{3}H/^{3}He$ Sampling. The Reston Chlorofluorocarbon Laboratory. http://water.usgs.gov/lab/3h3he/sampling/.

U.S. Geological Society, 2009a. Hydrologic Setting and Conceptual Hydrologic Model of the Walker River Basin, West-Central Nevada. U.S. Department of Interior, USGS, Scientific Investigations Report 2009-5155.

U.S. Geological Society, 2009b. Water Budgets of the Walker River Basin and Walker Lake, California and Nevada. U.S. Department of Interior, USGS, Scientific Investigations Report 2009-5157.

U.S. Geological Survey, 2013. National Water Information System, USGS Groundwater for Nevada: Water Levels, http://nwis.waterdata.usgs.gov /nv/nwis/gwlevels June 27.

Walker River Decree C-125, 1936 amended 1940. United States vs. Walker River Irrigation District, Docket C-125, District Court of the United States - District of Nevada.

Wanninkhof, R., J.R. Ledwell, and A. J. Watson, 1991. Analysis of sulfur hexafluoride in seawater. J. Geophys. Res - Oceans 96(C5), pp. 8733-8740.

Wilson, J.L., and H. Guan, 2004. Mountain-Block Hydrology and Mountain-Front Recharge. In: Groundwater Recharge in a Desert Environment: The Southwestern United States, edited by F.M. Phillips, J. Hogan, and B. Scanlon. AGU, Washington, DC.

WRCC, 2015. Yerington, Nevada (269229): Period NCDC 1894-2015 Monthly Normals. Western Regional Climate Center. http://www.wrcc.dri.edu/cgi-bin/cliMAIN.pl?nv9229.

Western Regional Climate Center (WRCC). 2017. Yerington, Nevada (269229) Period of Record Monthly Climate Summary, 1/1/1914 to 12/31/2005. http://www.wrcc.dri.edu/cgi-bin/cliMAIN.pl?nvyeri.

Zheng, C., G.D. Bennett, and C.B. Andrews, 1991. Analysis of Ground-Water Remedial Alternatives at a Superfund Site. Ground Water. Vol. 29, No. 6., pp. 838-848.

REMEDIAL INVESTIGATION REPORT
SITE-WIDE GROUNDWATER OPERABLE UNIT (OU-1)

ANACONDA COPPER MINE SITE
LYON COUNTY, NEVADA

OCTOBER 20, 2017

PREPARED FOR:

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LIST OF ACRONYMS AND ABREVIATIONS

AFCEE	Air Force Center for Environmental Excellence
AHA	Applied Hydrology Associates
Anaconda	Anaconda Companya
ARC	Atlantic Richfield Company
BC	Brown and Caldwell
BCL	Background Concentration Limit
BGQA	Background Groundwater Quality Assessment
BLM	Bureau of Land Management
CFC	Chlorofluorocarbon
COI	Chemical of Interest
DO	Dissolved Oxygen
DPT	Direct Push Technology
DSR	Data Summary Report
DQO	Data Quality Objective
DWMP	Domestic Well Monitoring Program
EA-IRMS	Elemental Analyzer-Isotopic Ratio Mass Spectrometer
EC	Electrical Conductivity
EPA	U.S. Environmental Protection Agency
ESI	Environmental Standards, Inc.
FEP	Finger Evaporation Ponds
FMS	Fluid Management System
FS	Feasibility Study
GC-ECD	Gas Chromatography with Electron Capture Detection
GMP	Groundwater Monitoring Plan
GMR	Groundwater Monitoring Report
HCSM	Hydrogeologic Conceptual Site Model
HDPE	High-Density Polyethylene
HFA	Hydrogeologic Framework Assessment
HLP	Heap Leach Pad
HHRA	Human Health Risk Assessment
HSR	Historical Summary Report
IAOC	Interim Administrative Settlement Agreement and Order on Consent
ICP-MS	Inductively Coupled Plasma Mass Spectroscopy
J	Estimated Concentration
K	Hydraulic Conductivity
Kd	Partition (or Distribution) Coefficient
LEP	Lined Evaporation Pond
MAROS	Monitoring and Remediation Optimization System
MCL	Maximum Contaminant Level
MFR	Mountain Front Recharge
NA	Not Applicable/Not Available
NAC	Nevada Administrative Code
NDEP	Nevada Division of Environmental Protection
NDWR	Nevada Division of Water Resources
NR	Not Recorded
NSA	North Study Area
NS	No Sample
O&M	Operation and Maintenance
ORP	Oxidation-Reduction Potential
OU	Operable Unit
PLS	Pregnant Leach Solution
POD	Point of Diversion
POU	Place of Use
PV	Pore Volume
PWS	Pumpback Well System
Q	Quarter
QA/QC	Quality Assurance/Quality Control
QAPP	Quality Assurance Project Plan
R	Retardation Coefficient
RAO	Remedial Action Objective
RER	Replicate Error Ratio
RI/FS	Remedial Investigation and Feasibility Study
RPD	Relative Percent Difference
RSIL	USGS Reston Stable Isotope Laboratory
RSL	Regional Screening Level
SCM	Surface Complexation Model
SERA	Southeast Recharge Area
SOP	Standard Operating Procedure
SOW	Scope of Work
SSPA	S.S. Papadopulos & Associates, Inc.
START	Superfund Technical Assessment and Response Team
STORET	STOrage and RETrieval
SWRA	Southwest Recharge Area
TC	Total Carbon
SX/EW	Solvent Extraction /Electrowinning
TIC	Total Inorganic Carbon
TDS	Total Dissolved Solids
TIMS	Thermal Ionization Mass Spectrometer
TOC	Total Organic Carbon
TU	Tritium Unit
U	Chemical not detected at the indicated sample detection limit
UAO	Unilateral Administrative Order
Ue	Uranium Excess
UEP	Unlined Evaporation Pond
UJ	Chemical not detected at the indicated estimated sample detection limit
USCS	Unified Soil Classification System
USGS	United States Geological Survey
UTL	Upper Tolerance Limit
VLT	Vat Leach Tailings
WRCC	Western Regional Climate Center

LIST OF ACRONYMS AND ABREVIATIONS - CONTINUED

WRD	Walker River Decree
WRID	Walker River Irrigation District
YPT	Yerington Paiute Tribe

%	percent
‰	per mil
amsl	above mean sea level
bgs	below ground surface
cu ft	cubic feet
cfs	cubic feet per second
°F	degrees Fahrenheit
°C	degrees Celsius or Centigrade
ft	foot/feet
ft/day	feet per day
ft/yr	feet per year
fmol/kg	femtomole per kilogram
gal	gallons
g/L	grams per liter
gpd	gallons per day
gpm	gallons per minute
L	liter
L/kg	liters per kilogram
µg	microgram
µm	micron or micrometer
mg	milligram
pCi/g	picocuries per gram
pCi/L	picocuries per liter
pCi	picocurie
pmol/kg	picomoles per kilogram
s.u.	standard units (pH)

MINERALS, CHEMICAL FORMULAS, AND ABBREVIATIONS

Barium Arsenate	$Ba_3(AsO_4)_2$
Ferric oxide	$Fe(OH)_3(a)$
Gypsum	$CaSO_4$
Hydroxy-green rust	$Fe_3(OH)_7(s)$ and $Fe_2(OH)_5(s)$
Jarosite (ss)	$(K_{0.77}Na_{0.03}H_{0.2})Fe_3(SO_4)_2(OH)_6(s)$
K-jarosite	$KFe_3(SO_4)_2(OH)_6(s)$
Na-jarosite	$NaFe_3(SO_4)_2(OH)_6(s)$
Schwertmannite	$Fe_8O_8(OH)_{4.8}(SO_4)_{1.6}(s)$
Scorodite	$FeAsO_4(s)$

(a)	Amorphous
(aq)	Aqueous
(s)	Solid
(ss)	Solid Solution

$\delta^{13}B$	Boron isotopes in water samples
$\delta^{36}Cl$	Chloride isotopes in water samples
$\delta^{34}S_{SO4}$	Sulfur isotopes in dissolved sulfate
$\delta^{34}O_{SO4}$	Oxygen isotopes in dissolved sulfate
$\delta^{15}N_{NO3}$	Nitrogen isotopes in dissolved nitrate
$\delta^{18}O_{NO3}$	Oxygen isotopes in dissolved nitrate

Nitric Acid	HNO_3
Sulfuric Acid	H_2SO_4
Sulfur Hexafluoride	SF_6
Sulfur Dioxide	SO_2

EXECUTIVE SUMMARY

This *Site-Wide Groundwater Operable Unit (OU-1) Remedial Investigation Report* (OU-1 RI Report) has been prepared by Atlantic Richfield Company (ARC) pursuant to Section 7.0 of the Scope of Work (SOW) attached to the Administrative Order for Remedial Investigation and Feasibility Study (RI/FS), CERCLA Docket No. 9-2007-0005 (2007 Order) for the Anaconda Copper Mine Site (Site). The 2007 Order (EPA 2007a) was issued to ARC by the U.S. Environmental Protection Agency - Region 9 (EPA) on January 12, 2007. Future work on the OU-1 RI/FS will proceed under oversight by the Nevada Division of Environmental Protection (NDEP) pursuant to the "Interim Administrative Settlement Agreement and Order on Consent for: (i) Remedial Design/Remedial Action, (ii) Site-Wide Remedial Investigation/Feasibility Study, and (iii) Fluid Management" entered into with NDEP (the IAOC) and the attached Statement of Work for RI/FS.

The term "Site" refers to the area where copper mining and ore processing activities historically occurred. The term "Study Area" in this document refers to a larger area encompassing both on-Site and off-Site areas in which OU-1 RI-related investigations have been conducted. The Site is a former copper mine that is located west and northwest of the City of Yerington. The 2007 Order identified eight OUs at the Site, which include:

- Site-Wide Groundwater (OU-1);
- Pit Lake (OU-2);
- Process Areas (OU-3);
- Evaporation Ponds (OU-4a) and Sulfide Tailings (OU-4b);
- Waste Rock Areas (OU-5);
- Oxide Tailings Areas (OU-6);
- Wabuska Drain (OU-7); and
- Arimetco Facilities (OU-8).

Consistent with the SOW attached to the 2007 Order (EPA 2007a) and general RI report objectives established by EPA (EPA 1988), this OU-1 RI Report:

- Summarizes activities conducted to characterize and monitor groundwater (including on- and off-Site locations), establish background groundwater quality, and determine the nature, extent, and transport of mine-related chemicals of interest (COIs) in groundwater;
- Integrates relevant historical operations and aspects of other OUs that represent potential sources of chemical loading to groundwater or have the potential to influence groundwater flow conditions;
- Describes the program for long-term monitoring of Site-wide groundwater conditions;
- Summarizes the domestic well monitoring program, which characterized the quality of groundwater used for drinking water or other domestic water supply purposes and determined eligibility for receiving bottled water as part of an interim response action; and
- Describes the process for completing the human health risk assessment, which is being addressed in a separate OU-1 Human Health Risk Assessment (HHRA) report, per EPA direction during a groundwater technical meeting held on June 30, 2016 attended by ARC, EPA, the NDEP, the Yerington Paiute Tribe (YPT), and other stakeholders.

The information provided in this OU-1 RI Report is considered sufficient to characterize the groundwater system, define the nature and extent of mine-related groundwater contamination, perform a risk assessment, and conduct a feasibility study. Numerous investigations and monitoring activities conducted by ARC and others provide substantial geologic, hydrogeologic, and water quality information relevant to OU-1. However, this OU-1 RI Report relies primarily on data obtained after 2005 to address the study elements specified in Section 7.0 of the SOW, characterize groundwater conditions, and refine the hydrogeologic conceptual site model (HCSM) to support the OU-1 RI/FS. Data obtained after 2005 have been selected for these purposes because: 1) data collection was performed pursuant to EPA-approved quality assurance/quality control (QA/QC) planning documents and OU-1 specific work plans that were developed with input from other stakeholders including the NDEP, YPT, and the Bureau of Land Management (BLM); 2) the spatial coverage and amount of data increased substantially after 2005; and 3) post-2005 sampling results better represent current conditions and potential risks at the Site, which is the proper focus of the RI and risk assessment.

The dataset obtained during August 2014 is emphasized in this OU-1 RI Report for the reasons previously cited, and because a variety of data types were concurrently collected (e.g., groundwater level data, groundwater quality data, and hydrologic tracer data) and/or evaluated (e.g., geochemical speciation modeling to help assess COI transport). Consequently, the August 2014 dataset is particularly useful for characterizing spatial aspects of OU-1 groundwater conditions.

Recognizing that groundwater characterization activities would largely involve monitor well installation, ARC and EPA adopted a multi-step sequential approach to field data collection to maximize usable data and optimize the design of a monitor well network intended to serve the data needs for both OU-1 RI characterization and long-term Site-Wide groundwater monitoring. In total, the groundwater RI characterization activities resulted in drilling 133 boreholes, logging approximately 33,000 linear feet of core, collecting and analyzing 624 zonal groundwater samples, installing 299 new monitor wells, and hydraulic (slug) testing of 296 wells.

After installation and development, new monitor wells were incorporated along with select existing monitor wells into the Site-Wide Groundwater Monitoring Program. Within the Study Area, the alluvial aquifer is up to 700 feet thick and is subdivided into Shallow, Intermediate and Deep zones (Deep zones 1 through 5). Underlying the alluvial aquifer is a bedrock groundwater flow system. The current monitor well network includes 360 wells at 170 locations: 133 wells in the Shallow zone, including 11 Pumpback Well System (PWS) wells formerly used for groundwater extraction that are currently inactive; 55 wells in the Intermediate zone; 105 wells in the Deep zone; and 67 bedrock wells. Of the 360 monitor wells, seven are used only for water level measurements, and the remaining 353 are monitored for both water levels and water quality.

The Site and Study Area are in the Mason Valley, a north-south trending structural valley (graben) in the Basin and Range Province that is filled with up to 1,000 feet of unconsolidated alluvial sediments. The valley is bordered to the west by the Singatse Range, to the east by the Wassuk Range, and to the north by the Desert Mountains. Regional metals mineralization and hydrothermal alteration associated with localized porphyry and skarn copper deposits occur throughout the Singatse Range and nearby portions of the Mason Valley.

Depositional processes have resulted in a complex sequence of laterally-discontinuous, heterogeneous, unconsolidated alluvial sediments that exhibit spatially-variable hydraulic properties (Brown and Caldwell [BC] 2014a). Clay layers or other low-permeability sediments are laterally discontinuous resulting in unconfined or semi-confined alluvial aquifer groundwater conditions. Based on groundwater flow model results (S.S. Papadopulos & Associates, Inc. [SSPA] 2014), the alluvial aquifer is primarily recharged by downward percolation of water from irrigated fields (49 percent [%]), leakage from irrigation ditches (29%), infiltration from the channel of the Walker River (20%), and mountain front recharge (2%) resulting from infiltration through bedrock of precipitation that falls on surrounding mountain ranges and minor tributary surface flows in ephemeral drainages. Recharge from precipitation falling directly on the valley floor is negligible (Huxel and Harris 1969; Lopes and Allander 2009a, 2009b).

The alluvial aquifer in the Mason Valley yields significant quantities of groundwater and the groundwater resource is pumped extensively for irrigation (Carroll et al. 2010; SSPA 2014). Alluvial groundwater near the Site generally flows to the northwest, but flow directions are locally affected by bedrock outcrops within and along the margins of the valley, drawdown from pumped wells (particularly in deeper zones of the alluvial aquifer), and recharge sources such as the Walker River, the West Campbell Ditch, and irrigation on the Hunewill Ranch and other agricultural fields. Groundwater in the alluvial aquifer moves relatively slowly, with flow velocities estimated to be less than 100 feet per year (BC 2014a). Agricultural pumping seasonally results in strong downward vertical gradients that are often 10 to 100 times greater than horizontal gradients.

Historic mining and copper ore beneficiation activities involved the use of sulfuric acid (H_2SO_4). The major past and/or ongoing sources of COIs to groundwater include: 1) OU-4a, the Evaporation Ponds (BC 2014a, 2014d); 2) OU-8, the Arimetco Facilities (CH2M Hill 2010, 2011a, 2011b); and 3) OU-3, the Process Areas (BC 2014a, 2014e). Concentrations of COIs in groundwater beneath OU-4b (Sulfide Tailings) are generally at least 10 to 100 times lower than COI concentrations in groundwater beneath OU-4a. Furthermore, OU-4b is located hydraulically upgradient or cross-gradient of OU-4a, and groundwater beneath OU-4b flows toward the higher COI concentrations under OU-4a.

The Pit Lake (OU-2), which was studied as part of the OU-1 RI (BC 2014a), is not a source of COIs to Site-wide groundwater because the lake elevation is lower than the surrounding potentiometric surface and the pre-mining groundwater level. The Pit Lake surface is projected to reach a steady-state level, where water inflow and evaporation are balanced, prior to 2030. The steady-state Pit Lake elevation is estimated to be in the range of 4,249 to 4,253 feet above mean sea level, and is projected to remain lower than the surrounding potentiometric surface even after reaching steady-state conditions. Consequently, the lake is and will continue to be a groundwater sink that does not discharge into the Site-wide groundwater system.

Results of the ongoing RI for the Wabuska Drain (OU-7) will be reported separately. Available data indicate that concentrations of mine-related chemicals decrease with distance from the Site and depth in the soil profile (EPA 2007, BC 2015b).

Mine-related COIs include acidity (i.e., low pH), total dissolved solids (TDS), major ions including sulfate, metals/metalloids (hereinafter referred to as metals), and radiochemicals including uranium (BC 2014a). Concentrations of mine-related chemicals in groundwater are most elevated in the Shallow zone of the alluvial aquifer beneath OU-4a features that include the Lined Evaporation Pond (LEP), Unlined Evaporation Pond (UEP), Finger Ponds, Phase IV Vat Leach Tailings (VLT) Heap Leach Pad (HLP), Phase IV VLT Pond, and the northern end of the Calcine Ditch. Chemical concentrations in groundwater generally decrease with vertical depth and horizontal distance from these facilities. To the extent localized downgradient increases in chemical concentrations are observed, they result from non-mine-related factors.

Hydraulic assessments and chemical distributions indicate that the PWS was only partially effective in capturing Shallow zone mine-impacted groundwater during its operational life from 1989 to 2009 (BC 2010), when it was shut down with EPA approval.

Geochemical evaluations of groundwater quality data (BC 2016a) indicate that sulfate and dissolved uranium form neutral or negatively-charged aqueous ionic complexes in groundwater throughout the Study Area (except beneath the Evaporation Ponds) and, thus, undergo very limited (if any) geochemical attenuation due to mineral precipitation or adsorption to aquifer materials during groundwater transport. Dissolved uranium in Study Area groundwater is predominantly present in complexes with carbonate plus or minus calcium, which reflect oxidizing, carbonate-rich groundwater conditions. Locally, dissolved uranium is also complexed with sulfate in Shallow zone groundwater beneath the Evaporation Ponds where pH is less than 5 and sulfate concentrations exceed 1,500 milligrams per liter (mg/L).

The spatial distributions of elevated concentrations of mobile parameters such as sulfate and uranium are significantly more extensive than the spatial distributions of acidity (as indicated by pH) and metals. The limited spatial extent of low pH values and elevated metal concentrations indicates that geochemical attenuation processes in Study Area groundwater limit the mobility of acidity and metals relative to the more mobile chemicals such as sulfate and uranium (EPA 2007b; BC 2016a, 2016b). Elevated metal concentrations in groundwater correlate strongly with low pH. Geochemical evaluations of groundwater quality data (BC 2016a) also indicate the likely precipitation of solid mineral phases (e.g., jarosite) primarily in the Shallow zone beneath the LEP, UEP, Thumb Pond, and Phase IV HLP. These mineral phases likely represent a potential ongoing source of COIs to groundwater.

Sulfate, uranium and arsenic (and other COIs) occur naturally in groundwater in Mason Valley because of groundwater contact with naturally-mineralized and/or hydrothermally-altered bedrock associated with copper deposits and/or alluvial sediments derived from mineralized bedrock (BC 2009a, 2014b). These regional groundwater conditions, unrelated to mining, affect COI concentrations at two key locations within the OU-1 groundwater Study Area. To the west of the Site and adjacent to the Singatse Range, naturally-occurring arsenic, other COIs, and elevated groundwater temperatures in alluvial aquifer groundwater are associated with subsurface water transmitted along fractures and faults (especially oblique range-front faults such as the Sales Fault).

These faults occur in arsenic-bearing volcanic and granitic bedrock formations that provide conduits for bedrock groundwater to discharge into the overlying alluvial aquifer. In the North Study Area (NSA), which refers to the portion of the OU-1 groundwater Study Area located northeast of West Campbell Ditch and north of the Sunset Hills, naturally-occurring arsenic concentrations as high as 83 micrograms per liter (µg/L) occurs in Deep zone groundwater. The elevated arsenic in this portion of the Study Area is likely related to bedrock discharge to the alluvial aquifer and is not related to agricultural activities that source COIs to the Shallow through Deep 2 zones of the alluvial groundwater, as discussed further below.

Groundwater quality in the NSA is influenced by agricultural activities but not by mining activities (BC 2016b). Multiple lines of evidence (including groundwater flow patterns, chemical distributions, groundwater age estimates, hydrologic tracers, and sulfur isotopes) confirm that groundwater in the NSA has been affected by agricultural practices and not by mining activities, resulting in concentrations of sulfate and uranium that are elevated above background values and/or Maximum Contaminant Levels (MCLs) or exhibit increasing trends.

Monitor well data from the NSA indicate that concentrations of nitrate, sulfate, calcium, uranium, and alkalinity in alluvial groundwater in the Shallow through Deep 2 zones increase along the flow path beneath the agricultural fields. Increases in nitrate are associated with fertilizer application on crop fields. Increases in sulfate and calcium concentrations are associated with application of gypsum ($CaSO_4$) as a soil amendment on crop fields, which dissolves in irrigation water that percolates down to the water table. Increases in uranium concentrations are associated with crop irrigation. Percolation of irrigation water through soils increases alkalinity in the soil moisture, which mobilizes and desorbs naturally-occurring uranium from sediments (as soluble complexes with sulfate, carbonate plus or minus calcium) resulting in elevated uranium concentrations in groundwater (Jurgens et al. 2010; Brown et al. 2007).

Alluvial sediments in the Mason Valley contain naturally-occurring uranium (BC 2009b). The impact of agricultural activities on uranium mobility in NSA groundwater within or near irrigated land is illustrated by the strong correlation between uranium, alkalinity and calcium. Increases in alkalinity and calcium are associated with increases in uranium concentrations that can exceed 100 µg/L. Evaporation of irrigation water derived from surface water and groundwater sources also serves to increase chemical concentrations in water that infiltrates and percolates to the water table.

The extent of mine-impacted groundwater has been defined using sulfate, dissolved uranium, and sulfur isotopes in sulfate because these parameters undergo very limited (if any) geochemical attenuation during groundwater transport and, thus, have traveled the farthest downgradient distance in the alluvial aquifer (BC 2016b). As noted by EPA (2016c), the background assessment conservatively over-estimated the area of mine-impacted groundwater and may not fully account for the range of chemical concentrations that occur naturally in groundwater within the Study Area. Portions of the aquifer where sulfate and uranium exceed background concentrations include: 1) all groundwater zones beneath portions of the Site; 2) Shallow zone groundwater extending north/northwest to the Sunset Hills located approximately three miles north of the Site boundary; and 3) deeper groundwater beneath the Site and extending northeast beneath portions of the Hunewill Ranch. The estimated volume of mine-impacted groundwater (i.e., the portion of the downgradient aquifer where sulfate and uranium exceed background concentrations) is 385,327 acre-feet, and contains an estimated 500,000 tons of sulfate and 100 tons of dissolved uranium.

Bedrock characterization information indicates: 1) a high degree of fracture heterogeneity and vertical hydraulic connection between the bedrock and alluvial groundwater systems; and 2) limited horizontal hydraulic connectivity and transmissivity of bedrock fractures, especially over horizontal distances that are relevant to the scale of the Site and the surrounding Study Area. In addition to a high degree of three-dimensional (i.e., anisotropic) variability in hydraulic characteristics and hydrologic tracer signatures, the bedrock groundwater system also exhibits high, three-dimensional spatial variability in chemical concentrations.

Concentrations of mine-related chemicals in the alluvial aquifer are most elevated in the Shallow zone beneath OU-4a, as noted previously. COI concentrations generally decrease with vertical depth and horizontal distance from the Site sources, resulting in values in bedrock groundwater that are 10 to over 1,000 times lower than the values in overlying alluvial groundwater. In addition, areas of elevated mine-related COIs in bedrock groundwater are small in comparison to the alluvial aquifer, highly localized, and found mostly on-Site.

The localized areas of elevated mine-related COIs in bedrock groundwater indicate that bedrock fractures have limited hydraulic connectivity and transmissivity over horizontal distances relevant to the scale of the Study Area. Despite localized areas of relatively high hydraulic conductivity, bedrock groundwater flow velocities, average volumetric flow rates and chemical fluxes through the bedrock groundwater system are low, and the bedrock groundwater system is not considered to be an important migration pathway at the Site (EPA 2015a). It is however an important source for elevated concentrations of arsenic, originating from bedrock and transported with mountain front recharge over much longer timescales.

Water quality monitoring of domestic, commercial, and irrigation wells (collectively referred to as domestic wells) located near the Site began in late 1983 and evolved over time. Results of domestic well monitoring have been used to: 1) characterize the quality of groundwater used for drinking water or other domestic uses; 2) assess potential risk, if any, to human health and the environment from the use of domestic well water for drinking water or agricultural purposes; and 3) determine eligibility for receiving bottled water as part of an interim response action.

The number of wells/properties included in the domestic well monitoring program (BC 2010) and receiving bottled water was substantially reduced in 2016 (ARC 2016a; EPA 2016f). As part of a settlement entered in the class action lawsuit *Roeder et al. v. Atlantic Richfield Company et al.*, D. Nev., Case No. 3-11-cv-00105-RCJ-WGC ("Roeder Settlement Agreement") ARC provided funding to the City of Yerington to extend municipal water service to then-existing residences located within that part of the settlement class area that was also within the City's projected future service area.

Domestic well owners who connected to the City of Yerington's municipal water system could elect to either abandon their well or apply for a state permit to authorize withdrawals of groundwater for outdoor use only (landscape watering). Each property owner who received a connection to the City Water System executed and recorded an environmental covenant either prohibiting future domestic use of groundwater altogether or limiting it to outdoor purposes. Construction of the expanded water system began in the fall of 2014, and the construction of new mains and service connections was completed in June 2016.

The first phase of well abandonments and system testing was completed as of August 1, 2016. The water system is functional, and domestic wells for all participating property owners have been abandoned or disconnected from the residences within the expansion area. A relatively small number of domestic wells located within the area of mine-impacted groundwater were not disconnected or converted to outdoor use in 2016. ARC has been in communication with the owners of most of these wells, and disconnections for all but a few are scheduled to occur in 2017.

There are no irrigation wells or municipal drinking water wells located within the plume of mine-impacted groundwater that was delineated during the background assessment.

The plume of mine-impacted groundwater is generally stable based on evaluations of changes in the estimated volume of contaminated groundwater, sulfate and uranium masses, and chemical centers-of-mass through time. A more comprehensive plume stability evaluation (including a statistical evaluation of chemical concentration trends in individual monitor wells) will be provided in a separate report. Plume stability is the result of very slow groundwater velocities and attenuation by dilution. The dilution occurs primarily as the result of recharge on the agricultural fields (specifically on the fields of the Hunewill Ranch) and leakage from irrigation ditches (specifically the West Campbell Ditch), and dispersion within the groundwater plume. Consequently, the plume is not currently adversely affecting and is not expected to affect the use of groundwater by agricultural irrigation and municipal drinking water wells. In addition, the plume of mine-impacted groundwater does not discharge to surface water.

SECTION 1.0

INTRODUCTION

Atlantic Richfield Company (ARC) prepared this *Site-Wide Groundwater Operable Unit (OU-1) Remedial Investigation Report* (OU-1 RI Report) pursuant to Section 7.0 of the Scope of Work (SOW) attached to the Administrative Order for Remedial Investigation and Feasibility Study (RI/FS), CERCLA Docket No. 9-2007-0005 (2007 Order) for the Anaconda Copper Mine Site (Site). The 2007 Order (EPA 2007a) was issued to ARC by the U.S. Environmental Protection Agency - Region 9 (EPA) on January 12, 2007. Future work on the OU-1 RI/FS will proceed under oversight by the Nevada Division of Environmental Protection (NDEP) pursuant to the "Interim Administrative Settlement Agreement and Order on Consent for: (i) Remedial Design/ Remedial Action, (ii) Site-Wide Remedial Investigation/Feasibility Study, and (iii) Fluid Management" entered into with NDEP (the IAOC) and the attached Statement of Work for RI/FS.

The term "Site" refers to the area where copper mining activities historically occurred. The Site is located west and northwest of the City of Yerington (Figure 1-1). Figure 1-2 depicts the Study Area boundary for OU-1 and the boundaries for the seven other OUs at the Site that were identified in the 2007 Order. The eight OUs identified in the 2007 Order include:

- Site-Wide Groundwater (OU-1);
- Pit Lake (OU-2);
- Process Areas (OU-3);
- Evaporation Ponds and Sulfide Tailings (OU-4);
- Waste Rock Areas (OU-5);
- Oxide Tailings Areas (OU-6);
- Wabuska Drain (OU-7); and
- Arimetco Facilities (OU-8).

Since the 2007 Order (EPA 2007a), substantial Site characterization activities have resulted in a better understanding of the nature and extent of chemicals of interest (COIs) within the various Site OUs, and the past and/or ongoing impacts to OU-1. Consequently, the EPA approved a subdivision of OU-4 into OU-4a (Evaporation Ponds) and OU-4b (Sulfide Tailings), as well as the transfer of the southern portion of the Calcine Ditch from OU-3 to OU-4a.

The EPA-approved OU-4 subdivision and transfer of a portion of the Calcine Ditch to OU-4a was based on a recognition of: 1) the different types of mine-waste materials in the Evaporation Ponds and Sulfide Tailings; 2) the similarity of mine-waste materials in the Calcine Ditch and portions of the Evaporation Ponds; and 3) the differences in the presence and magnitude of COIs in groundwater underlying the Evaporation Ponds and Sulfide Tailings. This OU-1 RI Report retains the OU-based framework in the 2007 Order (updated to include the EPA-approved restructuring). However, ARC, EPA and NDEP recognize that significant closure efficiencies will likely result from integrating EPA-designated OUs into geographic-based closure management units.

The term “Study Area” refers to on-Site and off-Site areas in which OU-1 RI-related investigations have been conducted. The Study Area boundary is based on the OU-1 hydrogeologic conceptual site model (HCSM) that was described in the EPA-approved *Site-Wide Groundwater Operable Unit (OU-1) Remedial Investigation Work Plan - Revision 1* (Revised Groundwater RI Work Plan; Brown and Caldwell [BC] 2014a).

1.1 Purpose of Report

Consistent with the SOW attached to the 2007 Order (EPA 2007a) and EPA (1988) guidance, this OU-1 RI Report: 1) summarizes activities conducted to “characterize and monitor groundwater in the vicinity of the Site (study area to be determined), including on- and off-Site locations”; 2) describes the nature and extent of mine-related COIs in groundwater; and 3) integrates relevant aspects of other OUs that represent potential sources of chemical loading to groundwater or have the potential to influence groundwater flow conditions. Additionally, this OU-1 RI Report addresses the fifteen study elements specified in Section 7.0 of the SOW (EPA 2007a), which served as the principal bases for RI planning, data collection, and analysis.

Given the complexity of Site-Wide groundwater conditions, several phases of investigations have been approved by EPA and conducted by ARC since 2005. During this time period, ARC, EPA, and other stakeholders including the Yerington Piaute Tribe (YPT), NDEP, and Bureau of Land Management (BLM) have periodically held groundwater technical meetings to discuss field data collection activities, technical findings, and remaining data gaps relative to: 1) the 15 study elements specified in Section 7.0 of the SOW attached to the 2007 Order; and 2) the Data Quality Objectives (DQOs) established in the draft and final versions of the remedial investigation work plans for OU-1 (BC and Integral Consulting, Inc. 2007 and BC 2014a, respectively). Table 1-1 relates the 15 study elements specified in the 2007 SOW to the DQOs presented in the Revised Groundwater RI Work Plan (BC 2014a).

Table 1-1. Comparison of Study Elements Specified in the SOW to the 2007 Order to DQOs Presented in the Revised Groundwater RI Work Plan

DQO	DQO Title	SOW Study Element														
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	Discriminate Background and Mine-Impacted Groundwater		X									X			X	
2	Identify Potential Chemical Loading Sources to Groundwater		X									X		X		X
3	Determine Geochemical Mobilization/Attenuation Processes											X				
4	Characterize Chemical Distribution and Migration Pathways	X						X	X	X	X	X			X	X
5	Determine Aquifer Properties								X				X			
6	Determine Groundwater Flow and Chemical Transport Rates	X	X		X	X	X	X		X	X	X				
7	Assess Anthropogenic Influences on Groundwater and Surface Water/Groundwater Interactions	X	X	X			X									
8	Determine Pumpback Well System Efficiency	X														
9	Assess Human Health and Ecological Effects							X	X	X	X	X		X	X	

Numerous investigations and monitoring activities conducted by ARC and others provide substantial geologic, hydrogeologic, and water quality information relevant to OU-1. However, this OU-1 RI Report relies primarily on data obtained after 2005 to address the study elements specified in Section 7.0 of the SOW, characterize groundwater conditions, and refine the HCSM to support the OU-1 RI/FS. Data obtained after 2005 have been selected for these purposes because: 1) data collection was performed pursuant to EPA-approved quality assurance/quality control (QA/QC) planning documents and OU-1 specific work plans that were developed with input from other stakeholders including the YPT, NDEP, and BLM; 2) the spatial coverage and amount of data increased substantially after 2005; and 3) post-2005 sampling results better represent current conditions and potential risks at the Site, which is the proper focus of the RI and risk assessment.

The August 2014 dataset is emphasized in this OU-1 RI Report for the reasons previously cited and because a variety of data types were concurrently collected (e.g., groundwater level data, groundwater quality data, and hydrologic tracer data) and/or evaluated (e.g., geochemical speciation modeling to help asses COI transport). Consequently, the August 2014 dataset is particularly informative for characterizing spatial aspects of OU-1 groundwater conditions. Temporal aspects of OU-1 groundwater conditions are based on post-2005 data, which indicate that the August 2014 dataset is generally representative of post-2005 groundwater conditions.

Long-term monitoring of Site-wide groundwater conditions is conducted pursuant to the *Site-Wide Groundwater Monitoring Plan - Revision 2* (GMP; BC 2012a), which was prepared by ARC pursuant to Section 6.0 of the 2007 SOW. The development of the monitoring program and a description of the monitor well network are also provided in this OU-1 RI Report.

Potential human health risks will be addressed more comprehensively in a separate OU-1 Human Health Risk Assessment (HHRA) report. This OU-1 RI Report provides the basis for ARC to identify remedial action objectives (RAOs) and screen/evaluate remedial alternatives for OU-1, which will occur during the feasibility study (FS).

1.2 Site and Study Area Description

The Site and Study Area are located in the Mason Valley in Lyon County, Nevada. The Site boundary includes portions of Township 13 North, Range 25 East, Sections 4, 5, 8, 9, 16, 17, 20, and 21 (Mount Diablo Baseline and Meridian) on the Mason Valley and Yerington United States Geological Survey (USGS) 7.5 minute quadrangles. The Site covers approximately 3,017 acres (4.7 square miles) of land altered by copper mining and processing activities. Including the Site, the Study Area covers approximately 19,300 acres (30.2 square miles).

The Mason Valley Basin (Basin no. 108, as defined by the Nevada Division of Water Resources [NDWR]) is located within the larger Walker River Hydrographic Basin (no.9). Mason Valley covers about 510 square miles, and the valley floor occurs at an elevation between 4,300 and 4,700 feet above mean sea level (amsl). The principal agricultural activities in the valley include farming (hay, grain, and onions) and cattle ranching (Lopes and Allander 2009a, 2009b; Carroll et al. 2010). Irrigation water is provided by surface water diversions from the Walker River and from pumped groundwater. The Walker River flows northerly and northeasterly between the Site and the City of Yerington. The river is within a quarter-mile of the southern portion of the Site (Figure 1-1).

1.3 Groundwater Zone Designations

Groundwater zone designations based on elevation have been used in previous groundwater-related reports, as well as this OU-1 RI Report, to identify and group monitor wells with similar screen interval elevations in the alluvial aquifer, as follows:

- Shallow (S): screen intervals that straddle the water table, or are within 50 feet of the water table when a shallower well does not exist, typically >4,300 feet amsl
- Intermediate (I): 4,250 to 4,300 feet amsl
- Deep (D): <4,250 feet amsl; given the thickness of alluvium, the Deep zone is further subdivided as follows:
    - Deep 1 (D1): 4,200 to 4,250 feet amsl
    - Deep 2 (D2): 4,120 to 4,200 feet amsl
    - Deep 3 (D3): 4,000 to 4,120 feet amsl
    - Deep 4 (D4): 3,900 to 4,000 feet amsl
    - Deep 5 (D5): <3,900 feet amsl

Monitor wells with screen intervals in bedrock, regardless of elevation, are designated as bedrock ("B") wells. The groundwater zone designation is included as a suffix to the monitor well identification number (e.g., the "S" suffix in monitor well identification B/W-1S indicates that the screen for this well is positioned in the Shallow zone).

1.4 Report Organization

Consistent with EPA guidance (EPA 1988) and recommendations provided during groundwater technical meetings in 2015 and 2016, the content and organization of this OU-1 RI Report is presented in this section.

Section 2.0 summarizes the Site operation history. Section 3.0 details the investigations related to OU-1 and relevant Site-wide studies and evaluations. Section 4.0 describes the physical characteristics of the Study Area. Section 5.0 describes the background groundwater quality assessment. This assessment served as the basis for determining the extent of mine-impacted groundwater, identifying agriculturally-affected groundwater, and assessing the occurrence of naturally-occurring COIs in groundwater. Section 5.0 also discusses the primary sources of past and/or ongoing releases of mine-related COIs to groundwater. Section 6.0 describes the fate and transport of contaminants in Study Area groundwater. Section 7.0 summarizes the HCSM for OU-1. Section 8.0 discusses the risk evaluation process and status. Section 9.0 lists the references cited in this OU-1 RI Report.

Appendix A provides historical mining-related information including the *Final Historical Summary Report* (HSR; CH2M Hill 2010) and historic Anaconda water supply and use information. Appendix B provides the *Shallow Zone Data Summary Report - Revision 1* (BC 2010a), which refined the distributions of select COIs in Shallow zone groundwater north of the Site and helped guide subsequent monitor well installation efforts. Appendix C presents information on the groundwater monitor wells including lithologic logs, well construction information, and depth-specific (zonal) groundwater quality data obtained during borehole drilling and well installation.

Appendix D presents water level and groundwater quality information. Appendix E provides soil sampling data. Appendix F presents hydraulic conductivity information and analyses. Appendix G presents regional and local surface water data. Appendix H presents hydrologic tracer data and supplemental information. Appendix I presents the *Bedrock Groundwater Assessment Technical Memorandum* (BC 2015a). Appendix J provides various groundwater studies, evaluations, and reports that were conducted to fulfill certain study elements specified in Section 7.0 of the SOW attached to the 2007 Order (EPA 2007a) and have been previously submitted to the EPA. These include an evaluation of the effectiveness of the Pumpback Well System (PWS), a Pit Lake water balance, public information pertaining to agricultural water use, the groundwater flow model report, the *Geochemical Characterization Data Summary Report - Revision 2* (BC 2016a), Site-specific chemical distribution coefficients, and the *Background Groundwater Quality Assessment - Revision 3* (BC 2016b). Appendix K presents maps illustrating the distributions of select COIs (including pH, sulfate, dissolved uranium, alkalinity, nitrate, and dissolved arsenic) in groundwater. Appendix L presents maps illustrating groundwater temperatures.

SECTION 2.0

SITE HISTORY

The following summary of the operational history of the Site paraphrases and/or is derived from the HSR (CH2M Hill 2010), which is provided in Appendix A-1. Topics covered in detail in the HSR include: 1) Site chronology; 2) processing operations utilized by the various owners and operators; 3) historic mine Site water usage and quality information; 4) uses and releases of chemicals; and 5) current Site status since 2000 focusing on removal actions conducted by EPA.

The following discussion focuses on key historic mining practices, releases, and features relevant to the historic and/or current aspects of the HCSM for OU-1. This summary is not intended to comprehensively cover all the information provided in the HSR. Historic mining-related features are shown on Figure 1-2. Historic ore processing facilities located within the Process Areas (OU-3) are shown on Figure 2-1.

2.1 Mining and Processing Operations

Copper in the Yerington district was initially discovered in the late 1860s, with large-scale exploration of the porphyry copper system occurring in the early 1900s when the area was organized into a mining district by Nevada-Empire Copper Mining and Smelting Company. Mining and ore processing operations at the Site were conducted by various owners from 1953 to November 1999.

2.1.1 Anaconda Operations

The Anaconda Company (Anaconda) became involved in the Site when it entered into a lease agreement and acquired the claims in 1941. Anaconda purchased the property in 1951 and the mine began producing copper in 1953, producing approximately 1.7 billion pounds of copper during its operations. Anaconda divested itself of the Site on June 30, 1978. Anaconda mining operations generated approximately 360 million tons of ore, 15 million tons of overburden and waste rock (400 acres), 3,000 acres of tailings, and 1,377 acres of disposal ponds.

Mined materials included oxide ore, sulfide ore, low-grade dump-leach ore, low-grade sulfide ore, and alluvium and waste rock overburden. Several processes were required to extract copper from the ore, as discussed further below. Briefly, all oxide and sulfide ore were crushed prior to leaching or processing in the various plant facilities. Copper was extracted from oxide ore using a sulfuric acid leach solution. The vast majority of leaching was conducted in vat leach tanks. A leach dump was operated over a much shorter period (discussed below). Pregnant copper solutions from the tanks and dump were stored in large solution tanks. Copper extracted from the oxide ore was recovered from the acidic leach solutions in the precipitation plant by precipitating (i.e., cementing) the copper onto iron scraps. A concentration/flotation process was used to extract copper from the sulfide minerals.

Dump Oxide Ore Processing

Crushed oxide ore was bedded into vat leach tanks capable of holding 12,000 dry tons of ore and 800,000 gallons of sulfuric acid leach solution. Spent ore, known as oxide tailings or vat leach tailings (VLT), was excavated from the vat leach tanks and disposed in the Oxide Tailings. The vats typically operated on a 96-hour or 120-hour leaching cycle, with an additional 32- to 40-hour wash period, and 24 hours required to excavate and refill. The entire cycle required approximately 8 days. Thus, eight leach vats were installed and used to process ore.

Following the leaching process, the ore underwent three wash cycles. Acidic leach solutions were recirculated and pumped at a rate of 2,000 gallons per minute (gpm). Copper-enriched wash solutions were put into three of the four open solution storage tanks located between the vat leach tanks and precipitation plant. The three solution tanks used for storing pregnant copper solutions had a total storage capacity of 1.4 million gallons. The additional storage tank, referred to as the wash water sump, stored up to 845,000 gallons of wash water from the leaching circuit, which included slurry from the scrubber in the sulfuric acid plant. Copper was recovered from the leach solution in the precipitation plant, which consisted of the iron launders, solution sumps, an adjacent launder pump station, scrap iron storage, and trommel screens.

The iron launders consisted of 20 parallel launders that were filled with scrap iron used to precipitate (i.e., cement) copper from the sulfuric acid leach solution pumped out of the leach vats and temporarily stored in the solution tanks. The waste product from the precipitation plant was an iron-sulfate solution that was conveyed in unlined ditches (such as the Calcine Ditch) to lined and unlined evaporation ponds in the northern portion of the Site (as further discussed in Section 2.2). Pregnant copper solution from dump leaching activities (discussed below) was also sent to the precipitation plant, but was kept separate from the vat leach solutions. Historical information on flows and chemical concentrations of solutions in various stages of the cementation circuit are provided in Table 2-1. Following cementation, the copper cement product was washed and dried to reduce moisture content prior to shipment off-Site for final smelting (Skillings 1972).

Table 2-1. Average Assay Values of Solutions at Various Stages in the Cementation Circuit

	Flow (gpm)	Cu (g/L)	H_2SO_4 (g/L)	Fe (g/L)	Fe^{3+} (g/L)
Primary and Scavenger Launders					
New Solution	700	20.0	5.8	7.2	5.4
Recirculated Solution	900	3.5	2.4	23.6	0.5 [a]
Total Feed (new solution plus recirculated solution)	1,600	10.7	3.8	16.4	2.6
Discharge	1,600	3.8	2.5	23.2	Trace
Secondary Launders					
Recirculated Solution (feed)	900	3.5	2.4	23.6	0.5
Discharge	900	1.0	2.1	26.4	[b]
Stripping/Settling Launders					
Feed	700	1.0	2.1	26.4	- -
Discharge	700	0.5	2.0	28.1	- -

Notes:
[a] The recirculated solution in the primary launders is the same strength as the recirculated solution in the secondary launders.
[b] The discharge solution in the secondary launders is the same strength as the feed solution to the stripping bank (U.S. Bureau of Mines 1958).
Cu = copper; H_2SO_4 = sulfuric acid; Fe = iron; Fe^{3+} = ferric iron; gpm = gallons per minute, g/L = grams per liter

Dump Leaching

In February 1965, Anaconda began dump leaching low-grade oxide ore in the W-3 Waste Rock Area. Copper-enriched solutions were stored in the Dump Leach Surge Pond (Figure 2-1) prior to conveyance to the iron launders for copper recovery. Copper extraction by heap leaching was in in its infancy at the time and recovery from the W-3 Waste Rock Area was inefficient because there were large quantities of ore that never came into contact with the acid-bearing leach solutions. Due to poor copper recovery, Anaconda ceased dump leaching in 1968.

Sulfide Ore Processing

To process sulfide ore, a froth flotation system was constructed and began operating on September 25, 1961. Flotation separation was accomplished by mixing very finely ground ore (pulp) with water and a chemical "collector" (typically xanthates and aerofloats) to make sulfide minerals hydrophobic, and then sparging air and a surfactant chemical "frother" (typically pine oil) through the mixture to create froth. The collector attaches to the sulfide mineral making it hydrophobic and susceptible to attachment to the stabilized air bubbles in the froth mixture, which was skimmed off as copper concentrate. The concentrate was further beneficiated in a scavenger flotation circuit, dewatered and dried, and subsequently hauled by truck to the Wabuska railroad spur and transported to the Washoe Smelter in Anaconda, Montana (Skillings 1972). Excess pulp after the flotation separation was disposed in the Sulfide Tailings area as a slurry mixture. Operation of the concentrator required approximately 3,000 gpm of water.

Acid Plant

Sulfuric acid was produced at the Site in the fluosolids and acid plant from 1952 to 1978. Raw sulfur ore (predominantly native sulfur and sulfide minerals) was hauled by truck to the Site from the Leviathan Mine located in Alpine County, California until 1962. The fluosolids system roasted the sulfur ore to generate sulfur dioxide (SO_2) gas, which was converted to sulfuric acid (H_2SO_4) in the contact acid plant. In 1962, Anaconda ceased mining sulfur ore from the Leviathan Mine. Between 1962 and 1978, previously stockpiled sulfur ore was blended with liquid sulfur, which was purchased from several suppliers and hauled to the Site where it was used as feed to the Acid Plant to generate sulfuric acid.

The final product was a 93 percent (%) sulfuric acid solution that was used in the vat leach tanks and dump leach of oxide ores. Byproducts such as selenium, were generated during production of sulfuric acid (CH2M Hill 2010). Operation of the sulfuric acid plant was discontinued in 1978 and the plant was dismantled by Arimetco, Inc. (Arimetco) in 1992. For its leaching operations, Arimetco purchased liquid sulfuric acid from off-Site vendors and stored it in tanks at the Site. The Acid Plant and surrounding area has subsequently been buried under the Arimetco Phase III South Heap Leach Pad (HLP).

2.1.2 Post-Anaconda Operations

Subsequent operators and lessees used some of the buildings within the Process Areas for operational support, storage, and various light industrial activities; however, the Anaconda-constructed processing components remained inactive after 1978.

In 1982, Copper Tek Corp. operated the mine under the ownership of Don Tibbals, and leased the Site for reprocessing tailings and low-grade copper ore using heap leaching and solvent extraction/electrowinning (SX/EW) processes in the area to the south of the Process Areas. In 1988, Don Tibbals sold his interests (except for the Weed Heights community and certain other parcels) to Arimetco. Prior to the sale, Arimetco (operating under the name Arizona Metals Company) had leased a large portion of the mine Site from Don Tibbals. By 1989, Arimetco had also acquired 90% of Copper Tek.

2.1.3 Arimetco Operations

From 1989 to November 1999, Arimetco conducted the following SX/EW operations on the Site:

- Phase I/II HLP: operated from 1990 to 1996, plus five months in 1997;
- Phase III South HLP: operated from August 1992 to early 1997, plus a few months in 1998;
- Phase III 4X HLP: operated from August 1995 to 1999;
- Phase IV Slot HLP: operated from March 1996 to November 1998; and
- Phase IV VLT HLP: operated from August 1998 to November 1998.

The HLPs (Figure 1-2) were constructed over high-density polyethylene (HDPE) liners with leak detection systems. The HLPs were leached with a sulfuric acid solution and the acidic, copper-laden draindown fluids were collected in HDPE-lined perimeter ditches, routed to HDPE-lined collection ponds, and conveyed to the SX/EW Plant. The copper-laden acid solution was then stripped of copper in a solvent extraction circuit using a mixture of kerosene and an organic hydroxyamine-based chelating agent (tradename ACORGA) in three process vats (total of approximately 200,000 gallons).

In the SX circuit, the copper in the dump leach liquor was concentrated by the organic in exchange for hydrogen ions producing a strong acid that became the electrolyte for the EW circuit. In the EW circuit, the copper was electroplated to stainless-steel sheets to produce 99.999% fine copper and in the process, additional sulfuric acid was generated. It was this strong acid in the EW circuit that was used to exchange copper from the loaded organic chelating agent.

Arimetco recirculated the acid solution from the EW vats back into the HLPs, which currently continue to drain fluids to the present. The electrolyte circulated between the EW plant and the tail end of the SX plant (called raffinate). The kerosene and organic reagent were also recirculated within the SX/EW circuit, being loaded and stripped repeatedly.

In January 2000, Arimetco, on the verge of bankruptcy and unable to make payroll, abandoned operations at the Site. From 2000 to 2004, NDEP managed HLP drain-down fluids by re-circulation and evaporation. In 2005, ARC was required by EPA to assume responsibility for fluid management operations at the Site. Since 2006, EPA has conducted various RI/FS and closure-related activities associated with the Arimetco Facilities (OU-8).

Inactive Arimetco HLPs that continue to produce drain-down fluids include the Phase I/II HLP, two Phase III HLPs, the Phase IV Slot HLP, and the Phase IV VLT HLP (BC 2014b). HLP drain-down fluids are currently stored and conveyed in a network of ponds, ditches, and 25,000 feet of pipe, collectively referred to as the fluid management system (FMS). The HLPs and associated FMS components are briefly described below. Additional FMS details are provided in annual operation and maintenance (O&M) reports for the FMS (e.g., BC 2014b).

Phase I/II Heap Leach Pads

The Phase I/II HLP covers an area of approximately 14 acres (Phase II was extended to the west and north of Phase I). A solution ditch with eleven leak detection points was constructed around the HLP. A variable two- to ten-foot-thick layer of VLT was placed on a single 40-mil (0.04-inch-thick) HDPE liner. The solution ditch that surrounds the Phase I/II HLPs drained to the Phase I Pond.

Phase III Heap Leach Pads

The 46-acre Phase III South HLP and the 50-acre Phase III 4X HLP were constructed by Arimetco to leach low-grade oxide ores. A single 40-mil HDPE liner was installed by Arimetco to recover drain-down solution, and the drainage ditch was designed with a leak detection system over a second, 40-mil HDPE liner. The solution ditches surrounding the Phase III South HLP and the Phase III 4X HLP drained to the Phase III Bathtub Pond and to the Mega Pond, respectively.

Phase IV Slot Heap Leach Pad

The approximate 86-acre Phase IV Slot HLP was constructed by Arimetco on a pad excavated into the W-3 waste rock dump and an asphalt-lined area, and was expanded northward between 1993 and 1996 on a 40-mil HDPE liner over a secondary liner of compacted clay. This HLP is surrounded by a berm and double HDPE-lined collection ditch with leak detection between the membranes and seven leak detection monitoring points. Drain-down solutions flow to one of two pregnant leach solution (PLS) ponds.

Until late 2003, drain-down solutions were pumped by NDEP from the PLS ponds to the surface of the HLP for evaporation. In 2006, EPA relined the northern Phase IV Slot PLS Pond, and solutions from this pond were routinely conveyed to the FMS Evaporation Pond (also known as the EPA 4-Acre Pond) constructed by EPA in 2007.

Phase IV VLT Heap Leach Pad

The 54-acre Phase IV VLT HLP was constructed by Arimetco on the southern portion of the former finger evaporation ponds, and on native alluvial soils, north of the Oxide Tailings OU, and consists of oxide tailings, and run-of-mine and crushed ore from the MacArthur Mine. The Phase IV VLT HLP was constructed on a 40-mil HDPE liner overlying a secondary liner of compacted clay. The solution drainage ditch includes a leak detection system over a 40-mil HDPE liner designed with five leak detection points, and drains to the northeast corner of the HLP to a single PLS pond (5.04 million-gallon capacity).

Drain-down solutions from the Phase IV VLT HLP flow by gravity to the VLT Pond and, as needed to improve evaporation efficiency of the FMS, are pumped to one of two new FMS Evaporation Ponds (B and C) described below. EPA completed a VLT pond liner replacement project in October 2012 (BC 2014b).

2.2 Evaporation Ponds

From the Process Areas, spent process solutions resulting from the beneficiation of copper oxide and sulfide ores were conveyed in unlined trenches to the lined and unlined evaporation ponds, and ponds in the northern portion of the Site. The evaporation ponds in the northern portion of the Site are identified on Figure 1-2 as the Unlined Evaporation Pond (UEP), the Lined Evaporation Pond (LEP), and the Finger Ponds. The Sulfide Tailings were also used to dispose spent oxide ore process solutions prior to the mining of sulfide ores. A brief description of these ponds follows:

- UEP: consists of a large northern section (98 acres) and a much smaller southern section (4.1 acres) constructed on alluvial soils without a liner surrounded by berms constructed of VLT. The volume of pond sediments contained in the UEP is approximately 270,230 cubic yards based on average thicknesses of approximately 1.5 and five feet in the northern and southern sections, respectively.
- LEP: consists of three sections (North, Middle and South), which were lined with a relatively thin (0.5 to one-inch-thick) liner consisting of a mixture of asphalt tar and crushed gravel. The asphalt liner was placed over one to 2.5 feet of VLT materials. The LEP has a total combined area of approximately 101 acres. The thickness of the pond sediments averages three to six inches, with a maximum measured thickness of approximately 12 inches within the central, topographically lower portion of the LEP. The volume of pond sediments contained in the LEP is approximately 65,800 cubic yards.
- Finger Ponds: consist of four narrow “Finger Ponds” and one larger “Thumb Pond”. The four Finger Ponds (17.8 acres) were lined similar to the LEP without the VLT sub-base. The estimated volume of sediments within the Finger Ponds is 5,838 cubic yards based on an average thickness of four inches. The unlined Thumb Pond has elevated embankments along its north and east margins. The exposed portion of the Thumb Pond (i.e., not covered by the Arimetco Phase IV VLT HLP) covers about 69 acres and was capped in 2010 with VLT materials. The volume of pond sediments contained within the Thumb Pond is 95,000 cubic yards based on an average thickness of 3.5 feet.

In 1955, the flow rate to the evaporation ponds averaged approximately 2,000,000 gallons per day or 1,385 gpm and water quality characteristics of the fluid showed a free acid concentration of 1.0 g/L, total soluble salts concentration of 171 g/L, and total iron concentration of 37.5 g/L (Nesbitt 1955; Dalton 1998).

Infiltration of process solutions at these locations due to increased hydraulic heads associated with impounded fluids, likely raised groundwater elevations and created mounding effects that influenced groundwater gradients, flow directions and velocities, and groundwater quality. Due to the net evaporative character of the Site, significantly less flux (if any) of residual process-related chemicals to groundwater occurs at the Site at present relative to historic periods when the mine facilities were operational. The term "evaporation ponds" used in the following sections refers to the LEP and UEP.

2.3 Historical Mine Site Groundwater Pumping, Distribution and Use

Details of Anaconda's historical groundwater pumping, distribution, and water management at the Site are provided in Appendix A-2 and summarized below.

Mine Site Water

Gill (1951) conducted a groundwater investigation to support open pit mining, and reported that the groundwater table around the proposed open pit was approximately 4,350 to 4,380 feet amsl, with variable water levels a result of bedrock compartmentalization of groundwater. Gill (1951) also reported that most groundwater in the proposed open pit was recharged by the Walker River. Dewatering of the pit in advance of mining operations in the early 1950s resulted in a depressed water table.

Groundwater produced from the pit area wells and other supply wells was primarily used in the beneficiation of copper oxide and sulfide ores in the Process Areas. Pit dewatering ended in 1978. The resulting Pit Lake functions as a hydraulic sink that captures alluvial and bedrock groundwater, as discussed in Section 3.3.2.

Historical Groundwater Pumping and Water Management

The known locations of historic wells used for mining-related activities are shown on Figure 2-2. These wells include those that have been abandoned per the State of Nevada Administrative Codes (NAC) 534.420, 534.4365 or 534.4371 and others that have not been abandoned but are not currently in active use.

Groundwater pumped by Anaconda was used for four general purposes: 1) to depress the water level in the open pit to achieve safe working conditions for mining operations; 2) copper ore beneficiation activities in the Process Areas; 3) residential use at Weed Heights, commonly referred to as the "Townsite" in archived documents (Anaconda 1953, 1955, and 1957); and 4) ancillary operations at the Site (e.g., fire protection, dust control, drilling, blasting, and supply to shops).

Groundwater use was less during the period from 1952 through 1963 when only oxide ores were leached than in the period from 1963 through 1978 when the copper sulfide ore milling circuit was added to the existing copper oxide ore leaching operations, which resulted in an increased demand for groundwater. References in archived documents to the "Plant" generally refer to oxide leaching facilities prior to 1963, and combined copper oxide and copper sulfide ore beneficiation operations after 1963. Groundwater supplies were obtained from four geographic areas: open pit area wells; evaporation area wells; well WW-10 in the Process Areas; and off-Site area wells. Excess pumped water, from pit dewatering activities, was discharged to the Walker River.

Discharge of water to the Walker River peaked in 1953 at 2,373 acre-feet per year, which is equivalent to approximately 1,471 gpm, and generally declined through 1963. At this point, pumped water to the combined Townsite and Plant rose steadily until 1974 at which time it reached 11,388 acre-feet per year (7,058 gpm). There was a general decline in total water pumped during the last four years of Anaconda operations. The annual average pumping rate at the Site ranged from 1,658 gpm in 1978 (the final year of operations) to 7,119 gpm in 1974 (the peak year of water production).

Although the monthly water reports did not specify on-Site water use, some details of water distribution to operational areas are available for 1964 and the first half of 1978 (Table 2-2). In 1964, the Plant received 2,055 acre-feet (45% of total) and the sulfide milling circuit (Concentrator) received 1,511 acre-feet (33% of total).

Table 2-2. Water Distributed to Operational Areas During 1964 and 1978

Operational Area or Use	1964 (acre-feet)	1964 Percent of Total	Jan-Jun 1978 (acre-feet)	Jan-Jun 1978 % of Total
Townsite	455	9.9%	58	4.3%
Roads	51	1.1%	31	2.3%
Leach Vats	2,055	44.7%	271	20.2%
Precipitation Plant	---	---	15	1.1%
Sulfide Concentrator	1,511	32.9%	---	---
Acid Plant	481	10.5%	538	40.1%
Water Discharged to Walker River	46	1.0%	0	---
W-3 Waste Rock Dump	---	---	259	19.3%
Dust System	---	---	169	12.6%
Total	4,600	100%	1,340	100%

Open pit area wells were installed during the period 1952-1954 (WW-1 through WW-7) and in 1959 (WW-36) to dewater the pit, supply water to the Townsite, and supply water for copper oxide ore beneficiation. During July 1955, the combined flow from six of the open pit area wells was estimated to be 2,454 gpm, and the total demand was 2,553 gpm. The use of recycled process water during this period made up for the approximate 100 gpm difference. In 1966, combined demand at the Plant and Townsite was 2,600 gpm.

Evaporation area wells were installed during the period 1959-1961 (WW-8, WW-9 and WW-11) and in 1965 (WW-12C) to provide the required make-up water (i.e., approximately 1,000 gpm) for the Sulfide Concentrator, which began operation in 1963. Based on 1964 monthly water reports, evaporation area wells had a combined pumping rate that ranged from 442 to 1,390 gpm with an annual average rate of 690 gpm. Well WW-10 was installed in the Process Areas in 1960 to provide additional water for the copper oxide and copper sulfide ore beneficiation operations.

Per the well log on file with the NDWR, the well was drilled to a depth of 610 feet, and penetrated 200 feet of alluvial materials before reaching bedrock. At that time, the depth to groundwater was 100 feet below ground surface (bgs). The well casing was perforated from 105 to 505 feet bgs, resulting in about 95 feet of alluvial materials and 305 feet of bedrock that could yield groundwater. When tested for two hours at a rate of 595 gpm, WW-10 exhibited a drawdown of 81 feet (close to the alluvium-bedrock contact).

Historical pumping records for WW-10 are limited. Table 2-3 summarizes 1964 monthly water reports for well WW-10. The monthly pumping rate was calculated by dividing the monthly volume by the number of days in each month and the number of minutes in each day. The pumping rate ranged from 102 gpm in January 1964 to 254 gpm in October 1964, with an average annual rate of approximately 169 gpm for the 10 months with pumping data.

Table 2-3. 1964 Monthly Pumping Volumes and Rates for Mine-Water Supply Well WW-10

Month, 1964	Volume Pumped (cu ft)	Volume Pumped (gal)	Average Pumping Rate (gpm)
January	606,470	4,537,000	102
February	NA	NA	NA
March	NA	NA	NA
April	1,135,410	8,494,000	190
May	1,230,851	9,208,000	206
June	1,329,595	9,946,700	223
July	1,134,621	8,488,100	190
August	1,362,839	10,195,400	228
September	1,227,109	9,180,000	206
October	1,514,771	11,332,000	254
November	1,220,291	9,129,000	205
December	1,139,420	8,524,000	191
Annual Values	11,901,377	89,034,200	169

NA = not available; cu ft = cubic feet; gpm = gallons per minute; gal = gallons

Groundwater quality samples were obtained from WW-10 from August 1991 to June 2006. From August 1991 through 1994, at least three samples were collected during each year. From 1995 through June 2006, samples were collected quarterly. Not all parameters were monitored in each sampling event. Results for sulfate, uranium and arsenic are discussed below.

Concentrations of sulfate in the 49 samples collected from August 1991 to June 2006 ranged from 457 to 2,485 milligrams per liter (mg/L). Concentrations of uranium in the 10 samples collected from September 2003 to June 2006 ranged from 190 to 310 micrograms per liter (µg/L). From August 1991 to June 2006, 95% (i.e. 35 of the 37) reported arsenic results were less than or approximately equal to the laboratory analytical reporting limits. Laboratory reporting limits for arsenic were commonly higher (i.e., 25 µg/L) during the early part of the monitoring history and lower (as low as 4 µg/L) during the latter part of the monitoring history. In September and October 1991, arsenic concentrations were reportedly 1,040 and 3,475 µg/L, respectively. The arsenic results for these two sampling events are inconsistent with and three orders of magnitude greater than the results for the other 35 sampling events.

2.4 Pumpback Well System

The PWS and associated monitor wells were constructed under an Administrative Order on Consent issued by NDEP on October 1, 1985. ARC operated the PWS located along the northern margin of the Site to collect shallow groundwater beginning in March 1986 (Piedmont 2001). The initial PWS consisted of five extraction wells (PW-1 through PW-5; see Figure 3-3) and a clay-lined 23-acre evaporation pond for containment of extracted groundwater.

In 1998, six additional extraction wells (PW-6 through PW-11; see Figure 3-3) were installed and operated as part of the PWS. Other improvements to the PWS included partitioning the 23-acre evaporation pond into three cells and installing an HDPE liner on top of the clay liners in the middle and south cells to protect the clay liners from desiccation during the summer dry season. No HDPE liner was placed on the north cell.

The pumpback wells are approximately 40 to 60 feet deep and are spaced at intervals ranging from approximately 380 feet (PW-2 to PW-3) to 1,400 feet (PW-5 to PW-6). Prior to March 25, 2009, the PWS operated continuously (i.e., 24 hours per day, 7 days per week), with individual wells temporarily taken off-line for maintenance and repairs of pumps and related equipment. For example, in 2006, individual well production rates ranged from 0.5 to 16.7 gpm with a total combined pumping rate of 56.4 gpm. Approximately 29.7 million gallons (91.1 acre-feet) of groundwater were pumped from the Shallow zone in 2006 (Norwest Applied Hydrology 2007).

EPA approved the shutdown of the PWS on March 25, 2009 to allow for a characterization of groundwater conditions at the northern Site margin. Subsequently, the pumpback wells were used as part of an aquifer test to characterize hydraulic properties of the Shallow zone (ARC 2010). The test data were used to: 1) delineate the hydraulic capture zones of the PWS; and 2) assess the historical effectiveness of the PWS in limiting the off-Site migration of Shallow groundwater. The PWS evaluation is discussed in Section 3.3.1. Since completion of hydraulic testing, the PWS has been shut down and wells PW-1 to PW-11 have been monitored pursuant to the Groundwater Monitoring Plan (GMP) (BC 2012a).

2.5 Wabuska Drain

The Wabuska Drain is a 13.8-mile long unlined ditch that extends from the Site to the Walker River. The grade of the Wabuska Drain between the Site and the southern margin of the YPT Reservation is approximately 0.15% over 4.1 miles. The grade increases to about 0.16% along the 1.1-mile length within the YPT Reservation. From the northern margin of the YPT Reservation to its intersection with the Walker River, the average grade is approximately 0.04% (BC 2015b). Adjacent surrounding agricultural fields slope gently toward the Wabuska Drain, or connect to the drain through lateral ditches that feed into the drain by gravity flow. The drain was constructed in the late 1930s, when the regional groundwater table was higher, to intercept shallow groundwater to stabilize areas north of the Site adjacent to the tracks of the former Nevada Copper Belt Railroad and several farms. The Wabuska Drain alignment near the Site has changed over time (BC 2015b; CH2M Hill 2010), as shown on Figure 2-3. Portions of these former alignments are now buried beneath the Evaporation Ponds and the Hunewill Ranch agricultural fields.

Currently the drain functions as one of many irrigation return-flow ditches in the northern Mason Valley. These drains collect irrigation tail water and run-off from agricultural fields, and convey water to downgradient agricultural areas for further irrigation uses and/or discharge to the Walker River (CH2M Hill 2010).

Historically, the Wabuska Drain alignments near the Site intercepted shallow groundwater (CH2M Hill 2010). However, the various drain alignments near the Site no longer intercept shallow groundwater due to basin-wide groundwater level declines (Section 4.9). In the northern part of the Wabuska Drain, inputs also include intercepted shallow groundwater and deeper water associated with alluvial groundwater discharge and geothermal springs that coincide with a series of northwest trending faults referred to as the Wabuska lineament (Stewart 1988). Other potential past and/or current inputs include discharges from, or groundwater influenced by, the Thompson smelter and various geothermal power production activities.

Details regarding the Wabuska Drain are provided in the HSR (CH2M Hill 2010; Appendix A-1). Results of the ongoing RI for the Wabuska Drain will be reported separately. Available data indicate that concentrations of mine-related chemicals decrease with distance from the Site and depth in the soil profile (EPA 2007a, BC 2015b).

SECTION 3.0
GROUNDWATER INVESTIGATIONS AND RELATED STUDIES

Numerous investigations and monitoring activities conducted prior to 2005 have provided substantial geologic, hydrogeologic, and water quality information pertaining to OU-1. These pre-2005 activities were primarily associated with a limited number of monitor wells (having screens positioned across the water table) located around the northern Site margin. Sampling methods and the quality of laboratory analytical results prior to 2005 were not well documented.

Pre-2005 investigations and reports for the Site and surrounding area are summarized in Section 3.1. Post-2005 investigations and reports performed and/or prepared by ARC are summarized in Section 3.2. Pre-2005 data are used to address historical aspects of the HCSM because historical conditions (e.g., groundwater elevations and flow directions) were different from current conditions due to mine operations, agricultural activities, groundwater and surface water usage, and weather conditions (BC 2014a). Historical aspects of the HCSM are generally more qualitative relative to aspects of the HCSM developed using data collected after 2005 because the historical data are typically limited (especially with respect to spatial coverage) and data quality is often not well documented.

Since 2005, numerous investigations and monitoring activities have been conducted by ARC with EPA and stakeholder involvement, and the sampling methods and quality of the laboratory analytical results since 2005 have been well documented. A draft Quality Assurance Project Plan (QAPP) that included standard operating procedures (SOPs) for sampling and field data collection methods was prepared in 2003 to establish and implement strict QA/QC procedures and, subsequently, was periodically revised to result in the current *Quality Assurance Project Plan - Revision 5* (Environmental Standards, Inc. [ESI] and BC 2009). Other QA planning documents that were prepared pursuant to the 2007 Order included the: 1) *Data Management Plan for the Yerington Mine Site* (BC 2007a); 2) GMP (BC 2012a); and 3) EPA-approved work plans specific to OU-1.

3.1 Pre-2005 Investigations

Investigations and reports relevant to the OU-1 Study Area that were conducted prior to 2005 are provided below, generally listed in chronological order:

- Gill, D.K., 1951. Groundwater at the Yerington Mine, Lyon County, Nevada, a consultant report prepared for The Anaconda Company that describes the results of aquifer testing, and provides projections of groundwater inflows and dewatering rates for the open pit.
- Huxel, C.J., Jr. and E.E. Harris, 1969. Water Resources and Development in Mason Valley, Lyon and Mineral Counties, Nevada, 1948-1965, NDWR Bulletin No. 38 prepared in cooperation with the USGS. This is a comprehensive hydrologic study of the Mason Valley area including water budgets and effects of agriculture on surface water and groundwater quality and quantity.
- Seitz, H., A.S. Van Denburgh, and R.J. La Camera, 1982. Ground Water Quality Downgradient from Copper Ore Milling Wastes at Weed Heights, Lyon County, Nevada, USGS Open File Report 80-1217. This study presents hydrologic and geochemical data on the effects of mining on groundwater quality from several monitor wells, most of which are no longer operational.
- Applied Hydrology Associates (AHA), 1983. Evaluation of Water Quality and Solids Leaching Data, a consultant report prepared for Anaconda Minerals Company. This report includes surface water and solids leaching data in addition to groundwater sampling data that are compared to the data reported by Seitz et al. (1982).
- Anaconda Minerals Company, 1984. Water Quality Investigation and Mitigation Plan, Yerington Mine Site, Yerington, Nevada, a report prepared for NDEP that summarized additional field data and groundwater conditions north of the Site.
- Proffett, J.M., Jr., and J.H. Dilles, 1984. Geologic Map of the Yerington District, Nevada, Nevada Bureau of Mines and Geology, Map 77.
- Nork, W., 1989. MacArthur Project Hydrogeologic Investigation, Lyon County, Nevada, a consultant report prepared for MacArthur Mining and Processing Co. that describes the general hydrogeologic conditions associated with a proposed project to develop an open pit mine located to the northwest of the Site.
- Dalton, D., 1998. *Arimetco Yerington Mine and Process Facility Site Assessment of Groundwater Quality*, a consultant report prepared for Arimetco for submittal to NDEP in response to NDEP's Finding of Alleged Violation and Order of February 1997.
- Lewis, B., 2000. *Geophysical Survey Results of the Yerington Mine, Mason Valley, Nevada*, a BLM report on electro-magnetic and resistivity surveys north of the Site.
- Superfund Technical Assessment and Response Team (START), 2000 and 2001. *Expanded Site Inspection: Yerington Mine* and *Anaconda, Yerington Mine Site Emergency Response Assessment Final Report,* reports prepared for the EPA that describe Site conditions including groundwater quality.

- Piedmont Engineering, Inc., 2001. *Yerington Shallow Aquifer Data Evaluation Report*, consultant prepared for ARC. Interpretations of data presented in this report related to the nature and extent of mine-impacted groundwater.
- AHA and Norwest Applied Hydrology, 2000 through 2007. *Annual Monitoring and Operation Summary: Pumpback Well System, Yerington Nevada*, annual consultant reports prepared for ARC. These reports provide groundwater elevation and water quality data for the pumpback system and associated monitor wells. The reports also include pumping rates and time-concentration plots for select chemicals.
- Brown and Caldwell, 2002. *Installation of Two Monitor Wells at the Yerington Mine Site, Lyon County, Nevada.* This letter report described the drilling and well construction activities of two monitor wells, which was an interim action required by NDEP, EPA, and BLM.

3.2 Post-2005 Investigations

A generalized chronology of the phased, groundwater-related field investigations conducted since 2005 is provided in Figure 3-1. The following subsections describe the post-2005 investigations and related evaluations by media. Groundwater characterization activities largely involved monitor well installation. Monitor wells installation procedures are described in Section 3.2.1. After installation, initial sampling and testing for OU-1 characterization purposes, these wells were subsequently incorporated into the Site-Wide Groundwater Monitoring Program, which is described in Section 3.2.3.

3.2.1 Monitor Well Installations

Recognizing that groundwater characterization activities would largely involve monitor well installation, ARC and EPA adopted the following sequential approach to field data collection to maximize usable data and optimize the design of a monitor well network intended to serve the data needs for both OU-1 RI characterization and long-term Site-Wide groundwater monitoring.

- Borehole drilling using a roto-sonic core drilling rig and lithologic logging of continuous cores to identify coarse-grained or potentially transmissive intervals where chemicals could potentially migrate.
- Depth-specific (zonal) groundwater sample collection in the alluvial aquifer at nominal 20-foot intervals from the top of the water table to the target depth of each borehole using low-flow, minimal drawdown purging and sampling procedures approved by EPA.

- Collection of field measurements from zonal samples including pH, specific conductivity, temperature, dissolved oxygen (DO), oxidation-reduction potential (ORP), sulfate, alkalinity, and total and ferrous iron, using routinely-calibrated field meters and accuracy-checked water quality field test kits.
- Laboratory analyses of zonal samples for total and dissolved uranium, total and dissolved arsenic, total organic carbon (TOC), and uranium isotopes (^{234}U, ^{235}U, and ^{238}U).
- Based on the zonal groundwater sample results, construction of new monitor wells in various groundwater zones using methods and materials specified in EPA-approved SOPs and work plans, with EPA approval of well screen lengths and positions.
- Surveying of well location coordinates and reference point elevations, followed by measurement of groundwater elevations in all new and existing monitor wells.
- Hydraulic (slug) testing of monitor wells and analysis of hydraulic test data.
- Deployment of pressure transducers and data loggers in select monitor wells with EPA approval to collect groundwater elevation data at four-hour intervals and assess temporal water level fluctuations.
- Collection of hydrologic tracers from monitor wells.
- Incorporation of the new monitor wells into the GMP (BC 2012a), discussed below in Section 3.2.3.

In total, the groundwater RI characterization activities described above resulted in drilling 133 boreholes, logging approximately 33,000 linear feet of core, collecting and analyzing 624 zonal groundwater samples, installing 299 new monitor wells, and hydraulic (slug) testing 296 wells. Appendix C provides monitor well information including: 1) borehole lithologic information and well construction diagrams; 2) well construction and location information for the active monitor wells; 3) construction information for abandoned and inactive wells not used for routine groundwater monitoring; and 4) zonal groundwater sample results.

The various investigations involving monitor well installations are integrated into the discussion of the Site-Wide groundwater monitoring program in the following section. Appendix D provides OU-1/Site-Wide groundwater monitoring information including water level and chemical data, water-level hydrographs, charts illustrating temporal changes in vertical gradients at monitor well clusters, and charts illustrating temporal changes in chemical concentrations at monitor wells.

3.2.2 Shallow Zone Groundwater Investigation

The 2009 Shallow zone investigation is detailed in the *Shallow Zone Data Summary Report - Revision 1* (BC 2010a; Appendix B) and summarized below. The Shallow zone investigation was designed to improve the understanding of hydrogeologic and geochemical conditions in the Shallow zone of the alluvial aquifer to the north of the Site by refining the distributions of sulfate, uranium, uranium isotopes, dissolved metals, TOC and alkalinity in Shallow zone groundwater. This information was used to evaluate potential sources of chemicals in groundwater in this portion of the Study Area and identify portions of the Intermediate or Deep zones in the alluvial aquifer that would warrant the installation of monitor wells.

Shallow zone characterization activities during 2009 included:

- Direct push technology (DPT) with Geoprobe® equipment was used to obtain continuous, high-resolution electrical conductivity (EC) measurements of subsurface materials at 93 locations. EC profiling was initially conducted at four locations (OU1-DPT-18, OU1-DPT-40, OU1-DPT-16, and OU1-DPT-24) where lithologic logging and zonal sampling had been previously conducted during borehole drilling and well installation at the B/W-2, B/W-3, B/W-18, and USGS-13S/W32DC-D well clusters, respectively, and one location (OU1-DPT-13) where geophysical logging had been conducted in 1983 (W5AB-2). This comparison was intended to help correlate EC data with clays and/or elevated solute concentrations in groundwater. In addition, EC data were also used to make decisions regarding the number and depths of sampling intervals at each individual DPT location.
- Field parameters were measured in groundwater samples collected from the sampled intervals within the Shallow zone including pH, specific conductivity, temperature, sulfate and total alkalinity (alkalinity) using routinely-calibrated field meters and accuracy-checked water quality field test kits.
- DPT equipment was used to collect groundwater samples at each location from as many as three intervals within the Shallow zone, and samples were submitted to the analytical laboratory for chemical analyses including total and dissolved uranium, TOC, 28 metals, uranium isotopes, and sulfur and oxygen isotopes in dissolved sulfate at EPA-selected locations.
- DPT locations were surveyed by a registered Nevada surveyor.
- Upon completion of EC profiling and/or groundwater sample collection, all boreholes were abandoned in compliance with Nevada regulatory requirements.

In 2010, DPT equipment and identical sample collection methods were used at 10 additional locations to obtain groundwater samples for laboratory analysis (BC 2013a). EC profiling was not conducted during the 2010 investigation. Both the 2009 and 2010 DPT locations are shown on Figure 3-2. Chemical distributions in the Shallow zone of the alluvial aquifer are shown on figures provided in Appendix B and are described as follows:

- The highest concentrations of major ions and metals (e.g., aluminum, copper, iron, manganese, nickel, vanadium and zinc) and uranium in the Shallow zone were typically detected beneath the central portion of the UEP, and the south-central and north-central portions of the LEP. Low pH values occur beneath the LEP and UEP. Alkalinity was depressed or non-detectable beneath the UEP. Elevated alkalinity (e.g., >500 mg/L) occurred down-gradient of the Weed Heights sewage lagoons.
- The high chemical concentrations beneath the evaporation ponds decrease laterally by varying orders of magnitude because of past and current physical and chemical attenuation processes. West of the LEP, concentrations of sulfate, other mobile chemicals, and metals decrease rapidly with distance from the Site. To the east beneath the agricultural fields, chemical concentrations are generally lower than other locations beneath or near the Site. Localized occurrences of elevated concentrations of select constituents in groundwater samples were observed from sample locations on the agricultural fields and included: alkalinity, manganese, molybdenum, nickel, potassium, selenium, sodium, uranium, vanadium, and zinc.

  The distribution of dissolved (i.e., filtered) uranium in the Shallow zone is generally consistent with the distribution of many other Site chemicals in that: 1) the highest concentrations occur beneath the central portion of the UEP, and the south-central and north-central portions of the LEP; 2) elevated concentrations extend beyond the Site boundary along a northwest alignment from the Evaporation Ponds; and 3) elevated chemical concentrations beneath the Evaporation Ponds decrease laterally by varying orders of magnitude. However, there are important differences that suggest that alkalinity and calcium influence the mobility/attenuation of uranium. Uranium concentrations rapidly decrease laterally to the west, similar to other chemicals, but do not decrease as rapidly to the east beneath the irrigated agricultural fields. Elevated concentrations of uranium in DPT locations including OU1-DPT-41, OU1-DPT-42, OU1-DPT-46, OU1-DPT-49, OU1-DPT-61, and OU1-DPT-72 are roughly coincident with: 1) the areas of locally high concentrations of alkalinity (over 300 mg/L) in Shallow zone groundwater at the northwest and northern edge of the agricultural fields; and 2) high calcium concentrations to the northwest of the agricultural fields and general widespread distribution of calcium throughout the agricultural fields.

- The distribution of arsenic in Shallow zone groundwater differs from the distributions of the parameters and chemicals described above. The highest concentrations of arsenic were detected in Shallow zone groundwater at OU1-DPT-23 (up to 620 ug/L), OU1-DPT-28 (up to 580 ug/L), and other nearby locations, which are located approximately 3,000 to 3,500 feet north of the Evaporation Ponds. Beneath the Evaporation Ponds, arsenic concentrations were much lower and typically ranged from approximately 10 to 160 ug/L. In this area, the lowest arsenic concentrations in Shallow zone groundwater occur along a northwest trend from the Weed Heights sewage lagoons. To the west of the LEP, arsenic occurs in Shallow groundwater at concentrations at or slightly above 50 ug/L.

3.2.3 Site-Wide Groundwater Monitoring Program

Groundwater monitoring in the Study Area has evolved over time in response to regulatory requirements and incorporation of new wells installed during the OU-1 RI. Currently, long-term Site-Wide groundwater monitoring is conducted in accordance with the GMP (BC 2012a) and EPA-approved modifications listed in Table 3-1. Provided below is a summary of the: 1) development of the monitoring program; 2) current active monitor well network; 3) water level monitoring activities; and 4) groundwater quality monitoring activities.

Monitoring Program Development

Table 3-1 provides a chronological summary of groundwater characterization and monitoring activities at the Site and the evolution of the monitor well network over time.

Table 3-1. Chronology of Groundwater Characterization and Monitoring Activities

Date	Activity
1976-1982	The USGS conducted groundwater investigations north of the Site boundary, which culminated in a report entitled: *Ground-water quality down-gradient from copper-ore milling wastes at Weed Heights, Lyon County, Nevada* (Seitz et al. 1982).
1982-1985	1982 – An NDEP Order required groundwater investigations near the Sulfide Tailings and Evaporation Ponds, and initial groundwater monitoring. 1985 – An NDEP Order required construction of the PWS and performance of associated O&M and groundwater monitoring activities.
1997	An NDEP Order was issued that required Arimetco to conduct groundwater investigations and monitoring of the Site, requesting both a complete hydrogeological assessment for the Yerington Mine (including existing and projected Pit Lake conditions), and a facility assessment to identify all areas where constituent concentrations in groundwater exceed the drinking water standards or background.
1999	Implementation of a Geoprobe® investigation of Shallow zone alluvial aquifer conditions north of the Site, which consisted of collecting 29 samples from 18 locations (AHA 2000).
2002	Two groundwater monitor wells, MW-2002-1 (subsequently re-named B/W-2S) and MW-2002-2, were installed (BC 2002) under an interim action directed by NDEP.
2004	Several groundwater characterization boreholes were drilled to collect groundwater grab samples, and three groundwater monitor wells were installed in the Process Areas, pursuant to the *Final Draft Process*

Table 3-1. Chronology of Groundwater Characterization and Monitoring Activities

Date	Activity
	Areas Work Plan (BC 2003).
2005	Implementation of the *First-Step Hydrogeologic Framework Assessment* (HFA; BC 2005) under the Unilateral Administrative Order (UAO) issued by EPA for Initial Response Activities, EPA Docket No. 9-2005-0011, including the installation of the first phase of B/W wells.
2007-2008	Implementation of the Second-Step HFA (BC 2007b) included a second phase of well installations, and the preparation of OU-specific work plans that describe additional on-Site monitor well installations under the 2007 Order. ARC submitted the *Draft Site-Wide Groundwater Monitoring Plan* (BC 2007c).
2008	Monitor well identification numbers modified to include a suffix designating the groundwater zone in which the well screen is positioned, including the Shallow, Intermediate, Deep and bedrock zones.
2008	EPA approved the elimination of well MW-1S from the monitoring network due to an obstruction well.
2008	Collection of groundwater grab samples and groundwater levels beneath the Anaconda Evaporation Ponds pursuant to the *Anaconda Evaporation Ponds Removal Action Characterization Work Plan* (BC 2008a).
2009	-Shutdown of the pumpback wells on March 25, 2009 with EPA approval. -Implementation of activities pursuant to the *Pumpback Well System Characterization Work Plan* (ARC 2008) including: 1) installation of nine groundwater monitor wells north of the PWS and the LEP; and 2) pumpback well aquifer testing pursuant to the *PWS Characterization Work Plan Addendum - Revision 2* (ARC 2010), which was performed in 2010. - Implementation of activities pursuant to the *Shallow Alluvial Aquifer Characterization Work Plan for Northern Portion of the Yerington Mine Site* (BC 2008b). -EPA approved the QAPP - Revision 5 dated May 20, 2009 (ESI and BC 2009), which contains SOPs for groundwater monitoring. -Implementation of a separate Domestic Well Monitoring Plan (BC 2010b) as a revision to the QAPP per EPA direction. The Domestic Well Monitoring Plan and related Bottled Water Program are discussed further in Section 3.4. -ARC submitted the *Site-Wide Groundwater Monitoring Plan - Revision 1* (BC 2009a).
2010-2011	Installation of 123 wells per the *2010 Groundwater Monitoring Well Work Plan - Revision 2* (BC 2010c) and the *Agricultural Fields Characterization Work Plan - Revision 2* (BC 2010d).
2011	-Installation of 58 wells per the the *On-Site Monitor Well Installation Work Plan - Revision 1* (BC 2011a). -Aquifer testing of an agricultural well (WDW019) north of the Site, including a 96-well observation network, pursuant to the *Aquifer Test Work Plan - Revision 1* (BC 2011b).
2012	Submittal of the *Site-Wide Groundwater Monitoring Plan - Revision 2* (BC 2012a). Addition of new well YPT-MW-15I to the monitoring program in November 2012.
2013	-Installation of 58 monitor wells per the *Additional Monitor Well Work Plan - Revision 1* (BC 2013b). -Addition of five EPA Arimetco wells, nine YPT wells, and the one MacArthur mine well (MMW-2) to the monitoring program after the 4Q 2011 event. -EPA (2013a) approved of eliminating well USEPA2S from the active monitor well network. EPA (2013b) approves of abandoning well USEPA2S and eliminating the following five metals from the analyte list for wells having at least four quarters of data: lead, silver, thallium, tin, and titanium. EPA (2013b) also approved of reducing the sampling frequency of 118 wells from quarterly to semi-annually, with sampling to be conducted in the first and third quarters of subsequent years.
2014	-EPA (2013c) approved the abandonment of well B/W-14S and the well was abandoned in January 2014. -Well USEPA2S was abandoned in April 2014 and was moved from the inactive to abandoned well list. -ARC submitted the *Technical Memorandum: Site-Wide Groundwater Monitoring Optimization* (ARC 2014) proposing several modifications to the GMP (BC 2012a). -EPA approved of reducing the frequency of manual water level monitoring in wells installed before 2013 from monthly to quarterly, to coincide with the quarterly sampling events (EPA 2014a). EPA also approved reducing the frequency of collecting groundwater samples from wells installed before 2013 for nitrate analysis from quarterly to semi-annually, with sampling to be conducted in the first and third quarters of subsequent years (EPA 2014a).
2015	Installation of six additional monitor wells (B/W-63 cluster) in the third quarter of 2015 (3Q 2015), pursuant to the *Additional Monitor Well Work Plan - Revision 1* (BC 2013b). Initial water level monitoring and sampling of these six wells in 4Q 2015.

The network development detailed in Table 3-1 included the addition and elimination of monitor locations as summarized in Table 3-2.

Table 3-2. Inventory of Monitor Well and Piezometer Locations (2007 - 2015)

Date (Through)	Total (1)	Monitor Wells and/or Piezometers	Pumpback Wells
2007	87	76	11
2008	101	90	11
1Q 2009	110	99	11
2Q 2009	114(2)	103(2)	11
3Q 2009	114(2)	103(2)	11
4Q 2009	114(2)	103(2)	11
1Q 2010	114(2)	103(2)	11
2Q 2010	114(2)	103(2)	11
3Q 2010	114(2)	103(2)	11
4Q 2010	114(2)	103(2)	11
1Q 2011	237(3)	226(3)	11
2Q 2011	237(3)	226(3)	11
3Q 2011	237(3)	226(3)	11
4Q 2011	242(4)	231(4)	11
1Q 2012	309(5)	298(5)	11
2Q 2012	309(5)	298(5)	11
3Q 2012	309(5)	298(5)	11
4Q 2012	310(6)	299(6)	11
1Q 2013	309(7)	298(7)	11
2Q 2013	309(7)	298(7)	11
3Q 2013	309(7)	298(7)	11
4Q 2013	309(7)	298(7)	11
1Q 2014	308(8)	297(8)	11
2Q 2014	325(9)	314(9)	11
3Q 2014	354(10)	343(10)	11
4Q 2014	354(10)	343(10)	11
1Q 2015	354(10)	343(10)	11
2Q 2015	354(10)	343(10)	11
3Q 2015	360(11)	349(11)	11
4Q 2015	360(11)	349(11)	11

Notes:

1) Total does not include domestic/supply wells that were part of the network until 2010. Total does include the eleven pumpback wells.
2) Includes four Lyon County wells.
3) Includes four Lyon County wells and 123 wells installed in 2010/2011.
4) Includes four Lyon County wells, 123 wells installed in 2010/2011, and five EPA Arimetco wells (sampled in 3Q 2011 and added to the monitoring program after the 4Q 2011 event).

5) Includes four Lyon County wells, 123 wells installed in 2010/2011, 58 wells installed in 2011/2012, five EPA Arimetco wells, eight YPT wells (excluding YPT-MW-7), and one MacArthur mine well (MMW-2). Prior to 1Q 2012, these wells were or may have been sampled; however, sample collection methods were either inconsistent with EPA-approved sample collection methods or were not documented.
6) Includes four Lyon County wells, 123 wells installed in 2010/2011, 58 wells installed in 2011/2012, five EPA Arimetco wells, nine YPT wells (including new well YPT-MW-15I in November 2012), and one MacArthur mine well (MMW-2).
7) With EPA approval, well USEPA2S moved to inactive well list in March 2013, subsequently proposed for abandonment in August 2013, and abandoned in April 2014.
8) With EPA approval, well B/W-14S was abandoned in January 2014.
9) Includes 17 wells installed in 2013/2014 and first sampled in 2Q 2014.
10) Includes 29 wells installed in 2013/2014 and first sampled in 3Q 2014.
11) Includes six wells (B/W-63 cluster) installed in 3Q 2015 and first sampled in 4Q 2015.

Active Monitor Well Network

The active monitor well network included 360 wells at 170 locations: 133 wells in the Shallow zone, including 11 PWS wells formerly used for groundwater extraction (currently in shutdown mode); 55 wells in the Intermediate zone; 105 wells in the Deep zone; and 67 bedrock wells (Table 3-3 and Figure 3-3). Of the 360 monitor wells, seven are used only for water level measurements, and the remaining 353 are monitored for both water levels and water quality.

A generalized cross-section that depicts alluvial monitor well screen intervals and groundwater zone designations for active wells within the monitoring network is presented in Figure 3-4. A generalized cross-section that depicts bedrock monitor well screen intervals is presented in Figure 3-5. All monitor wells in the network were surveyed by a Nevada-registered surveyor. Project datum is Nevada State Plane West Zone coordinate system (NAD27).

Table 3-3. Well Construction Details for the Active Groundwater Monitoring Network

Well Name (1)	Completion Date	Groundwater Zone	Well Type	Well Screen Interval
				feet amsl
Pumpback Wells				
PW-1S	10/1/85	Shallow	Sampling	4335.02 - 4312.52
PW-2S	10/1/85	Shallow	Sampling	4335.73 - 4315.23
PW-3S	10/1/85	Shallow	Sampling	4333.88 - 4313.38
PW-4S	10/1/85	Shallow	Sampling	4331.48 - 4311.98
PW-5S	10/1/85	Shallow	Sampling	4334.23 - 4313.73
PW-6S	10/21/98	Shallow	Sampling	4340.11 - 4323.11
PW-7S	10/22/98	Shallow	Sampling	4339.32 - 4319.82
PW-8S	10/22/98	Shallow	Sampling	4336.63 - 4316.63
PW-9S	10/23/98	Shallow	Sampling	4337.38 - 4317.38
PW-10S	10/23/98	Shallow	Sampling	4338.46 - 4318.46
PW-11S	10/24/98	Shallow	Sampling	4339.68 - 4319.68

Table 3-3. Well Construction Details for the Active Groundwater Monitoring Network

Well Name [(1)]	Completion Date	Groundwater Zone	Well Type	Well Screen Interval feet amsl
Shallow Zone Monitor Wells				
B-2S	5/18/89	Shallow	Water Level	NR - NR
B-3S	5/18/89	Shallow	Water Level	NR - NR
B/W-1S	1/23/08	Shallow	Sampling	4334.71 - 4314.71
B/W-2S	6/13/02	Shallow	Sampling	4330.95 - 4320.95
B/W-3S	9/26/07	Shallow	Sampling	4332.50 - 4312.50
B/W-4S	1/21/08	Shallow	Sampling	4316.74 - 4296.74
B/W-5RS	11/16/07	Shallow	Sampling	4326.12 - 4306.12
B/W-6S	1/30/08	Shallow	Sampling	4326.78 - 4306.78
B/W-8S	10/9/07	Shallow	Sampling	4325.95 - 4305.95
B/W-9S	11/7/07	Shallow	Sampling	4331.77 - 4311.77
B/W-10S	1/23/08	Shallow	Sampling	4321.56 - 4301.56
B/W-11S	11/4/07	Shallow	Sampling	4330.42 - 4310.42
B/W-13S	7/13/05	Shallow	Sampling	4364.14 - 4344.14
B/W-15S	7/22/05	Shallow	Sampling	4348.48 - 4328.48
B/W-16S	10/7/07	Shallow	Sampling	4328.68 - 4308.68
B/W-18S	2/19/08	Shallow	Sampling	4333.87 - 4308.87
B/W-19S	1/9/08	Shallow	Sampling	4331.43 - 4311.43
B/W-20S	7/13/07	Shallow	Sampling	4377.44 - 4357.44
B/W-21S	7/24/07	Shallow	Sampling	4338.99 - 4318.99
B/W-22S	7/18/07	Shallow	Sampling	4309.55 - 4289.55
B/W-25S	1/31/08	Shallow	Sampling	4322.63 - 4302.63
B/W-27S	2/7/08	Shallow	Sampling	4338.98 - 4318.98
B/W-28S	1/15/08	Shallow	Sampling	4331.67 - 4311.67
B/W-29S	1/6/08	Shallow	Sampling	4314.97 - 4294.97
B/W-30S	10/25/10	Shallow	Sampling	4325.10 - 4305.10
B/W-31S1	12/8/10	Shallow	Sampling	4330.77 - 4315.77
B/W-31S2	12/8/10	Shallow	Sampling	4304.95 - 4294.95
B/W-32S	1/11/11	Shallow	Sampling	4328.60 - 4308.60
B/W-33S	8/4/10	Shallow	Sampling	4328.23 - 4308.23
B/W-34S	12/5/10	Shallow	Sampling	4337.68 - 4317.68
B/W-36S	8/11/10	Shallow	Sampling	4329.76 - 4319.76
B/W-37S	6/6/10	Shallow	Sampling	4331.62 - 4311.62
B/W-38RS	10/11/10	Shallow	Sampling	4320.17 - 4300.17
B/W-40S	1/10/11	Shallow	Sampling	4318.41 - 4298.41
B/W-41S	2/8/11	Shallow	Sampling	4324.54 - 4304.54
B/W-42S	11/9/10	Shallow	Sampling	4326.05 - 4306.05
B/W-43S	12/17/10	Shallow	Sampling	4323.75 - 4303.75
B/W-44S	9/24/10	Shallow	Sampling	4324.88 - 4304.88

Table 3-3. Well Construction Details for the Active Groundwater Monitoring Network

Well Name (1)	Completion Date	Groundwater Zone	Well Type	Well Screen Interval feet amsl
B/W-45S	1/17/11	Shallow	Sampling	4331.84 - 4311.84
B/W-46S	11/8/10	Shallow	Sampling	4327.09 - 4307.09
B/W-50S (2)	2/11/14	Shallow	Sampling	4337.83 - 4317.83
B/W-51S	8/25/10	Shallow	Sampling	4303.87 - 4293.87
B/W-52S	8/18/10	Shallow	Sampling	4329.90 - 4309.90
B/W-53S1	1/20/11	Shallow	Sampling	4310.26 - 4290.26
B/W-53S2	1/19/11	Shallow	Sampling	4265.87 - 4255.87
B/W-54S	8/20/10	Shallow	Sampling	4298.38 - 4288.38
B/W-55S	10/20/10	Shallow	Sampling	4327.27 - 4307.27
B/W-56S	3/13/12	Shallow	Sampling	4334.12 - 4314.12
B/W-57S	3/15/12	Shallow	Sampling	4325.36 - 4305.36
B/W-58S	3/14/12	Shallow	Sampling	4294.04 - 4284.04
B/W-59S (2)	11/20/13	Shallow	Sampling	4338.55 - 4318.55
B/W-60S	1/8/11	Shallow	Sampling	4342.73 - 4322.73
B/W-61S	8/27/10	Shallow	Sampling	4342.05 - 4322.05
B/W-62S	11/22/10	Shallow	Sampling	4333.94 - 4313.94
B/W-63S (3)	8/9/15	Shallow	Sampling	4325.73 - 4305.73
B/W-64S	12/6/10	Shallow	Sampling	4348.03 - 4328.03
B/W-65S	9/29/10	Shallow	Sampling	4325.29 - 4305.29
B/W-66S	12/5/10	Shallow	Sampling	4313.88 - 4293.88
B/W-67S	1/23/11	Shallow	Sampling	4329.26 - 4309.26
B/W-68S (2)	4/30/14	Shallow	Sampling	4325.57 - 4305.57
B/W-69S (2)	4/15/14	Shallow	Sampling	4319.18 - 4299.18
B/W-70S	10/20/11	Shallow	Sampling	4338.80 - 4318.80
B/W-71S	10/12/11	Shallow	Sampling	4342.25 - 4322.25
B/W-73S	9/10/11	Shallow	Sampling	4357.74 - 4337.74
B/W-74S	10/26/11	Shallow	Sampling	4342.98 - 4322.98
B/W-75S	12/20/11	Shallow	Sampling	4346.69 - 4326.69
B/W-76S	12/15/11	Shallow	Sampling	4335.33 - 4315.33
B/W-77S (2)	4/24/14	Shallow	Sampling	4320.30 - 4300.30
B/W-78S (2)	4/23/14	Shallow	Sampling	4329.30 - 4309.30
B/W-79S (2)	4/25/14	Shallow	Sampling	4335.29 - 4315.29
B/W-81S (2)	3/10/14	Shallow	Sampling	4308.10 - 4288.10
B/W-82RS (2)	11/3/13	Shallow	Sampling	4310.40 - 4290.40
B/W-83S (2)	2/5/14	Shallow	Sampling	4326.66 - 4306.66
D4BC-1S	10/1/85	Shallow	Sampling	4333.98 - 4313.98
D5AC-1S	5/6/84	Shallow	Sampling	4332.48 - 4327.48
FMS-05S (4)	10/20/13	Shallow	Sampling	4335.34 - 4315.34
FMS-06S (4)	11/6/13	Shallow	Sampling	4336.55 - 4316.55

Table 3-3. Well Construction Details for the Active Groundwater Monitoring Network

Well Name (1)	Completion Date	Groundwater Zone	Well Type	Well Screen Interval
				feet amsl
FMS-07S (4)	11/14/13	Shallow	Sampling	4337.75 - 4317.75
HLP-03S (4)	11/16/13	Shallow	Sampling	4341.79 - 4321.79
HLP-04S (4)	10/8/13	Shallow	Sampling	4340.55 - 4320.55
HLP-08S (4)	10/21/13	Shallow	Sampling	4331.83 - 4311.83
LC-MW-1S (5)	1/18/06	Shallow	Sampling	NR - 4303.80(6)
LC-MW-2S (5)	1/18/06	Shallow	Sampling	NR - 4313.90(6)
LC-MW-3S (5)	1/18/06	Shallow	Sampling	NR - 4323.70(6)
LC-MW-5S (5)	NR	Shallow	Sampling	NR - 4323.10(6)
LEP-MW-1S	2/26/09	Shallow	Sampling	4330.92 - 4320.92
LEP-MW-2S	2/27/09	Shallow	Sampling	4331.46 - 4321.46
LEP-MW-3S	2/28/09	Shallow	Sampling	4333.75 - 4323.75
LEP-MW-5S	3/2/09	Shallow	Sampling	4336.35 - 4326.35
LEP-MW-6S	3/2/09	Shallow	Sampling	4327.51 - 4317.51
LEP-MW-7S	3/3/09	Shallow	Sampling	4342.81 - 4332.81
MW2002-2S	6/14/02	Shallow	Sampling	4323.78 - 4313.78
MW-2S	12/13/92	Shallow	Sampling	4326.61 - 4311.61
MW-4S	12/10/92	Shallow	Sampling	4325.68 - 4310.68
MW-5S	10/20/95	Shallow	Sampling	4330.79 - 4315.79
MW-SXN	7/26/09	Shallow	Sampling	4355.39 - 4335.39
MW-SXS	8/28/09	Shallow	Sampling	4354.32 - 4334.32
PA-MW-1S	1/20/05	Shallow	Sampling	4347.32 - 4327.32
PA-MW-2S	1/21/05	Shallow	Sampling	4347.37 - 4327.37
PA-MW-3S1	1/19/05	Shallow	Sampling	4348.13 - 4328.13
PA-MW-3S2	11/19/11	Shallow	Sampling	4309.85 - 4299.85
PA-MW-4S	10/18/11	Shallow	Sampling	4348.09 - 4328.09
PA-MW-5S1	11/17/11	Shallow	Sampling	4344.01 - 4324.01
PA-MW-5S2	11/14/11	Shallow	Sampling	4311.16 - 4301.16
PA-MW-7S	10/25/11	Shallow	Sampling	4317.46 - 4297.46
PLMW-2S	8/3/11	Shallow	Sampling	4369.05 - 4349.05
PLMW-4S	10/31/11	Shallow	Sampling	4319.72 - 4289.72
PW10-P1	9/27/05	Shallow	Water Level	4339.10 - 4319.10
USGS-13S	6/10/76	Shallow	Sampling	4342.06 - 4332.06
USGS-2BS	6/8/76	Shallow	Sampling	4326.34 - 4324.44
UW-1S	10/1/85	Shallow	Sampling	4333.32 - 4313.32
W5AA-2S	10/26/83	Shallow	Water Level	4333.65 - 4313.65
W5AA-3S	10/24/98	Shallow	Sampling	4342.86 - 4332.86
W5AB-2S	10/1/83	Shallow	Sampling	4337.68 - 4322.68
W5AD-1S	5/2/82	Shallow	Water Level	4330.91 - 4325.91
W5BB-S	10/23/83	Shallow	Sampling	4337.12 - 4307.12

Table 3-3. Well Construction Details for the Active Groundwater Monitoring Network

Well Name (1)	Completion Date	Groundwater Zone	Well Type	Well Screen Interval feet amsl
W5DB-S	10/9/10	Shallow	Sampling	4345.06 - 4325.06
WRP-1S	6/19/07	Shallow	Water Level	4382.53 - 4372.53
WRP-2S	6/19/07	Shallow	Water Level	4382.29 - 4372.29
YPT-MW-6S	1/11/02	Shallow	Sampling	4320.21 - 4315.21
YPT-MW-8S	1/9/02	Shallow	Sampling	4322.26 - 4317.26
YPT-MW-11S	1/11/02	Shallow	Sampling	4317.43 - 4312.43
Intermediate Zone Monitor Wells				
B/W-2I	10/17/07	Intermediate	Sampling	4279.78 - 4259.78
B/W-3I	9/27/07	Intermediate	Sampling	4266.40 - 4246.40
B/W-4I	1/21/08	Intermediate	Sampling	4276.50 - 4256.50
B/W-5RI	11/16/07	Intermediate	Sampling	4278.65 - 4258.65
B/W-6I	9/26/05	Intermediate	Sampling	4259.84 - 4249.84
B/W-7I	8/14/05	Intermediate	Sampling	4304.69 - 4284.69
B/W-8I	8/21/05	Intermediate	Sampling	4284.16 - 4264.16
B/W-9I	11/7/07	Intermediate	Sampling	4281.19 - 4261.19
B/W-19I	1/11/08	Intermediate	Sampling	4281.40 - 4261.40
B/W-27I	8/17/10	Intermediate	Sampling	4274.77 - 4254.77
B/W-28I	1/17/08	Intermediate	Sampling	4277.23 - 4257.23
B/W-29I	12/19/07	Intermediate	Sampling	4288.07 - 4278.07
B/W-30I	10/25/10	Intermediate	Sampling	4267.63 - 4247.63
B/W-31I	12/7/10	Intermediate	Sampling	4287.82 - 4246.82
B/W-32I	1/10/11	Intermediate	Sampling	4286.67 - 4266.67
B/W-33I	8/3/10	Intermediate	Sampling	4265.02 - 4255.02
B/W-34I	12/5/10	Intermediate	Sampling	4303.85 - 4283.85
B/W-37I	8/10/10	Intermediate	Sampling	4296.85 - 4276.85
B/W-38RI	10/9/10	Intermediate	Sampling	4287.91 - 4267.91
B/W-41I	2/7/11	Intermediate	Sampling	4278.31 - 4268.31
B/W-42I	11/8/10	Intermediate	Sampling	4266.21 - 4246.21
B/W-46I	11/7/10	Intermediate	Sampling	4276.66 - 4256.66
B/W-51I	9/9/10	Intermediate	Sampling	4264.06 - 4244.06
B/W-52I	8/20/10	Intermediate	Sampling	4296.06 - 4276.06
B/W-54I	8/21/10	Intermediate	Sampling	4277.24 - 4267.24
B/W-57I	3/14/12	Intermediate	Sampling	4270.47 - 4250.47
B/W-63I (3)	8/9/15	Intermediate	Sampling	4285.58 - 4265.58
B/W-65I	9/29/10	Intermediate	Sampling	4285.30 - 4265.30
B/W-66I	12/5/10	Intermediate	Sampling	4268.85 - 4248.85
B/W-67I	1/22/11	Intermediate	Sampling	4289.41 - 4269.41
B/W-70I	10/22/11	Intermediate	Sampling	4288.59 - 4268.59
B/W-71I	10/11/11	Intermediate	Sampling	4281.11 - 4261.11

Table 3-3. Well Construction Details for the Active Groundwater Monitoring Network

Well Name (1)	Completion Date	Groundwater Zone	Well Type	Well Screen Interval
				feet amsl
B/W-74I1	10/20/11	Intermediate	Sampling	4307.69 - 4297.69
B/W-74I2	10/21/11	Intermediate	Sampling	4277.50 - 4257.50
B/W-76I	12/13/11	Intermediate	Sampling	4276.82 - 4256.82
B/W-82RI (2)	11/2/13	Intermediate	Sampling	4280.35 - 4270.35
HLP-03I (4)	11/5/13	Intermediate	Sampling	4300.00 - 4280.00
HLP-08I (4)	10/20/13	Intermediate	Sampling	4296.56 - 4276.56
LEP-MW-4I	3/1/09	Intermediate	Sampling	4266.95 - 4256.95
LEP-MW-8I	3/4/09	Intermediate	Sampling	4271.83 - 4261.83
LEP-MW-9I	3/6/09	Intermediate	Sampling	4258.17 - 4248.17
MW-4I	8/30/10	Intermediate	Sampling	4285.18 - 4265.18
MW-5I	1/23/11	Intermediate	Sampling	4269.38 - 4249.38
PA-MW-2I	9/8/11	Intermediate	Sampling	4296.59 - 4276.59
PA-MW-3I	11/18/11	Intermediate	Sampling	4281.86 - 4271.86
PA-MW-4I	10/17/11	Intermediate	Sampling	4273.89 - 4253.89
W4CB-1I	10/27/83	Intermediate	Sampling	4280.31 - 4265.31
W4CB-2I	10/28/83	Intermediate	Sampling	4307.74 - 4295.74
W5AA-1I	10/26/83	Intermediate	Sampling	4293.56 - 4278.56
W5AB-3I	9/19/97	Intermediate	Sampling	4308.70 - 4284.20
W5DB-I	10/10/10	Intermediate	Sampling	4287.77 - 4267.77
YPT-MW-9I	1/8/02	Intermediate	Sampling	4282.60 - 4272.60
YPT-MW-12I	1/10/02	Intermediate	Sampling	4280.36 - 4270.36
YPT-MW-13I	7/20/04	Intermediate	Sampling	4287.78 - 4262.78
YPT-MW-15I	10/5/12	Intermediate	Sampling	4275.21 - 4270.21
Deep Zone Monitor Wells				
B/W-1D1	11/5/07	Deep	Sampling	4229.76 - 4209.76
B/W-1D2	10/22/07	Deep	Sampling	4139.92 - 4119.92
B/W-1D3	11/5/05	Deep	Sampling	4028.63 - 4018.63
B/W-1D5	1/7/11	Deep	Sampling	3877.18 - 3867.18
B/W-2D1	9/10/05	Deep	Sampling	4224.01 - 4204.01
B/W-2D3	1/23/11	Deep	Sampling	4049.28 - 4029.28
B/W-2D4	1/21/11	Deep	Sampling	3938.99 - 3918.99
B/W-3D1	8/31/05	Deep	Sampling	4221.87 - 4201.87
B/W-4D1	8/26/05	Deep	Sampling	4228.07 - 4208.07
B/W-5RD1	11/16/07	Deep	Sampling	4241.21 - 4221.21
B/W-9D2	9/14/05	Deep	Sampling	4206.72 - 4186.72
B/W-10D1	8/5/05	Deep	Sampling	4241.10 - 4221.10
B/W-11D2	9/28/05	Deep	Sampling	4197.64 - 4177.64
B/W-18D1	2/19/08	Deep	Sampling	4232.79 - 4212.79
B/W-18D2	12/15/07	Deep	Sampling	4194.17 - 4174.17

Table 3-3. Well Construction Details for the Active Groundwater Monitoring Network

Well Name (1)	Completion Date	Groundwater Zone	Well Type	Well Screen Interval
				feet amsl
B/W-19D1	6/14/07	Deep	Sampling	4216.51 - 4196.51
B/W-25D1	2/1/08	Deep	Sampling	4249.71 - 4229.71
B/W-25D2	1/19/08	Deep	Sampling	4133.82 - 4113.82
B/W-27D2	2/6/08	Deep	Sampling	4124.99 - 4104.99
B/W-27D3	1/6/11	Deep	Sampling	4022.95 - 4002.95
B/W-27D4(2)	2/21/14	Deep	Sampling	3944.83 - 3924.83
B/W-27D5(2)	2/11/14	Deep	Sampling	3879.66 - 3859.66
B/W-28D1	6/28/07	Deep	Sampling	4221.83 - 4201.83
B/W-29D1	12/16/07	Deep	Sampling	4225.24 - 4215.24
B/W-29D3	9/25/07	Deep	Sampling	4050.12 - 4030.12
B/W-30D1	10/26/10	Deep	Sampling	4228.86 - 4208.86
B/W-31D2	11/7/10	Deep	Sampling	4199.84 - 4179.84
B/W-32D2	1/9/11	Deep	Sampling	4147.42 - 4127.42
B/W-32D5	10/24/10	Deep	Sampling	3886.73 - 3866.73
B/W-33D1	7/29/10	Deep	Sampling	4239.39 - 4229.39
B/W-34D1	12/4/10	Deep	Sampling	4257.96 - 4237.96
B/W-37D1	6/5/10	Deep	Sampling	4218.80 - 4198.80
B/W-38RD1	10/10/10	Deep	Sampling	4210.93 - 4190.93
B/W-40D1	1/20/11	Deep	Sampling	4222.20 - 4202.20
B/W-40D3	11/3/10	Deep	Sampling	4057.58 - 4037.58
B/W-41D2	2/7/11	Deep	Sampling	4198.22 - 4178.22
B/W-41D4	2/5/11	Deep	Sampling	4004.14 - 3984.14
B/W-42D1	10/25/10	Deep	Sampling	4210.91 - 4190.91
B/W-44D1	9/23/10	Deep	Sampling	4229.65 - 4209.65
B/W-44D2	9/22/10	Deep	Sampling	4152.72 - 4132.72
B/W-45D1	1/18/11	Deep	Sampling	4252.78 - 4232.78
B/W-45D2	11/20/10	Deep	Sampling	4209.84 - 4189.84
B/W-46D1	11/6/10	Deep	Sampling	4219.76 - 4199.76
B/W-50D1(2)	2/10/14	Deep	Sampling	4206.81 - 4186.81
B/W-50D2(2)	2/8/14	Deep	Sampling	4125.75 - 4105.75
B/W-50D3(2)	2/5/14	Deep	Sampling	4024.73 - 4014.73
B/W-52D2	8/17/10	Deep	Sampling	4177.59 - 4157.59
B/W-55D1	10/20/10	Deep	Sampling	4251.44 - 4241.44
B/W-55D2	10/13/10	Deep	Sampling	4171.59 - 4151.59
B/W-57D1	3/14/12	Deep	Sampling	4212.37 - 4192.37
B/W-57D4	3/13/12	Deep	Sampling	3940.67 - 3920.67
B/W-58D1	3/16/12	Deep	Sampling	4234.41 - 4214.41
B/W-58D3	3/25/12	Deep	Sampling	4054.51 - 4044.51
B/W-59D3(2)	11/19/13	Deep	Sampling	4126.65 - 4106.65

Table 3-3. Well Construction Details for the Active Groundwater Monitoring Network

Well Name (1)	Completion Date	Groundwater Zone	Well Type	Well Screen Interval
				feet amsl
B/W-60D1	12/17/10	Deep	Sampling	4247.69 - 4227.69
B/W-60D3	12/16/10	Deep	Sampling	4036.75 - 4016.75
B/W-60D5	12/7/10	Deep	Sampling	3881.82 - 3861.82
B/W-61D1	8/23/10	Deep	Sampling	4247.00 - 4227.00
B/W-61D3	8/29/10	Deep	Sampling	4036.94 - 4016.94
B/W-62D1	11/21/10	Deep	Sampling	4243.89 - 4223.89
B/W-62D2	11/20/10	Deep	Sampling	4173.88 - 4153.88
B/W-62D4	11/19/10	Deep	Sampling	3953.94 - 3933.94
B/W-62D5	1/6/11	Deep	Sampling	3833.92 - 3813.92
B/W-63D1(3)	8/8/15	Deep	Sampling	4240.50 - 4220.50
B/W-63D2(3)	8/7/15	Deep	Sampling	4170.83 - 4150.83
B/W-63D3(3)	8/5/15	Deep	Sampling	4015.78 - 3995.78
B/W-63D5(3)	7/29/15	Deep	Sampling	3900.65 - 3880.65
B/W-64D1	12/5/10	Deep	Sampling	4260.09 - 4240.09
B/W-64D2	12/3/10	Deep	Sampling	4175.77 - 4155.77
B/W-65D1	9/27/10	Deep	Sampling	4213.36 - 4193.36
B/W-65D5	9/23/10	Deep	Sampling	3750.51 - 3740.51
B/W-66D1	12/4/10	Deep	Sampling	4208.81 - 4188.81
B/W-66D5	12/2/10	Deep	Sampling	3761.03 - 3751.03
B/W-67D1	1/21/11	Deep	Sampling	4245.24 - 4225.24
B/W-67D3	1/13/11	Deep	Sampling	4125.04 - 4105.04
B/W-68D1(2)	4/29/14	Deep	Sampling	4240.74 - 4220.74
B/W-68D4(2)	4/28/14	Deep	Sampling	3964.32 - 3954.32
B/W-69D1(2)	4/14/14	Deep	Sampling	4259.33 - 4239.33
B/W-69D2(2)	4/13/14	Deep	Sampling	4194.30 - 4174.30
B/W-69D5(2)	4/9/14	Deep	Sampling	3782.33 - 3772.33
B/W-70D2	10/25/11	Deep	Sampling	4143.64 - 4123.64
B/W-71D1	10/5/11	Deep	Sampling	4222.09 - 4202.09
B/W-71D3	10/3/11	Deep	Sampling	4094.16 - 4074.16
B/W-74D1	11/20/11	Deep	Sampling	4247.72 - 4227.72
B/W-76D1	10/4/11	Deep	Sampling	4251.74 - 4231.74
B/W-81D1(2)	3/9/14	Deep	Sampling	4243.06 - 4223.06
B/W-81D2(2)	3/10/14	Deep	Sampling	4153.13 - 4133.13
B/W-83D1(2)	2/4/14	Deep	Sampling	4216.67 - 4196.67
B/W-83D3(2)	1/29/14	Deep	Sampling	4066.59 - 4046.59
HLP-08D1(4)	10/19/13	Deep	Sampling	4249.87 - 4229.87
HLP-08D2(4)	10/15/13	Deep	Sampling	4174.99 - 4154.99
LEP-MW-2D1	10/25/10	Deep	Sampling	4229.98 - 4209.98
LEP-MW-2D3	10/22/10	Deep	Sampling	4100.11 - 4080.11

Table 3-3. Well Construction Details for the Active Groundwater Monitoring Network

Well Name (1)	Completion Date	Groundwater Zone	Well Type	Well Screen Interval
				feet amsl
MW-5D2	1/12/11	Deep	Sampling	4194.22 - 4174.22
MW-5D3	1/18/11	Deep	Sampling	4119.72 - 4099.72
MW2002-2D1	7/12/07	Deep	Sampling	4249.75 - 4239.75
PA-MW-4D2	10/15/11	Deep	Sampling	4192.92 - 4172.92
W32DC-D1	10/25/83	Deep	Sampling	4240.41 - 4197.41
W4CB-2D1	9/15/10	Deep	Sampling	4240.56 - 4220.56
W4CB-2D3	9/14/10	Deep	Sampling	4065.76 - 4045.76
W4CB-2D4	11/8/10	Deep	Sampling	3965.54 - 3955.54
W5DB-D1	10/19/98	Deep	Sampling	4239.49 - 4211.49
W5DB-D3	11/17/10	Deep	Sampling	4091.93 - 4071.93
W5DB-D4	10/25/10	Deep	Sampling	4009.93 - 3989.93
YPT-MW-14D1	7/21/04	Deep	Sampling	4255.83 - 4235.83
Bedrock Monitor Wells				
B/W-1B	5/19/10	Bedrock	Sampling	3700.10 - 3690.10
B/W-2B	1/12/11	Bedrock	Sampling	3839.17 - 3819.17
B/W-6B	1/25/11	Bedrock	Sampling	4172.04 - 4152.04
B/W-11B	11/3/07	Bedrock	Sampling	4132.88 - 4122.88
B/W-12RB	12/6/11	Bedrock	Sampling	4382.05 - 4302.05
B/W-17B	10/30/11	Bedrock	Sampling	4385.06 - 4365.06
B/W-22B	5/8/10	Bedrock	Sampling	4261.26 - 4241.26
B/W-23B	8/8/07	Bedrock	Sampling	4340.26 - 4330.26
B/W-26RB	11/3/11	Bedrock	Sampling	4367.92 - 4347.92
B/W-27B (2)	11/12/13	Bedrock	Sampling	3800.16 - 3780.16
B/W-33B	7/26/10	Bedrock	Sampling	4167.48 - 4157.48
B/W-34B	12/1/10	Bedrock	Sampling	4203.76 - 4183.76
B/W-36B	6/17/10	Bedrock	Sampling	4271.60 - 4261.60
B/W-37B	5/27/10	Bedrock	Sampling	4166.84 - 4146.84
B/W-38RB	10/8/10	Bedrock	Sampling	4166.90 - 4146.90
B/W-39B	10/7/10	Bedrock	Sampling	4309.10 - 4299.10
B/W-44B	9/16/10	Bedrock	Sampling	4124.48 - 4104.48
B/W-51B	6/25/10	Bedrock	Sampling	4198.79 - 4188.79
B/W-53B	12/17/10	Bedrock	Sampling	4240.77 - 4220.77
B/W-54B	7/10/10	Bedrock	Sampling	4261.30 - 4251.30
B/W-58B	2/4/12	Bedrock	Sampling	4014.50 - 3994.50
B/W-61B	7/9/10	Bedrock	Sampling	3684.05 - 3664.05
B/W-62B	9/25/10	Bedrock	Sampling	3690.87 - 3670.87
B/W-64B	12/2/10	Bedrock	Sampling	4089.75 - 4069.75
B/W-70B	8/30/11	Bedrock	Sampling	4060.86 - 4040.86
B/W-71B	9/1/11	Bedrock	Sampling	3931.06 - 3911.06

Table 3-3. Well Construction Details for the Active Groundwater Monitoring Network

Well Name (1)	Completion Date	Groundwater Zone	Well Type	Well Screen Interval
				feet amsl
B/W-73B	9/7/11	Bedrock	Sampling	4307.60 - 4287.60
B/W-74B	9/21/11	Bedrock	Sampling	4207.18 - 4187.18
B/W-75B	1/7/12	Bedrock	Sampling	4266.82 - 4246.82
B/W-82RB (2)	11/1/13	Bedrock	Sampling	4235.38 - 4215.38
B/W-83B (2)	1/24/14	Bedrock	Sampling	3943.51 - 3913.51
HLP-01B (4)	9/20/13	Bedrock	Sampling	4333.97 - 4313.97
HLP-02B (4)	9/22/13	Bedrock	Sampling	4406.47 - 4386.27
HLP-03B (4)	10/18/13	Bedrock	Sampling	4236.98 - 4206.98
HLP-05B (4)	10/5/13	Bedrock	Sampling	4346.26 - 4306.26
HLP-06B (4)	10/1/13	Bedrock	Sampling	4338.55 - 4318.55
HLP-07B (4)	9/24/13	Bedrock	Sampling	4345.04 - 4325.04
HLP-08B (4)	10/8/14	Bedrock	Sampling	4117.44 - 4097.44
LEP-MW-2B	10/13/10	Bedrock	Sampling	4040.47 - 4020.47
MMW-2	12/6/92	Bedrock	Sampling	4246.34 - 4186.34
MW-4B	8/28/10	Bedrock	Sampling	4251.41 - 4231.41
MW-5B	1/7/11	Bedrock	Sampling	3984.29 - 3964.29
MW-H12	8/6/09	Bedrock	Sampling	4353.58 - 4323.58
MW-H4SN	8/11/09	Bedrock	Sampling	4371.56 - 4341.56
MW-H4SS	8/13/09	Bedrock	Sampling	4360.63 - 4330.63
PA-MW-1B	8/6/11	Bedrock	Sampling	4290.87 - 4270.87
PA-MW-2B	9/3/11	Bedrock	Sampling	4210.44 - 4190.44
PA-MW-3B	10/11/11	Bedrock	Sampling	4246.82 - 4226.82
PA-MW-4B	9/14/11	Bedrock	Sampling	4157.96 - 4137.96
PA-MW-5B	8/20/11	Bedrock	Sampling	4281.60 - 4261.60
PA-MW-7B	9/30/11	Bedrock	Sampling	4174.49 - 4154.49
PLMW-1B	9/29/11	Bedrock	Sampling	4218.23 - 4168.23
PLMW-2B	8/2/11	Bedrock	Sampling	4313.20 - 4293.20
PLMW-3RB	11/12/11	Bedrock	Sampling	4237.72 - 4197.72
PLMW-4B	10/20/11	Bedrock	Sampling	4094.72 - 4064.72
PLMW-5B	9/18/11	Bedrock	Sampling	4243.58 - 4203.58
W4CB-2B	7/9/10	Bedrock	Sampling	3844.55 - 3824.55
W5DB-B	9/26/10	Bedrock	Sampling	3781.04 - 3761.04
WRA3-1B	10/1/11	Bedrock	Sampling	4369.32 - 4339.32
WRA3-2B	10/19/11	Bedrock	Sampling	4322.60 - 4302.60
WRA3-3B	12/5/11	Bedrock	Sampling	4330.39 - 4310.39
WW-1B	NR	Bedrock	Sampling	4364.42 - 4344.42
WW-2B	NR	Bedrock	Sampling	4342.48 - 4322.48
WW-36B	4/15/69	Bedrock	Sampling	4305.78 - 4105.78
WW-40B	NR	Bedrock	Sampling	NR - NR

Table 3-3. Well Construction Details for the Active Groundwater Monitoring Network

Well Name (1)	Completion Date	Groundwater Zone	Well Type	Well Screen Interval feet amsl
WW-59B	11/20/72	Bedrock	Sampling	4280.04 - 3888.04
YPT-MW-10B	1/7/02	Bedrock	Sampling	4107.46 - 4097.46

Notes:

1) The names of 117 wells for which the sampling frequency has been reduced from quarterly to semi-annually are bold and italicized. Well names for older wells reflect revisions based on their alluvial aquifer zone designations.
2) New well added to the monitor well network and first sampled in 3Q 2014.
3) New well added to the monitor well network and first sampled in 4Q 2015.
4) New well added to the monitor well network and first sampled in 4Q 2014.
5) Lyon County well.
6) The bottom of screen elevations for the Lyon County wells are based on a 2009 survey conducted for ARC and the total depth of each well measured in the field by BC. The measured well depths are not consistent with the information on the well logs provided by Lyon County (see Appendix C-1 for the well logs).
7) NR = not recorded on well construction logs. amsl = above mean sea level

Water Level Monitoring

Routine water level monitoring was initiated in 2006, to evaluate seasonal and temporal changes in groundwater flow directions and hydraulic gradients, and aquifer responses to irrigation practices. Water level elevation monitoring was historically conducted monthly, and subsequently reduced to quarterly in 2014 for wells installed before 2013, in accordance with the *Technical Memorandum: Site-Wide Groundwater Monitoring Optimization* (ARC 2014).

As outlined in the GMP (BC 2012a), water levels are measured within a three-day (or shorter) period, for representative aquifer conditions throughout the monitoring network. Water level elevations are also measured electronically using pressure transducers/data loggers, at four-hour intervals at select monitor wells, and at one-hour intervals at the Pit Lake. Water level data from transducers are typically downloaded in conjunction with monthly water level measurements. Appendix D provides groundwater level data, hydrographs, and vertical gradient information.

Groundwater Quality Monitoring

Monitor wells comprising the active monitoring network are sampled on a quarterly or semi-annual frequency pursuant to the GMP (BC 2012a) using EPA-approved low-flow, minimal drawdown purging and sampling procedures, where applicable. Groundwater samples are analyzed for the constituents listed in Table 3-4 pursuant to the data requirements presented in the QAPP (ESI and BC 2009).

Table 3-4. Analyte List for Active Monitor Well and Surface Water Sampling

Parameter or Analyte	Total/ Dissolved (1)	Method (2)	Reporting Limit (2)	Units
Physical Parameters and Major Anions/Cations				
Alkalinity, Bicarbonate (as $CaCO_3$)	Total	SM 2320B	2.0	mg/L
Alkalinity, Carbonate (as $CaCO_3$)	Total	SM 2320B	2.0	mg/L
Alkalinity, Total (as $CaCO_3$)	Total	SM 2320B	2.0	mg/L
Chloride	Total	EPA 300.0	0.5	mg/L
Fluoride	Total	EPA 300.0	0.5	mg/L
Nitrate, as N	Total	EPA 300.0	0.1	mg/L
Nitrate (NO_3 + NO_2 as N)	Total	EPA 300.0	0.1	mg/L
Nitrite, as N	Total	EPA 300.0	0.1	mg/L
Sulfate	Total	EPA 300.0	0.5	mg/L
pH (Lab)	Total	SM 4500B	0.1	sun.
Total Dissolved Solids (TDS) (3)	Total (Lab Filtered) (3)	SM 2540C	10	mg/L
Total Organic Carbon (TOC)	Total	SM 5310B	1.0	mg/L
Metals				
Aluminum	Total + Dissolved	EPA 200.7	0.05	mg/L
Antimony	Total + Dissolved	EPA 200.8	2.0	µg/L
Arsenic	Total + Dissolved	EPA 200.8	1.0	µg/L
Barium	Total + Dissolved	EPA 200.8	1.0	µg/L
Beryllium	Total + Dissolved	EPA 200.8	0.5	µg/L
Boron	Total + Dissolved	EPA 200.7	50	µg/L
Cadmium	Total + Dissolved	EPA 200.8	1.0	µg/L
Calcium	Total + Dissolved	EPA 200.7	0.1	mg/L
Chromium	Total + Dissolved	EPA 200.8	2.0	µg/L
Cobalt	Total + Dissolved	EPA 200.8	1.0	µg/L
Copper	Total + Dissolved	EPA 200.8	1.0	µg/L
Iron	Total + Dissolved	EPA 200.7	0.04	mg/L
Lead	Total + Dissolved	EPA 200.8	1.0	µg/L
Lithium	Total + Dissolved	EPA 200.7	50	µg/L
Magnesium	Total + Dissolved	EPA 200.7	0.02	mg/L
Manganese	Total + Dissolved	EPA 200.8	1.0	µg/L
Mercury	Total + Dissolved	EPA 245.1	0.2	µg/L
Molybdenum	Total + Dissolved	EPA 200.8	2.0	µg/L
Nickel	Total + Dissolved	EPA 200.8	2.0	µg/L
Phosphorus	Total + Dissolved	EPA 200.7	0.04	mg/L
Potassium	Total + Dissolved	EPA 200.7	0.5	mg/L
Selenium	Total + Dissolved	EPA 200.8	0.6	µg/L
Silica	Total + Dissolved	EPA 200.7	0.05	mg/L
Silver	Total + Dissolved	EPA 200.8	1.0	µg/L
Sodium	Total + Dissolved	EPA 200.7	0.5	mg/L
Strontium	Total + Dissolved	EPA 200.7	0.02	mg/L
Thallium	Total + Dissolved	EPA 200.8	1.0	µg/L
Tin	Total + Dissolved	EPA 200.7	100	µg/L

Table 3-4. Analyte List for Active Monitor Well and Surface Water Sampling

Parameter or Analyte	Total/ Dissolved (1)	Method (2)	Reporting Limit (2)	Units
Titanium	Total + Dissolved	EPA 200.7	0.005	mg/L
Uranium, Total	Total + Dissolved	EPA 200.8	1.0	µg/L
Vanadium	Total + Dissolved	EPA 200.8	2.0	µg/L
Zinc	Total + Dissolved	EPA 200.8	10	µg/L
Radiochemicals				
Gross Alpha	Dissolved	EPA 900.0	1.0	pCi/L
Gross Beta	Dissolved	EPA 900.0	1.0	pCi/L
Radium-226	Dissolved	EPA 903.0	1.0	pCi/L
Radium-228	Dissolved	EPA 904.0	1.0	pCi/L
Thorium-228	Dissolved	HASL 300	1.0	pCi/L
Thorium-230	Dissolved	HASL 300	1.0	pCi/L

Notes:

1) Dissolved constituents are field-filtered with a new disposable 0.45-micron (µm) filter. Dissolved (filtered) metals collected quarterly. Total (unfiltered) metals collected in two non-consecutive quarters once a well is installed and/or initially included in the GMP (BC 2012a).
2) Except for lithium and selenium, EPA laboratory analytical methods and reporting limits are consistent with those provided in Revision 5 of the QAPP (ESI and BC 2009); alternative analytical methods identified in the QAPP may also be used. For lithium, the lab was unable to get reproducible results using EPA Method 200.8 (as indicated in QAPP); therefore, the lab has used EPA Method 200.7 for lithium, which has a higher reporting limit than indicated in the QAPP. For selenium, the reporting limit of 0.6 µg/L is lower than that indicated in the QAPP (2 µg/L).
3) The samples for TDS are filtered in the analytical laboratory with a new disposable 0.45 µm filter.
4) s.u. = pH standard units; mg/L = milligrams per liter; µg/L = micrograms per liter; pCi/L = picocuries per liter.

Appendix D provides groundwater quality data associated with the Site-Wide groundwater monitoring program and charts illustrating temporal changes in chemical concentrations.

Dissolved versus Total Metals

Beginning with the 3Q 2010 sampling event, samples from monitor wells at the Site have been periodically collected in two different quarters from each well and analyzed for both dissolved (0.45 µm-filtered) and total (unfiltered) metals to determine whether the two sampling methods produce comparable results. The results of the comparative statistical analysis of the available dissolved and total metals datasets have been periodically reported in previous quarterly and annual groundwater monitoring reports (GMRs). The most recent and final sampling for dissolved and total metals occurred during the 3Q 2014 and 1Q 2015 events for 29 off-Site wells that were installed in 2013/2014 and first sampled in 3Q 2014. The statistical comparison of the complete dissolved and total metals datasets is presented in the 2015 Annual GMR (BC 2016c).

Based on the statistical analyses, differences between dissolved and total metals concentrations in groundwater samples collected from monitor wells are non-existent or are too small to be meaningful. It is concluded that groundwater sampling both with and without filtering of samples produce equivalent datasets.

3.2.4 Soil Sampling and Testing

Pursuant to the *Agricultural Fields Characterization Work Plan - Revision 2* (BC 2010d), soil samples were collected from select borehole cores in the Shallow, Intermediate and Deep zones. The types of samples collected, and a brief description of the sampling objectives, are provided below.

- Soil samples were collected for analysis of grain size distribution to generate laboratory-determined Unified Soil Classification System (USCS) soil descriptions for comparison to USCS descriptions made in the field at the time of drilling.
- Non-redox preserved soil samples were collected for bulk chemical analyses to characterize chemical concentrations in soils.
- Redox-preserved soil samples were collected using EPA-specified procedures that preserve the subsurface oxidation state of the sediments, and archived at the Site for potential testing pursuant to the *Aquifer Solids Testing Work Plan - Revision 1* (BC 2010e).

Soil sampling information is provided in Appendix E and discussed briefly below.

Grain Size Analysis

A total of 37 samples of aquifer materials were obtained from 16 borehole locations for grain size distribution analyses by sieving of material larger than 75 µm (i.e., retained on a No. 200 sieve). Laboratory reports with the grain size distribution data are provided in Appendix E-1. Grain size distribution results were used to generate laboratory-derived USCS lithologic classifications for comparison to the field-derived USCS lithologic classifications based on visual inspection of core during drilling. As shown in Table 3-5, field USCS classifications were generally consistent with laboratory USCS classifications, especially with respect to finer-grained materials.

Table 3-5. Sample Locations for Grain Size Analysis

Borehole Name	Sample Interval (feet bgs)	USCS Classification (Field)	Percent Fines (Field)	USCS Classification (Laboratory)	Percent Fines (Laboratory)
B/W-2	378-384	SW	5	SM	12.7
B/W-2	442-454	SC	35	SC	26.4
B/W-32	21-27	SM	15	SM	18.7
B/W-32	411-414	SW-SM	10	SM	13.5
B/W-36	57-71	SM	30	SM	13.5
B/W-37	111-117	CL	80	CL	82.0
B/W-38R	140-143	GW	5	SW-SM	7.8
B/W-38R	208-212	SC	35	SC	25.7
B/W-38R	249-253	SM	30	SM	18.6
B/W-40	220.5-226	SM	15	SM	19.2
B/W-40	451-456	SP	5	SM	20.9
B/W-42	159-165	SM	15	SP-SM	5.9
B/W-51	64-69	SC	35	SC	15.0
B/W-54	46-52	CL	65	CL	63.1
B/W-54	52-61	SW	10	SW-SM	8.3
B/W-55	42-51	CH	95	CL	74.4
B/W-55	118-125	SM	20	CL	51.2
B/W-55	135-145	SW	5	SP	4.9
B/W-55	175-185	SP	5	SW	2.9
B/W-60	32-36	SM	35	SM	23.3
B/W-60	132.5-136	ML	60	CL	70.1
B/W-60	450-456	SM	25	SM	22.6
B/W-61	299-306	SP	10	SP-SM	7.7
B/W-64	27-31	SP	10	SP-SM	12.0
B/W-64	43-47	CL	75	CL	93.0
B/W-64	67-77	SW	10	SP-SM	12.0
B/W-64	177-185	SW	10	SW	5.0
B/W-66	59-64	CH	70	CL	66.1
B/W-66	65.5-68	SC	40	SC	23.0
B/W-66	89-93	SC	20	SC	48.7
B/W-67	27-32	SP	5	SM	28.5
B/W-67	38-55	CL	60	CL	64.0
B/W-67	142-146	SC	40	SC	31.8
LEP-MW-2	61-66	CL	50	SC	22.1
LEP-MW-2	212-217	CH	95	SC	34.4
LEP-MW-2	266-273	SW-SM	10	SM	12.8
LEP-MW-2	341-346	CL	50	SC	36.2

Notes:
SW = Well Graded Sand or Well Graded Sand with Gravel (where gravel is more than 15%).
SP = Poorly Graded Sand or Poorly Graded Sand with Gravel (where gravel is more than 15%).
SW-SM = Well Graded Sand with Silt or Well Graded Sand with Silt and Gravel (where gravel is more than 15%).
SP-SM = Poorly Graded Sand with Silt or Poorly Graded Sand with Silt and Gravel (where gravel is more than 15%).
SC = Clayey Sand or Clayey Sand with Gravel (where gravel is more than 15%).
SM = Silty Sand or Silty Sand with Gravel (where gravel is more than 15%).
CL = Lean Clay, Lean Clay with Sand, Sandy Lean Clay or Sandy Lean Clay with Gravel (where gravel is more than 15%).
CH = Fat Clay, Fat Clay with Sand, Sandy Fat Clay or Sandy Fat Clay with Gravel (where gravel is more than 15%).
GW = Well Graded Gravel with Sand.

Solids Sampling for Bulk Chemistry

Samples of archived core were collected from select depths in boreholes B/W-1, B/W-31, B/W-32, B/W-42, B/W-46, B/W-61, B/W-62, B/W-65, B/W-66, B/W-67, and MW-5 and submitted to the laboratory for bulk chemical analysis of the parameters listed in Table 3-6. Sample collection methods conformed to SOP-11 of the QAPP. Concentrations of metal/metalloids (hereinafter referred to as metals) and radiochemicals in the solid soil samples were determined by microwave-assisted digestion using EPA Method 3051A (HNO_3). The locations, sample depths and laboratory results are summarized in Appendix E-2.

Table 3-6. Analyte List for Soil Samples

Parameter or Analyte	Method (1)	Reporting Limit (1)	Units (2)
Soil pH	EPA 9045C	0.1	s.u.
Total and Acid Soluble Sulfur	Method 9030B	0.4	mg/kg
Chloride	EPA 300.0	5	mg/kg
Nitrate (as N)	EPA 300.0	1.1	mg/kg
Sulfate	EPA 300.0 (4)	5.0	mg/kg
TOC, TC, TIC (3)	EPA LG601 (2)	1.0	mg/kg
Aluminum	EPA 6010B	10	mg/kg
Antimony	EPA 6020	1.0	mg/kg
Arsenic	EPA 6020	0.5	mg/kg
Barium	EPA 6020	0.5	mg/kg
Beryllium	EPA 6020	0.3	mg/kg
Boron	EPA 6010B	5.0	mg/kg
Cadmium	EPA 6020	0.5	mg/kg
Calcium	EPA 6010B	15	mg/kg
Chromium	EPA 6020	1.0	mg/kg
Cobalt	EPA 6020	0.5	mg/kg
Copper	EPA 6020	1.0	mg/kg
Iron	EPA 6010B	5.0	mg/kg
Lead	EPA 6020	0.5	mg/kg
Magnesium	EPA 6010B	10	mg/kg
Manganese	EPA 6020	0.5	mg/kg
Molybdenum	EPA 6020	1.0	mg/kg
Nickel	EPA 6020	1.0	mg/kg
Potassium	EPA 6010B	50	mg/kg
Selenium	EPA 6020	1.0	mg/kg
Sodium	EPA 6010B	50	mg/kg
Uranium, Total	EPA 6020	0.10	mg/kg
Vanadium	EPA 6020	1.0	mg/kg
Zinc	EPA 6020	10	mg/kg
Uranium-234, 235, 238	HASL 300 (U-02-RC)	1.0	pCi/g

Notes:

1) EPA laboratory analytical methods and reporting limits are consistent with those provided in QAPP (ESI and BC 2009); alternative analytical methods identified in the QAPP may also be used.
2) s.u. = standard units; mg/kg = milligrams per kilogram; pCi/g = picocuries per gram.
3) Total Organic Carbon (TOC), Total Carbon (TC), and Total Inorganic Carbon (TIC).
4) EPA Method LG601 (Dry Combustion, Infrared Detection) as described in EPA 2005.

Vertical profiling of chemical concentrations in soils beneath the agricultural fields was performed to help understand potential chemical loading to groundwater unrelated to mining. Other evaluations involving characterization of groundwater quality upgradient and downgradient of agricultural fields and the sulfur isotope signatures associated with gypsum, an agricultural fertilizer/soil amendment, proved more useful for evaluating groundwater impacts associated with agricultural activities (see Section 5.5).

Redox-Preserved Soil Sampling and Archiving

During the 2007 Second-Step HFA (BC 2008c) and 2010 field investigation (BC 2013a), soil samples were opportunistically collected using EPA-specified procedures that preserved the subsurface oxidation state of the sediments. Redox-preserved soil samples were collected at select borehole locations near the Evaporation Ponds (B/W-11, B/W-18, LEP-MW-9I, MW-5, and W4CB-2), the agricultural fields adjacent to the Site (B/W-61, B/W-65, and B/W-66), and at B/W-32 (i.e., at OU1-DPT-28, which was identified during the Shallow zone investigation in 2009).

The redox-preserved soil samples were archived at the Site for potential laboratory testing (BC 2010e) to evaluate geochemical processes that affect the release and/or attenuation of chemicals from/onto aquifer solids (in particular, chemical partitioning to various mineral fractions), and the mobility and transport of chemicals in groundwater at the Site. The disposition of archived, redox-preserved soil samples is described in Section 3.3.5, which addresses chemical transport evaluations.

3.2.5 Aquifer Hydraulic Properties Testing

The 2007 SOW (EPA 2007a) required "*Definition of aquifer properties (e.g., hydraulic conductivity, transmissivity, and storativity) by a program of aquifer testing to measure the hydraulic connection between areas and throughout the known extent of contamination*." In addition, characterization of aquifer hydraulic properties was identified as DQO #5 in the Revised Groundwater RI Work Plan (BC 2014a).

Hydraulic properties of the alluvial aquifer, as well as bedrock, are provided in Appendix F and have been estimated based on a variety of small- to large-scale test methods including:

- Slug testing of groundwater monitor wells;
- Analysis of steady-state drawdown data obtained during routine quarterly low-flow sampling of monitor wells;
- Constant-rate pumping tests of the eleven wells comprising the PWS during 2010;
- Slug testing of piezometers installed near the PWS that were used as observation wells during constant-rate pumping tests of the 11 wells comprising the PWS during 2010; and
- A constant-rate pumping test of agricultural well WDW019 using an observation network of 93 monitor wells, of which 61 exhibited pumping-related responses.

Small-scale test methods, such as slug testing, provide data that are useful for identifying spatial patterns related to geology, guiding characterization, and as a preliminary estimate of hydraulic conductivity. Because slug test data are available throughout the Study Area, this dataset is used to evaluate spatial patterns in hydraulic conductivity within the Study Area. Data from the pumping test at WDW019, the other large-scale pumping tests, and subsequent groundwater model development using a parameter estimation technique (Doherty 2009), have been used to develop representative field-scale estimates of hydraulic conductivity and, therefore, groundwater velocity.

3.2.6 Surface Water Characterization

The hydrology of the study area is dominated by groundwater recharge from surface water associated with agricultural irrigation (Carroll et al. 2010; Huxel and Harris 1969; Myers 2001). Therefore, understanding the flows in the Walker River and diversions for nearby agricultural activities is important for understanding and contextualizing the data collected in the Study Area. Both regional and local (i.e. Study Area) characterization activities were conducted.

To characterize regional surface water hydrology, daily stream flows for the Walker River are obtained at several gaging locations throughout the Mason Valley, both upstream and downstream of the Site. The data collected from the gaging stations are maintained by the USGS, often in cooperation with state and local agencies, and are available at the USGS website (http://waterdata.usgs.gov/nv/nwis/sw). Surface water quality in the Walker River is also routinely

monitored by various federal, state, and miscellaneous agencies/entities. Much of this data is assembled and made publicly-available through the EPA's STOrage and RETrieval (STORET) Data Warehouse. This dataset supplements the data collected by ARC.

To evaluate the quality of surface water used to irrigate the Hunewill Ranch agricultural fields next to the Site, samples were collected and analyzed from the West Campbell Ditch (SW-WCD-01) and the Walker River (SW-WR-01), pursuant to the *Agricultural Fields Characterization Work Plan - Revision 2* (BC 2010d). Sampling locations are shown on Figure 3-6. West Campbell Ditch receives its water directly from the Walker River. The Walker River monitoring point (SW-WR-01) is located less than 1,000 feet upstream of the diversion point for West Campbell Ditch. The monitoring location in West Campbell Ditch (SW-WCD-01) is located about three miles farther downstream from the diversion point. Potential temporal trends in surface water quality during non-irrigation and irrigation periods were addressed by collecting samples monthly at these locations for 12 months during 2010/2011.

Field parameters (temperature, pH, specific conductivity, DO, sulfate and turbidity) were measured at the time of sample collection, and samples were submitted for the analysis (total concentrations) of the parameters listed in Table 3-4. Surface water samples were collected using the direct-grab method described in SOP-18 in the QAPP. This surface water sample collection method is consistent with the method used by NDEP to collect samples at other surface water monitoring stations in the Mason Valley. Laboratory analyses were conducted in accordance with the QAPP. Surface water data are presented in Appendix G and summarized in Section 4.7.

3.2.7 Hydrologic Tracer Studies

Hydrologic tracer investigations were initiated to help characterize Study Area groundwater conditions, refine the HCSM, and identify background groundwater quality types (BC 2008c, 2012b, 2014a). A variety of hydrologic tracers were initially identified as having the potential to provide information on the origin, age, sources of dissolved constituents, and migration pathways of groundwater and surface water in the Study Area.

To evaluate the feasibility of using hydrologic tracers to support these objectives, samples were collected prior to 2010 from a select number of groundwater monitor wells and surface water features. Based on the apparent efficacy of using hydrologic tracers to assess Study Area groundwater conditions, additional EPA-approved hydrologic tracer sampling events were conducted. Over time, the hydrologic tracer sampling events evolved with changes primarily related to increases in the number of groundwater monitor wells that were sampled, opportunistic collection of standing rainwater samples, and elimination of select tracers considered less useful for characterizing groundwater conditions.

Table 3-7 provides a chronology of the various OU-1 hydrologic tracer sampling events.

Table 3-7. Chronology of Hydrologic Tracer Sampling Events

Date	Sampling Locations (1)	Hydrologic Tracers (2)	Information Source(s)
July/August 2008	Hydrologic tracer samples were collected from 47 of the 94 (50%) active groundwater monitor wells at the time that routine groundwater monitoring was conducted.	Uranium isotopes, sulfate isotopes, tritium, tritium/ helium, $\delta^{18}O/\delta^{2}H$ in water, and nitrate isotopes.	*Second-Step Hydrogeologic Framework Assessment Data Summary Report* (BC 2008c).
February 2011	Samples were collected from the Walker River and West Campbell Ditch, and from 127 of the 223 (57%) active groundwater monitor wells at the time of sampling.	Uranium isotopes, sulfate isotopes, tritium, tritium/ helium, $\delta^{18}O/\delta^{2}H$ in water, nitrate isotopes, CFCs, $\delta^{13}B$, and $\delta^{36}Cl$.	*Draft Site-Wide Groundwater Operable Unit (OU-1) Remedial Investigation Work Plan* (BC 2012b). Revised Groundwater RI Work Plan (BC 2014a).
May 2012	Samples were collected from: 1) three surface water locations (Pit Lake, Walker River and West Campbell Ditch); and 2) 279 of the 287 (97%) active groundwater monitor wells at the time of sampling.	Uranium isotopes, sulfate isotopes, tritium, tritium/ helium, CFCs, and SF_6.	Conclusions about the usefulness of specific hydrologic tracers collected in 2011 were noted in correspondence between ARC and EPA (2012a). With EPA approval (2012b), samples collected during May 2012 were not analyzed for stable isotopes in water or nitrate isotopes. May 2012 results were provided in the *Background Groundwater Quality Assessment - Revision 2* (BC 2015c).
July 2013	Collection of 14 standing rain water samples following a large precipitation event.	Uranium isotopes and sulfate isotopes.	July 2013 results provided in the *Background Groundwater Quality Assessment - Revision 2* (BC 2015c).
August 2014	Groundwater samples were collected from all (100%) of the new wells installed pursuant to the Additional Monitor Well Work Plan (BC 2013b) except well HLP-02B because it was dry. Also sampled were the four wells at the B/W-65 cluster, which were inaccessible in May 2012, and monitor well YPT-MW-15I, which was installed in October 2012. Five wells were resampled to evaluate the results reported in May 2012.	Uranium isotopes, sulfate isotopes, tritium, and tritium /helium.	August 2014 results provided in the *Background Groundwater Quality Assessment - Revision 2* (BC 2015c).

Notes:

1) Hydrologic tracer samples from monitor wells were collected in conjunction with routine groundwater monitoring events associated with the GMP (BC 2012a).
2) Uranium isotopes include ^{234}U, ^{235}U, and ^{238}U; Sulfate isotopes = $\delta^{34}S/\delta^{18}O$ in dissolved sulfate; Nitrate isotopes = $\delta^{15}N/\delta^{18}O$ in dissolved nitrate; $\delta^{13}B$ = boron isotopes in the water samples; $\delta^{36}Cl$ = chloride isotopes in the water samples; CFCs = chlorofluorocarbons; SF_6 = Sulfur Hexafluoride.

Hydrologic tracer samples were collected from monitor wells in conjunction with routine Site-Wide groundwater sampling events using low-flow, minimal drawdown sample collection procedures specified in the GMP (BC 2012a), as well as tracer-specific sampling protocols specified in SOP-17 of the QAPP (ESI and BC 2009). Surface water hydrologic tracer samples were collected using the direct-grab method described in SOP-18 of the QAPP. This surface water sample collection method is consistent with the method used by the NDEP to collect samples at other surface water monitoring stations in the Mason Valley. Table 3-8 presents the parameters, analytical methods, reporting limits, and accuracy and precision goals for the hydrologic tracer analyses.

Table 3-8. Analyte List for Hydrologic Tracer Samples

Parameter	Analytical Method	Analytical Precision (1)	Reporting Limit (2)	Matrix Spike Accuracy	Lab Control Sample Accuracy
Tritium (^{3}H)	wrd (^{3}He-ingrowth)	± 0.1 TU (3)	NA	NA	NA
Tritium/Helium (^{3}H/^{3}He)	Noble Gas MS	± 1%	NA	NA	NA
^{34}S in Sulfate	EA-IRMS (Combination to SO_2) USGS RSIL Lab Code 1951	± 0.5‰	NA	NA	NA
^{18}O in Sulfate	EA-IRMS (Combination to CO_2) USGS RSIL Lab Code 1951 (4)	± 0.5‰	NA	NA	NA
^{234}U, ^{235}U, ^{238}U	HASL-300 (U-02-RC) (5)	RPD<20% or RER<2	1 pCi/L	70-130%	75-125%
Total Uranium	EPA 200.8 ICP-MS	20%	0.1 µg/L	70-130%	80-120%
Chlorofluorocarbons (CFCs)	GC-ECD	0-2%	0.001×10^{-12} pmol/kg	NA	NA
Sulfur Hexafluoride (SF_6)	GC-ECD	1-3% (6)	0.01×10^{-15} fmol/kg	NA	NA

Notes:

1) Precision is the average standard deviation (1-sigma) in per mil units (‰). Precision limit applicable for matrix spike/matrix spike duplicate, laboratory duplicate, laboratory control sample/ laboratory control sample duplicate, or reference standard analyses.
2) The method detection limits presented are laboratory-derived limits.
3) TU = tritium unit; NA = not applicable; RPD = relative percent difference; RER = replicate error ratio; EA-IRMS = elemental analyzer-isotopic ratio mass spectrometer; ICP-MS = inductively coupled plasma mass spectroscopy; TIMS = thermal ionization mass spectrometer; GC-ECD = Gas Chromatography with Electron Capture Detection; % = percent
4) USGS Reston Stable Isotope Laboratory (RSIL) Lab Code 1951 (USGS 2006).
5) Method U-02-RC: see Isotopic Uranium in Biological and Environmental Materials for water samples as documented in HASL-300 (Rev. 1, February 2000) available at URL address: http://www.eml.st.dhs.gov/publications/procman/.
6) Wanninkhof et al. (1991); Law et al. (1994).
7) mg/L = milligrams per liter; µg/L = micrograms per liter; pmol/kg = picomoles per kilogram; fmol/kg = femtomole per kilogram; pCi/L = picocuries per liter.

Laboratory analytical results for hydrologic tracers achieved the completeness, accuracy and precision goals specified in relevant planning documents including the QAPP (ESI and BC 2009) and SOP-17. Hydrologic tracer information that relates directly to the groundwater recharge aspects of the HCSM and the background groundwater assessment was obtained in May 2012 and August 2014. These data are discussed in Section 5.0. Appendix H provides supplemental information about hydrologic tracer sampling and analysis including:

- A detailed discussion of the locations where hydrologic tracer samples were collected during May 2012, July 2013, and August 2014;
- Analytical results of hydrologic tracer samples of standing rain water impounded on mine waste features after a large rain event (average of 1.55 inches on-Site) on July 4, 2013;
- A detailed description of the sample collection procedures, analytical methods, laboratory precision goals for each hydrologic tracer, and QA/QC sample results;
- An evaluation and discussion of the limited usefulness of CFC and SF_6 data for estimating groundwater ages in the Study Area;
- A discussion of the principles and application of uranium isotopes to groundwater interpretation;
- A discussion of the principles of groundwater age estimation using data for tritium and tritium/helium in groundwater;
- A discussion of the additional sources of sulfate isotope data potentially relevant to groundwater conditions in the Study Area; and
- Electronic copies of the analytical results provided by the laboratory and laboratory-calculated apparent groundwater ages.

3.2.8 Bedrock Groundwater Characterization

Since 2005, phased field investigations associated with OU-1 have included characterization of both the alluvial and bedrock groundwater systems. The Revised Groundwater RI Work Plan (BC 2014a) presented available groundwater information through May 2012, and described an updated HCSM for the bedrock and alluvial groundwater systems. The Revised Groundwater RI Work Plan also outlined the approach for completing the bedrock groundwater study elements specified in the 2007 SOW. Bedrock characterization activities that were approved by EPA are described below in Table 3-9.

Table 3-9. Chronology of Bedrock Groundwater Characterization Activities

2004-2007	Bedrock characterization (including borehole drilling, lithologic logging, well installation, hydraulic testing, water level monitoring, and groundwater quality monitoring) conducted pursuant to the First-Step HFA Work Plan (BC 2005) and Second-Step HFA Work Plan (BC 2007b).
2007	Characterization of bedrock groundwater conditions is required under the Administrative Order for Remedial Investigation and Feasibility Study (RI/FS), CERCLA Docket No. 9-2007-0005 dated January 12, 2007.
2007-2011	Bedrock characterization (including borehole drilling, lithologic logging, well installation, hydraulic testing, water level monitoring, and groundwater quality monitoring) conducted pursuant to the *2010 Groundwater Monitor Well Work Plan - Revision 2* (BC 2010c), *Agricultural Fields Characterization Work Plan - Revision 2* (BC 2010d), *On-Site Monitor Well Installation Work Plan - Revision 1* (BC 2011a), and the *Addendum to the On-Site Monitor Well Installation Work Plan* (ARC 2011).
August 17, 2011	Groundwater technical meeting with EPA, ARC and stakeholders to discuss progress of the phased approach to groundwater RI activities, which resulted in concurrence to conduct initial bedrock characterization activities to support a more comprehensive assessment of bedrock groundwater conditions as part of the RI characterization.
September 29, 2011	EPA (2011a) provided comments on the *2010 Annual Site-Wide Groundwater Monitoring Report* dated April 15, 2011, and the First and Second Quarter (1Q and 2Q) 2011 Groundwater Monitoring Reports dated July 1, 2011 and August 26, 2011, respectively, that pertained to bedrock characterization.
January 5, 2012	ARC submitted the *Proposed Initial Bedrock Characterization Activities* (ARC 2012a).
April 12, 2012	EPA (2012c) provided comments on the *Proposed Initial Bedrock Characterization Activities* (ARC 2012a).
June 18, 2012	ARC submitted preliminary responses to EPA comments on the *Proposed Initial Bedrock Characterization Activities.*
August 28, 2012	Groundwater technical meeting with EPA, ARC and other stakeholders to resolve comments on the *Proposed Initial Bedrock Characterization Activities.*
October 11, 2012	Submittal of ARC final responses to EPA comments on the *Proposed Initial Bedrock Characterization Activities,* and submittal of the *Proposed Initial Bedrock Characterization Activities - Revision 1* (ARC 2012b).
October 22, 2012	EPA (2012d) approval of the *Proposed Initial Bedrock Characterization Activities - Revision 1,* included as Attachment D to the Revised Groundwater RI Work Plan (BC 2014a).
March 2013	ARC began implementation of the EPA-approved *Proposed Initial Bedrock Characterization Work Plan - Revision 1.*
November 20, 2013	ARC submitted the *Initial Bedrock Characterization Data Summery Report* (BC 2013c).
February 7, 2014	ARC submitted the *Site-Wide Groundwater Remedial Investigation Work Plan - Revision 1* (BC 2014a), which presented available groundwater information through May 2012, and described an updated HCSM for the bedrock and alluvial groundwater systems.
January 28, 2015	ARC submitted the *Bedrock Groundwater Assessment Technical Memorandum* (BC 2015a).
June 11, 2015	ARC submitted the *Additional Monitor Well Installation Data Summary Report* (BC 2015d) detailing installation and testing of bedrock and alluvial wells installed in 2013 and 2014.
July 31, 2016	EPA (2016a) approved the *Bedrock Groundwater Assessment Technical Memorandum* (BC 2015a).

After installation and testing of new bedrock monitor wells in late 2013 and 2014, and a technical meeting in May 2015 to discuss the full set of bedrock information, EPA (2015a) concluded that sufficient data had been collected to conclude that bedrock is not an important migration pathway

at the Site, and requested preparation of a technical memorandum to update the bedrock HCSM. The *Bedrock Groundwater Assessment Technical Memorandum* (BC 2015a) is provided in Appendix I and bedrock information is summarized in Section 4.9.

3.3 Site-Wide Groundwater Studies and Evaluations

Studies and evaluations relying on OU-1 RI data that were conducted to fulfill certain study elements specified in Section 7.0 of the SOW attached to the 2007 Order (EPA 2007a) are described below. Reports describing the approach, analysis, and results of these groundwater related studies and evaluations are provided in Appendix J.

3.3.1 Pumpback Well System Effectiveness

The effectiveness of the PWS in limiting the off-Site migration of mine-impacted groundwater was evaluated in accordance with the *Pumpback Well System Characterization Work Plan Addendum - Revision 2* (ARC 2010).

The 11 pumpback wells ceased pumping on March 25, 2009 and were subsequently hydraulically tested to generate information to support a capture zone analysis using an analytical element model. These activities provided a preliminary assessment sufficient to conclude that the PWS was only partially effective in capturing Shallow zone mine-impacted groundwater during its operational life. The PWS effectiveness evaluation is described in the *Summary of PWS Aquifer Testing* (BC 2010f), which is included as Appendix J-1.

3.3.2 Pit Lake Water Levels

The Pit Lake (OU-2), which is currently refilling with groundwater from bedrock and alluvial flow systems (BC 2014a), has been studied to better understand its influence on Site-wide groundwater conditions. Pit Lake studies related to OU-1 include routine monitoring of the Pit Lake water level elevation beginning in September 2007 and a water balance evaluation (Appendix J-2) to predict the future "steady-state" elevation of the Pit Lake.

Groundwater inflow, based on the lake water balance study, is estimated to be slightly greater than the current rate of evaporation. Thus, the lake level is slowly rising with time. The Pit Lake water balance and projection of the pit refilling curve (Figure 3-7) indicate that the lake is expected to reach a steady-state level, where water inflow and evaporation are balanced, prior to 2030. The steady-state Pit Lake elevation is estimated to be in the range of 4,249 to 4,253 feet amsl, with more recent data indicating that the steady-state elevation may fall within the lower end of this range. The steady-state Pit Lake elevation is approximately: 1) 100 feet lower than the pre-mining groundwater elevation range of 4,350 to 4,375 feet amsl reported by Gill (1951); 2) 140 feet lower than current groundwater levels in the alluvial aquifer adjacent to the Walker River just east of the Pit Lake; 3) 65 feet lower than the current groundwater levels beneath the Evaporation Ponds; and 4) 150 and 340 feet below the east and west pit rim elevations, respectively.

The steady-state Pit Lake level is projected to be lower than the pre-mining water level as the result of the significant evaporation that occurs from the Pit Lake surface. Consequently, the lake is and will continue to be a groundwater sink that creates a localized cone of depression (extending as far north as the Process Areas) with local groundwater flow toward the pit. Because the Pit Lake does not and will not in the future discharge into the Site-wide groundwater system, the Pit Lake is not a source of COIs to Site-Wide groundwater.

3.3.3 Groundwater Pumping and Surface Water Points of Diversion

Groundwater conditions in the Study Area are influenced by groundwater pumping and surface water diversion associated primarily with irrigation and, to a lesser extent, stock watering and mining/milling (BC 2014a; S.S. Papadopulos & Associates, Inc. [SSPA] 2014).

Publicly-available groundwater pumping and surface water diversion information applicable to the Study Area is provided in the *Revised Public Information for the Northern Portion of the Background Groundwater Study Area* (BC 2013d) included in Appendix J-3. That document also includes: well ownership, location and construction; underground and surface water rights and points of diversion (PODs); well pumping records from 1993 to 2010; sub-surface lithology and, as applicable, depth to bedrock; and groundwater elevations from the NDWR and the USGS.

PODs from an underground source (i.e., groundwater) for the wells with water rights within and adjacent to the Study Area are shown on Figure 3-8, along with diversion rates and annual duties. All agricultural wells within and near the Study Area are screened in the alluvial aquifer. Although well construction varies greatly, agricultural wells used to extract groundwater for crop irrigation are either screened beginning at or near the water table to the total depth of installation and/or have been installed with a permeable filter pack from above the water table surface to the total depth of installation. Annual pumping inventories (i.e., actual total amounts pumped each year) for wells in the Mason Valley from 1994 to 2003 and from 2004 to 2010 have been reported by Gallagher (2004) and Gallagher (2013), respectively.

Within the Study Area, there are 20 wells used for irrigation, four wells used for stock watering, one used for mining/milling, and one used for commercial purposes (Gallagher 2013). The 20 irrigation wells are currently permitted to irrigate a total of 5,509 acres using an annual duty of 15,788 acre-feet with a combined diversion rate of 46.36 cubic feet per second (cfs). Of the 36 active water rights, 26 allow for pumping to occur on a year-round basis, nine of the rights can only be pumped during the irrigation season, and one right can only be used in the winter.

The place of use (POU) of 37 surface water rights within and adjacent to the Study Area that are identified in the amended Walker River Decree (WRD), Case in Equity, C-125, filed April 24, 1940 (WRD C-125; WRD, 1940) are shown on Figure 3-9. This figure also shows the POUs of surface water rights approved by NDWR as either new appropriations or applications to change WRD rights. Additional information about the distribution and routing of surface water is included in the discussion of surface water hydrology in Section 4.7.

The POUs of flood waters permitted by NDWR Application 5528, Certificate 8859 are shown on Figure 3-10 by quarter-section. Application 5528 was filed by the Walker River Irrigation District (WRID) to divert flood waters from the Walker River for irrigation from May 1 to July 31 of each year. Application 5528 was certificated for 491.2 cfs, not to exceed 89,612 acre-feet per season (the total duty of water cannot exceed 4.0 acre-feet per acre per season from any and/or all sources). The lands irrigated under this Certificate during any one season cannot exceed 30,000 acres.

3.3.4 Groundwater Model Development

The 2007 SOW (EPA 2007a) specified that the OU-1 RI "extrapolate the future contaminant transport using a comprehensive groundwater flow and fate-and-transport model". In addition, determining groundwater flow and chemical transport rates was identified as DQO #6 in the Revised Groundwater RI Work Pan (BC 2014a).

The technical and programmatic framework to address quantitative numerical modeling of groundwater flow and chemical transport was developed during iterative technical discussions with the EPA, ARC, and other stakeholders, and documented in the Revised Groundwater RI Work Plan (BC 2014a). Table 3-10 summarizes the chronology of investigations, evaluations, communications, and documents related to groundwater flow modeling.

Table 3-10. Chronology of Groundwater Modeling Activities

2004-2007	Characterization of groundwater conditions in the Study Area pursuant to the First-Step HFA Work Plan (BC 2005) and Second-Step HFA Work Plan (BC 2007b).
2007	Characterization of bedrock groundwater conditions is required under the Administrative Order for Remedial Investigation and Feasibility Study (RI/FS), CERCLA Docket No. 9-2007-0005 dated January 12, 2007.
2007-2011	Characterization of groundwater conditions in the Study Area pursuant to the various work plans and related correspondence (BC 2008c, 2010c, 2010d, 2011a; ARC 2011).
May 16, 2011	Conference call with EPA, ARC and other stakeholders to discuss groundwater flow modeling.
August 17, 2011	Groundwater technical meeting with EPA, ARC and stakeholders to discuss the status of RI activities, which resulted in concurrence to conduct groundwater modeling to support a quantitative evaluation of groundwater flow and chemical transport.
June 4, 2012	Conference call with EPA, ARC and other stakeholders to discuss groundwater flow modeling activities, which resulted in a request by EPA that ARC submit a document describing key groundwater modeling deliverables and milestones, and a draft table of contents for a groundwater modeling work plan.
June 25, 2012	ARC submitted the *Groundwater Flow Modeling Deliverables* (ARC 2012c), which included: 1) a preliminary summary of key groundwater modeling deliverables and milestones; and 2) a draft table of contents for a groundwater flow model work plan.
July 11, 2012	EPA (2012e) provided comments on the *Groundwater Flow Modeling Deliverables* (ARC 2012c).
July 17, 2012	Groundwater technical meeting with EPA, ARC and stakeholders to discuss findings of the 2011 Monitor Well Installation investigation, and related RI activities, which resulted in an EPA request that ARC submit a document summarizing groundwater modeling objectives.
August 14, 2012	ARC submitted the *Objectives for Groundwater Modeling in the RI/FS Process, Yerington Mine Site* (SSPA 2012a).
August 29, 2012	Groundwater technical meeting with EPA, ARC, and other stakeholders to discuss the groundwater modeling objectives.
October 15, 2012	ARC submittal of the *Objectives for Groundwater Modeling in the RI/FS Process - Revision 1, Yerington Mine Site* (SSPA 2012b).
October 26, 2012	EPA (2012f) approval of the *Objectives for Groundwater Modeling in the RI/FS Process - Revision 1, Yerington Mine Site* (SSPA 2012b).

Table 3-10. Chronology of Groundwater Modeling Activities	
December 28, 2012	ARC submittal of the *Draft Groundwater Flow Model Work Plan for the Yerington Mine Site* (SSPA 2012c).
March 29, 2013	EPA (2013d) provided comments on the *Draft Groundwater Flow Model Work Plan for the Yerington Mine Site* (SSPA 2012c).
May 21, 2013	ARC submittal of the *Groundwater Flow Model Work Plan - Revision 1* (SSPA 2013) included as Attachment E to the Revised Groundwater RI Work Plan, along with responses to EPA comments on the *Draft Groundwater Flow Model Work Plan* (SSPA 2012c).
March 18, 2014	ARC submittal of the *Groundwater Flow Model Yerington Mine Site* (SSPA 2014). This report synthesized available hydrologic and geochemical information into a quantitative representation of the current and historic HCSM. The report also contained: 1) documentation of the study goals; 2) a discussion of the modeling strategy and assumptions; 3) details about model construction, calibration and validation; 4) a summary of model predictions; and 5) an analysis of the uncertainty associated with the model predictions.
October 28, 2014	EPA provided comments on the *Groundwater Flow Model Yerington Mine Site* (SSPA 2014).
February 3, 2015	ARC submits the *Flow Model "Supplemental" Materials* (SSPA 2015) in response to EPA comments.
May 18, 2015	EPA (2015b) provided comments on the *Flow Model "Supplemental" Materials* (SSPA 2015) and approved the *Groundwater Flow Model Yerington Mine Site* (SSPA 2014).

Based on review of the *Flow Model Supplemental Materials* (SSPA 2015), EPA (2015b) constrained the modeling objective and approved the groundwater flow model, noting that: "The primary goal foreseen for the Yerington groundwater model is to provide a management tool that can be used to evaluate possible remediation options. As such, its greatest value will be in allowing short-term comparisons of remedial designs and possible effectiveness of different remediation scenarios using a common tool and less so in predicting long-term migration of contaminants. It appears that this tool is adequate for that purpose".

The groundwater flow model is provided in Appendix J-4. The flow model domain, which encompasses an area of approximately 86 square miles, consists of that portion of the Mason Valley west of the Walker River and north of Mason that is underlain by saturated alluvium (Regional Domain). Nested within the model domain is the Study Area which encompasses an area of approximately 23 square miles that is bounded to the north by Campbell Lane, to the west by the Singatse Range, to the east by a north-south trending line located one mile east of Highway 95, and to the southeast by the Walker River (Local Domain). The Local Domain is nested within the Regional Domain so that appropriate boundary conditions along the northern and eastern boundaries of the overall model domain can be calculated. In addition, the model domain is subdivided to reflect two different sources of data, which may differ in data quality.

The vertical extent of the model domain extends from the ground surface to the alluvial/bedrock contact and into the portions of the bedrock groundwater system in hydrologic communication with the alluvial aquifer. The model domain extends laterally to include monitor well locations for identifying background groundwater quality and groundwater impacted by mining and other anthropogenic activities.

Since 2005, hydrogeologic data within the Local Domain have been and continue to be collected as part of the RI process, pursuant to EPA-approved planning documents and work plans. Thus, these data are high quality and there is a high degree of confidence in the data. Hydrogeologic data from outside the Local Domain but within the Regional Domain are from multiple sources and are of uncertain quality. Much of these data are from the USGS (e.g., water-level data) and the NDWR (e.g., well logs).

Temporal (e.g., seasonal, annual) variations in groundwater flow patterns and chemical concentrations continue to be assessed due to variability in hydrologic stresses on the groundwater system. Monitor wells installed for groundwater characterization purposes continue to be routinely monitored pursuant to the GMP (BC 2012a) to address temporal aspects of the study within the Local Domain. Within the Regional Domain, available water-level and surface water flow data from the USGS and NDWR will be used to assess temporal variations in groundwater conditions.

3.3.5 Chemical Transport Evaluations

The technical and programmatic framework for characterizing groundwater geochemical conditions and assessing geochemical processes that affect the release and subsequent mobility or attenuation of COIs during groundwater transport in the Study Area was presented as DQO #3 in Revised Groundwater RI Work Plan (BC 2014a).

Table 3-11 summarizes the chronology of investigations, evaluations, communications, and documents related to chemical transport evaluation.

Table 3-11. Chronology of Activities to Determine Geochemical Mobilization/Attenuation Processes

2008	The Second-Step HFA Work Plan (BC 2007b) included collecting and archiving redox-preserved samples of saturated and unsaturated alluvium. EPA technical staff observed the redox-sample collection and archiving methods, and provided input on locations and depth intervals for collecting an initial set of samples. These initial samples were collected for use in a "methods development" phase of work intended to develop Site-specific testing procedures.
June 21, 2010	ARC submitted the *Draft Aquifer Solids Testing Work Plan* (BC 2010g).
September 13, 2010	EPA (2010a) provided comments on the *Draft Aquifer Solids Testing Work Plan* (BC 2010g).
September 21, 2010	ARC submitted the *Aquifer Solids Testing Work Plan - Revision 1* (BC 2010e), which was revised in response to EPA comments.
September 30, 2010	EPA (2010b) approved the *Aquifer Solids Testing Work Plan - Revision 1* (BC 2010e).
2011	ARC developed Site-specific procedures and methods to physically separate redox-preserved samples into solid and liquid fractions for subsequent characterization of total metals concentrations, mineralogy, and porewater chemistry.
February 28, 2012	EPA technical staff visited the testing laboratory (Hazen Research, Inc. in Golden, Colorado) and observed the Site-specific testing procedures.
August 17, 2012	ARC submittal of *SOP-23: Aquifer Solids Testing SOP - Redox-Preserved Sample Preparation and Testing* (BC 2012c).
September 26, 2012	EPA (2012g) transmitted comments on *SOP-23: Aquifer Solids Testing SOP- Redox-Preserved Sample Preparation and Testing* (BC 2012c).
October 15, 2012	ARC submittal of *SOP-23: Aquifer Solids Testing SOP - Redox-Preserved Sample Preparation and Testing - Revision 1* (BC 2012d).
October 22, 2012	EPA (2012d) approval of SOP-23 Revision 1, pending minor changes. These minor changes were incorporated into SOP-23 Revision 2, included as Appendix H-1 to the Revised Groundwater RI Work Plan (BC 2014a).
February 7, 2014	ARC submitted the Revised Groundwater RI Work Plan (BC 2014a), which included: 1) DQO #3 pertaining to geochemical attenuation/mobilization; 2) the thermodynamic data for Site-specific geochemical modeling; and 3) Site-specific distribution coefficients (a simple, lumped-parameter variable that describes either the relative affinity of the aquifer matrix for a particular ion or the mobility of the ion in a groundwater flow system) based on chemical concentrations in co-located aquifer sediment and groundwater samples.
October 9, 2014	EPA (2014b) approved the Revised Groundwater RI Work Plan including the thermodynamic data presented in Appendix H-4 for Site-specific geochemical modeling, and directed ARC to prepare a Groundwater Geochemical Characterization Data Summary Report.
December 30, 2014	ARC submitted the *Groundwater Geochemical Characterization Data Summary Report* (BC 2014c). As noted in ARC's transmittal letter, the document partially fulfilled the requirements for the geochemical characterization and ARC recommended additional refinements to the thermodynamic database for geochemical modeling.
April 27, 2015	ARC transmitted recommendations to EPA for refining the thermodynamic database to be used for geochemical modeling (via e-mail).
May 4, 2015	EPA approved ARC's recommendations on refining the thermodynamic database to be used for geochemical modeling (also via e-mail).
September 23, 2015	EPA, ARC and other stakeholders agreed during a conference call that geochemical characterization to be performed for the OU-1 RI should focus on geochemical modeling of: 1) controls on the fate and transport of key COIs anticipated to drive decision-making in the FS; and 2) other chemicals that may affect their mobility and transport in groundwater.
December 11, 2015	ARC submitted the *Groundwater Geochemical Characterization Data Summary Report – Revision 1* (BC 2015e).

Table 3-11. Chronology of Activities to Determine Geochemical Mobilization/Attenuation Processes

July 2016	EPA conditionally approved the document on July 31, 2016 (EPA 2016b) subject to minor editorial changes and revision of statements referencing COI concentrations and spatial extent relative to background chemical concentrations presented in the *Background Groundwater Quality Assessment - Revision 2* (BC 2015c). EPA recommended that a revised version of the report be included as an appendix to the OU-1 RI Report.

The *Groundwater Geochemical Characterization Data Summary Report - Revision 2* (BC 2016a) is provided in Appendix J-5. The chemical speciation model and approach to calculating Site-specific distribution coefficients is summarized below.

Chemical Speciation Model Development

The specific objectives of the *Groundwater Geochemical Characterization Data Summary Report - Revision 2* are as follows:

- Describe the occurrence and distributions of select chemicals in Study Area groundwater based on the comprehensive set of monitor well data obtained during August 2014; and
- Using the EPA-approved thermodynamic database developed for the Site and geochemical modeling, evaluate the aqueous geochemical speciation of select COIs and potential formation of solid mineral phases in Study Area groundwater to assess chemical mobility/attenuation.

The primary geochemical data inputs used to identify the geochemical processes controlling chemical transport consist of: 1) groundwater chemical data from monitor wells installed in the groundwater zones in the alluvial aquifer and bedrock; 2) field parameter measurements that characterize the pH and redox status of the groundwater system (because these affect the aqueous speciation of inorganic chemicals and formation of mineral phases); and 3) thermodynamic data describing chemical reactions for each of the important aqueous species, minerals comprising the aquifer solids, gases, and adsorbed species. The geochemical assessment primarily relied on groundwater information associated with the August 2014 groundwater monitoring event. Approximately 2% of the August 2014 dataset had speciated charge imbalances outside the acceptable range of ±10%, and groundwater data obtained in October 2014 were substituted for August 2014 data.

Geochemical modeling using the Site-specific thermodynamic database with PHREEQC version 3.1.5 was conducted to determine the chemical speciation of aqueous constituents and the saturation indices of solid mineral phases in equilibrium with the groundwater samples. The geochemical modeling did not involve adsorption to aquifer soil/sediments or organics in aquifer materials. Details regarding the development of the Site-specific thermodynamic database are provided in Appendix J-5 and key modifications are discussed briefly below.

The WATEQ4F database was used as the starting point for database development because its major-element data are consistent with the Nordstrom et al. (1990) data compilation, which is a reliable and internally-consistent data set. Subsequently, the WATEQ4F database was modified by replacing aqueous speciation and solid-phase solubility data for uranium, phosphate, vanadium, sulfide, arsenic and copper with new data that have been critically reviewed by federal agencies (e.g., compilations prepared by the Nuclear Energy Agency were the principal sources of the uranium data in the ARC database) or in the peer-reviewed literature (e.g., Dong and Brooks 2006). Uranyl species $Ca_2UO_2(CO_3)_3^0$, $CaUO_2(CO_3)_3^{-2}$, $Mg_2UO_2(CO_3)_3^0$ and $MgUO_2(CO_3)_3^{-2}$ are of particular importance in evaluating the mobility of uranium; therefore, the thermodynamic data for these constituents were added to the Site-specific database. Thermodynamic solubility data for schwertmannite (an oxyhydroxide sulfate mineral) reported by Bigham et al. (1996) and confirmed by Sánchez-España et al. (2011) were included in the database. In addition, thermodynamic solubility data reported by Bourrié et al. (1999) for three hydroxy-green rusts were included in the database.

PHREEQC is a geochemical software model distributed by the USGS. The model assumes equilibrium mass transfer and does not account for the kinetics of mineral precipitation and dissolution reactions using applicable reaction rate laws (Parkhurst and Appelo 1999; EPA 2007b). Chemical speciation modeling describes the distribution of chemical mass between aqueous and solid mineral phases, and hence, predicts the geochemical conditions under which various constituents might be sequestered by mineral precipitation or remain mobile in the groundwater flow system. Both chemical speciation and mineral precipitation are pertinent data for evaluating the mobility of constituents in the groundwater system.

Information generated from the geochemical assessment is incorporated into the discussion of contaminant fate and transport in Section 6.0, and will be used to guide the development of quantitative approaches to representing chemical transport in the numerical groundwater flow model (SSPA 2014) to evaluate various remedial alternatives during the FS. As noted by the EPA (2016b), decisions will be made during the FS regarding the most appropriate reactive transport modelling approach and whether it will be necessary and/or beneficial to integrate the models or how that can be accomplished to efficiently meet the technical needs of the OU-1 RI/FS without introducing unnecessary complexity to the modeling efforts.

Distribution Coefficients

The partition (distribution) coefficient (K_d) is a simple, lumped-parameter variable that is used to assess contaminant transport by describing either the relative affinity of the aquifer matrix for a particular ion or the mobility of the ion in a groundwater flow system (EPA 2007b; Freeze and Cherry 1979).

The initial approach to developing Site-specific distribution coefficients based on chemical concentrations in co-located groundwater and aquifer sediment samples was presented in the Revised Groundwater RI Work Plan (BC 2014a) and is reproduced in this OU-1 RI Report as Appendix J-6. The approach to developing the distribution coefficients is summarized below.

Distribution coefficients were calculated for a variety of chemicals in Site groundwater including aluminum, arsenic, barium, boron, calcium, chloride, chromium, cobalt, copper, fluoride, iron, lead, lithium, magnesium, manganese, molybdenum, nickel, nitrate, potassium, selenium, sodium, sulfate, uranium, vanadium, and zinc. Distribution coefficients were not calculated for parameters that were only infrequently detected in groundwater or are not likely to be the subject of FS transport modeling including alkalinity, antimony, beryllium, cadmium, mercury, phosphorous, silica, silver, strontium, thallium, tin, and titanium.

Site-specific distribution coefficients were calculated using data from a single set of soil samples that were collected during the borehole drilling for monitor well installation and two distinct sets of water quality data. Soil samples were analyzed for a variety of bulk chemical concentrations (analyses were performed on liquid extracts from treatment of the solid samples by microwave-assisted digestion using EPA Method 3051A).

The first set of water quality data used in K_d calculations was the zonal water quality data that were collected at the time of borehole drilling. As discussed in Section 3.2.1, zonal groundwater samples were analyzed only for sulfate, uranium and arsenic. These data were collected over small depth intervals, typically ranging from three to five feet. Co-located zonal groundwater and soil samples were collected at multiple depth intervals in 13 locations throughout the Site that included B/W-1, B/W-2, B/W-3, B/W-4, B/W-11, B/W-31, B/W-32, B/W-42, B/W-46, B/W-61, B/W-62, B/W-65, and B/W-66.

The second set of water quality data used in K_d calculations included groundwater quality data obtained during quarterly sampling events from 15 monitor wells typically having a screen interval length of 20 feet. Monitor well samples were analyzed for the broader set of constituents listed in Table 3-4. The soil sample data used in the calculations were selected such that the sample intervals were within the screened interval of the well. The wells considered in this portion of the analysis were B/W-2D1, B/W-3I, B/W-4I, B/W-4D1, B/W-11D2, B/W-31S1, B/W-31S2, B/W-32S, B/W-42S, B/W-46S, B/W-61S, B/W-62S, B/W-65S, B/W-66S, and B/W-67S. The quarterly groundwater quality results collected closest to the date of the zonal soil sample collection for each particular well were used to calculate K_d values to minimize potential effects from variability in groundwater concentrations over time.

The distribution coefficient is calculated as the ratio of the concentration of a chemical adsorbed onto the solid phase (commonly expressed as milligrams [mg] of chemical per kilogram [kg] of solid) to the dissolved concentration of the chemical in the water (mg of chemical per liter [L] of solution) at equilibrium (Freeze and Cherry 1979). Based on the formulation below, K_d values are expressed in units of L/kg.

$$K_d = \frac{C_{\text{adsorbed}}}{C_{\text{water}}}$$

where: C_{adsorbed} = adsorbed chemical concentration (mg/kg)
C_{water} = dissolved chemical concentration in water (mg/L)

Initially, distribution coefficients were calculated using water chemical data and chemical concentrations in the aquifer sediment sample that were determined using EPA digestion Method 3051A. Because of the relatively aggressive digestion method, the aquifer sediment data represent the bulk (i.e., total) chemical concentration in the solid rather than the adsorbed chemical concentration. As recommended by EPA (1999), trace metals that are present in crystalline lattice sites of minerals present in soils do not participate in adsorption/desorption reactions and should not be included in the K_d calculation. Consequently, the original K_ds were revised for this OU-1 RI Report. To better estimate K_ds, the adsorbed amount of a chemical was estimated by subtracting the average chemical concentration in Sub-area A-1 soils (BC 2009b) from the bulk (i.e., total) chemical concentration in the individual aquifer sediment sample, as follows:

$$K_d = \frac{C_{\text{soil}} - C_{\text{bkgd}}}{C_{\text{water}}}$$

where: $C_{\text{adsorbed}} = C_{\text{soil}} - C_{\text{bkgd}}$
C_{soil} = bulk chemical concentration in the solid (mg/kg)
C_{bkgd} = average background chemical concentration in the solid (mg/kg)
C_{water} = dissolved chemical concentration in water (mg/L)

The revised Site-specific distribution coefficient values are presented in the contaminant fate and transport discussion in Section 6.0.

3.3.6 Background Groundwater Quality Assessment

Identifying background water types and defining the extent of mine-impacted groundwater was specified in the 2007 SOW (EPA 2007a) and identified as DQO #1 in the Revised Groundwater RI Work Plan (BC 2014a). The background groundwater quality assessment (BGQA) has been integrated into groundwater characterization activities performed in the Study Area since 2007.

Table 3-12 summarizes the chronology of the BGQA and other background-related orders, investigations and documents.

Table 3-12. Chronology of Activities Related to Establishing Background Groundwater Quality

2004-2008	Monitor wells B/W-13S, B/W-14S, B/W-15S, B/W-20S, and B/W-21S installed adjacent to Walker River and hydraulically up-gradient of the Site, pursuant to the First-Step HFA Work Plan (BC 2005) and the Second-Step HFA Work Plan (BC 2007b).
2007	Characterization of background groundwater quality is required under the Administrative Order for Remedial Investigation and Feasibility Study (RI/FS), CERCLA Docket No. 9-2007-0005 dated January 12, 2007.
2007-2011	Background characterization conducted pursuant to the *2010 Groundwater Monitor Well Installation Work Plan - Revision 2* (BC 2010c), *Agricultural Fields Characterization Work Plan - Revision 2* (BC 2010d), *On-Site Monitor Installation Work Plan - Revision 1* (BC 2011a), and the *Addendum to the On-Site Monitor Well Installation Work Plan* (ARC 2011).
August 17, 2011	Groundwater technical meeting with EPA, ARC and stakeholders to discuss progress of the phased approach to groundwater RI activities, which resulted in concurrence to accelerate background groundwater characterization activities and an EPA request for ARC to prepare and submit a BGQA. Also discussed were installation of additional well clusters (B/W-12R, B/W-17, and B/W-22R) in areas south and southwest of the Site, pursuant to the *On-Site Monitor Well Installation Work Plan* (BC 2011a), to support background groundwater characterization.
September 7, 2011	ARC submitted the *Addendum to the On-Site Monitor Well Installation Work Plan* (ARC 2011) proposing additional well clusters at B/W-12R, B/W-17, and B/W-26R to support background groundwater characterization.
September 28, 2011	ARC submitted the *Draft Background Groundwater Quality Assessment* (BC 2011c), which recommended the installation of three monitor well clusters (B/W-56, B/W-57 and B/W-58) located in the northern portion of the Study Area.
September 30, 2011	The *Addendum to the On-Site Monitor Well Installation Work Plan* (ARC 2011) was approved by EPA (2011b).
December 7, 2011	Via e-mail communication, ARC requests and receives EPA approval to install well clusters B/W-56, B/W-57, and B/W-58 proposed in the Draft BGQA during implementation of the *On-Site Monitor Well Installation Work Plan - Revision 1.*
February 7, 2012	EPA (2012a) provided comments on the Draft BGQA.
March 19, 2012	ARC (2012d) submitted a request to implement a comprehensive hydrologic tracer sampling event that was larger in scope than the sampling event proposed in the *On-Site Monitor Well Installation Work Plan - Revision 1* (BC 2011a) and to eliminate select hydrologic tracers. Hydrologic tracers are considered one line of evidence that may be useful for determining background groundwater quality.
April 18, 2012	ARC (2012e) submitted responses to EPA comments on the Draft BGQA.
April 27, 2012	EPA approved the comprehensive hydrologic tracer sampling event and request to eliminate select tracers (EPA 2012b).
May 2012	Comprehensive hydrologic tracer sampling event conducted concurrent with the 2Q 2012 quarterly groundwater monitoring event.
August 28, 2012	Groundwater technical meeting with EPA, ARC, and other stakeholders to clarify and resolve comments on the Draft BGQA.
November 19, 2012	Submittal of final ARC responses to EPA comments on the *Draft BGQA* and the *Background Groundwater Quality Assessment - Revision 1* as Attachment A to the *Draft Site-Wide Groundwater Operable Unit (OU-1) Remedial Investigation Work Plan* (BC 2012b).

Table 3-12. Chronology of Activities Related to Establishing Background Groundwater Quality

June 26, 2013	Submittal of the *Draft Additional Monitor Well Work Plan* (BC 2013e) as Attachment B to the *Draft Site-Wide Groundwater Operable Unit (OU-1) Remedial Investigation Work Plan* (BC 2012b), to address data gaps identified by ARC and EPA, including groundwater conditions in the north and northeastern portion of the Study Area. ARC recommended sampling of all wells proposed for hydrologic tracers to supplement data from the May 2012 hydrologic tracer sampling event.
July 29, 2013	EPA (2013e) provided comments on the *Draft Additional Monitor Well Work Plan*.
October 8, 2013	ARC submitted the *Additional Monitor Well Work Plan - Revision 1* (Additional Well Work Plan; BC 2013b). This work plan was also included as Attachment B to the Revised Groundwater RI Work Plan (BC 2014a). EPA (2014b) approved the Revised Groundwater RI Work Plan including Attachment B on October 9, 2014.
September 2013 to July 2014	Installation, development, and hydraulic testing of new wells installed pursuant the Additional Well Work Plan (BC 2013b).
August 2014	Hydrologic tracer sampling of new wells installed pursuant to the Additional Well Work Plan (BC 2013b).
May 2015	Receipt of hydrologic tracer laboratory analytical results for new wells installed pursuant to the Additional Well Work Plan (BC 2013b).
June 11, 2015	ARC submitted the *Additional Monitor Well Installation Data Summary Report* (BC 2015d).
July 2, 2015	ARC submitted the *BGQA – Revision 1 - Revision 2* (BC 2015c), which described: 1) the technical approach, scope, rationale and methods to establish background groundwater quality; and 2) multiple supporting lines of evidence for defining the extent of mine-impacted groundwater and identifying other anthropogenic groundwater impacts.
February 11, 2016	EPA (2016c) provided comments on the *Background Groundwater Quality Assessment - Revision 2*.
June 14, 2016	ARC (2016b) provided responses to EPA Comments on the *Background Groundwater Quality Assessment - Revision 2*.
June 29, 2016	EPA, ARC and other project stakeholders held a groundwater technical meeting to discuss the background assessment.
September 27, 2016	EPA (2016d) letter to ARC providing final direction on the background groundwater quality assessment including an attachment (EPA 2016e) dated September 2, 2016 and titled EPA Memorandum, Subject: Yerington Mine Site, Yerington Nevada (16-R09-003) Responses to ARC Responses to Comments on the Background Groundwater Quality Assessment - Revision 2.
November 11, 2016	ARC submitted the *Background Groundwater Quality Assessment - Revision 3* (BC 2016b).
February 16, 2017	EPA (2017) approved the *Background Groundwater Quality Assessment - Revision 3*.

The *Background Groundwater Quality Assessment - Revision 3* is provided in Appendix J-7 and the results of the background assessment are integrated into the discussion of the nature and extent of contamination in Section 5.0.

3.4 Former Domestic Well Monitoring and Bottled Water Programs

Water quality monitoring of domestic, commercial, and irrigation wells (collectively referred to as domestic wells) located near the Site has evolved over time.

Domestic well monitoring began in late 1983. Up through early 2009, domestic well monitoring activities were performed pursuant to:

- Paragraphs 15(e) and 15(f) of the Unilateral Administrative Order for Initial Response Activities, Docket No. 9-2005-0011 (2005 Order);
- Section 6.0 of the 2007 SOW; and
- The Administrative Order on Consent and Settlement Agreement for Removal Actions and Past Response Costs, Docket No. 09-2009-0010 (2009 Order).

In March 2009, EPA requested that ARC expand the domestic well monitoring program because of the EPA-approved shutdown of the PWS to evaluate OU-1 hydrogeologic conditions. The expanded domestic well monitoring program has been conducted pursuant to the *Domestic Well Monitoring Plan - Revision 3* (DWMP; BC 2010b), which was prepared as an addendum to the Site-Wide QAPP (ESI and BC 2009). Results of domestic well monitoring have been used to: 1) characterize the quality of groundwater used for drinking water or other domestic water supply purposes; 2) assess potential risk, if any, to human health and the environment by the use of groundwater extracted by domestic wells for drinking water or agricultural purposes; and 3) determine eligibility for receiving bottled water as part of an interim response action.

The Bottled Water Program was initiated in March 2004. Domestic well owners were deemed eligible to receive bottled water if uranium concentrations measured during domestic well monitoring exceeded 25 µg/L.

The number of wells/properties included in the DWMP and Bottled Water Program was substantially reduced in 2016 (ARC 2016a; EPA 2016f). As part of the settlement entered in the class action lawsuit *Roeder et al. v. Atlantic Richfield Company et al.*, D. Nev., Case No. 3-11-cv-00105-RCJ-WGC ("Roeder Settlement Agreement"), ARC provided funding to the City of Yerington to extend municipal water service to then-existing residences located within that part of the settlement class area that was also within the City's projected future service area. Domestic well owners who connected to the City of Yerington's municipal water system could elect to either abandon their well or apply for a state permit to authorize withdrawals of groundwater for outdoor use only (landscape watering). Each property owner who received a connection to the City Water System executed and recorded an environmental covenant either prohibiting future domestic use of groundwater altogether or limiting it to outdoor purposes.

Construction of the expanded water system began in the fall of 2014 and the construction of new mains and service connections was completed in June 2016. The first phase of well abandonments and system testing was completed as of August 1, 2016. The water system is functional, and domestic wells for all participating property owners have been abandoned or disconnected from the residences within the expansion area. A relatively small number of domestic wells located within the area of mine-impacted groundwater (see Figure 3-11) were not disconnected or converted to outdoor use only in 2016. ARC has been in communication with the owners of most of these wells, and disconnections for all but a few are scheduled to occur in 2017.

SECTION 4.0
PHYSICAL CHARACTERISTICS OF THE STUDY AREA

This section describes the physical characteristics of the Study Area including demographics, land use, climate, topography, geology and soils, hydrology and groundwater, ecological setting, and vegetation.

4.1 Demographics and Study Area Land Use

Lyon County, Nevada covers approximately 1,993 square miles, and its population in 2013 was 51,585 (U.S. Census Bureau 2015). Communities near the Site include Yerington (population 3,486), Weed Heights (population 500), and the YPT (approximate population 575). The regional population and industrial centers near the Site include Fernley (47 miles north), Fallon (59 miles northwest), Hawthorne (57 miles southeast), and Reno (85 miles northwest). Yerington's economic base is primarily agriculture.

Land use has included mine operations, ranching, agriculture, urban development, establishment of the YPT colony, BLM range land, and residential development. Mason Valley has long been the largest agricultural area in the Walker River basin and the most productive area in Nevada. In 2000, a total of 88,600 acres of irrigated land was mapped in the Walker River basin. Total irrigated land included 39,100 acres (44%) in Mason Valley (USGS 2009a).

4.2 Climate

Nevada is located on the leeward side (rain shadow) of the Sierra Nevada mountain range, which results in a dry climate. The climate in Lyon County is warm and arid. Snow melt is the primary natural source of streamflow and groundwater recharge in the Walker River Basin (USGS 2009b). The average annual precipitation in Yerington is approximately 5.1 inches, and average snowfall is 6.7 inches (Western Regional Climate Center [WRCC] 2015). The annual average precipitation rate is low relative to the regional pan evaporation rate of about 69 inches per year. The average monthly temperature for the period of record (March 1, 1894 through January 20, 2015) ranges from a maximum of 92.4 degrees Fahrenheit (°F) in July to a minimum of 17.8°F in January.

Tables 4-1 and 4-2 summarize monthly climate data for the City of Yerington weather station for the period from 1894 through 2015 (WRCC 2015). Table 4-1 summarizes monthly minimum and maximum temperatures, and monthly precipitation. Table 4-2 provides monthly average, maximum, and minimum precipitation values, and the one-day maximum rainfall event.

Table 4-1. Average Monthly Climate Data for the Yerington Weather Station #269229 (1894 - 2015)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Average Maximum. Temperature (°F) [1]	46.2	52.5	59.7	67.0	75.1	83.8	92.4	91.0	83.1	70.8	56.8	47.1	68.8
Average Minimum Temperature (°F) [1]	17.8	22.6	27.0	32.4	40.2	46.8	52.7	50.4	42.3	33.3	23.5	17.9	33.9
Average Total Precipitation[2]	0.57	0.53	0.42	0.41	0.63	0.46	0.26	0.25	0.24	0.35	0.42	0.52	5.06
Average Snow Fall [2]	1.9	1.2	1.0	0.4	0.1	0.0	0.0	0.0	0.0	0.1	0.8	1.2	6.7

Notes:

1) °F = Degrees Fahrenheit;
2) Precipitation values in inches

Table 4-2. Precipitation Data for the Yerington Weather Station #269229 (1894 - 2012)

Month	Mean	Maximum	Year	Minimum	Year	1-Day Maximum (Year)
January	0.57	3.67	1916	0.00	1915	1.40 (1943)
February	0.53	2.62	1962	0.00	1953	1.28 (1962)
March	0.42	1.83	1991	0.00	1914	0.98 (1941)
April	0.41	1.80	1990	0.00	1916	1.30 (1990)
May	0.63	3.04	1995	0.00	1916	1.90 (1939)
June	0.46	2.01	1997	0.00	1895	1.02 (1997)
July	0.26	2.00	2003	0.00	1916	1.75 (1984)
August	0.25	2.37	1983	0.00	1895	1.46 (1983)
September	0.24	2.15	1955	0.00	1920	2.02 (1955)
October	0.35	3.02	1993	0.00	1895	1.83 (1993)
November	0.42	2.39	1965	0.00	1894	1.04 (1974)
December	0.52	3.51	1955	0.00	1917	2.00 (1955)
Annual	5.06	10.58	1983	1.61	1947	2.02 (1955)

Notes:

1) Precipitation values presented in inches.
2) Most minimum values (11 of 12 months) of 0.00 inches were recorded prior to 1920.

Wind speed and direction at the Site vary on the local scale due, in part, to the heterogeneous natural topography (i.e., micro-climates) and modified topography due to surface mining operations. Meteorological data collected since 2002 indicate that wind direction is variable at the Site with no quadrant representing over 50% of the total measurements. However, when wind speeds are above 15 miles per hour, a predominant wind direction from southwest to northeast has been documented (BC, 2008c).

4.3 Topography

The Site is in Mason Valley, which is a north-south trending structural valley (graben) within the Basin and Range physiographic province filled with up to 1,000 feet of unconsolidated sediments. Mason Valley occupies a structural graben (i.e., down-dropped faulted basin) immediately east of the Singatse Range, Desert Mountains to the north, and the Wassuk Range to the east. Elevations in the Wassuk and Singatse Ranges reach 9,000 and 6,700 feet amsl, respectively (Huxel and Harris 1969). The valley ranges in width from about nine miles in the south to nearly 20 miles in the central part, and is about 40 miles long. The valley floor ranges from approximately 4,600 feet amsl in elevation at the south end to 4,290 feet amsl at the north end. The center of the Process Areas is at an elevation of approximately 4,450 feet amsl.

4.4 Ecological Setting

The Study Area is part of the Great Basin sagebrush-steppe ecosystem (Lopes and Allander 2009a). The Singatse Range to the west and the Mason Valley are dominated by a scrub brush community, except along the Walker River with s riparian community. These communities support resident and migrating birds, mammals, reptiles, amphibians and invertebrates. The Walker River flows within 0.25 mile of the southeastern end of the Site. Although riparian systems comprise an extremely small fraction of the Great Basin region, they are critical centers of biodiversity; more than 75% of the species in the region are strongly associated with riparian vegetation. The Study Area ecosystem has been impacted by anthropogenic activity, including mining, cattle ranching and agriculture. Site activities have resulted in the large piles of tailings and waste rock, which could be used as vantage points for predators surveying the surrounding area, and steep-sloped piles may potentially be used by nesting birds (e.g., swallows).

4.5 Vegetation

The terrestrial ecosystem in the Study Area not disturbed by anthropogenic activities supports an arid sagebrush-steppe vegetative community that is dominated by sagebrush and other low-lying woody vegetation, interspersed with a variety of forbs and grasses. The scrub brush community in the Study Area is predominately sparse greasewood, sagebrush, and rabbitbrush (Lopes and Allander 2009a). Livestock and wildlife preference for grasses contributes to the domination of vegetation in this system by sagebrush and other shrubs (Ricketts et al. 1999).

The riparian community along the Walker River supports a variety of trees, shrubs and grasses (USGS 2009b). Vegetation can be dense with large trees such as Freemont cottonwood, Russian olive, and invasive Tamarisk (Salt Cedar). Saltbush may be abundant where riverbank soil is saline. As previously stated, many areas on the Site have been disturbed to varying degrees by historical mining activities, but still retain areas of sandy soil interspersed with vegetation typical of the sagebrush-steppe vegetative mix of shrubs, forbs, and grasses. Mason Valley has long been the most agricultural part of the Walker River basin and remains one of the most productive agricultural areas in Nevada (Lopes and Allander 2009a). During the growing season, agricultural fields to the north may include onions, alfalfa, winter wheat and sorghum.

4.6 Regional and Site Geology

Mason Valley is a structural graben that has been filled with unconsolidated alluvial deposits derived by erosion of the emerging mountain horst blocks, and from materials transported into the valley by the East and West Walker Rivers (Huxel and Harris 1969). The alluvial apron and the valley floor are the two major land-forms comprising the lowland area. The mountain blocks, and bedrock beneath the basins, are primarily composed of granitic, metamorphic, and volcanic rocks of Precambrian to Tertiary age and, to a lesser extent, of consolidated to semi-consolidated sedimentary rocks of Paleozoic to Cenozoic age (Heath 1984; Proffett and Dilles 1984; Proffett 1977). Faults along the eastern margin of the Singatse Range are gently- to steeply-dipping normal faults that generally trend north-northeast (Figure 4-1) and dip to the east (Proffett and Dilles 1984; Proffett 1977). Faulting caused moderate to steeply westward tilting of the bedrock.

Unconsolidated deposits underlying the valley floor are collectively termed valley-fill deposits and, where saturated, constitute the valley-fill alluvial aquifer. Huxel and Harris (1969) reported that the valley-fill deposits include four stratigraphic units: 1) younger alluvium, including lacustrine deposits associated with Pleistocene Lake Lahontan (Reheis 1999); 2) younger alluvial fan deposits resulting from the uplift of mountain blocks; 3) older alluvium; and 4) older alluvial fan deposits.

Older and younger alluvial fan deposits are generally coarse-grained, poorly-sorted, and have relatively few inter-bedded clay lenses (Huxel and Harris 1969; Plume 1996; Mifflin 1988). The grain size of the valley-fill deposits generally decreases toward the center of Mason Valley (Huxel and Harris 1969; Plume 1996), and transitional facies have been identified in the Study Area (BC 2008c). Basin-scale variability in valley-fill deposits leads to variation in hydraulic properties of the alluvial aquifer, which is discussed in Section 4.9.6.

Bedrock and alluvial deposits in Mason Valley, and their associated hydrologic characteristics, are summarized in Table 4-3, which is reproduced from Huxel and Harris (1969). Lake Lahontan lacustrine deposits of Pleistocene age have been eroded or reworked by the Walker River as it meandered across Mason Valley. Lake Lahontan strandline units, consisting of beach, bar, and beach-ridge deposits, were formed for the most part on alluvial aprons between altitudes of 4,340 and 4,375 feet amsl (Huxel and Harris 1969). The occurrence of Lake Lahontan within Mason Valley had a relatively short life, and probably was less than 60 feet deep during much of its existence (Morrison 1964).

Table 4-3. Mason Valley Geologic Units: Lithologic and Hydrologic Characteristics (from Huxel and Harris, 1969)

Geologic Age		Geologic Unit		Thickness (feet)	Lithology	Hydrologic Characteristics
Quaternary	Pleistocene to Holocene	Valley Fill	Younger Alluvium	0-100±	Loose, well-sorted sand, gravel, cobbles, and boulders, with layers of silt or sandy clay. Comprises channel, flood-plain, and terrace deposits laid down by the Walker River and its major tributaries, plus strand-line and bottom deposits of Pleistocene Lake Lahontan. Bottom deposits consist of silt, fine sand, and clay.	Channel and flood-plain deposits are highly permeable and are good aquifers. Significant infiltration of surface waters, which recharges the alluvial-fill aquifer, occurs through the coarse deposits in the Holocene channels of the Walker River.
			Younger Fan Deposits	0-100±	Poorly-sorted gravelly clay, sandy clay, and fine sand with occasional stringers and lenses of sand and gravel. Locally, derived from erosion of older rocks and deposits in Mason Valley; generally equivalent to younger alluvium.	In general, younger and older fan deposits are of low permeability. However, stock watering and mining wells penetrating buried sand and gravel deposits yield small to moderate amounts of water. Properly constructed, large-diameter wells may yield up to several hundred gpm.
	Pleistocene		Older Fan Deposits	0-700±	Sandy- to gravelly-clay with abundant cobbles and boulders and occasional lenses of semi-consolidated to cemented sand and gravel. Locally-derived from erosion of consolidated rocks of the surrounding mountains. Equivalent in part to older alluvium.	
			Older Alluvium	0-500±	Similar in lithology to younger alluvium described above. Deposited by ancestral Walker River; underlies valley floor at depths greater than 100 feet. Not exposed at land surface.	Constitutes largest and most productive aquifer in the area, with tested transmissibility as high as 270,000 gallons per day/foot. Wells yield up to 3,000 gpm.
Tertiary	Miocene and Pliocene	Consolidated Rocks	Sedimentary Rocks	--	Sandstone, mudstone, shale, marl, diatomite, and limestone. Includes interbedded tuffaceous rocks, lava flows, and breccia.	Consolidated rocks generally have low permeability. However, where they are fractured or jointed, they yield small to moderate amounts of water to wells.
	Oligocene to Pliocene		Volcanic Rocks	--	Rhyolite flows and tuff, andesite and dacite lava flows, breccia, and agglomerate. Includes interbedded sedimentary rocks and, locally, thin basalt flows with interbeds and scoriaceous basalt breccia.	
Cretaceous			Granitic Rocks	--	Granodiorite, quartz monzonite, and granite porphyry.	
Permian to Jurassic			Metamorphic Rocks	--	Metamorphosed andesite, basalt, and rhyolite flows, tuff and breccia, metamorphosed limestone, lime shale, dolomite, and gypsum and volcanically-derived sedimentary rocks.	

Bedrock in the Study Area forms a U-shaped graben structure that reaches its lowest point beneath the north end of the Hunewill Ranch, at an elevation of approximately 3,600 feet amsl (700 feet bgs). The elevations of the alluvium-bedrock contact, shown in plan view on Figure 4-2, clearly depict this graben structure in the Study Area. From its lowest elevation, bedrock rises in elevation south toward the Site. The U-shaped graben ends at the open pit and the alluvial-bedrock contact is exposed on the pit walls. The bedrock exposed in the open pit is the host rock for the Yerington copper porphyry deposit. East and west of the Site, bedrock rises to mapped outcroppings associated with the Singatse Range (west) and Singatse Spur (east; this term refers to two adjacent bedrock outcrops located east of the Site called the Ground Hog Hills and McLeod Hills as shown on Figure 4-2. At the north end of the Study Area, bedrock outcrops occur in the Sunset Hills area. In the northeast portions of the Study Area (i.e., toward the Mason Butte bedrock outcrop), bedrock rises in elevation. Range-bounding faults in the Study Area include steeply-dipping and shallower-dipping normal faults (Proffett and Dilles 1984).

The unconsolidated alluvial deposits in the Study Area were derived primarily from erosion of the uplifted mountain block of the Singatse Range, with minor deposition of fluvial sediments in the Walker River flood-plain. In addition, lacustrine deposits derived from ancestral Lake Lahontan occur north of the Site (Reheis 1999). Uplift and erosion of the Singatse Range formed the east-dipping alluvial fan deposits, which include distal facies that extend into the transitional environment. Concurrent with the development of the alluvial fan, flat-lying fluvial sediments (e.g., sands and gravels) were deposited in the Walker River flood-plain. Flat-lying clay-rich deposits have been preserved in the transitional setting, and these deposits are interpreted to have formed within the ancestral Lake Lahontan depositional environment.

Regional metal mineralization and hydrothermal alteration occurs in portions of Mason Valley, and the Singatse Range in particular, in areas of localized porphyry and skarn copper deposits. The Yerington copper porphyry district is located within the productive Walker Lane mineralized belt in western Nevada (Tetra Tech 2010). The Walker Lane is a northwest-trending zone of active crustal movement (i.e., right-slip transcurrent faulting) that extends for more than 500 miles from Las Vegas, Nevada to beyond Honey Lake, California (Bell and Slemmons 1979).

In addition to the Yerington and MacArthur open pit mines along the eastern margin of the Singatse Range, other areas of mineralization include the Bluestone and Ann Mason mines, and the Bear deposit. Areas of known mineralization and ore deposits in the Mason Valley are shown on Figure 4-3. The Bear deposit is located beneath the Sulfide Tailings and Hunewill Ranch, in a structurally-uplifted segment of the Singatse Range. The Pumpkin Hollow copper skarn deposit, located across Mason Valley from the Site, occurs along the margin of the intrusive rocks that host the Yerington porphyry copper deposit.

4.7 Surface Water Hydrology

The Mason Valley Basin (Basin no. 108, as defined by the NDWR) is located within the larger Walker River Hydrographic Basin (no. 9). The Walker River Hydrographic Basin extends from the Sierra Nevada Mountain Range above Bridgeport, California and Topaz Lake to Walker Lake located north of Hawthorne, Nevada. Most streamflows in the basin originate as snowmelt in the Sierra Nevada, with headwaters at elevations of more than 12,000 feet amsl (Lopes and Allander 2009a, 2009b).

The Walker River originates in two distinct headwater areas in the Sierra Nevada that source the East and West Walker Rivers (Figure 3-6). The East Walker River is sourced above Bridgeport, California. Streamflows are regulated before flowing into the Mason Valley. The West Walker River is sourced above Topaz Lake, a reservoir located along the California-Nevada border, and passes through the town of Wellington, Nevada on its way to the Mason Valley. The confluence of the East and West Walker Rivers occurs in Mason Valley at a location approximately seven miles upstream (three miles directly south) of the Site. The main stem of the Walker River flows north past the Site at the City of Yerington, traverses the geothermal discharge area near the town of Wabuska, exits the north end of Mason Valley at Walker Gap approximately 4.5 miles east of the town of Wabuska, and then turns south and empties into Walker Lake (a terminal lake with no outlet).

4.7.1 Surface Water Flows

Mason Valley is the largest irrigated agricultural area within the Walker River Basin including irrigated areas along the West and East Forks, and the main stem, of the Walker River. Key documents providing information on stream flows and water budgets in the Mason Valley include Huxel and Harris (1969), Lopes and Allander (2009b), and Carroll et al. (2010).

Each of these three documents present information on streamflows and water budgets for different periods of time. Appendix G-1 presents surface water flow information for 1948 to 2001, a period longer than addressed in these three documents. Streamflow and water budget information from these three documents and Appendix G-1 are summarized in Table 4-4 and discussed below.

Table 4-4. Summary of Mason Valley Streamflow and Water Budget Information

	Huxel and Harris (1969)	Lopes and Allander (2009b)	Carroll et al. (2010)	Flow Data Appendix G-1
Period of Record	1948 - 1965	1971 - 2000	1996 - 2006	1948 - 2011
	18-year Average	30-year Average	11-year Average	48-year Average (1)
Stream Inflows (acre-feet) (2)	216,000	269,000	277,832	207,900
Stream Diversions (acre-feet)	140,000	117,000	139,643	NA
Stream Outflows (acre-feet) (3)	107,200	138,000	129,471	80,400
Total Stream Loss (acre-feet) (4)	109,300	131,000	148,361	127,500
Stream Loss as Percent of Inflow	50%	49%	62%	NA
Irrigated Area (acres)	30,000	38,964	38,721	NA
Surface Water Diversion Rate (ft/yr) (5)	3.6	3.4	3.8	NA
Groundwater Pumpage (acre-feet/yr)	4,000	40,000	77,423	NA
Groundwater Application Rate (ft/yr) (6)	0.1	1.0	2.0	NA
Crop Consumption Rate (ft/yr)	1.0	1.6 (7)	2.9 - 3.1	NA

Notes:
1) Excludes 1979 - 1994 because flow data were not collected during winter months (October through March).
2) Sum of streamflow at Hudson (East Walker River) and Strosnider Ditch (West Walker River) gages (USGS gages 10300000 and 10293500, respectively).
3) Streamflow at Wabuska gage (USGS gage 10301500).
4) Total Stream Loss = Stream Inflows - Stream Outflows.
5) Surface Water Diversion Rate = Total Stream Loss/Irrigated Area.
6) Groundwater Application Rate = Groundwater Pumpage/Irrigated Area.
7) Value of 1.6 ft/yr from Myers (2001) cited by Lopes and Allander (2009b).
8) ft/yr = feet per year; % = percent; NA = not available

Lopes and Allander (2009b) provide a surface water budget for Mason Valley based on data collected from 1971 to 2000. Combined average annual inflows to Mason Valley were estimated to be 269,000 acre-feet per year. The average annual outflow from Mason Valley was estimated to be 138,000 acre-feet per year. The average net annual diverted surface water in Mason Valley was estimated to be 117,000 acre-feet per year. Stream infiltration and riparian evapotranspiration was estimated to be 14,000 acre-feet per year (Lopes and Allander 2009b).

An analysis of Walker River streamflow data from 1948 to 2011 (Appendix G-1) indicates a median annual flow at the confluence of the East and West Walker Rivers of 207,900 acre-feet. The minimum recorded flow was 65,900 acre-feet per year, and the maximum recorded flow was 596,500 acre-feet per year. Outflows from the Mason Valley are recorded near Wabuska, north of the Study Area. The median annual outflow was 80,400 acre-feet. The minimum recorded outflow was 15,800 acre-feet per year. The maximum recorded out flow was 417,900 acre-feet per year. In all months of all years, combined flows at the confluence of the East and West Walker Rivers were greater than outflows from the Mason Valley, with greater differences observed in summer months compared to winter months. Differences between inflows and outflows are accounted for by seepage losses, evapotranspiration and diversions for crop irrigation.

The disposition and routing of surface water within the Mason Valley is complex. Detailed information is provided in appendices to the *Groundwater Flow Model Yerington Mine Site* (SSPA 2014).

4.7.2 Recharge to the Alluvial Aquifer

Percolation of surface water is the primary source of groundwater recharge to the alluvial aquifer in the Mason Valley, with mountain-front recharge contributing significantly less (Carroll et al. 2010; Huxel and Harris 1969; Myers 2001; SSPA 2014). The amount of recharge derived by infiltration from stream channels, ditches, and percolation from flooded agricultural fields varies from year to year, depending upon the volume of Walker River flow entering the basin, the amount of surface water diverted from the river for irrigation, and the amount of available groundwater storage.

Huxel and Harris (1969) estimated that the annual recharge from the sources listed above ranged from 30,000 to 100,000 acre-feet, with an average of about 70,000 acre-feet, for the period from 1948 to 1965. These estimates were calculated as inflows minus the sum of surface-water outflows and consumptive use by crops and pastures, and assumed that all stream flows not consumptively used for irrigation or flowing out of the valley recharged the valley-fill alluvial aquifer. Carroll et al. (2010) estimated that recharge from the sources listed above ranged from 60,400 to 99,400 acre-feet per year for the time period 1996 to 2006, and noted the consistency between their more recent estimates and those provided by Huxel and Harris (1969).

The groundwater flow model water budget (SSPA 2014) indicates that the alluvial aquifer is primarily recharged by downward percolation from irrigated fields (49%), leakage from irrigation ditches such as the West and East Campbell Ditches (29%), infiltration from the channel of the Walker River (20%), and infiltration through bedrock of precipitation that falls on surrounding mountain ranges and minor tributary surface flows in ephemeral drainages (2%). Recharge from precipitation falling directly on the valley floor is negligible based on work by Huxel and Harris (1969) and Lopes and Allander (2009a, 2009b), as well as data from stable isotope (i.e., oxygen/deuterium) analysis of precipitation and groundwater (BC 2014a; EPA 2012b).

4.7.3 Surface Water Quality

Surface water quality is discussed below with a focus on data at sample locations SW-WR-01 (Walker River) and SW-WCD-01 (West Campbell Ditch), and chemicals considered primary indicators of mine-impacted groundwater (i.e., sulfate and uranium). A detailed analysis of the surface water quality data is presented in Appendix G-2. Chemical concentrations in Walker River and West Campbell Ditch samples are similar with low total dissolved solids (TDS) (110 to 300 mg/L; average: 194 mg/L) and relatively low sulfate (7.7 to 54 mg/L; average: 29 mg/L) and dissolved uranium (3.7 to 19 µg/L; average 9.3 µg/L). Surface water pH is slightly alkaline (7.72 to 8.36 s.u.; average: 8.05 s.u.). Temporal trends indicate more elevated major ion (e.g., sulfate, calcium and chloride) values and trace metal (e.g., dissolved arsenic and dissolved uranium) values in samples at both locations during the winter months relative to the summer months. Overall, the STORET surface water quality data are similar to the surface water quality data collected by ARC.

Shallow alluvial groundwater near the Walker River and West Campbell Ditch exhibits similar chemical characteristics to surface water quality, which is the primary source of groundwater in Mason Valley (Carroll et al. 2010; Huxel and Harris 1969; Myers 2001; SSPA 2014). General ion chemistry in groundwater was found to be statistically similar to surface water for five of eight major ions. Calcium, chloride, and sulfate were found to be higher in groundwater than surface water. Dissolved metals in groundwater were found to be statistically similar to surface water for some parameters (14 of 27) but different for others (13 of 27). However, differences between surface water and Shallow alluvial groundwater in major ions and dissolved metals reflect changes in geochemical conditions in groundwater arising from the effects of residence time, presence (or absence) of dissolved atmospheric gasses, localized mineralization, and influences from land-surface features that alter groundwater quality as it recharges from surface water sources.

4.8 Mason Valley Regional Hydrogeology

Groundwater conditions in Mason Valley are based on: 1) general characteristics of groundwater flow for the Basin and Range province; 2) investigations specific to the Mason Valley and/or the Walker River Basin; and 3) groundwater data available from the USGS and/or NDWR. The general conceptual model for groundwater flow in the Basin and Range province (Heath 1984; Maurer et al. 2004) is movement of groundwater in unconsolidated sediments deposited within the basins that occur between uplifted mountain blocks comprised of consolidated bedrock.

The groundwater flow system in Mason Valley consists of: 1) a heterogeneous valley-fill alluvial aquifer system comprised of laterally-discontinuous confining units of clay or other low-permeability sediments, and unconfined (i.e., water table), semi-confined, and confined aquifers; and 2) a relatively impermeable bedrock flow system underlying and bounding the alluvial aquifer with limited primary permeability and groundwater flow focused along faults and fractures (Maurer et al. 2004; Thomas 1995; Tetra Tech 2010; Huxel and Harris 1969).

Groundwater in the alluvial aquifer within Mason Valley generally flows from south to north toward the topographically lowest part of the valley at the northern end of the valley (Figure 4-4).

Similar water-level patterns are depicted in Huxel and Harris (1969, Plate 2), Lopes and Allander (2009a, Plate 1), and Tetra Tech (2010, Figure 24-3). Locally, groundwater flow directions are affected by: 1) bedrock outcrops within and along the margins of the valley; 2) drawdown from pumped wells; and 3) irrigation activities on cultivated fields. The Walker River is generally a losing stream except in the far northeastern portion of the valley where it is generally a gaining stream. Water level elevations shown on Figure 4-4 are based on USGS monitor well data from October through December 2010 when agricultural pumping was limited or non-existent. Table 4-5 summarizes the USGS wells and water level data used to develop the water table (i.e., alluvial aquifer potentiometric surface) map shown on Figure 4-4.

Table 4-5. 2010 USGS Monitor Well Data for Mason Valley

USGS Site Number	Site Name	Latitude	Longitude	Surface Elev. (feet amsl)	Vertical Datum	Measure-ment Date	Depth to Water (feet)	Water Elev. NGVD29 (feet amsl)	Well Depth (feet bgs)	Boring Depth (feet bgs)	Number of Measurements
391655119330901	103 N16 E22 06ACD1 HIWAY 50	39.28200000	119.5524167	4352.1	NAVD88	10/13/10	55.4	4293.29	96	96	154
391729119294501	103 N17 E22 34DBDD1 EUREKA	39.29147220	119.4957500	4283.8	NAVD88	10/14/10	10.06	4270.35	35	35	101
391711119303301	103 N16 E22 04AAAD1 RA-4	39.28647220	119.5091667	4288.5	NAVD88	10/14/10	4.8	4280.30	14	14	69
391625119324801	103 N16 E22 07AAAA1 R-3	39.27352778	119.5468056	4303.9	NAVD88	10/14/10	9.07	4291.42	35	35	66
391605119331901	103 N16 E22 07ACCB1 R-2	39.26797220	119.5551389	4308.1	NAVD88	10/14/10	8.27	4296.41	30	30	64
384942119100801	108 N11 E25 10DBCD1	38.82802778	119.1703610	4565	NGVD29	11/23/10	98.14	4466.86	597	597	42
390715119095901	108 N15 E25 34ACDD1	39.12075170	119.1673767	4292	NGVD29	11/22/10	13.48	4278.52	370	370	41
390006119043901	108 N13 E26 09DBCC1	39.00158530	119.0784852	4396	NGVD29	11/24/10	60.37	4335.63	166	166	39
390011119060201	108 N13 E26 08CACA1	39.00297394	119.1015412	4367	NGVD29	11/24/10	21.88	4345.12	130	130	37
390127119030001	108 N13 E26 02BBCC1	39.02408569	119.0509851	4406	NGVD29	11/24/10	87.92	4318.08	203	203	36
390203119055101	108 N14 E26 32BDDD1	39.03408520	119.0984860	4352	NGVD29	11/30/10	13.56	4338.44	104	104	32
385903119073001	108 N13 E25 13DDDD1	38.98408457	119.1259859	4380	NGVD29	11/24/10	16.92	4363.08	280	280	32
390531119115901	108 N14 E25 08ADDC1	39.09186235	119.2007101	4320	NGVD29	11/22/10	30.73	4289.27	523	523	32
385720119085001	108 N13 E25 26DDCC1	38.95547285	119.1482085	4409	NGVD29	11/24/10	26.14	4382.86	160	NA	31
385255119090501	108 N12 E25 23DCC 1	38.88186075	119.1523750	4462	NGVD29	11/23/10	15.84	4446.16	325	325	31
385456119091901	108 N12 E25 11CACD1	38.91547224	119.1562641	4439	NGVD29	11/23/10	21.5	4417.50	245	245	31
390137119065402	108 N14 E26 31DCCC2	39.02686280	119.1159861	4357	NGVD29	11/30/10	13.44	4343.56	400	400	30
390558119094701	108 N14 E25 03DDDC1	39.09936270	119.1640431	4323	NGVD29	11/22/10	20.54	4302.46	85	258	30
390611119110301	108 N14 E25 04DACC1	39.10297367	119.1851545	4321	NGVD29	11/22/10	20.75	4300.25	451	451	30
385447119075901	108 N12 E25 12CDAA1	38.91297248	119.1340414	4476	NGVD29	11/23/10	59.94	4416.06	102	102	28
390004119103001	108 N13 E25 10CDB 1	39.00102868	119.1759868	4380	NGVD29	11/30/10	9.19	4370.81	328	328	27
390026119090401	108 N13 E25 11ACBD1	39.00714008	119.1520976	4370	NGVD29	11/24/10	13	4357.00	435	435	25
385717119080901	108 N13 E25 25CDDA2	38.95463960	119.1368194	4419	NGVD29	11/24/10	33.88	4385.12	106	106	21
385109119085601	108 N12 E25 35DCDD2	38.85241595	119.1498750	4505	NGVD29	11/22/10	35.38	4469.62	NA	NA	20

Table 4-5. 2010 USGS Monitor Well Data for Mason Valley

USGS Site Number	Site Name	Latitude	Longitude	Surface Elev. (feet amsl)	Vertical Datum	Measure-ment Date	Depth to Water (feet)	Water Elev. NGVD29 (feet amsl)	Well Depth (feet bgs)	Boring Depth (feet bgs)	Number of Measurements
385003119085201	108 N11 E25 11AACC1	38.83408240	119.1487638	4565	NGVD29	11/23/10	97.14	4467.86	256	256	19
390057119080001	108 N13 E25 01DBCC1	39.0157514	119.1343196	4365	NGVD29	11/19/10	19.96	4345.04	570	570	19
385047119080401	108 N11 E25 01ACCB1	38.84630495	119.1354302	4547	NGVD29	11/23/10	75.13	4471.87	526	526	18
385018119091101	108 N11 E25 02CDDD1	38.83813889	119.1538889	4544	NGVD29	11/23/10	73.59	4470.41	554	560	17
385718119101301	108 N13 E25 27DCCD2	38.95491700	119.1712645	4409	NGVD29	11/23/10	19	4390.00	440	440	17
390152119104401	108 N14 E25 34CBCA2	39.03102880	119.1798760	4362	NGVD29	11/30/10	25.56	4336.44	415	430	14
391741119150601	102 N17 E24 35DAAB1 OLD BUCKLANDS STATION	39.29472220	119.2516667	4203	NGVD29	10/12/10	16.23	4186.77	93	93	14
391610119115801	102 N16 E25 05DCCA1 USBLM	39.27464167	119.2004333	4219	NGVD29	10/12/10	70.24	4148.76	127	NA	12
391757119151801	102 N17 E24 35ACAA1 OLD WEEKS SIDING	39.29916667	119.3050000	4206	NGVD29	10/12/10	18.28	4187.72	23	23	11
392522119101901	102 N18 E25 15CBCA1 STUCCO	39.42288889	119.1718889	4213	NAVD88	10/12/10	57.72	4152.13	200	200	11
392546119121201	102 N18 E25 17BDAA TRAILER GRAVEYARD	39.42947220	119.2034167	4201	NAVD88	10/12/10	14.92	4182.94	170	170	11
392222119075101	103 N17 E25 01BAB1 E OF LAHONTAN	39.37283330	119.1307222	4202	NAVD88	10/12/10	61.18	4137.68	72	72	9
390416119112401	108 N14 E25 16DCCB1 CMPBLL SHALLOW	39.07097220	119.1900833	4336	NGVD29	11/22/10	20.14	4315.86	25	25	8
385249119221401	107 N12 E23 26ABAD1 85471	38.8803611	119.3706667	4729	NGVD29	11/18/10	13.76	4715.24	340	340	8
391727119190701	103 N17 E24 32CDBB1 BULL CANYON	39.29088889	119.3184722	4250.5	NAVD88	11/15/10	27.8	4219.363	41	41	8
391706119322601	103 N16 E22 05BACD1	39.28488889	119.5405556	4345	NAVD88	10/23/10	59.9	4281.691	182	182	8
391709119314001	103 N16 E22 04BBCB1 CARDELLI	39.28569444	119.5278333	4304.5	NAVD88	11/15/10	15.85	4285.244	39	39	2

Notes:

1) All groundwater elevation data downloaded from USGS website http://nwis.waterdata.usgs.gov/nv/nwis/gwlevels, accessed on August 15, 2011.
2) amsl = above mean sea level; bgs = below ground surface; NA = not available.

Hydraulic properties of the basin-fill sediments of Mason Valley vary both laterally and vertically because of variable depositional facies and environments observed in the valley. The transmissivity of the basin fill deposits was stated by Huxel and Harris (1969) to generally range from 6,700 ft^2/day to 27,000 ft^2/day. Based on an average basin-fill thickness of 500 feet, this is equivalent to average hydraulic conductivities in the range of 13 ft/day to 53 ft/day. Based on unspecified geotechnical investigations, Nork (1989) reported hydraulic conductivity values ranging from 0.35 to 0.50 feet per day (ft/day) for older alluvial fan deposits. Consolidated rocks beneath the unconsolidated basin-fill sediments and/or comprising the adjacent mountain ranges have low hydraulic conductivities, but may transmit water where fractures are open and interconnected (Lopes and Allander 2009a). Nork (1989) reported hydraulic conductivity values ranging from 0.23 to 1.5 ft/day for weathered intrusive rocks in the Mason Valley area.

Groundwater in Mason Valley is primarily recharged by downward percolation of surface water diverted from the Walker River to irrigation ditches and irrigated fields, downward percolation of groundwater applied to irrigated fields, and infiltration of surface water from the channel of the Walker River. To a lesser degree, valley-fill sediments are also recharged by mountain-front recharge (MFR), which includes a variety of hydrologic processes such as partitioning of precipitation and snowmelt into deep infiltration through bedrock (i.e., along faults and fractures), surface runoff, focused flow and subflow along mountain stream channels and alluvial fans, and diffuse movement of groundwater through the underlying mountain block (Wilson and Guan 2004; Huxel and Harris 1969; Myers 2001). Huxel and Harris (1969) considered recharge from direct precipitation on the valley floor to be negligible. Recharge from irrigation water and seasonal pumping of irrigation wells affects the vertical flow of groundwater in the alluvial aquifer (i.e., a seasonal increase in the downward vertical gradient in the alluvial aquifer).

Discharge from the Walker River Basin occurs as evapotranspiration from irrigated crops and natural vegetation (e.g., phreatophytes and wetland vegetation) as described by Heath (1984) and Carroll et al. (2010), and as direct evaporation from shallow groundwater (Huxel and Harris 1969; Lopes and Allander 2009a). Huxel and Harris (1969, Plate 2) identified an area of artesian

conditions (17 flowing wells) in the northern portion of Mason Valley where the alluvial aquifer thins and pinches out, and reported that groundwater in this area exhibited elevated specific conductance values (i.e., dissolved solids concentrations) due to evapoconcentration and possible effects of geothermal discharge associated with the Wabuska Lineament.

Lopes and Allander (2009a, 2009b) report that: 1) in 2008, no flowing wells were observed in the Wabuska area due to groundwater pumping; 2) water depths in this area were less than five feet, and efflorescent salts formed where groundwater evaporated from the shallow water table; and 3) pumping in Mason Valley since the early 1960s had caused groundwater levels to decline as much as 60 feet. The long-term decline in water levels is reflected in Site hydrographs for select monitor wells that cover the time period from 1985 to 2015, as shown on Figure 4-5. In addition to factors described above, the sharp decline in the 1980's in water levels in well UW-1S, located near the northern end of the Process Areas, is in part attributed to cessation of mining activities in 1978. Discharge of groundwater through bedrock from the Mason Valley Basin to other groundwater basins may occur, but is limited (Thomas 1995; Tetra Tech 2010).

4.9 Site and Study Area Local Hydrogeology

A generalized hydrogeologic south-north cross-section with a vertical exaggeration of 20V:1H is presented in Figure 4-7 (location shown on Figure 4-6). This cross-section (A-A') transects the Study Area and extends from well B/W-13S, which is the southernmost well in the Study Area, to a monitor well cluster, B/W-82R, which is located at the north end of the Study Area.

The south-north cross-section depicts: 1) the alluvial materials in the valley-fill alluvial aquifer within the Study Area; 2) the alluvial aquifer zone designations; 3) the occurrence of bedrock outcrops at the open pit and the north end of the Study Area; 4) the water table elevation in the alluvial aquifer in August 2015; 5) the depth of the open pit and the Pit Lake level in August 2015; and 6) the cone-of-depression associated with the open pit. The water table in the Shallow zone of the alluvial aquifer generally slopes toward the north on this cross-section, though the elevation of the water is relatively flat in much of the Site.

4.9.1 Depth to Groundwater

Contour maps of the depth to groundwater (i.e., depth to water table) below the ground surface in February 2015 and August 2015 are presented on Figures 4-8 and 4-9, respectively. February 2015 and August 2015 represent the non-irrigation and irrigation seasons, respectively. The depth to groundwater is typically less than 20 feet beneath irrigated areas such as the Hunewill Ranch and between monitor wells B/W-59S and B/W-68S. In areas beneath the Site, beneath the Sunset Hills neighborhood, and in the northern portions of the Study Area, the depth to groundwater is greater than 20 feet. To the west of the Site and beneath the Process Areas, the depth to groundwater exceeds 100 feet. Between February 2015 and August 2015, the depth to groundwater beneath irrigated portions of the Study Area as well as beneath the Evaporation Ponds uniformly increased by up to three feet (i.e., the water table declined) due to depletion of groundwater by agricultural pumping. Depth to groundwater fluctuations in other parts of the Study Area were minor.

4.9.2 Saturated Alluvial Thickness

The thickness of saturated alluvium in the Study Area in August 2015 is shown on Figure 4-10, which is similar in shape to the alluvium-bedrock contact map shown on Figure 4-2 (the similarity results from a relatively flat water table beneath the Study Area). On Figure 4-10, the line denoting the approximate lateral extent of saturated alluvium represents the zero-foot contour line (i.e., saturated alluvium does not occur outside of this contour line). Saturated alluvium is bounded to the west by the Singatse Range, to the northwest by the bedrock outcrops in the Sunset Hills area, to the northeast by the Mason Butte bedrock outcrop, to the east by the Singatse Spur, and to the south by the local bedrock high exposed within the open pit and, locally, by that portion of the Singatse Range located south of the Site. As shown on Figure 4-10, saturated alluvium is thickest (more than 700 feet) beneath the northern portion of the Hunewill Ranch.

4.9.3 Alluvial Groundwater

Potentiometric surface maps for the various alluvial aquifer zones in August 2015 are provided in Figure 4-11. Groundwater flow in August 2015 in the Study Area was generally to the north/northwest in the Shallow, Intermediate, and Deep 1 zones, and to the northeast in the Deep

2 through Deep 5 zones. Locally, the flow of groundwater in the Study Area is affected by: 1) the cone-of-depression around the Pit Lake, which is a hydraulic sink for alluvial and bedrock groundwater; 2) recharge sources such as the Walker River, the West Campbell Ditch and irrigation on the Hunewill Ranch; 3) bedrock in the Singatse Range to the west of the Site, which serves as a low flux boundary condition; 4) bedrock outcrops on the eastern margin of the Site (the Singatse Spur, comprised of the Ground Hog Hills and McLeod Hill), which impede groundwater flow from the West Campbell Ditch and the Walker River to the alluvium beneath the Site; 5) bedrock ridges north of the Site associated with the Sunset Hills and Mason Butte, which affect the direction of groundwater flow in the northeastern portions of the Study Area; and 6) drawdown from pumped wells (particularly in deeper zones of the alluvial aquifer).

As seen on the Shallow zone potentiometric surface map (Figure 4-11a), the Pit Lake is currently a hydraulic sink that is refilling with groundwater predominantly derived from alluvial groundwater recharged locally from the Walker River and, to a lesser extent, bedrock groundwater (Hershey 2002). As noted in Section 3.3.2, the lake is and will continue to be a groundwater sink due to the large amount of evaporation that occurs from the lake surface.

Saturated alluvium is in contact with the Pit Lake on the western margin of the open pit (Figure 4-11a). However, groundwater gradients in this area are toward the Pit Lake, and alluvial groundwater recharges the Pit Lake rather than the Pit Lake recharging the alluvial aquifer. On the eastern margin of the open pit, groundwater derived from seepage from the Walker River flows into the pit. Beneath the Process Areas, the Pit Lake cone-of-depression creates a groundwater divide in the Shallow zone (Figure 4-11a). Because of local bedrock elevations, only the Shallow, Intermediate, and a limited portion of the Deep 1 zones exist in this area (Figures 4-11 a through c, respectively).

North of the Site, recharge from the Walker River and its surface water diversions, as well as irrigation practices in the Study Area, are the primary influences on groundwater flow directions. In the Shallow, Intermediate, and Deep 1 zones, groundwater flow directions are away from, or parallel to, the Walker River and West Campbell Ditch (i.e., north/northwest), indicating recharge

of the alluvial aquifer from these features. In addition, groundwater mounding beneath irrigated areas is observed in these zones. As this recharged water percolates deeper into the Deep 2 through Deep 5 zones of the alluvial aquifer, the groundwater flow direction rotates to the northeast as relatively impermeable bedrock results in alluvial groundwater flow toward the trough in the alluvial-bedrock contact between the Sunset Hills and Mason Butte.

Irrigation practices on the Hunewill Ranch, located immediately north of the Site, locally affect groundwater flow conditions. Historically, irrigation practices on the Hunewill Ranch included seasonal diversion of surface water from the Walker River via the West Campbell Ditch and pumped groundwater, as necessary, from up to three wells. These three wells were located within 2,500 feet of the B/W-1 monitor well cluster and included Well Log No. 82983 (also referred to as WDW019), Well Log No. 26694, and Well Log No. 78925. Well WDW019 and other underground water rights points of diversion are shown on Figure 3-8. Groundwater pumping from the Hunewill Ranch wells to support agricultural irrigation ceased in September 2009. In 2011 and subsequent years, crops on the Hunewill Ranch were irrigated with surface water diverted from the Walker River and groundwater pumped from a nearby parcel located near the Walker River to the east. Additional information about these wells is provided in the *Aquifer Test Data Summary Report - Revision 1* (BC 2012e).

Potentiometric surface maps for the Shallow through Deep 2 zones (Figures 4-11a through 4-11d) have been outfitted with rose diagrams at select locations to illustrate seasonal changes in groundwater flow directions resulting from the historical and current irrigation practices on the Hunewill Ranch. Rose diagrams indicate the relative frequencies of groundwater flow directions over a period of time. Monthly groundwater flow directions were calculated by using water level measurements in sets of three monitoring wells to estimate the slope and direction of slope of a plane connecting the water levels in the three wells. This approach is commonly referred to as a "three-point problem" (EPA 2014c). Rose diagrams were generated for two time periods: 1) 2008 - 2009 to illustrate historical irrigation practices associated with operation of the Hunewill Ranch pumping wells; and 2) 2010 - 3Q 2015 to illustrate current irrigation practices.

Both historical and current irrigation practices for the Hunewill Ranch created a groundwater mound in the Shallow, Intermediate, and Deep 1 zones of the alluvial aquifer due to infiltration of applied irrigation water. Mounding was most pronounced beneath the Hunewill Ranch fields, and the mound extended beyond the edges of the fields including beneath the Wabuska Drain, which collects and diverts agricultural runoff. The rose diagrams for the Shallow, Intermediate, and Deep 1 zones (Figures 4-11a through 4-11c) indicate that, in both time periods, the mound beneath Wabuska Drain predominantly acted as a groundwater divide, directing recharged groundwater: 1) to the west/southwest beneath the Evaporation Ponds; and 2) to the east/northeast beneath the Hunewill Ranch. The rose diagrams also indicate that, in a small number of months, the groundwater divide was not present and groundwater flow directions were from the east beneath the Hunewill Ranch to the west beneath the Evaporation Ponds. This east-to-west flow predominantly occurred in winter months when irrigation was not occurring.

Historical irrigation practices for the Hunewill Ranch prior to 2010, which included seasonal groundwater pumping and surface application to the fields, created a cone-of-depression around WDW019 that was most pronounced in the Deep 1 through Deep 3 zones but was also manifested in the Shallow and Intermediate zones (BC 2014a). The cone-of-depression in the combined Deep 1 through Deep 3 zones extended beneath the Sulfide Tailings area and the Evaporation Ponds, and as far north as the Sunset Hills neighborhood. Figure 4-12 provides monthly water level hydrographs of Shallow and Deep monitor wells in the B/W-1 and B/W-27 well clusters (located beneath and adjacent to the Hunewill Ranch, respectively) that illustrate the hydraulic head drawdown during and after operation of the Hunewill Ranch pumping wells. Although agricultural pumping in the Study Area continues to affect hydraulic head in wells B/W-1D3 and B/W-27D2, hydraulic head drawdown in these wells was up to three times greater during operation of the Hunewill Ranch pumping wells than it has been in recent years.

The rose diagrams for the Deep 2 zone (Figure 4-11d) indicate that, under both historical and current irrigation practices, groundwater between the Site and the B/W-1 well cluster has been toward the northeast as the result of agricultural pumping, with occasional periods of northward groundwater flow corresponding with winter months when irrigation was not occurring. Beneath

the Evaporation Ponds, the rose diagrams indicate differing distributions of groundwater flow directions between historical and current irrigation practices. Groundwater flow directions in the Deep 2 zone beneath the Evaporation Ponds have been predominantly to the west/northwest in both time periods. However, the large cone of depression that was present during operation of the Hunewill Ranch pumping wells caused on-Site water beneath the Evaporation Ponds to occasionally flow east/northeast to off-Site areas beneath the Hunewill Ranch.

Figure 4-13 presents monthly vertical groundwater gradients in the alluvial aquifer at select locations. Vertical gradients were calculated as the difference in water levels between the shallowest and deepest alluvial monitoring wells in a cluster divided by the distance between the midpoints of the screened intervals of the wells. If a well was screened across the water table, then the water table elevation was used in place of the midpoint of the screened interval for that well. Monthly vertical gradients were calculated using water level measurements from 2013, which was the last full calendar year during which water levels in all active monitor wells were measured monthly. For wells installed after 2013 pursuant to the Additional Monitor Well Work Plan (BC 2013b), monthly vertical gradients were calculated using water level measurements from September 2014 through August 2015. Where available, monthly vertical gradients were also calculated using water level measurements from 2009 to illustrate groundwater conditions during operation of the Hunewill Ranch pumping wells.

Alluvial vertical gradients beneath the Process Areas are generally upward (PA-MW-4 well cluster), reflecting potential discharge of bedrock groundwater to alluvium as a potential source of groundwater to this portion of the Site (i.e., mountain-front recharge). Beneath the Evaporation Ponds (B/W-11 well cluster) and Hunewill Ranch (B/W-1 well cluster), alluvial vertical gradients are downward, with stronger vertical gradients corresponding to months when irrigation, and thus groundwater recharge and pumping, occurs. In addition, alluvial vertical gradients were even more strongly downward in these areas in 2009 when the Hunewill Ranch pumping wells were operating. In other irrigated areas (i.e., B/W-68 and B/W-81 well clusters), alluvial vertical gradients are also consistently downward, again with stronger vertical gradients in months when irrigation occurs.

Immediately northwest of the Site at the B/W-41 well cluster, vertical gradients are upward in the winter months, reflecting potential discharge of bedrock groundwater to alluvium (i.e., mountain-front recharge), and downward in the summer months, reflecting the influences of agricultural pumping. Downward vertical gradients at the B/W-41 well cluster are approximately two orders of magnitude smaller than the downward vertical gradients in irrigated areas, reflecting the greater distance of B/W-41 from irrigated areas. The B/W-28 well cluster (located in the Sunset Hills neighborhood) also exhibits seasonal changes in the direction of vertical gradients - upward vertical gradients occur in the winter (reflecting the non-irrigation season) and downward vertical gradients occur in the summer (reflecting the influences of agricultural pumping). In 2009, the effects of operation of the Hunewill Ranch pumping wells, in addition to other agricultural pumping in the Study Area, caused strongly downward vertical gradients that resulted in water levels in monitor well B/W-28S to decline below the bottom of the screened interval in August and September.

4.9.4 Groundwater Recharge

Recharge to the alluvial aquifer in the Mason Valley primarily occurs from surface water diverted from the Walker River within unlined irrigation ditches, infiltration of surface water and groundwater applied to irrigated fields, and infiltration of surface water from the channel of the Walker River. Recharge to the alluvial aquifer also occurs along the range front via a variety of hydrologic processes.

As indicated above, infiltration of surface water is the primary source of groundwater recharge to the alluvial aquifer in the Mason Valley, with MFR contributing significantly less (Carroll et al. 2010; Huxel and Harris 1969; Myers 2001; SSPA 2014). The annual amount of recharge derived by infiltration from stream channels, ditches, and agricultural fields is a function of Walker River flows, the volumes of surface water and groundwater used for irrigation, and water table depths within Mason Valley.

Hydrologic tracer data for tritium/helium ($^{3}H/^{3}He$) groundwater age estimates (Figure 4-14) and uranium isotopes (Figure 4-15) are consistent with the two principal recharge components of the HCSM: 1) seepage from the Walker River and irrigation ditches, and infiltration from irrigated fields on the east margins of the Study Area; and 2) MFR on the west side of the Study Area adjacent to the Singatse Range.

The use of groundwater uranium isotopes (and their relationship to tritium/helium groundwater age estimates) is briefly summarized as follows. In groundwater systems, ^{234}U is more environmentally mobile than ^{238}U due to physical recoil of the atom following alpha decay of ^{238}U, and the subsequent displacement of the ^{234}U atom to weaker binding sites within the crystalline lattice of the mineral in which it is contained. Thus, the two isotopes are released (weathered) at different rates, and the $^{234}U/^{238}U$ ratio is generally greater than unity in natural waters. Changes in the isotopic ratios (and uranium excess [Ue] values derived from the ratios) are assumed to be solely associated with transport/contact time between groundwater and aquifer solids. Consequently, high Ue values are associated with "long" periods of contact between groundwater and aquifer solids (i.e., "old" water) whereas low Ue values are associated with "short" periods of contact between groundwater and aquifer solids (i.e., "young" water). However, $^{234}U/^{238}U$ ratios in mine-impacted groundwater are also close to unity (resulting in low Ue values) because acidic process solutions leach both isotopes from ore material with equal effectiveness (Iles et al. 1995).

On the east side of the Study Area, Shallow zone alluvial groundwater directly recharged by surface water commonly exhibits younger, more modern age estimates and low Ue values. Low Ue values are also observed in mine-impacted Shallow zone groundwater beneath the Evaporation Ponds. In contrast, the older groundwater age estimates and highest Ue values commonly occur on the west side of the Study Area adjacent to the Singatse Range, in Deep alluvial groundwater, and in bedrock groundwater. An exception to the typical vertical distribution of higher Ue values and older groundwater age estimates is evident at the B/W-1 well cluster where younger groundwater age estimates and lower Ue values occur locally in the Deep groundwater zones.

This local pattern of Ue values and groundwater age estimates around the B/W-1 well cluster is consistent with the HSCM, which recognizes groundwater mixing due to agricultural pumping, especially former pumping at (which is located adjacent to the B/W-1 well cluster). Pumping at WDW019 has resulted in the migration of mine-impacted groundwater present beneath the Evaporation Ponds into the Intermediate and Deep zones of the alluvial aquifer beneath the Hunewill Ranch.

4.9.5 Alluvial Aquifer Hydraulic Property Data

Hydraulic conductivity values in alluvium from slug tests (Appendix F-1) range from 0.04 to 157 ft/day, with a median value of 6.8 ft/day. The 25th and 75th percentiles are 3.1 ft/day and 22.0 ft/day, respectively. Hydraulic conductivity values in alluvium calculated from an analysis of low-flow sampling data (Appendix F-2) range from 0.08 to 240 ft/day, with a median value of 18.4 ft/day. The 25th and 75th percentiles are 6.8 ft/day and 33.6 ft/day, respectively. Statistical analyses indicate that: 1) hydraulic conductivity values in each alluvial zone exhibit similar ranges, median values, and distributional shapes; and 2) hydraulic conductivity values throughout the alluvial aquifer are statistically equivalent in their distributions from zone to zone. Hydraulic conductivity estimates for the individual groundwater zone are provided in Table 4-6.

Table 4-6. Hydraulic Conductivity by Groundwater Zone (from Slug Test Data)

Zone	Median K (ft/day)	Standard Deviation (ft/day)	Count
Shallow	6	24	81
Intermediate	6	23	35
Deep 1	8	25	38
Deep 2	4	11	15
Deep 3	4	16	13
Deep 4	31	33	5
Deep 5	14	7	6
Bedrock	2	74	32

Notes: K = hydraulic conductivity.

Constant-rate testing of the eleven pumpback wells in 2010, which are screened in the Shallow zone (Appendix F-3), resulted in hydraulic conductivity estimates ranging from 0.9 to 47 ft/day (median of 9.4 ft/day). Slug testing of piezometers (33 in total, all screened in the Shallow zone) installed near the PWS, that were used as observation wells during constant-rate pumping tests of the 11 pumpback wells during 2010 (Appendix F-4), provided hydraulic conductivity estimates ranging from 1.1 to 83ft/day (median of 4.1 ft/day). Testing of five pumpback wells (PW-6, PW-7, PW-9, PW-10 and PW-11) in 2000 yielded hydraulic conductivity estimates that ranged from 6.4 to 33 ft/day, with a geometric mean of 16 ft/day, based on an assumed aquifer thickness of 50 feet (AHA 2000).

A constant-rate test of well WDW019, using an observation network of 93 monitor wells, resulted in estimated values for hydraulic conductivity and specific storage at 61 observation wells that exhibited pumping-related responses (Appendix F-5). Hydraulic conductivity values in alluvium derived from constant-rate pumping tests of WDW019 ranged from 4.9 to 1,200 ft/day, with a median value of 77 ft/day. The 25th and 75th percentiles are 38 ft/day and 195 ft/day, respectively. Five hydraulic conductivity values in bedrock ranged from 13.0 to 92 ft/day.

Specific storage values in alluvium from constant-rate pumping tests of WDW019 range from 1.45×10^{-8} to 1.46×10^{-3} $(\text{feet})^{-1}$, with a median value of 1.14×10^{-5} $(\text{feet})^{-1}$. The 25th and 75th percentiles are 5.16×10^{-6} $(\text{feet})^{-1}$ and 2.73×10^{-5} $(\text{feet})^{-1}$, respectively.

4.9.6 Spatial Variation in Hydraulic Conductivity

The spatial distributions of slug-test hydraulic conductivities in each alluvial groundwater zone are shown on Figure 4-16, and bedrock slug-test hydraulic conductivities are shown on Figure 4-17. Slug-test hydraulic conductivities represent the largest hydraulic conductivity dataset for evaluating spatial variation within the Study Area. To date, 295 measurements of hydraulic conductivity have been obtained using slug-test methods (Appendix F-1).

Although analysis of drawdown measurements during low-flow sampling of monitor wells has yielded more measurements of hydraulic conductivity than slug testing (318 measurements versus 295 measurements through August 2015), the approach has limitations that that do not capture the highest and lowest values of hydraulic conductivity in the Study Area. Due to the low flow rates used, measurable drawdown (i.e., drawdown exceeding 0.01 feet) does not occur during the sampling of many monitor wells that have sufficiently high hydraulic conductivities. In practice, hydraulic conductivities of greater than 100 ft/day cannot be determined with this method. Conversely, most monitor wells that have hydraulic conductivities less than 0.1 ft/day never achieve steady-state drawdown conditions during low-flow sampling (i.e., the water level in the monitor well continues to fall during the entire sampling period).

Spatial variation in slug-test hydraulic conductivities reflects the heterogeneous lithology of the alluvium underlying the Study Area. Alluvial slug-test hydraulic conductivities beneath the Site (i.e., beneath the Process Areas, Sulfide Tailings, and the Evaporation Ponds) are generally in the range of 1 to 10 ft/day, with some infrequent exceptions. To the west of the Site, along the margin of the Singatse Range, alluvial slug-test hydraulic conductivities extend into the range of 10 to 100 ft/day, with some locations still in the range of 1 to 10 ft/day. This trend continues north to towards the Sunset Hills. Beneath the Hunewill Ranch, alluvial aquifer slug-test hydraulic conductivity values generally range from 1 to 50 ft/day, with noted high conductivity exceptions at monitor wells B/W-60S, B/W-61S, and B/W-60D1.

Alluvial slug-test hydraulic conductivities near the Walker River (east of the Pit Lake) are generally higher than alluvial slug-test hydraulic conductivities beneath the Site, as evidenced by monitor wells B/W-13S, B/W-14S, B/W-15S, B/W-21S, and PLMW-2S. In this area, alluvial slug-test hydraulic conductivities are in the range of 10 to 50 ft/day. North of the Site and east of the West Campbell Ditch, alluvial slug-test hydraulic conductivities are also high, generally ranging from 10 to 100 ft/day or higher.

The spatial variability of alluvial slug-test hydraulic conductivity values reflects the varied depositional environments in Mason Valley, which are discussed in Section 4.8. The areas beneath the Site represent older fan deposits, which typically display lower permeability compared to the valley-fill sediments (i.e., younger and older alluvium). North of the Site, a transitional environment with higher permeability exists between the older fan deposits and the valley-fill sediments. Areas near the Walker River and generally to the east of West Campbell Ditch appear to represent valley-fill sediments, which exhibit the highest overall permeability. To the west of the Site, a narrow north-south trending band of higher permeability aquifer materials occurs along the flank of the Singatse Range, which represents coarser-grained alluvial fan materials eroded from the Singatse Range.

4.9.7 Bedrock Groundwater

The conceptual model of OU-1 bedrock groundwater flow conditions is based on regional and Site-specific information, including: 1) the lithologic and structural geology information presented in Proffett and Dilles (1984), and Proffett (1977); 2) a general understanding of bedrock groundwater flow in the Great Basin portion of the Basin-and-Range Physiographic Province; 3) hydrogeologic information obtained from drilling, lithologic logging, testing, and monitoring of 67 bedrock groundwater monitor wells located in the OU-1 Study Area (typically installed with 20-30 foot long screen intervals positioned in the upper 50 feet of bedrock); 4) evaluation of hydraulic head data in the bedrock and alluvial groundwater systems; 5) hydrologic tracer data for stable isotopes of oxygen and hydrogen in water ($^{18}O/^{2}H$), tritium/helium ($^{3}H/^{3}He$) groundwater age estimates, and uranium isotopes; and 6) bedrock monitor well chemical data.

As noted previously, the Site and surrounding Study Area are in a U-shaped graben structure on the western margin of Mason Valley. Within the Study Area, the depth to bedrock is highly variable and ranges from 0 to 750 feet bgs. Bedrock within the Mason Valley and Study Area is comprised of consolidated granitic, metamorphic, and volcanic rocks. The bedrock groundwater system consists of a fractured rock aquifer where water moves predominantly through fracture porosity, and matrix permeability is considered negligible. The fractures occupy only a small fraction of the bedrock.

Large-scale geologic structures (i.e., faults) result in structural compartmentalization of the bedrock groundwater system in the Study Area, with limited groundwater flow across and along faults that are commonly characterized as containing fine-grained, low-permeability fault gouge and brittle or plastic clay. The fractured rock aquifer exhibits high, three-dimensional (i.e., anisotropic) spatial variability in hydraulic conductivity (and hence groundwater flow rate). Hydraulic conductivity (K) values in bedrock monitor wells have been derived from slug tests performed after the wells were constructed, and from an analysis of low-flow sampling of bedrock monitor wells during groundwater monitoring activities (BC 2015a). Both methods yield comparable results. In addition, both methods provide estimates of hydraulic properties local to the test well and, consequently, are primarily used to assess the spatial distribution of bedrock hydraulic properties in the Study Area. Mapping of the hydraulic conductivity values indicate a high degree of spatial variability with significant changes (often greater than three orders of magnitude) over distances that are small relative to the size of the Study Area.

In bedrock, estimated conductivities range from approximately 0.002 to 334 feet/day, with the higher values measured in wells located near faults and the open pit (Figure 4-17). The 25th and 75th percentiles were 0.15 and 11.7 feet/day, respectively. The median bedrock slug-test K value was 1.7 feet/day. The lowest bedrock K values are up to two orders of magnitude lower than the lowest K values in alluvium in the Study Area. The minimum measured low-flow sampling K value in bedrock was 0.013 feet/day, and the maximum value was 67 feet/day. The 25th and 75th percentiles were 0.485 feet/day and 16.6 feet/day, respectively. The median bedrock low-flow sampling K value was 4.3 feet/day. Consistent with the slug-test data set, the lowest K values in bedrock are up to two orders of magnitude lower than the lowest K values in alluvium in the Study Area.

Similar water level responses in paired bedrock/alluvial monitor wells at any given location throughout the Study Area result from: 1) the interconnectivity between the bedrock and overlying alluvial groundwater flow systems (except locally around the B/W-1 well cluster where an aquitard separates the two flow systems); and 2) the transmission of stresses through the skeletal structure

of the aquifer solids. Seasonal fluctuations in bedrock groundwater levels (and vertical gradients between the bedrock and alluvial groundwater systems) due to agricultural pumping from the alluvial aquifer are observed beneath the Hunewill Ranch and Evaporation Ponds, and in the Sunset Hills area. Both the bedrock and alluvial groundwater systems exhibit similar long-term water level declines.

Vertical interconnection between bedrock and overlying alluvial groundwater is indicated by water level data (and the presence of locally-elevated concentrations of sulfate and uranium in bedrock groundwater that are sourced from overlying mine-impacted alluvial groundwater). Spatially, vertical gradients between bedrock and alluvium generally reflect the recharge components of the alluvial groundwater HCSM (BC 2014a), with downward vertical gradients east and north of the Site driven by recharge of surface water and irrigation water on crop fields, and upward vertical gradients in western portions of the Study Area driven by mountain-front recharge.

The largest vertical gradients between bedrock and alluvium occur: 1) within the Pit Lake cone of depression; and 2) beneath the Hunewill Ranch fields and Evaporation Ponds. In all other portions of the Study Area, vertical gradients between bedrock and alluvium are relatively small. Seasonal crop irrigation effects are observed near the Hunewill Ranch fields, Evaporation Ponds, and Sunset Hills, as represented by locations with both upward and downward vertical gradients.

Stable isotopes ($^{18}O/^{2}H$) in bedrock groundwater are generally more depleted with respect to Walker River surface water and alluvial groundwater (BC 2014a). The most depleted stable water isotope signatures in the bedrock groundwater are associated with the oldest apparent groundwater ages, as determined by $^{3}H/^{3}He$ age dating (Figure 4-18). The youngest groundwater ages are associated with the least depleted bedrock groundwater samples, which also overlap the region of cool season Walker River flows. Walker River samples display an evaporative fractionation signature, with less fractionated values occurring during periods of snowmelt runoff and more fractionated values occurring during periods of lower flows during the summer.

The greater degree of $^{18}O/^{2}H$ depletion of bedrock groundwater compared to the alluvial aquifer and Walker River surface water suggests different recharge processes. The depleted stable isotope signature indicates that bedrock groundwater is: 1) sourced from snowmelt recharged directly in the Singatse Range, which does not undergo the same evaporative fractionation as Walker River water, and/or fossil water recharged during the Pleistocene (a cooler and more humid climate than the current climate); and 2) older and of a different origin than surface water and alluvial groundwater. Bedrock groundwater ages are older than 1954, and essentially pre-date Site mining activities, occur throughout most the Study Area. Younger bedrock groundwater within and downgradient of the Singatse Spur, proximal to the Walker River, exhibits isotopic similarities between younger bedrock groundwater and cool season Walker River water.

Although groundwater ages exhibit some degree of spatial association, groundwater ages are not correlated with hydraulic conductivity. The widespread occurrence of older groundwater ages and localized occurrence of younger groundwater ages, irrespective of hydraulic conductivity, suggests slow and limited movement of bedrock groundwater. The spatial distribution of Ue values generally comports with the spatial distribution of $^{3}H/^{3}He$ groundwater ages. This pattern of widespread higher Ue values (i.e., "old" water) with localized areas of lower Ue values (i.e., "young" water), irrespective of hydraulic conductivity, again suggests slow/limited movement of bedrock groundwater.

In addition to a high degree of anisotropy in hydraulic characteristics and hydrologic tracer signatures, the bedrock groundwater system also exhibits three-dimensional (i.e., anisotropic) spatial variability in chemical concentrations. As noted in Brown and Caldwell (2014a) and discussed further in Section 5.0, concentrations of mine-related chemicals in groundwater are most elevated in the Shallow zone of the alluvial aquifer beneath the LEP, UEP, Finger Ponds, Phase IV VLT HLP, and Phase IV VLT Pond. COI concentrations decrease with vertical depth and horizontal distance from the Site sources, resulting in values in bedrock groundwater that are one to several orders of magnitude lower than the values in overlying alluvial groundwater.

In addition, areas of elevated COIs in bedrock groundwater are small in comparison to the alluvial aquifer, highly localized, and found mostly on-Site. The localized areas of elevated COI concentrations in bedrock groundwater indicate that bedrock fractures have limited hydraulic connectivity and transmissivity over horizontal distances relevant to the scale of the Study Area.

Collectively, the bedrock characterization information indicates: 1) a high degree of vertical hydraulic connection between the bedrock and alluvial groundwater systems; and 2) limited horizontal hydraulic connectivity and transmissivity of bedrock fractures, especially over horizontal distances that are relevant to the scale of the Site and the surrounding Study Area. Despite localized areas of relatively high hydraulic conductivity, bedrock groundwater flow velocities, average volumetric flow rates and chemical fluxes through the bedrock groundwater system are low.

SECTION 5.0

NATURE AND EXTENT OF GROUNDWATER CONTAMINATION

Identifying background groundwater quality and defining the extent of mine-impacted groundwater have been elements of the phased OU-1 groundwater characterization activities since 2005. This activity, referred to as the background assessment, was specifically identified as DQO #1 in both the draft and final versions of the remedial investigation work plans for OU-1 (BC and Integral Consulting, Inc. 2007 and BC 2014a, respectively).

5.1 Background Assessment Approach

The conventional approach to a background assessment described by EPA (2012a) involves obtaining groundwater chemical data from areas that were not impacted by Site sources to establish background chemical concentration ranges and background concentration limits (BCLs) for the COIs. Typically, the chemical concentration data are obtained from locations that are hydraulically upgradient or cross-gradient of Site sources. However, EPA and ARC recognized that there are constraints to relying solely on this conventional, statistical approach at the Site because locations where background wells can be installed hydraulically upgradient or cross-gradient of the Site sources do not fully account for all of the factors affecting groundwater quality downgradient of the Site, such as the following: 1) naturally-occurring variations in groundwater chemistry associated with geologic formations; 2) chemical inputs associated with application of agricultural fertilizers (e.g., nitrate and sulfate) and/or crop irrigation (e.g., uranium and sulfate); 3) increases in dissolved chemical concentrations associated with longer periods of contact between groundwater and aquifer sediments (i.e., longer groundwater residence times); and 4) spatial variations in groundwater flow conditions and the groundwater geochemical regime, which affect dissolved chemical concentrations.

Consequently, multiple lines of evidence are used to differentiate background groundwater quality from mine-impacted groundwater, including:

- Hydrogeologic Conceptual Site Model: The hydrogeologic information defines the current and plausible historic groundwater flow and chemical transport pathways, and related anthropogenic activities (including mining and agriculture). The HCSM: 1) incorporates observed temporal variations in groundwater flow conditions and chemical concentrations in groundwater based on an extensive Site-wide groundwater monitoring network, aquifer testing, and a groundwater flow model; and 2) constrains how chemical distributions in groundwater can be reasonably interpreted and related to mining and agricultural activities.
- Contoured Chemical Distributions: Chemical distributions outline distinct plumes of off-Site impacted groundwater that have physical continuity along plausible flow pathways linked to Site features that are known sources of groundwater impacts. Other areas where chemicals occur in groundwater at concentrations above Maximum Contaminant Levels (MCLs), such as the North Study Area (NSA; i.e., that portion of the Study Area located northeast of the West Campbell Ditch and north of Sunset Hills), are separate from and do not physically connect along groundwater flow pathways to the Site.
- Sulfur Isotope Signatures: Distinct sulfur isotope ($\delta^{34}S_{SO4}$) signatures associated with sulfate in the acidic process leach solutions are used to differentiate mine-impacted groundwater from groundwater that is unaffected by mining operations, and to delineate the extent of groundwater contamination associated with mining. Specifically, the extent of mine-impacted groundwater is constrained where the $\delta^{34}S_{SO4}$ value in alluvial groundwater downgradient of the Site exceeds the minimum background value of +4.93‰ at locations that are within predominant recharge areas to the alluvial aquifer. Such background areas of the alluvial aquifer are also consistent with contoured or numerically-modeled flow pathways from the Site.
- Conventional Approach: The conventional approach to defining background groundwater quality for the Site (EPA 2012a) relies on chemical data from the background monitor wells and EPA-recommended statistical procedures (EPA 2009) to calculate BCLs for COIs. BCLs are computed for each COI in three geographic recharge areas identified in the Study Area HCSM: 1) the Southeast Recharge Area (SERA) - representing recharge by infiltration and percolation of water associated with streams, ditches and agricultural fields; 2) the Southwest Recharge Area (SWRA) - representing mountain-front recharge; and 3) the NSA - representing groundwater lateral to the Site flowing into the NSA.

The BCLs are used for two purposes. BCLs for sulfate and dissolved uranium in the SERA and SWRA are used to confirm the extent of mine-impacted groundwater defined by $\delta^{34}S_{SO4}$ signatures. Sulfate and dissolved uranium are suitable chemicals for this purpose because these two chemicals are typically more mobile in groundwater relative to other indicators of mine-impacted groundwater such as iron and other metals (BC 2014a; EPA 2010d). BCLs are computed for other COIs, which can then be used to define areas within the extent of mine-impacted groundwater where chemical concentrations exceed background chemical concentrations.

Because the NSA BCLs characterize groundwater quality flowing into the NSA, they are not used to define the extent of mine-impacted groundwater but can instead be used to evaluate chemical loading to groundwater due to agricultural practices in this part of the Study Area. The steps identified in the BGQA - Revision 3 (BC 2016b) for performing the background groundwater assessment are illustrated on Figure 5-1 and summarized in Table 5-1.

Table 5-1. Site-Wide Background Groundwater Quality Assessment Approach

Step	Information Source(s)
Obtain and evaluate available OU-1 hydrogeologic and geochemical data with respect to data quality and relevance.	▪ Brown and Caldwell (BC 2014a) ▪ Brown and Caldwell (BC 2015e)
Refine the HCSM based on recent information obtained in 2013 and 2014 from existing wells and new wells installed pursuant to the Additional Well Work Plan (BC 2013b).	▪ Brown and Caldwell (BC 2015d) ▪ Brown and Caldwell (BC 2016b). Summarized below; see Section 3.0 in Appendix J-7 for details.
Define hydrogeologic areas that are considered representative of background conditions and/or other water quality types.	▪ Brown and Caldwell (BC 2016b). Summarized below; see Section 3.0 in Appendix J-7 for details.
Specify the types and quality of RI groundwater data selected as relevant and appropriate for the background assessment.	▪ Brown and Caldwell (BC 2016b). See Section 4.0 in Appendix J-7 for details.
Use hydrologic tracer results to refine the HCSM, especially as the results relate to the information inputs identified in DQO #1 for the background groundwater assessment. Use $\delta^{34}S_{SO4}$ signatures to differentiate mine-impacted groundwater from groundwater impacted by other anthropogenic activities.	▪ Brown and Caldwell (BC 2016b). Summarized below; see Section 6.0 in Appendix J-7 for details.
Establish quantitative background concentration ranges and calculate groundwater BCLs for each background area. Use sulfate and uranium BCLs to evaluate the extent of mine-impacted groundwater. Use BCLs for other COIs to define areas within the extent of mine-impacted groundwater where chemical concentrations exceed background chemical concentrations.	▪ Brown and Caldwell (BC 2016b). Summarized below; see Section 6.0 in Appendix J-7 for details.
Evaluate the consistency of the two approaches (i.e., $\delta^{34}S_{SO4}$ signatures tracers and BCLs) to identifying the extent of mine-impacted groundwater. Integrate the results of the two approaches along with other RI characterization information into a single boundary representing the extent of mine-impacted groundwater in each zone of the alluvial aquifer.	▪ Brown and Caldwell (BC 2016b). Summarized below; see Section 7.0 in Appendix J-7 for details.

Ultimately, the identification of the extent of mine-impacted groundwater in the Study Area integrates the three major elements of boundary delineation (i.e., $\delta^{34}S_{SO4}$ signatures, and BCLs for the two most mobile, aerially extensive, indicators of mine-impacted groundwater, sulfate and uranium), as well as other lines of evidence that include hydrogeologic information, chemical concentration data, and other hydrologic tracer data.

5.2 Contoured Chemical Distributions

The following sections discuss the distributions of select parameters and COIs in Study Area groundwater.

5.2.1 Alluvial Aquifer

To illustrate aspects of the HCSM discussed below, the distributions of six chemicals (pH, sulfate, uranium, alkalinity, nitrate, and arsenic) in groundwater during August 2014 are illustrated on cross sections (cross section locations shown on Figure 4-6) and plan view maps for the Shallow and Deep 3 groundwater zones (Figures 5-2 through 5-7). The distributions of the six chemicals in all the groundwater zones are shown on plan view maps in Appendix K. The distributions of the six chemicals have routinely been presented in various groundwater reports for the following reasons.

Historical operational information and groundwater quality data indicate that elevated acidity (i.e., low pH), sulfate, and uranium are indicator parameters for mine-impacted groundwater at the Site. Because sulfate and uranium, which are naturally-occurring in the Study Area, are more mobile in groundwater relative to other indicators of mine-impacted groundwater (e.g., iron), these mine-related chemicals have been used to preliminarily evaluate the extent of mine-impacted groundwater (BC 2014a). Alkalinity in groundwater is important because complexation of dissolved uranium with bicarbonate enhances its solubility and mobility in groundwater (EPA 2010d; BC 2014a).

Given their association with agricultural amendments and fertilizer, sulfate and nitrate in groundwater are also important indicators of agricultural-impacted groundwater (BC 2014a). Although arsenic is detected at locally high concentrations in both on-Site and off-Site locations, it occurs naturally in the Study Area (and throughout Nevada) and exhibits complex geochemical transport behavior, which limits its usefulness as an indicator of mine-impacted groundwater (EPA 2016e).

pH

The distributions of pH values in the Shallow and Deep 3 groundwater zones in August 2014 are shown on Figures 5-2a and 5-2b, respectively. The lowest pH values are observed in Shallow zone groundwater beneath the Evaporation Ponds and downgradient of the Phase IV VLT HLP and VLT Pond, and pH values increase laterally and vertically away from these structures by orders of magnitude.

Sulfate and Uranium

The distributions of sulfate and uranium in groundwater in August 2014 are illustrated on Figures 5-3 and 5-4, respectively. The most elevated concentrations of sulfate and uranium are also observed in Shallow zone groundwater beneath the Evaporation Ponds and downgradient of the Phase IV VLT HLP and VLT Pond, and concentrations decrease laterally and vertically away from these features by orders of magnitude.

In particular, elevated concentrations of sulfate and uranium in the alluvial aquifer occur in: 1) Shallow zone groundwater where sulfate (Figure 5-3a) and uranium (Figure 5-4a) distributions exhibit a northwest longitudinal orientation consistent with the northwest direction of groundwater flow across the Study Area; and 2) Deep zone alluvial groundwater where sulfate (Figure 5-3b) and uranium (Figure 5-4b) distributions exhibit a northeast longitudinal orientation from the northern portion of the Site to beneath the Hunewill Ranch toward former (e.g., WDW019) and existing agricultural wells used seasonally to extract groundwater for crop irrigation.

In addition, elevated concentrations of sulfate and uranium (as well as alkalinity and nitrate discussed below) occur in Shallow, Intermediate, and Deep 1 groundwater zones beneath agricultural fields in the NSA. Given the low concentrations of sulfate and uranium detected in all groundwater zones at well cluster B/W-27 (Figures 5-3d and 5-4d, respectively), elevated concentrations of these chemicals in groundwater beneath the agricultural fields located in the NSA are not physically connected along current and plausible historic groundwater flow paths back to known sources of mine-impacted groundwater beneath the Site. A more detailed discussion of data specific to the NSA is provided in Section 5.5.

Alkalinity

The distribution of alkalinity in groundwater in August 2014 is illustrated on Figure 5-5. The most elevated values of alkalinity occur beneath the Evaporation Ponds in the northern portion of the Site. In the Shallow zone beneath the UEP and downgradient of the Phase IV VLT HLP and VLT Pond, pH values are generally less than 4 s.u.. Similar to sulfate and uranium, elevated alkalinity occurs in: 1) Shallow zone groundwater where the distribution (Figure 5-5a) exhibits a northwest longitudinal orientation consistent with the northwest direction of groundwater flow across the Study Area; and 2) Deep zone alluvial groundwater where the distribution (Figure 5-5b) exhibits a northeast longitudinal orientation from the Evaporation Ponds, Phase IV VLT HLP and VLT Pond to beneath the Hunewill Ranch toward former (e.g., WDW019) and existing agricultural wells used seasonally to extract groundwater for crop irrigation. Alkalinity values above 200 mg/L occur beneath the Hunewill Ranch and other agricultural fields located in the northeastern portion of the Study Area.

Nitrate

The distribution of nitrate in groundwater in August 2014 is illustrated on Figure 5-6. The most elevated nitrate concentrations occur in groundwater beneath the Hunewill Ranch and other agricultural fields located in the northeast portion of the Study Area (Figure 5-6a). Beneath the Hunewill Ranch, nitrate concentrations in Shallow zone groundwater were as high as 42 mg/L during August 2014. Former groundwater extraction from high-capacity wells (especially WDW019) for irrigation of crops on the Hunewill Ranch has mobilized nitrate from the Shallow zone into the Intermediate and Deep zones of the alluvial aquifer system. Nitrate is subsequently transported in groundwater that flows northwest to the Sunset Hills area.

Nitrate concentrations in Shallow zone groundwater beneath the agricultural fields in the northeast Study Area were as high as 38 mg/L during August 2014 (Figure 5-6a). Groundwater extraction from high-capacity agricultural wells for crop irrigation on fields located in the northeastern portion of the Study Area has mobilized nitrate from the Shallow zone into the Intermediate and Deep zones of the alluvial aquifer system. Nitrate beneath these agricultural fields is subsequently transported in groundwater that flows north and northwest.

Nitrate concentrations in groundwater samples from the B/W-27 cluster have consistently been at low concentrations throughout their monitoring history. In August 2014, nitrate concentrations ranged from 0.13J to 0.88J mg/L. The nitrate data from the B/W-27 well cluster shows that the nitrate concentrations beneath the Hunewill Ranch and other agricultural fields in the northeast Study Area are physically separate. The horizontal and vertical patterns in nitrate concentrations in groundwater indicate that application of fertilizer on the agricultural fields has resulted in downward vertical migration of agricultural nitrate rather than horizontal transport of nitrate in the groundwater system. A more detailed discussion of data specific to the NSA is provided in Section 5.5.2.

Arsenic

The distribution of arsenic in alluvial groundwater in August 2014 (Figure 5-7) differs from the distributions observed for sulfate, nitrate, and alkalinity. The most elevated arsenic values occur in Shallow zone groundwater at off-Site wells B/W-77S (560 µg/L) and B/W-32S (420 µg/L), which are located approximately 2,500 feet north of the Evaporation Ponds (Figure 5-7a). Arsenic values decrease laterally and vertically from these two wells by at least an order of magnitude. In contrast to the elevated arsenic values at these two off-Site wells, the most elevated arsenic values in groundwater beneath the Site are approximately 3.5 times lower.

The most elevated arsenic concentrations in on-Site groundwater range from approximately 120 to 160 µg/L in Shallow zone wells MW-5S, FMS-06S, and MW-2S (Figure 5-7a). These three wells are located near the Thumb Pond and the Phase IV VLT HLP and VLT Pond. Historic process solutions discharged to the Thumb Pond were reported to contain 42 mg/L of arsenic (Seitz et al., 1982). Arsenic values in the range of 50 to 80 µg/L occur in the Shallow, Intermediate and Deep zones west and northwest of the Evaporation Ponds and below the Phase IV VLT HLP and VLT Pond.

In addition, data from zonal groundwater samples and monitor wells installed in the NSA indicate elevated concentrations of arsenic in Deep zone groundwater that inflows (i.e., recharges) the NSA and migrates beneath the agricultural fields. Groundwater arsenic concentrations in this portion of the Study Area increase as a function of depth in the alluvial aquifer (at a relatively uniform pH) as indicated best by the zonal groundwater sample data from wells B/W-56 and B/W-69 (Figure 5-8) where arsenic concentrations are as high as 83 ug/L. At other NSA monitoring locations (such as B/W-59, B/W-57 and B/W-68), chemical profiling did not extend as deep as the B/W-56 and B/W-69 locations. Nonetheless, arsenic concentrations at these three locations began increasing as a function of depth below 4,200 feet amsl. Had sampling been conducted to greater depths at these locations, elevated arsenic concentrations are expected since no known plausible hydrologic/geochemical explanation would limit arsenic enrichments strictly to those areas around B/W-56 and B/W-69.

Because profile locations B/W-56 and B/W-69 represents background (i.e., characterize groundwater inflows to the NSA), chemical concentrations at these locations represent naturally-occurring concentrations and are not related to advancement of mine-impacted groundwater from the south. Furthermore, the elevated arsenic concentrations at this depth are not associated with agricultural activity, which is shown in Section 5.5.2 to affect the Shallow, Intermediate and Deep1 zones in the NSA. Instead, these elevated arsenic concentrations appear to be associated with regional groundwater conditions in the Mason Valley, likely associated with deep bedrock discharge to the alluvial basin aquifer.

5.2.2 Bedrock Groundwater

Most of the bedrock wells have 20- to 30-foot long screens that are positioned in the upper 50 feet of the bedrock to straddle fractures that yield groundwater for monitoring purposes. The pH measurements and concentrations of sulfate, uranium, alkalinity, nitrate and arsenic in the bedrock groundwater system in August 2014 are shown on Figure 5-9. Most pH measurements in bedrock groundwater are near-neutral (i.e., approximately 7.0).

Sulfate and uranium were detected in bedrock groundwater during August 2014 at concentrations as high as 1,600 mg/L and 950J µg/L, respectively. For both chemicals, the most elevated concentrations were detected in bedrock groundwater within the mine Site, and somewhat lower concentrations were detected immediately west of the Evaporation Ponds below the VLT Pond. The most elevated sulfate concentrations in bedrock groundwater occurred beneath the Sulfide Tailings at well B/W-36B. Off-Site, sulfate was detected in bedrock groundwater at a concentration above 500 mg/L in well B/W-58B, which monitors groundwater emanating from the MacArthur Mine. The most elevated uranium concentrations in bedrock groundwater occurred at on-Site wells MW-5B and B/W-74B. Similarly, the most elevated alkalinity concentrations in bedrock groundwater occurred at on-Site wells MW-5B and B/W-74B (as well as MW-H4SN).

Nitrate concentrations were most elevated in bedrock groundwater at wells B/W-73B and HLP-06B, which are located to the west and southwest of the mine Site.

Elevated arsenic concentrations in bedrock groundwater occurred in three distinct areas. Elevated arsenic concentrations were detected in: 1) four wells (PA-MW-2B, PA-MW-4B, HLP-03B, and HLP-06B) located around the Phase III 4X HLP and nearby Calcine Ditch; 2) six wells (MW-4B, B/W-34B, B/W-6B, B/W-44B, LEP-MW-2B, and B/W-33B) located to the immediate west of the Evaporation Ponds in an area potentially influenced by MFR; and 3) in two wells (B/W-54B and YPT-MW-10B) located north of Sunset Hills.

5.3 Identification of Groundwater Impacts

5.3.1 Differentiating Groundwater Impacts Using Sulfur Isotopes

Sulfur Isotope Signature in Background Groundwater

The $\delta^{34}S_{SO4}$ signature used to differentiate mine-impacted groundwater from non-mine-impacted groundwater reflects the dominant background groundwater types in off-Site areas. Groundwater modeling (SSPA 2014) indicates that recharge to groundwater in the alluvial aquifer (98% of all recharge) in the Study Area results from irrigation field percolation (49%), leakage from irrigation ditches (29%), and seepage from the Walker River (20%).

Background wells associated with these water types include some, but not all, of the wells in the SERA and NSA recharge areas. Eight background wells that represent the dominant background groundwater types in off-Site areas, based on their locations in the groundwater flow field relative to the Walker River and agricultural features, include: B/W-15S, B/W-20S, B/W-21S, B/W-56S, B/W-59S, B/W-59D3, PLMW-2S and PLMW-2B. Values of $\delta^{34}S_{SO4}$ in groundwater samples from these wells range from +4.93 to +6.62‰.

Sulfur Isotope Signature in Mine-Impacted Groundwater

Sulfur isotopes in groundwater were used to differentiate the leading edge of mine-impacted groundwater from background groundwater or groundwater impacted by other anthropogenic activities within the Study Area because: 1) sulfur isotopes in dissolved sulfate can be used to infer groundwater movement because these isotopes are mobile tracers whose movement is not strongly retarded by the aquifer matrix in groundwater settings similar to the Study Area; and 2) early copper extraction operations at Yerington (during the 1950s and 1960s) primarily relied on sulfuric acid derived from sulfur ores (i.e., pyrite) from the Leviathan Mine in California (BC 2014a), which had a distinct sulfur isotopic signature (Taylor and Wheeler 1994). Sulfur sources with different (higher) isotopic signatures were used during later operations in the 1970s, 1980s, and 1990s. These different isotopic signatures may be used, along with chemical data and other information, to differentiate groundwater impacts associated with Anaconda and Arimetco operations.

Delineation of mine-impacted groundwater reasonably assumes that groundwater affected by the earliest operations at the Site has traveled the farthest downgradient distance in the alluvial aquifer. Therefore, the isotopic signature for sulfur sources used during the 1950s and 1960s serves as a potentially reliable tool for characterizing the leading edge of the plume and for differentiating mine-impacted water at the leading edge of the plume from background conditions. The median value reported by Taylor and Wheeler (1994) for $\delta^{34}S_{SO4}$ in aqueous samples collected from seeps and adit discharge at the Leviathan Mine is -17.6‰ (Table 5-5 in Appendix J-7).

Distinct $\delta^{34}S_{SO4}$ signatures associated with sulfate in the sulfuric acid process leach solutions used during early Site operations (most evident in groundwater at well W5DB-D3) and groundwater from the background monitor wells are used to evaluate the extent of mine-impacted groundwater. This approach conceptualizes initial infiltration of acidic process leach solutions exhibiting a diagnostic $\delta^{34}S_{SO4}$ signature of approximately -17‰ into originally un-impacted groundwater beneath the Evaporation Ponds.

The conceptual approach assumes a simplified aquifer geometry and flow configuration that account for mixing of a conservative (i.e., geochemically unreactive) tracer within the aquifer. Again, the isotope signature for the sulfur source used during the earliest processing operations at the Site would be representative of any mine-impacted water first entering the alluvial aquifer and now present at the leading, downgradient edge of the plume. The leading edge of mine-impacted groundwater is identified as locations where the $\delta^{34}S_{SO4}$ signature in groundwater associated with mining impacts cannot be differentiated from the $\delta^{34}S_{SO4}$ signature in background groundwater.

Quantitatively, mine-impacted groundwater can no longer be differentiated from background groundwater when the $\delta^{34}S_{SO4}$ value at a given location falls within the background $\delta^{34}S_{SO4}$ range (i.e., exceeds the minimum background value of +4.93‰). Higher isotope signatures measured inside the leading edge of the plume may be indicative of mixing with groundwater, subsequent sulfur releases derived from sources having a different isotopic signature, or some combination of these two processes.

Lateral and vertical patterns in $\delta^{34}S_{SO4}$ groundwater data are illustrated on Figure 5-10. The distinctly negative $\delta^{34}S_{SO4}$ signature of -17.6‰ associated with sulfate in the sulfuric acid process leach solutions used for copper recovery at Yerington is evident in Deep zone alluvial groundwater beneath the Evaporation Ponds, especially at well W5DB-D3, which has a strongly negative $\delta^{34}S_{SO4}$ signature of -17.12‰.

The low $\delta^{34}S_{SO4}$ values in Deep zone alluvial groundwater beneath the Evaporation Ponds also extend off-Site toward the Hunewill Ranch, particularly in the Deep 3, Deep 4, and Deep 5 zones. The region of low $\delta^{34}S_{SO4}$ values beneath the Evaporation Ponds is displayed on cross section A-A' (Figure 5-10c), centered around the W5DB well cluster. The low values of $\delta^{34}S_{SO4}$ that extend off-Site toward the Hunewill Ranch are visible on cross section B-B' (Figure 5-10d).

5.3.2 Differentiating Groundwater Impacts Using BCLs

A conventional approach to a BGQA emphasizes the groundwater flow regime to identify wells that are located hydraulically up-gradient and/or cross-gradient to sources of chemical loading to groundwater, as noted by the EPA (2012a) in comments on the Draft BGQA (BC 2011c). A background assessment may also consider groundwater recharge sources, the different geologic materials through which groundwater flows, and the residence time because these factors are recognized to naturally affect groundwater composition (BC 2014a; Hem 1985; Freeze and Cherry 1979). Key HCSM elements that are relevant to identifying background monitor wells include:

- Groundwater Flow Direction: Groundwater in the alluvial aquifer within the Study Area generally flows to the northwest, with flow directions locally affected by a variety of factors discussed previously in Section 4.0.
- Recharge Sources: The alluvial aquifer within the Study Area is primarily recharged by infiltration and percolation of water associated with stream channels, ditches, and irrigated agricultural fields located to the east of the mine Site. Limited recharge to the alluvial aquifer also occurs as mountain-front recharge to the west of the Site.
- Chemical Loading Sources: The northern portion of the Site (including the Evaporation Ponds, the Phase IV VLT HLP and the VLT Pond) is considered the primary source of chemicals that migrate off-Site. The most elevated acidity and chemical concentrations are observed in Shallow zone groundwater beneath this area, and concentrations decrease laterally away from this area by orders of magnitude. Furthermore, other Site sources are located hydraulically upgradient of the northern portion of the Site.

Based on these considerations, background monitor wells for the Study Area are categorized by geographic recharge area and described below.

- SERA: This background groundwater quality type is represented by seven monitor wells (B/W-15S, B/W-20S, B/W-21S, PLMW-2S, PLMW-2B, WRA3-1B and WRA3-2B) that are located up-gradient of the mine Site and near the Walker River. Data from these wells represent recharge of groundwater having a short residence time in the flow system.

- NSA: This background groundwater quality type is represented by three monitor wells (B/W-56S, B/W-59S and B/W-59D3) that are located upgradient of the NSA and represent both Shallow and Deep zone alluvial groundwater quality.
- SWRA: This background groundwater quality type is represented by six monitor wells (B/W-12RB, B/W-13S, B/W-23B, B/W-26RB, PLMW-3RB, and PLMW-4B) that are located up-gradient and west/southwest of the Site and, thus, represent mountain-front recharge.

The BCL for each COI for each background water quality type was calculated as the 95% upper tolerance limit (UTL) with 95% confidence, consistent with the sampling and statistical comparison strategy recommended in EPA guidance (EPA 1992). The 95% UTL is the numerical value below which 95% of the background data are expected to fall, with 95% confidence. That is, one can be 95% sure that 95% of data in the background population fall below this value. The upper bound of this interval is the 95/95 UTL.

The 95/95 UTL is calculated from a sample dataset and depends on the distribution, central tendency, and variability of the dataset, as well as sample size (EPA 2009). The statistical test used to calculate the 95/95 UTL also depends on the distribution of the dataset, the sample size, and the percentage of non-detects present. The ProUCL software program (version 5.0.00) (EPA 2013f) was used to perform statistical calculations of the 95/95 UTL. ProUCL evaluates a dataset to determine the likely form (or forms) of the distribution, calculates UTLs using numerous appropriate statistical methods, and provides a recommendation as to which method is most appropriate for a particular dataset.

Distributional testing in ProUCL is performed using the Shapiro-Wilk (S-W) test for normality on the untransformed data, the log-transformed data, and the gamma-transformed data. The S-W test may conclude that the data set conforms to multiple parametric distributions. In this case, the distribution with the highest probability of association (calculated p-value from the S-W test) is selected as the underlying parametric distribution. When an insufficient sample size or insufficient number of detected results existed to statistically calculate a 95/95 UTL, the maximum value of the dataset was selected, as is common practice in selecting upper threshold values in the absence

of adequate sample sizes (EPA 2009). For datasets with 100% non-detects, the lowest detection limit in the dataset was selected as the BCL. The calculated 95/95 UTLs for each constituent and background water quality type are provided in Table 5-2.

Table 5-2. Summary of Calculated Background Concentration Limits

Chemical	Units	Groundwater Standard	SERA	NSA Inflows	SWRA
pH (field)	s.u.	6.5-8.5	7.96	7.65	8.35
Alkalinity, Bicarbonate (as $CaCO_3$)	mg/L	--	180	160	210
Alkalinity, Carbonate (as $CaCO_3$)	mg/L	--	2	2	2
Alkalinity, Hydroxide (as $CaCO_3$)	mg/L	--	2	2	2
Alkalinity, Total (as $CaCO_3$)	mg/L	--	180	160	210
Total Dissolved Solids	mg/L	500	570	304	561
Total Organic Carbon (TOC)	mg/L	--	1.8	1.5	1.8
Calcium	mg/L	--	71	38	72
Magnesium	mg/L	--	13	11	16
Potassium	mg/L	--	5	7	5
Sodium	mg/L	--	96	51	130
Chloride	mg/L	250	59	17	72
Fluoride	mg/L	2	1	0.9	1.5
Sulfate	mg/L	250	160	57	180
Nitrate (as N)	mg/L	10	1.5	0.1	0.8
Nitrite (as N)	mg/L	1	0.1	0.2	0.4
Nitrate-Nitrite (as N)	mg/L	--	1.5	0.3	0.8
Aluminum	mg/L	0.2	0.04	0.03	0.05
Antimony	µg/L	6	0.41	0.31	0.96
Arsenic	µg/L	10	12	38	20
Barium	µg/L	2,000	50	141	41
Beryllium	µg/L	4	0.17	0.25	0.25
Boron	µg/L	--	680	410	920
Cadmium	µg/L	5	0.11	0.25	0.17
Chromium	µg/L	100	0.9	1.0	1.8
Cobalt	µg/L	--	1.5	1.4	2
Copper	µg/L	1,300	0.9	0.9	4.3
Iron	mg/L	0.3	0.1	0.3	1.4
Lead	µg/L	15	0.28	0.20	0.2
Lithium	µg/L	--	65	49	44
Manganese	µg/L	50	870	2,825	303
Mercury	µg/L	2	0.35	0.10	1.1
Molybdenum	µg/L	--	18	20	140
Nickel	µg/L	--	1.1	1.6	19
Phosphorus	mg/L	--	0.16	0.91	0.12
Selenium	µg/L	50	1.1	0.5	20
Silica	mg/L	--	44	40	55
Silver	µg/L	100	0.12	0.14	0.36
Strontium	mg/L	--	0.74	0.4	0.47

Table 5-2. Summary of Calculated Background Concentration Limits

Chemical	Units	Groundwater Standard	SERA	NSA Inflows	SWRA
Thallium	µg/L	2	0.2	0.2	0.2
Tin	µg/L	--	14	12	30
Titanium	mg/L	--	0.002	0.002	0.002
Uranium	µg/L	30	20	10	27
Vanadium	µg/L	--	8	5	16
Zinc	µg/L	5,000	6	4	120
Gross Alpha	pCi/L	15	12.2	6.7	21.3
Gross Beta	pCi/L	--	10.8	10.0	11.9
Radium-226	pCi/L	5 (combined 226 + 228)	0.8	1.0	1
Radium-228	pCi/L	5 (combined 226 + 228)	1	0.9	1.5
Thorium-228	pCi/L	--	0.5	0.4	0.5
Thorium-230	pCi/L	--	0.4	0.4	0.7

Notes:

1) SERA = Southeast Recharge Area; NSA = North Study Area; SWRA = Southwest Recharge Area
2) s.u. = standard units; µg/L = milligrams per liter; µg/L = micrograms per liter; pCi/L = picocuries per liter

5.3.3 Comparison of Methods

The extent of mine-impacted groundwater based on sulfate and uranium BCLs is generally similar to the extent of mine-impacted groundwater based on $\delta^{34}S_{SO4}$ signatures. Furthermore, the extent of mine-impacted groundwater in each zone of the alluvial aquifer varies in ways that are consistent with flow directions, chemical distributions, and other hydrologic tracer data presented in the HCSM. Differences in the spatial extent of mine-impacted groundwater delineated by the two background assessment approaches are considered minor and likely associated with local variations in transport behavior and locally variable evapoconcentration and chemical loading processes.

5.4 Extent of Mine-Impacted Groundwater

The extent of mine-impacted groundwater presented in this OU-1 RI Report reflects the outcome of discussions during a groundwater technical meeting on June 29, 2016 and EPA's subsequent direction to conservatively establish the extent of mine-impacted groundwater because "is in the best interest of the overall progress for completing the OU-1 Groundwater Remedial Investigation Report" (EPA 2016e).

EPA (2016e) noted that professional judgement is an inherent component of estimating the extent of mine-impacted groundwater in this complex setting, and that tools used in the background assessment to estimate the area of mine-impacted groundwater may not fully account for the range of chemical concentrations that occur naturally in groundwater within the Study Area. However, as noted during previous submittals (e.g., ARC 2016b) and during groundwater technical meetings, further refinements to the mine-impacted groundwater boundary may be warranted based on additional evaluations of monitoring data and other new information to better account for naturally-occurring chemical concentrations in Study Area groundwater.

As previously described, the identification of the extent of mine-impacted groundwater in the Study Area integrates the three major elements of boundary delineation (i.e., $\delta^{34}S_{SO4}$ signatures, and BCLs for the two most mobile, aerially extensive, indicators of mine-impacted groundwater, sulfate and uranium), as well as other lines of evidence that include hydrogeologic information, chemical concentration data, and other hydrologic tracer data. Also, the boundary delineating mine-impacted groundwater from unimpacted groundwater is conceptualized as a zone on a plan view map rather than a distinct line due to many factors including the size of the Study Area, age and complexity of the contaminant releases, occurrence and variability of naturally-occurring chemical concentrations, and complexities of subsurface contaminant transport and fate.

The extent of mine-impacted alluvial groundwater is shown on Figure 5-11, and can be generally described as follows, recognizing that mine-impacted groundwater is spatially more extensive in the Shallow, Intermediate and Deep 1 zones of the alluvial aquifer relative to the Deep 2 through Deep 5 zones. The northernmost extent of mine-impacted groundwater in the Shallow, Intermediate and Deep 1 zones of the alluvial aquifer is located near the Sunset Hills between well clusters B/W-10 and B/W-52. The eastern extent of mine-impacted groundwater in the Shallow, Intermediate and Deep 1 zones of the alluvial aquifer is approximately located near or beneath the West Campbell Ditch alignment. To the west of the Site, mine-impacted groundwater extends almost to the western extent of saturated alluvium between unimpacted wells/clusters B/W-16S and B/W-40, and impacted well clusters B/W-33, B/W-6 and B/W-22.

Mine-impacted groundwater in the deeper zones does not extend as far north as the upper three zones. In the Deep 2 through Deep 5 zones, the maximum northern extent of mine-impacted groundwater is near the northern end of the Hunewill Ranch fields. The eastern extent of mine-impacted groundwater in the Deep 2 through Deep 5 zones of the alluvial aquifer is located between well clusters B/W-27 and B/W-50. Particularly on the east, the area of mine-impacted groundwater in the Deep 3 through Deep 5 zones reflect the former influence of seasonal groundwater extraction for crop irrigation from agricultural wells (e.g., WDW019, located adjacent to the B/W-1 well cluster). To the west of the Site, mine-impacted groundwater in the Deep 3 through Deep 5 zones extends almost to the western extent of saturated alluvium.

Based on the background assessment methodology, the plume of mine-impacted groundwater in the various zones of the alluvial aquifer does not discharge to surface water. Estimates of the volume of mine-impacted groundwater and masses of sulfate and uranium in each groundwater zone are provided in Table 5-3.

Table 5-3. Estimated Volume and Masses of Sulfate and Uranium in Mine-Impacted Alluvial Groundwater

Zone	Zone Thickness (feet)	Volume of Mine-Impacted Alluvial Groundwater (acre-feet)	Sulfate Mass (tons)	Uranium Mass (tons)
Shallow	35	45,899	140,116	11.1
Intermediate	50	65,905	96,501	9.9
Deep 1	50	62,238	52,346	5.3
Deep 2	80	64,611	80,610	20.7
Deep 3	120	48,032	79,397	22.5
Deep 4	100	35,669	23,414	12.8
Deep 5	200	62,973	25,374	16.5
Total		**385,327**	**497,758**	**98.8**

The estimates in Table 5-3 are based on the thickness of each groundwater zone within the plume of mine-impacted groundwater shown on Figure 5-11 and the areas/average concentrations within the chemical concentration contouring. The volume of mine-impacted groundwater and masses of sulfate and uranium are large, and the following two analyses provide insights to FS considerations about aquifer cleanup.

Simple Analysis

In this simple analysis, PWS performance monitoring information and a simplifying assumption regarding chemical removal from aquifer sediments are used to estimate the time frame for aquifer cleanup.

From the early 2000s to March 25, 2009, the PWS operated continuously (i.e., 24 hours per day, 7 days per week), except during periods when individual wells were temporarily taken off line for maintenance and repairs of pumps and related equipment. The average pumping rate from the PWS from 1999 through 2008 was about 52 gpm. During this 10-year time period, approximately 800 acre-feet of water and approximately 5,000 tons of sulfate (average sulfate concentration in the pumped water of approximately 4,000 mg/L) were removed from the Shallow zone.

If it is assumed that three times the volume of mine-impacted Shallow zone groundwater (which is 45,899 acre-feet) must be removed to achieve aquifer cleanup, then at least 137,697 acre-feet of water would need to be removed from the Shallow zone. (This volume is about 172 times the volume of water removed by the PWS over the 10-year period). This volume does not address aquifer cleanup in the deeper zones of the alluvial aquifer or ongoing chemical loading to groundwater from impacted sediments and vadose zone soils, and dissolving sulfate or other minerals. Recognizing that the total volume of mine-impacted groundwater in the aquifer is 385,327 acre-feet, approximately 285 years of pumping at 2,500 gpm would be required to potentially achieve aquifer cleanup assuming that a volume of only three times the contaminated volume of mine-impacted groundwater would need to be removed. In reality, this estimate likely underestimates the actual time to cleanup.

Groundwater Modeling

In this analysis, the "batch flush" model (EPA 1988; Zheng et al. 1991) is used to estimate the minimum time (with an efficient extraction system) to restore groundwater quality to 500 mg/L sulfate. In this approach, the number of pore volumes (PV) of water that must be circulated through the contaminated zone having an initial concentration (Ci) to achieve cleanup to the specified standard (Cs) is calculated from the relationship:

$$\mathrm{PV} = -\mathrm{R}\ln \mathrm{Cs}/\mathrm{Ci}$$

In this relationship, R is the retardation coefficient for the target constituent. Based on this modeling approach, groundwater restoration to 500 mg/L sulfate would require approximately 100 years at a pumping rate of 2,300 gpm.

5.5 Sources of Impacted Groundwater

OU-1 RI characterization activities indicate that the past and/or ongoing major sources of COIs to Study Area groundwater include:

- Mine waste facilities, which have been grouped into the various Site OUs for individual RI/FS investigations;
- Agriculture activities that contribute COIs or affect the release of naturally occurring COIs in geologic materials (BC 2014a, 2016b); and
- Geologic materials containing naturally-occurring COIs (BC 2009a, 2014a, 2016b).

Section 7.0 of the 2007 SOW notes that the groundwater OU underlies all other OUs identified at the Site, and recommends that relevant elements of the other OUs be integrated with the OU-1 RI. Consistent with the SOW, this OU-1 RI Report discusses relevant source-related information for the other Site OUs that represent past or ongoing sources of chemical loading to groundwater (Section 5.5.1). In addition, the other major non-mining sources of COIs to groundwater are discussed in Sections 5.5.2 and 5.5.3.

5.5.1 Mine Waste Facilities

The major past and/or ongoing sources of COIs to groundwater include: 1) OU-4a, the Evaporation Ponds (BC 2014a); OU-8, the Arimetco Facilities (CH2M Hill 2010, 2011a, 2011b); and 3) OU-3, the Process Areas (BC 2014a). Concentrations of COIs in groundwater beneath OU-4b (Sulfide Tailings) are generally at least 10 times lower than COI concentrations in groundwater beneath OU-4a. Furthermore, OU-4b is located hydraulically upgradient or cross-gradient of OU-4a, and groundwater beneath OU-4b flows toward the higher COI concentrations under OU-4a.

Evaporation Ponds (OU-4a)

OU-4a RI field activities and characterization data are presented in reports by BC (e.g., 2009a, 2017a). OU-1 RI information that is particularly relevant to OU-4a includes the following: 1) the most elevated concentrations of mine-related chemicals occur in groundwater in this area; 2) concentrations of mine-related chemicals in groundwater beneath OU-4a are 100 or more times greater than chemical concentrations in groundwater beneath other OUs (Figures 5-2 to 5-7); and 3) the depth to water beneath OU-4a (i.e., vadose zone thickness) is generally smaller than the depth to water beneath other OUs. The depth to water beneath OU-4a ranges from approximately 20 to 40 feet bgs, except beneath the southern portion of the Calcine Ditch where the depth to water is up to approximately 70 feet bgs (Figures 4-8 and 4-9).

The summary below focuses on the magnitude and distribution of COIs in OU-4a mine waste materials and vadose zone soils, extent of contamination based on a comparison of OU-4a data to applicable soil BCLs, and the potential for vadose zone transport and chemical loading to groundwater based on vadose zone modeling and soil moisture probe data obtained during 2016. The highest COI concentrations in OU-4a mine waste materials are most commonly associated with pond sediments and calcines, which are typically located at depths ranging from approximately 0-3 feet bgs. Relative to the overlying pond sediments and calcines, the underlying alluvial soils generally exhibit lower concentrations of COIs.

Based on Site background soil concentrations presented in Table 5-3 of the *Background Soils Data Summary Report - Revision 1* (BC 2009b) for Sub-area A-1, located directly west of the Evaporation Pond and Calcine Ditch areas, approximate maximum depths of soil exceeding applicable BCLs within OU-4a include: 1) 17 to 20 feet bgs beneath the LEP; 2) 15 to 20 feet bgs beneath the UEP; 3) 47 to 52 feet bgs beneath the Finger Ponds; 4) 38 to 43 feet bgs beneath the Thumb Pond; and 5) 45 to 50 feet bgs at the north end of the Calcine Ditch and 75 to 80 feet bgs at the south end of the Calcine Ditch. These approximate maximum depths of alluvial soil contamination beneath the ponds and Calcine Ditch are primarily based on uranium, arsenic, selenium, iron, and copper.

Vadose zone model simulations were performed using the variably-saturated modeling code SVFlux™ to understand the potential for transport and chemical loading to groundwater beneath OU-4a. Vadose zone model results are summarized below (values presented in meters, input and output unit of measurement in the SVFlux™ modeling code):

- The LEP 'wet' areas simulation indicated a fairly constant downward net flux of soil water toward the water table. The cumulative flux at the deepest flux line in the profile was approximately 0.16 meters after 5 years of simulation.
- LEP 'dry' (non-ponded) areas showed a small downward net flux of water, approximately 0.013 meters after 15 years of simulation. Because the same soil moisture conditions for the 'wet' areas simulation was used for the 'dry' areas simulation, and because the soil moisture conditions for the 'dry' areas of the LEP are more likely to be similar to the conditions observed in the UEP, the numerical simulation likely over-predicted downward flux to the water table.
- The UEP simulation indicated a continuous upward net flux of water. The cumulative flux at the deepest flux line in the model was approximately 1.8 meters for 15 years of simulation (approximately 0.12 meters per year when averaged over the 15-year simulation period). For the 10-year period following the equilibration of the model, the cumulative flux was approximately 1.5 meters (approximately 0.15 meters per year).
- The Thumb Pond simulation indicated a very small upward net flux of water. The cumulative flux rate was approximately 4.0E-04 meters after 15 years of simulation (approximately 2.7E-05 meters per year when averaged over the simulation period). The simulation indicated both upward and downward flux of soil water in the upper portion of the profile, and a relatively constant upward flux in the deeper portion of the profile.
- The vadose zone simulation for the Finger Evaporation Ponds (FEPs) indicated a small downward flux of soil water during the 15-year simulation period, with a cumulative flux rate at the deepest flux line in the profile of approximately 0.043 meters after 15 years (approximately 2.9E-03 meters per year when averaged over the simulation period).

Integration of these estimated flux rates over the Pond acreages result in the following annual estimated volumes of soil water that could potentially flux to groundwater:

- Approximately 0.31 acre-feet per year (ac-ft/yr) for the LEP 'dry' areas, based on an estimated flux rate of 0.0012 m/yr and an area of 79.5 acres, equivalent to 0.19 gallons per minute (gpm);
- Approximately 1.13 ac-ft/yr for the LEP 'wet' areas, based on an estimated flux rate of 0.016 m/yr and an area of 21.5 acres, equivalent to 0.70 gpm; and

- Approximately 0.15 ac-ft/yr for FEP 1-4, based on an estimated flux rate of 0.0026 m/yr and an area of 17.8 acres, equivalent to 0.09 gpm.

Vadose zone modeling results indicated that: 1) the Thumb Pond and UEP exhibit an upward vertical flux of soil moisture to the atmosphere (i.e., no cumulative flux of soil moisture toward groundwater); and 2) the 'wet' areas of the LEP and FEPs 1-4 exhibit a cumulative downward flux of soil moisture toward the water table. Model results for the dry (peripheral) portions of the LEP indicate: 1) a net evaporative flux to the atmosphere; and 2) a downward flux of soil moisture during the latter third of the simulation period, resulting from wetter climate conditions.

Soil moisture data provide additional insights to the potential for transport and chemical loading to groundwater. Soil moisture has been monitored continuously since August 2016 and is ongoing. As part of the 2015–2016 field activities, soil moisture probes and porous cup lysimeters were installed at four locations. Further description of the installed equipment and the installation process is provided in the *Phase 1 Evaporation Ponds Characterization Data Summary Report* (BC 2017b). The monitoring locations are located at EP-VZC-2 (Thumb Pond), EP-VZC-3 (northern edge of the UEP), EP-VZC-6 (near the southern portion of the UEP and next to the Calcine Ditch), and EP-VZC-8 (northern edge of the LEP). Each location has soil moisture probes at three or four depth intervals, depending on the thickness of the vadose zone.

During the initial soil moisture monitoring period, a significant precipitation event occurred between January 4 and January 13, 2017, when 2.35 inches of precipitation fell over the 10-day period (WRCC 2017).

Soil moisture probe readings for EP-VZC-2 at the Thumb Pond, with the shallowest monitoring interval of 10 feet bgs, did not register any changes in vadose zone soil moisture at all monitored depths during and after the 10-day precipitation event. Soil moisture readings at EP-VZC-6, located near the southern tip of the UEP, registered moisture content increases in the shallow probes (2 and 6 feet bgs), but not at any greater depth during and following the January 2017 event. Soil moisture readings at EP-VZC-3, located in the northern portion of the UEP, registered a response to the January 2017 storm event at only the shallowest probe depth (1.5 feet bgs), but not

at the two deeper probes (5 and 15 feet bgs). Similarly, soil moisture readings at EP-VZC-8, located at the northern end of the LEP, registered a response to the January 2017 storm event at only the shallowest probe (3 feet bgs), but not at the two deeper probe depths (10 and 20 feet bgs).

In summary, there were no observable changes in soil moisture at depths greater than 6 feet bgs resulting from this significant precipitation event. At most locations, soil moisture data at the shallowest monitoring intervals (1.5 to 3 feet bgs) illustrate an abrupt increase in soil moisture immediately following the January 4-13 storm event. At some stations, soil moisture at 5 feet and 6 feet bgs also experienced changes following the January precipitation event, but were less pronounced than soil moisture changes at shallower intervals. Based upon these data, there does not appear to be evidence indicating moisture changes in deeper probes that result from an infiltration front moving vertically through the vadose zone.

Future data collection and evaluation may provide additional insight into the: 1) potential advancement of the wetting front to depths of 10 feet bgs and deeper; 2) effects of underlying native clay-rich alluvial layers on potential advancement of the wetting front and pore water chemistry; and 3) potential migration of chemicals within and between vadose zone materials based on lysimeter data from multiple points in time. However, the existing information suggests that: 1) the groundwater impacts beneath OU-4a are the result of past mining operations and fluid management; and 2) chemical loading to the groundwater system under current climatic conditions is very limited, based on vadose zone modeling and soil moisture probe data.

Arimetco Facilities (OU-8)

OU-8 components located throughout the Site include five HLPs (Phase I/II, Phase III South, Phase III 4X, Phase IV Slot, and Phase IV VLT), the FMS (which stores and conveys drain-down solution via a network of ponds, ditches, and 25,000 feet of pipe), and the SX/EW Plant.

RI activities characterized the nature and extent of radiochemicals, metals, and physical properties of the OU-8 HLPs and their associated ponds and ditches. Sources of contamination include:

- Leachable metals (aluminum, copper, iron, and manganese and, to a lesser extent, arsenic, beryllium, cadmium, chromium, cobalt mercury, and nickel) and other COIs on the surface and within the HLPs;
- Acidic draindown solutions containing COIs entrained within the HLPs;
- Acidic drain-down solutions containing COIs stored at the base of the HLPs or contained within their associated ponds and ditches; and
- Historic spills and releases containing COIs.

The OU-8 RI/FS determined that the areas affected by Arimetco operations include the footprints of each HLP and their associated drain-down FMS components, the SX/EW Plant, and historical spill areas (CH2M Hill 2011b). The environmental release or migration pathways of drain-down fluids are infiltration into the subsurface from unlined areas, through tears/breaches in liner systems and FMS components, and through tears/breaches due to potential settling/structural failure of the HLP liner systems (Ecology and Environment, Inc. 2013).

On the basis of groundwater monitoring results, these impacts are thought to extend vertically down to OU-1 groundwater (CH2M Hill 2011b). Furthermore, the OU-8 FS (CH2M Hill 2011b) also notes that additional characterization efforts are needed to fully determine the nature and extent of contamination in: 1) in OU-8 surface and subsurface soil due to releases of drain-down fluids from the Arimetco Facilities; and 2) OU-1 groundwater that may be attributed to OU-8 releases.

Numerous spills of process solution in connection with past Arimetco operations have been recorded, and all of the recorded spills report limited to no confirmation sampling data or post-remedial efforts (CH2M Hill 2010, 2011b). As noted by CH2M Hill (2011b), the spill report documentation in the HSR (CH2M Hill 2010) only generally describes the location and type of materials spilled, along with the estimated quantity of each spill and general response action that was taken. In some instances, these records appear to underestimate the overall quantity of materials spilled. On the basis of the existing spill reports and the suspected quantities of fluids released to the environment, further investigations may be required (CH2M Hill 2011b).

Process Areas (OU-3)

The OU-3 RI has involved extensive characterization to determine the vertical extent of impacted soils beneath known source areas and above known areas of impacted groundwater in the underlying alluvial aquifer (e.g., BC 2011a, 2014e). OU-3 RI activities have included: 1) soils and groundwater characterization in 2004-2005; 2) a variety of radiometric surveys; 3) groundwater monitor well installations in 2005; 4) sub-surface utility and dry well investigations during the period 2010-2013; 5) step-out (vertical and horizontal) soil characterization activities during the period 2013-2014; and 6) sampling and analysis of standing water in select locations during the 2013-2014 field program.

During the RI, a total of 3,385 samples of vadose zone alluvial soils were collected and analyzed from metals (57,764 analyses) and radiochemicals (9,172 analyses). Analytical results are discussed in the context of exceedances relative to the EPA Industrial regional screening level (RSL), a background level, and the maximum depth below ground surface that such exceedances occurred. A total of 198 metals exceedances, primarily arsenic and chromium, occurred in near-surface soils to approximately 15 feet bgs in every sub-area of OU-3. Metals exceedances also occurred at depths to 80 feet bgs at three primary waste solution conveyance ditches (Overflow, East Solution and Calcine Ditches) and the Acid Plant Pond. Fifty-one radiochemical exceedances, primarily for radium-226 and -228, occurred in shallow soils to depths of up to five feet bgs throughout OU-3. Three exceedances occurred in the southern Calcine Ditch (now included in OU-4a) to a depth of 20 feet.

COI concentrations in OU-3 groundwater are highest beneath the Precipitation Plant (Sub-area 5 on Figure 2-1), and are typically 10 times less than the concentrations in groundwater beneath OU-4a (Figures 5-2 to 5-7). The depth to groundwater beneath OU-3 ranges from 90 to more than 120 feet bgs (Figures 4-8 and 4-9). Vadose zone alluvial materials beneath OU-3 do not differ substantially from the vadose zone alluvial materials beneath OU-4a. Thus, to the extent that insights from the OU-4a vadose zone modeling results and soil moisture profiling are applicable to OU-3, groundwater impacts beneath OU-3 appear to be the result of past mining operations and fluid management rather than post-mining ambient Site climate conditions.

5.5.2 Agriculture

Agricultural influences on Study Area groundwater were identified and quantified during the background assessment and are summarized below.

Benson and Spencer (1983) noted that "agricultural practices strongly influence the concentration of uranium in Walker River and its East and West Forks. Irrigation practices induce significant losses of fluid through evaporation and evapotranspiration processes. This results in artificial increases in concentrations of uranium and other elements." Percolation of crop irrigation water through soils increases alkalinity in soil moisture, which has been shown at other sites (Jurgens et al. 2010; Brown et al. 2007) to solubilize and desorb naturally-occurring uranium from sediments resulting in elevated uranium concentrations in Shallow zone groundwater. Application of agricultural amendments and fertilizer on crop fields contributes sulfate, calcium, nitrate and other COIs to groundwater (Benson and Spencer 1983; BC 2014a, 2016b). Nitrate originating primarily from surface-applied fertilizers also plays a role in uranium solubilization leading to uranium mobilization (Nolan and Weber 2015).

Groundwater data from the NSA show that agricultural activities contribute sulfate, uranium, nitrate, alkalinity, and other COIs to groundwater. The NSA refers to the portion of the groundwater Study Area located northeast of West Campbell Ditch and north of the Sunset Hills. Monitor wells and well clusters located in the NSA include B/W-10(S, D1), B/W-50(S, D1, D2, D3), B/W-53(S1, S2, B), B/W-54(S, I, B), B/W-55(S, D1, D2), B/W-56S, B/W-57(S, I, D1, D4), B/W-58(S, D1, D3, B), B/W-59(S, D3), B/W-68(S, D1, D4), B/W-69(S, D1, D2, D5), B/W-81(S, D1, D2), B/W-82R(S, I, B), YPT-MW-(8S, 9I, 10B), YPT-MW-(11S, 12I), YPT-MW-(13I, 14D1) and MMW-2. Groundwater flow data and chemical distributions from monitor wells and clusters B/W-56, B/W-57, B/W-59, B/W-68, B/W-69, and B/W-81 discussed below illustrate the effects of agricultural practices on groundwater quality near agricultural fields in the northeastern part of the Study Area. The locations of these wells are shown on Figure 3-3 and potentiometric surface maps for the alluvial aquifer (Figures 4-11a through g) indicate that groundwater in the NSA flows to the north and northwest.

Groundwater near these wells in the NSA is recharged by infiltration from the East Campbell Ditch and irrigation on a series of agricultural fields (BC 2014a; SSPA 2014). During drilling and installation of monitor wells, zonal groundwater samples were collected to profile vertical chemical gradients in the alluvial aquifer upgradient and downgradient of the fields. Chemical profiles for sulfate, uranium, alkalinity, and arsenic in groundwater are provided on Figure 5-12 for B/W-59, B/W-68, and B/W-69, and on Figure 5-13 for B/W-56, B/W-57, and B/W-81. The wells are grouped in this manner to illustrate changes in groundwater chemistry along two parallel flow paths beneath the agricultural fields.

Except for arsenic, chemical concentrations in alluvial groundwater in the Shallow through Deep 2 zones (i.e., above 4,120 feet amsl) increase along the flow path beneath the agricultural fields (i.e., from B/W-59 and B/W-56 upgradient of the agricultural fields to B/W-68 and B/W-57 immediately downgradient of the agricultural fields). B/W-69 and B/W-81, located farther along their respective flow paths, also exhibit elevated values above 4,120 feet amsl, although the values are not as high as in B/W-68 and B/W-57 immediately downgradient of the agricultural fields. From B/W-56 to B/W-57, sulfate values exhibit more than a four-fold increase from about 30 mg/L at B/W-56 to a maximum of 137 mg/L at B/W-57. Uranium values exhibit more than a ten-fold increase from about 2 µg/L at B/W-56 to a maximum of 73 µg/L at B/W-57. Alkalinity exhibits a 2.5-fold increase from about 100 mg/L at B/W-56 to a maximum of 257 mg/L at B/W-57. From B/W-59 to B/W-68, sulfate values exhibit a two-fold increase from about 75 mg/L at B/W-59 to a maximum of 140 mg/L at B/W-68. Uranium values exhibit almost a two-fold increase from about 25 µg/L at B/W-59 to a maximum of 44 µg/L at B/W-68. Alkalinity exhibits a 20% increase from about 190 mg/L at B/W-59 to a maximum of 235 mg/L at B/W-68.

Arsenic exhibits increasing concentrations with depth at all locations, with the greatest increases observed in the Deep 3 through Deep 5 zones (i.e., below 4,120 feet amsl). Arsenic values generally increase from about 5 µg/L in the Shallow zone to approximately 80 µg/L in the Deep 5 zone. Arsenic values decrease along the flow path beneath the agricultural fields (the highest values are observed in B/W-59 and B/W-56, and the lowest values are observed in B/W-69 and B/W-81).

Data from well clusters B/W-59, B/W-68, B/W69, B/W-56, B/W-57 and B/W-81 indicate that concentrations of other constituents in addition to sulfate, uranium and alkalinity also increase in groundwater above 4,120 feet amsl along the flow path beneath the agricultural fields (Table 5-4). These constituents include TDS, calcium, chloride, magnesium, potassium, nitrate, and strontium. The average horizontal groundwater flow gradient in Shallow zone groundwater beneath the agricultural fields is approximately 0.002 feet/foot. Vertical (downward) groundwater flow gradients beneath the agricultural fields range between 0.02 feet/foot when agricultural pumping is not occurring and 0.1 feet/foot during pumping periods (calculated using water levels in B/W-57S and B/W-57D4).

Increasing alkalinity and calcium concentrations are important controls on mobilization of naturally-occurring uranium from aquifer solids (Bernhard et al. 2001). The correlation between increasing concentrations of alkalinity and calcium associated with agricultural activities, and increasing uranium concentrations as groundwater flows beneath agricultural fields in the NSA is discussed in Section 6.2.2.

Table 5-4. Concentrations of Constituents that Increase Beneath the Agricultural Fields in the North Study Area

Constituent	Units	Average Concentration in Monitor Well (May 2012 - October 2014)				
		B/W-59S	B/W-68S	B/W-68D1	B/W-69S	B/W-69D1 & B/W-69D2
Sulfate	mg/L	48	110	79	125	79
Uranium	µg/L	9	30	41	29	30
Alkalinity, bicarbonate (as $CaCO_3$)	mg/L	140	260	230	275	188
Total Dissolved Solids (TDS)	mg/L	260	530	440	540	400
Calcium	mg/L	31	49	76	78	64
Chloride	mg/L	16	20	20	25	20
Magnesium	mg/L	9	12	19	20	15
Potassium	mg/L	4	5	6	6	6
Nitrate (as N)	mg/L	0.06	5.0	2.9	1.2	0.9
Strontium	mg/L	0.3	0.5	0.6	0.7	0.6
Constituent	**Units**	**Average Concentration in Monitor Well (May 2012 - October 2014)**				
		B/W-56S	**B/W-57S**	**B/W-57I & B/W-57D1**	**B/W-81S**	**B/W-81D1 & B/W-81D2**
Sulfate	mg/L	41	62	142	70	62
Uranium	µg/L	4	11	75	4	36
Alkalinity, bicarbonate (as $CaCO_3$)	mg/L	140	174	293	160	213
Total Dissolved Solids (TDS)	mg/L	254	345	620	350	370
Calcium	mg/L	31	41	103	50	64
Chloride	mg/L	15	18	32	21	20
Magnesium	mg/L	8	11	25	13	15
Potassium	mg/L	5	3	9	5	7
Nitrate (as N)	mg/L	0.08	1.3	1.4	1.4	0.7
Strontium	mg/L	0.3	0.4	0.9	0.4	0.6

Notes: mg/L = milligrams per liter; µg/L = micrograms per liter

5.5.3 Naturally-Occurring Sources

Sulfate, uranium, arsenic, and other COIs occur naturally in groundwater in Mason Valley because of groundwater contact with naturally-mineralized and/or hydrothermally-altered bedrock associated with copper deposits and/or alluvial sediments derived from mineralized bedrock (BC 2014a, 2016b).

As noted in Section 5.4, the extent of mine-impacted groundwater was conservatively estimated under EPA direction because it “is in the best interest of the overall progress for completing the OU-1 Groundwater Remedial Investigation Report” and that the tools used in the background assessment to estimate the area of mine-impacted groundwater may not account for the full range of chemical concentrations that occur naturally in Study Area groundwater (EPA 2016c).

Extensive evidence of naturally-occurring sulfate, uranium, arsenic and other COIs in Mason Valley groundwater includes detectable concentrations of these chemicals in: 1) surface water, which is the primary component of alluvial aquifer recharge, at sampling points located upstream of the Site (Benson and Spencer 1983; BC 2014a); 2) groundwater and geothermal water in the discharge area at the northern end of Mason Valley (Benson and Leach 1979); 3) groundwater samples from Yerington municipal water supply wells that are located hydraulically upgradient and/or cross-gradient of the Site; 4) groundwater samples from monitor wells installed by ARC that are located hydraulically upgradient and/or cross-gradient of the Site (BC 2016b), with concentrations of sulfate and uranium occasionally above MCLs; 5) groundwater from private wells sampled by the USGS located hydraulically upgradient and/or cross-gradient of the Site, with concentrations of sulfate, uranium and arsenic occasionally above MCLs (Benson and Spencer 1983); and 6) groundwater samples from monitor wells installed by ARC that are located outside of the plume of mine-impacted groundwater in the NSA (BC 2016b), with concentrations of uranium as high as 100 µg/L or more.

Further evidence of naturally-occurring COIs in groundwater near the Site occurs in the SWRA where elevated arsenic, and possibly other COIs, appears to be associated with MFR hydrologic processes. These MFR processes include: 1) subsurface water transmitted along fractures and

faults (especially oblique range-front faults such as the Sales Fault) in arsenic-bearing volcanic and granitic bedrock that connect subsurface water in the mountain block and the basin aquifer; and 2) contributions of water at the mountain front from surface stream runoff and shallow subsurface water transmitted in stream bed sediments. Elevated arsenic in SWRA groundwater is associated with low concentrations of sulfate and uranium (the two primary indicators of mine-impacted groundwater), and hydrologic tracer data yield groundwater age estimates that pre-date mining (BC 2016b; EPA 2016b). Collectively, this information indicates that elevated arsenic and possibly other COIs in groundwater in this part of the Study Area are not associated with mining activities. Instead, elevated arsenic in this part of the Study Area is likely naturally-occurring. Elevated arsenic values have been associated with MFR, geothermal groundwater, and stagnant groundwater systems (Smedley and Kinniburgh 2001), and these characteristics apply to the sub-geothermal groundwater present in all groundwater zones to the west of the Site. The elevated temperature of groundwater to the west of the Site and adjacent to the Singatse Range, where MFR hydrologic processes predominate, are shown on figures provided in Appendix L.

SECTION 6.0
CONTAMINANT FATE AND TRANSPORT

The medium of concern in the OU-1 Study Area is groundwater and the mine-related COIs include acidity (i.e., low pH), TDS, major ions including sulfate, metals, and radiochemicals including uranium. The physical transport mechanisms and geochemical attenuation/mobilization processes that affect the movement of COIs in Study Area groundwater are discussed below.

6.1 Contaminant Transport

Transport mechanisms are physical processes controlling the movement of COIs from points of origin through the groundwater system. In the Study Area, COIs are (were) sourced to groundwater from Site sources and/or agricultural practices, and occur naturally in groundwater in Mason Valley because of groundwater contact with naturally-mineralized and/or hydrothermally-altered bedrock associated with copper deposits and/or alluvial sediments derived from mineralized bedrock.

The dominant solute transport mechanisms for COIs in groundwater are advection and dispersion. Advective transport is the migration of the COI with the groundwater. Groundwater moves from areas of recharge (i.e., high hydraulic head) to areas of discharge (i.e., low hydraulic head) and groundwater velocities are determined by solving the groundwater flow equation, which is a function of hydraulic conductivity, hydraulic gradient, and porosity. Groundwater levels in monitor wells provide hydraulic head and groundwater flow velocity information. Hydrodynamic dispersion describes the spread of COIs around an average groundwater flow path, beyond the region they would normally occupy due to advection alone. Hydrodynamic dispersion is the sum of two processes: mechanical dispersion and molecular diffusion. Mechanical dispersion results from mixing that occurs because of local variations in groundwater velocity and the aquifer's matrix. Molecular diffusion results from variations in solute concentrations within the groundwater system.

The primary influences on groundwater movement in the Study Area are subsurface lithology and structure, and local groundwater pumpage and irrigation associated with agriculture. Agricultural activities influence groundwater flow rates and directions, chemical migration pathways and transport rates, and contribute chemicals to groundwater via leaching of soil amendments and subsequent transport through the vadose zone to groundwater. Irrigation practices near the mine Site, including groundwater extraction using high-capacity wells and conveyance/irrigation of both water from the Walker River and groundwater, alter groundwater flow rates and directions during the irrigation season due to the alteration of the natural recharge/discharge rates and locations. These alterations in groundwater flow affect contaminant transport rates and directions.

6.2 Geochemical Attenuation/Mobilization Processes

Geochemical processes that affect the release and subsequent mobility/attenuation of mine-related COIs such as sulfate, uranium and metals during groundwater transport in the Study Area have been evaluated (BC 2016b; Appendix J-7) using: 1) Study Area groundwater data from August 2014 including field parameter measurements (i.e., pH, ORP and DO) and chemical concentrations; 2) the EPA-approved thermodynamic database developed for geochemical modeling Site geochemical attenuation/mobilization processes; and 3) correlations between common groundwater chemicals that affect uranium mobility.

6.2.1 Groundwater Geochemical Conditions and Chemical Speciation

Geochemical oxidation/reduction (redox) conditions within alluvial aquifer groundwater are variable; however, certain general trends and patterns are observed. In general, oxic conditions (i.e., DO > 1 mg/L and higher Eh values) occur in Shallow zone groundwater and suboxic to anoxic conditions (i.e., DO < 1 mg/L and lower Eh values) occur in Intermediate and Deep groundwater zones (Figure 6-1). Exceptions to this general pattern include the following: 1) in Shallow zone groundwater beneath much of the Site and off-Site to the north of the Evaporation Ponds, anoxic (rather than oxic) conditions occur; 2) in Deep groundwater zones beneath the Hunewill Ranch, oxic (rather than anoxic) conditions occur; and 3) on the west side of the Study Area adjacent to the Singatse Range, oxic conditions occur in the Shallow zone, as well as all deeper zones in this part of the Study Area.

Dissolved iron and the iron-system mineralogy, of all the metals present in groundwater, provide the most important constraints on pH, redox, and other metal solubilities in Study Area groundwater (BC 2016b; Appendix J-5). Ferric hydroxide solids in the aquifer sediments can adsorb significant concentrations of dissolved metals and metalloids such as uranium and arsenic, attenuating transport of these constituents. The importance of iron mineralogy and its widespread influence on the Study Area fluid chemistry are illustrated with two Eh-pH diagrams (Figures 6-2 and 6-3). The mineral stability fields in each diagram were constructed for groundwater pH values below, and above, 5.5 respectively, using chemical data from discrete groundwater populations. The individual samples were then plotted on each diagram. The populations were selected from similar chemical environments (samples from two or more unrelated populations are scattered and often obscure the trends).

Groundwater samples from two populations with strong mining impact (pH values below 5.5; Figure 6-2) clearly plot along the K-jarosite and schwertmannite phase boundaries and triple points. Sample alignment near and along the aqueous-mineral boundaries demonstrates the important role these minerals play in dominating and buffering the acidic groundwater at relatively oxidizing Eh levels, as noted above. Also shown on the figure is the specific sample from which the phase boundaries in the figure were computed.

Groundwater samples from two off-Site and more alkaline populations (pH values above 5.5; Figure 6-3) are aligned along the aqueous Fe^{2+} - $Fe(OH)_3(a)$ phase boundary. The mineral $Fe(OH)_3(a)$ is an important adsorptive phase that limits/attenuates the concentrations of other groundwater metals.

As noted previously, the strong alignment demonstrates the impact of the ferric hydroxide phase upon the groundwater redox and pH. The phase boundaries for this diagram were computed from the cluster centroid composition. Based on the groundwater redox conditions and geochemical modeling (BC 2016a; Appendix J-5), chemicals in Study Area groundwater exhibit the following:

- The dominant aqueous redox states determined in virtually all August 2014 groundwater samples were As(V), Fe(II), Mn(II) Se(IV) and U(VI). Vanadium was present in the V(V) redox state in all August 2014 groundwater samples from the Intermediate, Deep and bedrock wells. In Shallow zone groundwater, the V(IV) redox state predominated below a pH of about 5 and the V(V) redox state predominated above a pH of 5.
- Sulfur dissolved in Study Area groundwater is present as sulfate (a negatively-charged ion) and gypsum saturation is observed only in groundwater samples with sulfate concentrations exceeding approximately 1,500 mg/L.
- In the absence of sulfate reduction or gypsum precipitation, the negatively-charged sulfate ion is minimally attenuated in groundwater systems by adsorption. Consequently, in Study Area groundwater with sulfate concentrations less than approximately 1,500 mg/L, sulfate can be expected to be transported as a conservative constituent.
- U(VI) is the dominant oxidation state of dissolved uranium in all August 2014 groundwater samples. Differences in the aqueous speciation of uranium are related to the pH and availability of cations in solution, not redox conditions. Dissolved uranium in Study Area groundwater is predominantly present in complexes with sulfate, carbonate and/or calcium that form neutral or negatively-charged ions (e.g., $Ca_2UO_2(CO_3)_3^0$, $CaUO_2(CO_3)_3^{-2}$, $UO_2(SO_4)_2^{-2}$, and UO_2SO_4) (Figure 6-4). Samples with dominant calcium-uranyl-carbonate ligands reflect oxidizing, carbonate-rich groundwater conditions. Samples with dominant uranyl-sulfate ligands reflect oxidizing conditions with no detectable amounts of alkalinity and pH <5.
- Formation of neutral or negatively-charged aqueous uranium species has been shown to limit uranium adsorption and increase uranium mobility (Fox et al. 2006; Stewart et al. 2010). Since limited uranium adsorption onto hydrous ferric hydroxide solids and soils is expected in neutral to slightly alkaline groundwater (Hsi and Langmuir 1985; Echevarria et al. 2001), uranium attenuation during groundwater transport in off-Site portions of the Study Area can be assumed to be negligible as a conservative first approximation.
- As(V) arsenate is the dominant oxidation state for all August 2014 groundwater samples indicating oxic groundwater conditions, and arsenic speciation is dominated by the negatively-charged $H_2AsO_4^-$ and $HAsO_4^{-2}$ species. Geochemical modeling indicates the potential for precipitation of several arsenic mineral phases including scorodite and barium arsenate.
- Arsenate adsorption on sediments tends to decrease with increasing pH because of competition for adsorption sites between the negatively-charged arsenate aqueous species and OH^- or bicarbonate (Sø et al. 2008; Stachowicz et al. 2007).
- Geochemical modeling predicts the potential for jarosite mineral precipitation primarily in the Shallow zone under the LEP, UEP, Thumb Pond, and Phase IV HLP (Figure 6-5). Uranium and other metals associated with predicted jarosite mineral phases and aquifer sediments beneath these features potentially represent a persistent source of chemicals to groundwater.

- The spatial distributions of elevated concentrations of mobile parameters such as sulfate and uranium are significantly more extensive than the spatial distributions of acidity (as indicated by pH) and metals. The limited spatial extent of low pH values and elevated metal concentrations indicates that geochemical attenuation processes in Study Area groundwater reduces acidity and limits the mobility of metals relative to the more mobile chemicals such as sulfate and uranium. Elevated metal concentrations in groundwater correlate strongly with low pH.

6.2.2 Controls on Uranium Mobility in North Study Area Groundwater

As noted previously in Section 5.5.2, the concentrations of numerous COIs in groundwater increase along groundwater flowpaths beneath agricultural fields in the NSA. The correlation between increasing concentrations of alkalinity and calcium associated with agricultural activities, and increasing uranium concentrations as groundwater flows beneath agricultural fields in the NSA is shown on Figure 6-6. Increasing alkalinity and calcium concentrations are important controls on the formation of uranium species that have a low tendency to bind to aquifer solids (Bernhard et al. 2001) and, thus, uranium is mobilized from aquifer solids to adjacent groundwater as alkalinity and calcium concentrations increase. In addition, the observed correlation between increasing concentrations of alkalinity, calcium and uranium is consistent with the previously-noted geochemical modeling predictions of uranium speciation in Study Area groundwater.

The upper panel in Figure 6-6 displays data for all the alluvial monitor wells in the NSA that are located near agricultural fields. The lower panel in Figure 6-6 displays a subset of the data presented in the upper panel. Specifically, this lower panel displays data along a groundwater flow path from wells upgradient of the NSA agricultural fields (i.e., wells B/W-56 and B/W-59) to wells/well clusters located downgradient of the NSA agricultural fields (i.e., well cluster B/W-57 and well YPT-MW-12I). In wells located upgradient of the NSA, uranium concentrations are less than 12 µg/L. However, as groundwater flows beneath the NSA agricultural fields and concentrations of alkalinity and calcium increase, naturally-occurring uranium attached to aquifer solids is released. At well B/W-57I, elevated uranium concentrations range from approximately 48 to 72 µg/L and at well B/W-57D1 elevated uranium concentrations range from 73 to 110 µg/L.

Well YPT-MW-12I is located hydraulically downgradient of well cluster B/W-57, which provides additional information about chemical loading to alluvial groundwater associated with agricultural activities in the NSA. The influence of agricultural activities on chemical concentrations in YPT-MW-12I is shown on Figure 6-7. Although concentrations of uranium in groundwater at YPT-MW-12I have increased recently (upper panel), the trends in chemical concentrations in groundwater at this well are consistent with geochemical projections based on the control that calcium and alkalinity have on uranium mobility, and are not related to the Site.

As indicated in the lower panel, sulfate concentrations in well YPT-MW-12I are greater than 71 mg/L and exhibit seasonal variability, with elevated concentrations occurring in February of each year. Plume advancement cannot account for the magnitude of sulfate concentrations or seasonality observed in this well because sulfate concentrations are lower in wells to the southwest that demarcate the leading edge of mine-impacted groundwater (i.e., well clusters B/W-10, B/W-52, and B/W-55). Instead, the concentrations of sulfate in well YPT-MW-12I can only be accounted for by sulfate concentrations in upgradient wells B/W-57I and B/W-57D1, which are impacted by agricultural activities.

6.2.3 Site-Specific Distribution Coefficients

As groundwater migrates within the Study Area, certain geochemical reactions occur between the COIs in groundwater and the alluvial aquifer sediments. These reactions determine the relative rates at which chemicals migrate with respect to the advective front of groundwater. The primary process associated with the attenuation of inorganic COIs, particularly metals, in groundwater is adsorption onto the surfaces of minerals or organic material in the aquifer sediments.

The Site-specific distribution coefficient (K_d) discussed in Section 3.3.5 may be used to quantify adsorption reactions between COIs in groundwater and the alluvial aquifer sediments during groundwater flow and chemical transport simulations. It should be noted that the distribution coefficient is a bulk measurement and provides only indirect information on the type of adsorption interactions taking place on the alluvial aquifer sediments. Summary statistics for the revised K_d values calculated using zonal groundwater sample data are shown in Table 6-1.

Table 6-1. Summary Statistics for Zonal Sample K_d Values

Analyte	Distribution Coefficient Statistics (L/kg)				
	Minimum	Maximum	Mean	Geometric Mean	Median
Sulfate	0.05	0.62	0.18	0.15	0.16
Uranium	0.42	289	49	17	33
Arsenic	108	6,412	1,763	957	800

Notes: L/kg = liters per kilogram

K_d values less than 1 L/kg, as is the case for sulfate, indicate little if any partitioning of this negatively-charged ion from the dissolved (i.e., liquid) phase to the solids phase. The uranium K_d values are higher than K_d values for sulfate, indicating some tendency for uranium adsorption on aquifer sediments. Dissolved uranium in Study Area groundwater is predominantly present in neutral or negatively-charged complexes (Figure 6-4), which has been shown to limit uranium adsorption (Fox et al. 2006; Stewart et al. 2010). However, limited uranium adsorption onto hydrous ferric hydroxide solids and soils is expected in neutral to slightly alkaline groundwater (Hsi and Langmuir 1985; Echevarria et al. 2001; Li and Kaplan 2012), and likely explains the higher uranium K_d values.

K_d values for arsenic are substantially greater than 1 L/kg. These high K_d values reflect much higher concentrations of those chemicals in the solid phase versus the dissolved phase, which indicates a strong tendency for arsenic to partition from the dissolved to the solid phase.

Summary statistics for the K_d values calculated for the 25 chemicals and compounds using monitor well groundwater samples are shown in Table 6-2.

Table 6-2. Summary Statistics for Monitor Well K_d Values

Analyte	Distribution Coefficient Statistics [1]				
	Minimum	**Maximum**	**Mean**	**Geometric Mean**	**Median**
Aluminum	10,850	214,670	88,830	64,851	98,350
Arsenic	18.4	1,311	461.2	277.2	421
Boron	0.40	9.26	4.39	3.15	3.36
Barium	93.8	6,676	1,937	959	1,000
Calcium	0.38	20.6	7.62	3.47	4.74
Chloride	0.07	1.56	0.22	0.18	0.17
Cobalt	192.3	4,643	2,462	1,869	2625
Chromium	316	1,182	689	626	579
Copper	83.3	13,684	4,645	2,662	3,333
Fluoride	1.56	17.2	4.52	3.73	3.26
Iron	8.6	541,880	22,112	146,061	242,733
Potassium	5.1	292.4	109.0	72.7	97.5
Lithium	46.0	379.3	126.6	116.1	113.8
Magnesium	0.34	76.8	26.2	12.5	23.5
Manganese	56.8	3,838	795	351	291
Molybdenum	0.14	2,130	176.9	21.0	63.1
Sodium	0.21	1.3	0.78	0.64	0.88
Nickel	300	1,736	1,142	1030	1,200
Nitrate	0.03	4.0	0.30	0.16	0.15
Lead	1,000	48,100	14,983	8,355	9,600
Selenium	35.9	9,180	3,084	1,202	2154
Sulfate	0.03	1.04	0.186	0.15	0.17
Uranium	1.0	238.2	41.7	20.2	25.6
Vanadium	43.5	4,717	1,115	673	917
Zinc [2]	1,385	1,385	1,385	1,385	1,385

Notes:

1) L/kg = liters per kilogram.
2) For zinc, only one set of co-located sediment and water samples were available for calculating a K_d.

The majority of the K_d values calculated using the monitor well groundwater samples are greater than 1 L/kg. Chloride, nitrate, and sulfate (negatively charged ions in groundwater) and sodium were the only chemicals where the K_d values were consistently less than 1 L/kg. Boron, calcium and fluoride had K_d values in the range of 1 to 10 L/kg. All other chemicals and compounds had K_d values ranging from 10 L/kg up to approximately 500,000 L/kg.

The values at the high end of the range are influenced by the presence of non-detects in the data for the groundwater concentrations. In particular, groundwater concentrations for aluminum, iron and lead were almost universally below the detection limits. However, the concentrations in the soil samples for those same chemicals were nearly all above the detection limit. In these cases, the groundwater concentrations used to calculate K_d values typically represented the reporting limit for that particular chemical. Given that, the K_d values can be thought of as upper bounds for that particular chemical and indicate very little mobility in groundwater.

The variability between the K_d values for the same chemical or compound was, in general, consistent. Only a few chemicals had K_d values with variabilities of more than one order of magnitude. Typically, the wider-ranging K_d variabilities were expressed for those chemicals with non-detect results that were incorporated into the calculation.

Statistical parameters characterizing the uranium K_d values derived from zonal and monitor well groundwater sample data are similar. Uranium K_d values based on monitor well data vary by approximately two orders of magnitude. A correlation of uranium K_d values with Site geochemical data shows that uranium adsorption varies as a function of changes in pH and concentrations of alkalinity, calcium and magnesium. Consequently, use of a constant K_d approach to simulate uranium adsorption during predictive transport modeling may not accurately represent actual adsorption processes.

Instead, a surface complexation model (SCM), such as the general composite approach described by Davis et al. (2009), may be more suitable for modeling adsorption processes during transport at the Site because it can describe changes in adsorption reactions at mineral surfaces as chemical conditions and aqueous speciation(s) change. However, in off-Site portions of the Study Area where aqueous concentrations are lower and hydrous ferric hydroxide solid concentrations are more sporadic, it may be appropriate to assume negligible uranium attenuation during groundwater transport as a conservative first-order approximation.

6.3 Mine-Impacted Groundwater Plume Dynamics

Summarized below are the initial evaluations of mine-impacted groundwater plume dynamics that have been presented in previous reports (BC 2014f, 2015f) and/or discussed with EPA, NDEP and other stakeholders during groundwater technical meetings in 2015 and 2016. The results of these initial evaluations will be provided in a separate report, along with: 1) a statistical evaluation of chemical concentration trends in individual monitor wells, as requested by EPA; and 2) flow model predictions of future changes in plume dimensions and chemical concentrations.

Multiple approaches consisting of center-of-mass calculations and trend evaluations of the total masses and average concentrations of sulfate and uranium have been used to evaluate the dynamics of the plume of mine-impacted groundwater.

Methods

This evaluation was conducted using the Monitoring and Remediation Optimization System (MAROS) software that was developed by the U.S. Airforce Center for Environmental Excellence (AFCEE 2006). MAROS uses the Delaunay Triangulation/Voronoi Diagrams method (George and Borouchaki 1998) to partition the interpolation area into polygon-shaped sub-regions associated with each monitor well. The chemical concentration in an entire sub-region is represented by the concentration in the associated monitor well in a given sampling event. MAROS then calculates the location of the center-of-mass of the interpolated chemical distribution.

MAROS software allows for efficient and consistent computation of large groundwater datasets and depictions of the chemical center-of-mass over time, as well as providing output for computation of changes in chemical mass and average chemical concentration over time. However, the MAROS computation method uses polygon-shaped sub-areas that do not fully encompass the curvilinear area of mine-impacted groundwater. Consequently, although the MAROS output is consistently computed over time, the computed volumes (and derived chemical masses and average concentrations) are underestimated relative to the method used in Section 5.4 to estimate plume statistics.

Center-of-Mass Evaluation

The center-of-mass of plumes of the mine-related constituents sulfate and uranium and the total chemical mass in these plumes were evaluated over the three-year period 2012 through 2015 to assist in the evaluation of plume dynamics. The center-of-mass analysis requires a consistent set of data over time to make meaningful inferences about plume movement. Therefore, only wells that were monitored in every quarter from 1Q 2012 through 1Q 2016 were included in the analysis. Centers-of-mass for sulfate and uranium were calculated for the Shallow, Intermediate, Deep 1, Deep 2, Deep 3, and combined Deep 4 and 5 zones of the alluvial aquifer. The Deep 4 and 5 zones of the alluvial aquifer were combined due to the limited number of monitor wells in these zones.

In the evaluation, monitor well B/W-27D3a was included in the list of Deep 2 zone wells and monitor well B/W-41D4 was included in the list of Deep 3 zone wells to address areas within each zone that were lacking adequate spatial coverage. Monitor wells in the B/W-65 well cluster, located in the middle of an agricultural field, were not included in the analysis because the wells have been sampled sporadically due to lack of access during the irrigation season.

Prior to interpolation, chemical data from the 261 monitor wells were reviewed using time-concentration plots to screen for potential outliers. When outliers were identified for a particular sampling event, the value of the data point was replaced with the average value of the previous and subsequent sampling events. The number of outliers identified represents less than 0.2 percent of the data used in the analysis.

The calculated centers-of-mass for sulfate and uranium are located beneath the Evaporation Ponds (Figure 6-8), with the following exceptions:

- The uranium center-of-mass in the Deep 1 zone is located beneath the Hunewill Ranch (about 3,000 feet northwest of the monitor well B/W-25D1). This is consistent with the presence of collocated elevated concentrations of uranium and alkalinity beneath the agricultural fields in the Deep 1 zone compared to areas beneath the Site.
- The uranium center-of-mass in the Deep 4/5 zone is located beneath the Hunewill Ranch within a few hundred feet of the Site boundary.

From February 2012 to February 2016, the centers-of-mass for the sulfate and uranium plumes exhibit very little relative movement, an indication of stable plume behavior.

Total Mass and Average Concentrations

Over the 3-year monitoring period from February 2012 to February 2015, the masses of sulfate and uranium in each of the groundwater zones remained relatively stable, with typically less than five percent variation between the initial and more recent monitoring events (Figure 6-9). Also, clear trends (either increasing or decreasing) are not evident, with the exception of decreasing sulfate trends observed in the Shallow zone and decreasing sulfate and uranium trends in combined Deep 4 and Deep 5 zones. During the monitoring period, the calculated mass of sulfate in the Shallow zone decreased from about 97,000 to 85,000 tons (i.e., 12%) and the mass of sulfate in the Deep 4/5 zones decreased from about 13,000 to 10,000 tons (i.e., 25%). The mass of uranium in the combined Deep 4 and Deep 5 zones decreased from about 5.2 to 3.7 tons (i.e., 29%).

Because the various alluvial groundwater zones have different thicknesses and volumes, the total chemical masses in each individual zone are not directly comparable. For example, the Intermediate zone contains the smallest sulfate mass because it is the thinnest groundwater zone. Consequently, changes in average concentrations over time in the various groundwater zones are a more appropriate comparison. Changes over time in average concentrations of sulfate and uranium in the alluvial aquifer groundwater zones are also shown on Figure 6-9.

Clear trends (either increasing or decreasing) are not evident, with the exception of decreasing average sulfate concentrations in the Shallow zone and decreasing sulfate and uranium concentrations in the combined Deep 4 and 5 zones. During the monitoring period, the average concentration of sulfate in the Shallow zone decreased from 1,518 mg/L to 1,330 mg/L (i.e., 12%) and the average concentration of sulfate in the Deep 4/5 zones decreased from 90 mg/L to 67 mg/L (i.e., 25%). The concentration of uranium in the Deep 4/5 zone decreased from 35 to 25 ug/L (i.e., 29%).

The decrease in sulfate mass and average concentration in the Shallow zone is interpreted as dilution effects from irrigation practices in the agricultural fields north of the mine boundary. The cause of the observed decrease in calculated average uranium concentrations in the combined Deep 4 and Deep 5 zones is likely due to dilution and dispersion. The calculated decrease in total sulfate and uranium mass is likely an apparent effect due to the fewer data points for calculating chemical mass.

The results of these evaluations indicate that, in general, the plume of mine-impacted groundwater is stable. The plume stability is the result of very slow groundwater velocities and attenuation by dilution. The dilution occurs primarily as the result of recharge on the agricultural fields (specifically on the fields of the Hunewill Ranch) and leakage from irrigation ditches (specifically the West Campbell Ditch), and dispersion within the groundwater plume.

SECTION 7.0

HYDROGEOLOGIC CONCEPTUAL SITE MODEL

The Site is a former copper mine located in the west-central portion of the Mason Valley, a Basin-and-Range-type graben filled with up to 1,000 feet of unconsolidated valley-fill deposits of Tertiary and Quaternary age lying unconformably on a weathered surface of hydrothermally-altered Tertiary volcanic and Mesozoic intrusive bedrock. The valley is bordered to the west by the Singatse Range, to the east by the Wassuk Range, and to the north by the Desert Mountains. Regional metals mineralization and hydrothermal alteration associated with localized porphyry and skarn copper deposits occur in the Singatse Range and nearby portions of the Mason Valley.

The unconsolidated valley fill deposits were derived primarily from erosion of the uplifted mountain blocks and from deposition in the floodplain of the Walker River. In addition, lacustrine deposits derived from ancestral Lake Lahonton occur north of the Site. Depositional processes have resulted in a complex interbedded sequence of alluvial sediments.

Historically, regional groundwater flow patterns in the Mason Valley prior to Anaconda/Arimetco mining operations were similar to current conditions with groundwater moving generally from south to north, and discharging to surface seeps and geothermal springs in the northern portion of the basin. Locally, though, current flow patterns have been significantly altered from historical patterns by agricultural activities. The alluvial aquifer in the Mason Valley is very productive and groundwater is currently pumped extensively for irrigation (Carroll et al. 2010; SSPA 2014).

The alluvial aquifer is primarily recharged by downward percolation from irrigated fields (49%), leakage from irrigation ditches (29%), infiltration from the channel of the Walker River (20%), and MFR (2%), consisting of infiltration through bedrock of precipitation that falls on surrounding mountain ranges and minor tributary surface flows in ephemeral drainages (SSPA 2014). Recharge from precipitation falling directly on the valley floor is negligible (Huxel and Harris 1969; Lopes and Allander 2009a, 2009b).

Within the Study Area, the alluvial sediments are up to 700 feet thick and comprise a single aquifer. The alluvial aquifer is subdivided into a Shallow, an Intermediate and a Deep zone (which is further subdivided into Deep zones 1 through 5). These groundwater zone designations are based on elevation and used only to identify and group monitor wells with similar screen intervals at the same relative depth in the aquifer. Clay layers or other low-permeability sediments are laterally discontinuous resulting in unconfined or semi-confined alluvial aquifer groundwater conditions.

Alluvial groundwater near the Site generally flows to the northwest, but flow directions are locally affected by bedrock outcrops within and along the margins of the valley, drawdown from pumped wells (particularly in deeper zones of the alluvial aquifer), and recharge sources including the Walker River, the West Campbell Ditch and irrigation on the Hunewill Ranch and other agricultural fields. Groundwater in the alluvial aquifer moves relatively slowly, with flow velocities estimated to be less than 100 feet per year (BC 2014a).

Anthropogenic activities within the Study Area, especially agricultural activities, influence groundwater flow rates and directions, chemical migration pathways and transport rates, and contribute chemicals to groundwater via evapoconcentration and leaching of soil amendments and naturally-occurring chemicals in alluvial sediments, and subsequent transport through the vadose zone to groundwater. Irrigation practices near the mine Site, including groundwater extraction using high-capacity wells and conveyance/irrigation of both water from the Walker River and groundwater, alter groundwater flow rates and directions during the irrigation season due to the alteration of the natural recharge/discharge rates and locations. Agricultural pumping seasonally results in strong downward vertical gradients that are often 10 to 100 times greater than horizontal gradients.

Past and/or ongoing sources of COIs to Study Area groundwater include: 1) the mine waste facilities, which have been grouped into the various Site OUs; 2) naturally-occurring chemicals; and 3) agriculture. The major past and/or ongoing mine-related sources of COIs to groundwater include: 1) OU-4a, the Evaporation Ponds (BC 2014a, 2014d); OU-8, the Arimetco Facilities (CH2M Hill 2010, 2011a, 2011b); and 3) OU-3, the Process Areas (BC 2014a, 2014e).

Mine-related COIs include acidity (i.e., low pH) and elevated concentrations of TDS, major ions including sulfate, metals, and radiochemicals including uranium. Concentrations of mine-related chemicals in groundwater are most elevated in the Shallow zone of the alluvial aquifer beneath OU-4a features that include the LEP, UEP, Finger Ponds, Phase IV VLT HLP, Phase IV VLT Pond, and the Calcine Ditch. Chemical concentrations in groundwater decrease with vertical depth and horizontal distance from these facilities.

Hydraulic assessments and chemical distributions indicate that the PWS was only partially effective in capturing Shallow zone mine-impacted groundwater during its operational life from 1989 to 2009, when it was shut down with EPA approval.

Geochemical evaluations of groundwater quality data (BC 2016a) indicate that sulfate and dissolved uranium form neutral or negatively-charged aqueous ionic species in groundwater throughout Study Area (except beneath the Evaporation Ponds) and, thus, undergo very limited (if any) geochemical attenuation due to mineral precipitation or adsorption to aquifer materials during groundwater transport. Dissolved uranium in Study Area groundwater is predominantly present in complexes with carbonate plus or minus calcium, which reflect oxidizing, carbonate-rich groundwater conditions. Locally, dissolved uranium is also complexed with sulfate in Shallow zone groundwater beneath the Evaporation Ponds where pH is less than 5 and sulfate concentrations exceed 1,500 mg/L.

The spatial distributions of elevated concentrations of mobile parameters such as sulfate and uranium are significantly more extensive than the spatial distributions of acidity (as indicated by pH) and metals. The significantly more limited spatial extent of low pH values and elevated metal concentrations indicates that geochemical attenuation processes in Study Area groundwater reduce acidity and limit the mobility of metals relative to the more mobile chemicals such as sulfate and uranium (EPA 2007b; BC 2016a, 2016b). Elevated metal concentrations in groundwater correlate strongly with low pH.

Geochemical evaluations of groundwater quality data (BC 2016a) also indicate the likely precipitation of solid mineral phases (e.g., jarosite) primarily in the Shallow zone beneath the LEP, UEP, Thumb Pond and Phase IV HLP. These mineral phases likely represent a potential, ongoing source of COIs to groundwater.

Sulfate, uranium, and arsenic (and other COIs) occur naturally in groundwater in Mason Valley because of groundwater contact with naturally-mineralized and/or hydrothermally-altered bedrock associated with copper deposits and/or alluvial sediments derived from mineralized bedrock (BC 2014a, 2016b). To the west of the Site where sulfate and uranium concentrations are low, elevated concentrations of arsenic are associated with MFR and elevated groundwater temperatures. In addition, sulfate, uranium, and other COIs are sourced to groundwater due to agricultural activities (BC 2016b; EPA 2016c). The assessment of background groundwater quality conservatively established the maximum extent of mine-impacted groundwater and identified an area of groundwater in the northern part of the Study Area (i.e., the NSA) that has been impacted by agricultural activities rather than mining activities.

The extent of mine-impacted groundwater has been defined using sulfate, dissolved uranium, and sulfur isotopes in sulfate because these parameters are more mobile in groundwater relative to other mine-related COIs such as metals (EPA 2007b) and, thus, have traveled the farthest downgradient distance in the alluvial aquifer (BC 2016b). The extent of mine-impacted groundwater in the Study Area can be generally described as follows, recognizing that mine-impacted groundwater is spatially more extensive in the Shallow, Intermediate and Deep 1 zones of the alluvial aquifer relative to the Deep 2 through Deep 5 zones. The northernmost extent of mine-impacted groundwater in the Shallow, Intermediate and Deep 1 zones of the alluvial aquifer is located near the Sunset Hills between well clusters B/W-10 and B/W-52. The eastern extent of mine-impacted groundwater in the Shallow, Intermediate and Deep 1 zones of the alluvial aquifer is approximately located near or beneath the West Campbell Ditch alignment. To the west of the Site, mine-impacted groundwater extends almost to the western extent of saturated alluvium between unimpacted wells/clusters B/W-16S and B/W-40, and impacted well clusters B/W-33, B/W-6 and B/W-22.

Mine-impacted groundwater in the deeper zones does not extend as far north as the upper three zones. In the Deep 2 through Deep 5 zones, the maximum northern extent of mine-impacted groundwater is near the northern end of the Hunewill Ranch fields. The eastern extent of mine-impacted groundwater in the Deep 2 through Deep 5 zones of the alluvial aquifer is located between well clusters B/W-27 and B/W-50. On the east, the area of mine-impacted groundwater in the Deep 3 through Deep 5 zones reflects the former influence of seasonal groundwater extraction for crop irrigation from agricultural wells (e.g., WDW019, located adjacent to the B/W-1 well cluster). To the west of the Site, mine-impacted groundwater in the Deep 3 through Deep 5 zones extends almost to the western extent of saturated alluvium.

The estimated volume of mine-impacted groundwater (i.e., the portion of the downgradient aquifer where sulfate and uranium exceed background concentrations) is 385,327 acre-feet, and contains an estimated 0.5 million tons of sulfate and 100 tons of dissolved uranium. Irrigation wells and municipal wells are located outside of the plume of mine-impacted groundwater (Figure 3-13). In addition, the plume of mine-impacted groundwater does not discharge to surface water.

The plume of mine-impacted groundwater appears stable based on evaluations of changes in the estimated volume of contaminated groundwater, sulfate/uranium masses, and chemical centers-of-mass through time. Plume stability is the result of very slow groundwater velocities and attenuation by dilution. The dilution occurs primarily as the result of recharge on the agricultural fields (specifically on the fields of the Hunewill Ranch) and leakage from irrigation ditches (specifically the West Campbell Ditch), and dispersion within the groundwater plume.

Groundwater quality in the NSA has been impacted by agricultural activities rather than mining activities (BC 2016b) based on multiple lines of evidence including groundwater flow patterns, chemical distributions, groundwater age estimates, hydrologic tracers, and sulfur isotopes. These agricultural practices have resulted in concentrations of sulfate and uranium that are elevated above background values and/or MCLs and/or exhibit increasing trends.

Monitor well data from the NSA indicate that concentrations of nitrate, sulfate, calcium, uranium, and alkalinity in alluvial groundwater in the Shallow through Deep 2 zones increase along the flow path beneath the agricultural fields. Increases in nitrate are associated with organic fertilizer application on crop fields. Increases in sulfate and calcium concentrations are associated with application of gypsum ($CaSO_4$) as a soil amendment on crop fields, which dissolve in irrigation water that percolates down to the water table. Increases in uranium concentrations are associated with crop irrigation. Percolation of irrigation water through soils increases alkalinity in the soil moisture, which mobilizes and desorbs naturally-occurring uranium from sediments (as soluble complexes with sulfate, carbonate plus or minus calcium) resulting in elevated uranium concentrations in groundwater (Jurgens et al. 2010; Brown et al. 2007). Alluvial sediments in Mason Valley contain naturally-occurring uranium (BC 2009b). The impact of agriculture activities on uranium mobility in NSA groundwater within or near irrigated land is illustrated by the strong correlation between uranium, alkalinity and calcium. Increases in alkalinity and calcium are associated with increases in uranium concentrations that can exceed 100 µg/L.

SECTION 8.0
RISK EVALUATION

In a groundwater technical meeting held on June 30, 2016 attended by ARC, EPA and other stakeholders, EPA directed ARC to proceed with preparation and submittal of this OU-1 RI Report without including the risk evaluation. The risk evaluation is ongoing and will proceed on a separate but parallel path from this document. Potential human health risks are generally described herein, but will be addressed more comprehensively in a separate OU-1 HHRA report.

This OU-1 RI Report, in conjunction with the OU-1 HHRA, will provide the basis for ARC to identify RAOs and potential remedies for OU-1, which would occur during future FS scoping discussions.

SECTION 9.0
REFERENCES

Air Force Center for Environmental Excellence (AFCEE), 2006. Monitoring and Remediation Optimization System (MAROS), User's Guide, March 2006.

Anaconda Mining Company, 1958. Engineering Drawing WHE-201, Tailing Disposal Sulphide Plant - Tailings Pond General Arrangement. March 24.

Anaconda Mining Company, 1966. Engineering Drawing YG-20, Water Supply & Distribution - Daily Water Balance Diagram. Prepared July 15, 1953. Revised July 28.

Anaconda Mining Company, 1967. Engineering Drawing WHN-1208, Sulphide Plant Quantitative Flow Diagram. Prepared May 19, 1966. Revised January 9.

Anaconda Minerals Company, 1984. Water Quality Investigation and Mitigation Plan. Yerington Mine.

Applied Hydrology Associates, 1983. Evaluation of Water Quality and Solids Leaching Data. Yerington Mine. Prepared for Atlantic Richfield Company.

Applied Hydrology Associates (also Norwest Applied Hydrology), 2000-2007. 2000-2007 Annual Monitoring and Operation Summary reports, Prepared for Atlantic Richfield Company.

Atlantic Richfield Company, 2008. Pumpback Well System Characterization Work Plan. Yerington Mine Site, Lyon County, Nevada.

Atlantic Richfield Company, 2010. Pumpback Well System Characterization Work Plan Addendum - Revision 2. Yerington Mine Site, Lyon County, Nevada. February 17.

Atlantic Richfield Company, 2011. Addendum to the On-Site Monitor Well Installation Work Plan. Yerington Mine Site, Lyon County, Nevada. September 7.

Atlantic Richfield Company, 2012a. Proposed Initial Bedrock Characterization Activities, Yerington Mine Site, Lyon County, Nevada. January 5.

Atlantic Richfield Company, 2012b. Proposed Initial Bedrock Characterization Activities - Revision 1, Yerington Mine Site, Lyon County, Nevada. October 11.

Atlantic Richfield Company, 2012c. Groundwater Flow Modeling Deliverables, Yerington Mine Site, Lyon County, Yerington, Nevada. June 25.

Atlantic Richfield Company, 2012d. Comprehensive Hydrologic Tracer Sampling Event and Request to Eliminate Select Tracers, Yerington Mine Site, Lyon County, Nevada. March 19.

Atlantic Richfield Company, 2012e. Preliminary Responses to February 7, 2012 EPA Comments on the 2011 Background Groundwater Quality Assessment, Yerington Mine Site dated September 28, 2011; Administrative Order on Consent, EPA Region 9 CERCLA Docket No. 9-2007-0005. April 18.

Atlantic Richfield Company, 2014. Technical Memorandum: Site-Wide Groundwater Monitoring Optimization, Yerington Mine Site, Lyon County, Nevada. April 14.

Atlantic Richfield Company, 2016a. Letter to D. Seter, Subject: Yerington Mine Site, Lyon County Nevada, Site ID #09GU, Request to Modify Domestic Well Monitoring Program and Bottled Water Program. September 1.

Atlantic Richfield Company, 2016b. Responses to EPA Comments dated February 11, 2016 on the Background Groundwater Quality Assessment - Revision 2 dated July 2, 2015; Administrative Order on Consent, EPA Region 9 CERCLA Docket No. 9-2007-0005. June 14.

Bell, E.J. and D.B. Slemmons, 1979. Recent crustal movements in the central Sierra Nevada-Walker Lane region of California-Nevada--Part II, The Pyramid Lake right-slip fault zone segment of the Walker Lane: Tectonophysics, v. 52, p. 571-583.

Benson, L.V. and D. L. Leach, 1979. Uranium Transport in the Walker River Basin, California and Nevada. Journal of Geochemical Exploration, vol. 11, p. 227-248.

Benson, L.V. and R.J. Spencer, 1983. A Hydrochemical Reconnaissance Study of the Walker River Basin, California and Nevada. USGS Open-File Report 83-740.

Bernhard, G., G. Geipel, T. Reich, V. Brendler, S. Amayri, and H. Nitsche, 2001. Uranyl(VI) carbonate complex formation: Validation of the $Ca_2UO_2(CO_3)_3$ (aq) species. Radiochimica Acta, 89:511-518.

Bigham, J.M., U. Schwertmann, S.J. Traina, R.L. Winland, and M. Wolf, 1996. Schwertmannite and the chemical modeling of iron in acid sulfate waters. Geochimica et Cosmochimica Acta, Vol. 60, pp. 2111-2121.

Bourrié, G., F. Trolard, J.M. Génin, A. Jaffrezic, V. Maître, and M. Abdelmoula, 1999. Iron control by equilibria between hydroxy-green rusts and solutions in hydromorphic soils. Geochimica et Cosmochimica Acta, Vol. 63, pp. 3417-3427.

Brown, C.J., B.C. Jurgens, B.G. Katz, M.K. Landon, and S.E. Eberts, 2007. Arsenic and Uranium in Four Aquifer Settings: Occurrence, Distribution, and Mechanisms for Transport to

Supply Wells. NGWA Naturally Occurring Contaminants Conference: Arsenic, Radium, Radon, Uranium. March 22-23.

Brown and Caldwell, 2002. Installation of Two Monitor Wells at the Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company.

Brown and Caldwell, 2003. Final Draft Process Areas Work Plan. Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. December 15.

Brown and Caldwell, 2005. First-Step Hydrogeologic Framework Assessment Work Plan North of the Anaconda Mine Site. Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. April 22.

Brown and Caldwell, 2007a. Data Management Plan for the Yerington Mine Site, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. April 24.

Brown and Caldwell, 2007b. Second-Step Hydrogeologic Framework Assessment Work Plan, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. February 28.

Brown and Caldwell, 2007c. Draft Site-Wide Groundwater Monitoring Plan, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. August 8.

Brown and Caldwell, 2008, Anaconda Evaporation Ponds Removal Action Characterization Work Plan, Yerington Mine Site. Prepared for Atlantic Richfield Company. September 15.

Brown and Caldwell, 2008a. Anaconda Evaporation Ponds Removal Action Characterization Work Plan, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. September 15.

Brown and Caldwell, 2008b. Shallow Alluvial Aquifer Characterization Work Plan for the Northern Portion of the Yerington Mine Site, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. December 30.

Brown and Caldwell, 2008c. Second-Step Hydrogeologic Framework Assessment Data Summary Report, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. October 15.

Brown and Caldwell, 2009, Evaporation Ponds Removal Action Characterization Data Summary Report. June 12.

Brown and Caldwell, 2009a. Site-Wide Groundwater Monitoring Plan - Revision 1, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. December 15.

Brown and Caldwell, 2009b. Background Soils Data Summary Report - Revision 1, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. March 9.

Brown and Caldwell, 2010a. Shallow Zone Characterization Data Summary Report - Revision 1, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. January 29.

Brown and Caldwell, 2010b. Addendum to the Site-Wide Quality Assurance Project Plan, Domestic Well Monitoring Plan - Revision 3, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. July 1.

Brown and Caldwell, 2010c. 2010 Groundwater Monitor Well Work Plan - Revision 2, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. July 22.

Brown and Caldwell, 2010d. Agricultural Fields Characterization Work Plan - Revision 2, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. July 20.

Brown and Caldwell, 2010e. Aquifer Solids Testing Work Plan - Revision 1, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. September 21.

Brown and Caldwell, 2010f. Summary of PWS Aquifer Testing, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. September 24.

Brown and Caldwell, 2010g. Draft Aquifer Solids Testing Work Plan, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. June 21.

Brown and Caldwell, 2011a. On-Site Monitor Well Installation Work Plan - Revision 1, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. August 29.

Brown and Caldwell, 2011b. Aquifer Solids Testing Work Plan - Revision 1, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. September 21.

Brown and Caldwell, 2011c. Draft Background Groundwater Quality Assessment, Site-Wide Groundwater Operable Unit, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. September 28.

Brown and Caldwell, 2012a. Site-Wide Groundwater Monitoring Plan - Revision 2, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. July 19.

Brown and Caldwell, 2012b. Draft Site-Wide Groundwater Operable Unit (OU-1) Remedial Investigation Work Plan, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. November 19.

Brown and Caldwell, 2012c. SOP-23 Aquifer Solids Testing SOP - Redox-Preserved Sample Preparation and Testing, Yerington Mine Site, Hazen Research, Inc. Laboratory Facility, Golden, CO. Prepared for Atlantic Richfield Company. August 17.

Brown and Caldwell, 2012d. SOP-23 Aquifer Solids Testing SOP - Redox-Preserved Sample Preparation and Testing - Revision 1, Yerington Mine Site, Hazen Research, Inc. Laboratory Facility, Golden, CO. Prepared for Atlantic Richfield Company. October 15.

Brown and Caldwell, 2012e. Aquifer Test Data Summary Report - Revision 1, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. December 13.

Brown and Caldwell, 2013a. 2010 Monitor Well Installation and Agricultural Fields Characterization Data Summary Report - Revision 1. Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. January 18.

Brown and Caldwell, 2013b. Additional Monitor Well Work Plan - Revision 1, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. October 8.

Brown and Caldwell, 2013c. Initial Bedrock Characterization Data Summary Report, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. November 20.

Brown and Caldwell, 2013d. Revised Public Information for the Northern Portion of the Background Groundwater Study Area, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. August 5.

Brown and Caldwell, 2013e. Draft Additional Monitor Well Work Plan, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. June 26.

Brown and Caldwell, 2014a. Site-Wide Groundwater Operable Unit (OU-1) Remedial Investigation Work Plan - Revision 1, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. February 7.

Brown and Caldwell, 2014b. 2013 Annual Operations and Maintenance Report for the Arimetco Fluid Management System, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. June 9.

Brown and Caldwell, 2014c. Groundwater Geochemical Characterization Data Summary Report, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. December 30.

Brown and Caldwell, 2014d. Phase 1 Field Sampling and Analysis Plan Anaconda Evaporation Ponds, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. July 31.

Brown and Caldwell, 2014e. OU-3 Step-out Soils Characterization Data Summary Report, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. December 12.

Brown and Caldwell, 2014f. 2013 Annual Groundwater Monitoring Report, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. May 12.

Brown and Caldwell, 2015a. Bedrock Groundwater Assessment Technical Memorandum, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. January 28.

Brown and Caldwell, 2015b. Draft Wabuska Drain (OU-7) Remedial Investigation Work Plan - Conceptual Site Model and Data Quality Objectives, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. July 14.

Brown and Caldwell, 2015c. Background Groundwater Quality Assessment - Revision 2, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. July 2.

Brown and Caldwell, 2015d. Additional Monitor Well Installation Data Summary Report, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. June 11.

Brown and Caldwell, 2015e. Groundwater Geochemical Characterization Data Summary Report - Revision 1, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. December 11.

Brown and Caldwell, 2015f. Technical Memorandum: Draft Initial Screening of Remedial Alternatives, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. December 2.

Brown and Caldwell, 2016a. Groundwater Geochemical Characterization Data Summary Report - Revision 2, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company.

Brown and Caldwell, 2016b. Background Groundwater Quality Assessment - Revision 3, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. November 11.

Brown and Caldwell, 2016c. 2015 Annual Groundwater Monitoring Report, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. May 16.

BC, 2017. Technical Memorandum: Phase 1 Evaporation Ponds Characterization Data Summary Report. Prepared for Atlantic Richfield Company, March 16

Brown and Caldwell, 2017a. Technical Memorandum: Wabuska Drain (OU-7) Field Sampling and Analysis Plan Data Summary Report and Conceptual Site Model Update. Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. January 3

Brown and Caldwell, 2017b. Technical Memorandum: Phase 1 Evaporation Ponds Characterization Data Summary Report. Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. January 20.

Brown and Caldwell and Integral Consulting, Inc., 2007. Draft Remedial Investigation Work Plan for Site-Wide Groundwater Operable Unit 1, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. November 16.

Carroll, R.W.H., G. Pohll, D. McGraw, C. Garner, A. Knust, D. Boyle, T. Minor, S. Bassett, and K. Pohlmann, 2010. Mason Valley Groundwater Model: Linking Surface Water and Groundwater in the Walker River Basin, Nevada. Journal of American Water Resources Association.

CH2M Hill, 2010. Final Historical Summary Report, Anaconda-Yerington Mine Site, Yerington, Nevada. October.

CH2M Hill, 2011a. Final Supplemental Remedial Investigation Report Arimetco Facilities Operable Unit 8, Anaconda-Yerington Copper Mine. Yerington, Nevada. October.

CH2M Hill, 2011b. Feasibility Study for Arimetco Facilities Operable Unit 8 Heap Leach Pads and Drain-down Fluids, Anaconda-Yerington Copper Mine. Yerington, Nevada. July.

Dalton, D., 1998. Arimetco Yerington Mine and Process Facility Site Assessment of Groundwater Quality, Yerington, Nevada. Prepared for Arimetco, Inc. July.

Davis, J.A., S.P. Hyun, P.M. Fox, and K.F. Hayes, 2009. A surface complexation modeling approach for Uranium (VI) transport in groundwater. Abstracts of the International Mine Water Conference, Proceedings. October.

Doherty, J., 2009. PEST - Model-Independent Parameter Estimation & Uncertainty Analysis, Version 12.2. Watermark Computing. Brisbane, Australia.

Dong, W. and S.C. Brooks, 2006. Determination of the formation constants of ternary complexes of uranyl and carbonate with alkaline earth metals (Mg^{2+}, Ca^{2+}, Sr^{2+}, and Ba^{2+}) using anion exchange method. Environmental Science and Technology Vol. 40, pp. 4689–4695.

Echevarria, G., M.I. Sheppard, and J.L. Morel, 2001. Effect of pH on the sorption of uranium in soils. Journal of Environmental Radioactivity, Vol. 53, pp. 257-264.

Ecology and Environment, Inc., 2013. Technical Memorandum and Report of START Activities, Arimetco Pond Design and Perimeter Ditch Repair Field Observations and Operation and

Maintenance Recommendations, Yerington, Nevada. Prepared for the Atlantic Richfield Company. April 29.

Environmental Standards, Inc. and Brown and Caldwell, 2009. Quality Assurance Project Plan Yerington Mine Site, Revision 5. Prepared for Atlantic Richfield Company. May 20.

EPA, 1988. Interim Final Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA. EPA/540/G-89/004.

EPA, 1992. Guidance for Data Usability for Risk Assessment. (Part B). Final. Office of Emergency and Remedial Response. Washington D.C.

EPA, 1999. Understanding Variation in Partition Coefficient, Kd, Values. Volume I: The k_d Model, Methods of Measurement, and Application of Chemical Reaction Codes. EPA 402-R-99-004A.

EPA, 2005. Standard Operating Procedure for Analysis of Total Organic Carbon in Sediments (Dry Combustion, Infrared Detection). Method LG601. Revision 04. March.

EPA, 2007a. Administrative Order for the Remedial Investigation and Feasibility Study. In the matter of Anaconda / Yerington Mine Site, Yerington, Lyon County, Nevada. Atlantic Richfield, Respondent. U.S. EPA Region 9, Docket No. 9-2007-0005. Proceeding under Section 106(a) of CERCLA, as amended, 42 USC § 9606(a). Including Attachment A: Scope of Work for the Remedial Investigations / Feasibility Studies Continued Response Action. January 12, 2007.

EPA, 2007b. Monitored Natural Attenuation of Inorganic Constituents in Ground Water, Volume 1 Technical Basis for Assessment. EPA/600/R-07-139.

EPA, 2008. A Systematic Approach to Evaluation of Capture Zones at Pump and Treat Systems, Final Project Report. EPA 600/R-8/003.

EPA, 2009. Statistical Analysis of Groundwater Monitoring Data at RCRA Facilities, Unified Guidance. EPA/530/R-09-007.

EPA, 2010a. Letter from EPA to Atlantic Richfield Company RE: Comments on the Draft Aquifer Solids Testing Work Plan. September 13.

EPA, 2010b. Letter from EPA to Atlantic Richfield Company RE: Aquifer Solids Testing Work Plan - Revision 1. September 30.

EPA, 2010d. Monitored Natural Attenuation of Inorganic Constituents in Ground Water, Volume 3, Assessment for Radionuclides Including Tritium, Radon, Strontium, Technetium, Uranium, Iodine, Radium, Thorium, Cesium, and Plutonium-Americium. EPA/600/R-10/039.

EPA, 2011a. Letter from EPA to Atlantic Richfield Company RE: Comments on the 2010 Annual Groundwater Monitoring Report (April 15, 2011), the First Quarter 2011 Groundwater Monitoring Report (July 1, 2011), and the Second Quarter 2011 Groundwater Monitoring Report (August 26, 2011) for the Anaconda Mine Site. September 29.

EPA, 2011b. Letter from EPA to Atlantic Richfield Company RE: Approval of the Addendum to the On-Site Monitor Well Installation Work Plan. September 30.

EPA, 2012a. Letter from EPA to Atlantic Richfield Company RE: Comments on the Draft Background Groundwater Quality Assessment, Yerington Mine Site, Nevada. February 7.

EPA, 2012b. Letter from EPA to Atlantic Richfield Company RE: Comprehensive Hydrologic Tracer Sampling Event and Request to Eliminate Select Tracers, Yerington Mine Site, Nevada. April 27.

EPA, 2012c. Letter from EPA to Atlantic Richfield Company RE: Comments on the Proposed Initial Bedrock Characterization Activities for the Anaconda Mine Site. April 12.

EPA, 2012d. Letter from EPA to Atlantic Richfield Company. October 22.

EPA, 2012e. Letter from EPA to Atlantic Richfield Company RE: Groundwater Flow Modeling Deliverables Anaconda Mine Site, Nevada. July 11.

EPA, 2012f. Letter from EPA to Atlantic Richfield Company. October 26.

EPA, 2012g. Letter from EPA to Atlantic Richfield Company RE: Comments on SOP-23 Aquifer Solids Testing - Redox-Preserved Sample Preservation and Testing Dated August 14, 2012. September 26.

EPA, 2013a. Letter from EPA to Atlantic Richfield Company RE: Comments on 2011 Annual Groundwater Monitoring Report, Anaconda Yerington Mine Site. March 27.

EPA, 2013b. Letter from EPA to Atlantic Richfield Company RE: Comments on 2012 Annual Groundwater Monitoring Report, Anaconda Yerington Mine Site. August 1.

EPA, 2013c. Letter from EPA to Atlantic Richfield Company RE: EPA Approval to Abandon Well B/W-14S, Anaconda Yerington Mine Site. November 22.

EPA, 2013d. Letter from EPA to Atlantic Richfield Company RE: Comments on the Draft Groundwater Flow Model Work Plan, Anaconda Yerington Mine Site. March 29.

EPA, 2013e. Letter from EPA to Atlantic Richfield Company RE: Comments on the Draft Additional Monitor Well Work Plan, Anaconda Yerington Mine Site. July 29.

EPA, 2013f. Statistical Software ProUCL 5.0.00 for Environmental Applications for Data Sets with and without Nondetect Observations.

EPA, 2014a. Letter from EPA to Atlantic Richfield Company RE: EPA Approval of Site-Wide Groundwater Monitoring Optimization, Anaconda Yerington Mine Site. June 26.

EPA, 2014b. Letter from EPA to Atlantic Richfield Company RE: Anaconda Yerington Mine Site OU1, Approval of Site-Wide Groundwater RI Work Plan Revision 1. October 9.

EPA, 2014c. 3PE: A Tool for Estimating Groundwater Flow Vectors. EPA 600/R-14/273.

EPA, 2015a. Letter from EPA to Atlantic Richfield Company RE: Anaconda Yerington Mine Site OU-1 Request for Bedrock Characterization DSR in Place of Work Plan. May 18.

EPA, 2015b. Letter from EPA to Atlantic Richfield Company RE: Approval of Groundwater Flow Model Report and Supplemental Materials, Anaconda Yerington Mine Site OU-1.

EPA, 2016a. Letter from EPA to Atlantic Richfield Company RE: Anaconda Copper Mine Site OU-1 Approval of Bedrock Groundwater Assessment Technical Memorandum. July 31.

EPA, 2016b. Letter from EPA to the Atlantic Richfield Company RE: Anaconda Yerington Mine Site OU-1, Approval of Geochemical Characterization DSR with Conditions. July.

EPA, 2016c. Letter from EPA to Atlantic Richfield Company RE: Anaconda Mine Site, Comments on the Background Groundwater Quality Assessment - Revision 2 dated July 2, 2015. February 11.

EPA, 2016d. Letter from EPA to Atlantic Richfield Company RE: Anaconda Copper Mine OU-1, Background Groundwater Quality Assessment. September 27.

EPA, 2016e. Memorandum from Dr. R. Ford (USEPA Land Remediation & Pollution Control Division) and Mr. S. Acree (USEPA Applied Research and Technical Support Branch) to Mr. D. Seter (USEPA Region 9), Subject: Yerington Mine Site, Yerington Nevada (16-R09-003) Responses to ARC Responses to Comments on the Background Groundwater Quality Assessment - Revision 2. September 2.

EPA, 2016f. Letter from EPA to Atlantic Richfield Company RE: Anaconda Copper Mine, Domestic Well Monitoring Program (DWMP) and Bottled Water Program (BWP). October 25.

EPA, 2017. Letter to the Atlantic Richfield Company RE: Anaconda Copper Mine Site OU-1, OU-1 Background Water Quality Assessment - Revision 3. February 16.

Fox, P.M., J.A. Davis, and J.M. Zachara, 2006. The effect of calcium on aqueous uranium(VI) speciation and adsorption to ferrihydrite and quartz. Geochimica et Cosmochimica Acta, Vol. 70, pp. 1379-1387.

Freeze, R.A. and J.A. Cherry, 1979. Groundwater. Prentice-Hall, Upper Saddle River, NJ.

Gallagher, T. K., 2004. Estimated Annual Ground-Water Pumpage 1994 - 2003, Smith Valley and Mason Valley, Lyon County, Nevada, Nevada Department of Conservation and Natural Resources, Division of Water Resources.

Gallagher, T. K., 2013. Estimated Annual Ground-Water Pumpage 2004 - 2010, Smith Valley and Mason Valley, Lyon County, Nevada, Nevada Department of Conservation and Natural Resources, Division of Water Resources.

George, P. L. and H. Borouchaki, 1998, Delaunay Triangulation and Meshing Application to Finite Elements, Paris, Hermes.

Gill, D. K., 1951. Groundwater at the Yerington Mine, Lyon County, Nevada. Report prepared for the Anaconda Mining Company. March.

Heath, R.C., 1984. Ground-Water Regions of the United States. U.S. Geological Survey (USGS) Water-Supply Paper 2242.

Hem, J., 1985. Study and Interpretation of the Chemical Characteristics of Natural Water. 3rd Ed. U.S. Geological Survey (USGS) Water-Supply Paper 2254.

Hershey, R.L., 2002. Hydrology and water quality of the Yerington Pit Lake, In: Geological Society of Nevada 2002 Spring Field Trip Guidebook Special Publication No. 35, Jurassic Magmatism and Metal Deposits in Western Nevada, Yerington Mine District, Humboldt Mafic Complex, June 15-16, 2003, Ed. Bob Thomas, pp. 93-98.

Hsi, C. K. D., and D. Langmuir, 1985. Adsorption of uranyl onto ferric oxyhydroxides: application to the surface complexation site-binding model. Geochimica et Cosmochimica Acta, Vol. 49, pp. 1931-1941.

Huxel, C.J., and E.E. Harris, 1969. Water resources and development in Mason Valley, Lyon and Mineral Counties, Nevada, 1948-65. State of Nevada Department of Conservation and Natural Resources, Division of Water Resources, Water Resources Bulletin No. 38.

Jurgens, B.C., M.S. Fram, K. Belitz, K.R. Burow, and M.K. Landon, 2010. Effects of Groundwater Development on Uranium: Central Valley, California, USA. Ground Water. Vol. 48, pp. 913-928.

Lewis, B., 2000. Geophysical Survey Results of the Yerington Mine, Mason Valley, Nevada, Prepared by the U.S. Bureau of Land Management - National Science and Technology Center. August.

Li, D., and D. I. Kaplan, 2012. Sorption coefficients and molecular mechanisms of Pu, U, Np, Am and Tc to Fe (hydr)oxides: A review. Journal of Hazardous Materials. Vol. 243, pp. 1-18.

Lopes, T.J., and K.K. Allander, 2009a. Hydrologic Setting and Conceptual Hydrologic Model of the Walker River Basin, West-Central Nevada. USGS Scientific Investigations Report 2009-5155.

Lopes, T.J., and K.K. Allander, 2009b. Water Budgets of the Walker River Basin and Walker Lake, California and Nevada. USGS Scientific Investigations Report 2009-5157.

Maurer, D.K., T.J. Lopes, R.L. Medina, and J.L. Smith, 2004. Hydrogeology and Hydrologic Landscapes of Nevada. USGS Scientific Investigations Report 2004-5131.

Mifflin, M.D., 1988. Region 5, Great Basin. In Hydrogeology, the Geology of North America, DNAG volume, vol. 0-2; ed. W. Back, J.S. Rosenshein, and P.R. Seaber, 60-78. Boulder, Colorado: Geological Society of America.

Morrison, R.B., 1964. Lake Lahontan: Geology of the southern Carson Desert. U.S. Geological Survey (USGS) Professional Paper 401.

Myers, T., 2001. Hydrogeology of the Basin Fill Aquifer in Mason Valley, Nevada: Effects of Water Rights Transferred. Prepared for the U.S. Bureau of Land Management, Carson City Field Office, Carson City, NV. Public Resources Associates, Inc., Reno, Nevada.

Nesbitt, M., 1955. Memorandum to A. J. Gould, Plant Superintendent, Anaconda Company. July 27.

Nevada Department of Conservation and Natural Resources, Division of Water Resources, 2013a, NDWR-Water Rights Database Advanced Search (Special Hydrographic Abstract), http://water.nv.gov/data/hydrographic/ June 4, 2013.

Nevada Department of Conservation and Natural Resources, Division of Water Resources, 2013b, Well Log Database Query Tool, http://water.nv.gov/data/welllog/ June 5, 2013.

Nevada Department of Conservation and Natural Resources, Division of Water Resources, 2013c, Water Level Data, http://water.nv.gov/data/waterlevel/ June 27, 2013.

Nevada Division of Water Resources, 2015. Memorandum titled “Curtailment Order in Mason and Smith Valley”. Department of Conservation and Natural Resources, Division of Water Resources. February 3.

Nolan, J., and K.A. Weber, 2015. Natural Uranium Contamination in Major U.S. Aquifers Linked to Nitrate. Environ. Sci. Technol. Lett., Vol. 2, pp. 215-220.

Nordstrom, K., L.N. Plummer, D. Langmuir, and E. Busenburg, 1990. Revised Chemical Equilibrium Data for Major Water-Mineral Reactions and Their Limitations, in "Chemical Modeling of Aqueous Systems II," Chapter 31, pp. 398-413.

Nork, W.E., 1989. MacArthur Project Hydrogeologic Investigation Lyon County, Nevada. Prepared for MacArthur Mining and Processing Company, Inc. August 14.

Norwest Applied Hydrology, 2007. Pumpback Well System 2006 Operations and Monitoring Summary, Yerington Mine Site. Prepared for Atlantic Richfield Company. April 30.

Parkhurst, D.L., and C.A.J. Appelo, 1999. User's Guide to PHREEQC (Version 2) - A Computer Program for Speciation, Batch-Reaction, One-Dimensional Transport, and Inverse Geochemical Calculations. Water-Resources Investigations Report 99-4259, U.S. Geological Survey, Denver, Colorado.

Piedmont Engineering Inc., 2001. Yerington Shallow Aquifer Data Evaluation Report. Prepared for ARCO Environmental Remediation L.L.C.

Plume, R.W., 1996. Hydrogeologic framework of the Great Basin region of Nevada, Utah, and adjacent states. USGS Professional Paper 1409-B.

Proffett, J.M., 1977. Cenozoic geology of the Yerington District, Nevada, and implications for the nature and origin of Basin and Range faulting. Geologic Society of America Bulletin, Vol. 88, pp. 247-266.

Proffett, J.M., Jr., and J.H. Dilles, 1984. Geologic Map of the Yerington District, Nevada. Nevada Bureau of Mines and Geology, Map 77.

Reheis, M., 1999. Extent of Pleistocene Lakes in the Western Great Basin. USGS Miscellaneous Field Studies Map MF-2323.

Ricketts, T.H., E. Dinerstein, D.M. Olson, and C.J. Loucks, 1999. Terrestrial ecoregions of North America: a conservation assessment. Island Press, Washington, D.C.

Sánchez-España, J. I. Yusta, and M. Diez-Ercilla, 2011. Schwertmannite and hydrobasaluminite: A re-evaluation of their solubility and control on the iron and aluminum concentration in acidic Pit Lakes. Applied Geochemistry, Vol. 26, pp.1752-1774.

Seitz, H.R., A.S. Van Denburgh, and R.J. La Carma, 1982. Ground-Water Quality Down-gradient from Copper-One Milling Wastes at Weed Heights, Lyon County, Nevada. USGS Open-File Report 80-1217.

Skillings Jr., D.N., 1972. Yerington Copper Mine. Skillings Mining review. Vol. 61, No. 21.

Smedley, P.L. and D.G. Kinniburgh, 2001. A review of the source, behavior and distribution of arsenic in natural waters. Applied geochemistry, Vol. 17, pp. 517-568

Sø, H.U., D. Postma, R. Jakobsen, and F. Larsen, 2008. Sorption and desorption of arsenate and arsenite on calcite. Geochimica et Cosmochimica Acta, Vol. 72, pp. 5871-5884.

S.S. Papadopulos & Associates, Inc., 2012a. Objectives for Groundwater Modeling in the RI/FS Process, Yerington Mine Site. Prepared for Atlantic Richfield Company. August 14.

S.S. Papadopulos & Associates, Inc., 2012b. Objectives for Groundwater Modeling in the RI/FS Process - Revision 1, Yerington Mine Site. Prepared for Atlantic Richfield Company. October 15.

S.S. Papadopulos & Associates, Inc., 2012c. Draft Groundwater Flow Model, Work Plan for the Yerington Mine Site. Lyon County, Nevada. Prepared for Atlantic Richfield Company. December 28.

S.S. Papadopulos & Associates, Inc., 2013. Groundwater Flow Model Work Plan for the Yerington Mine Site - Revision 1, Lyon County, Nevada. Prepared for Atlantic Richfield Company. May 21.

S.S. Papadopulos & Associates, Inc., 2014. Groundwater Flow Model, Yerington Mine Site, Nevada. Prepared for Atlantic Richfield Company. March 18.

S.S. Papadopulos & Associates, Inc., 2015. Flow Model Supplemental Materials, Yerington Mine Site, Nevada. Prepared for Atlantic Richfield Company. March 18.

Stachowicz, M., T. Hiemstra, and W.H. van Riemsdijk, 2007. Arsenic-bicarbonate interaction on goethite particles. Environmental Science and Technology, Vol. 41, pp. 5620-5625.

Stewart, J.H., 1988. Tectonics of the Walker Lane belt, western Great Basin: Mesozoic and Cenozoic deformation in a zone of shear. In Ernst, W.G., Metamorphism and crustal evolution of the western United States, Rubey volume VII: Prentice Hall, Englewood Cliffs, N.J.

Stewart, B.D., M.A. Mayes, and S. Fendorf, 2010. Impact of uranyl-calcium-carbonate complexes on uranium(VI) adsorption to synthetic and natural sediments. Environmental Science and Technology, Vol. 44, pp. 928-934.

Superfund Technical Assessment Response Team (START), 2000. Anaconda Copper Company, Yerington Mine Site, Expanded Site Inspection, Yerington, Lyon County, Nevada. Prepared by Ecology & Environment Incorporated. December.

Superfund Technical Assessment Response Team (START), 2001. Anaconda Copper Company, Yerington Mine Site, Emergency Response Assessment, Yerington, Lyon County, Nevada. Prepared by Ecology & Environment Incorporated. June.

Taylor, B.E., and M.C. Wheeler, 1994. Sulfur- and Oxygen-Isotope Geochemistry of Acid Mine Drainage in the Western United States. Chptr. 30. Environmental Geochemistry of Sulfide Oxidation. Eds. C.W. Alpers and D.W. Blowes.

Tetra Tech, 2010. Preliminary Economic Assessment Update Pumpkin Hollow Copper Project, Lyon County, Nevada. Prepared for Nevada Copper Corp. January 13.

Thomas, J.M., 1995. Water Budget and Salinity of Walker Lake, Western Nevada. USGS Fact Sheet FS-115-98.

U.S. Bureau of Mines, 1958. Methods and Operations at the Yerington Copper Mine and Plant of the Anaconda Company, Weed Heights, Nev., by M. Claire Smith; Information Circular 7848, Department of the Interior.

U.S. Census Bureau, 2015. State and County Quickfacts. Available at: http://www.census.gov/quickfacts/table/PST045215/32019.

U.S. Geological Survey, 2006. Determination of the Delta ($^{34}S/^{32}S$) of Sulfate in Water, RSIL Lab Code 1951. Techniques and Methods of the Reston Stable Isotope Laboratory, Chapter 10.

U.S. Geological Survey, 2008. $^{3}H/^{3}He$ Sampling. The Reston Chlorofluorocarbon Laboratory. http://water.usgs.gov/lab/3h3he/sampling/.

U.S. Geological Society, 2009a. Hydrologic Setting and Conceptual Hydrologic Model of the Walker River Basin, West-Central Nevada. U.S. Department of Interior, USGS, Scientific Investigations Report 2009-5155.

U.S. Geological Society, 2009b. Water Budgets of the Walker River Basin and Walker Lake, California and Nevada. U.S. Department of Interior, USGS, Scientific Investigations Report 2009-5157.

U.S. Geological Survey, 2013. National Water Information System, USGS Groundwater for Nevada: Water Levels, http://nwis.waterdata.usgs.gov /nv/nwis/gwlevels June 27.

Walker River Decree C-125, 1936 amended 1940. United States vs. Walker River Irrigation District, Docket C-125, District Court of the United States - District of Nevada.

Wanninkhof, R., J.R. Ledwell, and A. J. Watson, 1991. Analysis of sulfur hexafluoride in seawater. J. Geophys. Res - Oceans 96(C5), pp. 8733-8740.

Wilson, J.L., and H. Guan, 2004. Mountain-Block Hydrology and Mountain-Front Recharge. In: Groundwater Recharge in a Desert Environment: The Southwestern United States, edited by F.M. Phillips, J. Hogan, and B. Scanlon. AGU, Washington, DC.

WRCC, 2015. Yerington, Nevada (269229): Period NCDC 1894-2015 Monthly Normals. Western Regional Climate Center. http://www.wrcc.dri.edu/cgi-bin/cliMAIN.pl?nv9229.

Western Regional Climate Center (WRCC). 2017. Yerington, Nevada (269229) Period of Record Monthly Climate Summary, 1/1/1914 to 12/31/2005. http://www.wrcc.dri.edu/cgi-bin/cliMAIN.pl?nvyeri.

Zheng, C., G.D. Bennett, and C.B. Andrews, 1991. Analysis of Ground-Water Remedial Alternatives at a Superfund Site. Ground Water. Vol. 29, No. 6., pp. 838-848.

REMEDIAL INVESTIGATION REPORT
SITE-WIDE GROUNDWATER OPERABLE UNIT (OU-1)

ANACONDA COPPER MINE SITE
LYON COUNTY, NEVADA

OCTOBER 20, 2017

PREPARED FOR:

Atlantic Richfield Company

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LIST OF ACRONYMS AND ABREVIATIONS

AFCEE	Air Force Center for Environmental Excellence
AHA	Applied Hydrology Associates
Anaconda	Anaconda Companya
ARC	Atlantic Richfield Company
BC	Brown and Caldwell
BCL	Background Concentration Limit
BGQA	Background Groundwater Quality Assessment
BLM	Bureau of Land Management
CFC	Chlorofluorocarbon
COI	Chemical of Interest
DO	Dissolved Oxygen
DPT	Direct Push Technology
DSR	Data Summary Report
DQO	Data Quality Objective
DWMP	Domestic Well Monitoring Program
EA-IRMS	Elemental Analyzer-Isotopic Ratio Mass Spectrometer
EC	Electrical Conductivity
EPA	U.S. Environmental Protection Agency
ESI	Environmental Standards, Inc.
FEP	Finger Evaporation Ponds
FMS	Fluid Management System
FS	Feasibility Study
GC-ECD	Gas Chromatography with Electron Capture Detection
GMP	Groundwater Monitoring Plan
GMR	Groundwater Monitoring Report
HCSM	Hydrogeologic Conceptual Site Model
HDPE	High-Density Polyethylene
HFA	Hydrogeologic Framework Assessment
HLP	Heap Leach Pad
HHRA	Human Health Risk Assessment
HSR	Historical Summary Report
IAOC	Interim Administrative Settlement Agreement and Order on Consent
ICP-MS	Inductively Coupled Plasma Mass Spectroscopy
J	Estimated Concentration
K	Hydraulic Conductivity
Kd	Partition (or Distribution) Coefficient
LEP	Lined Evaporation Pond
MAROS	Monitoring and Remediation Optimization System
MCL	Maximum Contaminant Level
MFR	Mountain Front Recharge
NA	Not Applicable/Not Available
NAC	Nevada Administrative Code
NDEP	Nevada Division of Environmental Protection
NDWR	Nevada Division of Water Resources
NR	Not Recorded
NSA	North Study Area
NS	No Sample
O&M	Operation and Maintenance
ORP	Oxidation-Reduction Potential
OU	Operable Unit
PLS	Pregnant Leach Solution
POD	Point of Diversion
POU	Place of Use
PV	Pore Volume
PWS	Pumpback Well System
Q	Quarter
QA/QC	Quality Assurance/Quality Control
QAPP	Quality Assurance Project Plan
R	Retardation Coefficient
RAO	Remedial Action Objective
RER	Replicate Error Ratio
RI/FS	Remedial Investigation and Feasibility Study
RPD	Relative Percent Difference
RSIL	USGS Reston Stable Isotope Laboratory
RSL	Regional Screening Level
SCM	Surface Complexation Model
SERA	Southeast Recharge Area
SOP	Standard Operating Procedure
SOW	Scope of Work
SSPA	S.S. Papadopulos & Associates, Inc.
START	Superfund Technical Assessment and Response Team
STORET	STOrage and RETrieval
SWRA	Southwest Recharge Area
TC	Total Carbon
SX/EW	Solvent Extraction /Electrowinning
TIC	Total Inorganic Carbon
TDS	Total Dissolved Solids
TIMS	Thermal Ionization Mass Spectrometer
TOC	Total Organic Carbon
TU	Tritium Unit
U	Chemical not detected at the indicated sample detection limit
UAO	Unilateral Administrative Order
Ue	Uranium Excess
UEP	Unlined Evaporation Pond
UJ	Chemical not detected at the indicated estimated sample detection limit
USCS	Unified Soil Classification System
USGS	United States Geological Survey
UTL	Upper Tolerance Limit
VLT	Vat Leach Tailings
WRCC	Western Regional Climate Center

LIST OF ACRONYMS AND ABREVIATIONS - CONTINUED

WRD	Walker River Decree
WRID	Walker River Irrigation District
YPT	Yerington Paiute Tribe

%	percent
‰	per mil
amsl	above mean sea level
bgs	below ground surface
cu ft	cubic feet
cfs	cubic feet per second
°F	degrees Fahrenheit
°C	degrees Celsius or Centigrade
ft	foot/feet
ft/day	feet per day
ft/yr	feet per year
fmol/kg	femtomole per kilogram
gal	gallons
g/L	grams per liter

gpd	gallons per day
gpm	gallons per minute
L	liter
L/kg	liters per kilogram
µg	microgram
µm	micron or micrometer
mg	milligram
pCi/g	picocuries per gram
pCi/L	picocuries per liter
pCi	picocurie
pmol/kg	picomoles per kilogram
s.u.	standard units (pH)

MINERALS, CHEMICAL FORMULAS, AND ABBREVIATIONS

Barium Arsenate	$Ba_3(AsO_4)_2$
Ferric oxide	$Fe(OH)_3(a)$
Gypsum	$CaSO_4$
Hydroxy-green rust	$Fe_3(OH)_7(s)$ and $Fe_2(OH)_5(s)$
Jarosite (ss)	$(K_{0.77}Na_{0.03}H_{0.2})Fe_3(SO_4)_2(OH)_6(s)$
K-jarosite	$KFe_3(SO_4)_2(OH)_6(s)$
Na-jarosite	$NaFe_3(SO_4)_2(OH)_6(s)$
Schwertmannite	$Fe_8O_8(OH)_{4.8}(SO_4)_{1.6}(s)$
Scorodite	$FeAsO_4(s)$

(a)	Amorphous
(aq)	Aqueous
(s)	Solid
(ss)	Solid Solution

$\delta^{13}B$	Boron isotopes in water samples
$\delta^{36}Cl$	Chloride isotopes in water samples
$\delta^{34}S_{SO4}$	Sulfur isotopes in dissolved sulfate
$\delta^{34}O_{SO4}$	Oxygen isotopes in dissolved sulfate
$\delta^{15}N_{NO3}$	Nitrogen isotopes in dissolved nitrate
$\delta^{18}O_{NO3}$	Oxygen isotopes in dissolved nitrate

Nitric Acid	HNO_3
Sulfuric Acid	H_2SO_4
Sulfur Hexafluoride	SF_6
Sulfur Dioxide	SO_2

EXECUTIVE SUMMARY

This *Site-Wide Groundwater Operable Unit (OU-1) Remedial Investigation Report* (OU-1 RI Report) has been prepared by Atlantic Richfield Company (ARC) pursuant to Section 7.0 of the Scope of Work (SOW) attached to the Administrative Order for Remedial Investigation and Feasibility Study (RI/FS), CERCLA Docket No. 9-2007-0005 (2007 Order) for the Anaconda Copper Mine Site (Site). The 2007 Order (EPA 2007a) was issued to ARC by the U.S. Environmental Protection Agency - Region 9 (EPA) on January 12, 2007. Future work on the OU-1 RI/FS will proceed under oversight by the Nevada Division of Environmental Protection (NDEP) pursuant to the "Interim Administrative Settlement Agreement and Order on Consent for: (i) Remedial Design/Remedial Action, (ii) Site-Wide Remedial Investigation/Feasibility Study, and (iii) Fluid Management" entered into with NDEP (the IAOC) and the attached Statement of Work for RI/FS.

The term "Site" refers to the area where copper mining and ore processing activities historically occurred. The term "Study Area" in this document refers to a larger area encompassing both on-Site and off-Site areas in which OU-1 RI-related investigations have been conducted. The Site is a former copper mine that is located west and northwest of the City of Yerington. The 2007 Order identified eight OUs at the Site, which include:

- Site-Wide Groundwater (OU-1);
- Pit Lake (OU-2);
- Process Areas (OU-3);
- Evaporation Ponds (OU-4a) and Sulfide Tailings (OU-4b);
- Waste Rock Areas (OU-5);
- Oxide Tailings Areas (OU-6);
- Wabuska Drain (OU-7); and
- Arimetco Facilities (OU-8).

Consistent with the SOW attached to the 2007 Order (EPA 2007a) and general RI report objectives established by EPA (EPA 1988), this OU-1 RI Report:

- Summarizes activities conducted to characterize and monitor groundwater (including on- and off-Site locations), establish background groundwater quality, and determine the nature, extent, and transport of mine-related chemicals of interest (COIs) in groundwater;
- Integrates relevant historical operations and aspects of other OUs that represent potential sources of chemical loading to groundwater or have the potential to influence groundwater flow conditions;
- Describes the program for long-term monitoring of Site-wide groundwater conditions;
- Summarizes the domestic well monitoring program, which characterized the quality of groundwater used for drinking water or other domestic water supply purposes and determined eligibility for receiving bottled water as part of an interim response action; and
- Describes the process for completing the human health risk assessment, which is being addressed in a separate OU-1 Human Health Risk Assessment (HHRA) report, per EPA direction during a groundwater technical meeting held on June 30, 2016 attended by ARC, EPA, the NDEP, the Yerington Paiute Tribe (YPT), and other stakeholders.

The information provided in this OU-1 RI Report is considered sufficient to characterize the groundwater system, define the nature and extent of mine-related groundwater contamination, perform a risk assessment, and conduct a feasibility study. Numerous investigations and monitoring activities conducted by ARC and others provide substantial geologic, hydrogeologic, and water quality information relevant to OU-1. However, this OU-1 RI Report relies primarily on data obtained after 2005 to address the study elements specified in Section 7.0 of the SOW, characterize groundwater conditions, and refine the hydrogeologic conceptual site model (HCSM) to support the OU-1 RI/FS. Data obtained after 2005 have been selected for these purposes because: 1) data collection was performed pursuant to EPA-approved quality assurance/quality control (QA/QC) planning documents and OU-1 specific work plans that were developed with input from other stakeholders including the NDEP, YPT, and the Bureau of Land Management (BLM); 2) the spatial coverage and amount of data increased substantially after 2005; and 3) post-2005 sampling results better represent current conditions and potential risks at the Site, which is the proper focus of the RI and risk assessment.

The dataset obtained during August 2014 is emphasized in this OU-1 RI Report for the reasons previously cited, and because a variety of data types were concurrently collected (e.g., groundwater level data, groundwater quality data, and hydrologic tracer data) and/or evaluated (e.g., geochemical speciation modeling to help assess COI transport). Consequently, the August 2014 dataset is particularly useful for characterizing spatial aspects of OU-1 groundwater conditions.

Recognizing that groundwater characterization activities would largely involve monitor well installation, ARC and EPA adopted a multi-step sequential approach to field data collection to maximize usable data and optimize the design of a monitor well network intended to serve the data needs for both OU-1 RI characterization and long-term Site-Wide groundwater monitoring. In total, the groundwater RI characterization activities resulted in drilling 133 boreholes, logging approximately 33,000 linear feet of core, collecting and analyzing 624 zonal groundwater samples, installing 299 new monitor wells, and hydraulic (slug) testing of 296 wells.

After installation and development, new monitor wells were incorporated along with select existing monitor wells into the Site-Wide Groundwater Monitoring Program. Within the Study Area, the alluvial aquifer is up to 700 feet thick and is subdivided into Shallow, Intermediate and Deep zones (Deep zones 1 through 5). Underlying the alluvial aquifer is a bedrock groundwater flow system. The current monitor well network includes 360 wells at 170 locations: 133 wells in the Shallow zone, including 11 Pumpback Well System (PWS) wells formerly used for groundwater extraction that are currently inactive; 55 wells in the Intermediate zone; 105 wells in the Deep zone; and 67 bedrock wells. Of the 360 monitor wells, seven are used only for water level measurements, and the remaining 353 are monitored for both water levels and water quality.

The Site and Study Area are in the Mason Valley, a north-south trending structural valley (graben) in the Basin and Range Province that is filled with up to 1,000 feet of unconsolidated alluvial sediments. The valley is bordered to the west by the Singatse Range, to the east by the Wassuk Range, and to the north by the Desert Mountains. Regional metals mineralization and hydrothermal alteration associated with localized porphyry and skarn copper deposits occur throughout the Singatse Range and nearby portions of the Mason Valley.

Depositional processes have resulted in a complex sequence of laterally-discontinuous, heterogeneous, unconsolidated alluvial sediments that exhibit spatially-variable hydraulic properties (Brown and Caldwell [BC] 2014a). Clay layers or other low-permeability sediments are laterally discontinuous resulting in unconfined or semi-confined alluvial aquifer groundwater conditions. Based on groundwater flow model results (S.S. Papadopulos & Associates, Inc. [SSPA] 2014), the alluvial aquifer is primarily recharged by downward percolation of water from irrigated fields (49 percent [%]), leakage from irrigation ditches (29%), infiltration from the channel of the Walker River (20%), and mountain front recharge (2%) resulting from infiltration through bedrock of precipitation that falls on surrounding mountain ranges and minor tributary surface flows in ephemeral drainages. Recharge from precipitation falling directly on the valley floor is negligible (Huxel and Harris 1969; Lopes and Allander 2009a, 2009b).

The alluvial aquifer in the Mason Valley yields significant quantities of groundwater and the groundwater resource is pumped extensively for irrigation (Carroll et al. 2010; SSPA 2014). Alluvial groundwater near the Site generally flows to the northwest, but flow directions are locally affected by bedrock outcrops within and along the margins of the valley, drawdown from pumped wells (particularly in deeper zones of the alluvial aquifer), and recharge sources such as the Walker River, the West Campbell Ditch, and irrigation on the Hunewill Ranch and other agricultural fields. Groundwater in the alluvial aquifer moves relatively slowly, with flow velocities estimated to be less than 100 feet per year (BC 2014a). Agricultural pumping seasonally results in strong downward vertical gradients that are often 10 to 100 times greater than horizontal gradients.

Historic mining and copper ore beneficiation activities involved the use of sulfuric acid (H_2SO_4). The major past and/or ongoing sources of COIs to groundwater include: 1) OU-4a, the Evaporation Ponds (BC 2014a, 2014d); 2) OU-8, the Arimetco Facilities (CH2M Hill 2010, 2011a, 2011b); and 3) OU-3, the Process Areas (BC 2014a, 2014e). Concentrations of COIs in groundwater beneath OU-4b (Sulfide Tailings) are generally at least 10 to 100 times lower than COI concentrations in groundwater beneath OU-4a. Furthermore, OU-4b is located hydraulically upgradient or cross-gradient of OU-4a, and groundwater beneath OU-4b flows toward the higher COI concentrations under OU-4a.

The Pit Lake (OU-2), which was studied as part of the OU-1 RI (BC 2014a), is not a source of COIs to Site-wide groundwater because the lake elevation is lower than the surrounding potentiometric surface and the pre-mining groundwater level. The Pit Lake surface is projected to reach a steady-state level, where water inflow and evaporation are balanced, prior to 2030. The steady-state Pit Lake elevation is estimated to be in the range of 4,249 to 4,253 feet above mean sea level, and is projected to remain lower than the surrounding potentiometric surface even after reaching steady-state conditions. Consequently, the lake is and will continue to be a groundwater sink that does not discharge into the Site-wide groundwater system.

Results of the ongoing RI for the Wabuska Drain (OU-7) will be reported separately. Available data indicate that concentrations of mine-related chemicals decrease with distance from the Site and depth in the soil profile (EPA 2007, BC 2015b).

Mine-related COIs include acidity (i.e., low pH), total dissolved solids (TDS), major ions including sulfate, metals/metalloids (hereinafter referred to as metals), and radiochemicals including uranium (BC 2014a). Concentrations of mine-related chemicals in groundwater are most elevated in the Shallow zone of the alluvial aquifer beneath OU-4a features that include the Lined Evaporation Pond (LEP), Unlined Evaporation Pond (UEP), Finger Ponds, Phase IV Vat Leach Tailings (VLT) Heap Leach Pad (HLP), Phase IV VLT Pond, and the northern end of the Calcine Ditch. Chemical concentrations in groundwater generally decrease with vertical depth and horizontal distance from these facilities. To the extent localized downgradient increases in chemical concentrations are observed, they result from non-mine-related factors.

Hydraulic assessments and chemical distributions indicate that the PWS was only partially effective in capturing Shallow zone mine-impacted groundwater during its operational life from 1989 to 2009 (BC 2010), when it was shut down with EPA approval.

Geochemical evaluations of groundwater quality data (BC 2016a) indicate that sulfate and dissolved uranium form neutral or negatively-charged aqueous ionic complexes in groundwater throughout the Study Area (except beneath the Evaporation Ponds) and, thus, undergo very limited (if any) geochemical attenuation due to mineral precipitation or adsorption to aquifer materials during groundwater transport. Dissolved uranium in Study Area groundwater is predominantly present in complexes with carbonate plus or minus calcium, which reflect oxidizing, carbonate-rich groundwater conditions. Locally, dissolved uranium is also complexed with sulfate in Shallow zone groundwater beneath the Evaporation Ponds where pH is less than 5 and sulfate concentrations exceed 1,500 milligrams per liter (mg/L).

The spatial distributions of elevated concentrations of mobile parameters such as sulfate and uranium are significantly more extensive than the spatial distributions of acidity (as indicated by pH) and metals. The limited spatial extent of low pH values and elevated metal concentrations indicates that geochemical attenuation processes in Study Area groundwater limit the mobility of acidity and metals relative to the more mobile chemicals such as sulfate and uranium (EPA 2007b; BC 2016a, 2016b). Elevated metal concentrations in groundwater correlate strongly with low pH. Geochemical evaluations of groundwater quality data (BC 2016a) also indicate the likely precipitation of solid mineral phases (e.g., jarosite) primarily in the Shallow zone beneath the LEP, UEP, Thumb Pond, and Phase IV HLP. These mineral phases likely represent a potential ongoing source of COIs to groundwater.

Sulfate, uranium and arsenic (and other COIs) occur naturally in groundwater in Mason Valley because of groundwater contact with naturally-mineralized and/or hydrothermally-altered bedrock associated with copper deposits and/or alluvial sediments derived from mineralized bedrock (BC 2009a, 2014b). These regional groundwater conditions, unrelated to mining, affect COI concentrations at two key locations within the OU-1 groundwater Study Area. To the west of the Site and adjacent to the Singatse Range, naturally-occurring arsenic, other COIs, and elevated groundwater temperatures in alluvial aquifer groundwater are associated with subsurface water transmitted along fractures and faults (especially oblique range-front faults such as the Sales Fault).

These faults occur in arsenic-bearing volcanic and granitic bedrock formations that provide conduits for bedrock groundwater to discharge into the overlying alluvial aquifer. In the North Study Area (NSA), which refers to the portion of the OU-1 groundwater Study Area located northeast of West Campbell Ditch and north of the Sunset Hills, naturally-occurring arsenic concentrations as high as 83 micrograms per liter (µg/L) occurs in Deep zone groundwater. The elevated arsenic in this portion of the Study Area is likely related to bedrock discharge to the alluvial aquifer and is not related to agricultural activities that source COIs to the Shallow through Deep 2 zones of the alluvial groundwater, as discussed further below.

Groundwater quality in the NSA is influenced by agricultural activities but not by mining activities (BC 2016b). Multiple lines of evidence (including groundwater flow patterns, chemical distributions, groundwater age estimates, hydrologic tracers, and sulfur isotopes) confirm that groundwater in the NSA has been affected by agricultural practices and not by mining activities, resulting in concentrations of sulfate and uranium that are elevated above background values and/or Maximum Contaminant Levels (MCLs) or exhibit increasing trends.

Monitor well data from the NSA indicate that concentrations of nitrate, sulfate, calcium, uranium, and alkalinity in alluvial groundwater in the Shallow through Deep 2 zones increase along the flow path beneath the agricultural fields. Increases in nitrate are associated with fertilizer application on crop fields. Increases in sulfate and calcium concentrations are associated with application of gypsum ($CaSO_4$) as a soil amendment on crop fields, which dissolves in irrigation water that percolates down to the water table. Increases in uranium concentrations are associated with crop irrigation. Percolation of irrigation water through soils increases alkalinity in the soil moisture, which mobilizes and desorbs naturally-occurring uranium from sediments (as soluble complexes with sulfate, carbonate plus or minus calcium) resulting in elevated uranium concentrations in groundwater (Jurgens et al. 2010; Brown et al. 2007).

Alluvial sediments in the Mason Valley contain naturally-occurring uranium (BC 2009b). The impact of agricultural activities on uranium mobility in NSA groundwater within or near irrigated land is illustrated by the strong correlation between uranium, alkalinity and calcium. Increases in alkalinity and calcium are associated with increases in uranium concentrations that can exceed 100 µg/L. Evaporation of irrigation water derived from surface water and groundwater sources also serves to increase chemical concentrations in water that infiltrates and percolates to the water table.

The extent of mine-impacted groundwater has been defined using sulfate, dissolved uranium, and sulfur isotopes in sulfate because these parameters undergo very limited (if any) geochemical attenuation during groundwater transport and, thus, have traveled the farthest downgradient distance in the alluvial aquifer (BC 2016b). As noted by EPA (2016c), the background assessment conservatively over-estimated the area of mine-impacted groundwater and may not fully account for the range of chemical concentrations that occur naturally in groundwater within the Study Area. Portions of the aquifer where sulfate and uranium exceed background concentrations include: 1) all groundwater zones beneath portions of the Site; 2) Shallow zone groundwater extending north/northwest to the Sunset Hills located approximately three miles north of the Site boundary; and 3) deeper groundwater beneath the Site and extending northeast beneath portions of the Hunewill Ranch. The estimated volume of mine-impacted groundwater (i.e., the portion of the downgradient aquifer where sulfate and uranium exceed background concentrations) is 385,327 acre-feet, and contains an estimated 500,000 tons of sulfate and 100 tons of dissolved uranium.

Bedrock characterization information indicates: 1) a high degree of fracture heterogeneity and vertical hydraulic connection between the bedrock and alluvial groundwater systems; and 2) limited horizontal hydraulic connectivity and transmissivity of bedrock fractures, especially over horizontal distances that are relevant to the scale of the Site and the surrounding Study Area. In addition to a high degree of three-dimensional (i.e., anisotropic) variability in hydraulic characteristics and hydrologic tracer signatures, the bedrock groundwater system also exhibits high, three-dimensional spatial variability in chemical concentrations.

Concentrations of mine-related chemicals in the alluvial aquifer are most elevated in the Shallow zone beneath OU-4a, as noted previously. COI concentrations generally decrease with vertical depth and horizontal distance from the Site sources, resulting in values in bedrock groundwater that are 10 to over 1,000 times lower than the values in overlying alluvial groundwater. In addition, areas of elevated mine-related COIs in bedrock groundwater are small in comparison to the alluvial aquifer, highly localized, and found mostly on-Site.

The localized areas of elevated mine-related COIs in bedrock groundwater indicate that bedrock fractures have limited hydraulic connectivity and transmissivity over horizontal distances relevant to the scale of the Study Area. Despite localized areas of relatively high hydraulic conductivity, bedrock groundwater flow velocities, average volumetric flow rates and chemical fluxes through the bedrock groundwater system are low, and the bedrock groundwater system is not considered to be an important migration pathway at the Site (EPA 2015a). It is however an important source for elevated concentrations of arsenic, originating from bedrock and transported with mountain front recharge over much longer timescales.

Water quality monitoring of domestic, commercial, and irrigation wells (collectively referred to as domestic wells) located near the Site began in late 1983 and evolved over time. Results of domestic well monitoring have been used to: 1) characterize the quality of groundwater used for drinking water or other domestic uses; 2) assess potential risk, if any, to human health and the environment from the use of domestic well water for drinking water or agricultural purposes; and 3) determine eligibility for receiving bottled water as part of an interim response action.

The number of wells/properties included in the domestic well monitoring program (BC 2010) and receiving bottled water was substantially reduced in 2016 (ARC 2016a; EPA 2016f). As part of a settlement entered in the class action lawsuit *Roeder et al. v. Atlantic Richfield Company et al.*, D. Nev., Case No. 3-11-cv-00105-RCJ-WGC ("Roeder Settlement Agreement") ARC provided funding to the City of Yerington to extend municipal water service to then-existing residences located within that part of the settlement class area that was also within the City's projected future service area.

Domestic well owners who connected to the City of Yerington's municipal water system could elect to either abandon their well or apply for a state permit to authorize withdrawals of groundwater for outdoor use only (landscape watering). Each property owner who received a connection to the City Water System executed and recorded an environmental covenant either prohibiting future domestic use of groundwater altogether or limiting it to outdoor purposes. Construction of the expanded water system began in the fall of 2014, and the construction of new mains and service connections was completed in June 2016.

The first phase of well abandonments and system testing was completed as of August 1, 2016. The water system is functional, and domestic wells for all participating property owners have been abandoned or disconnected from the residences within the expansion area. A relatively small number of domestic wells located within the area of mine-impacted groundwater were not disconnected or converted to outdoor use in 2016. ARC has been in communication with the owners of most of these wells, and disconnections for all but a few are scheduled to occur in 2017.

There are no irrigation wells or municipal drinking water wells located within the plume of mine-impacted groundwater that was delineated during the background assessment.

The plume of mine-impacted groundwater is generally stable based on evaluations of changes in the estimated volume of contaminated groundwater, sulfate and uranium masses, and chemical centers-of-mass through time. A more comprehensive plume stability evaluation (including a statistical evaluation of chemical concentration trends in individual monitor wells) will be provided in a separate report. Plume stability is the result of very slow groundwater velocities and attenuation by dilution. The dilution occurs primarily as the result of recharge on the agricultural fields (specifically on the fields of the Hunewill Ranch) and leakage from irrigation ditches (specifically the West Campbell Ditch), and dispersion within the groundwater plume. Consequently, the plume is not currently adversely affecting and is not expected to affect the use of groundwater by agricultural irrigation and municipal drinking water wells. In addition, the plume of mine-impacted groundwater does not discharge to surface water.

SECTION 1.0
INTRODUCTION

Atlantic Richfield Company (ARC) prepared this *Site-Wide Groundwater Operable Unit (OU-1) Remedial Investigation Report* (OU-1 RI Report) pursuant to Section 7.0 of the Scope of Work (SOW) attached to the Administrative Order for Remedial Investigation and Feasibility Study (RI/FS), CERCLA Docket No. 9-2007-0005 (2007 Order) for the Anaconda Copper Mine Site (Site). The 2007 Order (EPA 2007a) was issued to ARC by the U.S. Environmental Protection Agency - Region 9 (EPA) on January 12, 2007. Future work on the OU-1 RI/FS will proceed under oversight by the Nevada Division of Environmental Protection (NDEP) pursuant to the "Interim Administrative Settlement Agreement and Order on Consent for: (i) Remedial Design/ Remedial Action, (ii) Site-Wide Remedial Investigation/Feasibility Study, and (iii) Fluid Management" entered into with NDEP (the IAOC) and the attached Statement of Work for RI/FS.

The term "Site" refers to the area where copper mining activities historically occurred. The Site is located west and northwest of the City of Yerington (Figure 1-1). Figure 1-2 depicts the Study Area boundary for OU-1 and the boundaries for the seven other OUs at the Site that were identified in the 2007 Order. The eight OUs identified in the 2007 Order include:

- Site-Wide Groundwater (OU-1);
- Pit Lake (OU-2);
- Process Areas (OU-3);
- Evaporation Ponds and Sulfide Tailings (OU-4);
- Waste Rock Areas (OU-5);
- Oxide Tailings Areas (OU-6);
- Wabuska Drain (OU-7); and
- Arimetco Facilities (OU-8).

Since the 2007 Order (EPA 2007a), substantial Site characterization activities have resulted in a better understanding of the nature and extent of chemicals of interest (COIs) within the various Site OUs, and the past and/or ongoing impacts to OU-1. Consequently, the EPA approved a subdivision of OU-4 into OU-4a (Evaporation Ponds) and OU-4b (Sulfide Tailings), as well as the transfer of the southern portion of the Calcine Ditch from OU-3 to OU-4a.

The EPA-approved OU-4 subdivision and transfer of a portion of the Calcine Ditch to OU-4a was based on a recognition of: 1) the different types of mine-waste materials in the Evaporation Ponds and Sulfide Tailings; 2) the similarity of mine-waste materials in the Calcine Ditch and portions of the Evaporation Ponds; and 3) the differences in the presence and magnitude of COIs in groundwater underlying the Evaporation Ponds and Sulfide Tailings. This OU-1 RI Report retains the OU-based framework in the 2007 Order (updated to include the EPA-approved restructuring). However, ARC, EPA and NDEP recognize that significant closure efficiencies will likely result from integrating EPA-designated OUs into geographic-based closure management units.

The term "Study Area" refers to on-Site and off-Site areas in which OU-1 RI-related investigations have been conducted. The Study Area boundary is based on the OU-1 hydrogeologic conceptual site model (HCSM) that was described in the EPA-approved *Site-Wide Groundwater Operable Unit (OU-1) Remedial Investigation Work Plan - Revision 1* (Revised Groundwater RI Work Plan; Brown and Caldwell [BC] 2014a).

1.1 Purpose of Report

Consistent with the SOW attached to the 2007 Order (EPA 2007a) and EPA (1988) guidance, this OU-1 RI Report: 1) summarizes activities conducted to "characterize and monitor groundwater in the vicinity of the Site (study area to be determined), including on- and off-Site locations"; 2) describes the nature and extent of mine-related COIs in groundwater; and 3) integrates relevant aspects of other OUs that represent potential sources of chemical loading to groundwater or have the potential to influence groundwater flow conditions. Additionally, this OU-1 RI Report addresses the fifteen study elements specified in Section 7.0 of the SOW (EPA 2007a), which served as the principal bases for RI planning, data collection, and analysis.

Given the complexity of Site-Wide groundwater conditions, several phases of investigations have been approved by EPA and conducted by ARC since 2005. During this time period, ARC, EPA, and other stakeholders including the Yerington Piaute Tribe (YPT), NDEP, and Bureau of Land Management (BLM) have periodically held groundwater technical meetings to discuss field data collection activities, technical findings, and remaining data gaps relative to: 1) the 15 study elements specified in Section 7.0 of the SOW attached to the 2007 Order; and 2) the Data Quality Objectives (DQOs) established in the draft and final versions of the remedial investigation work plans for OU-1 (BC and Integral Consulting, Inc. 2007 and BC 2014a, respectively). Table 1-1 relates the 15 study elements specified in the 2007 SOW to the DQOs presented in the Revised Groundwater RI Work Plan (BC 2014a).

Table 1-1. Comparison of Study Elements Specified in the SOW to the 2007 Order to DQOs Presented in the Revised Groundwater RI Work Plan

DQO	DQO Title	SOW Study Element														
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	Discriminate Background and Mine-Impacted Groundwater		X									X			X	
2	Identify Potential Chemical Loading Sources to Groundwater		X									X		X		X
3	Determine Geochemical Mobilization/Attenuation Processes											X				
4	Characterize Chemical Distribution and Migration Pathways	X						X	X	X	X	X			X	X
5	Determine Aquifer Properties								X				X			
6	Determine Groundwater Flow and Chemical Transport Rates	X	X		X	X	X	X		X	X	X				
7	Assess Anthropogenic Influences on Groundwater and Surface Water/Groundwater Interactions	X	X	X			X									
8	Determine Pumpback Well System Efficiency	X														
9	Assess Human Health and Ecological Effects							X	X	X	X	X		X	X	

Numerous investigations and monitoring activities conducted by ARC and others provide substantial geologic, hydrogeologic, and water quality information relevant to OU-1. However, this OU-1 RI Report relies primarily on data obtained after 2005 to address the study elements specified in Section 7.0 of the SOW, characterize groundwater conditions, and refine the HCSM to support the OU-1 RI/FS. Data obtained after 2005 have been selected for these purposes because: 1) data collection was performed pursuant to EPA-approved quality assurance/quality control (QA/QC) planning documents and OU-1 specific work plans that were developed with input from other stakeholders including the YPT, NDEP, and BLM; 2) the spatial coverage and amount of data increased substantially after 2005; and 3) post-2005 sampling results better represent current conditions and potential risks at the Site, which is the proper focus of the RI and risk assessment.

The August 2014 dataset is emphasized in this OU-1 RI Report for the reasons previously cited and because a variety of data types were concurrently collected (e.g., groundwater level data, groundwater quality data, and hydrologic tracer data) and/or evaluated (e.g., geochemical speciation modeling to help asses COI transport). Consequently, the August 2014 dataset is particularly informative for characterizing spatial aspects of OU-1 groundwater conditions. Temporal aspects of OU-1 groundwater conditions are based on post-2005 data, which indicate that the August 2014 dataset is generally representative of post-2005 groundwater conditions.

Long-term monitoring of Site-wide groundwater conditions is conducted pursuant to the *Site-Wide Groundwater Monitoring Plan - Revision 2* (GMP; BC 2012a), which was prepared by ARC pursuant to Section 6.0 of the 2007 SOW. The development of the monitoring program and a description of the monitor well network are also provided in this OU-1 RI Report.

Potential human health risks will be addressed more comprehensively in a separate OU-1 Human Health Risk Assessment (HHRA) report. This OU-1 RI Report provides the basis for ARC to identify remedial action objectives (RAOs) and screen/evaluate remedial alternatives for OU-1, which will occur during the feasibility study (FS).

1.2 Site and Study Area Description

The Site and Study Area are located in the Mason Valley in Lyon County, Nevada. The Site boundary includes portions of Township 13 North, Range 25 East, Sections 4, 5, 8, 9, 16, 17, 20, and 21 (Mount Diablo Baseline and Meridian) on the Mason Valley and Yerington United States Geological Survey (USGS) 7.5 minute quadrangles. The Site covers approximately 3,017 acres (4.7 square miles) of land altered by copper mining and processing activities. Including the Site, the Study Area covers approximately 19,300 acres (30.2 square miles).

The Mason Valley Basin (Basin no. 108, as defined by the Nevada Division of Water Resources [NDWR]) is located within the larger Walker River Hydrographic Basin (no.9). Mason Valley covers about 510 square miles, and the valley floor occurs at an elevation between 4,300 and 4,700 feet above mean sea level (amsl). The principal agricultural activities in the valley include farming (hay, grain, and onions) and cattle ranching (Lopes and Allander 2009a, 2009b; Carroll et al. 2010). Irrigation water is provided by surface water diversions from the Walker River and from pumped groundwater. The Walker River flows northerly and northeasterly between the Site and the City of Yerington. The river is within a quarter-mile of the southern portion of the Site (Figure 1-1).

1.3 Groundwater Zone Designations

Groundwater zone designations based on elevation have been used in previous groundwater-related reports, as well as this OU-1 RI Report, to identify and group monitor wells with similar screen interval elevations in the alluvial aquifer, as follows:

- Shallow (S): screen intervals that straddle the water table, or are within 50 feet of the water table when a shallower well does not exist, typically >4,300 feet amsl
- Intermediate (I): 4,250 to 4,300 feet amsl
- Deep (D): <4,250 feet amsl; given the thickness of alluvium, the Deep zone is further subdivided as follows:
    - Deep 1 (D1): 4,200 to 4,250 feet amsl
    - Deep 2 (D2): 4,120 to 4,200 feet amsl
    - Deep 3 (D3): 4,000 to 4,120 feet amsl
    - Deep 4 (D4): 3,900 to 4,000 feet amsl
    - Deep 5 (D5): <3,900 feet amsl

Monitor wells with screen intervals in bedrock, regardless of elevation, are designated as bedrock ("B") wells. The groundwater zone designation is included as a suffix to the monitor well identification number (e.g., the "S" suffix in monitor well identification B/W-1S indicates that the screen for this well is positioned in the Shallow zone).

1.4 Report Organization

Consistent with EPA guidance (EPA 1988) and recommendations provided during groundwater technical meetings in 2015 and 2016, the content and organization of this OU-1 RI Report is presented in this section.

Section 2.0 summarizes the Site operation history. Section 3.0 details the investigations related to OU-1 and relevant Site-wide studies and evaluations. Section 4.0 describes the physical characteristics of the Study Area. Section 5.0 describes the background groundwater quality assessment. This assessment served as the basis for determining the extent of mine-impacted groundwater, identifying agriculturally-affected groundwater, and assessing the occurrence of naturally-occurring COIs in groundwater. Section 5.0 also discusses the primary sources of past and/or ongoing releases of mine-related COIs to groundwater. Section 6.0 describes the fate and transport of contaminants in Study Area groundwater. Section 7.0 summarizes the HCSM for OU-1. Section 8.0 discusses the risk evaluation process and status. Section 9.0 lists the references cited in this OU-1 RI Report.

Appendix A provides historical mining-related information including the *Final Historical Summary Report* (HSR; CH2M Hill 2010) and historic Anaconda water supply and use information. Appendix B provides the *Shallow Zone Data Summary Report - Revision 1* (BC 2010a), which refined the distributions of select COIs in Shallow zone groundwater north of the Site and helped guide subsequent monitor well installation efforts. Appendix C presents information on the groundwater monitor wells including lithologic logs, well construction information, and depth-specific (zonal) groundwater quality data obtained during borehole drilling and well installation.

Appendix D presents water level and groundwater quality information. Appendix E provides soil sampling data. Appendix F presents hydraulic conductivity information and analyses. Appendix G presents regional and local surface water data. Appendix H presents hydrologic tracer data and supplemental information. Appendix I presents the *Bedrock Groundwater Assessment Technical Memorandum* (BC 2015a). Appendix J provides various groundwater studies, evaluations, and reports that were conducted to fulfill certain study elements specified in Section 7.0 of the SOW attached to the 2007 Order (EPA 2007a) and have been previously submitted to the EPA. These include an evaluation of the effectiveness of the Pumpback Well System (PWS), a Pit Lake water balance, public information pertaining to agricultural water use, the groundwater flow model report, the *Geochemical Characterization Data Summary Report - Revision 2* (BC 2016a), Site-specific chemical distribution coefficients, and the *Background Groundwater Quality Assessment - Revision 3* (BC 2016b). Appendix K presents maps illustrating the distributions of select COIs (including pH, sulfate, dissolved uranium, alkalinity, nitrate, and dissolved arsenic) in groundwater. Appendix L presents maps illustrating groundwater temperatures.

SECTION 2.0
SITE HISTORY

The following summary of the operational history of the Site paraphrases and/or is derived from the HSR (CH2M Hill 2010), which is provided in Appendix A-1. Topics covered in detail in the HSR include: 1) Site chronology; 2) processing operations utilized by the various owners and operators; 3) historic mine Site water usage and quality information; 4) uses and releases of chemicals; and 5) current Site status since 2000 focusing on removal actions conducted by EPA.

The following discussion focuses on key historic mining practices, releases, and features relevant to the historic and/or current aspects of the HCSM for OU-1. This summary is not intended to comprehensively cover all the information provided in the HSR. Historic mining-related features are shown on Figure 1-2. Historic ore processing facilities located within the Process Areas (OU-3) are shown on Figure 2-1.

2.1 Mining and Processing Operations

Copper in the Yerington district was initially discovered in the late 1860s, with large-scale exploration of the porphyry copper system occurring in the early 1900s when the area was organized into a mining district by Nevada-Empire Copper Mining and Smelting Company. Mining and ore processing operations at the Site were conducted by various owners from 1953 to November 1999.

2.1.1 Anaconda Operations

The Anaconda Company (Anaconda) became involved in the Site when it entered into a lease agreement and acquired the claims in 1941. Anaconda purchased the property in 1951 and the mine began producing copper in 1953, producing approximately 1.7 billion pounds of copper during its operations. Anaconda divested itself of the Site on June 30, 1978. Anaconda mining operations generated approximately 360 million tons of ore, 15 million tons of overburden and waste rock (400 acres), 3,000 acres of tailings, and 1,377 acres of disposal ponds.

Mined materials included oxide ore, sulfide ore, low-grade dump-leach ore, low-grade sulfide ore, and alluvium and waste rock overburden. Several processes were required to extract copper from the ore, as discussed further below. Briefly, all oxide and sulfide ore were crushed prior to leaching or processing in the various plant facilities. Copper was extracted from oxide ore using a sulfuric acid leach solution. The vast majority of leaching was conducted in vat leach tanks. A leach dump was operated over a much shorter period (discussed below). Pregnant copper solutions from the tanks and dump were stored in large solution tanks. Copper extracted from the oxide ore was recovered from the acidic leach solutions in the precipitation plant by precipitating (i.e., cementing) the copper onto iron scraps. A concentration/flotation process was used to extract copper from the sulfide minerals.

Dump Oxide Ore Processing

Crushed oxide ore was bedded into vat leach tanks capable of holding 12,000 dry tons of ore and 800,000 gallons of sulfuric acid leach solution. Spent ore, known as oxide tailings or vat leach tailings (VLT), was excavated from the vat leach tanks and disposed in the Oxide Tailings. The vats typically operated on a 96-hour or 120-hour leaching cycle, with an additional 32- to 40-hour wash period, and 24 hours required to excavate and refill. The entire cycle required approximately 8 days. Thus, eight leach vats were installed and used to process ore.

Following the leaching process, the ore underwent three wash cycles. Acidic leach solutions were recirculated and pumped at a rate of 2,000 gallons per minute (gpm). Copper-enriched wash solutions were put into three of the four open solution storage tanks located between the vat leach tanks and precipitation plant. The three solution tanks used for storing pregnant copper solutions had a total storage capacity of 1.4 million gallons. The additional storage tank, referred to as the wash water sump, stored up to 845,000 gallons of wash water from the leaching circuit, which included slurry from the scrubber in the sulfuric acid plant. Copper was recovered from the leach solution in the precipitation plant, which consisted of the iron launders, solution sumps, an adjacent launder pump station, scrap iron storage, and trommel screens.

The iron launders consisted of 20 parallel launders that were filled with scrap iron used to precipitate (i.e., cement) copper from the sulfuric acid leach solution pumped out of the leach vats and temporarily stored in the solution tanks. The waste product from the precipitation plant was an iron-sulfate solution that was conveyed in unlined ditches (such as the Calcine Ditch) to lined and unlined evaporation ponds in the northern portion of the Site (as further discussed in Section 2.2). Pregnant copper solution from dump leaching activities (discussed below) was also sent to the precipitation plant, but was kept separate from the vat leach solutions. Historical information on flows and chemical concentrations of solutions in various stages of the cementation circuit are provided in Table 2-1. Following cementation, the copper cement product was washed and dried to reduce moisture content prior to shipment off-Site for final smelting (Skillings 1972).

Table 2-1. Average Assay Values of Solutions at Various Stages in the Cementation Circuit

	Flow (gpm)	Cu (g/L)	H_2SO_4 (g/L)	Fe (g/L)	Fe^{3+} (g/L)
Primary and Scavenger Launders					
New Solution	700	20.0	5.8	7.2	5.4
Recirculated Solution	900	3.5	2.4	23.6	0.5 [a]
Total Feed (new solution plus recirculated solution)	1,600	10.7	3.8	16.4	2.6
Discharge	1,600	3.8	2.5	23.2	Trace
Secondary Launders					
Recirculated Solution (feed)	900	3.5	2.4	23.6	0.5
Discharge	900	1.0	2.1	26.4	[b]
Stripping/Settling Launders					
Feed	700	1.0	2.1	26.4	- -
Discharge	700	0.5	2.0	28.1	- -

Notes:
[a] The recirculated solution in the primary launders is the same strength as the recirculated solution in the secondary launders.
[b] The discharge solution in the secondary launders is the same strength as the feed solution to the stripping bank (U.S. Bureau of Mines 1958).
Cu = copper; H_2SO_4 = sulfuric acid; Fe = iron; Fe^{3+} = ferric iron; gpm = gallons per minute, g/L = grams per liter

Dump Leaching

In February 1965, Anaconda began dump leaching low-grade oxide ore in the W-3 Waste Rock Area. Copper-enriched solutions were stored in the Dump Leach Surge Pond (Figure 2-1) prior to conveyance to the iron launders for copper recovery. Copper extraction by heap leaching was in in its infancy at the time and recovery from the W-3 Waste Rock Area was inefficient because there were large quantities of ore that never came into contact with the acid-bearing leach solutions. Due to poor copper recovery, Anaconda ceased dump leaching in 1968.

Sulfide Ore Processing

To process sulfide ore, a froth flotation system was constructed and began operating on September 25, 1961. Flotation separation was accomplished by mixing very finely ground ore (pulp) with water and a chemical “collector” (typically xanthates and aerofloats) to make sulfide minerals hydrophobic, and then sparging air and a surfactant chemical “frother” (typically pine oil) through the mixture to create froth. The collector attaches to the sulfide mineral making it hydrophobic and susceptible to attachment to the stabilized air bubbles in the froth mixture, which was skimmed off as copper concentrate. The concentrate was further beneficiated in a scavenger flotation circuit, dewatered and dried, and subsequently hauled by truck to the Wabuska railroad spur and transported to the Washoe Smelter in Anaconda, Montana (Skillings 1972). Excess pulp after the flotation separation was disposed in the Sulfide Tailings area as a slurry mixture. Operation of the concentrator required approximately 3,000 gpm of water.

Acid Plant

Sulfuric acid was produced at the Site in the fluosolids and acid plant from 1952 to 1978. Raw sulfur ore (predominantly native sulfur and sulfide minerals) was hauled by truck to the Site from the Leviathan Mine located in Alpine County, California until 1962. The fluosolids system roasted the sulfur ore to generate sulfur dioxide (SO_2) gas, which was converted to sulfuric acid (H_2SO_4) in the contact acid plant. In 1962, Anaconda ceased mining sulfur ore from the Leviathan Mine. Between 1962 and 1978, previously stockpiled sulfur ore was blended with liquid sulfur, which was purchased from several suppliers and hauled to the Site where it was used as feed to the Acid Plant to generate sulfuric acid.

The final product was a 93 percent (%) sulfuric acid solution that was used in the vat leach tanks and dump leach of oxide ores. Byproducts such as selenium, were generated during production of sulfuric acid (CH2M Hill 2010). Operation of the sulfuric acid plant was discontinued in 1978 and the plant was dismantled by Arimetco, Inc. (Arimetco) in 1992. For its leaching operations, Arimetco purchased liquid sulfuric acid from off-Site vendors and stored it in tanks at the Site. The Acid Plant and surrounding area has subsequently been buried under the Arimetco Phase III South Heap Leach Pad (HLP).

2.1.2 Post-Anaconda Operations

Subsequent operators and lessees used some of the buildings within the Process Areas for operational support, storage, and various light industrial activities; however, the Anaconda-constructed processing components remained inactive after 1978.

In 1982, Copper Tek Corp. operated the mine under the ownership of Don Tibbals, and leased the Site for reprocessing tailings and low-grade copper ore using heap leaching and solvent extraction/electrowinning (SX/EW) processes in the area to the south of the Process Areas. In 1988, Don Tibbals sold his interests (except for the Weed Heights community and certain other parcels) to Arimetco. Prior to the sale, Arimetco (operating under the name Arizona Metals Company) had leased a large portion of the mine Site from Don Tibbals. By 1989, Arimetco had also acquired 90% of Copper Tek.

2.1.3 Arimetco Operations

From 1989 to November 1999, Arimetco conducted the following SX/EW operations on the Site:

- Phase I/II HLP: operated from 1990 to 1996, plus five months in 1997;
- Phase III South HLP: operated from August 1992 to early 1997, plus a few months in 1998;
- Phase III 4X HLP: operated from August 1995 to 1999;
- Phase IV Slot HLP: operated from March 1996 to November 1998; and
- Phase IV VLT HLP: operated from August 1998 to November 1998.

The HLPs (Figure 1-2) were constructed over high-density polyethylene (HDPE) liners with leak detection systems. The HLPs were leached with a sulfuric acid solution and the acidic, copper-laden draindown fluids were collected in HDPE-lined perimeter ditches, routed to HDPE-lined collection ponds, and conveyed to the SX/EW Plant. The copper-laden acid solution was then stripped of copper in a solvent extraction circuit using a mixture of kerosene and an organic hydroxyamine-based chelating agent (tradename ACORGA) in three process vats (total of approximately 200,000 gallons).

In the SX circuit, the copper in the dump leach liquor was concentrated by the organic in exchange for hydrogen ions producing a strong acid that became the electrolyte for the EW circuit. In the EW circuit, the copper was electroplated to stainless-steel sheets to produce 99.999% fine copper and in the process, additional sulfuric acid was generated. It was this strong acid in the EW circuit that was used to exchange copper from the loaded organic chelating agent.

Arimetco recirculated the acid solution from the EW vats back into the HLPs, which currently continue to drain fluids to the present. The electrolyte circulated between the EW plant and the tail end of the SX plant (called raffinate). The kerosene and organic reagent were also recirculated within the SX/EW circuit, being loaded and stripped repeatedly.

In January 2000, Arimetco, on the verge of bankruptcy and unable to make payroll, abandoned operations at the Site. From 2000 to 2004, NDEP managed HLP drain-down fluids by re-circulation and evaporation. In 2005, ARC was required by EPA to assume responsibility for fluid management operations at the Site. Since 2006, EPA has conducted various RI/FS and closure-related activities associated with the Arimetco Facilities (OU-8).

Inactive Arimetco HLPs that continue to produce drain-down fluids include the Phase I/II HLP, two Phase III HLPs, the Phase IV Slot HLP, and the Phase IV VLT HLP (BC 2014b). HLP drain-down fluids are currently stored and conveyed in a network of ponds, ditches, and 25,000 feet of pipe, collectively referred to as the fluid management system (FMS). The HLPs and associated FMS components are briefly described below. Additional FMS details are provided in annual operation and maintenance (O&M) reports for the FMS (e.g., BC 2014b).

Phase I/II Heap Leach Pads

The Phase I/II HLP covers an area of approximately 14 acres (Phase II was extended to the west and north of Phase I). A solution ditch with eleven leak detection points was constructed around the HLP. A variable two- to ten-foot-thick layer of VLT was placed on a single 40-mil (0.04-inch-thick) HDPE liner. The solution ditch that surrounds the Phase I/II HLPs drained to the Phase I Pond.

Phase III Heap Leach Pads

The 46-acre Phase III South HLP and the 50-acre Phase III 4X HLP were constructed by Arimetco to leach low-grade oxide ores. A single 40-mil HDPE liner was installed by Arimetco to recover drain-down solution, and the drainage ditch was designed with a leak detection system over a second, 40-mil HDPE liner. The solution ditches surrounding the Phase III South HLP and the Phase III 4X HLP drained to the Phase III Bathtub Pond and to the Mega Pond, respectively.

Phase IV Slot Heap Leach Pad

The approximate 86-acre Phase IV Slot HLP was constructed by Arimetco on a pad excavated into the W-3 waste rock dump and an asphalt-lined area, and was expanded northward between 1993 and 1996 on a 40-mil HDPE liner over a secondary liner of compacted clay. This HLP is surrounded by a berm and double HDPE-lined collection ditch with leak detection between the membranes and seven leak detection monitoring points. Drain-down solutions flow to one of two pregnant leach solution (PLS) ponds.

Until late 2003, drain-down solutions were pumped by NDEP from the PLS ponds to the surface of the HLP for evaporation. In 2006, EPA relined the northern Phase IV Slot PLS Pond, and solutions from this pond were routinely conveyed to the FMS Evaporation Pond (also known as the EPA 4-Acre Pond) constructed by EPA in 2007.

Phase IV VLT Heap Leach Pad

The 54-acre Phase IV VLT HLP was constructed by Arimetco on the southern portion of the former finger evaporation ponds, and on native alluvial soils, north of the Oxide Tailings OU, and consists of oxide tailings, and run-of-mine and crushed ore from the MacArthur Mine. The Phase IV VLT HLP was constructed on a 40-mil HDPE liner overlying a secondary liner of compacted clay. The solution drainage ditch includes a leak detection system over a 40-mil HDPE liner designed with five leak detection points, and drains to the northeast corner of the HLP to a single PLS pond (5.04 million-gallon capacity).

Drain-down solutions from the Phase IV VLT HLP flow by gravity to the VLT Pond and, as needed to improve evaporation efficiency of the FMS, are pumped to one of two new FMS Evaporation Ponds (B and C) described below. EPA completed a VLT pond liner replacement project in October 2012 (BC 2014b).

2.2 Evaporation Ponds

From the Process Areas, spent process solutions resulting from the beneficiation of copper oxide and sulfide ores were conveyed in unlined trenches to the lined and unlined evaporation ponds, and ponds in the northern portion of the Site. The evaporation ponds in the northern portion of the Site are identified on Figure 1-2 as the Unlined Evaporation Pond (UEP), the Lined Evaporation Pond (LEP), and the Finger Ponds. The Sulfide Tailings were also used to dispose spent oxide ore process solutions prior to the mining of sulfide ores. A brief description of these ponds follows:

- <u>UEP</u>: consists of a large northern section (98 acres) and a much smaller southern section (4.1 acres) constructed on alluvial soils without a liner surrounded by berms constructed of VLT. The volume of pond sediments contained in the UEP is approximately 270,230 cubic yards based on average thicknesses of approximately 1.5 and five feet in the northern and southern sections, respectively.
- <u>LEP</u>: consists of three sections (North, Middle and South), which were lined with a relatively thin (0.5 to one-inch-thick) liner consisting of a mixture of asphalt tar and crushed gravel. The asphalt liner was placed over one to 2.5 feet of VLT materials. The LEP has a total combined area of approximately 101 acres. The thickness of the pond sediments averages three to six inches, with a maximum measured thickness of approximately 12 inches within the central, topographically lower portion of the LEP. The volume of pond sediments contained in the LEP is approximately 65,800 cubic yards.
- <u>Finger Ponds</u>: consist of four narrow "Finger Ponds" and one larger "Thumb Pond". The four Finger Ponds (17.8 acres) were lined similar to the LEP without the VLT sub-base. The estimated volume of sediments within the Finger Ponds is 5,838 cubic yards based on an average thickness of four inches. The unlined Thumb Pond has elevated embankments along its north and east margins. The exposed portion of the Thumb Pond (i.e., not covered by the Arimetco Phase IV VLT HLP) covers about 69 acres and was capped in 2010 with VLT materials. The volume of pond sediments contained within the Thumb Pond is 95,000 cubic yards based on an average thickness of 3.5 feet.

In 1955, the flow rate to the evaporation ponds averaged approximately 2,000,000 gallons per day or 1,385 gpm and water quality characteristics of the fluid showed a free acid concentration of 1.0 g/L, total soluble salts concentration of 171 g/L, and total iron concentration of 37.5 g/L (Nesbitt 1955; Dalton 1998).

Infiltration of process solutions at these locations due to increased hydraulic heads associated with impounded fluids, likely raised groundwater elevations and created mounding effects that influenced groundwater gradients, flow directions and velocities, and groundwater quality. Due to the net evaporative character of the Site, significantly less flux (if any) of residual process-related chemicals to groundwater occurs at the Site at present relative to historic periods when the mine facilities were operational. The term “evaporation ponds” used in the following sections refers to the LEP and UEP.

2.3 Historical Mine Site Groundwater Pumping, Distribution and Use

Details of Anaconda’s historical groundwater pumping, distribution, and water management at the Site are provided in Appendix A-2 and summarized below.

Mine Site Water

Gill (1951) conducted a groundwater investigation to support open pit mining, and reported that the groundwater table around the proposed open pit was approximately 4,350 to 4,380 feet amsl, with variable water levels a result of bedrock compartmentalization of groundwater. Gill (1951) also reported that most groundwater in the proposed open pit was recharged by the Walker River. Dewatering of the pit in advance of mining operations in the early 1950s resulted in a depressed water table.

Groundwater produced from the pit area wells and other supply wells was primarily used in the beneficiation of copper oxide and sulfide ores in the Process Areas. Pit dewatering ended in 1978. The resulting Pit Lake functions as a hydraulic sink that captures alluvial and bedrock groundwater, as discussed in Section 3.3.2.

Historical Groundwater Pumping and Water Management

The known locations of historic wells used for mining-related activities are shown on Figure 2-2. These wells include those that have been abandoned per the State of Nevada Administrative Codes (NAC) 534.420, 534.4365 or 534.4371 and others that have not been abandoned but are not currently in active use.

Groundwater pumped by Anaconda was used for four general purposes: 1) to depress the water level in the open pit to achieve safe working conditions for mining operations; 2) copper ore beneficiation activities in the Process Areas; 3) residential use at Weed Heights, commonly referred to as the "Townsite" in archived documents (Anaconda 1953, 1955, and 1957); and 4) ancillary operations at the Site (e.g., fire protection, dust control, drilling, blasting, and supply to shops).

Groundwater use was less during the period from 1952 through 1963 when only oxide ores were leached than in the period from 1963 through 1978 when the copper sulfide ore milling circuit was added to the existing copper oxide ore leaching operations, which resulted in an increased demand for groundwater. References in archived documents to the "Plant" generally refer to oxide leaching facilities prior to 1963, and combined copper oxide and copper sulfide ore beneficiation operations after 1963. Groundwater supplies were obtained from four geographic areas: open pit area wells; evaporation area wells; well WW-10 in the Process Areas; and off-Site area wells. Excess pumped water, from pit dewatering activities, was discharged to the Walker River.

Discharge of water to the Walker River peaked in 1953 at 2,373 acre-feet per year, which is equivalent to approximately 1,471 gpm, and generally declined through 1963. At this point, pumped water to the combined Townsite and Plant rose steadily until 1974 at which time it reached 11,388 acre-feet per year (7,058 gpm). There was a general decline in total water pumped during the last four years of Anaconda operations. The annual average pumping rate at the Site ranged from 1,658 gpm in 1978 (the final year of operations) to 7,119 gpm in 1974 (the peak year of water production).

Although the monthly water reports did not specify on-Site water use, some details of water distribution to operational areas are available for 1964 and the first half of 1978 (Table 2-2). In 1964, the Plant received 2,055 acre-feet (45% of total) and the sulfide milling circuit (Concentrator) received 1,511 acre-feet (33% of total).

Table 2-2. Water Distributed to Operational Areas During 1964 and 1978

Operational Area or Use	1964 (acre-feet)	1964 Percent of Total	Jan-Jun 1978 (acre-feet)	Jan-Jun 1978 % of Total
Townsite	455	9.9%	58	4.3%
Roads	51	1.1%	31	2.3%
Leach Vats	2,055	44.7%	271	20.2%
Precipitation Plant	---	---	15	1.1%
Sulfide Concentrator	1,511	32.9%	---	---
Acid Plant	481	10.5%	538	40.1%
Water Discharged to Walker River	46	1.0%	0	---
W-3 Waste Rock Dump	---	---	259	19.3%
Dust System	---	---	169	12.6%
Total	4,600	100%	1,340	100%

Open pit area wells were installed during the period 1952-1954 (WW-1 through WW-7) and in 1959 (WW-36) to dewater the pit, supply water to the Townsite, and supply water for copper oxide ore beneficiation. During July 1955, the combined flow from six of the open pit area wells was estimated to be 2,454 gpm, and the total demand was 2,553 gpm. The use of recycled process water during this period made up for the approximate 100 gpm difference. In 1966, combined demand at the Plant and Townsite was 2,600 gpm.

Evaporation area wells were installed during the period 1959-1961 (WW-8, WW-9 and WW-11) and in 1965 (WW-12C) to provide the required make-up water (i.e., approximately 1,000 gpm) for the Sulfide Concentrator, which began operation in 1963. Based on 1964 monthly water reports, evaporation area wells had a combined pumping rate that ranged from 442 to 1,390 gpm with an annual average rate of 690 gpm. Well WW-10 was installed in the Process Areas in 1960 to provide additional water for the copper oxide and copper sulfide ore beneficiation operations.

Per the well log on file with the NDWR, the well was drilled to a depth of 610 feet, and penetrated 200 feet of alluvial materials before reaching bedrock. At that time, the depth to groundwater was 100 feet below ground surface (bgs). The well casing was perforated from 105 to 505 feet bgs, resulting in about 95 feet of alluvial materials and 305 feet of bedrock that could yield groundwater. When tested for two hours at a rate of 595 gpm, WW-10 exhibited a drawdown of 81 feet (close to the alluvium-bedrock contact).

Historical pumping records for WW-10 are limited. Table 2-3 summarizes 1964 monthly water reports for well WW-10. The monthly pumping rate was calculated by dividing the monthly volume by the number of days in each month and the number of minutes in each day. The pumping rate ranged from 102 gpm in January 1964 to 254 gpm in October 1964, with an average annual rate of approximately 169 gpm for the 10 months with pumping data.

Table 2-3. 1964 Monthly Pumping Volumes and Rates for Mine-Water Supply Well WW-10

Month, 1964	Volume Pumped (cu ft)	Volume Pumped (gal)	Average Pumping Rate (gpm)
January	606,470	4,537,000	102
February	NA	NA	NA
March	NA	NA	NA
April	1,135,410	8,494,000	190
May	1,230,851	9,208,000	206
June	1,329,595	9,946,700	223
July	1,134,621	8,488,100	190
August	1,362,839	10,195,400	228
September	1,227,109	9,180,000	206
October	1,514,771	11,332,000	254
November	1,220,291	9,129,000	205
December	1,139,420	8,524,000	191
Annual Values	11,901,377	89,034,200	169

NA = not available; cu ft = cubic feet; gpm = gallons per minute; gal = gallons

Groundwater quality samples were obtained from WW-10 from August 1991 to June 2006. From August 1991 through 1994, at least three samples were collected during each year. From 1995 through June 2006, samples were collected quarterly. Not all parameters were monitored in each sampling event. Results for sulfate, uranium and arsenic are discussed below.

Concentrations of sulfate in the 49 samples collected from August 1991 to June 2006 ranged from 457 to 2,485 milligrams per liter (mg/L). Concentrations of uranium in the 10 samples collected from September 2003 to June 2006 ranged from 190 to 310 micrograms per liter (µg/L). From August 1991 to June 2006, 95% (i.e. 35 of the 37) reported arsenic results were less than or approximately equal to the laboratory analytical reporting limits. Laboratory reporting limits for arsenic were commonly higher (i.e., 25 µg/L) during the early part of the monitoring history and lower (as low as 4 µg/L) during the latter part of the monitoring history. In September and October 1991, arsenic concentrations were reportedly 1,040 and 3,475 µg/L, respectively. The arsenic results for these two sampling events are inconsistent with and three orders of magnitude greater than the results for the other 35 sampling events.

2.4 Pumpback Well System

The PWS and associated monitor wells were constructed under an Administrative Order on Consent issued by NDEP on October 1, 1985. ARC operated the PWS located along the northern margin of the Site to collect shallow groundwater beginning in March 1986 (Piedmont 2001). The initial PWS consisted of five extraction wells (PW-1 through PW-5; see Figure 3-3) and a clay-lined 23-acre evaporation pond for containment of extracted groundwater.

In 1998, six additional extraction wells (PW-6 through PW-11; see Figure 3-3) were installed and operated as part of the PWS. Other improvements to the PWS included partitioning the 23-acre evaporation pond into three cells and installing an HDPE liner on top of the clay liners in the middle and south cells to protect the clay liners from desiccation during the summer dry season. No HDPE liner was placed on the north cell.

The pumpback wells are approximately 40 to 60 feet deep and are spaced at intervals ranging from approximately 380 feet (PW-2 to PW-3) to 1,400 feet (PW-5 to PW-6). Prior to March 25, 2009, the PWS operated continuously (i.e., 24 hours per day, 7 days per week), with individual wells temporarily taken off-line for maintenance and repairs of pumps and related equipment. For example, in 2006, individual well production rates ranged from 0.5 to 16.7 gpm with a total combined pumping rate of 56.4 gpm. Approximately 29.7 million gallons (91.1 acre-feet) of groundwater were pumped from the Shallow zone in 2006 (Norwest Applied Hydrology 2007).

EPA approved the shutdown of the PWS on March 25, 2009 to allow for a characterization of groundwater conditions at the northern Site margin. Subsequently, the pumpback wells were used as part of an aquifer test to characterize hydraulic properties of the Shallow zone (ARC 2010). The test data were used to: 1) delineate the hydraulic capture zones of the PWS; and 2) assess the historical effectiveness of the PWS in limiting the off-Site migration of Shallow groundwater. The PWS evaluation is discussed in Section 3.3.1. Since completion of hydraulic testing, the PWS has been shut down and wells PW-1 to PW-11 have been monitored pursuant to the Groundwater Monitoring Plan (GMP) (BC 2012a).

2.5 Wabuska Drain

The Wabuska Drain is a 13.8-mile long unlined ditch that extends from the Site to the Walker River. The grade of the Wabuska Drain between the Site and the southern margin of the YPT Reservation is approximately 0.15% over 4.1 miles. The grade increases to about 0.16% along the 1.1-mile length within the YPT Reservation. From the northern margin of the YPT Reservation to its intersection with the Walker River, the average grade is approximately 0.04% (BC 2015b). Adjacent surrounding agricultural fields slope gently toward the Wabuska Drain, or connect to the drain through lateral ditches that feed into the drain by gravity flow. The drain was constructed in the late 1930s, when the regional groundwater table was higher, to intercept shallow groundwater to stabilize areas north of the Site adjacent to the tracks of the former Nevada Copper Belt Railroad and several farms. The Wabuska Drain alignment near the Site has changed over time (BC 2015b; CH2M Hill 2010), as shown on Figure 2-3. Portions of these former alignments are now buried beneath the Evaporation Ponds and the Hunewill Ranch agricultural fields.

Currently the drain functions as one of many irrigation return-flow ditches in the northern Mason Valley. These drains collect irrigation tail water and run-off from agricultural fields, and convey water to downgradient agricultural areas for further irrigation uses and/or discharge to the Walker River (CH2M Hill 2010).

Historically, the Wabuska Drain alignments near the Site intercepted shallow groundwater (CH2M Hill 2010). However, the various drain alignments near the Site no longer intercept shallow groundwater due to basin-wide groundwater level declines (Section 4.9). In the northern part of the Wabuska Drain, inputs also include intercepted shallow groundwater and deeper water associated with alluvial groundwater discharge and geothermal springs that coincide with a series of northwest trending faults referred to as the Wabuska lineament (Stewart 1988). Other potential past and/or current inputs include discharges from, or groundwater influenced by, the Thompson smelter and various geothermal power production activities.

Details regarding the Wabuska Drain are provided in the HSR (CH2M Hill 2010; Appendix A-1). Results of the ongoing RI for the Wabuska Drain will be reported separately. Available data indicate that concentrations of mine-related chemicals decrease with distance from the Site and depth in the soil profile (EPA 2007a, BC 2015b).

SECTION 3.0
GROUNDWATER INVESTIGATIONS AND RELATED STUDIES

Numerous investigations and monitoring activities conducted prior to 2005 have provided substantial geologic, hydrogeologic, and water quality information pertaining to OU-1. These pre-2005 activities were primarily associated with a limited number of monitor wells (having screens positioned across the water table) located around the northern Site margin. Sampling methods and the quality of laboratory analytical results prior to 2005 were not well documented.

Pre-2005 investigations and reports for the Site and surrounding area are summarized in Section 3.1. Post-2005 investigations and reports performed and/or prepared by ARC are summarized in Section 3.2. Pre-2005 data are used to address historical aspects of the HCSM because historical conditions (e.g., groundwater elevations and flow directions) were different from current conditions due to mine operations, agricultural activities, groundwater and surface water usage, and weather conditions (BC 2014a). Historical aspects of the HCSM are generally more qualitative relative to aspects of the HCSM developed using data collected after 2005 because the historical data are typically limited (especially with respect to spatial coverage) and data quality is often not well documented.

Since 2005, numerous investigations and monitoring activities have been conducted by ARC with EPA and stakeholder involvement, and the sampling methods and quality of the laboratory analytical results since 2005 have been well documented. A draft Quality Assurance Project Plan (QAPP) that included standard operating procedures (SOPs) for sampling and field data collection methods was prepared in 2003 to establish and implement strict QA/QC procedures and, subsequently, was periodically revised to result in the current *Quality Assurance Project Plan - Revision 5* (Environmental Standards, Inc. [ESI] and BC 2009). Other QA planning documents that were prepared pursuant to the 2007 Order included the: 1) *Data Management Plan for the Yerington Mine Site* (BC 2007a); 2) GMP (BC 2012a); and 3) EPA-approved work plans specific to OU-1.

3.1 Pre-2005 Investigations

Investigations and reports relevant to the OU-1 Study Area that were conducted prior to 2005 are provided below, generally listed in chronological order:

- Gill, D.K., 1951. Groundwater at the Yerington Mine, Lyon County, Nevada, a consultant report prepared for The Anaconda Company that describes the results of aquifer testing, and provides projections of groundwater inflows and dewatering rates for the open pit.
- Huxel, C.J., Jr. and E.E. Harris, 1969. Water Resources and Development in Mason Valley, Lyon and Mineral Counties, Nevada, 1948-1965, NDWR Bulletin No. 38 prepared in cooperation with the USGS. This is a comprehensive hydrologic study of the Mason Valley area including water budgets and effects of agriculture on surface water and groundwater quality and quantity.
- Seitz, H., A.S. Van Denburgh, and R.J. La Camera, 1982. Ground Water Quality Downgradient from Copper Ore Milling Wastes at Weed Heights, Lyon County, Nevada, USGS Open File Report 80-1217. This study presents hydrologic and geochemical data on the effects of mining on groundwater quality from several monitor wells, most of which are no longer operational.
- Applied Hydrology Associates (AHA), 1983. Evaluation of Water Quality and Solids Leaching Data, a consultant report prepared for Anaconda Minerals Company. This report includes surface water and solids leaching data in addition to groundwater sampling data that are compared to the data reported by Seitz et al. (1982).
- Anaconda Minerals Company, 1984. Water Quality Investigation and Mitigation Plan, Yerington Mine Site, Yerington, Nevada, a report prepared for NDEP that summarized additional field data and groundwater conditions north of the Site.
- Proffett, J.M., Jr., and J.H. Dilles, 1984. Geologic Map of the Yerington District, Nevada, Nevada Bureau of Mines and Geology, Map 77.
- Nork, W., 1989. MacArthur Project Hydrogeologic Investigation, Lyon County, Nevada, a consultant report prepared for MacArthur Mining and Processing Co. that describes the general hydrogeologic conditions associated with a proposed project to develop an open pit mine located to the northwest of the Site.
- Dalton, D., 1998. *Arimetco Yerington Mine and Process Facility Site Assessment of Groundwater Quality*, a consultant report prepared for Arimetco for submittal to NDEP in response to NDEP’s Finding of Alleged Violation and Order of February 1997.
- Lewis, B., 2000. *Geophysical Survey Results of the Yerington Mine, Mason Valley, Nevada*, a BLM report on electro-magnetic and resistivity surveys north of the Site.
- Superfund Technical Assessment and Response Team (START), 2000 and 2001. *Expanded Site Inspection: Yerington Mine* and *Anaconda, Yerington Mine Site Emergency Response Assessment Final Report,* reports prepared for the EPA that describe Site conditions including groundwater quality.

- Piedmont Engineering, Inc., 2001. *Yerington Shallow Aquifer Data Evaluation Report*, consultant prepared for ARC. Interpretations of data presented in this report related to the nature and extent of mine-impacted groundwater.
- AHA and Norwest Applied Hydrology, 2000 through 2007. *Annual Monitoring and Operation Summary: Pumpback Well System, Yerington Nevada*, annual consultant reports prepared for ARC. These reports provide groundwater elevation and water quality data for the pumpback system and associated monitor wells. The reports also include pumping rates and time-concentration plots for select chemicals.
- Brown and Caldwell, 2002. *Installation of Two Monitor Wells at the Yerington Mine Site, Lyon County, Nevada.* This letter report described the drilling and well construction activities of two monitor wells, which was an interim action required by NDEP, EPA, and BLM.

3.2 Post-2005 Investigations

A generalized chronology of the phased, groundwater-related field investigations conducted since 2005 is provided in Figure 3-1. The following subsections describe the post-2005 investigations and related evaluations by media. Groundwater characterization activities largely involved monitor well installation. Monitor wells installation procedures are described in Section 3.2.1. After installation, initial sampling and testing for OU-1 characterization purposes, these wells were subsequently incorporated into the Site-Wide Groundwater Monitoring Program, which is described in Section 3.2.3.

3.2.1 Monitor Well Installations

Recognizing that groundwater characterization activities would largely involve monitor well installation, ARC and EPA adopted the following sequential approach to field data collection to maximize usable data and optimize the design of a monitor well network intended to serve the data needs for both OU-1 RI characterization and long-term Site-Wide groundwater monitoring.

- Borehole drilling using a roto-sonic core drilling rig and lithologic logging of continuous cores to identify coarse-grained or potentially transmissive intervals where chemicals could potentially migrate.
- Depth-specific (zonal) groundwater sample collection in the alluvial aquifer at nominal 20-foot intervals from the top of the water table to the target depth of each borehole using low-flow, minimal drawdown purging and sampling procedures approved by EPA.

- Collection of field measurements from zonal samples including pH, specific conductivity, temperature, dissolved oxygen (DO), oxidation-reduction potential (ORP), sulfate, alkalinity, and total and ferrous iron, using routinely-calibrated field meters and accuracy-checked water quality field test kits.
- Laboratory analyses of zonal samples for total and dissolved uranium, total and dissolved arsenic, total organic carbon (TOC), and uranium isotopes (^{234}U, ^{235}U, and ^{238}U).
- Based on the zonal groundwater sample results, construction of new monitor wells in various groundwater zones using methods and materials specified in EPA-approved SOPs and work plans, with EPA approval of well screen lengths and positions.
- Surveying of well location coordinates and reference point elevations, followed by measurement of groundwater elevations in all new and existing monitor wells.
- Hydraulic (slug) testing of monitor wells and analysis of hydraulic test data.
- Deployment of pressure transducers and data loggers in select monitor wells with EPA approval to collect groundwater elevation data at four-hour intervals and assess temporal water level fluctuations.
- Collection of hydrologic tracers from monitor wells.
- Incorporation of the new monitor wells into the GMP (BC 2012a), discussed below in Section 3.2.3.

In total, the groundwater RI characterization activities described above resulted in drilling 133 boreholes, logging approximately 33,000 linear feet of core, collecting and analyzing 624 zonal groundwater samples, installing 299 new monitor wells, and hydraulic (slug) testing 296 wells. Appendix C provides monitor well information including: 1) borehole lithologic information and well construction diagrams; 2) well construction and location information for the active monitor wells; 3) construction information for abandoned and inactive wells not used for routine groundwater monitoring; and 4) zonal groundwater sample results.

The various investigations involving monitor well installations are integrated into the discussion of the Site-Wide groundwater monitoring program in the following section. Appendix D provides OU-1/Site-Wide groundwater monitoring information including water level and chemical data, water-level hydrographs, charts illustrating temporal changes in vertical gradients at monitor well clusters, and charts illustrating temporal changes in chemical concentrations at monitor wells.

3.2.2 Shallow Zone Groundwater Investigation

The 2009 Shallow zone investigation is detailed in the *Shallow Zone Data Summary Report - Revision 1* (BC 2010a; Appendix B) and summarized below. The Shallow zone investigation was designed to improve the understanding of hydrogeologic and geochemical conditions in the Shallow zone of the alluvial aquifer to the north of the Site by refining the distributions of sulfate, uranium, uranium isotopes, dissolved metals, TOC and alkalinity in Shallow zone groundwater. This information was used to evaluate potential sources of chemicals in groundwater in this portion of the Study Area and identify portions of the Intermediate or Deep zones in the alluvial aquifer that would warrant the installation of monitor wells.

Shallow zone characterization activities during 2009 included:

- Direct push technology (DPT) with Geoprobe® equipment was used to obtain continuous, high-resolution electrical conductivity (EC) measurements of subsurface materials at 93 locations. EC profiling was initially conducted at four locations (OU1-DPT-18, OU1-DPT-40, OU1-DPT-16, and OU1-DPT-24) where lithologic logging and zonal sampling had been previously conducted during borehole drilling and well installation at the B/W-2, B/W-3, B/W-18, and USGS-13S/W32DC-D well clusters, respectively, and one location (OU1-DPT-13) where geophysical logging had been conducted in 1983 (W5AB-2). This comparison was intended to help correlate EC data with clays and/or elevated solute concentrations in groundwater. In addition, EC data were also used to make decisions regarding the number and depths of sampling intervals at each individual DPT location.
- Field parameters were measured in groundwater samples collected from the sampled intervals within the Shallow zone including pH, specific conductivity, temperature, sulfate and total alkalinity (alkalinity) using routinely-calibrated field meters and accuracy-checked water quality field test kits.
- DPT equipment was used to collect groundwater samples at each location from as many as three intervals within the Shallow zone, and samples were submitted to the analytical laboratory for chemical analyses including total and dissolved uranium, TOC, 28 metals, uranium isotopes, and sulfur and oxygen isotopes in dissolved sulfate at EPA-selected locations.
- DPT locations were surveyed by a registered Nevada surveyor.
- Upon completion of EC profiling and/or groundwater sample collection, all boreholes were abandoned in compliance with Nevada regulatory requirements.

In 2010, DPT equipment and identical sample collection methods were used at 10 additional locations to obtain groundwater samples for laboratory analysis (BC 2013a). EC profiling was not conducted during the 2010 investigation. Both the 2009 and 2010 DPT locations are shown on Figure 3-2. Chemical distributions in the Shallow zone of the alluvial aquifer are shown on figures provided in Appendix B and are described as follows:

- The highest concentrations of major ions and metals (e.g., aluminum, copper, iron, manganese, nickel, vanadium and zinc) and uranium in the Shallow zone were typically detected beneath the central portion of the UEP, and the south-central and north-central portions of the LEP. Low pH values occur beneath the LEP and UEP. Alkalinity was depressed or non-detectable beneath the UEP. Elevated alkalinity (e.g., >500 mg/L) occurred down-gradient of the Weed Heights sewage lagoons.
- The high chemical concentrations beneath the evaporation ponds decrease laterally by varying orders of magnitude because of past and current physical and chemical attenuation processes. West of the LEP, concentrations of sulfate, other mobile chemicals, and metals decrease rapidly with distance from the Site. To the east beneath the agricultural fields, chemical concentrations are generally lower than other locations beneath or near the Site. Localized occurrences of elevated concentrations of select constituents in groundwater samples were observed from sample locations on the agricultural fields and included: alkalinity, manganese, molybdenum, nickel, potassium, selenium, sodium, uranium, vanadium, and zinc.

  The distribution of dissolved (i.e., filtered) uranium in the Shallow zone is generally consistent with the distribution of many other Site chemicals in that: 1) the highest concentrations occur beneath the central portion of the UEP, and the south-central and north-central portions of the LEP; 2) elevated concentrations extend beyond the Site boundary along a northwest alignment from the Evaporation Ponds; and 3) elevated chemical concentrations beneath the Evaporation Ponds decrease laterally by varying orders of magnitude. However, there are important differences that suggest that alkalinity and calcium influence the mobility/attenuation of uranium. Uranium concentrations rapidly decrease laterally to the west, similar to other chemicals, but do not decrease as rapidly to the east beneath the irrigated agricultural fields. Elevated concentrations of uranium in DPT locations including OU1-DPT-41, OU1-DPT-42, OU1-DPT-46, OU1-DPT-49, OU1-DPT-61, and OU1-DPT-72 are roughly coincident with: 1) the areas of locally high concentrations of alkalinity (over 300 mg/L) in Shallow zone groundwater at the northwest and northern edge of the agricultural fields; and 2) high calcium concentrations to the northwest of the agricultural fields and general widespread distribution of calcium throughout the agricultural fields.

- The distribution of arsenic in Shallow zone groundwater differs from the distributions of the parameters and chemicals described above. The highest concentrations of arsenic were detected in Shallow zone groundwater at OU1-DPT-23 (up to 620 ug/L), OU1-DPT-28 (up to 580 ug/L), and other nearby locations, which are located approximately 3,000 to 3,500 feet north of the Evaporation Ponds. Beneath the Evaporation Ponds, arsenic concentrations were much lower and typically ranged from approximately 10 to 160 ug/L. In this area, the lowest arsenic concentrations in Shallow zone groundwater occur along a northwest trend from the Weed Heights sewage lagoons. To the west of the LEP, arsenic occurs in Shallow groundwater at concentrations at or slightly above 50 ug/L.

3.2.3 Site-Wide Groundwater Monitoring Program

Groundwater monitoring in the Study Area has evolved over time in response to regulatory requirements and incorporation of new wells installed during the OU-1 RI. Currently, long-term Site-Wide groundwater monitoring is conducted in accordance with the GMP (BC 2012a) and EPA-approved modifications listed in Table 3-1. Provided below is a summary of the: 1) development of the monitoring program; 2) current active monitor well network; 3) water level monitoring activities; and 4) groundwater quality monitoring activities.

Monitoring Program Development

Table 3-1 provides a chronological summary of groundwater characterization and monitoring activities at the Site and the evolution of the monitor well network over time.

Table 3-1. Chronology of Groundwater Characterization and Monitoring Activities

Date	Activity
1976-1982	The USGS conducted groundwater investigations north of the Site boundary, which culminated in a report entitled: *Ground-water quality down-gradient from copper-ore milling wastes at Weed Heights, Lyon County, Nevada* (Seitz et al. 1982).
1982-1985	1982 – An NDEP Order required groundwater investigations near the Sulfide Tailings and Evaporation Ponds, and initial groundwater monitoring. 1985 – An NDEP Order required construction of the PWS and performance of associated O&M and groundwater monitoring activities.
1997	An NDEP Order was issued that required Arimetco to conduct groundwater investigations and monitoring of the Site, requesting both a complete hydrogeological assessment for the Yerington Mine (including existing and projected Pit Lake conditions), and a facility assessment to identify all areas where constituent concentrations in groundwater exceed the drinking water standards or background.
1999	Implementation of a Geoprobe® investigation of Shallow zone alluvial aquifer conditions north of the Site, which consisted of collecting 29 samples from 18 locations (AHA 2000).
2002	Two groundwater monitor wells, MW-2002-1 (subsequently re-named B/W-2S) and MW-2002-2, were installed (BC 2002) under an interim action directed by NDEP.
2004	Several groundwater characterization boreholes were drilled to collect groundwater grab samples, and three groundwater monitor wells were installed in the Process Areas, pursuant to the *Final Draft Process*

Table 3-1. Chronology of Groundwater Characterization and Monitoring Activities

Date	Activity
	Areas Work Plan (BC 2003).
2005	Implementation of the *First-Step Hydrogeologic Framework Assessment* (HFA; BC 2005) under the Unilateral Administrative Order (UAO) issued by EPA for Initial Response Activities, EPA Docket No. 9-2005-0011, including the installation of the first phase of B/W wells.
2007-2008	Implementation of the Second-Step HFA (BC 2007b) included a second phase of well installations, and the preparation of OU-specific work plans that describe additional on-Site monitor well installations under the 2007 Order. ARC submitted the *Draft Site-Wide Groundwater Monitoring Plan* (BC 2007c).
2008	Monitor well identification numbers modified to include a suffix designating the groundwater zone in which the well screen is positioned, including the Shallow, Intermediate, Deep and bedrock zones.
2008	EPA approved the elimination of well MW-1S from the monitoring network due to an obstruction well.
2008	Collection of groundwater grab samples and groundwater levels beneath the Anaconda Evaporation Ponds pursuant to the *Anaconda Evaporation Ponds Removal Action Characterization Work Plan* (BC 2008a).
2009	-Shutdown of the pumpback wells on March 25, 2009 with EPA approval. -Implementation of activities pursuant to the *Pumpback Well System Characterization Work Plan* (ARC 2008) including: 1) installation of nine groundwater monitor wells north of the PWS and the LEP; and 2) pumpback well aquifer testing pursuant to the *PWS Characterization Work Plan Addendum - Revision 2* (ARC 2010), which was performed in 2010. - Implementation of activities pursuant to the *Shallow Alluvial Aquifer Characterization Work Plan for Northern Portion of the Yerington Mine Site* (BC 2008b). -EPA approved the QAPP - Revision 5 dated May 20, 2009 (ESI and BC 2009), which contains SOPs for groundwater monitoring. -Implementation of a separate Domestic Well Monitoring Plan (BC 2010b) as a revision to the QAPP per EPA direction. The Domestic Well Monitoring Plan and related Bottled Water Program are discussed further in Section 3.4. -ARC submitted the *Site-Wide Groundwater Monitoring Plan - Revision 1* (BC 2009a).
2010-2011	Installation of 123 wells per the *2010 Groundwater Monitoring Well Work Plan - Revision 2* (BC 2010c) and the *Agricultural Fields Characterization Work Plan - Revision 2* (BC 2010d).
2011	-Installation of 58 wells per the the *On-Site Monitor Well Installation Work Plan - Revision 1* (BC 2011a). -Aquifer testing of an agricultural well (WDW019) north of the Site, including a 96-well observation network, pursuant to the *Aquifer Test Work Plan - Revision 1* (BC 2011b).
2012	Submittal of the *Site-Wide Groundwater Monitoring Plan - Revision 2* (BC 2012a). Addition of new well YPT-MW-15I to the monitoring program in November 2012.
2013	-Installation of 58 monitor wells per the *Additional Monitor Well Work Plan - Revision 1* (BC 2013b). -Addition of five EPA Arimetco wells, nine YPT wells, and the one MacArthur mine well (MMW-2) to the monitoring program after the 4Q 2011 event. -EPA (2013a) approved of eliminating well USEPA2S from the active monitor well network. EPA (2013b) approves of abandoning well USEPA2S and eliminating the following five metals from the analyte list for wells having at least four quarters of data: lead, silver, thallium, tin, and titanium. EPA (2013b) also approved of reducing the sampling frequency of 118 wells from quarterly to semi-annually, with sampling to be conducted in the first and third quarters of subsequent years.
2014	-EPA (2013c) approved the abandonment of well B/W-14S and the well was abandoned in January 2014. -Well USEPA2S was abandoned in April 2014 and was moved from the inactive to abandoned well list. -ARC submitted the *Technical Memorandum: Site-Wide Groundwater Monitoring Optimization* (ARC 2014) proposing several modifications to the GMP (BC 2012a). -EPA approved of reducing the frequency of manual water level monitoring in wells installed before 2013 from monthly to quarterly, to coincide with the quarterly sampling events (EPA 2014a). EPA also approved reducing the frequency of collecting groundwater samples from wells installed before 2013 for nitrate analysis from quarterly to semi-annually, with sampling to be conducted in the first and third quarters of subsequent years (EPA 2014a).
2015	Installation of six additional monitor wells (B/W-63 cluster) in the third quarter of 2015 (3Q 2015), pursuant to the *Additional Monitor Well Work Plan - Revision 1* (BC 2013b). Initial water level monitoring and sampling of these six wells in 4Q 2015.

The network development detailed in Table 3-1 included the addition and elimination of monitor locations as summarized in Table 3-2.

Table 3-2. Inventory of Monitor Well and Piezometer Locations (2007 - 2015)

Date (Through)	Total (1)	Monitor Wells and/or Piezometers	Pumpback Wells
2007	87	76	11
2008	101	90	11
1Q 2009	110	99	11
2Q 2009	114(2)	103(2)	11
3Q 2009	114(2)	103(2)	11
4Q 2009	114(2)	103(2)	11
1Q 2010	114(2)	103(2)	11
2Q 2010	114(2)	103(2)	11
3Q 2010	114(2)	103(2)	11
4Q 2010	114(2)	103(2)	11
1Q 2011	237(3)	226(3)	11
2Q 2011	237(3)	226(3)	11
3Q 2011	237(3)	226(3)	11
4Q 2011	242(4)	231(4)	11
1Q 2012	309(5)	298(5)	11
2Q 2012	309(5)	298(5)	11
3Q 2012	309(5)	298(5)	11
4Q 2012	310(6)	299(6)	11
1Q 2013	309(7)	298(7)	11
2Q 2013	309(7)	298(7)	11
3Q 2013	309(7)	298(7)	11
4Q 2013	309(7)	298(7)	11
1Q 2014	308(8)	297(8)	11
2Q 2014	325(9)	314(9)	11
3Q 2014	354(10)	343(10)	11
4Q 2014	354(10)	343(10)	11
1Q 2015	354(10)	343(10)	11
2Q 2015	354(10)	343(10)	11
3Q 2015	360(11)	349(11)	11
4Q 2015	360(11)	349(11)	11

Notes:

1) Total does not include domestic/supply wells that were part of the network until 2010. Total does include the eleven pumpback wells.
2) Includes four Lyon County wells.
3) Includes four Lyon County wells and 123 wells installed in 2010/2011.
4) Includes four Lyon County wells, 123 wells installed in 2010/2011, and five EPA Arimetco wells (sampled in 3Q 2011 and added to the monitoring program after the 4Q 2011 event).

5) Includes four Lyon County wells, 123 wells installed in 2010/2011, 58 wells installed in 2011/2012, five EPA Arimetco wells, eight YPT wells (excluding YPT-MW-7), and one MacArthur mine well (MMW-2). Prior to 1Q 2012, these wells were or may have been sampled; however, sample collection methods were either inconsistent with EPA-approved sample collection methods or were not documented.
6) Includes four Lyon County wells, 123 wells installed in 2010/2011, 58 wells installed in 2011/2012, five EPA Arimetco wells, nine YPT wells (including new well YPT-MW-15I in November 2012), and one MacArthur mine well (MMW-2).
7) With EPA approval, well USEPA2S moved to inactive well list in March 2013, subsequently proposed for abandonment in August 2013, and abandoned in April 2014.
8) With EPA approval, well B/W-14S was abandoned in January 2014.
9) Includes 17 wells installed in 2013/2014 and first sampled in 2Q 2014.
10) Includes 29 wells installed in 2013/2014 and first sampled in 3Q 2014.
11) Includes six wells (B/W-63 cluster) installed in 3Q 2015 and first sampled in 4Q 2015.

Active Monitor Well Network

The active monitor well network included 360 wells at 170 locations: 133 wells in the Shallow zone, including 11 PWS wells formerly used for groundwater extraction (currently in shutdown mode); 55 wells in the Intermediate zone; 105 wells in the Deep zone; and 67 bedrock wells (Table 3-3 and Figure 3-3). Of the 360 monitor wells, seven are used only for water level measurements, and the remaining 353 are monitored for both water levels and water quality.

A generalized cross-section that depicts alluvial monitor well screen intervals and groundwater zone designations for active wells within the monitoring network is presented in Figure 3-4. A generalized cross-section that depicts bedrock monitor well screen intervals is presented in Figure 3-5. All monitor wells in the network were surveyed by a Nevada-registered surveyor. Project datum is Nevada State Plane West Zone coordinate system (NAD27).

Table 3-3. Well Construction Details for the Active Groundwater Monitoring Network

Well Name [(1)]	Completion Date	Groundwater Zone	Well Type	Well Screen Interval
				feet amsl
Pumpback Wells				
PW-1S	10/1/85	Shallow	Sampling	4335.02 - 4312.52
PW-2S	10/1/85	Shallow	Sampling	4335.73 - 4315.23
PW-3S	10/1/85	Shallow	Sampling	4333.88 - 4313.38
PW-4S	10/1/85	Shallow	Sampling	4331.48 - 4311.98
PW-5S	10/1/85	Shallow	Sampling	4334.23 - 4313.73
PW-6S	10/21/98	Shallow	Sampling	4340.11 - 4323.11
PW-7S	10/22/98	Shallow	Sampling	4339.32 - 4319.82
PW-8S	10/22/98	Shallow	Sampling	4336.63 - 4316.63
PW-9S	10/23/98	Shallow	Sampling	4337.38 - 4317.38
PW-10S	10/23/98	Shallow	Sampling	4338.46 - 4318.46
PW-11S	10/24/98	Shallow	Sampling	4339.68 - 4319.68

Table 3-3. Well Construction Details for the Active Groundwater Monitoring Network

Well Name (1)	Completion Date	Groundwater Zone	Well Type	Well Screen Interval		
				feet amsl		
Shallow Zone Monitor Wells						
B-2S	5/18/89	Shallow	Water Level	NR	-	NR
B-3S	5/18/89	Shallow	Water Level	NR	-	NR
B/W-1S	1/23/08	Shallow	Sampling	4334.71	-	4314.71
B/W-2S	6/13/02	Shallow	Sampling	4330.95	-	4320.95
B/W-3S	9/26/07	Shallow	Sampling	4332.50	-	4312.50
B/W-4S	1/21/08	Shallow	Sampling	4316.74	-	4296.74
B/W-5RS	11/16/07	Shallow	Sampling	4326.12	-	4306.12
B/W-6S	1/30/08	Shallow	Sampling	4326.78	-	4306.78
B/W-8S	10/9/07	Shallow	Sampling	4325.95	-	4305.95
B/W-9S	11/7/07	Shallow	Sampling	4331.77	-	4311.77
B/W-10S	1/23/08	Shallow	Sampling	4321.56	-	4301.56
B/W-11S	11/4/07	Shallow	Sampling	4330.42	-	4310.42
B/W-13S	7/13/05	Shallow	Sampling	4364.14	-	4344.14
B/W-15S	7/22/05	Shallow	Sampling	4348.48	-	4328.48
B/W-16S	10/7/07	Shallow	Sampling	4328.68	-	4308.68
B/W-18S	2/19/08	Shallow	Sampling	4333.87	-	4308.87
B/W-19S	1/9/08	Shallow	Sampling	4331.43	-	4311.43
B/W-20S	7/13/07	Shallow	Sampling	4377.44	-	4357.44
B/W-21S	7/24/07	Shallow	Sampling	4338.99	-	4318.99
B/W-22S	7/18/07	Shallow	Sampling	4309.55	-	4289.55
B/W-25S	1/31/08	Shallow	Sampling	4322.63	-	4302.63
B/W-27S	2/7/08	Shallow	Sampling	4338.98	-	4318.98
B/W-28S	1/15/08	Shallow	Sampling	4331.67	-	4311.67
B/W-29S	1/6/08	Shallow	Sampling	4314.97	-	4294.97
B/W-30S	10/25/10	Shallow	Sampling	4325.10	-	4305.10
B/W-31S1	12/8/10	Shallow	Sampling	4330.77	-	4315.77
B/W-31S2	12/8/10	Shallow	Sampling	4304.95	-	4294.95
B/W-32S	1/11/11	Shallow	Sampling	4328.60	-	4308.60
B/W-33S	8/4/10	Shallow	Sampling	4328.23	-	4308.23
B/W-34S	12/5/10	Shallow	Sampling	4337.68	-	4317.68
B/W-36S	8/11/10	Shallow	Sampling	4329.76	-	4319.76
B/W-37S	6/6/10	Shallow	Sampling	4331.62	-	4311.62
B/W-38RS	10/11/10	Shallow	Sampling	4320.17	-	4300.17
B/W-40S	1/10/11	Shallow	Sampling	4318.41	-	4298.41
B/W-41S	2/8/11	Shallow	Sampling	4324.54	-	4304.54
B/W-42S	11/9/10	Shallow	Sampling	4326.05	-	4306.05
B/W-43S	12/17/10	Shallow	Sampling	4323.75	-	4303.75
B/W-44S	9/24/10	Shallow	Sampling	4324.88	-	4304.88

Table 3-3. Well Construction Details for the Active Groundwater Monitoring Network

Well Name (1)	Completion Date	Groundwater Zone	Well Type	Well Screen Interval
				feet amsl
B/W-45S	1/17/11	Shallow	Sampling	4331.84 - 4311.84
B/W-46S	11/8/10	Shallow	Sampling	4327.09 - 4307.09
B/W-50S (2)	2/11/14	Shallow	Sampling	4337.83 - 4317.83
B/W-51S	8/25/10	Shallow	Sampling	4303.87 - 4293.87
B/W-52S	8/18/10	Shallow	Sampling	4329.90 - 4309.90
B/W-53S1	1/20/11	Shallow	Sampling	4310.26 - 4290.26
B/W-53S2	1/19/11	Shallow	Sampling	4265.87 - 4255.87
B/W-54S	8/20/10	Shallow	Sampling	4298.38 - 4288.38
B/W-55S	10/20/10	Shallow	Sampling	4327.27 - 4307.27
B/W-56S	3/13/12	Shallow	Sampling	4334.12 - 4314.12
B/W-57S	3/15/12	Shallow	Sampling	4325.36 - 4305.36
B/W-58S	3/14/12	Shallow	Sampling	4294.04 - 4284.04
B/W-59S (2)	11/20/13	Shallow	Sampling	4338.55 - 4318.55
B/W-60S	1/8/11	Shallow	Sampling	4342.73 - 4322.73
B/W-61S	8/27/10	Shallow	Sampling	4342.05 - 4322.05
B/W-62S	11/22/10	Shallow	Sampling	4333.94 - 4313.94
B/W-63S (3)	8/9/15	Shallow	Sampling	4325.73 - 4305.73
B/W-64S	12/6/10	Shallow	Sampling	4348.03 - 4328.03
B/W-65S	9/29/10	Shallow	Sampling	4325.29 - 4305.29
B/W-66S	12/5/10	Shallow	Sampling	4313.88 - 4293.88
B/W-67S	1/23/11	Shallow	Sampling	4329.26 - 4309.26
B/W-68S (2)	4/30/14	Shallow	Sampling	4325.57 - 4305.57
B/W-69S (2)	4/15/14	Shallow	Sampling	4319.18 - 4299.18
B/W-70S	10/20/11	Shallow	Sampling	4338.80 - 4318.80
B/W-71S	10/12/11	Shallow	Sampling	4342.25 - 4322.25
B/W-73S	9/10/11	Shallow	Sampling	4357.74 - 4337.74
B/W-74S	10/26/11	Shallow	Sampling	4342.98 - 4322.98
B/W-75S	12/20/11	Shallow	Sampling	4346.69 - 4326.69
B/W-76S	12/15/11	Shallow	Sampling	4335.33 - 4315.33
B/W-77S (2)	4/24/14	Shallow	Sampling	4320.30 - 4300.30
B/W-78S (2)	4/23/14	Shallow	Sampling	4329.30 - 4309.30
B/W-79S (2)	4/25/14	Shallow	Sampling	4335.29 - 4315.29
B/W-81S (2)	3/10/14	Shallow	Sampling	4308.10 - 4288.10
B/W-82RS (2)	11/3/13	Shallow	Sampling	4310.40 - 4290.40
B/W-83S (2)	2/5/14	Shallow	Sampling	4326.66 - 4306.66
D4BC-1S	10/1/85	Shallow	Sampling	4333.98 - 4313.98
D5AC-1S	5/6/84	Shallow	Sampling	4332.48 - 4327.48
FMS-05S (4)	10/20/13	Shallow	Sampling	4335.34 - 4315.34
FMS-06S (4)	11/6/13	Shallow	Sampling	4336.55 - 4316.55

Table 3-3. Well Construction Details for the Active Groundwater Monitoring Network

Well Name (1)	Completion Date	Groundwater Zone	Well Type	Well Screen Interval
				feet amsl
FMS-07S (4)	11/14/13	Shallow	Sampling	4337.75 - 4317.75
HLP-03S (4)	11/16/13	Shallow	Sampling	4341.79 - 4321.79
HLP-04S (4)	10/8/13	Shallow	Sampling	4340.55 - 4320.55
HLP-08S (4)	10/21/13	Shallow	Sampling	4331.83 - 4311.83
LC-MW-1S (5)	1/18/06	Shallow	Sampling	NR - 4303.80(6)
LC-MW-2S (5)	1/18/06	Shallow	Sampling	NR - 4313.90(6)
LC-MW-3S (5)	1/18/06	Shallow	Sampling	NR - 4323.70(6)
LC-MW-5S (5)	NR	Shallow	Sampling	NR - 4323.10(6)
LEP-MW-1S	2/26/09	Shallow	Sampling	4330.92 - 4320.92
LEP-MW-2S	2/27/09	Shallow	Sampling	4331.46 - 4321.46
LEP-MW-3S	2/28/09	Shallow	Sampling	4333.75 - 4323.75
LEP-MW-5S	3/2/09	Shallow	Sampling	4336.35 - 4326.35
LEP-MW-6S	3/2/09	Shallow	Sampling	4327.51 - 4317.51
LEP-MW-7S	3/3/09	Shallow	Sampling	4342.81 - 4332.81
MW2002-2S	6/14/02	Shallow	Sampling	4323.78 - 4313.78
MW-2S	12/13/92	Shallow	Sampling	4326.61 - 4311.61
MW-4S	12/10/92	Shallow	Sampling	4325.68 - 4310.68
MW-5S	10/20/95	Shallow	Sampling	4330.79 - 4315.79
MW-SXN	7/26/09	Shallow	Sampling	4355.39 - 4335.39
MW-SXS	8/28/09	Shallow	Sampling	4354.32 - 4334.32
PA-MW-1S	1/20/05	Shallow	Sampling	4347.32 - 4327.32
PA-MW-2S	1/21/05	Shallow	Sampling	4347.37 - 4327.37
PA-MW-3S1	1/19/05	Shallow	Sampling	4348.13 - 4328.13
PA-MW-3S2	11/19/11	Shallow	Sampling	4309.85 - 4299.85
PA-MW-4S	10/18/11	Shallow	Sampling	4348.09 - 4328.09
PA-MW-5S1	11/17/11	Shallow	Sampling	4344.01 - 4324.01
PA-MW-5S2	11/14/11	Shallow	Sampling	4311.16 - 4301.16
PA-MW-7S	10/25/11	Shallow	Sampling	4317.46 - 4297.46
PLMW-2S	8/3/11	Shallow	Sampling	4369.05 - 4349.05
PLMW-4S	10/31/11	Shallow	Sampling	4319.72 - 4289.72
PW10-P1	9/27/05	Shallow	Water Level	4339.10 - 4319.10
USGS-13S	6/10/76	Shallow	Sampling	4342.06 - 4332.06
USGS-2BS	6/8/76	Shallow	Sampling	4326.34 - 4324.44
UW-1S	10/1/85	Shallow	Sampling	4333.32 - 4313.32
W5AA-2S	10/26/83	Shallow	Water Level	4333.65 - 4313.65
W5AA-3S	10/24/98	Shallow	Sampling	4342.86 - 4332.86
W5AB-2S	10/1/83	Shallow	Sampling	4337.68 - 4322.68
W5AD-1S	5/2/82	Shallow	Water Level	4330.91 - 4325.91
W5BB-S	10/23/83	Shallow	Sampling	4337.12 - 4307.12

Table 3-3. Well Construction Details for the Active Groundwater Monitoring Network

Well Name (1)	Completion Date	Groundwater Zone	Well Type	Well Screen Interval
				feet amsl
W5DB-S	10/9/10	Shallow	Sampling	4345.06 - 4325.06
WRP-1S	6/19/07	Shallow	Water Level	4382.53 - 4372.53
WRP-2S	6/19/07	Shallow	Water Level	4382.29 - 4372.29
YPT-MW-6S	1/11/02	Shallow	Sampling	4320.21 - 4315.21
YPT-MW-8S	1/9/02	Shallow	Sampling	4322.26 - 4317.26
YPT-MW-11S	1/11/02	Shallow	Sampling	4317.43 - 4312.43
Intermediate Zone Monitor Wells				
B/W-2I	10/17/07	Intermediate	Sampling	4279.78 - 4259.78
B/W-3I	9/27/07	Intermediate	Sampling	4266.40 - 4246.40
B/W-4I	1/21/08	Intermediate	Sampling	4276.50 - 4256.50
B/W-5RI	11/16/07	Intermediate	Sampling	4278.65 - 4258.65
B/W-6I	9/26/05	Intermediate	Sampling	4259.84 - 4249.84
B/W-7I	8/14/05	Intermediate	Sampling	4304.69 - 4284.69
B/W-8I	8/21/05	Intermediate	Sampling	4284.16 - 4264.16
B/W-9I	11/7/07	Intermediate	Sampling	4281.19 - 4261.19
B/W-19I	1/11/08	Intermediate	Sampling	4281.40 - 4261.40
B/W-27I	8/17/10	Intermediate	Sampling	4274.77 - 4254.77
B/W-28I	1/17/08	Intermediate	Sampling	4277.23 - 4257.23
B/W-29I	12/19/07	Intermediate	Sampling	4288.07 - 4278.07
B/W-30I	10/25/10	Intermediate	Sampling	4267.63 - 4247.63
B/W-31I	12/7/10	Intermediate	Sampling	4287.82 - 4246.82
B/W-32I	1/10/11	Intermediate	Sampling	4286.67 - 4266.67
B/W-33I	8/3/10	Intermediate	Sampling	4265.02 - 4255.02
B/W-34I	12/5/10	Intermediate	Sampling	4303.85 - 4283.85
B/W-37I	8/10/10	Intermediate	Sampling	4296.85 - 4276.85
B/W-38RI	10/9/10	Intermediate	Sampling	4287.91 - 4267.91
B/W-41I	2/7/11	Intermediate	Sampling	4278.31 - 4268.31
B/W-42I	11/8/10	Intermediate	Sampling	4266.21 - 4246.21
B/W-46I	11/7/10	Intermediate	Sampling	4276.66 - 4256.66
B/W-51I	9/9/10	Intermediate	Sampling	4264.06 - 4244.06
B/W-52I	8/20/10	Intermediate	Sampling	4296.06 - 4276.06
B/W-54I	8/21/10	Intermediate	Sampling	4277.24 - 4267.24
B/W-57I	3/14/12	Intermediate	Sampling	4270.47 - 4250.47
B/W-63I (3)	8/9/15	Intermediate	Sampling	4285.58 - 4265.58
B/W-65I	9/29/10	Intermediate	Sampling	4285.30 - 4265.30
B/W-66I	12/5/10	Intermediate	Sampling	4268.85 - 4248.85
B/W-67I	1/22/11	Intermediate	Sampling	4289.41 - 4269.41
B/W-70I	10/22/11	Intermediate	Sampling	4288.59 - 4268.59
B/W-71I	10/11/11	Intermediate	Sampling	4281.11 - 4261.11

Table 3-3. Well Construction Details for the Active Groundwater Monitoring Network

Well Name (1)	Completion Date	Groundwater Zone	Well Type	Well Screen Interval feet amsl
B/W-74I1	10/20/11	Intermediate	Sampling	4307.69 - 4297.69
B/W-74I2	10/21/11	Intermediate	Sampling	4277.50 - 4257.50
B/W-76I	12/13/11	Intermediate	Sampling	4276.82 - 4256.82
B/W-82RI (2)	11/2/13	Intermediate	Sampling	4280.35 - 4270.35
HLP-03I (4)	11/5/13	Intermediate	Sampling	4300.00 - 4280.00
HLP-08I (4)	10/20/13	Intermediate	Sampling	4296.56 - 4276.56
LEP-MW-4I	3/1/09	Intermediate	Sampling	4266.95 - 4256.95
LEP-MW-8I	3/4/09	Intermediate	Sampling	4271.83 - 4261.83
LEP-MW-9I	3/6/09	Intermediate	Sampling	4258.17 - 4248.17
MW-4I	8/30/10	Intermediate	Sampling	4285.18 - 4265.18
MW-5I	1/23/11	Intermediate	Sampling	4269.38 - 4249.38
PA-MW-2I	9/8/11	Intermediate	Sampling	4296.59 - 4276.59
PA-MW-3I	11/18/11	Intermediate	Sampling	4281.86 - 4271.86
PA-MW-4I	10/17/11	Intermediate	Sampling	4273.89 - 4253.89
W4CB-1I	10/27/83	Intermediate	Sampling	4280.31 - 4265.31
W4CB-2I	10/28/83	Intermediate	Sampling	4307.74 - 4295.74
W5AA-1I	10/26/83	Intermediate	Sampling	4293.56 - 4278.56
W5AB-3I	9/19/97	Intermediate	Sampling	4308.70 - 4284.20
W5DB-I	10/10/10	Intermediate	Sampling	4287.77 - 4267.77
YPT-MW-9I	1/8/02	Intermediate	Sampling	4282.60 - 4272.60
YPT-MW-12I	1/10/02	Intermediate	Sampling	4280.36 - 4270.36
YPT-MW-13I	7/20/04	Intermediate	Sampling	4287.78 - 4262.78
YPT-MW-15I	10/5/12	Intermediate	Sampling	4275.21 - 4270.21
Deep Zone Monitor Wells				
B/W-1D1	11/5/07	Deep	Sampling	4229.76 - 4209.76
B/W-1D2	10/22/07	Deep	Sampling	4139.92 - 4119.92
B/W-1D3	11/5/05	Deep	Sampling	4028.63 - 4018.63
B/W-1D5	1/7/11	Deep	Sampling	3877.18 - 3867.18
B/W-2D1	9/10/05	Deep	Sampling	4224.01 - 4204.01
B/W-2D3	1/23/11	Deep	Sampling	4049.28 - 4029.28
B/W-2D4	1/21/11	Deep	Sampling	3938.99 - 3918.99
B/W-3D1	8/31/05	Deep	Sampling	4221.87 - 4201.87
B/W-4D1	8/26/05	Deep	Sampling	4228.07 - 4208.07
B/W-5RD1	11/16/07	Deep	Sampling	4241.21 - 4221.21
B/W-9D2	9/14/05	Deep	Sampling	4206.72 - 4186.72
B/W-10D1	8/5/05	Deep	Sampling	4241.10 - 4221.10
B/W-11D2	9/28/05	Deep	Sampling	4197.64 - 4177.64
B/W-18D1	2/19/08	Deep	Sampling	4232.79 - 4212.79
B/W-18D2	12/15/07	Deep	Sampling	4194.17 - 4174.17

Table 3-3. Well Construction Details for the Active Groundwater Monitoring Network

Well Name (1)	Completion Date	Groundwater Zone	Well Type	Well Screen Interval
				feet amsl
B/W-19D1	6/14/07	Deep	Sampling	4216.51 - 4196.51
B/W-25D1	2/1/08	Deep	Sampling	4249.71 - 4229.71
B/W-25D2	1/19/08	Deep	Sampling	4133.82 - 4113.82
B/W-27D2	2/6/08	Deep	Sampling	4124.99 - 4104.99
B/W-27D3	1/6/11	Deep	Sampling	4022.95 - 4002.95
B/W-27D4(2)	2/21/14	Deep	Sampling	3944.83 - 3924.83
B/W-27D5(2)	2/11/14	Deep	Sampling	3879.66 - 3859.66
B/W-28D1	6/28/07	Deep	Sampling	4221.83 - 4201.83
B/W-29D1	12/16/07	Deep	Sampling	4225.24 - 4215.24
B/W-29D3	9/25/07	Deep	Sampling	4050.12 - 4030.12
B/W-30D1	10/26/10	Deep	Sampling	4228.86 - 4208.86
B/W-31D2	11/7/10	Deep	Sampling	4199.84 - 4179.84
B/W-32D2	1/9/11	Deep	Sampling	4147.42 - 4127.42
B/W-32D5	10/24/10	Deep	Sampling	3886.73 - 3866.73
B/W-33D1	7/29/10	Deep	Sampling	4239.39 - 4229.39
B/W-34D1	12/4/10	Deep	Sampling	4257.96 - 4237.96
B/W-37D1	6/5/10	Deep	Sampling	4218.80 - 4198.80
B/W-38RD1	10/10/10	Deep	Sampling	4210.93 - 4190.93
B/W-40D1	1/20/11	Deep	Sampling	4222.20 - 4202.20
B/W-40D3	11/3/10	Deep	Sampling	4057.58 - 4037.58
B/W-41D2	2/7/11	Deep	Sampling	4198.22 - 4178.22
B/W-41D4	2/5/11	Deep	Sampling	4004.14 - 3984.14
B/W-42D1	10/25/10	Deep	Sampling	4210.91 - 4190.91
B/W-44D1	9/23/10	Deep	Sampling	4229.65 - 4209.65
B/W-44D2	9/22/10	Deep	Sampling	4152.72 - 4132.72
B/W-45D1	1/18/11	Deep	Sampling	4252.78 - 4232.78
B/W-45D2	11/20/10	Deep	Sampling	4209.84 - 4189.84
B/W-46D1	11/6/10	Deep	Sampling	4219.76 - 4199.76
B/W-50D1(2)	2/10/14	Deep	Sampling	4206.81 - 4186.81
B/W-50D2(2)	2/8/14	Deep	Sampling	4125.75 - 4105.75
B/W-50D3(2)	2/5/14	Deep	Sampling	4024.73 - 4014.73
B/W-52D2	8/17/10	Deep	Sampling	4177.59 - 4157.59
B/W-55D1	10/20/10	Deep	Sampling	4251.44 - 4241.44
B/W-55D2	10/13/10	Deep	Sampling	4171.59 - 4151.59
B/W-57D1	3/14/12	Deep	Sampling	4212.37 - 4192.37
B/W-57D4	3/13/12	Deep	Sampling	3940.67 - 3920.67
B/W-58D1	3/16/12	Deep	Sampling	4234.41 - 4214.41
B/W-58D3	3/25/12	Deep	Sampling	4054.51 - 4044.51
B/W-59D3(2)	11/19/13	Deep	Sampling	4126.65 - 4106.65

Table 3-3. Well Construction Details for the Active Groundwater Monitoring Network

Well Name (1)	Completion Date	Groundwater Zone	Well Type	Well Screen Interval
				feet amsl
B/W-60D1	12/17/10	Deep	Sampling	4247.69 - 4227.69
B/W-60D3	12/16/10	Deep	Sampling	4036.75 - 4016.75
B/W-60D5	12/7/10	Deep	Sampling	3881.82 - 3861.82
B/W-61D1	8/23/10	Deep	Sampling	4247.00 - 4227.00
B/W-61D3	8/29/10	Deep	Sampling	4036.94 - 4016.94
B/W-62D1	11/21/10	Deep	Sampling	4243.89 - 4223.89
B/W-62D2	11/20/10	Deep	Sampling	4173.88 - 4153.88
B/W-62D4	11/19/10	Deep	Sampling	3953.94 - 3933.94
B/W-62D5	1/6/11	Deep	Sampling	3833.92 - 3813.92
B/W-63D1(3)	8/8/15	Deep	Sampling	4240.50 - 4220.50
B/W-63D2(3)	8/7/15	Deep	Sampling	4170.83 - 4150.83
B/W-63D3(3)	8/5/15	Deep	Sampling	4015.78 - 3995.78
B/W-63D5(3)	7/29/15	Deep	Sampling	3900.65 - 3880.65
B/W-64D1	12/5/10	Deep	Sampling	4260.09 - 4240.09
B/W-64D2	12/3/10	Deep	Sampling	4175.77 - 4155.77
B/W-65D1	9/27/10	Deep	Sampling	4213.36 - 4193.36
B/W-65D5	9/23/10	Deep	Sampling	3750.51 - 3740.51
B/W-66D1	12/4/10	Deep	Sampling	4208.81 - 4188.81
B/W-66D5	12/2/10	Deep	Sampling	3761.03 - 3751.03
B/W-67D1	1/21/11	Deep	Sampling	4245.24 - 4225.24
B/W-67D3	1/13/11	Deep	Sampling	4125.04 - 4105.04
B/W-68D1(2)	4/29/14	Deep	Sampling	4240.74 - 4220.74
B/W-68D4(2)	4/28/14	Deep	Sampling	3964.32 - 3954.32
B/W-69D1(2)	4/14/14	Deep	Sampling	4259.33 - 4239.33
B/W-69D2(2)	4/13/14	Deep	Sampling	4194.30 - 4174.30
B/W-69D5(2)	4/9/14	Deep	Sampling	3782.33 - 3772.33
B/W-70D2	10/25/11	Deep	Sampling	4143.64 - 4123.64
B/W-71D1	10/5/11	Deep	Sampling	4222.09 - 4202.09
B/W-71D3	10/3/11	Deep	Sampling	4094.16 - 4074.16
B/W-74D1	11/20/11	Deep	Sampling	4247.72 - 4227.72
B/W-76D1	10/4/11	Deep	Sampling	4251.74 - 4231.74
B/W-81D1(2)	3/9/14	Deep	Sampling	4243.06 - 4223.06
B/W-81D2(2)	3/10/14	Deep	Sampling	4153.13 - 4133.13
B/W-83D1(2)	2/4/14	Deep	Sampling	4216.67 - 4196.67
B/W-83D3(2)	1/29/14	Deep	Sampling	4066.59 - 4046.59
HLP-08D1(4)	10/19/13	Deep	Sampling	4249.87 - 4229.87
HLP-08D2(4)	10/15/13	Deep	Sampling	4174.99 - 4154.99
LEP-MW-2D1	10/25/10	Deep	Sampling	4229.98 - 4209.98
LEP-MW-2D3	10/22/10	Deep	Sampling	4100.11 - 4080.11

Table 3-3. Well Construction Details for the Active Groundwater Monitoring Network

Well Name (1)	Completion Date	Groundwater Zone	Well Type	Well Screen Interval
				feet amsl
MW-5D2	1/12/11	Deep	Sampling	4194.22 - 4174.22
MW-5D3	1/18/11	Deep	Sampling	4119.72 - 4099.72
MW2002-2D1	7/12/07	Deep	Sampling	4249.75 - 4239.75
PA-MW-4D2	10/15/11	Deep	Sampling	4192.92 - 4172.92
W32DC-D1	10/25/83	Deep	Sampling	4240.41 - 4197.41
W4CB-2D1	9/15/10	Deep	Sampling	4240.56 - 4220.56
W4CB-2D3	9/14/10	Deep	Sampling	4065.76 - 4045.76
W4CB-2D4	11/8/10	Deep	Sampling	3965.54 - 3955.54
W5DB-D1	10/19/98	Deep	Sampling	4239.49 - 4211.49
W5DB-D3	11/17/10	Deep	Sampling	4091.93 - 4071.93
W5DB-D4	10/25/10	Deep	Sampling	4009.93 - 3989.93
YPT-MW-14D1	7/21/04	Deep	Sampling	4255.83 - 4235.83
Bedrock Monitor Wells				
B/W-1B	5/19/10	Bedrock	Sampling	3700.10 - 3690.10
B/W-2B	1/12/11	Bedrock	Sampling	3839.17 - 3819.17
B/W-6B	1/25/11	Bedrock	Sampling	4172.04 - 4152.04
B/W-11B	11/3/07	Bedrock	Sampling	4132.88 - 4122.88
B/W-12RB	12/6/11	Bedrock	Sampling	4382.05 - 4302.05
B/W-17B	10/30/11	Bedrock	Sampling	4385.06 - 4365.06
B/W-22B	5/8/10	Bedrock	Sampling	4261.26 - 4241.26
B/W-23B	8/8/07	Bedrock	Sampling	4340.26 - 4330.26
B/W-26RB	11/3/11	Bedrock	Sampling	4367.92 - 4347.92
B/W-27B (2)	11/12/13	Bedrock	Sampling	3800.16 - 3780.16
B/W-33B	7/26/10	Bedrock	Sampling	4167.48 - 4157.48
B/W-34B	12/1/10	Bedrock	Sampling	4203.76 - 4183.76
B/W-36B	6/17/10	Bedrock	Sampling	4271.60 - 4261.60
B/W-37B	5/27/10	Bedrock	Sampling	4166.84 - 4146.84
B/W-38RB	10/8/10	Bedrock	Sampling	4166.90 - 4146.90
B/W-39B	10/7/10	Bedrock	Sampling	4309.10 - 4299.10
B/W-44B	9/16/10	Bedrock	Sampling	4124.48 - 4104.48
B/W-51B	6/25/10	Bedrock	Sampling	4198.79 - 4188.79
B/W-53B	12/17/10	Bedrock	Sampling	4240.77 - 4220.77
B/W-54B	7/10/10	Bedrock	Sampling	4261.30 - 4251.30
B/W-58B	2/4/12	Bedrock	Sampling	4014.50 - 3994.50
B/W-61B	7/9/10	Bedrock	Sampling	3684.05 - 3664.05
B/W-62B	9/25/10	Bedrock	Sampling	3690.87 - 3670.87
B/W-64B	12/2/10	Bedrock	Sampling	4089.75 - 4069.75
B/W-70B	8/30/11	Bedrock	Sampling	4060.86 - 4040.86
B/W-71B	9/1/11	Bedrock	Sampling	3931.06 - 3911.06

Table 3-3. Well Construction Details for the Active Groundwater Monitoring Network

Well Name (1)	Completion Date	Groundwater Zone	Well Type	Well Screen Interval
				feet amsl
B/W-73B	9/7/11	Bedrock	Sampling	4307.60 - 4287.60
B/W-74B	9/21/11	Bedrock	Sampling	4207.18 - 4187.18
B/W-75B	1/7/12	Bedrock	Sampling	4266.82 - 4246.82
B/W-82RB (2)	11/1/13	Bedrock	Sampling	4235.38 - 4215.38
B/W-83B (2)	1/24/14	Bedrock	Sampling	3943.51 - 3913.51
HLP-01B (4)	9/20/13	Bedrock	Sampling	4333.97 - 4313.97
HLP-02B (4)	9/22/13	Bedrock	Sampling	4406.47 - 4386.27
HLP-03B (4)	10/18/13	Bedrock	Sampling	4236.98 - 4206.98
HLP-05B (4)	10/5/13	Bedrock	Sampling	4346.26 - 4306.26
HLP-06B (4)	10/1/13	Bedrock	Sampling	4338.55 - 4318.55
HLP-07B (4)	9/24/13	Bedrock	Sampling	4345.04 - 4325.04
HLP-08B (4)	10/8/14	Bedrock	Sampling	4117.44 - 4097.44
LEP-MW-2B	10/13/10	Bedrock	Sampling	4040.47 - 4020.47
MMW-2	12/6/92	Bedrock	Sampling	4246.34 - 4186.34
MW-4B	8/28/10	Bedrock	Sampling	4251.41 - 4231.41
MW-5B	1/7/11	Bedrock	Sampling	3984.29 - 3964.29
MW-H12	8/6/09	Bedrock	Sampling	4353.58 - 4323.58
MW-H4SN	8/11/09	Bedrock	Sampling	4371.56 - 4341.56
MW-H4SS	8/13/09	Bedrock	Sampling	4360.63 - 4330.63
PA-MW-1B	8/6/11	Bedrock	Sampling	4290.87 - 4270.87
PA-MW-2B	9/3/11	Bedrock	Sampling	4210.44 - 4190.44
PA-MW-3B	10/11/11	Bedrock	Sampling	4246.82 - 4226.82
PA-MW-4B	9/14/11	Bedrock	Sampling	4157.96 - 4137.96
PA-MW-5B	8/20/11	Bedrock	Sampling	4281.60 - 4261.60
PA-MW-7B	9/30/11	Bedrock	Sampling	4174.49 - 4154.49
PLMW-1B	9/29/11	Bedrock	Sampling	4218.23 - 4168.23
PLMW-2B	8/2/11	Bedrock	Sampling	4313.20 - 4293.20
PLMW-3RB	11/12/11	Bedrock	Sampling	4237.72 - 4197.72
PLMW-4B	10/20/11	Bedrock	Sampling	4094.72 - 4064.72
PLMW-5B	9/18/11	Bedrock	Sampling	4243.58 - 4203.58
W4CB-2B	7/9/10	Bedrock	Sampling	3844.55 - 3824.55
W5DB-B	9/26/10	Bedrock	Sampling	3781.04 - 3761.04
WRA3-1B	10/1/11	Bedrock	Sampling	4369.32 - 4339.32
WRA3-2B	10/19/11	Bedrock	Sampling	4322.60 - 4302.60
WRA3-3B	12/5/11	Bedrock	Sampling	4330.39 - 4310.39
WW-1B	NR	Bedrock	Sampling	4364.42 - 4344.42
WW-2B	NR	Bedrock	Sampling	4342.48 - 4322.48
WW-36B	4/15/69	Bedrock	Sampling	4305.78 - 4105.78
WW-40B	NR	Bedrock	Sampling	NR - NR

Table 3-3. Well Construction Details for the Active Groundwater Monitoring Network

Well Name (1)	Completion Date	Groundwater Zone	Well Type	Well Screen Interval
				feet amsl
WW-59B	11/20/72	Bedrock	Sampling	4280.04 - 3888.04
YPT-MW-10B	1/7/02	Bedrock	Sampling	4107.46 - 4097.46

Notes:

1) The names of 117 wells for which the sampling frequency has been reduced from quarterly to semi-annually are bold and italicized. Well names for older wells reflect revisions based on their alluvial aquifer zone designations.
2) New well added to the monitor well network and first sampled in 3Q 2014.
3) New well added to the monitor well network and first sampled in 4Q 2015.
4) New well added to the monitor well network and first sampled in 4Q 2014.
5) Lyon County well.
6) The bottom of screen elevations for the Lyon County wells are based on a 2009 survey conducted for ARC and the total depth of each well measured in the field by BC. The measured well depths are not consistent with the information on the well logs provided by Lyon County (see Appendix C-1 for the well logs).
7) NR = not recorded on well construction logs. amsl = above mean sea level

Water Level Monitoring

Routine water level monitoring was initiated in 2006, to evaluate seasonal and temporal changes in groundwater flow directions and hydraulic gradients, and aquifer responses to irrigation practices. Water level elevation monitoring was historically conducted monthly, and subsequently reduced to quarterly in 2014 for wells installed before 2013, in accordance with the *Technical Memorandum: Site-Wide Groundwater Monitoring Optimization* (ARC 2014).

As outlined in the GMP (BC 2012a), water levels are measured within a three-day (or shorter) period, for representative aquifer conditions throughout the monitoring network. Water level elevations are also measured electronically using pressure transducers/data loggers, at four-hour intervals at select monitor wells, and at one-hour intervals at the Pit Lake. Water level data from transducers are typically downloaded in conjunction with monthly water level measurements. Appendix D provides groundwater level data, hydrographs, and vertical gradient information.

Groundwater Quality Monitoring

Monitor wells comprising the active monitoring network are sampled on a quarterly or semi-annual frequency pursuant to the GMP (BC 2012a) using EPA-approved low-flow, minimal drawdown purging and sampling procedures, where applicable. Groundwater samples are analyzed for the constituents listed in Table 3-4 pursuant to the data requirements presented in the QAPP (ESI and BC 2009).

Table 3-4. Analyte List for Active Monitor Well and Surface Water Sampling

Parameter or Analyte	Total/ Dissolved (1)	Method (2)	Reporting Limit (2)	Units
Physical Parameters and Major Anions/Cations				
Alkalinity, Bicarbonate (as $CaCO_3$)	Total	SM 2320B	2.0	mg/L
Alkalinity, Carbonate (as $CaCO_3$)	Total	SM 2320B	2.0	mg/L
Alkalinity, Total (as $CaCO_3$)	Total	SM 2320B	2.0	mg/L
Chloride	Total	EPA 300.0	0.5	mg/L
Fluoride	Total	EPA 300.0	0.5	mg/L
Nitrate, as N	Total	EPA 300.0	0.1	mg/L
Nitrate (NO_3 + NO_2 as N)	Total	EPA 300.0	0.1	mg/L
Nitrite, as N	Total	EPA 300.0	0.1	mg/L
Sulfate	Total	EPA 300.0	0.5	mg/L
pH (Lab)	Total	SM 4500B	0.1	sun.
Total Dissolved Solids (TDS) (3)	Total (Lab Filtered) (3)	SM 2540C	10	mg/L
Total Organic Carbon (TOC)	Total	SM 5310B	1.0	mg/L
Metals				
Aluminum	Total + Dissolved	EPA 200.7	0.05	mg/L
Antimony	Total + Dissolved	EPA 200.8	2.0	µg/L
Arsenic	Total + Dissolved	EPA 200.8	1.0	µg/L
Barium	Total + Dissolved	EPA 200.8	1.0	µg/L
Beryllium	Total + Dissolved	EPA 200.8	0.5	µg/L
Boron	Total + Dissolved	EPA 200.7	50	µg/L
Cadmium	Total + Dissolved	EPA 200.8	1.0	µg/L
Calcium	Total + Dissolved	EPA 200.7	0.1	mg/L
Chromium	Total + Dissolved	EPA 200.8	2.0	µg/L
Cobalt	Total + Dissolved	EPA 200.8	1.0	µg/L
Copper	Total + Dissolved	EPA 200.8	1.0	µg/L
Iron	Total + Dissolved	EPA 200.7	0.04	mg/L
Lead	Total + Dissolved	EPA 200.8	1.0	µg/L
Lithium	Total + Dissolved	EPA 200.7	50	µg/L
Magnesium	Total + Dissolved	EPA 200.7	0.02	mg/L
Manganese	Total + Dissolved	EPA 200.8	1.0	µg/L
Mercury	Total + Dissolved	EPA 245.1	0.2	µg/L
Molybdenum	Total + Dissolved	EPA 200.8	2.0	µg/L
Nickel	Total + Dissolved	EPA 200.8	2.0	µg/L
Phosphorus	Total + Dissolved	EPA 200.7	0.04	mg/L
Potassium	Total + Dissolved	EPA 200.7	0.5	mg/L
Selenium	Total + Dissolved	EPA 200.8	0.6	µg/L
Silica	Total + Dissolved	EPA 200.7	0.05	mg/L
Silver	Total + Dissolved	EPA 200.8	1.0	µg/L
Sodium	Total + Dissolved	EPA 200.7	0.5	mg/L
Strontium	Total + Dissolved	EPA 200.7	0.02	mg/L
Thallium	Total + Dissolved	EPA 200.8	1.0	µg/L
Tin	Total + Dissolved	EPA 200.7	100	µg/L

Table 3-4. Analyte List for Active Monitor Well and Surface Water Sampling

Parameter or Analyte	Total/ Dissolved (1)	Method (2)	Reporting Limit (2)	Units
Titanium	Total + Dissolved	EPA 200.7	0.005	mg/L
Uranium, Total	Total + Dissolved	EPA 200.8	1.0	µg/L
Vanadium	Total + Dissolved	EPA 200.8	2.0	µg/L
Zinc	Total + Dissolved	EPA 200.8	10	µg/L
Radiochemicals				
Gross Alpha	Dissolved	EPA 900.0	1.0	pCi/L
Gross Beta	Dissolved	EPA 900.0	1.0	pCi/L
Radium-226	Dissolved	EPA 903.0	1.0	pCi/L
Radium-228	Dissolved	EPA 904.0	1.0	pCi/L
Thorium-228	Dissolved	HASL 300	1.0	pCi/L
Thorium-230	Dissolved	HASL 300	1.0	pCi/L

Notes:

1) Dissolved constituents are field-filtered with a new disposable 0.45-micron (µm) filter. Dissolved (filtered) metals collected quarterly. Total (unfiltered) metals collected in two non-consecutive quarters once a well is installed and/or initially included in the GMP (BC 2012a).
2) Except for lithium and selenium, EPA laboratory analytical methods and reporting limits are consistent with those provided in Revision 5 of the QAPP (ESI and BC 2009); alternative analytical methods identified in the QAPP may also be used. For lithium, the lab was unable to get reproducible results using EPA Method 200.8 (as indicated in QAPP); therefore, the lab has used EPA Method 200.7 for lithium, which has a higher reporting limit than indicated in the QAPP. For selenium, the reporting limit of 0.6 µg/L is lower than that indicated in the QAPP (2 µg/L).
3) The samples for TDS are filtered in the analytical laboratory with a new disposable 0.45 µm filter.
4) s.u. = pH standard units; mg/L = milligrams per liter; µg/L = micrograms per liter; pCi/L = picocuries per liter.

Appendix D provides groundwater quality data associated with the Site-Wide groundwater monitoring program and charts illustrating temporal changes in chemical concentrations.

Dissolved versus Total Metals

Beginning with the 3Q 2010 sampling event, samples from monitor wells at the Site have been periodically collected in two different quarters from each well and analyzed for both dissolved (0.45 µm-filtered) and total (unfiltered) metals to determine whether the two sampling methods produce comparable results. The results of the comparative statistical analysis of the available dissolved and total metals datasets have been periodically reported in previous quarterly and annual groundwater monitoring reports (GMRs). The most recent and final sampling for dissolved and total metals occurred during the 3Q 2014 and 1Q 2015 events for 29 off-Site wells that were installed in 2013/2014 and first sampled in 3Q 2014. The statistical comparison of the complete dissolved and total metals datasets is presented in the 2015 Annual GMR (BC 2016c).

Based on the statistical analyses, differences between dissolved and total metals concentrations in groundwater samples collected from monitor wells are non-existent or are too small to be meaningful. It is concluded that groundwater sampling both with and without filtering of samples produce equivalent datasets.

3.2.4 Soil Sampling and Testing

Pursuant to the *Agricultural Fields Characterization Work Plan - Revision 2* (BC 2010d), soil samples were collected from select borehole cores in the Shallow, Intermediate and Deep zones. The types of samples collected, and a brief description of the sampling objectives, are provided below.

- Soil samples were collected for analysis of grain size distribution to generate laboratory-determined Unified Soil Classification System (USCS) soil descriptions for comparison to USCS descriptions made in the field at the time of drilling.
- Non-redox preserved soil samples were collected for bulk chemical analyses to characterize chemical concentrations in soils.
- Redox-preserved soil samples were collected using EPA-specified procedures that preserve the subsurface oxidation state of the sediments, and archived at the Site for potential testing pursuant to the *Aquifer Solids Testing Work Plan - Revision 1* (BC 2010e).

Soil sampling information is provided in Appendix E and discussed briefly below.

<u>Grain Size Analysis</u>

A total of 37 samples of aquifer materials were obtained from 16 borehole locations for grain size distribution analyses by sieving of material larger than 75 µm (i.e., retained on a No. 200 sieve). Laboratory reports with the grain size distribution data are provided in Appendix E-1. Grain size distribution results were used to generate laboratory-derived USCS lithologic classifications for comparison to the field-derived USCS lithologic classifications based on visual inspection of core during drilling. As shown in Table 3-5, field USCS classifications were generally consistent with laboratory USCS classifications, especially with respect to finer-grained materials.

Table 3-5. Sample Locations for Grain Size Analysis

Borehole Name	Sample Interval (feet bgs)	USCS Classification (Field)	Percent Fines (Field)	USCS Classification (Laboratory)	Percent Fines (Laboratory)
B/W-2	378-384	SW	5	SM	12.7
B/W-2	442-454	SC	35	SC	26.4
B/W-32	21-27	SM	15	SM	18.7
B/W-32	411-414	SW-SM	10	SM	13.5
B/W-36	57-71	SM	30	SM	13.5
B/W-37	111-117	CL	80	CL	82.0
B/W-38R	140-143	GW	5	SW-SM	7.8
B/W-38R	208-212	SC	35	SC	25.7
B/W-38R	249-253	SM	30	SM	18.6
B/W-40	220.5-226	SM	15	SM	19.2
B/W-40	451-456	SP	5	SM	20.9
B/W-42	159-165	SM	15	SP-SM	5.9
B/W-51	64-69	SC	35	SC	15.0
B/W-54	46-52	CL	65	CL	63.1
B/W-54	52-61	SW	10	SW-SM	8.3
B/W-55	42-51	CH	95	CL	74.4
B/W-55	118-125	SM	20	CL	51.2
B/W-55	135-145	SW	5	SP	4.9
B/W-55	175-185	SP	5	SW	2.9
B/W-60	32-36	SM	35	SM	23.3
B/W-60	132.5-136	ML	60	CL	70.1
B/W-60	450-456	SM	25	SM	22.6
B/W-61	299-306	SP	10	SP-SM	7.7
B/W-64	27-31	SP	10	SP-SM	12.0
B/W-64	43-47	CL	75	CL	93.0
B/W-64	67-77	SW	10	SP-SM	12.0
B/W-64	177-185	SW	10	SW	5.0
B/W-66	59-64	CH	70	CL	66.1
B/W-66	65.5-68	SC	40	SC	23.0
B/W-66	89-93	SC	20	SC	48.7
B/W-67	27-32	SP	5	SM	28.5
B/W-67	38-55	CL	60	CL	64.0
B/W-67	142-146	SC	40	SC	31.8
LEP-MW-2	61-66	CL	50	SC	22.1
LEP-MW-2	212-217	CH	95	SC	34.4
LEP-MW-2	266-273	SW-SM	10	SM	12.8
LEP-MW-2	341-346	CL	50	SC	36.2

Notes: SW = Well Graded Sand or Well Graded Sand with Gravel (where gravel is more than 15%).
SP = Poorly Graded Sand or Poorly Graded Sand with Gravel (where gravel is more than 15%).
SW-SM = Well Graded Sand with Silt or Well Graded Sand with Silt and Gravel (where gravel is more than 15%).
SP-SM = Poorly Graded Sand with Silt or Poorly Graded Sand with Silt and Gravel (where gravel is more than 15%).
SC = Clayey Sand or Clayey Sand with Gravel (where gravel is more than 15%).
SM = Silty Sand or Silty Sand with Gravel (where gravel is more than 15%).
CL = Lean Clay, Lean Clay with Sand, Sandy Lean Clay or Sandy Lean Clay with Gravel (where gravel is more than 15%).
CH = Fat Clay, Fat Clay with Sand, Sandy Fat Clay or Sandy Fat Clay with Gravel (where gravel is more than 15%).
GW = Well Graded Gravel with Sand.

Solids Sampling for Bulk Chemistry

Samples of archived core were collected from select depths in boreholes B/W-1, B/W-31, B/W-32, B/W-42, B/W-46, B/W-61, B/W-62, B/W-65, B/W-66, B/W-67, and MW-5 and submitted to the laboratory for bulk chemical analysis of the parameters listed in Table 3-6. Sample collection methods conformed to SOP-11 of the QAPP. Concentrations of metal/metalloids (hereinafter referred to as metals) and radiochemicals in the solid soil samples were determined by microwave-assisted digestion using EPA Method 3051A (HNO_3). The locations, sample depths and laboratory results are summarized in Appendix E-2.

Table 3-6. Analyte List for Soil Samples

Parameter or Analyte	Method (1)	Reporting Limit (1)	Units (2)
Soil pH	EPA 9045C	0.1	s.u.
Total and Acid Soluble Sulfur	Method 9030B	0.4	mg/kg
Chloride	EPA 300.0	5	mg/kg
Nitrate (as N)	EPA 300.0	1.1	mg/kg
Sulfate	EPA 300.0 (4)	5.0	mg/kg
TOC, TC, TIC (3)	EPA LG601 (2)	1.0	mg/kg
Aluminum	EPA 6010B	10	mg/kg
Antimony	EPA 6020	1.0	mg/kg
Arsenic	EPA 6020	0.5	mg/kg
Barium	EPA 6020	0.5	mg/kg
Beryllium	EPA 6020	0.3	mg/kg
Boron	EPA 6010B	5.0	mg/kg
Cadmium	EPA 6020	0.5	mg/kg
Calcium	EPA 6010B	15	mg/kg
Chromium	EPA 6020	1.0	mg/kg
Cobalt	EPA 6020	0.5	mg/kg
Copper	EPA 6020	1.0	mg/kg
Iron	EPA 6010B	5.0	mg/kg
Lead	EPA 6020	0.5	mg/kg
Magnesium	EPA 6010B	10	mg/kg
Manganese	EPA 6020	0.5	mg/kg
Molybdenum	EPA 6020	1.0	mg/kg
Nickel	EPA 6020	1.0	mg/kg
Potassium	EPA 6010B	50	mg/kg
Selenium	EPA 6020	1.0	mg/kg
Sodium	EPA 6010B	50	mg/kg
Uranium, Total	EPA 6020	0.10	mg/kg
Vanadium	EPA 6020	1.0	mg/kg
Zinc	EPA 6020	10	mg/kg
Uranium-234, 235, 238	HASL 300 (U-02-RC)	1.0	pCi/g

Notes:

1) EPA laboratory analytical methods and reporting limits are consistent with those provided in QAPP (ESI and BC 2009); alternative analytical methods identified in the QAPP may also be used.
2) s.u. = standard units; mg/kg = milligrams per kilogram; pCi/g = picocuries per gram.
3) Total Organic Carbon (TOC), Total Carbon (TC), and Total Inorganic Carbon (TIC).
4) EPA Method LG601 (Dry Combustion, Infrared Detection) as described in EPA 2005.

Vertical profiling of chemical concentrations in soils beneath the agricultural fields was performed to help understand potential chemical loading to groundwater unrelated to mining. Other evaluations involving characterization of groundwater quality upgradient and downgradient of agricultural fields and the sulfur isotope signatures associated with gypsum, an agricultural fertilizer/soil amendment, proved more useful for evaluating groundwater impacts associated with agricultural activities (see Section 5.5).

Redox-Preserved Soil Sampling and Archiving

During the 2007 Second-Step HFA (BC 2008c) and 2010 field investigation (BC 2013a), soil samples were opportunistically collected using EPA-specified procedures that preserved the subsurface oxidation state of the sediments. Redox-preserved soil samples were collected at select borehole locations near the Evaporation Ponds (B/W-11, B/W-18, LEP-MW-9I, MW-5, and W4CB-2), the agricultural fields adjacent to the Site (B/W-61, B/W-65, and B/W-66), and at B/W-32 (i.e., at OU1-DPT-28, which was identified during the Shallow zone investigation in 2009).

The redox-preserved soil samples were archived at the Site for potential laboratory testing (BC 2010e) to evaluate geochemical processes that affect the release and/or attenuation of chemicals from/onto aquifer solids (in particular, chemical partitioning to various mineral fractions), and the mobility and transport of chemicals in groundwater at the Site. The disposition of archived, redox-preserved soil samples is described in Section 3.3.5, which addresses chemical transport evaluations.

3.2.5 Aquifer Hydraulic Properties Testing

The 2007 SOW (EPA 2007a) required "*Definition of aquifer properties (e.g., hydraulic conductivity, transmissivity, and storativity) by a program of aquifer testing to measure the hydraulic connection between areas and throughout the known extent of contamination*." In addition, characterization of aquifer hydraulic properties was identified as DQO #5 in the Revised Groundwater RI Work Plan (BC 2014a).

Hydraulic properties of the alluvial aquifer, as well as bedrock, are provided in Appendix F and have been estimated based on a variety of small- to large-scale test methods including:

- Slug testing of groundwater monitor wells;
- Analysis of steady-state drawdown data obtained during routine quarterly low-flow sampling of monitor wells;
- Constant-rate pumping tests of the eleven wells comprising the PWS during 2010;
- Slug testing of piezometers installed near the PWS that were used as observation wells during constant-rate pumping tests of the 11 wells comprising the PWS during 2010; and
- A constant-rate pumping test of agricultural well WDW019 using an observation network of 93 monitor wells, of which 61 exhibited pumping-related responses.

Small-scale test methods, such as slug testing, provide data that are useful for identifying spatial patterns related to geology, guiding characterization, and as a preliminary estimate of hydraulic conductivity. Because slug test data are available throughout the Study Area, this dataset is used to evaluate spatial patterns in hydraulic conductivity within the Study Area. Data from the pumping test at WDW019, the other large-scale pumping tests, and subsequent groundwater model development using a parameter estimation technique (Doherty 2009), have been used to develop representative field-scale estimates of hydraulic conductivity and, therefore, groundwater velocity.

3.2.6 Surface Water Characterization

The hydrology of the study area is dominated by groundwater recharge from surface water associated with agricultural irrigation (Carroll et al. 2010; Huxel and Harris 1969; Myers 2001). Therefore, understanding the flows in the Walker River and diversions for nearby agricultural activities is important for understanding and contextualizing the data collected in the Study Area. Both regional and local (i.e. Study Area) characterization activities were conducted.

To characterize regional surface water hydrology, daily stream flows for the Walker River are obtained at several gaging locations throughout the Mason Valley, both upstream and downstream of the Site. The data collected from the gaging stations are maintained by the USGS, often in cooperation with state and local agencies, and are available at the USGS website (http://waterdata.usgs.gov/nv/nwis/sw). Surface water quality in the Walker River is also routinely

monitored by various federal, state, and miscellaneous agencies/entities. Much of this data is assembled and made publicly-available through the EPA's STOrage and RETrieval (STORET) Data Warehouse. This dataset supplements the data collected by ARC.

To evaluate the quality of surface water used to irrigate the Hunewill Ranch agricultural fields next to the Site, samples were collected and analyzed from the West Campbell Ditch (SW-WCD-01) and the Walker River (SW-WR-01), pursuant to the *Agricultural Fields Characterization Work Plan - Revision 2* (BC 2010d). Sampling locations are shown on Figure 3-6. West Campbell Ditch receives its water directly from the Walker River. The Walker River monitoring point (SW-WR-01) is located less than 1,000 feet upstream of the diversion point for West Campbell Ditch. The monitoring location in West Campbell Ditch (SW-WCD-01) is located about three miles farther downstream from the diversion point. Potential temporal trends in surface water quality during non-irrigation and irrigation periods were addressed by collecting samples monthly at these locations for 12 months during 2010/2011.

Field parameters (temperature, pH, specific conductivity, DO, sulfate and turbidity) were measured at the time of sample collection, and samples were submitted for the analysis (total concentrations) of the parameters listed in Table 3-4. Surface water samples were collected using the direct-grab method described in SOP-18 in the QAPP. This surface water sample collection method is consistent with the method used by NDEP to collect samples at other surface water monitoring stations in the Mason Valley. Laboratory analyses were conducted in accordance with the QAPP. Surface water data are presented in Appendix G and summarized in Section 4.7.

3.2.7 Hydrologic Tracer Studies

Hydrologic tracer investigations were initiated to help characterize Study Area groundwater conditions, refine the HCSM, and identify background groundwater quality types (BC 2008c, 2012b, 2014a). A variety of hydrologic tracers were initially identified as having the potential to provide information on the origin, age, sources of dissolved constituents, and migration pathways of groundwater and surface water in the Study Area.

To evaluate the feasibility of using hydrologic tracers to support these objectives, samples were collected prior to 2010 from a select number of groundwater monitor wells and surface water features. Based on the apparent efficacy of using hydrologic tracers to assess Study Area groundwater conditions, additional EPA-approved hydrologic tracer sampling events were conducted. Over time, the hydrologic tracer sampling events evolved with changes primarily related to increases in the number of groundwater monitor wells that were sampled, opportunistic collection of standing rainwater samples, and elimination of select tracers considered less useful for characterizing groundwater conditions.

Table 3-7 provides a chronology of the various OU-1 hydrologic tracer sampling events.

Table 3-7. Chronology of Hydrologic Tracer Sampling Events

Date	Sampling Locations (1)	Hydrologic Tracers (2)	Information Source(s)
July/August 2008	Hydrologic tracer samples were collected from 47 of the 94 (50%) active groundwater monitor wells at the time that routine groundwater monitoring was conducted.	Uranium isotopes, sulfate isotopes, tritium, tritium/ helium, $\delta^{18}O/\delta^{2}H$ in water, and nitrate isotopes.	*Second-Step Hydrogeologic Framework Assessment Data Summary Report* (BC 2008c).
February 2011	Samples were collected from the Walker River and West Campbell Ditch, and from 127 of the 223 (57%) active groundwater monitor wells at the time of sampling.	Uranium isotopes, sulfate isotopes, tritium, tritium/ helium, $\delta^{18}O/\delta^{2}H$ in water, nitrate isotopes, CFCs, $\delta^{13}B$, and $\delta^{36}Cl$.	*Draft Site-Wide Groundwater Operable Unit (OU-1) Remedial Investigation Work Plan* (BC 2012b). Revised Groundwater RI Work Plan (BC 2014a).
May 2012	Samples were collected from: 1) three surface water locations (Pit Lake, Walker River and West Campbell Ditch); and 2) 279 of the 287 (97%) active groundwater monitor wells at the time of sampling.	Uranium isotopes, sulfate isotopes, tritium, tritium/ helium, CFCs, and SF_6.	Conclusions about the usefulness of specific hydrologic tracers collected in 2011 were noted in correspondence between ARC and EPA (2012a). With EPA approval (2012b), samples collected during May 2012 were not analyzed for stable isotopes in water or nitrate isotopes. May 2012 results were provided in the *Background Groundwater Quality Assessment - Revision 2* (BC 2015c).
July 2013	Collection of 14 standing rain water samples following a large precipitation event.	Uranium isotopes and sulfate isotopes.	July 2013 results provided in the *Background Groundwater Quality Assessment - Revision 2* (BC 2015c).
August 2014	Groundwater samples were collected from all (100%) of the new wells installed pursuant to the Additional Monitor Well Work Plan (BC 2013b) except well HLP-02B because it was dry. Also sampled were the four wells at the B/W-65 cluster, which were inaccessible in May 2012, and monitor well YPT-MW-15I, which was installed in October 2012. Five wells were resampled to evaluate the results reported in May 2012.	Uranium isotopes, sulfate isotopes, tritium, and tritium /helium.	August 2014 results provided in the *Background Groundwater Quality Assessment - Revision 2* (BC 2015c).

Notes:

1) Hydrologic tracer samples from monitor wells were collected in conjunction with routine groundwater monitoring events associated with the GMP (BC 2012a).
2) Uranium isotopes include ^{234}U, ^{235}U, and ^{238}U; Sulfate isotopes = $\delta^{34}S/\delta^{18}O$ in dissolved sulfate; Nitrate isotopes = $\delta^{15}N/\delta^{18}O$ in dissolved nitrate; $\delta^{13}B$ = boron isotopes in the water samples; $\delta^{36}Cl$ = chloride isotopes in the water samples; CFCs = chlorofluorocarbons; SF_6 = Sulfur Hexafluoride.

Hydrologic tracer samples were collected from monitor wells in conjunction with routine Site-Wide groundwater sampling events using low-flow, minimal drawdown sample collection procedures specified in the GMP (BC 2012a), as well as tracer-specific sampling protocols specified in SOP-17 of the QAPP (ESI and BC 2009). Surface water hydrologic tracer samples were collected using the direct-grab method described in SOP-18 of the QAPP. This surface water sample collection method is consistent with the method used by the NDEP to collect samples at other surface water monitoring stations in the Mason Valley. Table 3-8 presents the parameters, analytical methods, reporting limits, and accuracy and precision goals for the hydrologic tracer analyses.

Table 3-8. Analyte List for Hydrologic Tracer Samples

Parameter	Analytical Method	Analytical Precision (1)	Reporting Limit (2)	Matrix Spike Accuracy	Lab Control Sample Accuracy
Tritium (^3H)	wrd (^3He-ingrowth)	± 0.1 TU (3)	NA	NA	NA
Tritium/Helium ($^3H/^3He$)	Noble Gas MS	± 1%	NA	NA	NA
^{34}S in Sulfate	EA-IRMS (Combination to SO_2) USGS RSIL Lab Code 1951	± 0.5‰	NA	NA	NA
^{18}O in Sulfate	EA-IRMS (Combination to CO_2) USGS RSIL Lab Code 1951 (4)	± 0.5‰	NA	NA	NA
^{234}U, ^{235}U, ^{238}U	HASL-300 (U-02-RC) (5)	RPD<20% or RER<2	1 pCi/L	70-130%	75-125%
Total Uranium	EPA 200.8 ICP-MS	20%	0.1 µg/L	70-130%	80-120%
Chlorofluorocarbons (CFCs)	GC-ECD	0-2%	0.001×10^{-12} pmol/kg	NA	NA
Sulfur Hexafluoride (SF_6)	GC-ECD	1-3% (6)	0.01×10^{-15} fmol/kg	NA	NA

Notes:

1) Precision is the average standard deviation (1-sigma) in per mil units (‰). Precision limit applicable for matrix spike/matrix spike duplicate, laboratory duplicate, laboratory control sample/ laboratory control sample duplicate, or reference standard analyses.
2) The method detection limits presented are laboratory-derived limits.
3) TU = tritium unit; NA = not applicable; RPD = relative percent difference; RER = replicate error ratio; EA-IRMS = elemental analyzer-isotopic ratio mass spectrometer; ICP-MS = inductively coupled plasma mass spectroscopy; TIMS = thermal ionization mass spectrometer; GC-ECD = Gas Chromatography with Electron Capture Detection; % = percent
4) USGS Reston Stable Isotope Laboratory (RSIL) Lab Code 1951 (USGS 2006).
5) Method U-02-RC: see Isotopic Uranium in Biological and Environmental Materials for water samples as documented in HASL-300 (Rev. 1, February 2000) available at URL address: http://www.eml.st.dhs.gov/publications/procman/.
6) Wanninkhof et al. (1991); Law et al. (1994).
7) mg/L = milligrams per liter; µg/L = micrograms per liter; pmol/kg = picomoles per kilogram; fmol/kg = femtomole per kilogram; pCi/L = picocuries per liter.

Laboratory analytical results for hydrologic tracers achieved the completeness, accuracy and precision goals specified in relevant planning documents including the QAPP (ESI and BC 2009) and SOP-17. Hydrologic tracer information that relates directly to the groundwater recharge aspects of the HCSM and the background groundwater assessment was obtained in May 2012 and August 2014. These data are discussed in Section 5.0. Appendix H provides supplemental information about hydrologic tracer sampling and analysis including:

- A detailed discussion of the locations where hydrologic tracer samples were collected during May 2012, July 2013, and August 2014;
- Analytical results of hydrologic tracer samples of standing rain water impounded on mine waste features after a large rain event (average of 1.55 inches on-Site) on July 4, 2013;
- A detailed description of the sample collection procedures, analytical methods, laboratory precision goals for each hydrologic tracer, and QA/QC sample results;
- An evaluation and discussion of the limited usefulness of CFC and SF_6 data for estimating groundwater ages in the Study Area;
- A discussion of the principles and application of uranium isotopes to groundwater interpretation;
- A discussion of the principles of groundwater age estimation using data for tritium and tritium/helium in groundwater;
- A discussion of the additional sources of sulfate isotope data potentially relevant to groundwater conditions in the Study Area; and
- Electronic copies of the analytical results provided by the laboratory and laboratory-calculated apparent groundwater ages.

3.2.8 Bedrock Groundwater Characterization

Since 2005, phased field investigations associated with OU-1 have included characterization of both the alluvial and bedrock groundwater systems. The Revised Groundwater RI Work Plan (BC 2014a) presented available groundwater information through May 2012, and described an updated HCSM for the bedrock and alluvial groundwater systems. The Revised Groundwater RI Work Plan also outlined the approach for completing the bedrock groundwater study elements specified in the 2007 SOW. Bedrock characterization activities that were approved by EPA are described below in Table 3-9.

Table 3-9. Chronology of Bedrock Groundwater Characterization Activities

2004-2007	Bedrock characterization (including borehole drilling, lithologic logging, well installation, hydraulic testing, water level monitoring, and groundwater quality monitoring) conducted pursuant to the First-Step HFA Work Plan (BC 2005) and Second-Step HFA Work Plan (BC 2007b).
2007	Characterization of bedrock groundwater conditions is required under the Administrative Order for Remedial Investigation and Feasibility Study (RI/FS), CERCLA Docket No. 9-2007-0005 dated January 12, 2007.
2007-2011	Bedrock characterization (including borehole drilling, lithologic logging, well installation, hydraulic testing, water level monitoring, and groundwater quality monitoring) conducted pursuant to the *2010 Groundwater Monitor Well Work Plan - Revision 2* (BC 2010c), *Agricultural Fields Characterization Work Plan - Revision 2* (BC 2010d), *On-Site Monitor Well Installation Work Plan - Revision 1* (BC 2011a), and the *Addendum to the On-Site Monitor Well Installation Work Plan* (ARC 2011).
August 17, 2011	Groundwater technical meeting with EPA, ARC and stakeholders to discuss progress of the phased approach to groundwater RI activities, which resulted in concurrence to conduct initial bedrock characterization activities to support a more comprehensive assessment of bedrock groundwater conditions as part of the RI characterization.
September 29, 2011	EPA (2011a) provided comments on the *2010 Annual Site-Wide Groundwater Monitoring Report* dated April 15, 2011, and the First and Second Quarter (1Q and 2Q) 2011 Groundwater Monitoring Reports dated July 1, 2011 and August 26, 2011, respectively, that pertained to bedrock characterization.
January 5, 2012	ARC submitted the *Proposed Initial Bedrock Characterization Activities* (ARC 2012a).
April 12, 2012	EPA (2012c) provided comments on the *Proposed Initial Bedrock Characterization Activities* (ARC 2012a).
June 18, 2012	ARC submitted preliminary responses to EPA comments on the *Proposed Initial Bedrock Characterization Activities.*
August 28, 2012	Groundwater technical meeting with EPA, ARC and other stakeholders to resolve comments on the *Proposed Initial Bedrock Characterization Activities.*
October 11, 2012	Submittal of ARC final responses to EPA comments on the *Proposed Initial Bedrock Characterization Activities,* and submittal of the *Proposed Initial Bedrock Characterization Activities - Revision 1* (ARC 2012b).
October 22, 2012	EPA (2012d) approval of the *Proposed Initial Bedrock Characterization Activities - Revision 1,* included as Attachment D to the Revised Groundwater RI Work Plan (BC 2014a).
March 2013	ARC began implementation of the EPA-approved *Proposed Initial Bedrock Characterization Work Plan - Revision 1.*
November 20, 2013	ARC submitted the *Initial Bedrock Characterization Data Summery Report* (BC 2013c).
February 7, 2014	ARC submitted the *Site-Wide Groundwater Remedial Investigation Work Plan - Revision 1* (BC 2014a), which presented available groundwater information through May 2012, and described an updated HCSM for the bedrock and alluvial groundwater systems.
January 28, 2015	ARC submitted the *Bedrock Groundwater Assessment Technical Memorandum* (BC 2015a).
June 11, 2015	ARC submitted the *Additional Monitor Well Installation Data Summary Report* (BC 2015d) detailing installation and testing of bedrock and alluvial wells installed in 2013 and 2014.
July 31, 2016	EPA (2016a) approved the *Bedrock Groundwater Assessment Technical Memorandum* (BC 2015a).

After installation and testing of new bedrock monitor wells in late 2013 and 2014, and a technical meeting in May 2015 to discuss the full set of bedrock information, EPA (2015a) concluded that sufficient data had been collected to conclude that bedrock is not an important migration pathway

at the Site, and requested preparation of a technical memorandum to update the bedrock HCSM. The *Bedrock Groundwater Assessment Technical Memorandum* (BC 2015a) is provided in Appendix I and bedrock information is summarized in Section 4.9.

3.3 Site-Wide Groundwater Studies and Evaluations

Studies and evaluations relying on OU-1 RI data that were conducted to fulfill certain study elements specified in Section 7.0 of the SOW attached to the 2007 Order (EPA 2007a) are described below. Reports describing the approach, analysis, and results of these groundwater related studies and evaluations are provided in Appendix J.

3.3.1 Pumpback Well System Effectiveness

The effectiveness of the PWS in limiting the off-Site migration of mine-impacted groundwater was evaluated in accordance with the *Pumpback Well System Characterization Work Plan Addendum - Revision 2* (ARC 2010).

The 11 pumpback wells ceased pumping on March 25, 2009 and were subsequently hydraulically tested to generate information to support a capture zone analysis using an analytical element model. These activities provided a preliminary assessment sufficient to conclude that the PWS was only partially effective in capturing Shallow zone mine-impacted groundwater during its operational life. The PWS effectiveness evaluation is described in the *Summary of PWS Aquifer Testing* (BC 2010f), which is included as Appendix J-1.

3.3.2 Pit Lake Water Levels

The Pit Lake (OU-2), which is currently refilling with groundwater from bedrock and alluvial flow systems (BC 2014a), has been studied to better understand its influence on Site-wide groundwater conditions. Pit Lake studies related to OU-1 include routine monitoring of the Pit Lake water level elevation beginning in September 2007 and a water balance evaluation (Appendix J-2) to predict the future “steady-state” elevation of the Pit Lake.

Groundwater inflow, based on the lake water balance study, is estimated to be slightly greater than the current rate of evaporation. Thus, the lake level is slowly rising with time. The Pit Lake water balance and projection of the pit refilling curve (Figure 3-7) indicate that the lake is expected to reach a steady-state level, where water inflow and evaporation are balanced, prior to 2030. The steady-state Pit Lake elevation is estimated to be in the range of 4,249 to 4,253 feet amsl, with more recent data indicating that the steady-state elevation may fall within the lower end of this range. The steady-state Pit Lake elevation is approximately: 1) 100 feet lower than the pre-mining groundwater elevation range of 4,350 to 4,375 feet amsl reported by Gill (1951); 2) 140 feet lower than current groundwater levels in the alluvial aquifer adjacent to the Walker River just east of the Pit Lake; 3) 65 feet lower than the current groundwater levels beneath the Evaporation Ponds; and 4) 150 and 340 feet below the east and west pit rim elevations, respectively.

The steady-state Pit Lake level is projected to be lower than the pre-mining water level as the result of the significant evaporation that occurs from the Pit Lake surface. Consequently, the lake is and will continue to be a groundwater sink that creates a localized cone of depression (extending as far north as the Process Areas) with local groundwater flow toward the pit. Because the Pit Lake does not and will not in the future discharge into the Site-wide groundwater system, the Pit Lake is not a source of COIs to Site-Wide groundwater.

3.3.3 Groundwater Pumping and Surface Water Points of Diversion

Groundwater conditions in the Study Area are influenced by groundwater pumping and surface water diversion associated primarily with irrigation and, to a lesser extent, stock watering and mining/milling (BC 2014a; S.S. Papadopulos & Associates, Inc. [SSPA] 2014).

Publicly-available groundwater pumping and surface water diversion information applicable to the Study Area is provided in the *Revised Public Information for the Northern Portion of the Background Groundwater Study Area* (BC 2013d) included in Appendix J-3. That document also includes: well ownership, location and construction; underground and surface water rights and points of diversion (PODs); well pumping records from 1993 to 2010; sub-surface lithology and, as applicable, depth to bedrock; and groundwater elevations from the NDWR and the USGS.

PODs from an underground source (i.e., groundwater) for the wells with water rights within and adjacent to the Study Area are shown on Figure 3-8, along with diversion rates and annual duties. All agricultural wells within and near the Study Area are screened in the alluvial aquifer. Although well construction varies greatly, agricultural wells used to extract groundwater for crop irrigation are either screened beginning at or near the water table to the total depth of installation and/or have been installed with a permeable filter pack from above the water table surface to the total depth of installation. Annual pumping inventories (i.e., actual total amounts pumped each year) for wells in the Mason Valley from 1994 to 2003 and from 2004 to 2010 have been reported by Gallagher (2004) and Gallagher (2013), respectively.

Within the Study Area, there are 20 wells used for irrigation, four wells used for stock watering, one used for mining/milling, and one used for commercial purposes (Gallagher 2013). The 20 irrigation wells are currently permitted to irrigate a total of 5,509 acres using an annual duty of 15,788 acre-feet with a combined diversion rate of 46.36 cubic feet per second (cfs). Of the 36 active water rights, 26 allow for pumping to occur on a year-round basis, nine of the rights can only be pumped during the irrigation season, and one right can only be used in the winter.

The place of use (POU) of 37 surface water rights within and adjacent to the Study Area that are identified in the amended Walker River Decree (WRD), Case in Equity, C-125, filed April 24, 1940 (WRD C-125; WRD, 1940) are shown on Figure 3-9. This figure also shows the POUs of surface water rights approved by NDWR as either new appropriations or applications to change WRD rights. Additional information about the distribution and routing of surface water is included in the discussion of surface water hydrology in Section 4.7.

The POUs of flood waters permitted by NDWR Application 5528, Certificate 8859 are shown on Figure 3-10 by quarter-section. Application 5528 was filed by the Walker River Irrigation District (WRID) to divert flood waters from the Walker River for irrigation from May 1 to July 31 of each year. Application 5528 was certificated for 491.2 cfs, not to exceed 89,612 acre-feet per season (the total duty of water cannot exceed 4.0 acre-feet per acre per season from any and/or all sources). The lands irrigated under this Certificate during any one season cannot exceed 30,000 acres.

3.3.4 Groundwater Model Development

The 2007 SOW (EPA 2007a) specified that the OU-1 RI "extrapolate the future contaminant transport using a comprehensive groundwater flow and fate-and-transport model". In addition, determining groundwater flow and chemical transport rates was identified as DQO #6 in the Revised Groundwater RI Work Pan (BC 2014a).

The technical and programmatic framework to address quantitative numerical modeling of groundwater flow and chemical transport was developed during iterative technical discussions with the EPA, ARC, and other stakeholders, and documented in the Revised Groundwater RI Work Plan (BC 2014a). Table 3-10 summarizes the chronology of investigations, evaluations, communications, and documents related to groundwater flow modeling.

Table 3-10. Chronology of Groundwater Modeling Activities

2004-2007	Characterization of groundwater conditions in the Study Area pursuant to the First-Step HFA Work Plan (BC 2005) and Second-Step HFA Work Plan (BC 2007b).
2007	Characterization of bedrock groundwater conditions is required under the Administrative Order for Remedial Investigation and Feasibility Study (RI/FS), CERCLA Docket No. 9-2007-0005 dated January 12, 2007.
2007-2011	Characterization of groundwater conditions in the Study Area pursuant to the various work plans and related correspondence (BC 2008c, 2010c, 2010d, 2011a; ARC 2011).
May 16, 2011	Conference call with EPA, ARC and other stakeholders to discuss groundwater flow modeling.
August 17, 2011	Groundwater technical meeting with EPA, ARC and stakeholders to discuss the status of RI activities, which resulted in concurrence to conduct groundwater modeling to support a quantitative evaluation of groundwater flow and chemical transport.
June 4, 2012	Conference call with EPA, ARC and other stakeholders to discuss groundwater flow modeling activities, which resulted in a request by EPA that ARC submit a document describing key groundwater modeling deliverables and milestones, and a draft table of contents for a groundwater modeling work plan.
June 25, 2012	ARC submitted the *Groundwater Flow Modeling Deliverables* (ARC 2012c), which included: 1) a preliminary summary of key groundwater modeling deliverables and milestones; and 2) a draft table of contents for a groundwater flow model work plan.
July 11, 2012	EPA (2012e) provided comments on the *Groundwater Flow Modeling Deliverables* (ARC 2012c).
July 17, 2012	Groundwater technical meeting with EPA, ARC and stakeholders to discuss findings of the 2011 Monitor Well Installation investigation, and related RI activities, which resulted in an EPA request that ARC submit a document summarizing groundwater modeling objectives.
August 14, 2012	ARC submitted the *Objectives for Groundwater Modeling in the RI/FS Process, Yerington Mine Site* (SSPA 2012a).
August 29, 2012	Groundwater technical meeting with EPA, ARC, and other stakeholders to discuss the groundwater modeling objectives.
October 15, 2012	ARC submittal of the *Objectives for Groundwater Modeling in the RI/FS Process - Revision 1, Yerington Mine Site* (SSPA 2012b).
October 26, 2012	EPA (2012f) approval of the *Objectives for Groundwater Modeling in the RI/FS Process - Revision 1, Yerington Mine Site* (SSPA 2012b).

Table 3-10. Chronology of Groundwater Modeling Activities	
December 28, 2012	ARC submittal of the *Draft Groundwater Flow Model Work Plan for the Yerington Mine Site* (SSPA 2012c).
March 29, 2013	EPA (2013d) provided comments on the *Draft Groundwater Flow Model Work Plan for the Yerington Mine Site* (SSPA 2012c).
May 21, 2013	ARC submittal of the *Groundwater Flow Model Work Plan - Revision 1* (SSPA 2013) included as Attachment E to the Revised Groundwater RI Work Plan, along with responses to EPA comments on the *Draft Groundwater Flow Model Work Plan* (SSPA 2012c).
March 18, 2014	ARC submittal of the *Groundwater Flow Model Yerington Mine Site* (SSPA 2014). This report synthesized available hydrologic and geochemical information into a quantitative representation of the current and historic HCSM. The report also contained: 1) documentation of the study goals; 2) a discussion of the modeling strategy and assumptions; 3) details about model construction, calibration and validation; 4) a summary of model predictions; and 5) an analysis of the uncertainty associated with the model predictions.
October 28, 2014	EPA provided comments on the *Groundwater Flow Model Yerington Mine Site* (SSPA 2014).
February 3, 2015	ARC submits the *Flow Model "Supplemental" Materials* (SSPA 2015) in response to EPA comments.
May 18, 2015	EPA (2015b) provided comments on the *Flow Model "Supplemental" Materials* (SSPA 2015) and approved the *Groundwater Flow Model Yerington Mine Site* (SSPA 2014).

Based on review of the *Flow Model Supplemental Materials* (SSPA 2015), EPA (2015b) constrained the modeling objective and approved the groundwater flow model, noting that: "The primary goal foreseen for the Yerington groundwater model is to provide a management tool that can be used to evaluate possible remediation options. As such, its greatest value will be in allowing short-term comparisons of remedial designs and possible effectiveness of different remediation scenarios using a common tool and less so in predicting long-term migration of contaminants. It appears that this tool is adequate for that purpose".

The groundwater flow model is provided in Appendix J-4. The flow model domain, which encompasses an area of approximately 86 square miles, consists of that portion of the Mason Valley west of the Walker River and north of Mason that is underlain by saturated alluvium (Regional Domain). Nested within the model domain is the Study Area which encompasses an area of approximately 23 square miles that is bounded to the north by Campbell Lane, to the west by the Singatse Range, to the east by a north-south trending line located one mile east of Highway 95, and to the southeast by the Walker River (Local Domain). The Local Domain is nested within the Regional Domain so that appropriate boundary conditions along the northern and eastern boundaries of the overall model domain can be calculated. In addition, the model domain is subdivided to reflect two different sources of data, which may differ in data quality.

The vertical extent of the model domain extends from the ground surface to the alluvial/bedrock contact and into the portions of the bedrock groundwater system in hydrologic communication with the alluvial aquifer. The model domain extends laterally to include monitor well locations for identifying background groundwater quality and groundwater impacted by mining and other anthropogenic activities.

Since 2005, hydrogeologic data within the Local Domain have been and continue to be collected as part of the RI process, pursuant to EPA-approved planning documents and work plans. Thus, these data are high quality and there is a high degree of confidence in the data. Hydrogeologic data from outside the Local Domain but within the Regional Domain are from multiple sources and are of uncertain quality. Much of these data are from the USGS (e.g., water-level data) and the NDWR (e.g., well logs).

Temporal (e.g., seasonal, annual) variations in groundwater flow patterns and chemical concentrations continue to be assessed due to variability in hydrologic stresses on the groundwater system. Monitor wells installed for groundwater characterization purposes continue to be routinely monitored pursuant to the GMP (BC 2012a) to address temporal aspects of the study within the Local Domain. Within the Regional Domain, available water-level and surface water flow data from the USGS and NDWR will be used to assess temporal variations in groundwater conditions.

3.3.5 Chemical Transport Evaluations

The technical and programmatic framework for characterizing groundwater geochemical conditions and assessing geochemical processes that affect the release and subsequent mobility or attenuation of COIs during groundwater transport in the Study Area was presented as DQO #3 in Revised Groundwater RI Work Plan (BC 2014a).

Table 3-11 summarizes the chronology of investigations, evaluations, communications, and documents related to chemical transport evaluation.

Table 3-11. Chronology of Activities to Determine Geochemical Mobilization/Attenuation Processes	
2008	The Second-Step HFA Work Plan (BC 2007b) included collecting and archiving redox-preserved samples of saturated and unsaturated alluvium. EPA technical staff observed the redox-sample collection and archiving methods, and provided input on locations and depth intervals for collecting an initial set of samples. These initial samples were collected for use in a "methods development" phase of work intended to develop Site-specific testing procedures.
June 21, 2010	ARC submitted the *Draft Aquifer Solids Testing Work Plan* (BC 2010g).
September 13, 2010	EPA (2010a) provided comments on the *Draft Aquifer Solids Testing Work Plan* (BC 2010g).
September 21, 2010	ARC submitted the *Aquifer Solids Testing Work Plan - Revision 1* (BC 2010e), which was revised in response to EPA comments.
September 30, 2010	EPA (2010b) approved the *Aquifer Solids Testing Work Plan - Revision 1* (BC 2010e).
2011	ARC developed Site-specific procedures and methods to physically separate redox-preserved samples into solid and liquid fractions for subsequent characterization of total metals concentrations, mineralogy, and porewater chemistry.
February 28, 2012	EPA technical staff visited the testing laboratory (Hazen Research, Inc. in Golden, Colorado) and observed the Site-specific testing procedures.
August 17, 2012	ARC submittal of *SOP-23: Aquifer Solids Testing SOP - Redox-Preserved Sample Preparation and Testing* (BC 2012c).
September 26, 2012	EPA (2012g) transmitted comments on *SOP-23: Aquifer Solids Testing SOP- Redox-Preserved Sample Preparation and Testing* (BC 2012c).
October 15, 2012	ARC submittal of *SOP-23: Aquifer Solids Testing SOP - Redox-Preserved Sample Preparation and Testing - Revision 1* (BC 2012d).
October 22, 2012	EPA (2012d) approval of SOP-23 Revision 1, pending minor changes. These minor changes were incorporated into SOP-23 Revision 2*,* included as Appendix H-1 to the Revised Groundwater RI Work Plan (BC 2014a).
February 7, 2014	ARC submitted the Revised Groundwater RI Work Plan (BC 2014a), which included: 1) DQO #3 pertaining to geochemical attenuation/mobilization; 2) the thermodynamic data for Site-specific geochemical modeling; and 3) Site-specific distribution coefficients (a simple, lumped-parameter variable that describes either the relative affinity of the aquifer matrix for a particular ion or the mobility of the ion in a groundwater flow system) based on chemical concentrations in co-located aquifer sediment and groundwater samples.
October 9, 2014	EPA (2014b) approved the Revised Groundwater RI Work Plan including the thermodynamic data presented in Appendix H-4 for Site-specific geochemical modeling, and directed ARC to prepare a Groundwater Geochemical Characterization Data Summary Report.
December 30, 2014	ARC submitted the *Groundwater Geochemical Characterization Data Summary Report* (BC 2014c). As noted in ARC's transmittal letter, the document partially fulfilled the requirements for the geochemical characterization and ARC recommended additional refinements to the thermodynamic database for geochemical modeling.
April 27, 2015	ARC transmitted recommendations to EPA for refining the thermodynamic database to be used for geochemical modeling (via e-mail).
May 4, 2015	EPA approved ARC's recommendations on refining the thermodynamic database to be used for geochemical modeling (also via e-mail).
September 23, 2015	EPA, ARC and other stakeholders agreed during a conference call that geochemical characterization to be performed for the OU-1 RI should focus on geochemical modeling of: 1) controls on the fate and transport of key COIs anticipated to drive decision-making in the FS; and 2) other chemicals that may affect their mobility and transport in groundwater.
December 11, 2015	ARC submitted the *Groundwater Geochemical Characterization Data Summary Report – Revision 1* (BC 2015e).

Table 3-11. Chronology of Activities to Determine Geochemical Mobilization/Attenuation Processes

July 2016	EPA conditionally approved the document on July 31, 2016 (EPA 2016b) subject to minor editorial changes and revision of statements referencing COI concentrations and spatial extent relative to background chemical concentrations presented in the *Background Groundwater Quality Assessment - Revision 2* (BC 2015c). EPA recommended that a revised version of the report be included as an appendix to the OU-1 RI Report.

The *Groundwater Geochemical Characterization Data Summary Report - Revision 2* (BC 2016a) is provided in Appendix J-5. The chemical speciation model and approach to calculating Site-specific distribution coefficients is summarized below.

Chemical Speciation Model Development

The specific objectives of the *Groundwater Geochemical Characterization Data Summary Report - Revision 2* are as follows:

- Describe the occurrence and distributions of select chemicals in Study Area groundwater based on the comprehensive set of monitor well data obtained during August 2014; and
- Using the EPA-approved thermodynamic database developed for the Site and geochemical modeling, evaluate the aqueous geochemical speciation of select COIs and potential formation of solid mineral phases in Study Area groundwater to assess chemical mobility/attenuation.

The primary geochemical data inputs used to identify the geochemical processes controlling chemical transport consist of: 1) groundwater chemical data from monitor wells installed in the groundwater zones in the alluvial aquifer and bedrock; 2) field parameter measurements that characterize the pH and redox status of the groundwater system (because these affect the aqueous speciation of inorganic chemicals and formation of mineral phases); and 3) thermodynamic data describing chemical reactions for each of the important aqueous species, minerals comprising the aquifer solids, gases, and adsorbed species. The geochemical assessment primarily relied on groundwater information associated with the August 2014 groundwater monitoring event. Approximately 2% of the August 2014 dataset had speciated charge imbalances outside the acceptable range of ±10%, and groundwater data obtained in October 2014 were substituted for August 2014 data.

Geochemical modeling using the Site-specific thermodynamic database with PHREEQC version 3.1.5 was conducted to determine the chemical speciation of aqueous constituents and the saturation indices of solid mineral phases in equilibrium with the groundwater samples. The geochemical modeling did not involve adsorption to aquifer soil/sediments or organics in aquifer materials. Details regarding the development of the Site-specific thermodynamic database are provided in Appendix J-5 and key modifications are discussed briefly below.

The WATEQ4F database was used as the starting point for database development because its major-element data are consistent with the Nordstrom et al. (1990) data compilation, which is a reliable and internally-consistent data set. Subsequently, the WATEQ4F database was modified by replacing aqueous speciation and solid-phase solubility data for uranium, phosphate, vanadium, sulfide, arsenic and copper with new data that have been critically reviewed by federal agencies (e.g., compilations prepared by the Nuclear Energy Agency were the principal sources of the uranium data in the ARC database) or in the peer-reviewed literature (e.g., Dong and Brooks 2006). Uranyl species $Ca_2UO_2(CO_3)_3^0$, $CaUO_2(CO_3)_3^{-2}$, $Mg_2UO_2(CO_3)_3^0$ and $MgUO_2(CO_3)_3^{-2}$ are of particular importance in evaluating the mobility of uranium; therefore, the thermodynamic data for these constituents were added to the Site-specific database. Thermodynamic solubility data for schwertmannite (an oxyhydroxide sulfate mineral) reported by Bigham et al. (1996) and confirmed by Sánchez-España et al. (2011) were included in the database. In addition, thermodynamic solubility data reported by Bourrié et al. (1999) for three hydroxy-green rusts were included in the database.

PHREEQC is a geochemical software model distributed by the USGS. The model assumes equilibrium mass transfer and does not account for the kinetics of mineral precipitation and dissolution reactions using applicable reaction rate laws (Parkhurst and Appelo 1999; EPA 2007b). Chemical speciation modeling describes the distribution of chemical mass between aqueous and solid mineral phases, and hence, predicts the geochemical conditions under which various constituents might be sequestered by mineral precipitation or remain mobile in the groundwater flow system. Both chemical speciation and mineral precipitation are pertinent data for evaluating the mobility of constituents in the groundwater system.

Information generated from the geochemical assessment is incorporated into the discussion of contaminant fate and transport in Section 6.0, and will be used to guide the development of quantitative approaches to representing chemical transport in the numerical groundwater flow model (SSPA 2014) to evaluate various remedial alternatives during the FS. As noted by the EPA (2016b), decisions will be made during the FS regarding the most appropriate reactive transport modelling approach and whether it will be necessary and/or beneficial to integrate the models or how that can be accomplished to efficiently meet the technical needs of the OU-1 RI/FS without introducing unnecessary complexity to the modeling efforts.

Distribution Coefficients

The partition (distribution) coefficient (K_d) is a simple, lumped-parameter variable that is used to assess contaminant transport by describing either the relative affinity of the aquifer matrix for a particular ion or the mobility of the ion in a groundwater flow system (EPA 2007b; Freeze and Cherry 1979).

The initial approach to developing Site-specific distribution coefficients based on chemical concentrations in co-located groundwater and aquifer sediment samples was presented in the Revised Groundwater RI Work Plan (BC 2014a) and is reproduced in this OU-1 RI Report as Appendix J-6. The approach to developing the distribution coefficients is summarized below.

Distribution coefficients were calculated for a variety of chemicals in Site groundwater including aluminum, arsenic, barium, boron, calcium, chloride, chromium, cobalt, copper, fluoride, iron, lead, lithium, magnesium, manganese, molybdenum, nickel, nitrate, potassium, selenium, sodium, sulfate, uranium, vanadium, and zinc. Distribution coefficients were not calculated for parameters that were only infrequently detected in groundwater or are not likely to be the subject of FS transport modeling including alkalinity, antimony, beryllium, cadmium, mercury, phosphorous, silica, silver, strontium, thallium, tin, and titanium.

Site-specific distribution coefficients were calculated using data from a single set of soil samples that were collected during the borehole drilling for monitor well installation and two distinct sets of water quality data. Soil samples were analyzed for a variety of bulk chemical concentrations (analyses were performed on liquid extracts from treatment of the solid samples by microwave-assisted digestion using EPA Method 3051A).

The first set of water quality data used in K_d calculations was the zonal water quality data that were collected at the time of borehole drilling. As discussed in Section 3.2.1, zonal groundwater samples were analyzed only for sulfate, uranium and arsenic. These data were collected over small depth intervals, typically ranging from three to five feet. Co-located zonal groundwater and soil samples were collected at multiple depth intervals in 13 locations throughout the Site that included B/W-1, B/W-2, B/W-3, B/W-4, B/W-11, B/W-31, B/W-32, B/W-42, B/W-46, B/W-61, B/W-62, B/W-65, and B/W-66.

The second set of water quality data used in K_d calculations included groundwater quality data obtained during quarterly sampling events from 15 monitor wells typically having a screen interval length of 20 feet. Monitor well samples were analyzed for the broader set of constituents listed in Table 3-4. The soil sample data used in the calculations were selected such that the sample intervals were within the screened interval of the well. The wells considered in this portion of the analysis were B/W-2D1, B/W-3I, B/W-4I, B/W-4D1, B/W-11D2, B/W-31S1, B/W-31S2, B/W-32S, B/W-42S, B/W-46S, B/W-61S, B/W-62S, B/W-65S, B/W-66S, and B/W-67S. The quarterly groundwater quality results collected closest to the date of the zonal soil sample collection for each particular well were used to calculate K_d values to minimize potential effects from variability in groundwater concentrations over time.

The distribution coefficient is calculated as the ratio of the concentration of a chemical adsorbed onto the solid phase (commonly expressed as milligrams [mg] of chemical per kilogram [kg] of solid) to the dissolved concentration of the chemical in the water (mg of chemical per liter [L] of solution) at equilibrium (Freeze and Cherry 1979). Based on the formulation below, K_d values are expressed in units of L/kg.

$$K_d = \frac{C_{\text{adsorbed}}}{C_{\text{water}}}$$

where: C_{adsorbed} = adsorbed chemical concentration (mg/kg)
C_{water} = dissolved chemical concentration in water (mg/L)

Initially, distribution coefficients were calculated using water chemical data and chemical concentrations in the aquifer sediment sample that were determined using EPA digestion Method 3051A. Because of the relatively aggressive digestion method, the aquifer sediment data represent the bulk (i.e., total) chemical concentration in the solid rather than the adsorbed chemical concentration. As recommended by EPA (1999), trace metals that are present in crystalline lattice sites of minerals present in soils do not participate in adsorption/desorption reactions and should not be included in the K_d calculation. Consequently, the original K_ds were revised for this OU-1 RI Report. To better estimate K_ds, the adsorbed amount of a chemical was estimated by subtracting the average chemical concentration in Sub-area A-1 soils (BC 2009b) from the bulk (i.e., total) chemical concentration in the individual aquifer sediment sample, as follows:

$$K_d = \frac{C_{\text{soil}} - C_{\text{bkgd}}}{C_{\text{water}}}$$

where: $C_{\text{adsorbed}} = C_{\text{soil}} - C_{\text{bkgd}}$
C_{soil} = bulk chemical concentration in the solid (mg/kg)
C_{bkgd} = average background chemical concentration in the solid (mg/kg)
C_{water} = dissolved chemical concentration in water (mg/L)

The revised Site-specific distribution coefficient values are presented in the contaminant fate and transport discussion in Section 6.0.

3.3.6 Background Groundwater Quality Assessment

Identifying background water types and defining the extent of mine-impacted groundwater was specified in the 2007 SOW (EPA 2007a) and identified as DQO #1 in the Revised Groundwater RI Work Plan (BC 2014a). The background groundwater quality assessment (BGQA) has been integrated into groundwater characterization activities performed in the Study Area since 2007.

Table 3-12 summarizes the chronology of the BGQA and other background-related orders, investigations and documents.

Table 3-12. Chronology of Activities Related to Establishing Background Groundwater Quality

2004-2008	Monitor wells B/W-13S, B/W-14S, B/W-15S, B/W-20S, and B/W-21S installed adjacent to Walker River and hydraulically up-gradient of the Site, pursuant to the First-Step HFA Work Plan (BC 2005) and the Second-Step HFA Work Plan (BC 2007b).
2007	Characterization of background groundwater quality is required under the Administrative Order for Remedial Investigation and Feasibility Study (RI/FS), CERCLA Docket No. 9-2007-0005 dated January 12, 2007.
2007-2011	Background characterization conducted pursuant to the *2010 Groundwater Monitor Well Installation Work Plan - Revision 2* (BC 2010c), *Agricultural Fields Characterization Work Plan - Revision 2* (BC 2010d), *On-Site Monitor Installation Work Plan - Revision 1* (BC 2011a), and the *Addendum to the On-Site Monitor Well Installation Work Plan* (ARC 2011).
August 17, 2011	Groundwater technical meeting with EPA, ARC and stakeholders to discuss progress of the phased approach to groundwater RI activities, which resulted in concurrence to accelerate background groundwater characterization activities and an EPA request for ARC to prepare and submit a BGQA. Also discussed were installation of additional well clusters (B/W-12R, B/W-17, and B/W-22R) in areas south and southwest of the Site, pursuant to the *On-Site Monitor Well Installation Work Plan* (BC 2011a), to support background groundwater characterization.
September 7, 2011	ARC submitted the *Addendum to the On-Site Monitor Well Installation Work Plan* (ARC 2011) proposing additional well clusters at B/W-12R, B/W-17, and B/W-26R to support background groundwater characterization.
September 28, 2011	ARC submitted the *Draft Background Groundwater Quality Assessment* (BC 2011c), which recommended the installation of three monitor well clusters (B/W-56, B/W-57 and B/W-58) located in the northern portion of the Study Area.
September 30, 2011	The *Addendum to the On-Site Monitor Well Installation Work Plan* (ARC 2011) was approved by EPA (2011b).
December 7, 2011	Via e-mail communication, ARC requests and receives EPA approval to install well clusters B/W-56, B/W-57, and B/W-58 proposed in the Draft BGQA during implementation of the *On-Site Monitor Well Installation Work Plan - Revision 1.*
February 7, 2012	EPA (2012a) provided comments on the Draft BGQA.
March 19, 2012	ARC (2012d) submitted a request to implement a comprehensive hydrologic tracer sampling event that was larger in scope than the sampling event proposed in the *On-Site Monitor Well Installation Work Plan - Revision 1* (BC 2011a) and to eliminate select hydrologic tracers. Hydrologic tracers are considered one line of evidence that may be useful for determining background groundwater quality.
April 18, 2012	ARC (2012e) submitted responses to EPA comments on the Draft BGQA.
April 27, 2012	EPA approved the comprehensive hydrologic tracer sampling event and request to eliminate select tracers (EPA 2012b).
May 2012	Comprehensive hydrologic tracer sampling event conducted concurrent with the 2Q 2012 quarterly groundwater monitoring event.
August 28, 2012	Groundwater technical meeting with EPA, ARC, and other stakeholders to clarify and resolve comments on the Draft BGQA.
November 19, 2012	Submittal of final ARC responses to EPA comments on the *Draft BGQA* and the *Background Groundwater Quality Assessment - Revision 1* as Attachment A to the *Draft Site-Wide Groundwater Operable Unit (OU-1) Remedial Investigation Work Plan* (BC 2012b).

Table 3-12. Chronology of Activities Related to Establishing Background Groundwater Quality

June 26, 2013	Submittal of the *Draft Additional Monitor Well Work Plan* (BC 2013e) as Attachment B to the *Draft Site-Wide Groundwater Operable Unit (OU-1) Remedial Investigation Work Plan* (BC 2012b), to address data gaps identified by ARC and EPA, including groundwater conditions in the north and northeastern portion of the Study Area. ARC recommended sampling of all wells proposed for hydrologic tracers to supplement data from the May 2012 hydrologic tracer sampling event.
July 29, 2013	EPA (2013e) provided comments on the *Draft Additional Monitor Well Work Plan*.
October 8, 2013	ARC submitted the *Additional Monitor Well Work Plan - Revision 1* (Additional Well Work Plan; BC 2013b). This work plan was also included as Attachment B to the Revised Groundwater RI Work Plan (BC 2014a). EPA (2014b) approved the Revised Groundwater RI Work Plan including Attachment B on October 9, 2014.
September 2013 to July 2014	Installation, development, and hydraulic testing of new wells installed pursuant the Additional Well Work Plan (BC 2013b).
August 2014	Hydrologic tracer sampling of new wells installed pursuant to the Additional Well Work Plan (BC 2013b).
May 2015	Receipt of hydrologic tracer laboratory analytical results for new wells installed pursuant to the Additional Well Work Plan (BC 2013b).
June 11, 2015	ARC submitted the *Additional Monitor Well Installation Data Summary Report* (BC 2015d).
July 2, 2015	ARC submitted the *BGQA – Revision 1 - Revision 2* (BC 2015c), which described: 1) the technical approach, scope, rationale and methods to establish background groundwater quality; and 2) multiple supporting lines of evidence for defining the extent of mine-impacted groundwater and identifying other anthropogenic groundwater impacts.
February 11, 2016	EPA (2016c) provided comments on the *Background Groundwater Quality Assessment - Revision 2*.
June 14, 2016	ARC (2016b) provided responses to EPA Comments on the *Background Groundwater Quality Assessment - Revision 2*.
June 29, 2016	EPA, ARC and other project stakeholders held a groundwater technical meeting to discuss the background assessment.
September 27, 2016	EPA (2016d) letter to ARC providing final direction on the background groundwater quality assessment including an attachment (EPA 2016e) dated September 2, 2016 and titled EPA Memorandum, Subject: Yerington Mine Site, Yerington Nevada (16-R09-003) Responses to ARC Responses to Comments on the Background Groundwater Quality Assessment - Revision 2.
November 11, 2016	ARC submitted the *Background Groundwater Quality Assessment - Revision 3* (BC 2016b).
February 16, 2017	EPA (2017) approved the *Background Groundwater Quality Assessment - Revision 3*.

The *Background Groundwater Quality Assessment - Revision 3* is provided in Appendix J-7 and the results of the background assessment are integrated into the discussion of the nature and extent of contamination in Section 5.0.

3.4 Former Domestic Well Monitoring and Bottled Water Programs

Water quality monitoring of domestic, commercial, and irrigation wells (collectively referred to as domestic wells) located near the Site has evolved over time.

Domestic well monitoring began in late 1983. Up through early 2009, domestic well monitoring activities were performed pursuant to:

- Paragraphs 15(e) and 15(f) of the Unilateral Administrative Order for Initial Response Activities, Docket No. 9-2005-0011 (2005 Order);
- Section 6.0 of the 2007 SOW; and
- The Administrative Order on Consent and Settlement Agreement for Removal Actions and Past Response Costs, Docket No. 09-2009-0010 (2009 Order).

In March 2009, EPA requested that ARC expand the domestic well monitoring program because of the EPA-approved shutdown of the PWS to evaluate OU-1 hydrogeologic conditions. The expanded domestic well monitoring program has been conducted pursuant to the *Domestic Well Monitoring Plan - Revision 3* (DWMP; BC 2010b), which was prepared as an addendum to the Site-Wide QAPP (ESI and BC 2009). Results of domestic well monitoring have been used to: 1) characterize the quality of groundwater used for drinking water or other domestic water supply purposes; 2) assess potential risk, if any, to human health and the environment by the use of groundwater extracted by domestic wells for drinking water or agricultural purposes; and 3) determine eligibility for receiving bottled water as part of an interim response action.

The Bottled Water Program was initiated in March 2004. Domestic well owners were deemed eligible to receive bottled water if uranium concentrations measured during domestic well monitoring exceeded 25 µg/L.

The number of wells/properties included in the DWMP and Bottled Water Program was substantially reduced in 2016 (ARC 2016a; EPA 2016f). As part of the settlement entered in the class action lawsuit *Roeder et al. v. Atlantic Richfield Company et al.*, D. Nev., Case No. 3-11-cv-00105-RCJ-WGC (“Roeder Settlement Agreement”), ARC provided funding to the City of Yerington to extend municipal water service to then-existing residences located within that part of the settlement class area that was also within the City’s projected future service area. Domestic well owners who connected to the City of Yerington’s municipal water system could elect to either abandon their well or apply for a state permit to authorize withdrawals of groundwater for outdoor use only (landscape watering). Each property owner who received a connection to the City Water System executed and recorded an environmental covenant either prohibiting future domestic use of groundwater altogether or limiting it to outdoor purposes.

Construction of the expanded water system began in the fall of 2014 and the construction of new mains and service connections was completed in June 2016. The first phase of well abandonments and system testing was completed as of August 1, 2016. The water system is functional, and domestic wells for all participating property owners have been abandoned or disconnected from the residences within the expansion area. A relatively small number of domestic wells located within the area of mine-impacted groundwater (see Figure 3-11) were not disconnected or converted to outdoor use only in 2016. ARC has been in communication with the owners of most of these wells, and disconnections for all but a few are scheduled to occur in 2017.

SECTION 4.0

PHYSICAL CHARACTERISTICS OF THE STUDY AREA

This section describes the physical characteristics of the Study Area including demographics, land use, climate, topography, geology and soils, hydrology and groundwater, ecological setting, and vegetation.

4.1 Demographics and Study Area Land Use

Lyon County, Nevada covers approximately 1,993 square miles, and its population in 2013 was 51,585 (U.S. Census Bureau 2015). Communities near the Site include Yerington (population 3,486), Weed Heights (population 500), and the YPT (approximate population 575). The regional population and industrial centers near the Site include Fernley (47 miles north), Fallon (59 miles northwest), Hawthorne (57 miles southeast), and Reno (85 miles northwest). Yerington's economic base is primarily agriculture.

Land use has included mine operations, ranching, agriculture, urban development, establishment of the YPT colony, BLM range land, and residential development. Mason Valley has long been the largest agricultural area in the Walker River basin and the most productive area in Nevada. In 2000, a total of 88,600 acres of irrigated land was mapped in the Walker River basin. Total irrigated land included 39,100 acres (44%) in Mason Valley (USGS 2009a).

4.2 Climate

Nevada is located on the leeward side (rain shadow) of the Sierra Nevada mountain range, which results in a dry climate. The climate in Lyon County is warm and arid. Snow melt is the primary natural source of streamflow and groundwater recharge in the Walker River Basin (USGS 2009b). The average annual precipitation in Yerington is approximately 5.1 inches, and average snowfall is 6.7 inches (Western Regional Climate Center [WRCC] 2015). The annual average precipitation rate is low relative to the regional pan evaporation rate of about 69 inches per year. The average monthly temperature for the period of record (March 1, 1894 through January 20, 2015) ranges from a maximum of 92.4 degrees Fahrenheit (°F) in July to a minimum of 17.8°F in January.

Tables 4-1 and 4-2 summarize monthly climate data for the City of Yerington weather station for the period from 1894 through 2015 (WRCC 2015). Table 4-1 summarizes monthly minimum and maximum temperatures, and monthly precipitation. Table 4-2 provides monthly average, maximum, and minimum precipitation values, and the one-day maximum rainfall event.

Table 4-1. Average Monthly Climate Data for the Yerington Weather Station #269229 (1894 - 2015)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Average Maximum. Temperature (°F) [1]	46.2	52.5	59.7	67.0	75.1	83.8	92.4	91.0	83.1	70.8	56.8	47.1	68.8
Average Minimum Temperature (°F) [1]	17.8	22.6	27.0	32.4	40.2	46.8	52.7	50.4	42.3	33.3	23.5	17.9	33.9
Average Total Precipitation[2]	0.57	0.53	0.42	0.41	0.63	0.46	0.26	0.25	0.24	0.35	0.42	0.52	5.06
Average Snow Fall [2]	1.9	1.2	1.0	0.4	0.1	0.0	0.0	0.0	0.0	0.1	0.8	1.2	6.7

Notes:

1) °F = Degrees Fahrenheit;
2) Precipitation values in inches

Table 4-2. Precipitation Data for the Yerington Weather Station #269229 (1894 - 2012)

Month	Mean	Maximum	Year	Minimum	Year	1-Day Maximum (Year)
January	0.57	3.67	1916	0.00	1915	1.40 (1943)
February	0.53	2.62	1962	0.00	1953	1.28 (1962)
March	0.42	1.83	1991	0.00	1914	0.98 (1941)
April	0.41	1.80	1990	0.00	1916	1.30 (1990)
May	0.63	3.04	1995	0.00	1916	1.90 (1939)
June	0.46	2.01	1997	0.00	1895	1.02 (1997)
July	0.26	2.00	2003	0.00	1916	1.75 (1984)
August	0.25	2.37	1983	0.00	1895	1.46 (1983)
September	0.24	2.15	1955	0.00	1920	2.02 (1955)
October	0.35	3.02	1993	0.00	1895	1.83 (1993)
November	0.42	2.39	1965	0.00	1894	1.04 (1974)
December	0.52	3.51	1955	0.00	1917	2.00 (1955)
Annual	5.06	10.58	1983	1.61	1947	2.02 (1955)

Notes:

1) Precipitation values presented in inches.
2) Most minimum values (11 of 12 months) of 0.00 inches were recorded prior to 1920.

Wind speed and direction at the Site vary on the local scale due, in part, to the heterogeneous natural topography (i.e., micro-climates) and modified topography due to surface mining operations. Meteorological data collected since 2002 indicate that wind direction is variable at the Site with no quadrant representing over 50% of the total measurements. However, when wind speeds are above 15 miles per hour, a predominant wind direction from southwest to northeast has been documented (BC, 2008c).

4.3 Topography

The Site is in Mason Valley, which is a north-south trending structural valley (graben) within the Basin and Range physiographic province filled with up to 1,000 feet of unconsolidated sediments. Mason Valley occupies a structural graben (i.e., down-dropped faulted basin) immediately east of the Singatse Range, Desert Mountains to the north, and the Wassuk Range to the east. Elevations in the Wassuk and Singatse Ranges reach 9,000 and 6,700 feet amsl, respectively (Huxel and Harris 1969). The valley ranges in width from about nine miles in the south to nearly 20 miles in the central part, and is about 40 miles long. The valley floor ranges from approximately 4,600 feet amsl in elevation at the south end to 4,290 feet amsl at the north end. The center of the Process Areas is at an elevation of approximately 4,450 feet amsl.

4.4 Ecological Setting

The Study Area is part of the Great Basin sagebrush-steppe ecosystem (Lopes and Allander 2009a). The Singatse Range to the west and the Mason Valley are dominated by a scrub brush community, except along the Walker River with s riparian community. These communities support resident and migrating birds, mammals, reptiles, amphibians and invertebrates. The Walker River flows within 0.25 mile of the southeastern end of the Site. Although riparian systems comprise an extremely small fraction of the Great Basin region, they are critical centers of biodiversity; more than 75% of the species in the region are strongly associated with riparian vegetation. The Study Area ecosystem has been impacted by anthropogenic activity, including mining, cattle ranching and agriculture. Site activities have resulted in the large piles of tailings and waste rock, which could be used as vantage points for predators surveying the surrounding area, and steep-sloped piles may potentially be used by nesting birds (e.g., swallows).

4.5 Vegetation

The terrestrial ecosystem in the Study Area not disturbed by anthropogenic activities supports an arid sagebrush-steppe vegetative community that is dominated by sagebrush and other low-lying woody vegetation, interspersed with a variety of forbs and grasses. The scrub brush community in the Study Area is predominately sparse greasewood, sagebrush, and rabbitbrush (Lopes and Allander 2009a). Livestock and wildlife preference for grasses contributes to the domination of vegetation in this system by sagebrush and other shrubs (Ricketts et al. 1999).

The riparian community along the Walker River supports a variety of trees, shrubs and grasses (USGS 2009b). Vegetation can be dense with large trees such as Freemont cottonwood, Russian olive, and invasive Tamarisk (Salt Cedar). Saltbush may be abundant where riverbank soil is saline. As previously stated, many areas on the Site have been disturbed to varying degrees by historical mining activities, but still retain areas of sandy soil interspersed with vegetation typical of the sagebrush-steppe vegetative mix of shrubs, forbs, and grasses. Mason Valley has long been the most agricultural part of the Walker River basin and remains one of the most productive agricultural areas in Nevada (Lopes and Allander 2009a). During the growing season, agricultural fields to the north may include onions, alfalfa, winter wheat and sorghum.

4.6 Regional and Site Geology

Mason Valley is a structural graben that has been filled with unconsolidated alluvial deposits derived by erosion of the emerging mountain horst blocks, and from materials transported into the valley by the East and West Walker Rivers (Huxel and Harris 1969). The alluvial apron and the valley floor are the two major land-forms comprising the lowland area. The mountain blocks, and bedrock beneath the basins, are primarily composed of granitic, metamorphic, and volcanic rocks of Precambrian to Tertiary age and, to a lesser extent, of consolidated to semi-consolidated sedimentary rocks of Paleozoic to Cenozoic age (Heath 1984; Proffett and Dilles 1984; Proffett 1977). Faults along the eastern margin of the Singatse Range are gently- to steeply-dipping normal faults that generally trend north-northeast (Figure 4-1) and dip to the east (Proffett and Dilles 1984; Proffett 1977). Faulting caused moderate to steeply westward tilting of the bedrock.

Unconsolidated deposits underlying the valley floor are collectively termed valley-fill deposits and, where saturated, constitute the valley-fill alluvial aquifer. Huxel and Harris (1969) reported that the valley-fill deposits include four stratigraphic units: 1) younger alluvium, including lacustrine deposits associated with Pleistocene Lake Lahontan (Reheis 1999); 2) younger alluvial fan deposits resulting from the uplift of mountain blocks; 3) older alluvium; and 4) older alluvial fan deposits.

Older and younger alluvial fan deposits are generally coarse-grained, poorly-sorted, and have relatively few inter-bedded clay lenses (Huxel and Harris 1969; Plume 1996; Mifflin 1988). The grain size of the valley-fill deposits generally decreases toward the center of Mason Valley (Huxel and Harris 1969; Plume 1996), and transitional facies have been identified in the Study Area (BC 2008c). Basin-scale variability in valley-fill deposits leads to variation in hydraulic properties of the alluvial aquifer, which is discussed in Section 4.9.6.

Bedrock and alluvial deposits in Mason Valley, and their associated hydrologic characteristics, are summarized in Table 4-3, which is reproduced from Huxel and Harris (1969). Lake Lahontan lacustrine deposits of Pleistocene age have been eroded or reworked by the Walker River as it meandered across Mason Valley. Lake Lahontan strandline units, consisting of beach, bar, and beach-ridge deposits, were formed for the most part on alluvial aprons between altitudes of 4,340 and 4,375 feet amsl (Huxel and Harris 1969). The occurrence of Lake Lahontan within Mason Valley had a relatively short life, and probably was less than 60 feet deep during much of its existence (Morrison 1964).

Table 4-3. Mason Valley Geologic Units: Lithologic and Hydrologic Characteristics (from Huxel and Harris, 1969)

Geologic Age		Geologic Unit		Thickness (feet)	Lithology	Hydrologic Characteristics
Quaternary	Pleistocene to Holocene	Valley Fill	Younger Alluvium	0-100±	Loose, well-sorted sand, gravel, cobbles, and boulders, with layers of silt or sandy clay. Comprises channel, flood-plain, and terrace deposits laid down by the Walker River and its major tributaries, plus strand-line and bottom deposits of Pleistocene Lake Lahontan. Bottom deposits consist of silt, fine sand, and clay.	Channel and flood-plain deposits are highly permeable and are good aquifers. Significant infiltration of surface waters, which recharges the alluvial-fill aquifer, occurs through the coarse deposits in the Holocene channels of the Walker River.
			Younger Fan Deposits	0-100±	Poorly-sorted gravelly clay, sandy clay, and fine sand with occasional stringers and lenses of sand and gravel. Locally, derived from erosion of older rocks and deposits in Mason Valley; generally equivalent to younger alluvium.	In general, younger and older fan deposits are of low permeability. However, stock watering and mining wells penetrating buried sand and gravel deposits yield small to moderate amounts of water. Properly constructed, large-diameter wells may yield up to several hundred gpm.
	Pleistocene		Older Fan Deposits	0-700±	Sandy- to gravelly-clay with abundant cobbles and boulders and occasional lenses of semi-consolidated to cemented sand and gravel. Locally-derived from erosion of consolidated rocks of the surrounding mountains. Equivalent in part to older alluvium.	
			Older Alluvium	0-500±	Similar in lithology to younger alluvium described above. Deposited by ancestral Walker River; underlies valley floor at depths greater than 100 feet. Not exposed at land surface.	Constitutes largest and most productive aquifer in the area, with tested transmissibility as high as 270,000 gallons per day/foot. Wells yield up to 3,000 gpm.
Tertiary	Miocene and Pliocene	Consolidated Rocks	Sedimentary Rocks	--	Sandstone, mudstone, shale, marl, diatomite, and limestone. Includes interbedded tuffaceous rocks, lava flows, and breccia.	Consolidated rocks generally have low permeability. However, where they are fractured or jointed, they yield small to moderate amounts of water to wells.
	Oligocene to Pliocene		Volcanic Rocks	--	Rhyolite flows and tuff, andesite and dacite lava flows, breccia, and agglomerate. Includes interbedded sedimentary rocks and, locally, thin basalt flows with interbeds and scoriaceous basalt breccia.	
Cretaceous			Granitic Rocks	--	Granodiorite, quartz monzonite, and granite porphyry.	
Permian to Jurassic			Metamorphic Rocks	--	Metamorphosed andesite, basalt, and rhyolite flows, tuff and breccia, metamorphosed limestone, lime shale, dolomite, and gypsum and volcanically-derived sedimentary rocks.	

Bedrock in the Study Area forms a U-shaped graben structure that reaches its lowest point beneath the north end of the Hunewill Ranch, at an elevation of approximately 3,600 feet amsl (700 feet bgs). The elevations of the alluvium-bedrock contact, shown in plan view on Figure 4-2, clearly depict this graben structure in the Study Area. From its lowest elevation, bedrock rises in elevation south toward the Site. The U-shaped graben ends at the open pit and the alluvial-bedrock contact is exposed on the pit walls. The bedrock exposed in the open pit is the host rock for the Yerington copper porphyry deposit. East and west of the Site, bedrock rises to mapped outcroppings associated with the Singatse Range (west) and Singatse Spur (east; this term refers to two adjacent bedrock outcrops located east of the Site called the Ground Hog Hills and McLeod Hills as shown on Figure 4-2. At the north end of the Study Area, bedrock outcrops occur in the Sunset Hills area. In the northeast portions of the Study Area (i.e., toward the Mason Butte bedrock outcrop), bedrock rises in elevation. Range-bounding faults in the Study Area include steeply-dipping and shallower-dipping normal faults (Proffett and Dilles 1984).

The unconsolidated alluvial deposits in the Study Area were derived primarily from erosion of the uplifted mountain block of the Singatse Range, with minor deposition of fluvial sediments in the Walker River flood-plain. In addition, lacustrine deposits derived from ancestral Lake Lahontan occur north of the Site (Reheis 1999). Uplift and erosion of the Singatse Range formed the east-dipping alluvial fan deposits, which include distal facies that extend into the transitional environment. Concurrent with the development of the alluvial fan, flat-lying fluvial sediments (e.g., sands and gravels) were deposited in the Walker River flood-plain. Flat-lying clay-rich deposits have been preserved in the transitional setting, and these deposits are interpreted to have formed within the ancestral Lake Lahontan depositional environment.

Regional metal mineralization and hydrothermal alteration occurs in portions of Mason Valley, and the Singatse Range in particular, in areas of localized porphyry and skarn copper deposits. The Yerington copper porphyry district is located within the productive Walker Lane mineralized belt in western Nevada (Tetra Tech 2010). The Walker Lane is a northwest-trending zone of active crustal movement (i.e., right-slip transcurrent faulting) that extends for more than 500 miles from Las Vegas, Nevada to beyond Honey Lake, California (Bell and Slemmons 1979).

In addition to the Yerington and MacArthur open pit mines along the eastern margin of the Singatse Range, other areas of mineralization include the Bluestone and Ann Mason mines, and the Bear deposit. Areas of known mineralization and ore deposits in the Mason Valley are shown on Figure 4-3. The Bear deposit is located beneath the Sulfide Tailings and Hunewill Ranch, in a structurally-uplifted segment of the Singatse Range. The Pumpkin Hollow copper skarn deposit, located across Mason Valley from the Site, occurs along the margin of the intrusive rocks that host the Yerington porphyry copper deposit.

4.7 Surface Water Hydrology

The Mason Valley Basin (Basin no. 108, as defined by the NDWR) is located within the larger Walker River Hydrographic Basin (no. 9). The Walker River Hydrographic Basin extends from the Sierra Nevada Mountain Range above Bridgeport, California and Topaz Lake to Walker Lake located north of Hawthorne, Nevada. Most streamflows in the basin originate as snowmelt in the Sierra Nevada, with headwaters at elevations of more than 12,000 feet amsl (Lopes and Allander 2009a, 2009b).

The Walker River originates in two distinct headwater areas in the Sierra Nevada that source the East and West Walker Rivers (Figure 3-6). The East Walker River is sourced above Bridgeport, California. Streamflows are regulated before flowing into the Mason Valley. The West Walker River is sourced above Topaz Lake, a reservoir located along the California-Nevada border, and passes through the town of Wellington, Nevada on its way to the Mason Valley. The confluence of the East and West Walker Rivers occurs in Mason Valley at a location approximately seven miles upstream (three miles directly south) of the Site. The main stem of the Walker River flows north past the Site at the City of Yerington, traverses the geothermal discharge area near the town of Wabuska, exits the north end of Mason Valley at Walker Gap approximately 4.5 miles east of the town of Wabuska, and then turns south and empties into Walker Lake (a terminal lake with no outlet).

4.7.1 Surface Water Flows

Mason Valley is the largest irrigated agricultural area within the Walker River Basin including irrigated areas along the West and East Forks, and the main stem, of the Walker River. Key documents providing information on stream flows and water budgets in the Mason Valley include Huxel and Harris (1969), Lopes and Allander (2009b), and Carroll et al. (2010).

Each of these three documents present information on streamflows and water budgets for different periods of time. Appendix G-1 presents surface water flow information for 1948 to 2001, a period longer than addressed in these three documents. Streamflow and water budget information from these three documents and Appendix G-1 are summarized in Table 4-4 and discussed below.

Table 4-4. Summary of Mason Valley Streamflow and Water Budget Information

	Huxel and Harris (1969)	Lopes and Allander (2009b)	Carroll et al. (2010)	Flow Data Appendix G-1
Period of Record	1948 - 1965	1971 - 2000	1996 - 2006	1948 - 2011
	18-year Average	30-year Average	11-year Average	48-year Average (1)
Stream Inflows (acre-feet) (2)	216,000	269,000	277,832	207,900
Stream Diversions (acre-feet)	140,000	117,000	139,643	NA
Stream Outflows (acre-feet) (3)	107,200	138,000	129,471	80,400
Total Stream Loss (acre-feet) (4)	109,300	131,000	148,361	127,500
Stream Loss as Percent of Inflow	50%	49%	62%	NA
Irrigated Area (acres)	30,000	38,964	38,721	NA
Surface Water Diversion Rate (ft/yr) (5)	3.6	3.4	3.8	NA
Groundwater Pumpage (acre-feet/yr)	4,000	40,000	77,423	NA
Groundwater Application Rate (ft/yr) (6)	0.1	1.0	2.0	NA
Crop Consumption Rate (ft/yr)	1.0	1.6 (7)	2.9 - 3.1	NA

Notes:

1) Excludes 1979 - 1994 because flow data were not collected during winter months (October through March).
2) Sum of streamflow at Hudson (East Walker River) and Strosnider Ditch (West Walker River) gages (USGS gages 10300000 and 10293500, respectively).
3) Streamflow at Wabuska gage (USGS gage 10301500).
4) Total Stream Loss = Stream Inflows - Stream Outflows.
5) Surface Water Diversion Rate = Total Stream Loss/Irrigated Area.
6) Groundwater Application Rate = Groundwater Pumpage/Irrigated Area.
7) Value of 1.6 ft/yr from Myers (2001) cited by Lopes and Allander (2009b).
8) ft/yr = feet per year; % = percent; NA = not available

Lopes and Allander (2009b) provide a surface water budget for Mason Valley based on data collected from 1971 to 2000. Combined average annual inflows to Mason Valley were estimated to be 269,000 acre-feet per year. The average annual outflow from Mason Valley was estimated to be 138,000 acre-feet per year. The average net annual diverted surface water in Mason Valley was estimated to be 117,000 acre-feet per year. Stream infiltration and riparian evapotranspiration was estimated to be 14,000 acre-feet per year (Lopes and Allander 2009b).

An analysis of Walker River streamflow data from 1948 to 2011 (Appendix G-1) indicates a median annual flow at the confluence of the East and West Walker Rivers of 207,900 acre-feet. The minimum recorded flow was 65,900 acre-feet per year, and the maximum recorded flow was 596,500 acre-feet per year. Outflows from the Mason Valley are recorded near Wabuska, north of the Study Area. The median annual outflow was 80,400 acre-feet. The minimum recorded outflow was 15,800 acre-feet per year. The maximum recorded out flow was 417,900 acre-feet per year. In all months of all years, combined flows at the confluence of the East and West Walker Rivers were greater than outflows from the Mason Valley, with greater differences observed in summer months compared to winter months. Differences between inflows and outflows are accounted for by seepage losses, evapotranspiration and diversions for crop irrigation.

The disposition and routing of surface water within the Mason Valley is complex. Detailed information is provided in appendices to the *Groundwater Flow Model Yerington Mine Site* (SSPA 2014).

4.7.2 Recharge to the Alluvial Aquifer

Percolation of surface water is the primary source of groundwater recharge to the alluvial aquifer in the Mason Valley, with mountain-front recharge contributing significantly less (Carroll et al. 2010; Huxel and Harris 1969; Myers 2001; SSPA 2014). The amount of recharge derived by infiltration from stream channels, ditches, and percolation from flooded agricultural fields varies from year to year, depending upon the volume of Walker River flow entering the basin, the amount of surface water diverted from the river for irrigation, and the amount of available groundwater storage.

Huxel and Harris (1969) estimated that the annual recharge from the sources listed above ranged from 30,000 to 100,000 acre-feet, with an average of about 70,000 acre-feet, for the period from 1948 to 1965. These estimates were calculated as inflows minus the sum of surface-water outflows and consumptive use by crops and pastures, and assumed that all stream flows not consumptively used for irrigation or flowing out of the valley recharged the valley-fill alluvial aquifer. Carroll et al. (2010) estimated that recharge from the sources listed above ranged from 60,400 to 99,400 acre-feet per year for the time period 1996 to 2006, and noted the consistency between their more recent estimates and those provided by Huxel and Harris (1969).

The groundwater flow model water budget (SSPA 2014) indicates that the alluvial aquifer is primarily recharged by downward percolation from irrigated fields (49%), leakage from irrigation ditches such as the West and East Campbell Ditches (29%), infiltration from the channel of the Walker River (20%), and infiltration through bedrock of precipitation that falls on surrounding mountain ranges and minor tributary surface flows in ephemeral drainages (2%). Recharge from precipitation falling directly on the valley floor is negligible based on work by Huxel and Harris (1969) and Lopes and Allander (2009a, 2009b), as well as data from stable isotope (i.e., oxygen/deuterium) analysis of precipitation and groundwater (BC 2014a; EPA 2012b).

4.7.3 Surface Water Quality

Surface water quality is discussed below with a focus on data at sample locations SW-WR-01 (Walker River) and SW-WCD-01 (West Campbell Ditch), and chemicals considered primary indicators of mine-impacted groundwater (i.e., sulfate and uranium). A detailed analysis of the surface water quality data is presented in Appendix G-2. Chemical concentrations in Walker River and West Campbell Ditch samples are similar with low total dissolved solids (TDS) (110 to 300 mg/L; average: 194 mg/L) and relatively low sulfate (7.7 to 54 mg/L; average: 29 mg/L) and dissolved uranium (3.7 to 19 µg/L; average 9.3 µg/L). Surface water pH is slightly alkaline (7.72 to 8.36 s.u.; average: 8.05 s.u.). Temporal trends indicate more elevated major ion (e.g., sulfate, calcium and chloride) values and trace metal (e.g., dissolved arsenic and dissolved uranium) values in samples at both locations during the winter months relative to the summer months. Overall, the STORET surface water quality data are similar to the surface water quality data collected by ARC.

Shallow alluvial groundwater near the Walker River and West Campbell Ditch exhibits similar chemical characteristics to surface water quality, which is the primary source of groundwater in Mason Valley (Carroll et al. 2010; Huxel and Harris 1969; Myers 2001; SSPA 2014). General ion chemistry in groundwater was found to be statistically similar to surface water for five of eight major ions. Calcium, chloride, and sulfate were found to be higher in groundwater than surface water. Dissolved metals in groundwater were found to be statistically similar to surface water for some parameters (14 of 27) but different for others (13 of 27). However, differences between surface water and Shallow alluvial groundwater in major ions and dissolved metals reflect changes in geochemical conditions in groundwater arising from the effects of residence time, presence (or absence) of dissolved atmospheric gasses, localized mineralization, and influences from land-surface features that alter groundwater quality as it recharges from surface water sources.

4.8 Mason Valley Regional Hydrogeology

Groundwater conditions in Mason Valley are based on: 1) general characteristics of groundwater flow for the Basin and Range province; 2) investigations specific to the Mason Valley and/or the Walker River Basin; and 3) groundwater data available from the USGS and/or NDWR. The general conceptual model for groundwater flow in the Basin and Range province (Heath 1984; Maurer et al. 2004) is movement of groundwater in unconsolidated sediments deposited within the basins that occur between uplifted mountain blocks comprised of consolidated bedrock.

The groundwater flow system in Mason Valley consists of: 1) a heterogeneous valley-fill alluvial aquifer system comprised of laterally-discontinuous confining units of clay or other low-permeability sediments, and unconfined (i.e., water table), semi-confined, and confined aquifers; and 2) a relatively impermeable bedrock flow system underlying and bounding the alluvial aquifer with limited primary permeability and groundwater flow focused along faults and fractures (Maurer et al. 2004; Thomas 1995; Tetra Tech 2010; Huxel and Harris 1969).

Groundwater in the alluvial aquifer within Mason Valley generally flows from south to north toward the topographically lowest part of the valley at the northern end of the valley (Figure 4-4).

Similar water-level patterns are depicted in Huxel and Harris (1969, Plate 2), Lopes and Allander (2009a, Plate 1), and Tetra Tech (2010, Figure 24-3). Locally, groundwater flow directions are affected by: 1) bedrock outcrops within and along the margins of the valley; 2) drawdown from pumped wells; and 3) irrigation activities on cultivated fields. The Walker River is generally a losing stream except in the far northeastern portion of the valley where it is generally a gaining stream. Water level elevations shown on Figure 4-4 are based on USGS monitor well data from October through December 2010 when agricultural pumping was limited or non-existent. Table 4-5 summarizes the USGS wells and water level data used to develop the water table (i.e., alluvial aquifer potentiometric surface) map shown on Figure 4-4.

Table 4-5. 2010 USGS Monitor Well Data for Mason Valley

USGS Site Number	Site Name	Latitude	Longitude	Surface Elev. (feet amsl)	Vertical Datum	Measure-ment Date	Depth to Water (feet)	Water Elev. NGVD29 (feet amsl)	Well Depth (feet bgs)	Boring Depth (feet bgs)	Number of Measurements
391655119330901	103 N16 E22 06ACD1 HIWAY 50	39.28200000	119.5524167	4352.1	NAVD88	10/13/10	55.4	4293.29	96	96	154
391729119294501	103 N17 E22 34DBDD1 EUREKA	39.29147220	119.4957500	4283.8	NAVD88	10/14/10	10.06	4270.35	35	35	101
391711119303301	103 N16 E22 04AAAD1 RA-4	39.28647220	119.5091667	4288.5	NAVD88	10/14/10	4.8	4280.30	14	14	69
391625119324801	103 N16 E22 07AAAA1 R-3	39.27352778	119.5468056	4303.9	NAVD88	10/14/10	9.07	4291.42	35	35	66
391605119331901	103 N16 E22 07ACCB1 R-2	39.26797220	119.5551389	4308.1	NAVD88	10/14/10	8.27	4296.41	30	30	64
384942119100801	108 N11 E25 10DBCD1	38.82802778	119.1703610	4565	NGVD29	11/23/10	98.14	4466.86	597	597	42
390715119095901	108 N15 E25 34ACDD1	39.12075170	119.1673767	4292	NGVD29	11/22/10	13.48	4278.52	370	370	41
390006119043901	108 N13 E26 09DBCC1	39.00158530	119.0784852	4396	NGVD29	11/24/10	60.37	4335.63	166	166	39
390011119060201	108 N13 E26 08CACA1	39.00297394	119.1015412	4367	NGVD29	11/24/10	21.88	4345.12	130	130	37
390127119030001	108 N13 E26 02BBCC1	39.02408569	119.0509851	4406	NGVD29	11/24/10	87.92	4318.08	203	203	36
390203119055101	108 N14 E26 32BDDD1	39.03408520	119.0984860	4352	NGVD29	11/30/10	13.56	4338.44	104	104	32
385903119073001	108 N13 E25 13DDDD1	38.98408457	119.1259859	4380	NGVD29	11/24/10	16.92	4363.08	280	280	32
390531119115901	108 N14 E25 08ADDC1	39.09186235	119.2007101	4320	NGVD29	11/22/10	30.73	4289.27	523	523	32
385720119085001	108 N13 E25 26DDCC1	38.95547285	119.1482085	4409	NGVD29	11/24/10	26.14	4382.86	160	NA	31
385255119090501	108 N12 E25 23DCC 1	38.88186075	119.1523750	4462	NGVD29	11/23/10	15.84	4446.16	325	325	31
385456119091901	108 N12 E25 11CACD1	38.91547224	119.1562641	4439	NGVD29	11/23/10	21.5	4417.50	245	245	31
390137119065402	108 N14 E26 31DCCC2	39.02686280	119.1159861	4357	NGVD29	11/30/10	13.44	4343.56	400	400	30
390558119094701	108 N14 E25 03DDDC1	39.09936270	119.1640431	4323	NGVD29	11/22/10	20.54	4302.46	85	258	30
390611119110301	108 N14 E25 04DACC1	39.10297367	119.1851545	4321	NGVD29	11/22/10	20.75	4300.25	451	451	30
385447119075901	108 N12 E25 12CDAA1	38.91297248	119.1340414	4476	NGVD29	11/23/10	59.94	4416.06	102	102	28
390004119103001	108 N13 E25 10CDB 1	39.00102868	119.1759868	4380	NGVD29	11/30/10	9.19	4370.81	328	328	27
390026119090401	108 N13 E25 11ACBD1	39.00714008	119.1520976	4370	NGVD29	11/24/10	13	4357.00	435	435	25
385717119080901	108 N13 E25 25CDDA2	38.95463960	119.1368194	4419	NGVD29	11/24/10	33.88	4385.12	106	106	21
385109119085601	108 N12 E25 35DCDD2	38.85241595	119.1498750	4505	NGVD29	11/22/10	35.38	4469.62	NA	NA	20

Table 4-5. 2010 USGS Monitor Well Data for Mason Valley

USGS Site Number	Site Name	Latitude	Longitude	Surface Elev. (feet amsl)	Vertical Datum	Measurement Date	Depth to Water (feet)	Water Elev. NGVD29 (feet amsl)	Well Depth (feet bgs)	Boring Depth (feet bgs)	Number of Measurements
385003119085201	108 N11 E25 11AACC1	38.83408240	119.1487638	4565	NGVD29	11/23/10	97.14	4467.86	256	256	19
390057119080001	108 N13 E25 01DBCC1	39.0157514	119.1343196	4365	NGVD29	11/19/10	19.96	4345.04	570	570	19
385047119080401	108 N11 E25 01ACCB1	38.84630495	119.1354302	4547	NGVD29	11/23/10	75.13	4471.87	526	526	18
385018119091101	108 N11 E25 02CDDD1	38.83813889	119.1538889	4544	NGVD29	11/23/10	73.59	4470.41	554	560	17
385718119101301	108 N13 E25 27DCCD2	38.95491700	119.1712645	4409	NGVD29	11/23/10	19	4390.00	440	440	17
390152119104401	108 N14 E25 34CBCA2	39.03102880	119.1798760	4362	NGVD29	11/30/10	25.56	4336.44	415	430	14
391741119150601	102 N17 E24 35DAAB1 OLD BUCKLANDS STATION	39.29472220	119.2516667	4203	NGVD29	10/12/10	16.23	4186.77	93	93	14
391610119115801	102 N16 E25 05DCCA1 USBLM	39.27464167	119.2004333	4219	NGVD29	10/12/10	70.24	4148.76	127	NA	12
391757119151801	102 N17 E24 35ACAA1 OLD WEEKS SIDING	39.29916667	119.3050000	4206	NGVD29	10/12/10	18.28	4187.72	23	23	11
392522119101901	102 N18 E25 15CBCA1 STUCCO	39.42288889	119.1718889	4213	NAVD88	10/12/10	57.72	4152.13	200	200	11
392546119121201	102 N18 E25 17BDAA TRAILER GRAVEYARD	39.42947220	119.2034167	4201	NAVD88	10/12/10	14.92	4182.94	170	170	11
392222119075101	103 N17 E25 01BAB1 E OF LAHONTAN	39.37283330	119.1307222	4202	NAVD88	10/12/10	61.18	4137.68	72	72	9
390416119112401	108 N14 E25 16DCCB1 CMPBLL SHALLOW	39.07097220	119.1900833	4336	NGVD29	11/22/10	20.14	4315.86	25	25	8
385249119221401	107 N12 E23 26ABAD1 85471	38.8803611	119.3706667	4729	NGVD29	11/18/10	13.76	4715.24	340	340	8
391727119190701	103 N17 E24 32CDBB1 BULL CANYON	39.29088889	119.3184722	4250.5	NAVD88	11/15/10	27.8	4219.363	41	41	8
391706119322601	103 N16 E22 05BACD1	39.28488889	119.5405556	4345	NAVD88	10/23/10	59.9	4281.691	182	182	8
391709119314001	103 N16 E22 04BBCB1 CARDELLI	39.28569444	119.5278333	4304.5	NAVD88	11/15/10	15.85	4285.244	39	39	2

Notes:

1) All groundwater elevation data downloaded from USGS website http://nwis.waterdata.usgs.gov/nv/nwis/gwlevels, accessed on August 15, 2011.
2) amsl = above mean sea level; bgs = below ground surface; NA = not available.

Hydraulic properties of the basin-fill sediments of Mason Valley vary both laterally and vertically because of variable depositional facies and environments observed in the valley. The transmissivity of the basin fill deposits was stated by Huxel and Harris (1969) to generally range from 6,700 ft^2/day to 27,000 ft^2/day. Based on an average basin-fill thickness of 500 feet, this is equivalent to average hydraulic conductivities in the range of 13 ft/day to 53 ft/day. Based on unspecified geotechnical investigations, Nork (1989) reported hydraulic conductivity values ranging from 0.35 to 0.50 feet per day (ft/day) for older alluvial fan deposits. Consolidated rocks beneath the unconsolidated basin-fill sediments and/or comprising the adjacent mountain ranges have low hydraulic conductivities, but may transmit water where fractures are open and interconnected (Lopes and Allander 2009a). Nork (1989) reported hydraulic conductivity values ranging from 0.23 to 1.5 ft/day for weathered intrusive rocks in the Mason Valley area.

Groundwater in Mason Valley is primarily recharged by downward percolation of surface water diverted from the Walker River to irrigation ditches and irrigated fields, downward percolation of groundwater applied to irrigated fields, and infiltration of surface water from the channel of the Walker River. To a lesser degree, valley-fill sediments are also recharged by mountain-front recharge (MFR), which includes a variety of hydrologic processes such as partitioning of precipitation and snowmelt into deep infiltration through bedrock (i.e., along faults and fractures), surface runoff, focused flow and subflow along mountain stream channels and alluvial fans, and diffuse movement of groundwater through the underlying mountain block (Wilson and Guan 2004; Huxel and Harris 1969; Myers 2001). Huxel and Harris (1969) considered recharge from direct precipitation on the valley floor to be negligible. Recharge from irrigation water and seasonal pumping of irrigation wells affects the vertical flow of groundwater in the alluvial aquifer (i.e., a seasonal increase in the downward vertical gradient in the alluvial aquifer).

Discharge from the Walker River Basin occurs as evapotranspiration from irrigated crops and natural vegetation (e.g., phreatophytes and wetland vegetation) as described by Heath (1984) and Carroll et al. (2010), and as direct evaporation from shallow groundwater (Huxel and Harris 1969; Lopes and Allander 2009a). Huxel and Harris (1969, Plate 2) identified an area of artesian

conditions (17 flowing wells) in the northern portion of Mason Valley where the alluvial aquifer thins and pinches out, and reported that groundwater in this area exhibited elevated specific conductance values (i.e., dissolved solids concentrations) due to evapoconcentration and possible effects of geothermal discharge associated with the Wabuska Lineament.

Lopes and Allander (2009a, 2009b) report that: 1) in 2008, no flowing wells were observed in the Wabuska area due to groundwater pumping; 2) water depths in this area were less than five feet, and efflorescent salts formed where groundwater evaporated from the shallow water table; and 3) pumping in Mason Valley since the early 1960s had caused groundwater levels to decline as much as 60 feet. The long-term decline in water levels is reflected in Site hydrographs for select monitor wells that cover the time period from 1985 to 2015, as shown on Figure 4-5. In addition to factors described above, the sharp decline in the 1980's in water levels in well UW-1S, located near the northern end of the Process Areas, is in part attributed to cessation of mining activities in 1978. Discharge of groundwater through bedrock from the Mason Valley Basin to other groundwater basins may occur, but is limited (Thomas 1995; Tetra Tech 2010).

4.9 Site and Study Area Local Hydrogeology

A generalized hydrogeologic south-north cross-section with a vertical exaggeration of 20V:1H is presented in Figure 4-7 (location shown on Figure 4-6). This cross-section (A-A') transects the Study Area and extends from well B/W-13S, which is the southernmost well in the Study Area, to a monitor well cluster, B/W-82R, which is located at the north end of the Study Area.

The south-north cross-section depicts: 1) the alluvial materials in the valley-fill alluvial aquifer within the Study Area; 2) the alluvial aquifer zone designations; 3) the occurrence of bedrock outcrops at the open pit and the north end of the Study Area; 4) the water table elevation in the alluvial aquifer in August 2015; 5) the depth of the open pit and the Pit Lake level in August 2015; and 6) the cone-of-depression associated with the open pit. The water table in the Shallow zone of the alluvial aquifer generally slopes toward the north on this cross-section, though the elevation of the water is relatively flat in much of the Site.

4.9.1 Depth to Groundwater

Contour maps of the depth to groundwater (i.e., depth to water table) below the ground surface in February 2015 and August 2015 are presented on Figures 4-8 and 4-9, respectively. February 2015 and August 2015 represent the non-irrigation and irrigation seasons, respectively. The depth to groundwater is typically less than 20 feet beneath irrigated areas such as the Hunewill Ranch and between monitor wells B/W-59S and B/W-68S. In areas beneath the Site, beneath the Sunset Hills neighborhood, and in the northern portions of the Study Area, the depth to groundwater is greater than 20 feet. To the west of the Site and beneath the Process Areas, the depth to groundwater exceeds 100 feet. Between February 2015 and August 2015, the depth to groundwater beneath irrigated portions of the Study Area as well as beneath the Evaporation Ponds uniformly increased by up to three feet (i.e., the water table declined) due to depletion of groundwater by agricultural pumping. Depth to groundwater fluctuations in other parts of the Study Area were minor.

4.9.2 Saturated Alluvial Thickness

The thickness of saturated alluvium in the Study Area in August 2015 is shown on Figure 4-10, which is similar in shape to the alluvium-bedrock contact map shown on Figure 4-2 (the similarity results from a relatively flat water table beneath the Study Area). On Figure 4-10, the line denoting the approximate lateral extent of saturated alluvium represents the zero-foot contour line (i.e., saturated alluvium does not occur outside of this contour line). Saturated alluvium is bounded to the west by the Singatse Range, to the northwest by the bedrock outcrops in the Sunset Hills area, to the northeast by the Mason Butte bedrock outcrop, to the east by the Singatse Spur, and to the south by the local bedrock high exposed within the open pit and, locally, by that portion of the Singatse Range located south of the Site. As shown on Figure 4-10, saturated alluvium is thickest (more than 700 feet) beneath the northern portion of the Hunewill Ranch.

4.9.3 Alluvial Groundwater

Potentiometric surface maps for the various alluvial aquifer zones in August 2015 are provided in Figure 4-11. Groundwater flow in August 2015 in the Study Area was generally to the north/northwest in the Shallow, Intermediate, and Deep 1 zones, and to the northeast in the Deep

2 through Deep 5 zones. Locally, the flow of groundwater in the Study Area is affected by: 1) the cone-of-depression around the Pit Lake, which is a hydraulic sink for alluvial and bedrock groundwater; 2) recharge sources such as the Walker River, the West Campbell Ditch and irrigation on the Hunewill Ranch; 3) bedrock in the Singatse Range to the west of the Site, which serves as a low flux boundary condition; 4) bedrock outcrops on the eastern margin of the Site (the Singatse Spur, comprised of the Ground Hog Hills and McLeod Hill), which impede groundwater flow from the West Campbell Ditch and the Walker River to the alluvium beneath the Site; 5) bedrock ridges north of the Site associated with the Sunset Hills and Mason Butte, which affect the direction of groundwater flow in the northeastern portions of the Study Area; and 6) drawdown from pumped wells (particularly in deeper zones of the alluvial aquifer).

As seen on the Shallow zone potentiometric surface map (Figure 4-11a), the Pit Lake is currently a hydraulic sink that is refilling with groundwater predominantly derived from alluvial groundwater recharged locally from the Walker River and, to a lesser extent, bedrock groundwater (Hershey 2002). As noted in Section 3.3.2, the lake is and will continue to be a groundwater sink due to the large amount of evaporation that occurs from the lake surface.

Saturated alluvium is in contact with the Pit Lake on the western margin of the open pit (Figure 4-11a). However, groundwater gradients in this area are toward the Pit Lake, and alluvial groundwater recharges the Pit Lake rather than the Pit Lake recharging the alluvial aquifer. On the eastern margin of the open pit, groundwater derived from seepage from the Walker River flows into the pit. Beneath the Process Areas, the Pit Lake cone-of-depression creates a groundwater divide in the Shallow zone (Figure 4-11a). Because of local bedrock elevations, only the Shallow, Intermediate, and a limited portion of the Deep 1 zones exist in this area (Figures 4-11 a through c, respectively).

North of the Site, recharge from the Walker River and its surface water diversions, as well as irrigation practices in the Study Area, are the primary influences on groundwater flow directions. In the Shallow, Intermediate, and Deep 1 zones, groundwater flow directions are away from, or parallel to, the Walker River and West Campbell Ditch (i.e., north/northwest), indicating recharge

of the alluvial aquifer from these features. In addition, groundwater mounding beneath irrigated areas is observed in these zones. As this recharged water percolates deeper into the Deep 2 through Deep 5 zones of the alluvial aquifer, the groundwater flow direction rotates to the northeast as relatively impermeable bedrock results in alluvial groundwater flow toward the trough in the alluvial-bedrock contact between the Sunset Hills and Mason Butte.

Irrigation practices on the Hunewill Ranch, located immediately north of the Site, locally affect groundwater flow conditions. Historically, irrigation practices on the Hunewill Ranch included seasonal diversion of surface water from the Walker River via the West Campbell Ditch and pumped groundwater, as necessary, from up to three wells. These three wells were located within 2,500 feet of the B/W-1 monitor well cluster and included Well Log No. 82983 (also referred to as WDW019), Well Log No. 26694, and Well Log No. 78925. Well WDW019 and other underground water rights points of diversion are shown on Figure 3-8. Groundwater pumping from the Hunewill Ranch wells to support agricultural irrigation ceased in September 2009. In 2011 and subsequent years, crops on the Hunewill Ranch were irrigated with surface water diverted from the Walker River and groundwater pumped from a nearby parcel located near the Walker River to the east. Additional information about these wells is provided in the *Aquifer Test Data Summary Report - Revision 1* (BC 2012e).

Potentiometric surface maps for the Shallow through Deep 2 zones (Figures 4-11a through 4-11d) have been outfitted with rose diagrams at select locations to illustrate seasonal changes in groundwater flow directions resulting from the historical and current irrigation practices on the Hunewill Ranch. Rose diagrams indicate the relative frequencies of groundwater flow directions over a period of time. Monthly groundwater flow directions were calculated by using water level measurements in sets of three monitoring wells to estimate the slope and direction of slope of a plane connecting the water levels in the three wells. This approach is commonly referred to as a "three-point problem" (EPA 2014c). Rose diagrams were generated for two time periods: 1) 2008 - 2009 to illustrate historical irrigation practices associated with operation of the Hunewill Ranch pumping wells; and 2) 2010 - 3Q 2015 to illustrate current irrigation practices.

Both historical and current irrigation practices for the Hunewill Ranch created a groundwater mound in the Shallow, Intermediate, and Deep 1 zones of the alluvial aquifer due to infiltration of applied irrigation water. Mounding was most pronounced beneath the Hunewill Ranch fields, and the mound extended beyond the edges of the fields including beneath the Wabuska Drain, which collects and diverts agricultural runoff. The rose diagrams for the Shallow, Intermediate, and Deep 1 zones (Figures 4-11a through 4-11c) indicate that, in both time periods, the mound beneath Wabuska Drain predominantly acted as a groundwater divide, directing recharged groundwater: 1) to the west/southwest beneath the Evaporation Ponds; and 2) to the east/northeast beneath the Hunewill Ranch. The rose diagrams also indicate that, in a small number of months, the groundwater divide was not present and groundwater flow directions were from the east beneath the Hunewill Ranch to the west beneath the Evaporation Ponds. This east-to-west flow predominantly occurred in winter months when irrigation was not occurring.

Historical irrigation practices for the Hunewill Ranch prior to 2010, which included seasonal groundwater pumping and surface application to the fields, created a cone-of-depression around WDW019 that was most pronounced in the Deep 1 through Deep 3 zones but was also manifested in the Shallow and Intermediate zones (BC 2014a). The cone-of-depression in the combined Deep 1 through Deep 3 zones extended beneath the Sulfide Tailings area and the Evaporation Ponds, and as far north as the Sunset Hills neighborhood. Figure 4-12 provides monthly water level hydrographs of Shallow and Deep monitor wells in the B/W-1 and B/W-27 well clusters (located beneath and adjacent to the Hunewill Ranch, respectively) that illustrate the hydraulic head drawdown during and after operation of the Hunewill Ranch pumping wells. Although agricultural pumping in the Study Area continues to affect hydraulic head in wells B/W-1D3 and B/W-27D2, hydraulic head drawdown in these wells was up to three times greater during operation of the Hunewill Ranch pumping wells than it has been in recent years.

The rose diagrams for the Deep 2 zone (Figure 4-11d) indicate that, under both historical and current irrigation practices, groundwater between the Site and the B/W-1 well cluster has been toward the northeast as the result of agricultural pumping, with occasional periods of northward groundwater flow corresponding with winter months when irrigation was not occurring. Beneath

the Evaporation Ponds, the rose diagrams indicate differing distributions of groundwater flow directions between historical and current irrigation practices. Groundwater flow directions in the Deep 2 zone beneath the Evaporation Ponds have been predominantly to the west/northwest in both time periods. However, the large cone of depression that was present during operation of the Hunewill Ranch pumping wells caused on-Site water beneath the Evaporation Ponds to occasionally flow east/northeast to off-Site areas beneath the Hunewill Ranch.

Figure 4-13 presents monthly vertical groundwater gradients in the alluvial aquifer at select locations. Vertical gradients were calculated as the difference in water levels between the shallowest and deepest alluvial monitoring wells in a cluster divided by the distance between the midpoints of the screened intervals of the wells. If a well was screened across the water table, then the water table elevation was used in place of the midpoint of the screened interval for that well. Monthly vertical gradients were calculated using water level measurements from 2013, which was the last full calendar year during which water levels in all active monitor wells were measured monthly. For wells installed after 2013 pursuant to the Additional Monitor Well Work Plan (BC 2013b), monthly vertical gradients were calculated using water level measurements from September 2014 through August 2015. Where available, monthly vertical gradients were also calculated using water level measurements from 2009 to illustrate groundwater conditions during operation of the Hunewill Ranch pumping wells.

Alluvial vertical gradients beneath the Process Areas are generally upward (PA-MW-4 well cluster), reflecting potential discharge of bedrock groundwater to alluvium as a potential source of groundwater to this portion of the Site (i.e., mountain-front recharge). Beneath the Evaporation Ponds (B/W-11 well cluster) and Hunewill Ranch (B/W-1 well cluster), alluvial vertical gradients are downward, with stronger vertical gradients corresponding to months when irrigation, and thus groundwater recharge and pumping, occurs. In addition, alluvial vertical gradients were even more strongly downward in these areas in 2009 when the Hunewill Ranch pumping wells were operating. In other irrigated areas (i.e., B/W-68 and B/W-81 well clusters), alluvial vertical gradients are also consistently downward, again with stronger vertical gradients in months when irrigation occurs.

Immediately northwest of the Site at the B/W-41 well cluster, vertical gradients are upward in the winter months, reflecting potential discharge of bedrock groundwater to alluvium (i.e., mountain-front recharge), and downward in the summer months, reflecting the influences of agricultural pumping. Downward vertical gradients at the B/W-41 well cluster are approximately two orders of magnitude smaller than the downward vertical gradients in irrigated areas, reflecting the greater distance of B/W-41 from irrigated areas. The B/W-28 well cluster (located in the Sunset Hills neighborhood) also exhibits seasonal changes in the direction of vertical gradients - upward vertical gradients occur in the winter (reflecting the non-irrigation season) and downward vertical gradients occur in the summer (reflecting the influences of agricultural pumping). In 2009, the effects of operation of the Hunewill Ranch pumping wells, in addition to other agricultural pumping in the Study Area, caused strongly downward vertical gradients that resulted in water levels in monitor well B/W-28S to decline below the bottom of the screened interval in August and September.

4.9.4 Groundwater Recharge

Recharge to the alluvial aquifer in the Mason Valley primarily occurs from surface water diverted from the Walker River within unlined irrigation ditches, infiltration of surface water and groundwater applied to irrigated fields, and infiltration of surface water from the channel of the Walker River. Recharge to the alluvial aquifer also occurs along the range front via a variety of hydrologic processes.

As indicated above, infiltration of surface water is the primary source of groundwater recharge to the alluvial aquifer in the Mason Valley, with MFR contributing significantly less (Carroll et al. 2010; Huxel and Harris 1969; Myers 2001; SSPA 2014). The annual amount of recharge derived by infiltration from stream channels, ditches, and agricultural fields is a function of Walker River flows, the volumes of surface water and groundwater used for irrigation, and water table depths within Mason Valley.

Hydrologic tracer data for tritium/helium ($^3H/^3He$) groundwater age estimates (Figure 4-14) and uranium isotopes (Figure 4-15) are consistent with the two principal recharge components of the HCSM: 1) seepage from the Walker River and irrigation ditches, and infiltration from irrigated fields on the east margins of the Study Area; and 2) MFR on the west side of the Study Area adjacent to the Singatse Range.

The use of groundwater uranium isotopes (and their relationship to tritium/helium groundwater age estimates) is briefly summarized as follows. In groundwater systems, ^{234}U is more environmentally mobile than ^{238}U due to physical recoil of the atom following alpha decay of ^{238}U, and the subsequent displacement of the ^{234}U atom to weaker binding sites within the crystalline lattice of the mineral in which it is contained. Thus, the two isotopes are released (weathered) at different rates, and the $^{234}U/^{238}U$ ratio is generally greater than unity in natural waters. Changes in the isotopic ratios (and uranium excess [Ue] values derived from the ratios) are assumed to be solely associated with transport/contact time between groundwater and aquifer solids. Consequently, high Ue values are associated with “long” periods of contact between groundwater and aquifer solids (i.e., “old” water) whereas low Ue values are associated with “short” periods of contact between groundwater and aquifer solids (i.e., “young” water). However, $^{234}U/^{238}U$ ratios in mine-impacted groundwater are also close to unity (resulting in low Ue values) because acidic process solutions leach both isotopes from ore material with equal effectiveness (Iles et al. 1995).

On the east side of the Study Area, Shallow zone alluvial groundwater directly recharged by surface water commonly exhibits younger, more modern age estimates and low Ue values. Low Ue values are also observed in mine-impacted Shallow zone groundwater beneath the Evaporation Ponds. In contrast, the older groundwater age estimates and highest Ue values commonly occur on the west side of the Study Area adjacent to the Singatse Range, in Deep alluvial groundwater, and in bedrock groundwater. An exception to the typical vertical distribution of higher Ue values and older groundwater age estimates is evident at the B/W-1 well cluster where younger groundwater age estimates and lower Ue values occur locally in the Deep groundwater zones.

This local pattern of Ue values and groundwater age estimates around the B/W-1 well cluster is consistent with the HSCM, which recognizes groundwater mixing due to agricultural pumping, especially former pumping at (which is located adjacent to the B/W-1 well cluster). Pumping at WDW019 has resulted in the migration of mine-impacted groundwater present beneath the Evaporation Ponds into the Intermediate and Deep zones of the alluvial aquifer beneath the Hunewill Ranch.

4.9.5 Alluvial Aquifer Hydraulic Property Data

Hydraulic conductivity values in alluvium from slug tests (Appendix F-1) range from 0.04 to 157 ft/day, with a median value of 6.8 ft/day. The 25th and 75th percentiles are 3.1 ft/day and 22.0 ft/day, respectively. Hydraulic conductivity values in alluvium calculated from an analysis of low-flow sampling data (Appendix F-2) range from 0.08 to 240 ft/day, with a median value of 18.4 ft/day. The 25th and 75th percentiles are 6.8 ft/day and 33.6 ft/day, respectively. Statistical analyses indicate that: 1) hydraulic conductivity values in each alluvial zone exhibit similar ranges, median values, and distributional shapes; and 2) hydraulic conductivity values throughout the alluvial aquifer are statistically equivalent in their distributions from zone to zone. Hydraulic conductivity estimates for the individual groundwater zone are provided in Table 4-6.

Table 4-6. Hydraulic Conductivity by Groundwater Zone (from Slug Test Data)

Zone	Median K (ft/day)	Standard Deviation (ft/day)	Count
Shallow	6	24	81
Intermediate	6	23	35
Deep 1	8	25	38
Deep 2	4	11	15
Deep 3	4	16	13
Deep 4	31	33	5
Deep 5	14	7	6
Bedrock	2	74	32

Notes: K = hydraulic conductivity.

Constant-rate testing of the eleven pumpback wells in 2010, which are screened in the Shallow zone (Appendix F-3), resulted in hydraulic conductivity estimates ranging from 0.9 to 47 ft/day (median of 9.4 ft/day). Slug testing of piezometers (33 in total, all screened in the Shallow zone) installed near the PWS, that were used as observation wells during constant-rate pumping tests of the 11 pumpback wells during 2010 (Appendix F-4), provided hydraulic conductivity estimates ranging from 1.1 to 83ft/day (median of 4.1 ft/day). Testing of five pumpback wells (PW-6, PW-7, PW-9, PW-10 and PW-11) in 2000 yielded hydraulic conductivity estimates that ranged from 6.4 to 33 ft/day, with a geometric mean of 16 ft/day, based on an assumed aquifer thickness of 50 feet (AHA 2000).

A constant-rate test of well WDW019, using an observation network of 93 monitor wells, resulted in estimated values for hydraulic conductivity and specific storage at 61 observation wells that exhibited pumping-related responses (Appendix F-5). Hydraulic conductivity values in alluvium derived from constant-rate pumping tests of WDW019 ranged from 4.9 to 1,200 ft/day, with a median value of 77 ft/day. The 25th and 75th percentiles are 38 ft/day and 195 ft/day, respectively. Five hydraulic conductivity values in bedrock ranged from 13.0 to 92 ft/day.

Specific storage values in alluvium from constant-rate pumping tests of WDW019 range from 1.45×10^{-8} to 1.46×10^{-3} $(\text{feet})^{-1}$, with a median value of 1.14×10^{-5} $(\text{feet})^{-1}$. The 25th and 75th percentiles are 5.16×10^{-6} $(\text{feet})^{-1}$ and 2.73×10^{-5} $(\text{feet})^{-1}$, respectively.

4.9.6 Spatial Variation in Hydraulic Conductivity

The spatial distributions of slug-test hydraulic conductivities in each alluvial groundwater zone are shown on Figure 4-16, and bedrock slug-test hydraulic conductivities are shown on Figure 4-17. Slug-test hydraulic conductivities represent the largest hydraulic conductivity dataset for evaluating spatial variation within the Study Area. To date, 295 measurements of hydraulic conductivity have been obtained using slug-test methods (Appendix F-1).

Although analysis of drawdown measurements during low-flow sampling of monitor wells has yielded more measurements of hydraulic conductivity than slug testing (318 measurements versus 295 measurements through August 2015), the approach has limitations that that do not capture the highest and lowest values of hydraulic conductivity in the Study Area. Due to the low flow rates used, measurable drawdown (i.e., drawdown exceeding 0.01 feet) does not occur during the sampling of many monitor wells that have sufficiently high hydraulic conductivities. In practice, hydraulic conductivities of greater than 100 ft/day cannot be determined with this method. Conversely, most monitor wells that have hydraulic conductivities less than 0.1 ft/day never achieve steady-state drawdown conditions during low-flow sampling (i.e., the water level in the monitor well continues to fall during the entire sampling period).

Spatial variation in slug-test hydraulic conductivities reflects the heterogeneous lithology of the alluvium underlying the Study Area. Alluvial slug-test hydraulic conductivities beneath the Site (i.e., beneath the Process Areas, Sulfide Tailings, and the Evaporation Ponds) are generally in the range of 1 to 10 ft/day, with some infrequent exceptions. To the west of the Site, along the margin of the Singatse Range, alluvial slug-test hydraulic conductivities extend into the range of 10 to 100 ft/day, with some locations still in the range of 1 to 10 ft/day. This trend continues north to towards the Sunset Hills. Beneath the Hunewill Ranch, alluvial aquifer slug-test hydraulic conductivity values generally range from 1 to 50 ft/day, with noted high conductivity exceptions at monitor wells B/W-60S, B/W-61S, and B/W-60D1.

Alluvial slug-test hydraulic conductivities near the Walker River (east of the Pit Lake) are generally higher than alluvial slug-test hydraulic conductivities beneath the Site, as evidenced by monitor wells B/W-13S, B/W-14S, B/W-15S, B/W-21S, and PLMW-2S. In this area, alluvial slug-test hydraulic conductivities are in the range of 10 to 50 ft/day. North of the Site and east of the West Campbell Ditch, alluvial slug-test hydraulic conductivities are also high, generally ranging from 10 to 100 ft/day or higher.

The spatial variability of alluvial slug-test hydraulic conductivity values reflects the varied depositional environments in Mason Valley, which are discussed in Section 4.8. The areas beneath the Site represent older fan deposits, which typically display lower permeability compared to the valley-fill sediments (i.e., younger and older alluvium). North of the Site, a transitional environment with higher permeability exists between the older fan deposits and the valley-fill sediments. Areas near the Walker River and generally to the east of West Campbell Ditch appear to represent valley-fill sediments, which exhibit the highest overall permeability. To the west of the Site, a narrow north-south trending band of higher permeability aquifer materials occurs along the flank of the Singatse Range, which represents coarser-grained alluvial fan materials eroded from the Singatse Range.

4.9.7 Bedrock Groundwater

The conceptual model of OU-1 bedrock groundwater flow conditions is based on regional and Site-specific information, including: 1) the lithologic and structural geology information presented in Proffett and Dilles (1984), and Proffett (1977); 2) a general understanding of bedrock groundwater flow in the Great Basin portion of the Basin-and-Range Physiographic Province; 3) hydrogeologic information obtained from drilling, lithologic logging, testing, and monitoring of 67 bedrock groundwater monitor wells located in the OU-1 Study Area (typically installed with 20-30 foot long screen intervals positioned in the upper 50 feet of bedrock); 4) evaluation of hydraulic head data in the bedrock and alluvial groundwater systems; 5) hydrologic tracer data for stable isotopes of oxygen and hydrogen in water ($^{18}O/^{2}H$), tritium/helium ($^{3}H/^{3}He$) groundwater age estimates, and uranium isotopes; and 6) bedrock monitor well chemical data.

As noted previously, the Site and surrounding Study Area are in a U-shaped graben structure on the western margin of Mason Valley. Within the Study Area, the depth to bedrock is highly variable and ranges from 0 to 750 feet bgs. Bedrock within the Mason Valley and Study Area is comprised of consolidated granitic, metamorphic, and volcanic rocks. The bedrock groundwater system consists of a fractured rock aquifer where water moves predominantly through fracture porosity, and matrix permeability is considered negligible. The fractures occupy only a small fraction of the bedrock.

Large-scale geologic structures (i.e., faults) result in structural compartmentalization of the bedrock groundwater system in the Study Area, with limited groundwater flow across and along faults that are commonly characterized as containing fine-grained, low-permeability fault gouge and brittle or plastic clay. The fractured rock aquifer exhibits high, three-dimensional (i.e., anisotropic) spatial variability in hydraulic conductivity (and hence groundwater flow rate). Hydraulic conductivity (K) values in bedrock monitor wells have been derived from slug tests performed after the wells were constructed, and from an analysis of low-flow sampling of bedrock monitor wells during groundwater monitoring activities (BC 2015a). Both methods yield comparable results. In addition, both methods provide estimates of hydraulic properties local to the test well and, consequently, are primarily used to assess the spatial distribution of bedrock hydraulic properties in the Study Area. Mapping of the hydraulic conductivity values indicate a high degree of spatial variability with significant changes (often greater than three orders of magnitude) over distances that are small relative to the size of the Study Area.

In bedrock, estimated conductivities range from approximately 0.002 to 334 feet/day, with the higher values measured in wells located near faults and the open pit (Figure 4-17). The 25th and 75th percentiles were 0.15 and 11.7 feet/day, respectively. The median bedrock slug-test K value was 1.7 feet/day. The lowest bedrock K values are up to two orders of magnitude lower than the lowest K values in alluvium in the Study Area. The minimum measured low-flow sampling K value in bedrock was 0.013 feet/day, and the maximum value was 67 feet/day. The 25th and 75th percentiles were 0.485 feet/day and 16.6 feet/day, respectively. The median bedrock low-flow sampling K value was 4.3 feet/day. Consistent with the slug-test data set, the lowest K values in bedrock are up to two orders of magnitude lower than the lowest K values in alluvium in the Study Area.

Similar water level responses in paired bedrock/alluvial monitor wells at any given location throughout the Study Area result from: 1) the interconnectivity between the bedrock and overlying alluvial groundwater flow systems (except locally around the B/W-1 well cluster where an aquitard separates the two flow systems); and 2) the transmission of stresses through the skeletal structure

of the aquifer solids. Seasonal fluctuations in bedrock groundwater levels (and vertical gradients between the bedrock and alluvial groundwater systems) due to agricultural pumping from the alluvial aquifer are observed beneath the Hunewill Ranch and Evaporation Ponds, and in the Sunset Hills area. Both the bedrock and alluvial groundwater systems exhibit similar long-term water level declines.

Vertical interconnection between bedrock and overlying alluvial groundwater is indicated by water level data (and the presence of locally-elevated concentrations of sulfate and uranium in bedrock groundwater that are sourced from overlying mine-impacted alluvial groundwater). Spatially, vertical gradients between bedrock and alluvium generally reflect the recharge components of the alluvial groundwater HCSM (BC 2014a), with downward vertical gradients east and north of the Site driven by recharge of surface water and irrigation water on crop fields, and upward vertical gradients in western portions of the Study Area driven by mountain-front recharge.

The largest vertical gradients between bedrock and alluvium occur: 1) within the Pit Lake cone of depression; and 2) beneath the Hunewill Ranch fields and Evaporation Ponds. In all other portions of the Study Area, vertical gradients between bedrock and alluvium are relatively small. Seasonal crop irrigation effects are observed near the Hunewill Ranch fields, Evaporation Ponds, and Sunset Hills, as represented by locations with both upward and downward vertical gradients.

Stable isotopes ($^{18}O/^{2}H$) in bedrock groundwater are generally more depleted with respect to Walker River surface water and alluvial groundwater (BC 2014a). The most depleted stable water isotope signatures in the bedrock groundwater are associated with the oldest apparent groundwater ages, as determined by $^{3}H/^{3}He$ age dating (Figure 4-18). The youngest groundwater ages are associated with the least depleted bedrock groundwater samples, which also overlap the region of cool season Walker River flows. Walker River samples display an evaporative fractionation signature, with less fractionated values occurring during periods of snowmelt runoff and more fractionated values occurring during periods of lower flows during the summer.

The greater degree of $^{18}O/^{2}H$ depletion of bedrock groundwater compared to the alluvial aquifer and Walker River surface water suggests different recharge processes. The depleted stable isotope signature indicates that bedrock groundwater is: 1) sourced from snowmelt recharged directly in the Singatse Range, which does not undergo the same evaporative fractionation as Walker River water, and/or fossil water recharged during the Pleistocene (a cooler and more humid climate than the current climate); and 2) older and of a different origin than surface water and alluvial groundwater. Bedrock groundwater ages are older than 1954, and essentially pre-date Site mining activities, occur throughout most the Study Area. Younger bedrock groundwater within and downgradient of the Singatse Spur, proximal to the Walker River, exhibits isotopic similarities between younger bedrock groundwater and cool season Walker River water.

Although groundwater ages exhibit some degree of spatial association, groundwater ages are not correlated with hydraulic conductivity. The widespread occurrence of older groundwater ages and localized occurrence of younger groundwater ages, irrespective of hydraulic conductivity, suggests slow and limited movement of bedrock groundwater. The spatial distribution of Ue values generally comports with the spatial distribution of $^{3}H/^{3}He$ groundwater ages. This pattern of widespread higher Ue values (i.e., “old” water) with localized areas of lower Ue values (i.e., “young” water), irrespective of hydraulic conductivity, again suggests slow/limited movement of bedrock groundwater.

In addition to a high degree of anisotropy in hydraulic characteristics and hydrologic tracer signatures, the bedrock groundwater system also exhibits three-dimensional (i.e., anisotropic) spatial variability in chemical concentrations. As noted in Brown and Caldwell (2014a) and discussed further in Section 5.0, concentrations of mine-related chemicals in groundwater are most elevated in the Shallow zone of the alluvial aquifer beneath the LEP, UEP, Finger Ponds, Phase IV VLT HLP, and Phase IV VLT Pond. COI concentrations decrease with vertical depth and horizontal distance from the Site sources, resulting in values in bedrock groundwater that are one to several orders of magnitude lower than the values in overlying alluvial groundwater.

In addition, areas of elevated COIs in bedrock groundwater are small in comparison to the alluvial aquifer, highly localized, and found mostly on-Site. The localized areas of elevated COI concentrations in bedrock groundwater indicate that bedrock fractures have limited hydraulic connectivity and transmissivity over horizontal distances relevant to the scale of the Study Area.

Collectively, the bedrock characterization information indicates: 1) a high degree of vertical hydraulic connection between the bedrock and alluvial groundwater systems; and 2) limited horizontal hydraulic connectivity and transmissivity of bedrock fractures, especially over horizontal distances that are relevant to the scale of the Site and the surrounding Study Area. Despite localized areas of relatively high hydraulic conductivity, bedrock groundwater flow velocities, average volumetric flow rates and chemical fluxes through the bedrock groundwater system are low.

SECTION 5.0
NATURE AND EXTENT OF GROUNDWATER CONTAMINATION

Identifying background groundwater quality and defining the extent of mine-impacted groundwater have been elements of the phased OU-1 groundwater characterization activities since 2005. This activity, referred to as the background assessment, was specifically identified as DQO #1 in both the draft and final versions of the remedial investigation work plans for OU-1 (BC and Integral Consulting, Inc. 2007 and BC 2014a, respectively).

5.1 Background Assessment Approach

The conventional approach to a background assessment described by EPA (2012a) involves obtaining groundwater chemical data from areas that were not impacted by Site sources to establish background chemical concentration ranges and background concentration limits (BCLs) for the COIs. Typically, the chemical concentration data are obtained from locations that are hydraulically upgradient or cross-gradient of Site sources. However, EPA and ARC recognized that there are constraints to relying solely on this conventional, statistical approach at the Site because locations where background wells can be installed hydraulically upgradient or cross-gradient of the Site sources do not fully account for all of the factors affecting groundwater quality downgradient of the Site, such as the following: 1) naturally-occurring variations in groundwater chemistry associated with geologic formations; 2) chemical inputs associated with application of agricultural fertilizers (e.g., nitrate and sulfate) and/or crop irrigation (e.g., uranium and sulfate); 3) increases in dissolved chemical concentrations associated with longer periods of contact between groundwater and aquifer sediments (i.e., longer groundwater residence times); and 4) spatial variations in groundwater flow conditions and the groundwater geochemical regime, which affect dissolved chemical concentrations.

Consequently, multiple lines of evidence are used to differentiate background groundwater quality from mine-impacted groundwater, including:

- Hydrogeologic Conceptual Site Model: The hydrogeologic information defines the current and plausible historic groundwater flow and chemical transport pathways, and related anthropogenic activities (including mining and agriculture). The HCSM: 1) incorporates observed temporal variations in groundwater flow conditions and chemical concentrations in groundwater based on an extensive Site-wide groundwater monitoring network, aquifer testing, and a groundwater flow model; and 2) constrains how chemical distributions in groundwater can be reasonably interpreted and related to mining and agricultural activities.
- Contoured Chemical Distributions: Chemical distributions outline distinct plumes of off-Site impacted groundwater that have physical continuity along plausible flow pathways linked to Site features that are known sources of groundwater impacts. Other areas where chemicals occur in groundwater at concentrations above Maximum Contaminant Levels (MCLs), such as the North Study Area (NSA; i.e., that portion of the Study Area located northeast of the West Campbell Ditch and north of Sunset Hills), are separate from and do not physically connect along groundwater flow pathways to the Site.
- Sulfur Isotope Signatures: Distinct sulfur isotope ($\delta^{34}S_{SO4}$) signatures associated with sulfate in the acidic process leach solutions are used to differentiate mine-impacted groundwater from groundwater that is unaffected by mining operations, and to delineate the extent of groundwater contamination associated with mining. Specifically, the extent of mine-impacted groundwater is constrained where the $\delta^{34}S_{SO4}$ value in alluvial groundwater downgradient of the Site exceeds the minimum background value of +4.93‰ at locations that are within predominant recharge areas to the alluvial aquifer. Such background areas of the alluvial aquifer are also consistent with contoured or numerically-modeled flow pathways from the Site.
- Conventional Approach: The conventional approach to defining background groundwater quality for the Site (EPA 2012a) relies on chemical data from the background monitor wells and EPA-recommended statistical procedures (EPA 2009) to calculate BCLs for COIs. BCLs are computed for each COI in three geographic recharge areas identified in the Study Area HCSM: 1) the Southeast Recharge Area (SERA) - representing recharge by infiltration and percolation of water associated with streams, ditches and agricultural fields; 2) the Southwest Recharge Area (SWRA) - representing mountain-front recharge; and 3) the NSA - representing groundwater lateral to the Site flowing into the NSA.

The BCLs are used for two purposes. BCLs for sulfate and dissolved uranium in the SERA and SWRA are used to confirm the extent of mine-impacted groundwater defined by $\delta^{34}S_{SO4}$ signatures. Sulfate and dissolved uranium are suitable chemicals for this purpose because these two chemicals are typically more mobile in groundwater relative to other indicators of mine-impacted groundwater such as iron and other metals (BC 2014a; EPA 2010d). BCLs are computed for other COIs, which can then be used to define areas within the extent of mine-impacted groundwater where chemical concentrations exceed background chemical concentrations.

Because the NSA BCLs characterize groundwater quality flowing into the NSA, they are not used to define the extent of mine-impacted groundwater but can instead be used to evaluate chemical loading to groundwater due to agricultural practices in this part of the Study Area. The steps identified in the BGQA - Revision 3 (BC 2016b) for performing the background groundwater assessment are illustrated on Figure 5-1 and summarized in Table 5-1.

Table 5-1. Site-Wide Background Groundwater Quality Assessment Approach

Step	Information Source(s)
Obtain and evaluate available OU-1 hydrogeologic and geochemical data with respect to data quality and relevance.	▪ Brown and Caldwell (BC 2014a) ▪ Brown and Caldwell (BC 2015e)
Refine the HCSM based on recent information obtained in 2013 and 2014 from existing wells and new wells installed pursuant to the Additional Well Work Plan (BC 2013b).	▪ Brown and Caldwell (BC 2015d) ▪ Brown and Caldwell (BC 2016b). Summarized below; see Section 3.0 in Appendix J-7 for details.
Define hydrogeologic areas that are considered representative of background conditions and/or other water quality types.	▪ Brown and Caldwell (BC 2016b). Summarized below; see Section 3.0 in Appendix J-7 for details.
Specify the types and quality of RI groundwater data selected as relevant and appropriate for the background assessment.	▪ Brown and Caldwell (BC 2016b). See Section 4.0 in Appendix J-7 for details.
Use hydrologic tracer results to refine the HCSM, especially as the results relate to the information inputs identified in DQO #1 for the background groundwater assessment. Use $\delta^{34}S_{SO4}$ signatures to differentiate mine-impacted groundwater from groundwater impacted by other anthropogenic activities.	▪ Brown and Caldwell (BC 2016b). Summarized below; see Section 6.0 in Appendix J-7 for details.
Establish quantitative background concentration ranges and calculate groundwater BCLs for each background area. Use sulfate and uranium BCLs to evaluate the extent of mine-impacted groundwater. Use BCLs for other COIs to define areas within the extent of mine-impacted groundwater where chemical concentrations exceed background chemical concentrations.	▪ Brown and Caldwell (BC 2016b). Summarized below; see Section 6.0 in Appendix J-7 for details.
Evaluate the consistency of the two approaches (i.e., $\delta^{34}S_{SO4}$ signatures tracers and BCLs) to identifying the extent of mine-impacted groundwater. Integrate the results of the two approaches along with other RI characterization information into a single boundary representing the extent of mine-impacted groundwater in each zone of the alluvial aquifer.	▪ Brown and Caldwell (BC 2016b). Summarized below; see Section 7.0 in Appendix J-7 for details.

Ultimately, the identification of the extent of mine-impacted groundwater in the Study Area integrates the three major elements of boundary delineation (i.e., $\delta^{34}S_{SO4}$ signatures, and BCLs for the two most mobile, aerially extensive, indicators of mine-impacted groundwater, sulfate and uranium), as well as other lines of evidence that include hydrogeologic information, chemical concentration data, and other hydrologic tracer data.

5.2 Contoured Chemical Distributions

The following sections discuss the distributions of select parameters and COIs in Study Area groundwater.

5.2.1 Alluvial Aquifer

To illustrate aspects of the HCSM discussed below, the distributions of six chemicals (pH, sulfate, uranium, alkalinity, nitrate, and arsenic) in groundwater during August 2014 are illustrated on cross sections (cross section locations shown on Figure 4-6) and plan view maps for the Shallow and Deep 3 groundwater zones (Figures 5-2 through 5-7). The distributions of the six chemicals in all the groundwater zones are shown on plan view maps in Appendix K. The distributions of the six chemicals have routinely been presented in various groundwater reports for the following reasons.

Historical operational information and groundwater quality data indicate that elevated acidity (i.e., low pH), sulfate, and uranium are indicator parameters for mine-impacted groundwater at the Site. Because sulfate and uranium, which are naturally-occurring in the Study Area, are more mobile in groundwater relative to other indicators of mine-impacted groundwater (e.g., iron), these mine-related chemicals have been used to preliminarily evaluate the extent of mine-impacted groundwater (BC 2014a). Alkalinity in groundwater is important because complexation of dissolved uranium with bicarbonate enhances its solubility and mobility in groundwater (EPA 2010d; BC 2014a).

Given their association with agricultural amendments and fertilizer, sulfate and nitrate in groundwater are also important indicators of agricultural-impacted groundwater (BC 2014a). Although arsenic is detected at locally high concentrations in both on-Site and off-Site locations, it occurs naturally in the Study Area (and throughout Nevada) and exhibits complex geochemical transport behavior, which limits its usefulness as an indicator of mine-impacted groundwater (EPA 2016e).

pH

The distributions of pH values in the Shallow and Deep 3 groundwater zones in August 2014 are shown on Figures 5-2a and 5-2b, respectively. The lowest pH values are observed in Shallow zone groundwater beneath the Evaporation Ponds and downgradient of the Phase IV VLT HLP and VLT Pond, and pH values increase laterally and vertically away from these structures by orders of magnitude.

Sulfate and Uranium

The distributions of sulfate and uranium in groundwater in August 2014 are illustrated on Figures 5-3 and 5-4, respectively. The most elevated concentrations of sulfate and uranium are also observed in Shallow zone groundwater beneath the Evaporation Ponds and downgradient of the Phase IV VLT HLP and VLT Pond, and concentrations decrease laterally and vertically away from these features by orders of magnitude.

In particular, elevated concentrations of sulfate and uranium in the alluvial aquifer occur in: 1) Shallow zone groundwater where sulfate (Figure 5-3a) and uranium (Figure 5-4a) distributions exhibit a northwest longitudinal orientation consistent with the northwest direction of groundwater flow across the Study Area; and 2) Deep zone alluvial groundwater where sulfate (Figure 5-3b) and uranium (Figure 5-4b) distributions exhibit a northeast longitudinal orientation from the northern portion of the Site to beneath the Hunewill Ranch toward former (e.g., WDW019) and existing agricultural wells used seasonally to extract groundwater for crop irrigation.

In addition, elevated concentrations of sulfate and uranium (as well as alkalinity and nitrate discussed below) occur in Shallow, Intermediate, and Deep 1 groundwater zones beneath agricultural fields in the NSA. Given the low concentrations of sulfate and uranium detected in all groundwater zones at well cluster B/W-27 (Figures 5-3d and 5-4d, respectively), elevated concentrations of these chemicals in groundwater beneath the agricultural fields located in the NSA are not physically connected along current and plausible historic groundwater flow paths back to known sources of mine-impacted groundwater beneath the Site. A more detailed discussion of data specific to the NSA is provided in Section 5.5.

Alkalinity

The distribution of alkalinity in groundwater in August 2014 is illustrated on Figure 5-5. The most elevated values of alkalinity occur beneath the Evaporation Ponds in the northern portion of the Site. In the Shallow zone beneath the UEP and downgradient of the Phase IV VLT HLP and VLT Pond, pH values are generally less than 4 s.u.. Similar to sulfate and uranium, elevated alkalinity occurs in: 1) Shallow zone groundwater where the distribution (Figure 5-5a) exhibits a northwest longitudinal orientation consistent with the northwest direction of groundwater flow across the Study Area; and 2) Deep zone alluvial groundwater where the distribution (Figure 5-5b) exhibits a northeast longitudinal orientation from the Evaporation Ponds, Phase IV VLT HLP and VLT Pond to beneath the Hunewill Ranch toward former (e.g., WDW019) and existing agricultural wells used seasonally to extract groundwater for crop irrigation. Alkalinity values above 200 mg/L occur beneath the Hunewill Ranch and other agricultural fields located in the northeastern portion of the Study Area.

Nitrate

The distribution of nitrate in groundwater in August 2014 is illustrated on Figure 5-6. The most elevated nitrate concentrations occur in groundwater beneath the Hunewill Ranch and other agricultural fields located in the northeast portion of the Study Area (Figure 5-6a). Beneath the Hunewill Ranch, nitrate concentrations in Shallow zone groundwater were as high as 42 mg/L during August 2014. Former groundwater extraction from high-capacity wells (especially WDW019) for irrigation of crops on the Hunewill Ranch has mobilized nitrate from the Shallow zone into the Intermediate and Deep zones of the alluvial aquifer system. Nitrate is subsequently transported in groundwater that flows northwest to the Sunset Hills area.

Nitrate concentrations in Shallow zone groundwater beneath the agricultural fields in the northeast Study Area were as high as 38 mg/L during August 2014 (Figure 5-6a). Groundwater extraction from high-capacity agricultural wells for crop irrigation on fields located in the northeastern portion of the Study Area has mobilized nitrate from the Shallow zone into the Intermediate and Deep zones of the alluvial aquifer system. Nitrate beneath these agricultural fields is subsequently transported in groundwater that flows north and northwest.

Nitrate concentrations in groundwater samples from the B/W-27 cluster have consistently been at low concentrations throughout their monitoring history. In August 2014, nitrate concentrations ranged from 0.13J to 0.88J mg/L. The nitrate data from the B/W-27 well cluster shows that the nitrate concentrations beneath the Hunewill Ranch and other agricultural fields in the northeast Study Area are physically separate. The horizontal and vertical patterns in nitrate concentrations in groundwater indicate that application of fertilizer on the agricultural fields has resulted in downward vertical migration of agricultural nitrate rather than horizontal transport of nitrate in the groundwater system. A more detailed discussion of data specific to the NSA is provided in Section 5.5.2.

Arsenic

The distribution of arsenic in alluvial groundwater in August 2014 (Figure 5-7) differs from the distributions observed for sulfate, nitrate, and alkalinity. The most elevated arsenic values occur in Shallow zone groundwater at off-Site wells B/W-77S (560 µg/L) and B/W-32S (420 µg/L), which are located approximately 2,500 feet north of the Evaporation Ponds (Figure 5-7a). Arsenic values decrease laterally and vertically from these two wells by at least an order of magnitude. In contrast to the elevated arsenic values at these two off-Site wells, the most elevated arsenic values in groundwater beneath the Site are approximately 3.5 times lower.

The most elevated arsenic concentrations in on-Site groundwater range from approximately 120 to 160 µg/L in Shallow zone wells MW-5S, FMS-06S, and MW-2S (Figure 5-7a). These three wells are located near the Thumb Pond and the Phase IV VLT HLP and VLT Pond. Historic process solutions discharged to the Thumb Pond were reported to contain 42 mg/L of arsenic (Seitz et al., 1982). Arsenic values in the range of 50 to 80 µg/L occur in the Shallow, Intermediate and Deep zones west and northwest of the Evaporation Ponds and below the Phase IV VLT HLP and VLT Pond.

In addition, data from zonal groundwater samples and monitor wells installed in the NSA indicate elevated concentrations of arsenic in Deep zone groundwater that inflows (i.e., recharges) the NSA and migrates beneath the agricultural fields. Groundwater arsenic concentrations in this portion of the Study Area increase as a function of depth in the alluvial aquifer (at a relatively uniform pH) as indicated best by the zonal groundwater sample data from wells B/W-56 and B/W-69 (Figure 5-8) where arsenic concentrations are as high as 83 ug/L. At other NSA monitoring locations (such as B/W-59, B/W-57 and B/W-68), chemical profiling did not extend as deep as the B/W-56 and B/W-69 locations. Nonetheless, arsenic concentrations at these three locations began increasing as a function of depth below 4,200 feet amsl. Had sampling been conducted to greater depths at these locations, elevated arsenic concentrations are expected since no known plausible hydrologic/geochemical explanation would limit arsenic enrichments strictly to those areas around B/W-56 and B/W-69.

Because profile locations B/W-56 and B/W-69 represents background (i.e., characterize groundwater inflows to the NSA), chemical concentrations at these locations represent naturally-occurring concentrations and are not related to advancement of mine-impacted groundwater from the south. Furthermore, the elevated arsenic concentrations at this depth are not associated with agricultural activity, which is shown in Section 5.5.2 to affect the Shallow, Intermediate and Deep1 zones in the NSA. Instead, these elevated arsenic concentrations appear to be associated with regional groundwater conditions in the Mason Valley, likely associated with deep bedrock discharge to the alluvial basin aquifer.

5.2.2 Bedrock Groundwater

Most of the bedrock wells have 20- to 30-foot long screens that are positioned in the upper 50 feet of the bedrock to straddle fractures that yield groundwater for monitoring purposes. The pH measurements and concentrations of sulfate, uranium, alkalinity, nitrate and arsenic in the bedrock groundwater system in August 2014 are shown on Figure 5-9. Most pH measurements in bedrock groundwater are near-neutral (i.e., approximately 7.0).

Sulfate and uranium were detected in bedrock groundwater during August 2014 at concentrations as high as 1,600 mg/L and 950J µg/L, respectively. For both chemicals, the most elevated concentrations were detected in bedrock groundwater within the mine Site, and somewhat lower concentrations were detected immediately west of the Evaporation Ponds below the VLT Pond. The most elevated sulfate concentrations in bedrock groundwater occurred beneath the Sulfide Tailings at well B/W-36B. Off-Site, sulfate was detected in bedrock groundwater at a concentration above 500 mg/L in well B/W-58B, which monitors groundwater emanating from the MacArthur Mine. The most elevated uranium concentrations in bedrock groundwater occurred at on-Site wells MW-5B and B/W-74B. Similarly, the most elevated alkalinity concentrations in bedrock groundwater occurred at on-Site wells MW-5B and B/W-74B (as well as MW-H4SN).

Nitrate concentrations were most elevated in bedrock groundwater at wells B/W-73B and HLP-06B, which are located to the west and southwest of the mine Site.

Elevated arsenic concentrations in bedrock groundwater occurred in three distinct areas. Elevated arsenic concentrations were detected in: 1) four wells (PA-MW-2B, PA-MW-4B, HLP-03B, and HLP-06B) located around the Phase III 4X HLP and nearby Calcine Ditch; 2) six wells (MW-4B, B/W-34B, B/W-6B, B/W-44B, LEP-MW-2B, and B/W-33B) located to the immediate west of the Evaporation Ponds in an area potentially influenced by MFR; and 3) in two wells (B/W-54B and YPT-MW-10B) located north of Sunset Hills.

5.3 Identification of Groundwater Impacts

5.3.1 Differentiating Groundwater Impacts Using Sulfur Isotopes

Sulfur Isotope Signature in Background Groundwater

The $\delta^{34}S_{SO4}$ signature used to differentiate mine-impacted groundwater from non-mine-impacted groundwater reflects the dominant background groundwater types in off-Site areas. Groundwater modeling (SSPA 2014) indicates that recharge to groundwater in the alluvial aquifer (98% of all recharge) in the Study Area results from irrigation field percolation (49%), leakage from irrigation ditches (29%), and seepage from the Walker River (20%).

Background wells associated with these water types include some, but not all, of the wells in the SERA and NSA recharge areas. Eight background wells that represent the dominant background groundwater types in off-Site areas, based on their locations in the groundwater flow field relative to the Walker River and agricultural features, include: B/W-15S, B/W-20S, B/W-21S, B/W-56S, B/W-59S, B/W-59D3, PLMW-2S and PLMW-2B. Values of $\delta^{34}S_{SO4}$ in groundwater samples from these wells range from +4.93 to +6.62‰.

Sulfur Isotope Signature in Mine-Impacted Groundwater

Sulfur isotopes in groundwater were used to differentiate the leading edge of mine-impacted groundwater from background groundwater or groundwater impacted by other anthropogenic activities within the Study Area because: 1) sulfur isotopes in dissolved sulfate can be used to infer groundwater movement because these isotopes are mobile tracers whose movement is not strongly retarded by the aquifer matrix in groundwater settings similar to the Study Area; and 2) early copper extraction operations at Yerington (during the 1950s and 1960s) primarily relied on sulfuric acid derived from sulfur ores (i.e., pyrite) from the Leviathan Mine in California (BC 2014a), which had a distinct sulfur isotopic signature (Taylor and Wheeler 1994). Sulfur sources with different (higher) isotopic signatures were used during later operations in the 1970s, 1980s, and 1990s. These different isotopic signatures may be used, along with chemical data and other information, to differentiate groundwater impacts associated with Anaconda and Arimetco operations.

Delineation of mine-impacted groundwater reasonably assumes that groundwater affected by the earliest operations at the Site has traveled the farthest downgradient distance in the alluvial aquifer. Therefore, the isotopic signature for sulfur sources used during the 1950s and 1960s serves as a potentially reliable tool for characterizing the leading edge of the plume and for differentiating mine-impacted water at the leading edge of the plume from background conditions. The median value reported by Taylor and Wheeler (1994) for $\delta^{34}S_{SO4}$ in aqueous samples collected from seeps and adit discharge at the Leviathan Mine is -17.6‰ (Table 5-5 in Appendix J-7).

Distinct $\delta^{34}S_{SO4}$ signatures associated with sulfate in the sulfuric acid process leach solutions used during early Site operations (most evident in groundwater at well W5DB-D3) and groundwater from the background monitor wells are used to evaluate the extent of mine-impacted groundwater. This approach conceptualizes initial infiltration of acidic process leach solutions exhibiting a diagnostic $\delta^{34}S_{SO4}$ signature of approximately -17‰ into originally un-impacted groundwater beneath the Evaporation Ponds.

The conceptual approach assumes a simplified aquifer geometry and flow configuration that account for mixing of a conservative (i.e., geochemically unreactive) tracer within the aquifer. Again, the isotope signature for the sulfur source used during the earliest processing operations at the Site would be representative of any mine-impacted water first entering the alluvial aquifer and now present at the leading, downgradient edge of the plume. The leading edge of mine-impacted groundwater is identified as locations where the $\delta^{34}S_{SO4}$ signature in groundwater associated with mining impacts cannot be differentiated from the $\delta^{34}S_{SO4}$ signature in background groundwater.

Quantitatively, mine-impacted groundwater can no longer be differentiated from background groundwater when the $\delta^{34}S_{SO4}$ value at a given location falls within the background $\delta^{34}S_{SO4}$ range (i.e., exceeds the minimum background value of +4.93‰). Higher isotope signatures measured inside the leading edge of the plume may be indicative of mixing with groundwater, subsequent sulfur releases derived from sources having a different isotopic signature, or some combination of these two processes.

Lateral and vertical patterns in $\delta^{34}S_{SO4}$ groundwater data are illustrated on Figure 5-10. The distinctly negative $\delta^{34}S_{SO4}$ signature of -17.6‰ associated with sulfate in the sulfuric acid process leach solutions used for copper recovery at Yerington is evident in Deep zone alluvial groundwater beneath the Evaporation Ponds, especially at well W5DB-D3, which has a strongly negative $\delta^{34}S_{SO4}$ signature of -17.12‰.

The low $\delta^{34}S_{SO4}$ values in Deep zone alluvial groundwater beneath the Evaporation Ponds also extend off-Site toward the Hunewill Ranch, particularly in the Deep 3, Deep 4, and Deep 5 zones. The region of low $\delta^{34}S_{SO4}$ values beneath the Evaporation Ponds is displayed on cross section A-A' (Figure 5-10c), centered around the W5DB well cluster. The low values of $\delta^{34}S_{SO4}$ that extend off-Site toward the Hunewill Ranch are visible on cross section B-B' (Figure 5-10d).

5.3.2 Differentiating Groundwater Impacts Using BCLs

A conventional approach to a BGQA emphasizes the groundwater flow regime to identify wells that are located hydraulically up-gradient and/or cross-gradient to sources of chemical loading to groundwater, as noted by the EPA (2012a) in comments on the Draft BGQA (BC 2011c). A background assessment may also consider groundwater recharge sources, the different geologic materials through which groundwater flows, and the residence time because these factors are recognized to naturally affect groundwater composition (BC 2014a; Hem 1985; Freeze and Cherry 1979). Key HCSM elements that are relevant to identifying background monitor wells include:

- Groundwater Flow Direction: Groundwater in the alluvial aquifer within the Study Area generally flows to the northwest, with flow directions locally affected by a variety of factors discussed previously in Section 4.0.
- Recharge Sources: The alluvial aquifer within the Study Area is primarily recharged by infiltration and percolation of water associated with stream channels, ditches, and irrigated agricultural fields located to the east of the mine Site. Limited recharge to the alluvial aquifer also occurs as mountain-front recharge to the west of the Site.
- Chemical Loading Sources: The northern portion of the Site (including the Evaporation Ponds, the Phase IV VLT HLP and the VLT Pond) is considered the primary source of chemicals that migrate off-Site. The most elevated acidity and chemical concentrations are observed in Shallow zone groundwater beneath this area, and concentrations decrease laterally away from this area by orders of magnitude. Furthermore, other Site sources are located hydraulically upgradient of the northern portion of the Site.

Based on these considerations, background monitor wells for the Study Area are categorized by geographic recharge area and described below.

- SERA: This background groundwater quality type is represented by seven monitor wells (B/W-15S, B/W-20S, B/W-21S, PLMW-2S, PLMW-2B, WRA3-1B and WRA3-2B) that are located up-gradient of the mine Site and near the Walker River. Data from these wells represent recharge of groundwater having a short residence time in the flow system.

- NSA: This background groundwater quality type is represented by three monitor wells (B/W-56S, B/W-59S and B/W-59D3) that are located upgradient of the NSA and represent both Shallow and Deep zone alluvial groundwater quality.
- SWRA: This background groundwater quality type is represented by six monitor wells (B/W-12RB, B/W-13S, B/W-23B, B/W-26RB, PLMW-3RB, and PLMW-4B) that are located up-gradient and west/southwest of the Site and, thus, represent mountain-front recharge.

The BCL for each COI for each background water quality type was calculated as the 95% upper tolerance limit (UTL) with 95% confidence, consistent with the sampling and statistical comparison strategy recommended in EPA guidance (EPA 1992). The 95% UTL is the numerical value below which 95% of the background data are expected to fall, with 95% confidence. That is, one can be 95% sure that 95% of data in the background population fall below this value. The upper bound of this interval is the 95/95 UTL.

The 95/95 UTL is calculated from a sample dataset and depends on the distribution, central tendency, and variability of the dataset, as well as sample size (EPA 2009). The statistical test used to calculate the 95/95 UTL also depends on the distribution of the dataset, the sample size, and the percentage of non-detects present. The ProUCL software program (version 5.0.00) (EPA 2013f) was used to perform statistical calculations of the 95/95 UTL. ProUCL evaluates a dataset to determine the likely form (or forms) of the distribution, calculates UTLs using numerous appropriate statistical methods, and provides a recommendation as to which method is most appropriate for a particular dataset.

Distributional testing in ProUCL is performed using the Shapiro-Wilk (S-W) test for normality on the untransformed data, the log-transformed data, and the gamma-transformed data. The S-W test may conclude that the data set conforms to multiple parametric distributions. In this case, the distribution with the highest probability of association (calculated p-value from the S-W test) is selected as the underlying parametric distribution. When an insufficient sample size or insufficient number of detected results existed to statistically calculate a 95/95 UTL, the maximum value of the dataset was selected, as is common practice in selecting upper threshold values in the absence

of adequate sample sizes (EPA 2009). For datasets with 100% non-detects, the lowest detection limit in the dataset was selected as the BCL. The calculated 95/95 UTLs for each constituent and background water quality type are provided in Table 5-2.

Table 5-2. Summary of Calculated Background Concentration Limits

Chemical	Units	Groundwater Standard	SERA	NSA Inflows	SWRA
pH (field)	s.u.	6.5-8.5	7.96	7.65	8.35
Alkalinity, Bicarbonate (as $CaCO_3$)	mg/L	--	180	160	210
Alkalinity, Carbonate (as $CaCO_3$)	mg/L	--	2	2	2
Alkalinity, Hydroxide (as $CaCO_3$)	mg/L	--	2	2	2
Alkalinity, Total (as $CaCO_3$)	mg/L	--	180	160	210
Total Dissolved Solids	mg/L	500	570	304	561
Total Organic Carbon (TOC)	mg/L	--	1.8	1.5	1.8
Calcium	mg/L	--	71	38	72
Magnesium	mg/L	--	13	11	16
Potassium	mg/L	--	5	7	5
Sodium	mg/L	--	96	51	130
Chloride	mg/L	250	59	17	72
Fluoride	mg/L	2	1	0.9	1.5
Sulfate	mg/L	250	160	57	180
Nitrate (as N)	mg/L	10	1.5	0.1	0.8
Nitrite (as N)	mg/L	1	0.1	0.2	0.4
Nitrate-Nitrite (as N)	mg/L	--	1.5	0.3	0.8
Aluminum	mg/L	0.2	0.04	0.03	0.05
Antimony	µg/L	6	0.41	0.31	0.96
Arsenic	µg/L	10	12	38	20
Barium	µg/L	2,000	50	141	41
Beryllium	µg/L	4	0.17	0.25	0.25
Boron	µg/L	--	680	410	920
Cadmium	µg/L	5	0.11	0.25	0.17
Chromium	µg/L	100	0.9	1.0	1.8
Cobalt	µg/L	--	1.5	1.4	2
Copper	µg/L	1,300	0.9	0.9	4.3
Iron	mg/L	0.3	0.1	0.3	1.4
Lead	µg/L	15	0.28	0.20	0.2
Lithium	µg/L	--	65	49	44
Manganese	µg/L	50	870	2,825	303
Mercury	µg/L	2	0.35	0.10	1.1
Molybdenum	µg/L	--	18	20	140
Nickel	µg/L	--	1.1	1.6	19
Phosphorus	mg/L	--	0.16	0.91	0.12
Selenium	µg/L	50	1.1	0.5	20
Silica	mg/L	--	44	40	55
Silver	µg/L	100	0.12	0.14	0.36
Strontium	mg/L	--	0.74	0.4	0.47

Table 5-2. Summary of Calculated Background Concentration Limits

Chemical	Units	Groundwater Standard	SERA	NSA Inflows	SWRA
Thallium	µg/L	2	0.2	0.2	0.2
Tin	µg/L	--	14	12	30
Titanium	mg/L	--	0.002	0.002	0.002
Uranium	µg/L	30	20	10	27
Vanadium	µg/L	--	8	5	16
Zinc	µg/L	5,000	6	4	120
Gross Alpha	pCi/L	15	12.2	6.7	21.3
Gross Beta	pCi/L	--	10.8	10.0	11.9
Radium-226	pCi/L	5 (combined 226 + 228)	0.8	1.0	1
Radium-228	pCi/L	5 (combined 226 + 228)	1	0.9	1.5
Thorium-228	pCi/L	--	0.5	0.4	0.5
Thorium-230	pCi/L	--	0.4	0.4	0.7

Notes:

1) SERA = Southeast Recharge Area; NSA = North Study Area; SWRA = Southwest Recharge Area
2) s.u. = standard units; µg/L = milligrams per liter; µg/L = micrograms per liter; pCi/L = picocuries per liter

5.3.3 Comparison of Methods

The extent of mine-impacted groundwater based on sulfate and uranium BCLs is generally similar to the extent of mine-impacted groundwater based on $\delta^{34}S_{SO4}$ signatures. Furthermore, the extent of mine-impacted groundwater in each zone of the alluvial aquifer varies in ways that are consistent with flow directions, chemical distributions, and other hydrologic tracer data presented in the HCSM. Differences in the spatial extent of mine-impacted groundwater delineated by the two background assessment approaches are considered minor and likely associated with local variations in transport behavior and locally variable evapoconcentration and chemical loading processes.

5.4 Extent of Mine-Impacted Groundwater

The extent of mine-impacted groundwater presented in this OU-1 RI Report reflects the outcome of discussions during a groundwater technical meeting on June 29, 2016 and EPA's subsequent direction to conservatively establish the extent of mine-impacted groundwater because "is in the best interest of the overall progress for completing the OU-1 Groundwater Remedial Investigation Report" (EPA 2016e).

EPA (2016e) noted that professional judgement is an inherent component of estimating the extent of mine-impacted groundwater in this complex setting, and that tools used in the background assessment to estimate the area of mine-impacted groundwater may not fully account for the range of chemical concentrations that occur naturally in groundwater within the Study Area. However, as noted during previous submittals (e.g., ARC 2016b) and during groundwater technical meetings, further refinements to the mine-impacted groundwater boundary may be warranted based on additional evaluations of monitoring data and other new information to better account for naturally-occurring chemical concentrations in Study Area groundwater.

As previously described, the identification of the extent of mine-impacted groundwater in the Study Area integrates the three major elements of boundary delineation (i.e., $\delta^{34}S_{SO4}$ signatures, and BCLs for the two most mobile, aerially extensive, indicators of mine-impacted groundwater, sulfate and uranium), as well as other lines of evidence that include hydrogeologic information, chemical concentration data, and other hydrologic tracer data. Also, the boundary delineating mine-impacted groundwater from unimpacted groundwater is conceptualized as a zone on a plan view map rather than a distinct line due to many factors including the size of the Study Area, age and complexity of the contaminant releases, occurrence and variability of naturally-occurring chemical concentrations, and complexities of subsurface contaminant transport and fate.

The extent of mine-impacted alluvial groundwater is shown on Figure 5-11, and can be generally described as follows, recognizing that mine-impacted groundwater is spatially more extensive in the Shallow, Intermediate and Deep 1 zones of the alluvial aquifer relative to the Deep 2 through Deep 5 zones. The northernmost extent of mine-impacted groundwater in the Shallow, Intermediate and Deep 1 zones of the alluvial aquifer is located near the Sunset Hills between well clusters B/W-10 and B/W-52. The eastern extent of mine-impacted groundwater in the Shallow, Intermediate and Deep 1 zones of the alluvial aquifer is approximately located near or beneath the West Campbell Ditch alignment. To the west of the Site, mine-impacted groundwater extends almost to the western extent of saturated alluvium between unimpacted wells/clusters B/W-16S and B/W-40, and impacted well clusters B/W-33, B/W-6 and B/W-22.

Mine-impacted groundwater in the deeper zones does not extend as far north as the upper three zones. In the Deep 2 through Deep 5 zones, the maximum northern extent of mine-impacted groundwater is near the northern end of the Hunewill Ranch fields. The eastern extent of mine-impacted groundwater in the Deep 2 through Deep 5 zones of the alluvial aquifer is located between well clusters B/W-27 and B/W-50. Particularly on the east, the area of mine-impacted groundwater in the Deep 3 through Deep 5 zones reflect the former influence of seasonal groundwater extraction for crop irrigation from agricultural wells (e.g., WDW019, located adjacent to the B/W-1 well cluster). To the west of the Site, mine-impacted groundwater in the Deep 3 through Deep 5 zones extends almost to the western extent of saturated alluvium.

Based on the background assessment methodology, the plume of mine-impacted groundwater in the various zones of the alluvial aquifer does not discharge to surface water. Estimates of the volume of mine-impacted groundwater and masses of sulfate and uranium in each groundwater zone are provided in Table 5-3.

Table 5-3. Estimated Volume and Masses of Sulfate and Uranium in Mine-Impacted Alluvial Groundwater

Zone	Zone Thickness (feet)	Volume of Mine-Impacted Alluvial Groundwater (acre-feet)	Sulfate Mass (tons)	Uranium Mass (tons)
Shallow	35	45,899	140,116	11.1
Intermediate	50	65,905	96,501	9.9
Deep 1	50	62,238	52,346	5.3
Deep 2	80	64,611	80,610	20.7
Deep 3	120	48,032	79,397	22.5
Deep 4	100	35,669	23,414	12.8
Deep 5	200	62,973	25,374	16.5
Total		**385,327**	**497,758**	**98.8**

The estimates in Table 5-3 are based on the thickness of each groundwater zone within the plume of mine-impacted groundwater shown on Figure 5-11 and the areas/average concentrations within the chemical concentration contouring. The volume of mine-impacted groundwater and masses of sulfate and uranium are large, and the following two analyses provide insights to FS considerations about aquifer cleanup.

Simple Analysis

In this simple analysis, PWS performance monitoring information and a simplifying assumption regarding chemical removal from aquifer sediments are used to estimate the time frame for aquifer cleanup.

From the early 2000s to March 25, 2009, the PWS operated continuously (i.e., 24 hours per day, 7 days per week), except during periods when individual wells were temporarily taken off line for maintenance and repairs of pumps and related equipment. The average pumping rate from the PWS from 1999 through 2008 was about 52 gpm. During this 10-year time period, approximately 800 acre-feet of water and approximately 5,000 tons of sulfate (average sulfate concentration in the pumped water of approximately 4,000 mg/L) were removed from the Shallow zone.

If it is assumed that three times the volume of mine-impacted Shallow zone groundwater (which is 45,899 acre-feet) must be removed to achieve aquifer cleanup, then at least 137,697 acre-feet of water would need to be removed from the Shallow zone. (This volume is about 172 times the volume of water removed by the PWS over the 10-year period). This volume does not address aquifer cleanup in the deeper zones of the alluvial aquifer or ongoing chemical loading to groundwater from impacted sediments and vadose zone soils, and dissolving sulfate or other minerals. Recognizing that the total volume of mine-impacted groundwater in the aquifer is 385,327 acre-feet, approximately 285 years of pumping at 2,500 gpm would be required to potentially achieve aquifer cleanup assuming that a volume of only three times the contaminated volume of mine-impacted groundwater would need to be removed. In reality, this estimate likely underestimates the actual time to cleanup.

Groundwater Modeling

In this analysis, the “batch flush” model (EPA 1988; Zheng et al. 1991) is used to estimate the minimum time (with an efficient extraction system) to restore groundwater quality to 500 mg/L sulfate. In this approach, the number of pore volumes (PV) of water that must be circulated through the contaminated zone having an initial concentration (Ci) to achieve cleanup to the specified standard (Cs) is calculated from the relationship:

$$\mathrm{PV} = -\mathrm{R}\ln \mathrm{Cs}/\mathrm{Ci}$$

In this relationship, R is the retardation coefficient for the target constituent. Based on this modeling approach, groundwater restoration to 500 mg/L sulfate would require approximately 100 years at a pumping rate of 2,300 gpm.

5.5 Sources of Impacted Groundwater

OU-1 RI characterization activities indicate that the past and/or ongoing major sources of COIs to Study Area groundwater include:

- Mine waste facilities, which have been grouped into the various Site OUs for individual RI/FS investigations;
- Agriculture activities that contribute COIs or affect the release of naturally occurring COIs in geologic materials (BC 2014a, 2016b); and
- Geologic materials containing naturally-occurring COIs (BC 2009a, 2014a, 2016b).

Section 7.0 of the 2007 SOW notes that the groundwater OU underlies all other OUs identified at the Site, and recommends that relevant elements of the other OUs be integrated with the OU-1 RI. Consistent with the SOW, this OU-1 RI Report discusses relevant source-related information for the other Site OUs that represent past or ongoing sources of chemical loading to groundwater (Section 5.5.1). In addition, the other major non-mining sources of COIs to groundwater are discussed in Sections 5.5.2 and 5.5.3.

5.5.1 Mine Waste Facilities

The major past and/or ongoing sources of COIs to groundwater include: 1) OU-4a, the Evaporation Ponds (BC 2014a); OU-8, the Arimetco Facilities (CH2M Hill 2010, 2011a, 2011b); and 3) OU-3, the Process Areas (BC 2014a). Concentrations of COIs in groundwater beneath OU-4b (Sulfide Tailings) are generally at least 10 times lower than COI concentrations in groundwater beneath OU-4a. Furthermore, OU-4b is located hydraulically upgradient or cross-gradient of OU-4a, and groundwater beneath OU-4b flows toward the higher COI concentrations under OU-4a.

Evaporation Ponds (OU-4a)

OU-4a RI field activities and characterization data are presented in reports by BC (e.g., 2009a, 2017a). OU-1 RI information that is particularly relevant to OU-4a includes the following: 1) the most elevated concentrations of mine-related chemicals occur in groundwater in this area; 2) concentrations of mine-related chemicals in groundwater beneath OU-4a are 100 or more times greater than chemical concentrations in groundwater beneath other OUs (Figures 5-2 to 5-7); and 3) the depth to water beneath OU-4a (i.e., vadose zone thickness) is generally smaller than the depth to water beneath other OUs. The depth to water beneath OU-4a ranges from approximately 20 to 40 feet bgs, except beneath the southern portion of the Calcine Ditch where the depth to water is up to approximately 70 feet bgs (Figures 4-8 and 4-9).

The summary below focuses on the magnitude and distribution of COIs in OU-4a mine waste materials and vadose zone soils, extent of contamination based on a comparison of OU-4a data to applicable soil BCLs, and the potential for vadose zone transport and chemical loading to groundwater based on vadose zone modeling and soil moisture probe data obtained during 2016. The highest COI concentrations in OU-4a mine waste materials are most commonly associated with pond sediments and calcines, which are typically located at depths ranging from approximately 0-3 feet bgs. Relative to the overlying pond sediments and calcines, the underlying alluvial soils generally exhibit lower concentrations of COIs.

Based on Site background soil concentrations presented in Table 5-3 of the *Background Soils Data Summary Report - Revision 1* (BC 2009b) for Sub-area A-1, located directly west of the Evaporation Pond and Calcine Ditch areas, approximate maximum depths of soil exceeding applicable BCLs within OU-4a include: 1) 17 to 20 feet bgs beneath the LEP; 2) 15 to 20 feet bgs beneath the UEP; 3) 47 to 52 feet bgs beneath the Finger Ponds; 4) 38 to 43 feet bgs beneath the Thumb Pond; and 5) 45 to 50 feet bgs at the north end of the Calcine Ditch and 75 to 80 feet bgs at the south end of the Calcine Ditch. These approximate maximum depths of alluvial soil contamination beneath the ponds and Calcine Ditch are primarily based on uranium, arsenic, selenium, iron, and copper.

Vadose zone model simulations were performed using the variably-saturated modeling code SVFlux™ to understand the potential for transport and chemical loading to groundwater beneath OU-4a. Vadose zone model results are summarized below (values presented in meters, input and output unit of measurement in the SVFlux™ modeling code):

- The LEP 'wet' areas simulation indicated a fairly constant downward net flux of soil water toward the water table. The cumulative flux at the deepest flux line in the profile was approximately 0.16 meters after 5 years of simulation.
- LEP 'dry' (non-ponded) areas showed a small downward net flux of water, approximately 0.013 meters after 15 years of simulation. Because the same soil moisture conditions for the 'wet' areas simulation was used for the 'dry' areas simulation, and because the soil moisture conditions for the 'dry' areas of the LEP are more likely to be similar to the conditions observed in the UEP, the numerical simulation likely over-predicted downward flux to the water table.
- The UEP simulation indicated a continuous upward net flux of water. The cumulative flux at the deepest flux line in the model was approximately 1.8 meters for 15 years of simulation (approximately 0.12 meters per year when averaged over the 15-year simulation period). For the 10-year period following the equilibration of the model, the cumulative flux was approximately 1.5 meters (approximately 0.15 meters per year).
- The Thumb Pond simulation indicated a very small upward net flux of water. The cumulative flux rate was approximately 4.0E-04 meters after 15 years of simulation (approximately 2.7E-05 meters per year when averaged over the simulation period). The simulation indicated both upward and downward flux of soil water in the upper portion of the profile, and a relatively constant upward flux in the deeper portion of the profile.
- The vadose zone simulation for the Finger Evaporation Ponds (FEPs) indicated a small downward flux of soil water during the 15-year simulation period, with a cumulative flux rate at the deepest flux line in the profile of approximately 0.043 meters after 15 years (approximately 2.9E-03 meters per year when averaged over the simulation period).

Integration of these estimated flux rates over the Pond acreages result in the following annual estimated volumes of soil water that could potentially flux to groundwater:

- Approximately 0.31 acre-feet per year (ac-ft/yr) for the LEP 'dry' areas, based on an estimated flux rate of 0.0012 m/yr and an area of 79.5 acres, equivalent to 0.19 gallons per minute (gpm);
- Approximately 1.13 ac-ft/yr for the LEP 'wet' areas, based on an estimated flux rate of 0.016 m/yr and an area of 21.5 acres, equivalent to 0.70 gpm; and

- Approximately 0.15 ac-ft/yr for FEP 1-4, based on an estimated flux rate of 0.0026 m/yr and an area of 17.8 acres, equivalent to 0.09 gpm.

Vadose zone modeling results indicated that: 1) the Thumb Pond and UEP exhibit an upward vertical flux of soil moisture to the atmosphere (i.e., no cumulative flux of soil moisture toward groundwater); and 2) the 'wet' areas of the LEP and FEPs 1-4 exhibit a cumulative downward flux of soil moisture toward the water table. Model results for the dry (peripheral) portions of the LEP indicate: 1) a net evaporative flux to the atmosphere; and 2) a downward flux of soil moisture during the latter third of the simulation period, resulting from wetter climate conditions.

Soil moisture data provide additional insights to the potential for transport and chemical loading to groundwater. Soil moisture has been monitored continuously since August 2016 and is ongoing. As part of the 2015–2016 field activities, soil moisture probes and porous cup lysimeters were installed at four locations. Further description of the installed equipment and the installation process is provided in the *Phase 1 Evaporation Ponds Characterization Data Summary Report* (BC 2017b). The monitoring locations are located at EP-VZC-2 (Thumb Pond), EP-VZC-3 (northern edge of the UEP), EP-VZC-6 (near the southern portion of the UEP and next to the Calcine Ditch), and EP-VZC-8 (northern edge of the LEP). Each location has soil moisture probes at three or four depth intervals, depending on the thickness of the vadose zone.

During the initial soil moisture monitoring period, a significant precipitation event occurred between January 4 and January 13, 2017, when 2.35 inches of precipitation fell over the 10-day period (WRCC 2017).

Soil moisture probe readings for EP-VZC-2 at the Thumb Pond, with the shallowest monitoring interval of 10 feet bgs, did not register any changes in vadose zone soil moisture at all monitored depths during and after the 10-day precipitation event. Soil moisture readings at EP-VZC-6, located near the southern tip of the UEP, registered moisture content increases in the shallow probes (2 and 6 feet bgs), but not at any greater depth during and following the January 2017 event. Soil moisture readings at EP-VZC-3, located in the northern portion of the UEP, registered a response to the January 2017 storm event at only the shallowest probe depth (1.5 feet bgs), but not

at the two deeper probes (5 and 15 feet bgs). Similarly, soil moisture readings at EP-VZC-8, located at the northern end of the LEP, registered a response to the January 2017 storm event at only the shallowest probe (3 feet bgs), but not at the two deeper probe depths (10 and 20 feet bgs).

In summary, there were no observable changes in soil moisture at depths greater than 6 feet bgs resulting from this significant precipitation event. At most locations, soil moisture data at the shallowest monitoring intervals (1.5 to 3 feet bgs) illustrate an abrupt increase in soil moisture immediately following the January 4-13 storm event. At some stations, soil moisture at 5 feet and 6 feet bgs also experienced changes following the January precipitation event, but were less pronounced than soil moisture changes at shallower intervals. Based upon these data, there does not appear to be evidence indicating moisture changes in deeper probes that result from an infiltration front moving vertically through the vadose zone.

Future data collection and evaluation may provide additional insight into the: 1) potential advancement of the wetting front to depths of 10 feet bgs and deeper; 2) effects of underlying native clay-rich alluvial layers on potential advancement of the wetting front and pore water chemistry; and 3) potential migration of chemicals within and between vadose zone materials based on lysimeter data from multiple points in time. However, the existing information suggests that: 1) the groundwater impacts beneath OU-4a are the result of past mining operations and fluid management; and 2) chemical loading to the groundwater system under current climatic conditions is very limited, based on vadose zone modeling and soil moisture probe data.

Arimetco Facilities (OU-8)

OU-8 components located throughout the Site include five HLPs (Phase I/II, Phase III South, Phase III 4X, Phase IV Slot, and Phase IV VLT), the FMS (which stores and conveys drain-down solution via a network of ponds, ditches, and 25,000 feet of pipe), and the SX/EW Plant.

RI activities characterized the nature and extent of radiochemicals, metals, and physical properties of the OU-8 HLPs and their associated ponds and ditches. Sources of contamination include:

- Leachable metals (aluminum, copper, iron, and manganese and, to a lesser extent, arsenic, beryllium, cadmium, chromium, cobalt mercury, and nickel) and other COIs on the surface and within the HLPs;
- Acidic draindown solutions containing COIs entrained within the HLPs;
- Acidic drain-down solutions containing COIs stored at the base of the HLPs or contained within their associated ponds and ditches; and
- Historic spills and releases containing COIs.

The OU-8 RI/FS determined that the areas affected by Arimetco operations include the footprints of each HLP and their associated drain-down FMS components, the SX/EW Plant, and historical spill areas (CH2M Hill 2011b). The environmental release or migration pathways of drain-down fluids are infiltration into the subsurface from unlined areas, through tears/breaches in liner systems and FMS components, and through tears/breaches due to potential settling/structural failure of the HLP liner systems (Ecology and Environment, Inc. 2013).

On the basis of groundwater monitoring results, these impacts are thought to extend vertically down to OU-1 groundwater (CH2M Hill 2011b). Furthermore, the OU-8 FS (CH2M Hill 2011b) also notes that additional characterization efforts are needed to fully determine the nature and extent of contamination in: 1) in OU-8 surface and subsurface soil due to releases of drain-down fluids from the Arimetco Facilities; and 2) OU-1 groundwater that may be attributed to OU-8 releases.

Numerous spills of process solution in connection with past Arimetco operations have been recorded, and all of the recorded spills report limited to no confirmation sampling data or post-remedial efforts (CH2M Hill 2010, 2011b). As noted by CH2M Hill (2011b), the spill report documentation in the HSR (CH2M Hill 2010) only generally describes the location and type of materials spilled, along with the estimated quantity of each spill and general response action that was taken. In some instances, these records appear to underestimate the overall quantity of materials spilled. On the basis of the existing spill reports and the suspected quantities of fluids released to the environment, further investigations may be required (CH2M Hill 2011b).

Process Areas (OU-3)

The OU-3 RI has involved extensive characterization to determine the vertical extent of impacted soils beneath known source areas and above known areas of impacted groundwater in the underlying alluvial aquifer (e.g., BC 2011a, 2014e). OU-3 RI activities have included: 1) soils and groundwater characterization in 2004-2005; 2) a variety of radiometric surveys; 3) groundwater monitor well installations in 2005; 4) sub-surface utility and dry well investigations during the period 2010-2013; 5) step-out (vertical and horizontal) soil characterization activities during the period 2013-2014; and 6) sampling and analysis of standing water in select locations during the 2013-2014 field program.

During the RI, a total of 3,385 samples of vadose zone alluvial soils were collected and analyzed from metals (57,764 analyses) and radiochemicals (9,172 analyses). Analytical results are discussed in the context of exceedances relative to the EPA Industrial regional screening level (RSL), a background level, and the maximum depth below ground surface that such exceedances occurred. A total of 198 metals exceedances, primarily arsenic and chromium, occurred in near-surface soils to approximately 15 feet bgs in every sub-area of OU-3. Metals exceedances also occurred at depths to 80 feet bgs at three primary waste solution conveyance ditches (Overflow, East Solution and Calcine Ditches) and the Acid Plant Pond. Fifty-one radiochemical exceedances, primarily for radium-226 and -228, occurred in shallow soils to depths of up to five feet bgs throughout OU-3. Three exceedances occurred in the southern Calcine Ditch (now included in OU-4a) to a depth of 20 feet.

COI concentrations in OU-3 groundwater are highest beneath the Precipitation Plant (Sub-area 5 on Figure 2-1), and are typically 10 times less than the concentrations in groundwater beneath OU-4a (Figures 5-2 to 5-7). The depth to groundwater beneath OU-3 ranges from 90 to more than 120 feet bgs (Figures 4-8 and 4-9). Vadose zone alluvial materials beneath OU-3 do not differ substantially from the vadose zone alluvial materials beneath OU-4a. Thus, to the extent that insights from the OU-4a vadose zone modeling results and soil moisture profiling are applicable to OU-3, groundwater impacts beneath OU-3 appear to be the result of past mining operations and fluid management rather than post-mining ambient Site climate conditions.

5.5.2 Agriculture

Agricultural influences on Study Area groundwater were identified and quantified during the background assessment and are summarized below.

Benson and Spencer (1983) noted that "agricultural practices strongly influence the concentration of uranium in Walker River and its East and West Forks. Irrigation practices induce significant losses of fluid through evaporation and evapotranspiration processes. This results in artificial increases in concentrations of uranium and other elements." Percolation of crop irrigation water through soils increases alkalinity in soil moisture, which has been shown at other sites (Jurgens et al. 2010; Brown et al. 2007) to solubilize and desorb naturally-occurring uranium from sediments resulting in elevated uranium concentrations in Shallow zone groundwater. Application of agricultural amendments and fertilizer on crop fields contributes sulfate, calcium, nitrate and other COIs to groundwater (Benson and Spencer 1983; BC 2014a, 2016b). Nitrate originating primarily from surface-applied fertilizers also plays a role in uranium solubilization leading to uranium mobilization (Nolan and Weber 2015).

Groundwater data from the NSA show that agricultural activities contribute sulfate, uranium, nitrate, alkalinity, and other COIs to groundwater. The NSA refers to the portion of the groundwater Study Area located northeast of West Campbell Ditch and north of the Sunset Hills. Monitor wells and well clusters located in the NSA include B/W-10(S, D1), B/W-50(S, D1, D2, D3), B/W-53(S1, S2, B), B/W-54(S, I, B), B/W-55(S, D1, D2), B/W-56S, B/W-57(S, I, D1, D4), B/W-58(S, D1, D3, B), B/W-59(S, D3), B/W-68(S, D1, D4), B/W-69(S, D1, D2, D5), B/W-81(S, D1, D2), B/W-82R(S, I, B), YPT-MW-(8S, 9I, 10B), YPT-MW-(11S, 12I), YPT-MW-(13I, 14D1) and MMW-2. Groundwater flow data and chemical distributions from monitor wells and clusters B/W-56, B/W-57, B/W-59, B/W-68, B/W-69, and B/W-81 discussed below illustrate the effects of agricultural practices on groundwater quality near agricultural fields in the northeastern part of the Study Area. The locations of these wells are shown on Figure 3-3 and potentiometric surface maps for the alluvial aquifer (Figures 4-11a through g) indicate that groundwater in the NSA flows to the north and northwest.

Groundwater near these wells in the NSA is recharged by infiltration from the East Campbell Ditch and irrigation on a series of agricultural fields (BC 2014a; SSPA 2014). During drilling and installation of monitor wells, zonal groundwater samples were collected to profile vertical chemical gradients in the alluvial aquifer upgradient and downgradient of the fields. Chemical profiles for sulfate, uranium, alkalinity, and arsenic in groundwater are provided on Figure 5-12 for B/W-59, B/W-68, and B/W-69, and on Figure 5-13 for B/W-56, B/W-57, and B/W-81. The wells are grouped in this manner to illustrate changes in groundwater chemistry along two parallel flow paths beneath the agricultural fields.

Except for arsenic, chemical concentrations in alluvial groundwater in the Shallow through Deep 2 zones (i.e., above 4,120 feet amsl) increase along the flow path beneath the agricultural fields (i.e., from B/W-59 and B/W-56 upgradient of the agricultural fields to B/W-68 and B/W-57 immediately downgradient of the agricultural fields). B/W-69 and B/W-81, located farther along their respective flow paths, also exhibit elevated values above 4,120 feet amsl, although the values are not as high as in B/W-68 and B/W-57 immediately downgradient of the agricultural fields. From B/W-56 to B/W-57, sulfate values exhibit more than a four-fold increase from about 30 mg/L at B/W-56 to a maximum of 137 mg/L at B/W-57. Uranium values exhibit more than a ten-fold increase from about 2 µg/L at B/W-56 to a maximum of 73 µg/L at B/W-57. Alkalinity exhibits a 2.5-fold increase from about 100 mg/L at B/W-56 to a maximum of 257 mg/L at B/W-57. From B/W-59 to B/W-68, sulfate values exhibit a two-fold increase from about 75 mg/L at B/W-59 to a maximum of 140 mg/L at B/W-68. Uranium values exhibit almost a two-fold increase from about 25 µg/L at B/W-59 to a maximum of 44 µg/L at B/W-68. Alkalinity exhibits a 20% increase from about 190 mg/L at B/W-59 to a maximum of 235 mg/L at B/W-68.

Arsenic exhibits increasing concentrations with depth at all locations, with the greatest increases observed in the Deep 3 through Deep 5 zones (i.e., below 4,120 feet amsl). Arsenic values generally increase from about 5 µg/L in the Shallow zone to approximately 80 µg/L in the Deep 5 zone. Arsenic values decrease along the flow path beneath the agricultural fields (the highest values are observed in B/W-59 and B/W-56, and the lowest values are observed in B/W-69 and B/W-81).

Data from well clusters B/W-59, B/W-68, B/W69, B/W-56, B/W-57 and B/W-81 indicate that concentrations of other constituents in addition to sulfate, uranium and alkalinity also increase in groundwater above 4,120 feet amsl along the flow path beneath the agricultural fields (Table 5-4). These constituents include TDS, calcium, chloride, magnesium, potassium, nitrate, and strontium. The average horizontal groundwater flow gradient in Shallow zone groundwater beneath the agricultural fields is approximately 0.002 feet/foot. Vertical (downward) groundwater flow gradients beneath the agricultural fields range between 0.02 feet/foot when agricultural pumping is not occurring and 0.1 feet/foot during pumping periods (calculated using water levels in B/W-57S and B/W-57D4).

Increasing alkalinity and calcium concentrations are important controls on mobilization of naturally-occurring uranium from aquifer solids (Bernhard et al. 2001). The correlation between increasing concentrations of alkalinity and calcium associated with agricultural activities, and increasing uranium concentrations as groundwater flows beneath agricultural fields in the NSA is discussed in Section 6.2.2.

Table 5-4. Concentrations of Constituents that Increase Beneath the Agricultural Fields in the North Study Area

Constituent	Units	Average Concentration in Monitor Well (May 2012 - October 2014)				
		B/W-59S	B/W-68S	B/W-68D1	B/W-69S	B/W-69D1 & B/W-69D2
Sulfate	mg/L	48	110	79	125	79
Uranium	µg/L	9	30	41	29	30
Alkalinity, bicarbonate (as $CaCO_3$)	mg/L	140	260	230	275	188
Total Dissolved Solids (TDS)	mg/L	260	530	440	540	400
Calcium	mg/L	31	49	76	78	64
Chloride	mg/L	16	20	20	25	20
Magnesium	mg/L	9	12	19	20	15
Potassium	mg/L	4	5	6	6	6
Nitrate (as N)	mg/L	0.06	5.0	2.9	1.2	0.9
Strontium	mg/L	0.3	0.5	0.6	0.7	0.6
Constituent	**Units**	**Average Concentration in Monitor Well (May 2012 - October 2014)**				
		B/W-56S	**B/W-57S**	**B/W-57I & B/W-57D1**	**B/W-81S**	**B/W-81D1 & B/W-81D2**
Sulfate	mg/L	41	62	142	70	62
Uranium	µg/L	4	11	75	4	36
Alkalinity, bicarbonate (as $CaCO_3$)	mg/L	140	174	293	160	213
Total Dissolved Solids (TDS)	mg/L	254	345	620	350	370
Calcium	mg/L	31	41	103	50	64
Chloride	mg/L	15	18	32	21	20
Magnesium	mg/L	8	11	25	13	15
Potassium	mg/L	5	3	9	5	7
Nitrate (as N)	mg/L	0.08	1.3	1.4	1.4	0.7
Strontium	mg/L	0.3	0.4	0.9	0.4	0.6

Notes: mg/L = milligrams per liter; µg/L = micrograms per liter

5.5.3 Naturally-Occurring Sources

Sulfate, uranium, arsenic, and other COIs occur naturally in groundwater in Mason Valley because of groundwater contact with naturally-mineralized and/or hydrothermally-altered bedrock associated with copper deposits and/or alluvial sediments derived from mineralized bedrock (BC 2014a, 2016b).

As noted in Section 5.4, the extent of mine-impacted groundwater was conservatively estimated under EPA direction because it "is in the best interest of the overall progress for completing the OU-1 Groundwater Remedial Investigation Report" and that the tools used in the background assessment to estimate the area of mine-impacted groundwater may not account for the full range of chemical concentrations that occur naturally in Study Area groundwater (EPA 2016c).

Extensive evidence of naturally-occurring sulfate, uranium, arsenic and other COIs in Mason Valley groundwater includes detectable concentrations of these chemicals in: 1) surface water, which is the primary component of alluvial aquifer recharge, at sampling points located upstream of the Site (Benson and Spencer 1983; BC 2014a); 2) groundwater and geothermal water in the discharge area at the northern end of Mason Valley (Benson and Leach 1979); 3) groundwater samples from Yerington municipal water supply wells that are located hydraulically upgradient and/or cross-gradient of the Site; 4) groundwater samples from monitor wells installed by ARC that are located hydraulically upgradient and/or cross-gradient of the Site (BC 2016b), with concentrations of sulfate and uranium occasionally above MCLs; 5) groundwater from private wells sampled by the USGS located hydraulically upgradient and/or cross-gradient of the Site, with concentrations of sulfate, uranium and arsenic occasionally above MCLs (Benson and Spencer 1983); and 6) groundwater samples from monitor wells installed by ARC that are located outside of the plume of mine-impacted groundwater in the NSA (BC 2016b), with concentrations of uranium as high as 100 µg/L or more.

Further evidence of naturally-occurring COIs in groundwater near the Site occurs in the SWRA where elevated arsenic, and possibly other COIs, appears to be associated with MFR hydrologic processes. These MFR processes include: 1) subsurface water transmitted along fractures and

faults (especially oblique range-front faults such as the Sales Fault) in arsenic-bearing volcanic and granitic bedrock that connect subsurface water in the mountain block and the basin aquifer; and 2) contributions of water at the mountain front from surface stream runoff and shallow subsurface water transmitted in stream bed sediments. Elevated arsenic in SWRA groundwater is associated with low concentrations of sulfate and uranium (the two primary indicators of mine-impacted groundwater), and hydrologic tracer data yield groundwater age estimates that pre-date mining (BC 2016b; EPA 2016b). Collectively, this information indicates that elevated arsenic and possibly other COIs in groundwater in this part of the Study Area are not associated with mining activities. Instead, elevated arsenic in this part of the Study Area is likely naturally-occurring. Elevated arsenic values have been associated with MFR, geothermal groundwater, and stagnant groundwater systems (Smedley and Kinniburgh 2001), and these characteristics apply to the sub-geothermal groundwater present in all groundwater zones to the west of the Site. The elevated temperature of groundwater to the west of the Site and adjacent to the Singatse Range, where MFR hydrologic processes predominate, are shown on figures provided in Appendix L.

SECTION 6.0
CONTAMINANT FATE AND TRANSPORT

The medium of concern in the OU-1 Study Area is groundwater and the mine-related COIs include acidity (i.e., low pH), TDS, major ions including sulfate, metals, and radiochemicals including uranium. The physical transport mechanisms and geochemical attenuation/mobilization processes that affect the movement of COIs in Study Area groundwater are discussed below.

6.1 Contaminant Transport

Transport mechanisms are physical processes controlling the movement of COIs from points of origin through the groundwater system. In the Study Area, COIs are (were) sourced to groundwater from Site sources and/or agricultural practices, and occur naturally in groundwater in Mason Valley because of groundwater contact with naturally-mineralized and/or hydrothermally-altered bedrock associated with copper deposits and/or alluvial sediments derived from mineralized bedrock.

The dominant solute transport mechanisms for COIs in groundwater are advection and dispersion. Advective transport is the migration of the COI with the groundwater. Groundwater moves from areas of recharge (i.e., high hydraulic head) to areas of discharge (i.e., low hydraulic head) and groundwater velocities are determined by solving the groundwater flow equation, which is a function of hydraulic conductivity, hydraulic gradient, and porosity. Groundwater levels in monitor wells provide hydraulic head and groundwater flow velocity information. Hydrodynamic dispersion describes the spread of COIs around an average groundwater flow path, beyond the region they would normally occupy due to advection alone. Hydrodynamic dispersion is the sum of two processes: mechanical dispersion and molecular diffusion. Mechanical dispersion results from mixing that occurs because of local variations in groundwater velocity and the aquifer's matrix. Molecular diffusion results from variations in solute concentrations within the groundwater system.

The primary influences on groundwater movement in the Study Area are subsurface lithology and structure, and local groundwater pumpage and irrigation associated with agriculture. Agricultural activities influence groundwater flow rates and directions, chemical migration pathways and transport rates, and contribute chemicals to groundwater via leaching of soil amendments and subsequent transport through the vadose zone to groundwater. Irrigation practices near the mine Site, including groundwater extraction using high-capacity wells and conveyance/irrigation of both water from the Walker River and groundwater, alter groundwater flow rates and directions during the irrigation season due to the alteration of the natural recharge/discharge rates and locations. These alterations in groundwater flow affect contaminant transport rates and directions.

6.2 Geochemical Attenuation/Mobilization Processes

Geochemical processes that affect the release and subsequent mobility/attenuation of mine-related COIs such as sulfate, uranium and metals during groundwater transport in the Study Area have been evaluated (BC 2016b; Appendix J-7) using: 1) Study Area groundwater data from August 2014 including field parameter measurements (i.e., pH, ORP and DO) and chemical concentrations; 2) the EPA-approved thermodynamic database developed for geochemical modeling Site geochemical attenuation/mobilization processes; and 3) correlations between common groundwater chemicals that affect uranium mobility.

6.2.1 Groundwater Geochemical Conditions and Chemical Speciation

Geochemical oxidation/reduction (redox) conditions within alluvial aquifer groundwater are variable; however, certain general trends and patterns are observed. In general, oxic conditions (i.e., DO > 1 mg/L and higher Eh values) occur in Shallow zone groundwater and suboxic to anoxic conditions (i.e., DO < 1 mg/L and lower Eh values) occur in Intermediate and Deep groundwater zones (Figure 6-1). Exceptions to this general pattern include the following: 1) in Shallow zone groundwater beneath much of the Site and off-Site to the north of the Evaporation Ponds, anoxic (rather than oxic) conditions occur; 2) in Deep groundwater zones beneath the Hunewill Ranch, oxic (rather than anoxic) conditions occur; and 3) on the west side of the Study Area adjacent to the Singatse Range, oxic conditions occur in the Shallow zone, as well as all deeper zones in this part of the Study Area.

Dissolved iron and the iron-system mineralogy, of all the metals present in groundwater, provide the most important constraints on pH, redox, and other metal solubilities in Study Area groundwater (BC 2016b; Appendix J-5). Ferric hydroxide solids in the aquifer sediments can adsorb significant concentrations of dissolved metals and metalloids such as uranium and arsenic, attenuating transport of these constituents. The importance of iron mineralogy and its widespread influence on the Study Area fluid chemistry are illustrated with two Eh-pH diagrams (Figures 6-2 and 6-3). The mineral stability fields in each diagram were constructed for groundwater pH values below, and above, 5.5 respectively, using chemical data from discrete groundwater populations. The individual samples were then plotted on each diagram. The populations were selected from similar chemical environments (samples from two or more unrelated populations are scattered and often obscure the trends).

Groundwater samples from two populations with strong mining impact (pH values below 5.5; Figure 6-2) clearly plot along the K-jarosite and schwertmannite phase boundaries and triple points. Sample alignment near and along the aqueous-mineral boundaries demonstrates the important role these minerals play in dominating and buffering the acidic groundwater at relatively oxidizing Eh levels, as noted above. Also shown on the figure is the specific sample from which the phase boundaries in the figure were computed.

Groundwater samples from two off-Site and more alkaline populations (pH values above 5.5; Figure 6-3) are aligned along the aqueous Fe^{2+} - $Fe(OH)_3(a)$ phase boundary. The mineral $Fe(OH)_3(a)$ is an important adsorptive phase that limits/attenuates the concentrations of other groundwater metals.

As noted previously, the strong alignment demonstrates the impact of the ferric hydroxide phase upon the groundwater redox and pH. The phase boundaries for this diagram were computed from the cluster centroid composition. Based on the groundwater redox conditions and geochemical modeling (BC 2016a; Appendix J-5), chemicals in Study Area groundwater exhibit the following:

- The dominant aqueous redox states determined in virtually all August 2014 groundwater samples were As(V), Fe(II), Mn(II) Se(IV) and U(VI). Vanadium was present in the V(V) redox state in all August 2014 groundwater samples from the Intermediate, Deep and bedrock wells. In Shallow zone groundwater, the V(IV) redox state predominated below a pH of about 5 and the V(V) redox state predominated above a pH of 5.
- Sulfur dissolved in Study Area groundwater is present as sulfate (a negatively-charged ion) and gypsum saturation is observed only in groundwater samples with sulfate concentrations exceeding approximately 1,500 mg/L.
- In the absence of sulfate reduction or gypsum precipitation, the negatively-charged sulfate ion is minimally attenuated in groundwater systems by adsorption. Consequently, in Study Area groundwater with sulfate concentrations less than approximately 1,500 mg/L, sulfate can be expected to be transported as a conservative constituent.
- U(VI) is the dominant oxidation state of dissolved uranium in all August 2014 groundwater samples. Differences in the aqueous speciation of uranium are related to the pH and availability of cations in solution, not redox conditions. Dissolved uranium in Study Area groundwater is predominantly present in complexes with sulfate, carbonate and/or calcium that form neutral or negatively-charged ions (e.g., $Ca_2UO_2(CO_3)_3^0$, $CaUO_2(CO_3)_3^{-2}$, $UO_2(SO_4)_2^{-2}$, and UO_2SO_4) (Figure 6-4). Samples with dominant calcium-uranyl-carbonate ligands reflect oxidizing, carbonate-rich groundwater conditions. Samples with dominant uranyl-sulfate ligands reflect oxidizing conditions with no detectable amounts of alkalinity and pH <5.
- Formation of neutral or negatively-charged aqueous uranium species has been shown to limit uranium adsorption and increase uranium mobility (Fox et al. 2006; Stewart et al. 2010). Since limited uranium adsorption onto hydrous ferric hydroxide solids and soils is expected in neutral to slightly alkaline groundwater (Hsi and Langmuir 1985; Echevarria et al. 2001), uranium attenuation during groundwater transport in off-Site portions of the Study Area can be assumed to be negligible as a conservative first approximation.
- As(V) arsenate is the dominant oxidation state for all August 2014 groundwater samples indicating oxic groundwater conditions, and arsenic speciation is dominated by the negatively-charged $H_2AsO_4^-$ and $HAsO_4^{-2}$ species. Geochemical modeling indicates the potential for precipitation of several arsenic mineral phases including scorodite and barium arsenate.
- Arsenate adsorption on sediments tends to decrease with increasing pH because of competition for adsorption sites between the negatively-charged arsenate aqueous species and OH^- or bicarbonate (Sø et al. 2008; Stachowicz et al. 2007).
- Geochemical modeling predicts the potential for jarosite mineral precipitation primarily in the Shallow zone under the LEP, UEP, Thumb Pond, and Phase IV HLP (Figure 6-5). Uranium and other metals associated with predicted jarosite mineral phases and aquifer sediments beneath these features potentially represent a persistent source of chemicals to groundwater.

- The spatial distributions of elevated concentrations of mobile parameters such as sulfate and uranium are significantly more extensive than the spatial distributions of acidity (as indicated by pH) and metals. The limited spatial extent of low pH values and elevated metal concentrations indicates that geochemical attenuation processes in Study Area groundwater reduces acidity and limits the mobility of metals relative to the more mobile chemicals such as sulfate and uranium. Elevated metal concentrations in groundwater correlate strongly with low pH.

6.2.2 Controls on Uranium Mobility in North Study Area Groundwater

As noted previously in Section 5.5.2, the concentrations of numerous COIs in groundwater increase along groundwater flowpaths beneath agricultural fields in the NSA. The correlation between increasing concentrations of alkalinity and calcium associated with agricultural activities, and increasing uranium concentrations as groundwater flows beneath agricultural fields in the NSA is shown on Figure 6-6. Increasing alkalinity and calcium concentrations are important controls on the formation of uranium species that have a low tendency to bind to aquifer solids (Bernhard et al. 2001) and, thus, uranium is mobilized from aquifer solids to adjacent groundwater as alkalinity and calcium concentrations increase. In addition, the observed correlation between increasing concentrations of alkalinity, calcium and uranium is consistent with the previously-noted geochemical modeling predictions of uranium speciation in Study Area groundwater.

The upper panel in Figure 6-6 displays data for all the alluvial monitor wells in the NSA that are located near agricultural fields. The lower panel in Figure 6-6 displays a subset of the data presented in the upper panel. Specifically, this lower panel displays data along a groundwater flow path from wells upgradient of the NSA agricultural fields (i.e., wells B/W-56 and B/W-59) to wells/well clusters located downgradient of the NSA agricultural fields (i.e., well cluster B/W-57 and well YPT-MW-12I). In wells located upgradient of the NSA, uranium concentrations are less than 12 µg/L. However, as groundwater flows beneath the NSA agricultural fields and concentrations of alkalinity and calcium increase, naturally-occurring uranium attached to aquifer solids is released. At well B/W-57I, elevated uranium concentrations range from approximately 48 to 72 µg/L and at well B/W-57D1 elevated uranium concentrations range from 73 to 110 µg/L.

Well YPT-MW-12I is located hydraulically downgradient of well cluster B/W-57, which provides additional information about chemical loading to alluvial groundwater associated with agricultural activities in the NSA. The influence of agricultural activities on chemical concentrations in YPT-MW-12I is shown on Figure 6-7. Although concentrations of uranium in groundwater at YPT-MW-12I have increased recently (upper panel), the trends in chemical concentrations in groundwater at this well are consistent with geochemical projections based on the control that calcium and alkalinity have on uranium mobility, and are not related to the Site.

As indicated in the lower panel, sulfate concentrations in well YPT-MW-12I are greater than 71 mg/L and exhibit seasonal variability, with elevated concentrations occurring in February of each year. Plume advancement cannot account for the magnitude of sulfate concentrations or seasonality observed in this well because sulfate concentrations are lower in wells to the southwest that demarcate the leading edge of mine-impacted groundwater (i.e., well clusters B/W-10, B/W-52, and B/W-55). Instead, the concentrations of sulfate in well YPT-MW-12I can only be accounted for by sulfate concentrations in upgradient wells B/W-57I and B/W-57D1, which are impacted by agricultural activities.

6.2.3 Site-Specific Distribution Coefficients

As groundwater migrates within the Study Area, certain geochemical reactions occur between the COIs in groundwater and the alluvial aquifer sediments. These reactions determine the relative rates at which chemicals migrate with respect to the advective front of groundwater. The primary process associated with the attenuation of inorganic COIs, particularly metals, in groundwater is adsorption onto the surfaces of minerals or organic material in the aquifer sediments.

The Site-specific distribution coefficient (K_d) discussed in Section 3.3.5 may be used to quantify adsorption reactions between COIs in groundwater and the alluvial aquifer sediments during groundwater flow and chemical transport simulations. It should be noted that the distribution coefficient is a bulk measurement and provides only indirect information on the type of adsorption interactions taking place on the alluvial aquifer sediments. Summary statistics for the revised K_d values calculated using zonal groundwater sample data are shown in Table 6-1.

Table 6-1. Summary Statistics for Zonal Sample K_d Values

Analyte	Distribution Coefficient Statistics (L/kg)				
	Minimum	Maximum	Mean	Geometric Mean	Median
Sulfate	0.05	0.62	0.18	0.15	0.16
Uranium	0.42	289	49	17	33
Arsenic	108	6,412	1,763	957	800

Notes: L/kg = liters per kilogram

K_d values less than 1 L/kg, as is the case for sulfate, indicate little if any partitioning of this negatively-charged ion from the dissolved (i.e., liquid) phase to the solids phase. The uranium K_d values are higher than K_d values for sulfate, indicating some tendency for uranium adsorption on aquifer sediments. Dissolved uranium in Study Area groundwater is predominantly present in neutral or negatively-charged complexes (Figure 6-4), which has been shown to limit uranium adsorption (Fox et al. 2006; Stewart et al. 2010). However, limited uranium adsorption onto hydrous ferric hydroxide solids and soils is expected in neutral to slightly alkaline groundwater (Hsi and Langmuir 1985; Echevarria et al. 2001; Li and Kaplan 2012), and likely explains the higher uranium K_d values.

K_d values for arsenic are substantially greater than 1 L/kg. These high K_d values reflect much higher concentrations of those chemicals in the solid phase versus the dissolved phase, which indicates a strong tendency for arsenic to partition from the dissolved to the solid phase.

Summary statistics for the K_d values calculated for the 25 chemicals and compounds using monitor well groundwater samples are shown in Table 6-2.

Table 6-2. Summary Statistics for Monitor Well K_d Values

Analyte	Distribution Coefficient Statistics (1)				
	Minimum	Maximum	Mean	Geometric Mean	Median
Aluminum	10,850	214,670	88,830	64,851	98,350
Arsenic	18.4	1,311	461.2	277.2	421
Boron	0.40	9.26	4.39	3.15	3.36
Barium	93.8	6,676	1,937	959	1,000
Calcium	0.38	20.6	7.62	3.47	4.74
Chloride	0.07	1.56	0.22	0.18	0.17
Cobalt	192.3	4,643	2,462	1,869	2625
Chromium	316	1,182	689	626	579
Copper	83.3	13,684	4,645	2,662	3,333
Fluoride	1.56	17.2	4.52	3.73	3.26
Iron	8.6	541,880	22,112	146,061	242,733
Potassium	5.1	292.4	109.0	72.7	97.5
Lithium	46.0	379.3	126.6	116.1	113.8
Magnesium	0.34	76.8	26.2	12.5	23.5
Manganese	56.8	3,838	795	351	291
Molybdenum	0.14	2,130	176.9	21.0	63.1
Sodium	0.21	1.3	0.78	0.64	0.88
Nickel	300	1,736	1,142	1030	1,200
Nitrate	0.03	4.0	0.30	0.16	0.15
Lead	1,000	48,100	14,983	8,355	9,600
Selenium	35.9	9,180	3,084	1,202	2154
Sulfate	0.03	1.04	0.186	0.15	0.17
Uranium	1.0	238.2	41.7	20.2	25.6
Vanadium	43.5	4,717	1,115	673	917
Zinc (2)	1,385	1,385	1,385	1,385	1,385

Notes:

1) L/kg = liters per kilogram.
2) For zinc, only one set of co-located sediment and water samples were available for calculating a K_d.

The majority of the K_d values calculated using the monitor well groundwater samples are greater than 1 L/kg. Chloride, nitrate, and sulfate (negatively charged ions in groundwater) and sodium were the only chemicals where the K_d values were consistently less than 1 L/kg. Boron, calcium and fluoride had K_d values in the range of 1 to 10 L/kg. All other chemicals and compounds had K_d values ranging from 10 L/kg up to approximately 500,000 L/kg.

The values at the high end of the range are influenced by the presence of non-detects in the data for the groundwater concentrations. In particular, groundwater concentrations for aluminum, iron and lead were almost universally below the detection limits. However, the concentrations in the soil samples for those same chemicals were nearly all above the detection limit. In these cases, the groundwater concentrations used to calculate K_d values typically represented the reporting limit for that particular chemical. Given that, the K_d values can be thought of as upper bounds for that particular chemical and indicate very little mobility in groundwater.

The variability between the K_d values for the same chemical or compound was, in general, consistent. Only a few chemicals had K_d values with variabilities of more than one order of magnitude. Typically, the wider-ranging K_d variabilities were expressed for those chemicals with non-detect results that were incorporated into the calculation.

Statistical parameters characterizing the uranium K_d values derived from zonal and monitor well groundwater sample data are similar. Uranium K_d values based on monitor well data vary by approximately two orders of magnitude. A correlation of uranium K_d values with Site geochemical data shows that uranium adsorption varies as a function of changes in pH and concentrations of alkalinity, calcium and magnesium. Consequently, use of a constant K_d approach to simulate uranium adsorption during predictive transport modeling may not accurately represent actual adsorption processes.

Instead, a surface complexation model (SCM), such as the general composite approach described by Davis et al. (2009), may be more suitable for modeling adsorption processes during transport at the Site because it can describe changes in adsorption reactions at mineral surfaces as chemical conditions and aqueous speciation(s) change. However, in off-Site portions of the Study Area where aqueous concentrations are lower and hydrous ferric hydroxide solid concentrations are more sporadic, it may be appropriate to assume negligible uranium attenuation during groundwater transport as a conservative first-order approximation.

6.3 Mine-Impacted Groundwater Plume Dynamics

Summarized below are the initial evaluations of mine-impacted groundwater plume dynamics that have been presented in previous reports (BC 2014f, 2015f) and/or discussed with EPA, NDEP and other stakeholders during groundwater technical meetings in 2015 and 2016. The results of these initial evaluations will be provided in a separate report, along with: 1) a statistical evaluation of chemical concentration trends in individual monitor wells, as requested by EPA; and 2) flow model predictions of future changes in plume dimensions and chemical concentrations.

Multiple approaches consisting of center-of-mass calculations and trend evaluations of the total masses and average concentrations of sulfate and uranium have been used to evaluate the dynamics of the plume of mine-impacted groundwater.

Methods

This evaluation was conducted using the Monitoring and Remediation Optimization System (MAROS) software that was developed by the U.S. Airforce Center for Environmental Excellence (AFCEE 2006). MAROS uses the Delaunay Triangulation/Voronoi Diagrams method (George and Borouchaki 1998) to partition the interpolation area into polygon-shaped sub-regions associated with each monitor well. The chemical concentration in an entire sub-region is represented by the concentration in the associated monitor well in a given sampling event. MAROS then calculates the location of the center-of-mass of the interpolated chemical distribution.

MAROS software allows for efficient and consistent computation of large groundwater datasets and depictions of the chemical center-of-mass over time, as well as providing output for computation of changes in chemical mass and average chemical concentration over time. However, the MAROS computation method uses polygon-shaped sub-areas that do not fully encompass the curvilinear area of mine-impacted groundwater. Consequently, although the MAROS output is consistently computed over time, the computed volumes (and derived chemical masses and average concentrations) are underestimated relative to the method used in Section 5.4 to estimate plume statistics.

Center-of-Mass Evaluation

The center-of-mass of plumes of the mine-related constituents sulfate and uranium and the total chemical mass in these plumes were evaluated over the three-year period 2012 through 2015 to assist in the evaluation of plume dynamics. The center-of-mass analysis requires a consistent set of data over time to make meaningful inferences about plume movement. Therefore, only wells that were monitored in every quarter from 1Q 2012 through 1Q 2016 were included in the analysis. Centers-of-mass for sulfate and uranium were calculated for the Shallow, Intermediate, Deep 1, Deep 2, Deep 3, and combined Deep 4 and 5 zones of the alluvial aquifer. The Deep 4 and 5 zones of the alluvial aquifer were combined due to the limited number of monitor wells in these zones.

In the evaluation, monitor well B/W-27D3a was included in the list of Deep 2 zone wells and monitor well B/W-41D4 was included in the list of Deep 3 zone wells to address areas within each zone that were lacking adequate spatial coverage. Monitor wells in the B/W-65 well cluster, located in the middle of an agricultural field, were not included in the analysis because the wells have been sampled sporadically due to lack of access during the irrigation season.

Prior to interpolation, chemical data from the 261 monitor wells were reviewed using time-concentration plots to screen for potential outliers. When outliers were identified for a particular sampling event, the value of the data point was replaced with the average value of the previous and subsequent sampling events. The number of outliers identified represents less than 0.2 percent of the data used in the analysis.

The calculated centers-of-mass for sulfate and uranium are located beneath the Evaporation Ponds (Figure 6-8), with the following exceptions:

- The uranium center-of-mass in the Deep 1 zone is located beneath the Hunewill Ranch (about 3,000 feet northwest of the monitor well B/W-25D1). This is consistent with the presence of collocated elevated concentrations of uranium and alkalinity beneath the agricultural fields in the Deep 1 zone compared to areas beneath the Site.
- The uranium center-of-mass in the Deep 4/5 zone is located beneath the Hunewill Ranch within a few hundred feet of the Site boundary.

From February 2012 to February 2016, the centers-of-mass for the sulfate and uranium plumes exhibit very little relative movement, an indication of stable plume behavior.

Total Mass and Average Concentrations

Over the 3-year monitoring period from February 2012 to February 2015, the masses of sulfate and uranium in each of the groundwater zones remained relatively stable, with typically less than five percent variation between the initial and more recent monitoring events (Figure 6-9). Also, clear trends (either increasing or decreasing) are not evident, with the exception of decreasing sulfate trends observed in the Shallow zone and decreasing sulfate and uranium trends in combined Deep 4 and Deep 5 zones. During the monitoring period, the calculated mass of sulfate in the Shallow zone decreased from about 97,000 to 85,000 tons (i.e., 12%) and the mass of sulfate in the Deep 4/5 zones decreased from about 13,000 to 10,000 tons (i.e., 25%). The mass of uranium in the combined Deep 4 and Deep 5 zones decreased from about 5.2 to 3.7 tons (i.e., 29%).

Because the various alluvial groundwater zones have different thicknesses and volumes, the total chemical masses in each individual zone are not directly comparable. For example, the Intermediate zone contains the smallest sulfate mass because it is the thinnest groundwater zone. Consequently, changes in average concentrations over time in the various groundwater zones are a more appropriate comparison. Changes over time in average concentrations of sulfate and uranium in the alluvial aquifer groundwater zones are also shown on Figure 6-9.

Clear trends (either increasing or decreasing) are not evident, with the exception of decreasing average sulfate concentrations in the Shallow zone and decreasing sulfate and uranium concentrations in the combined Deep 4 and 5 zones. During the monitoring period, the average concentration of sulfate in the Shallow zone decreased from 1,518 mg/L to 1,330 mg/L (i.e., 12%) and the average concentration of sulfate in the Deep 4/5 zones decreased from 90 mg/L to 67 mg/L (i.e., 25%). The concentration of uranium in the Deep 4/5 zone decreased from 35 to 25 ug/L (i.e., 29%).

The decrease in sulfate mass and average concentration in the Shallow zone is interpreted as dilution effects from irrigation practices in the agricultural fields north of the mine boundary. The cause of the observed decrease in calculated average uranium concentrations in the combined Deep 4 and Deep 5 zones is likely due to dilution and dispersion. The calculated decrease in total sulfate and uranium mass is likely an apparent effect due to the fewer data points for calculating chemical mass.

The results of these evaluations indicate that, in general, the plume of mine-impacted groundwater is stable. The plume stability is the result of very slow groundwater velocities and attenuation by dilution. The dilution occurs primarily as the result of recharge on the agricultural fields (specifically on the fields of the Hunewill Ranch) and leakage from irrigation ditches (specifically the West Campbell Ditch), and dispersion within the groundwater plume.

SECTION 7.0

HYDROGEOLOGIC CONCEPTUAL SITE MODEL

The Site is a former copper mine located in the west-central portion of the Mason Valley, a Basin-and-Range-type graben filled with up to 1,000 feet of unconsolidated valley-fill deposits of Tertiary and Quaternary age lying unconformably on a weathered surface of hydrothermally-altered Tertiary volcanic and Mesozoic intrusive bedrock. The valley is bordered to the west by the Singatse Range, to the east by the Wassuk Range, and to the north by the Desert Mountains. Regional metals mineralization and hydrothermal alteration associated with localized porphyry and skarn copper deposits occur in the Singatse Range and nearby portions of the Mason Valley.

The unconsolidated valley fill deposits were derived primarily from erosion of the uplifted mountain blocks and from deposition in the floodplain of the Walker River. In addition, lacustrine deposits derived from ancestral Lake Lahonton occur north of the Site. Depositional processes have resulted in a complex interbedded sequence of alluvial sediments.

Historically, regional groundwater flow patterns in the Mason Valley prior to Anaconda/Arimetco mining operations were similar to current conditions with groundwater moving generally from south to north, and discharging to surface seeps and geothermal springs in the northern portion of the basin. Locally, though, current flow patterns have been significantly altered from historical patterns by agricultural activities. The alluvial aquifer in the Mason Valley is very productive and groundwater is currently pumped extensively for irrigation (Carroll et al. 2010; SSPA 2014).

The alluvial aquifer is primarily recharged by downward percolation from irrigated fields (49%), leakage from irrigation ditches (29%), infiltration from the channel of the Walker River (20%), and MFR (2%), consisting of infiltration through bedrock of precipitation that falls on surrounding mountain ranges and minor tributary surface flows in ephemeral drainages (SSPA 2014). Recharge from precipitation falling directly on the valley floor is negligible (Huxel and Harris 1969; Lopes and Allander 2009a, 2009b).

Within the Study Area, the alluvial sediments are up to 700 feet thick and comprise a single aquifer. The alluvial aquifer is subdivided into a Shallow, an Intermediate and a Deep zone (which is further subdivided into Deep zones 1 through 5). These groundwater zone designations are based on elevation and used only to identify and group monitor wells with similar screen intervals at the same relative depth in the aquifer. Clay layers or other low-permeability sediments are laterally discontinuous resulting in unconfined or semi-confined alluvial aquifer groundwater conditions.

Alluvial groundwater near the Site generally flows to the northwest, but flow directions are locally affected by bedrock outcrops within and along the margins of the valley, drawdown from pumped wells (particularly in deeper zones of the alluvial aquifer), and recharge sources including the Walker River, the West Campbell Ditch and irrigation on the Hunewill Ranch and other agricultural fields. Groundwater in the alluvial aquifer moves relatively slowly, with flow velocities estimated to be less than 100 feet per year (BC 2014a).

Anthropogenic activities within the Study Area, especially agricultural activities, influence groundwater flow rates and directions, chemical migration pathways and transport rates, and contribute chemicals to groundwater via evapoconcentration and leaching of soil amendments and naturally-occurring chemicals in alluvial sediments, and subsequent transport through the vadose zone to groundwater. Irrigation practices near the mine Site, including groundwater extraction using high-capacity wells and conveyance/irrigation of both water from the Walker River and groundwater, alter groundwater flow rates and directions during the irrigation season due to the alteration of the natural recharge/discharge rates and locations. Agricultural pumping seasonally results in strong downward vertical gradients that are often 10 to 100 times greater than horizontal gradients.

Past and/or ongoing sources of COIs to Study Area groundwater include: 1) the mine waste facilities, which have been grouped into the various Site OUs; 2) naturally-occurring chemicals; and 3) agriculture. The major past and/or ongoing mine-related sources of COIs to groundwater include: 1) OU-4a, the Evaporation Ponds (BC 2014a, 2014d); OU-8, the Arimetco Facilities (CH2M Hill 2010, 2011a, 2011b); and 3) OU-3, the Process Areas (BC 2014a, 2014e).

Mine-related COIs include acidity (i.e., low pH) and elevated concentrations of TDS, major ions including sulfate, metals, and radiochemicals including uranium. Concentrations of mine-related chemicals in groundwater are most elevated in the Shallow zone of the alluvial aquifer beneath OU-4a features that include the LEP, UEP, Finger Ponds, Phase IV VLT HLP, Phase IV VLT Pond, and the Calcine Ditch. Chemical concentrations in groundwater decrease with vertical depth and horizontal distance from these facilities.

Hydraulic assessments and chemical distributions indicate that the PWS was only partially effective in capturing Shallow zone mine-impacted groundwater during its operational life from 1989 to 2009, when it was shut down with EPA approval.

Geochemical evaluations of groundwater quality data (BC 2016a) indicate that sulfate and dissolved uranium form neutral or negatively-charged aqueous ionic species in groundwater throughout Study Area (except beneath the Evaporation Ponds) and, thus, undergo very limited (if any) geochemical attenuation due to mineral precipitation or adsorption to aquifer materials during groundwater transport. Dissolved uranium in Study Area groundwater is predominantly present in complexes with carbonate plus or minus calcium, which reflect oxidizing, carbonate-rich groundwater conditions. Locally, dissolved uranium is also complexed with sulfate in Shallow zone groundwater beneath the Evaporation Ponds where pH is less than 5 and sulfate concentrations exceed 1,500 mg/L.

The spatial distributions of elevated concentrations of mobile parameters such as sulfate and uranium are significantly more extensive than the spatial distributions of acidity (as indicated by pH) and metals. The significantly more limited spatial extent of low pH values and elevated metal concentrations indicates that geochemical attenuation processes in Study Area groundwater reduce acidity and limit the mobility of metals relative to the more mobile chemicals such as sulfate and uranium (EPA 2007b; BC 2016a, 2016b). Elevated metal concentrations in groundwater correlate strongly with low pH.

Geochemical evaluations of groundwater quality data (BC 2016a) also indicate the likely precipitation of solid mineral phases (e.g., jarosite) primarily in the Shallow zone beneath the LEP, UEP, Thumb Pond and Phase IV HLP. These mineral phases likely represent a potential, ongoing source of COIs to groundwater.

Sulfate, uranium, and arsenic (and other COIs) occur naturally in groundwater in Mason Valley because of groundwater contact with naturally-mineralized and/or hydrothermally-altered bedrock associated with copper deposits and/or alluvial sediments derived from mineralized bedrock (BC 2014a, 2016b). To the west of the Site where sulfate and uranium concentrations are low, elevated concentrations of arsenic are associated with MFR and elevated groundwater temperatures. In addition, sulfate, uranium, and other COIs are sourced to groundwater due to agricultural activities (BC 2016b; EPA 2016c). The assessment of background groundwater quality conservatively established the maximum extent of mine-impacted groundwater and identified an area of groundwater in the northern part of the Study Area (i.e., the NSA) that has been impacted by agricultural activities rather than mining activities.

The extent of mine-impacted groundwater has been defined using sulfate, dissolved uranium, and sulfur isotopes in sulfate because these parameters are more mobile in groundwater relative to other mine-related COIs such as metals (EPA 2007b) and, thus, have traveled the farthest downgradient distance in the alluvial aquifer (BC 2016b). The extent of mine-impacted groundwater in the Study Area can be generally described as follows, recognizing that mine-impacted groundwater is spatially more extensive in the Shallow, Intermediate and Deep 1 zones of the alluvial aquifer relative to the Deep 2 through Deep 5 zones. The northernmost extent of mine-impacted groundwater in the Shallow, Intermediate and Deep 1 zones of the alluvial aquifer is located near the Sunset Hills between well clusters B/W-10 and B/W-52. The eastern extent of mine-impacted groundwater in the Shallow, Intermediate and Deep 1 zones of the alluvial aquifer is approximately located near or beneath the West Campbell Ditch alignment. To the west of the Site, mine-impacted groundwater extends almost to the western extent of saturated alluvium between unimpacted wells/clusters B/W-16S and B/W-40, and impacted well clusters B/W-33, B/W-6 and B/W-22.

Mine-impacted groundwater in the deeper zones does not extend as far north as the upper three zones. In the Deep 2 through Deep 5 zones, the maximum northern extent of mine-impacted groundwater is near the northern end of the Hunewill Ranch fields. The eastern extent of mine-impacted groundwater in the Deep 2 through Deep 5 zones of the alluvial aquifer is located between well clusters B/W-27 and B/W-50. On the east, the area of mine-impacted groundwater in the Deep 3 through Deep 5 zones reflects the former influence of seasonal groundwater extraction for crop irrigation from agricultural wells (e.g., WDW019, located adjacent to the B/W-1 well cluster). To the west of the Site, mine-impacted groundwater in the Deep 3 through Deep 5 zones extends almost to the western extent of saturated alluvium.

The estimated volume of mine-impacted groundwater (i.e., the portion of the downgradient aquifer where sulfate and uranium exceed background concentrations) is 385,327 acre-feet, and contains an estimated 0.5 million tons of sulfate and 100 tons of dissolved uranium. Irrigation wells and municipal wells are located outside of the plume of mine-impacted groundwater (Figure 3-13). In addition, the plume of mine-impacted groundwater does not discharge to surface water.

The plume of mine-impacted groundwater appears stable based on evaluations of changes in the estimated volume of contaminated groundwater, sulfate/uranium masses, and chemical centers-of-mass through time. Plume stability is the result of very slow groundwater velocities and attenuation by dilution. The dilution occurs primarily as the result of recharge on the agricultural fields (specifically on the fields of the Hunewill Ranch) and leakage from irrigation ditches (specifically the West Campbell Ditch), and dispersion within the groundwater plume.

Groundwater quality in the NSA has been impacted by agricultural activities rather than mining activities (BC 2016b) based on multiple lines of evidence including groundwater flow patterns, chemical distributions, groundwater age estimates, hydrologic tracers, and sulfur isotopes. These agricultural practices have resulted in concentrations of sulfate and uranium that are elevated above background values and/or MCLs and/or exhibit increasing trends.

Monitor well data from the NSA indicate that concentrations of nitrate, sulfate, calcium, uranium, and alkalinity in alluvial groundwater in the Shallow through Deep 2 zones increase along the flow path beneath the agricultural fields. Increases in nitrate are associated with organic fertilizer application on crop fields. Increases in sulfate and calcium concentrations are associated with application of gypsum ($CaSO_4$) as a soil amendment on crop fields, which dissolve in irrigation water that percolates down to the water table. Increases in uranium concentrations are associated with crop irrigation. Percolation of irrigation water through soils increases alkalinity in the soil moisture, which mobilizes and desorbs naturally-occurring uranium from sediments (as soluble complexes with sulfate, carbonate plus or minus calcium) resulting in elevated uranium concentrations in groundwater (Jurgens et al. 2010; Brown et al. 2007). Alluvial sediments in Mason Valley contain naturally-occurring uranium (BC 2009b). The impact of agriculture activities on uranium mobility in NSA groundwater within or near irrigated land is illustrated by the strong correlation between uranium, alkalinity and calcium. Increases in alkalinity and calcium are associated with increases in uranium concentrations that can exceed 100 µg/L.

SECTION 8.0
RISK EVALUATION

In a groundwater technical meeting held on June 30, 2016 attended by ARC, EPA and other stakeholders, EPA directed ARC to proceed with preparation and submittal of this OU-1 RI Report without including the risk evaluation. The risk evaluation is ongoing and will proceed on a separate but parallel path from this document. Potential human health risks are generally described herein, but will be addressed more comprehensively in a separate OU-1 HHRA report.

This OU-1 RI Report, in conjunction with the OU-1 HHRA, will provide the basis for ARC to identify RAOs and potential remedies for OU-1, which would occur during future FS scoping discussions.

SECTION 9.0
REFERENCES

Air Force Center for Environmental Excellence (AFCEE), 2006. Monitoring and Remediation Optimization System (MAROS), User's Guide, March 2006.

Anaconda Mining Company, 1958. Engineering Drawing WHE-201, Tailing Disposal Sulphide Plant - Tailings Pond General Arrangement. March 24.

Anaconda Mining Company, 1966. Engineering Drawing YG-20, Water Supply & Distribution - Daily Water Balance Diagram. Prepared July 15, 1953. Revised July 28.

Anaconda Mining Company, 1967. Engineering Drawing WHN-1208, Sulphide Plant Quantitative Flow Diagram. Prepared May 19, 1966. Revised January 9.

Anaconda Minerals Company, 1984. Water Quality Investigation and Mitigation Plan. Yerington Mine.

Applied Hydrology Associates, 1983. Evaluation of Water Quality and Solids Leaching Data. Yerington Mine. Prepared for Atlantic Richfield Company.

Applied Hydrology Associates (also Norwest Applied Hydrology), 2000-2007. 2000-2007 Annual Monitoring and Operation Summary reports, Prepared for Atlantic Richfield Company.

Atlantic Richfield Company, 2008. Pumpback Well System Characterization Work Plan. Yerington Mine Site, Lyon County, Nevada.

Atlantic Richfield Company, 2010. Pumpback Well System Characterization Work Plan Addendum - Revision 2. Yerington Mine Site, Lyon County, Nevada. February 17.

Atlantic Richfield Company, 2011. Addendum to the On-Site Monitor Well Installation Work Plan. Yerington Mine Site, Lyon County, Nevada. September 7.

Atlantic Richfield Company, 2012a. Proposed Initial Bedrock Characterization Activities, Yerington Mine Site, Lyon County, Nevada. January 5.

Atlantic Richfield Company, 2012b. Proposed Initial Bedrock Characterization Activities - Revision 1, Yerington Mine Site, Lyon County, Nevada. October 11.

Atlantic Richfield Company, 2012c. Groundwater Flow Modeling Deliverables, Yerington Mine Site, Lyon County, Yerington, Nevada. June 25.

Atlantic Richfield Company, 2012d. Comprehensive Hydrologic Tracer Sampling Event and Request to Eliminate Select Tracers, Yerington Mine Site, Lyon County, Nevada. March 19.

Atlantic Richfield Company, 2012e. Preliminary Responses to February 7, 2012 EPA Comments on the 2011 Background Groundwater Quality Assessment, Yerington Mine Site dated September 28, 2011; Administrative Order on Consent, EPA Region 9 CERCLA Docket No. 9-2007-0005. April 18.

Atlantic Richfield Company, 2014. Technical Memorandum: Site-Wide Groundwater Monitoring Optimization, Yerington Mine Site, Lyon County, Nevada. April 14.

Atlantic Richfield Company, 2016a. Letter to D. Seter, Subject: Yerington Mine Site, Lyon County Nevada, Site ID #09GU, Request to Modify Domestic Well Monitoring Program and Bottled Water Program. September 1.

Atlantic Richfield Company, 2016b. Responses to EPA Comments dated February 11, 2016 on the Background Groundwater Quality Assessment - Revision 2 dated July 2, 2015; Administrative Order on Consent, EPA Region 9 CERCLA Docket No. 9-2007-0005. June 14.

Bell, E.J. and D.B. Slemmons, 1979. Recent crustal movements in the central Sierra Nevada-Walker Lane region of California-Nevada--Part II, The Pyramid Lake right-slip fault zone segment of the Walker Lane: Tectonophysics, v. 52, p. 571-583.

Benson, L.V. and D. L. Leach, 1979. Uranium Transport in the Walker River Basin, California and Nevada. Journal of Geochemical Exploration, vol. 11, p. 227-248.

Benson, L.V. and R.J. Spencer, 1983. A Hydrochemical Reconnaissance Study of the Walker River Basin, California and Nevada. USGS Open-File Report 83-740.

Bernhard, G., G. Geipel, T. Reich, V. Brendler, S. Amayri, and H. Nitsche, 2001. Uranyl(VI) carbonate complex formation: Validation of the $Ca_2UO_2(CO_3)_3$ (aq) species. Radiochimica Acta, 89:511-518.

Bigham, J.M., U. Schwertmann, S.J. Traina, R.L. Winland, and M. Wolf, 1996. Schwertmannite and the chemical modeling of iron in acid sulfate waters. Geochimica et Cosmochimica Acta, Vol. 60, pp. 2111-2121.

Bourrié, G., F. Trolard, J.M. Génin, A. Jaffrezic, V. Maître, and M. Abdelmoula, 1999. Iron control by equilibria between hydroxy-green rusts and solutions in hydromorphic soils. Geochimica et Cosmochimica Acta, Vol. 63, pp. 3417-3427.

Brown, C.J., B.C. Jurgens, B.G. Katz, M.K. Landon, and S.E. Eberts, 2007. Arsenic and Uranium in Four Aquifer Settings: Occurrence, Distribution, and Mechanisms for Transport to

Supply Wells. NGWA Naturally Occurring Contaminants Conference: Arsenic, Radium, Radon, Uranium. March 22-23.

Brown and Caldwell, 2002. Installation of Two Monitor Wells at the Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company.

Brown and Caldwell, 2003. Final Draft Process Areas Work Plan. Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. December 15.

Brown and Caldwell, 2005. First-Step Hydrogeologic Framework Assessment Work Plan North of the Anaconda Mine Site. Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. April 22.

Brown and Caldwell, 2007a. Data Management Plan for the Yerington Mine Site, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. April 24.

Brown and Caldwell, 2007b. Second-Step Hydrogeologic Framework Assessment Work Plan, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. February 28.

Brown and Caldwell, 2007c. Draft Site-Wide Groundwater Monitoring Plan, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. August 8.

Brown and Caldwell, 2008, Anaconda Evaporation Ponds Removal Action Characterization Work Plan, Yerington Mine Site. Prepared for Atlantic Richfield Company. September 15.

Brown and Caldwell, 2008a. Anaconda Evaporation Ponds Removal Action Characterization Work Plan, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. September 15.

Brown and Caldwell, 2008b. Shallow Alluvial Aquifer Characterization Work Plan for the Northern Portion of the Yerington Mine Site, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. December 30.

Brown and Caldwell, 2008c. Second-Step Hydrogeologic Framework Assessment Data Summary Report, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. October 15.

Brown and Caldwell, 2009, Evaporation Ponds Removal Action Characterization Data Summary Report. June 12.

Brown and Caldwell, 2009a. Site-Wide Groundwater Monitoring Plan - Revision 1, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. December 15.

Brown and Caldwell, 2009b. Background Soils Data Summary Report - Revision 1, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. March 9.

Brown and Caldwell, 2010a. Shallow Zone Characterization Data Summary Report - Revision 1, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. January 29.

Brown and Caldwell, 2010b. Addendum to the Site-Wide Quality Assurance Project Plan, Domestic Well Monitoring Plan - Revision 3, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. July 1.

Brown and Caldwell, 2010c. 2010 Groundwater Monitor Well Work Plan - Revision 2, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. July 22.

Brown and Caldwell, 2010d. Agricultural Fields Characterization Work Plan - Revision 2, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. July 20.

Brown and Caldwell, 2010e. Aquifer Solids Testing Work Plan - Revision 1, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. September 21.

Brown and Caldwell, 2010f. Summary of PWS Aquifer Testing, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. September 24.

Brown and Caldwell, 2010g. Draft Aquifer Solids Testing Work Plan, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. June 21.

Brown and Caldwell, 2011a. On-Site Monitor Well Installation Work Plan - Revision 1, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. August 29.

Brown and Caldwell, 2011b. Aquifer Solids Testing Work Plan - Revision 1, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. September 21.

Brown and Caldwell, 2011c. Draft Background Groundwater Quality Assessment, Site-Wide Groundwater Operable Unit, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. September 28.

Brown and Caldwell, 2012a. Site-Wide Groundwater Monitoring Plan - Revision 2, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. July 19.

Brown and Caldwell, 2012b. Draft Site-Wide Groundwater Operable Unit (OU-1) Remedial Investigation Work Plan, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. November 19.

Brown and Caldwell, 2012c. SOP-23 Aquifer Solids Testing SOP - Redox-Preserved Sample Preparation and Testing, Yerington Mine Site, Hazen Research, Inc. Laboratory Facility, Golden, CO. Prepared for Atlantic Richfield Company. August 17.

Brown and Caldwell, 2012d. SOP-23 Aquifer Solids Testing SOP - Redox-Preserved Sample Preparation and Testing - Revision 1, Yerington Mine Site, Hazen Research, Inc. Laboratory Facility, Golden, CO. Prepared for Atlantic Richfield Company. October 15.

Brown and Caldwell, 2012e. Aquifer Test Data Summary Report - Revision 1, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. December 13.

Brown and Caldwell, 2013a. 2010 Monitor Well Installation and Agricultural Fields Characterization Data Summary Report - Revision 1. Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. January 18.

Brown and Caldwell, 2013b. Additional Monitor Well Work Plan - Revision 1, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. October 8.

Brown and Caldwell, 2013c. Initial Bedrock Characterization Data Summary Report, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. November 20.

Brown and Caldwell, 2013d. Revised Public Information for the Northern Portion of the Background Groundwater Study Area, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. August 5.

Brown and Caldwell, 2013e. Draft Additional Monitor Well Work Plan, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. June 26.

Brown and Caldwell, 2014a. Site-Wide Groundwater Operable Unit (OU-1) Remedial Investigation Work Plan - Revision 1, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. February 7.

Brown and Caldwell, 2014b. 2013 Annual Operations and Maintenance Report for the Arimetco Fluid Management System, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. June 9.

Brown and Caldwell, 2014c. Groundwater Geochemical Characterization Data Summary Report, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. December 30.

Brown and Caldwell, 2014d. Phase 1 Field Sampling and Analysis Plan Anaconda Evaporation Ponds, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. July 31.

Brown and Caldwell, 2014e. OU-3 Step-out Soils Characterization Data Summary Report, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. December 12.

Brown and Caldwell, 2014f. 2013 Annual Groundwater Monitoring Report, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. May 12.

Brown and Caldwell, 2015a. Bedrock Groundwater Assessment Technical Memorandum, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. January 28.

Brown and Caldwell, 2015b. Draft Wabuska Drain (OU-7) Remedial Investigation Work Plan - Conceptual Site Model and Data Quality Objectives, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. July 14.

Brown and Caldwell, 2015c. Background Groundwater Quality Assessment - Revision 2, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. July 2.

Brown and Caldwell, 2015d. Additional Monitor Well Installation Data Summary Report, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. June 11.

Brown and Caldwell, 2015e. Groundwater Geochemical Characterization Data Summary Report - Revision 1, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. December 11.

Brown and Caldwell, 2015f. Technical Memorandum: Draft Initial Screening of Remedial Alternatives, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. December 2.

Brown and Caldwell, 2016a. Groundwater Geochemical Characterization Data Summary Report - Revision 2, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company.

Brown and Caldwell, 2016b. Background Groundwater Quality Assessment - Revision 3, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. November 11.

Brown and Caldwell, 2016c. 2015 Annual Groundwater Monitoring Report, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. May 16.

BC, 2017. Technical Memorandum: Phase 1 Evaporation Ponds Characterization Data Summary Report. Prepared for Atlantic Richfield Company, March 16

Brown and Caldwell, 2017a. Technical Memorandum: Wabuska Drain (OU-7) Field Sampling and Analysis Plan Data Summary Report and Conceptual Site Model Update. Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. January 3

Brown and Caldwell, 2017b. Technical Memorandum: Phase 1 Evaporation Ponds Characterization Data Summary Report. Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. January 20.

Brown and Caldwell and Integral Consulting, Inc., 2007. Draft Remedial Investigation Work Plan for Site-Wide Groundwater Operable Unit 1, Yerington Mine Site, Lyon County, Nevada. Prepared for Atlantic Richfield Company. November 16.

Carroll, R.W.H., G. Pohll, D. McGraw, C. Garner, A. Knust, D. Boyle, T. Minor, S. Bassett, and K. Pohlmann, 2010. Mason Valley Groundwater Model: Linking Surface Water and Groundwater in the Walker River Basin, Nevada. Journal of American Water Resources Association.

CH2M Hill, 2010. Final Historical Summary Report, Anaconda-Yerington Mine Site, Yerington, Nevada. October.

CH2M Hill, 2011a. Final Supplemental Remedial Investigation Report Arimetco Facilities Operable Unit 8, Anaconda-Yerington Copper Mine. Yerington, Nevada. October.

CH2M Hill, 2011b. Feasibility Study for Arimetco Facilities Operable Unit 8 Heap Leach Pads and Drain-down Fluids, Anaconda-Yerington Copper Mine. Yerington, Nevada. July.

Dalton, D., 1998. Arimetco Yerington Mine and Process Facility Site Assessment of Groundwater Quality, Yerington, Nevada. Prepared for Arimetco, Inc. July.

Davis, J.A., S.P. Hyun, P.M. Fox, and K.F. Hayes, 2009. A surface complexation modeling approach for Uranium (VI) transport in groundwater. Abstracts of the International Mine Water Conference, Proceedings. October.

Doherty, J., 2009. PEST - Model-Independent Parameter Estimation & Uncertainty Analysis, Version 12.2. Watermark Computing. Brisbane, Australia.

Dong, W. and S.C. Brooks, 2006. Determination of the formation constants of ternary complexes of uranyl and carbonate with alkaline earth metals (Mg^{2+}, Ca^{2+}, Sr^{2+}, and Ba^{2+}) using anion exchange method. Environmental Science and Technology Vol. 40, pp. 4689–4695.

Echevarria, G., M.I. Sheppard, and J.L. Morel, 2001. Effect of pH on the sorption of uranium in soils. Journal of Environmental Radioactivity, Vol. 53, pp. 257-264.

Ecology and Environment, Inc., 2013. Technical Memorandum and Report of START Activities, Arimetco Pond Design and Perimeter Ditch Repair Field Observations and Operation and

Maintenance Recommendations, Yerington, Nevada. Prepared for the Atlantic Richfield Company. April 29.

Environmental Standards, Inc. and Brown and Caldwell, 2009. Quality Assurance Project Plan Yerington Mine Site, Revision 5. Prepared for Atlantic Richfield Company. May 20.

EPA, 1988. Interim Final Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA. EPA/540/G-89/004.

EPA, 1992. Guidance for Data Usability for Risk Assessment. (Part B). Final. Office of Emergency and Remedial Response. Washington D.C.

EPA, 1999. Understanding Variation in Partition Coefficient, Kd, Values. Volume I: The k_d Model, Methods of Measurement, and Application of Chemical Reaction Codes. EPA 402-R-99-004A.

EPA, 2005. Standard Operating Procedure for Analysis of Total Organic Carbon in Sediments (Dry Combustion, Infrared Detection). Method LG601. Revision 04. March.

EPA, 2007a. Administrative Order for the Remedial Investigation and Feasibility Study. In the matter of Anaconda / Yerington Mine Site, Yerington, Lyon County, Nevada. Atlantic Richfield, Respondent. U.S. EPA Region 9, Docket No. 9-2007-0005. Proceeding under Section 106(a) of CERCLA, as amended, 42 USC § 9606(a). Including Attachment A: Scope of Work for the Remedial Investigations / Feasibility Studies Continued Response Action. January 12, 2007.

EPA, 2007b. Monitored Natural Attenuation of Inorganic Constituents in Ground Water, Volume 1 Technical Basis for Assessment. EPA/600/R-07-139.

EPA, 2008. A Systematic Approach to Evaluation of Capture Zones at Pump and Treat Systems, Final Project Report. EPA 600/R-8/003.

EPA, 2009. Statistical Analysis of Groundwater Monitoring Data at RCRA Facilities, Unified Guidance. EPA/530/R-09-007.

EPA, 2010a. Letter from EPA to Atlantic Richfield Company RE: Comments on the Draft Aquifer Solids Testing Work Plan. September 13.

EPA, 2010b. Letter from EPA to Atlantic Richfield Company RE: Aquifer Solids Testing Work Plan - Revision 1. September 30.

EPA, 2010d. Monitored Natural Attenuation of Inorganic Constituents in Ground Water, Volume 3, Assessment for Radionuclides Including Tritium, Radon, Strontium, Technetium, Uranium, Iodine, Radium, Thorium, Cesium, and Plutonium-Americium. EPA/600/R-10/039.

EPA, 2011a. Letter from EPA to Atlantic Richfield Company RE: Comments on the 2010 Annual Groundwater Monitoring Report (April 15, 2011), the First Quarter 2011 Groundwater Monitoring Report (July 1, 2011), and the Second Quarter 2011 Groundwater Monitoring Report (August 26, 2011) for the Anaconda Mine Site. September 29.

EPA, 2011b. Letter from EPA to Atlantic Richfield Company RE: Approval of the Addendum to the On-Site Monitor Well Installation Work Plan. September 30.

EPA, 2012a. Letter from EPA to Atlantic Richfield Company RE: Comments on the Draft Background Groundwater Quality Assessment, Yerington Mine Site, Nevada. February 7.

EPA, 2012b. Letter from EPA to Atlantic Richfield Company RE: Comprehensive Hydrologic Tracer Sampling Event and Request to Eliminate Select Tracers, Yerington Mine Site, Nevada. April 27.

EPA, 2012c. Letter from EPA to Atlantic Richfield Company RE: Comments on the Proposed Initial Bedrock Characterization Activities for the Anaconda Mine Site. April 12.

EPA, 2012d. Letter from EPA to Atlantic Richfield Company. October 22.

EPA, 2012e. Letter from EPA to Atlantic Richfield Company RE: Groundwater Flow Modeling Deliverables Anaconda Mine Site, Nevada. July 11.

EPA, 2012f. Letter from EPA to Atlantic Richfield Company. October 26.

EPA, 2012g. Letter from EPA to Atlantic Richfield Company RE: Comments on SOP-23 Aquifer Solids Testing - Redox-Preserved Sample Preservation and Testing Dated August 14, 2012. September 26.

EPA, 2013a. Letter from EPA to Atlantic Richfield Company RE: Comments on 2011 Annual Groundwater Monitoring Report, Anaconda Yerington Mine Site. March 27.

EPA, 2013b. Letter from EPA to Atlantic Richfield Company RE: Comments on 2012 Annual Groundwater Monitoring Report, Anaconda Yerington Mine Site. August 1.

EPA, 2013c. Letter from EPA to Atlantic Richfield Company RE: EPA Approval to Abandon Well B/W-14S, Anaconda Yerington Mine Site. November 22.

EPA, 2013d. Letter from EPA to Atlantic Richfield Company RE: Comments on the Draft Groundwater Flow Model Work Plan, Anaconda Yerington Mine Site. March 29.

EPA, 2013e. Letter from EPA to Atlantic Richfield Company RE: Comments on the Draft Additional Monitor Well Work Plan, Anaconda Yerington Mine Site. July 29.

EPA, 2013f. Statistical Software ProUCL 5.0.00 for Environmental Applications for Data Sets with and without Nondetect Observations.

EPA, 2014a. Letter from EPA to Atlantic Richfield Company RE: EPA Approval of Site-Wide Groundwater Monitoring Optimization, Anaconda Yerington Mine Site. June 26.

EPA, 2014b. Letter from EPA to Atlantic Richfield Company RE: Anaconda Yerington Mine Site OU1, Approval of Site-Wide Groundwater RI Work Plan Revision 1. October 9.

EPA, 2014c. 3PE: A Tool for Estimating Groundwater Flow Vectors. EPA 600/R-14/273.

EPA, 2015a. Letter from EPA to Atlantic Richfield Company RE: Anaconda Yerington Mine Site OU-1 Request for Bedrock Characterization DSR in Place of Work Plan. May 18.

EPA, 2015b. Letter from EPA to Atlantic Richfield Company RE: Approval of Groundwater Flow Model Report and Supplemental Materials, Anaconda Yerington Mine Site OU-1.

EPA, 2016a. Letter from EPA to Atlantic Richfield Company RE: Anaconda Copper Mine Site OU-1 Approval of Bedrock Groundwater Assessment Technical Memorandum. July 31.

EPA, 2016b. Letter from EPA to the Atlantic Richfield Company RE: Anaconda Yerington Mine Site OU-1, Approval of Geochemical Characterization DSR with Conditions. July.

EPA, 2016c. Letter from EPA to Atlantic Richfield Company RE: Anaconda Mine Site, Comments on the Background Groundwater Quality Assessment - Revision 2 dated July 2, 2015. February 11.

EPA, 2016d. Letter from EPA to Atlantic Richfield Company RE: Anaconda Copper Mine OU-1, Background Groundwater Quality Assessment. September 27.

EPA, 2016e. Memorandum from Dr. R. Ford (USEPA Land Remediation & Pollution Control Division) and Mr. S. Acree (USEPA Applied Research and Technical Support Branch) to Mr. D. Seter (USEPA Region 9), Subject: Yerington Mine Site, Yerington Nevada (16-R09-003) Responses to ARC Responses to Comments on the Background Groundwater Quality Assessment - Revision 2. September 2.

EPA, 2016f. Letter from EPA to Atlantic Richfield Company RE: Anaconda Copper Mine, Domestic Well Monitoring Program (DWMP) and Bottled Water Program (BWP). October 25.

EPA, 2017. Letter to the Atlantic Richfield Company RE: Anaconda Copper Mine Site OU-1, OU-1 Background Water Quality Assessment - Revision 3. February 16.

Fox, P.M., J.A. Davis, and J.M. Zachara, 2006. The effect of calcium on aqueous uranium(VI) speciation and adsorption to ferrihydrite and quartz. Geochimica et Cosmochimica Acta, Vol. 70, pp. 1379-1387.

Freeze, R.A. and J.A. Cherry, 1979. Groundwater. Prentice-Hall, Upper Saddle River, NJ.

Gallagher, T. K., 2004. Estimated Annual Ground-Water Pumpage 1994 - 2003, Smith Valley and Mason Valley, Lyon County, Nevada, Nevada Department of Conservation and Natural Resources, Division of Water Resources.

Gallagher, T. K., 2013. Estimated Annual Ground-Water Pumpage 2004 - 2010, Smith Valley and Mason Valley, Lyon County, Nevada, Nevada Department of Conservation and Natural Resources, Division of Water Resources.

George, P. L. and H. Borouchaki, 1998, Delaunay Triangulation and Meshing Application to Finite Elements, Paris, Hermes.

Gill, D. K., 1951. Groundwater at the Yerington Mine, Lyon County, Nevada. Report prepared for the Anaconda Mining Company. March.

Heath, R.C., 1984. Ground-Water Regions of the United States. U.S. Geological Survey (USGS) Water-Supply Paper 2242.

Hem, J., 1985. Study and Interpretation of the Chemical Characteristics of Natural Water. 3rd Ed. U.S. Geological Survey (USGS) Water-Supply Paper 2254.

Hershey, R.L., 2002. Hydrology and water quality of the Yerington Pit Lake, In: Geological Society of Nevada 2002 Spring Field Trip Guidebook Special Publication No. 35, Jurassic Magmatism and Metal Deposits in Western Nevada, Yerington Mine District, Humboldt Mafic Complex, June 15-16, 2003, Ed. Bob Thomas, pp. 93-98.

Hsi, C. K. D., and D. Langmuir, 1985. Adsorption of uranyl onto ferric oxyhydroxides: application to the surface complexation site-binding model. Geochimica et Cosmochimica Acta, Vol. 49, pp. 1931-1941.

Huxel, C.J., and E.E. Harris, 1969. Water resources and development in Mason Valley, Lyon and Mineral Counties, Nevada, 1948-65. State of Nevada Department of Conservation and Natural Resources, Division of Water Resources, Water Resources Bulletin No. 38.

Jurgens, B.C., M.S. Fram, K. Belitz, K.R. Burow, and M.K. Landon, 2010. Effects of Groundwater Development on Uranium: Central Valley, California, USA. Ground Water. Vol. 48, pp. 913-928.

Lewis, B., 2000. Geophysical Survey Results of the Yerington Mine, Mason Valley, Nevada, Prepared by the U.S. Bureau of Land Management - National Science and Technology Center. August.

Li, D., and D. I. Kaplan, 2012. Sorption coefficients and molecular mechanisms of Pu, U, Np, Am and Tc to Fe (hydr)oxides: A review. Journal of Hazardous Materials. Vol. 243, pp. 1-18.

Lopes, T.J., and K.K. Allander, 2009a. Hydrologic Setting and Conceptual Hydrologic Model of the Walker River Basin, West-Central Nevada. USGS Scientific Investigations Report 2009-5155.

Lopes, T.J., and K.K. Allander, 2009b. Water Budgets of the Walker River Basin and Walker Lake, California and Nevada. USGS Scientific Investigations Report 2009-5157.

Maurer, D.K., T.J. Lopes, R.L. Medina, and J.L. Smith, 2004. Hydrogeology and Hydrologic Landscapes of Nevada. USGS Scientific Investigations Report 2004-5131.

Mifflin, M.D., 1988. Region 5, Great Basin. In Hydrogeology, the Geology of North America, DNAG volume, vol. 0-2; ed. W. Back, J.S. Rosenshein, and P.R. Seaber, 60-78. Boulder, Colorado: Geological Society of America.

Morrison, R.B., 1964. Lake Lahontan: Geology of the southern Carson Desert. U.S. Geological Survey (USGS) Professional Paper 401.

Myers, T., 2001. Hydrogeology of the Basin Fill Aquifer in Mason Valley, Nevada: Effects of Water Rights Transferred. Prepared for the U.S. Bureau of Land Management, Carson City Field Office, Carson City, NV. Public Resources Associates, Inc., Reno, Nevada.

Nesbitt, M., 1955. Memorandum to A. J. Gould, Plant Superintendent, Anaconda Company. July 27.

Nevada Department of Conservation and Natural Resources, Division of Water Resources, 2013a, NDWR-Water Rights Database Advanced Search (Special Hydrographic Abstract), http://water.nv.gov/data/hydrographic/ June 4, 2013.

Nevada Department of Conservation and Natural Resources, Division of Water Resources, 2013b, Well Log Database Query Tool, http://water.nv.gov/data/welllog/ June 5, 2013.

Nevada Department of Conservation and Natural Resources, Division of Water Resources, 2013c, Water Level Data, http://water.nv.gov/data/waterlevel/ June 27, 2013.

Nevada Division of Water Resources, 2015. Memorandum titled "Curtailment Order in Mason and Smith Valley". Department of Conservation and Natural Resources, Division of Water Resources. February 3.

Nolan, J., and K.A. Weber, 2015. Natural Uranium Contamination in Major U.S. Aquifers Linked to Nitrate. Environ. Sci. Technol. Lett., Vol. 2, pp. 215-220.

Nordstrom, K., L.N. Plummer, D. Langmuir, and E. Busenburg, 1990. Revised Chemical Equilibrium Data for Major Water-Mineral Reactions and Their Limitations, in “Chemical Modeling of Aqueous Systems II,” Chapter 31, pp. 398-413.

Nork, W.E., 1989. MacArthur Project Hydrogeologic Investigation Lyon County, Nevada. Prepared for MacArthur Mining and Processing Company, Inc. August 14.

Norwest Applied Hydrology, 2007. Pumpback Well System 2006 Operations and Monitoring Summary, Yerington Mine Site. Prepared for Atlantic Richfield Company. April 30.

Parkhurst, D.L., and C.A.J. Appelo, 1999. User’s Guide to PHREEQC (Version 2) - A Computer Program for Speciation, Batch-Reaction, One-Dimensional Transport, and Inverse Geochemical Calculations. Water-Resources Investigations Report 99-4259, U.S. Geological Survey, Denver, Colorado.

Piedmont Engineering Inc., 2001. Yerington Shallow Aquifer Data Evaluation Report. Prepared for ARCO Environmental Remediation L.L.C.

Plume, R.W., 1996. Hydrogeologic framework of the Great Basin region of Nevada, Utah, and adjacent states. USGS Professional Paper 1409-B.

Proffett, J.M., 1977. Cenozoic geology of the Yerington District, Nevada, and implications for the nature and origin of Basin and Range faulting. Geologic Society of America Bulletin, Vol. 88, pp. 247-266.

Proffett, J.M., Jr., and J.H. Dilles, 1984. Geologic Map of the Yerington District, Nevada. Nevada Bureau of Mines and Geology, Map 77.

Reheis, M., 1999. Extent of Pleistocene Lakes in the Western Great Basin. USGS Miscellaneous Field Studies Map MF-2323.

Ricketts, T.H., E. Dinerstein, D.M. Olson, and C.J. Loucks, 1999. Terrestrial ecoregions of North America: a conservation assessment. Island Press, Washington, D.C.

Sánchez-España, J. I. Yusta, and M. Diez-Ercilla, 2011. Schwertmannite and hydrobasaluminite: A re-evaluation of their solubility and control on the iron and aluminum concentration in acidic Pit Lakes. Applied Geochemistry, Vol. 26, pp.1752-1774.

Seitz, H.R., A.S. Van Denburgh, and R.J. La Carma, 1982. Ground-Water Quality Down-gradient from Copper-One Milling Wastes at Weed Heights, Lyon County, Nevada. USGS Open-File Report 80-1217.

Skillings Jr., D.N., 1972. Yerington Copper Mine. Skillings Mining review. Vol. 61, No. 21.

Smedley, P.L. and D.G. Kinniburgh, 2001. A review of the source, behavior and distribution of arsenic in natural waters. Applied geochemistry, Vol. 17, pp. 517-568

Sø, H.U., D. Postma, R. Jakobsen, and F. Larsen, 2008. Sorption and desorption of arsenate and arsenite on calcite. Geochimica et Cosmochimica Acta, Vol. 72, pp. 5871-5884.

S.S. Papadopulos & Associates, Inc., 2012a. Objectives for Groundwater Modeling in the RI/FS Process, Yerington Mine Site. Prepared for Atlantic Richfield Company. August 14.

S.S. Papadopulos & Associates, Inc., 2012b. Objectives for Groundwater Modeling in the RI/FS Process - Revision 1, Yerington Mine Site. Prepared for Atlantic Richfield Company. October 15.

S.S. Papadopulos & Associates, Inc., 2012c. Draft Groundwater Flow Model, Work Plan for the Yerington Mine Site. Lyon County, Nevada. Prepared for Atlantic Richfield Company. December 28.

S.S. Papadopulos & Associates, Inc., 2013. Groundwater Flow Model Work Plan for the Yerington Mine Site - Revision 1, Lyon County, Nevada. Prepared for Atlantic Richfield Company. May 21.

S.S. Papadopulos & Associates, Inc., 2014. Groundwater Flow Model, Yerington Mine Site, Nevada. Prepared for Atlantic Richfield Company. March 18.

S.S. Papadopulos & Associates, Inc., 2015. Flow Model Supplemental Materials, Yerington Mine Site, Nevada. Prepared for Atlantic Richfield Company. March 18.

Stachowicz, M., T. Hiemstra, and W.H. van Riemsdijk, 2007. Arsenic-bicarbonate interaction on goethite particles. Environmental Science and Technology, Vol. 41, pp. 5620-5625.

Stewart, J.H., 1988. Tectonics of the Walker Lane belt, western Great Basin: Mesozoic and Cenozoic deformation in a zone of shear. In Ernst, W.G., Metamorphism and crustal evolution of the western United States, Rubey volume VII: Prentice Hall, Englewood Cliffs, N.J.

Stewart, B.D., M.A. Mayes, and S. Fendorf, 2010. Impact of uranyl-calcium-carbonate complexes on uranium(VI) adsorption to synthetic and natural sediments. Environmental Science and Technology, Vol. 44, pp. 928-934.

Superfund Technical Assessment Response Team (START), 2000. Anaconda Copper Company, Yerington Mine Site, Expanded Site Inspection, Yerington, Lyon County, Nevada. Prepared by Ecology & Environment Incorporated. December.

Superfund Technical Assessment Response Team (START), 2001. Anaconda Copper Company, Yerington Mine Site, Emergency Response Assessment, Yerington, Lyon County, Nevada. Prepared by Ecology & Environment Incorporated. June.

Taylor, B.E., and M.C. Wheeler, 1994. Sulfur- and Oxygen-Isotope Geochemistry of Acid Mine Drainage in the Western United States. Chptr. 30. Environmental Geochemistry of Sulfide Oxidation. Eds. C.W. Alpers and D.W. Blowes.

Tetra Tech, 2010. Preliminary Economic Assessment Update Pumpkin Hollow Copper Project, Lyon County, Nevada. Prepared for Nevada Copper Corp. January 13.

Thomas, J.M., 1995. Water Budget and Salinity of Walker Lake, Western Nevada. USGS Fact Sheet FS-115-98.

U.S. Bureau of Mines, 1958. Methods and Operations at the Yerington Copper Mine and Plant of the Anaconda Company, Weed Heights, Nev., by M. Claire Smith; Information Circular 7848, Department of the Interior.

U.S. Census Bureau, 2015. State and County Quickfacts. Available at: http://www.census.gov/quickfacts/table/PST045215/32019.

U.S. Geological Survey, 2006. Determination of the Delta ($^{34}S/^{32}S$) of Sulfate in Water, RSIL Lab Code 1951. Techniques and Methods of the Reston Stable Isotope Laboratory, Chapter 10.

U.S. Geological Survey, 2008. $^{3}H/^{3}He$ Sampling. The Reston Chlorofluorocarbon Laboratory. http://water.usgs.gov/lab/3h3he/sampling/.

U.S. Geological Society, 2009a. Hydrologic Setting and Conceptual Hydrologic Model of the Walker River Basin, West-Central Nevada. U.S. Department of Interior, USGS, Scientific Investigations Report 2009-5155.

U.S. Geological Society, 2009b. Water Budgets of the Walker River Basin and Walker Lake, California and Nevada. U.S. Department of Interior, USGS, Scientific Investigations Report 2009-5157.

U.S. Geological Survey, 2013. National Water Information System, USGS Groundwater for Nevada: Water Levels, http://nwis.waterdata.usgs.gov /nv/nwis/gwlevels June 27.

Walker River Decree C-125, 1936 amended 1940. United States vs. Walker River Irrigation District, Docket C-125, District Court of the United States - District of Nevada.

Wanninkhof, R., J.R. Ledwell, and A. J. Watson, 1991. Analysis of sulfur hexafluoride in seawater. J. Geophys. Res - Oceans 96(C5), pp. 8733-8740.

Wilson, J.L., and H. Guan, 2004. Mountain-Block Hydrology and Mountain-Front Recharge. In: Groundwater Recharge in a Desert Environment: The Southwestern United States, edited by F.M. Phillips, J. Hogan, and B. Scanlon. AGU, Washington, DC.

WRCC, 2015. Yerington, Nevada (269229): Period NCDC 1894-2015 Monthly Normals. Western Regional Climate Center. http://www.wrcc.dri.edu/cgi-bin/cliMAIN.pl?nv9229.

Western Regional Climate Center (WRCC). 2017. Yerington, Nevada (269229) Period of Record Monthly Climate Summary, 1/1/1914 to 12/31/2005. http://www.wrcc.dri.edu/cgi-bin/cliMAIN.pl?nvyeri.

Zheng, C., G.D. Bennett, and C.B. Andrews, 1991. Analysis of Ground-Water Remedial Alternatives at a Superfund Site. Ground Water. Vol. 29, No. 6., pp. 838-848.