GROUNDWATER AND SUBSURFACE PETROLEUM PRODUCT EVALUATION AT THE FORMER HADNOT POINT FUEL FARM AND BUILDING 1115 AREAS MARINE CORPS BASE, CAMP LEJEUNE, NORTH CAROLINA

A Preliminary Draft Report

INTRODUCTION

Data on groundwater elevations, petroleum product thicknesses, and BTEX concentrations have been collected at the former Hadnot Point Fuel Farm (HPFF) since 1987. In a separate but parallel project, similar data have been collected from the Building 1115 site since 1993. In this effort Baker has combined the data from these two study areas to present an analysis of the petroleum product from both sources and suggest an approach to delineating the horizontal and vertical extent of the floating product as well as the dissolved benzene plumes.

Both sites are shown on Figure 1: Hadnot Point Fuel Farm being at the east corner of Gibb Road and Ash Street and Building 1115 being at the west corner of Center Road and Ash Street.

MODEL SELECTION

SpillCAD (ES&T, 1994) is a relational database and an analytical model with a graphical interface that is capable of displaying contoured data sets of water levels, product thicknesses and dissolved concentrations. SpillCAD can also estimate the volume of petroleum product in the subsurface based on measured oil thicknesses (using the soil and fluid properties to convert the apparent oil thickness to actual thickness) and/or based on TPH concentrations in the soil. SpillCAD was used to display past and present data and to estimate the volume of product released from the Building 1115 site and the former HPFF (during more than 50 years of operation).

SpillCAD has the ability to generate flowlines (pathlines) based on the contoured groundwater elevation data. This is useful in determining flow directions in a non-uniform flow field like that at the former HPFF and Building 1115 sites. SpillCAD also has the ability to model the dissolved plume of one contaminant in a uniform flow field. However, since the flow field at the two sites in question is not uniform, this application was of little value to this effort.

MODEL INPUTS

Because SpillCAD is an analytical, two-dimensional model, only one value of aquifer permeability was needed as input. This value was taken from the raw data of the pumping tests performed on pumping wells RW-1 and RW-2. Because of an erroneous assumption by O'Brien & Gere (O&G) in the pumping test data analysis, the raw data for both tests were re-evaluated by Baker and found to yield values of 1 foot/day (see Appendix A). This value was used as input to SpillCAD for this analysis. Because the values of permeability were nearly identical in two places across the former HPFF site (RW-1 and RW-2), the aquifer homogeneity can be reasonably assumed for the areas of interest.

SpillCAD also uses inputs of fluid and soil properties. An earlier fingerprint analysis of the product phase indicated that gasoline was the major constituent (O&G, 1990). The properties of a typical gasoline were used as input for the model (as supplied by SpillCAD's internal database). The soil properties were input from results of on-site pumping tests (as discussed above) and from the grain size analyses done by Richard Catlin and Associates (RCA, 1996).

As part of its input, SpillCAD uses the depths to water and oil to determine the true hydrostatic elevation of the water table and actual floating product thickness. These values were input into the model's database. SpillCAD converted the apparent values to actual values based on the properties of the soil and petroleum product (non-aqueous) phase fluid.

MODEL RESULTS

The data were split into two subsets based on the status of the former HPFF pump and treat system: pre-pumping (1988 to mid-1991) and post-pumping (1992 to present). The pre-pumping data exist only at the former HPFF site, no data exist prior to 1993 for the Building 1115 site. Post-pumping data exist at both sites. In the following analyses, the maximum product thicknesses and the average water table elevations (as measured under non-pumping conditions) were used to calculate the volume of released product. Soil TPH data exist but they represent a "snapshot in time" when the borings were performed, hence they were not used in this preliminary analysis. They may be useful in a more detailed evaluation.

Groundwater Flow Direction

1988-1991 Data

Figure 2 shows the average water table elevation from 1988-91 before pumping started. North is at the top of the page and the scale is about 1" = 200' (as on all subsequent figures). Southwest of Ash Street, the horizontal groundwater flow direction is generally west-southwest with the elevation of the water table decreasing from about 21 feet msl near the fuel farm to about 15 feet msl near Holcomb Boulevard. There also appears to have been a localized "high" point near Building 1115. Northeast of Ash Street, the elevation of the water table varies from 18 to 21 feet msl. An apparent groundwater sink exists beneath the former HPFF which cannot be readily explained. It is possible that recharge from precipitation beneath the product phase (and the associated smear zone) has been reduced such that this feature was induced. It is also possible that a localized structural feature is responsible for inducing a downward gradient by preferentially allowing groundwater to flow vertically.

The effect of this feature is that the horizontal flow direction reverses locally and serves to "contain" the horizontal extent of the product phase. The horizontal containment is not complete however, because there are two low points near wells MW-3 and MW-11 which may allow some product to escape laterally.

No data regarding vertical gradients existed before 1995 at either of the sites. However, the sink implies the existence of a downward vertical gradient in groundwater flow.

1995-1996 Data

Figure 3 shows the average water table elevations (measured under non-pumping conditions) from 1995 and 1996. The aforementioned water table sink still is evident beneath the former HPFF and, generally, the horizontal groundwater flow directions are the same. The additional detail made possible by the new data from the Building 1115 site clearly shows the presence of a localized groundwater divide directly beneath Building 1115. North of Building 1115 groundwater flows north and south of the building it flows south.

The vertical gradient in the vicinity of the former HPFF has been documented to be downward at a value of 0.040 (between wells HPFF-5 and HPFF-9) indicating that the area of the former HPFF is a significant recharge area (RCA, 1996). In Figures 4 and 5, vertical flow nets superimposed on cross-sections of the former HPFF site indicate a strongly downward flow component. Locations of these cross-sections are shown on Figure 3. Figure 4 (cross-section A-A') shows that as groundwater migrates west-southwest (coming out of the page toward the reader), it also moves downward, "funneled" toward the area beneath MW-18. The sink is not just a surface feature but is an indication of the three-dimensional flow pattern. The apparent groundwater sink (beneath the former HPFF) thus serves as a localized entrance point for groundwater recharge.

Figure 5 (cross-section B-B') shows the flow pattern below the groundwater sink (near MW-17 and SB-5) and the "mound" (near MW-5 and RW-1). According to the contours, groundwater flow beneath the former HPFF is generally from right to left across the page in a west-southwest direction. In the former HPFF area, regardless of the water table surface being a sink or mound, water infiltrating to recharge the groundwater flow deepens as it flows downgradient. This is corroborated by the vertical distribution of dissolved benzene at the former HPFF (discussed in detail later).

At the Building 1115 site, a more extensive study of vertical gradients was undertaken (RCA, 1995). The vertical gradients measured between 30 and 50 feet below ground surface (bgs) ranged from 0.010 to 0.100. The vertical gradients measured between 50 and 80 feet bgs ranged from 0.030 to 0.050. Figures 6 and 7 show vertical flow nets of the Building 1115 site. The downward flow component is evident in both figures. The locations of these cross-sections are shown on Figure 3. Figure 6 (cross-section C-C') is oriented perpendicular to the general groundwater flow direction (west-southwest, coming out of the page) and clearly shows that groundwater also moves downward.

Figure 7 (cross-section D-D') is oriented almost parallel to the general groundwater flow direction (west-southwest, left to right) and shows the vertical and horizontal components of groundwater flow. This is further corroborated by extensive vertical (downward) migration of dissolved BTEX constituents that has been documented at both sites. This will be discussed in more detail in a later section.

Floating Product

The volume estimate of petroleum product floating on the water table using the pre-pumping (1988-91) data was 1,061,901 gallons of product (mostly gasoline according to an earlier analysis by O&G) spread over 11,933,614 ft^2 (274 acres = 0.43 mi^2). While this estimated volume seems incredibly large, it must be remembered that this took place over 50 years, yielding an average loss of over 21,200 gallons/year (or 58 gallons/day). Figure 8 shows the product thicknesses for the 1988-91 period and indicates that there may have been at least three source areas for the spills: near MW-12 (maximum floating product thickness > 7 feet), MW-16 (>13 feet) and MW-18 (>4 feet).

Figure 8 shows that two of these three indicated source areas (near MW-12 and MW-16) are directly beneath the unloading zones for railroad tank cars on the tracks adjacent to the tank farm. The third indicated source area (near MW-18) is near the southeastern edge of the fuel farm.

Figure 9 shows the results of the data from 1992 to the present: the estimated volume of floating product is now 830,324 gallons over an area of 11,392,186 ft^2 (262 acres = 0.41 mi^2). The area for the former HPFF floating product has diminished but there is now floating product apparently emanating from Building 1115 that has kept the total area about the same as the original estimate. This floating product at the Building 1115 site may have existed before 1993, which would make the original estimate biased lower than the actual total volume.

From a comparison of Figures 8 and 9 it appears that there has been some movement of the floating product atop the water table at the former HPFF in four areas (possibly indicating the effects of the four pumping wells RW-1 though RW-4). Southward product phase migration is indicated near MW-1. Figure 10 shows the increase in product thickness versus time in MW-1. This seems to be attributable to the pumping and the resulting induced migration toward RW-2.

No movement is indicated near MW-2. Figure 11 shows that the product thickness in MW-2 has remained relatively constant over time. Apparently this area is out of the capture zone of the existing pumping wells.

Another area where it appears the product has migrated is near MW-12. This could be the result of product phase migration toward RW-4. Figure 12 shows the decrease in product thickness in MW-12 versus time. The two apparent source areas beneath the railroad tracks that were separate (near wells MW-12 and MW-16 in Figure 8) seem to have coalesced into one area. However, the current areal shape of the floating product in Figure 9 could be an artifact caused by the lack of current data at former monitoring wells MW-7 and MW-8. Apparently these wells were destroyed and possibly replaced, but were not used as data collection points after 1989. It is not known whether the replacement wells still exist or not. These two former monitoring wells provided data that detailed the shape of the floating product that does not currently exist.

Product phase migration may be indicated near MW-16 toward RW-1 as shown in Figure 13 by the decreasing product thickness versus time. This also may be shown by the comparison of Figures 8 and 9.

Movement of the product phase is also indicated near MW-18. Figure 14 shows the decrease in product thickness versus time in MW-18. This is consistent with the pumping and induced migration toward RW-3.

It is not known whether any product phase petroleum has migrated off-site from the former HPFF. As shown on Figure 9, the product may have migrated in a southwest direction from MW-12 toward or even across Ash Street to coalesce with the product phase migrating from Building 1115. This has not been confirmed by actual well measurements but has been suggested by the data. Since MW-8 was destroyed, no wells exist between MW-5 and MW-11 to confirm this theory.

SpillCAD calculated that, of the more than 830,000 gallons of floating product, just over 500,000 gallons are recoverable because of the soil and fluid properties.

Dissolved Plume

In this preliminary analysis only dissolved benzene concentrations were input into the database.

1988-1991 Data

The dissolved benzene plume from the 1988-91 data set is shown in Figure 15. The shape of this plume is very similar to the shape of the floating product in Figure 8. The highest benzene concentrations are directly beneath the thickest parts of the floating product.

From 1988 to 1991, no deep wells existed at the former HPFF to determine the benzene concentrations at depth.

1993-1996 Data

The dissolved benzene plume(s) appear quite different with the more recent data (Figure 16) than in the previous figure. The original plume (at the surface) seems to have diminished in concentration although this may be an artifact caused by the fact that in the recent data set the wells with floating product were not sampled. This may mean that the highest concentrations in the dissolved benzene plume are not be represented on this figure. Nonetheless, a reduction in the benzene concentrations in the plume would be expected due to weathering of the floating product phase over time and due to migration of the highest concentrations away from the source.

From Figure 16, two new benzene plumes are now evident: one beneath Building 1115 and one beneath the new fuel farm (adjacent to the former HPFF). These appear to be more recent releases because of the higher benzene concentrations near the surface than in the older release at the former HPFF. At the Building 1115 site, the effect of the localized groundwater divide can be seen in the southeastern (and possibly northwest) spreading of the benzene plume. Four wells at the Building 1115 site were installed at 80 feet bgs and have detected dissolved benzene at significant concentrations ranging from 523 ppb to 8,220 ppb.

The highest concentrations associated with the original plume appear to have migrated away from the source area both laterally and vertically. Figure 17 shows the dissolved concentrations at an approximate depth of 50 feet bgs. This theory makes sense because the groundwater flow direction at this depth is southwest as shown on Figure 18. The "heart" of the benzene plume now appears to be beneath Buildings 1101 and 1108, more than 600 lateral feet from the former HPFF. The northern end of the deep benzene plume appears to be moving in a northwesterly direction, which is consistent with the divergence of flow shown on Figure 17.

Figures 19 through 22 show vertical cross-sections through the dissolved benzene plumes. Figure 19 shows cross-section A-A' through the former (and current) HPFF. Two plumes are represented here, one form the former HPFF (MW-18) and the other from the unloading area near the railroad tracks (HP-9). Since this cross-section is perpendicular to groundwater flow, this figure represents cross-sections of the benzene plumes as well. The vertical extent of the plumes have not been delineated.

Figure 20 is oriented more or less parallel to groundwater flow and shows the profile of two benzene plumes, one from the former HPFF (MW-17, 22GW-1) and another from the new HPFF (HP-4). The vertical extent of the benzene plumes have not been delineated.

Figure 21 (oriented perpendicular to flow) shows the cross-sections of at least two benzene plumes, one at depth between Buildings 1101 and 1108 (well 1115-20), and another at depth beneath Holcomb Boulevard (well 1115-17). There may be a third benzene plume associated with well 1115-11 at the surface and it is unclear what, if any, connection exists between this and the deep plumes. The vertical extent of these benzene plumes have not been delineated.

Figure 22 is parallel to groundwater flow and shows the profile of what appears to be three plumes: one shallow plume from the Building 1115 area (wells 1115-12 and 1115-5), one at depth possible emanating form the former HPFF (well 1115-18) and another at depth possibly emanating from the Building 1115 area near 1115-11 (wells 1115-21 and 1115-24).

In summary, there appear to be five source areas from which benzene is originating: one within the former HPFF, one from the unloading area adjacent to the former HPFF, one from the new HPFF, and two from the Building 1115 area. The vertical extent of the dissolved benzene has not been delineated below these benzene plumes. The benzene has migrated to at least 80 feet bgs in two areas: beneath well 1115-17 and beneath Buildings 1101 and 1108. The horizontal extent has not been delineated in three areas: southwest of Buildings 1101 and 1108, north of Building 1115, and west of Holcomb Boulevard.

RECOMMENDATIONS

Due to the typical shallow approach to UST investigations, and due to the unexpectedly large vertical gradients near the HPFF and Building 1115 sites, the dissolved contamination has migrated almost vertically downward and has not been delineated by the existing wells at these two sites. The following recommendations would help to provide additional necessary information:

A well inventory and survey should be conducted over the entire HPFF/Bldg. 1115 area. This will make the water table elevations and product thickness calculations consistent. Typically, the wells were surveyed soon after installation. They have not all been surveyed at the same time using the same surveyor.

To date, the wells have been sampled piecemeal in accordance with the different site schedules. A complete resampling event with all wells would allow a consistent picture to be seen. BTEX analyses and samples of the floating product from the separate areas is recommended. The analysis of the product should be a fingerprint to determine product type.

Because of the substantial volume of floating product still present, the extraction wells/system should be enhanced with vacuum recovery and/or bioslurping. Computer modeling (using MOVER or another equivalent model) may be helpful in determining the time involved for that process to take place and whether any additional extraction points are needed.

Additional wells, both deep and shallow are needed to delineate the horizontal and vertical extents of the dissolved benzene (and other contaminant) plumes. The following additional wells are recommended:

- one shallow monitoring well between MW-5 and MW-11 to determine if floating product has migrated southward toward Ash Street (or determine if MW-8R still exists)

- eight to ten additional deep wells to delineate the plumes beneath Buildings 1101, 1108, and 1115 (temporary wells could be used to place the wells at the proper depths)

In order to get a realistic representation of the dissolved plume directly beneath the floating product, it is necessary to sample below the product using an innovative method. One such method would be to lower a small diameter PVC pipe into the shallow wells with floating product. The use of positive pressure while lowering the pipe would keep the product out. The smaller diameter pipe would then be used to collect water samples with a bailer or peristaltic pump.

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List of Figures

Appendix A -- Re-evaluated Pumping Test Results for RW-1 and RW-2

Figure 1 -- HPFF and Building 1115 Site Map with Wells

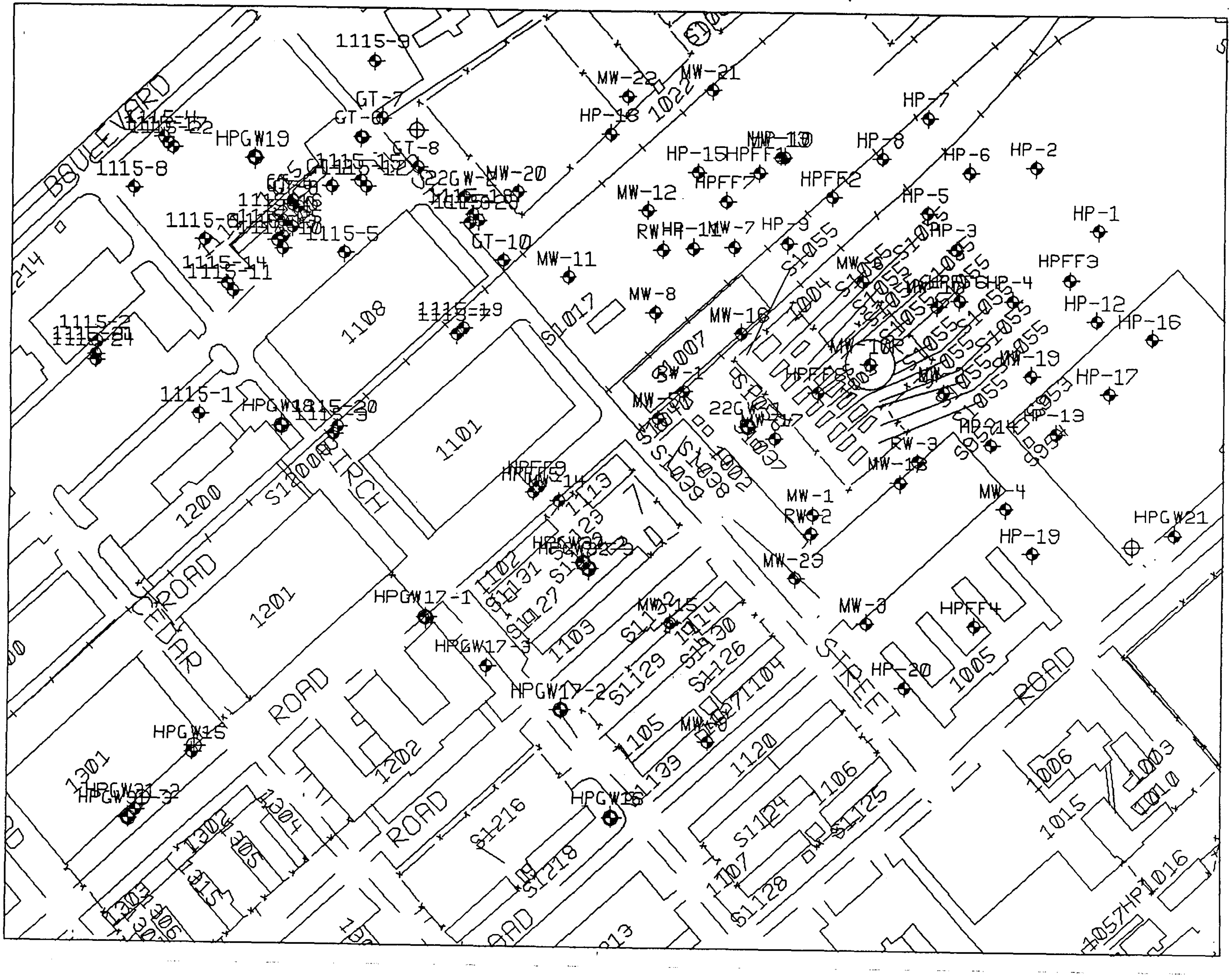


Figure 2 -- Average Water Table Elevations 1988-1991

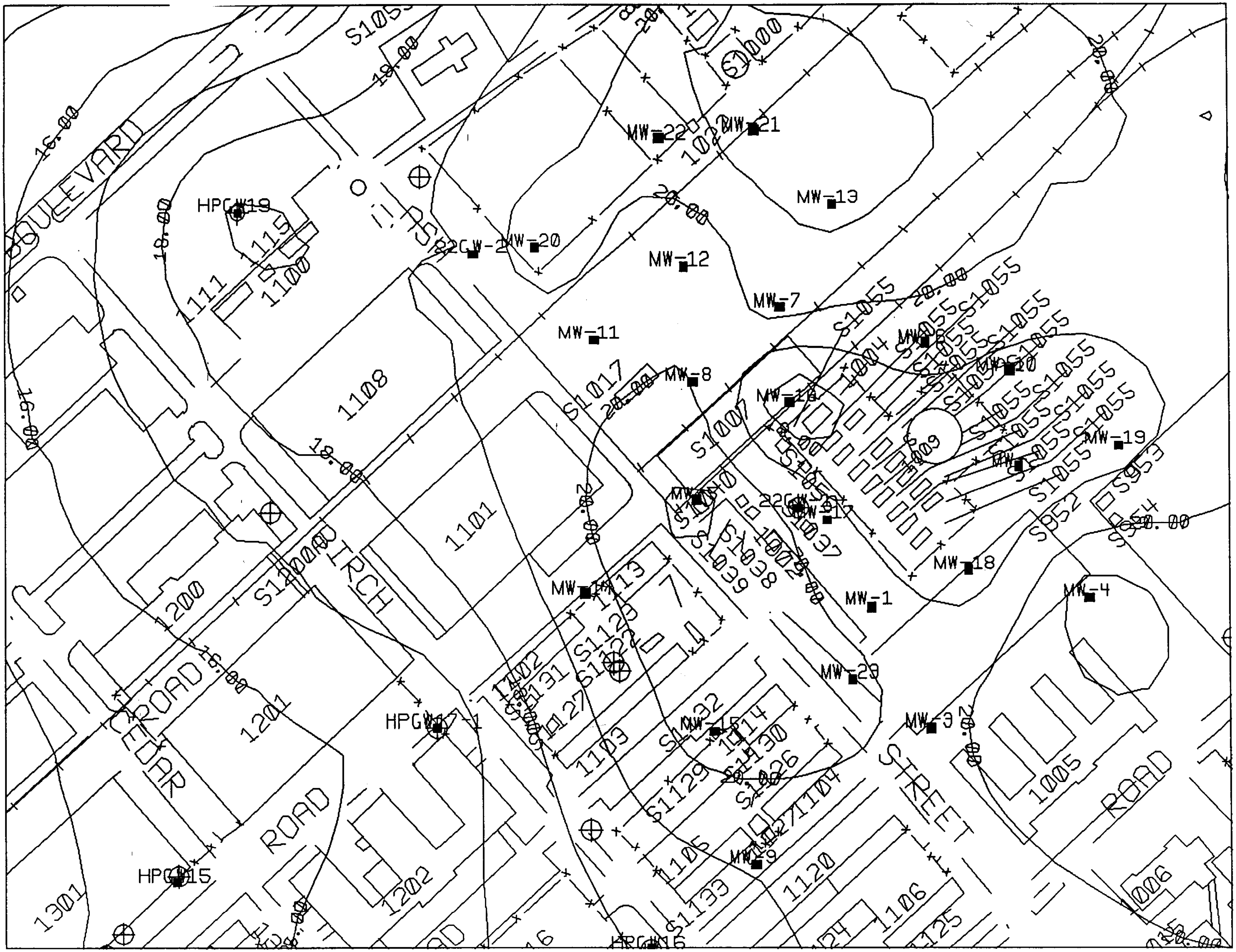


Figure 3 -- Average Water Table Elevations 1995-1996

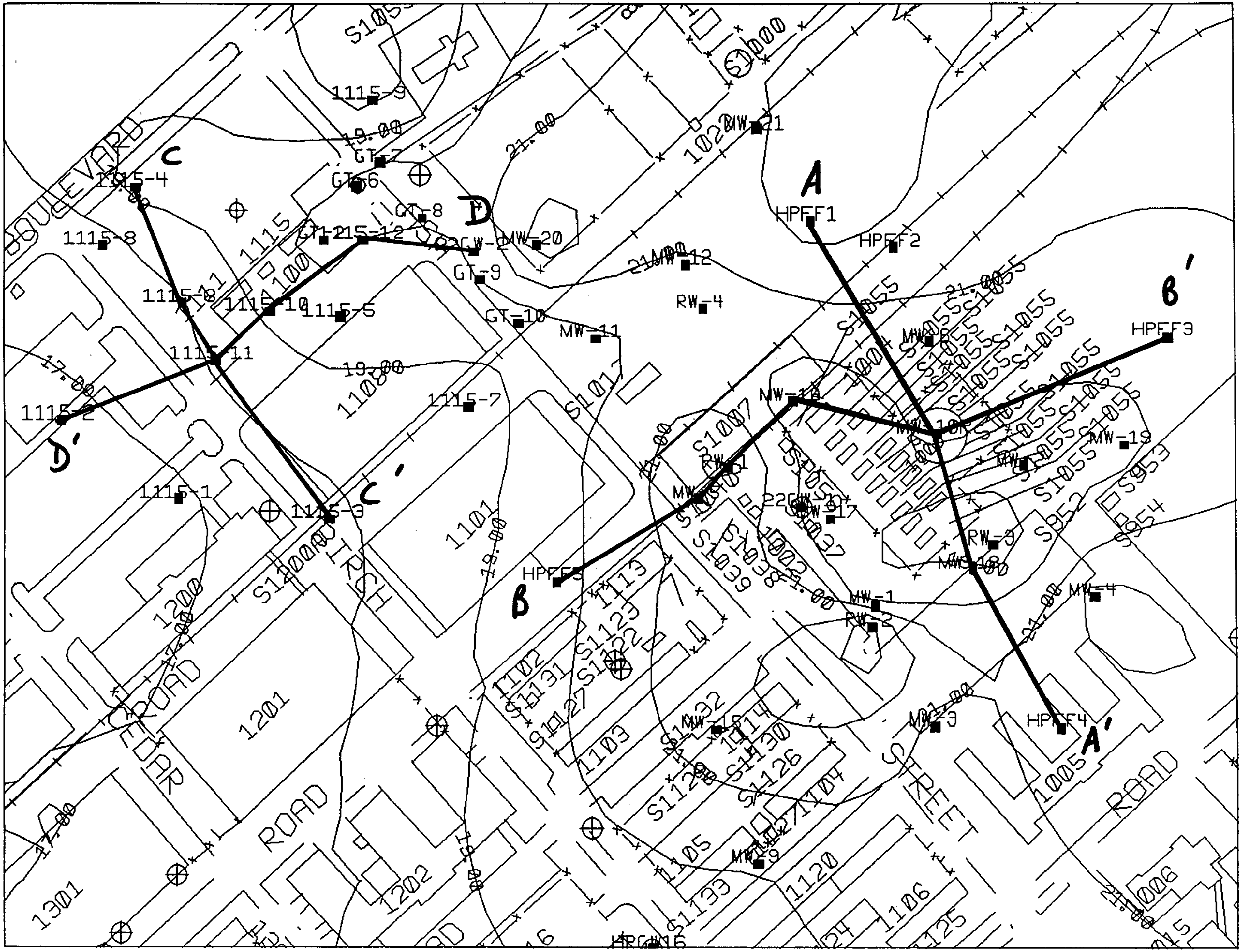
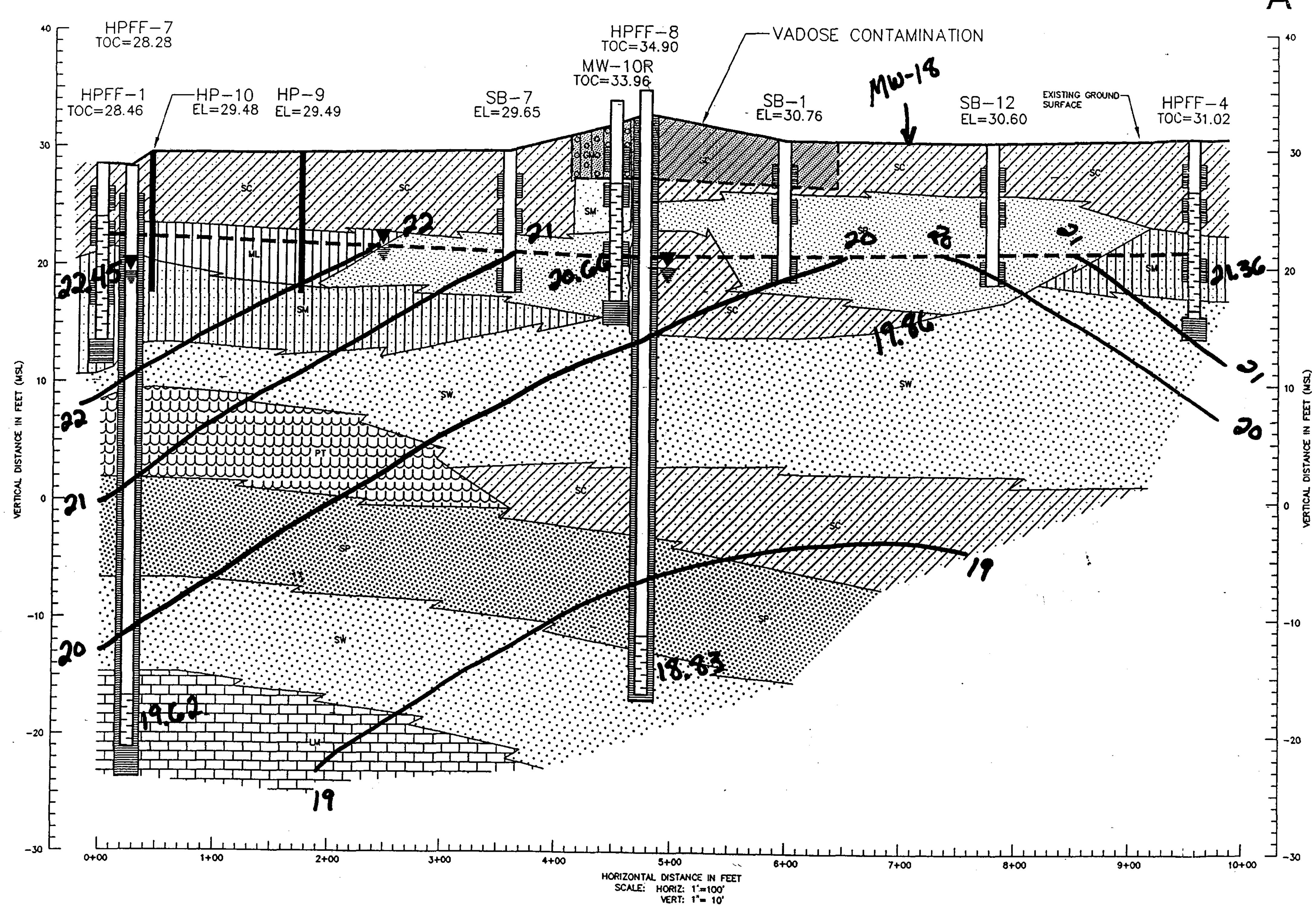


Figure 4 -- Hydrologic Cross-section A-A'



NOTE: CONTACTS REPRESENT GRADATIONAL CHANGES BETWEEN SEDIMENTS AND ARE APPROXIMATE.

LEGEND

- SW — WELL GRADED SANDS OR GRAVELLY SANDS, LITTLE OR NO FINES
- SP — POORLY GRADED SANDS OR GRAVELLY SANDS, LITTLE OR NO FINES
- SM — SILTY SANDS, SAND-SILT MIXTURES
- SC — CLAYEY SANDS, SAND-CLAY MIXTURES
- GM — SILTY GRAVELS, GRAVEL-SAND-SILT MIXTURES
- ML — INORGANIC SILTS AND VERY FINE SANDS, ROCK FLOUR, SILTY OR CLAYEY FINE SANDS OR CLAYEY SILTS WITH SLIGHT PLASTICITY
- PT — PEAT AND OTHER HIGHLY ORGANIC SOILS
- LM — WEATHERED LIMESTONE
- TOC — TOP OF CASING ELEVATION IN FEET
- EL — ELEVATION IN FEET
- WATER TABLE ELEVATION IN FEET ABOVE MEAN SEA LEVEL AS OF 11/29/95
- SOIL SAMPLE INTERVAL
- SCREEN INTERVAL
- AREA OF VADOSE CONTAMINATION AT LEVELS ABOVE NCDEHNR ACTION LEVELS

FIGURE 4

TITLE: CROSS SECTION A – A'

PROJECT: HADNOT POINT FUEL FARM, MARINE CORPS BASE, CAMP LEJEUNE, N.C.

JOB NO. 950930SA | DATE: DEC. 1995 | SCALE: AS NOTED | DRAWN BY: WHW | CHECKED BY: TM

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DESIGNED BY: | DRAWN BY: | CHECKED BY: | APPROVED BY: | DATE:

NO.	DESCRIPTION	BY	DATE

REVISIONS

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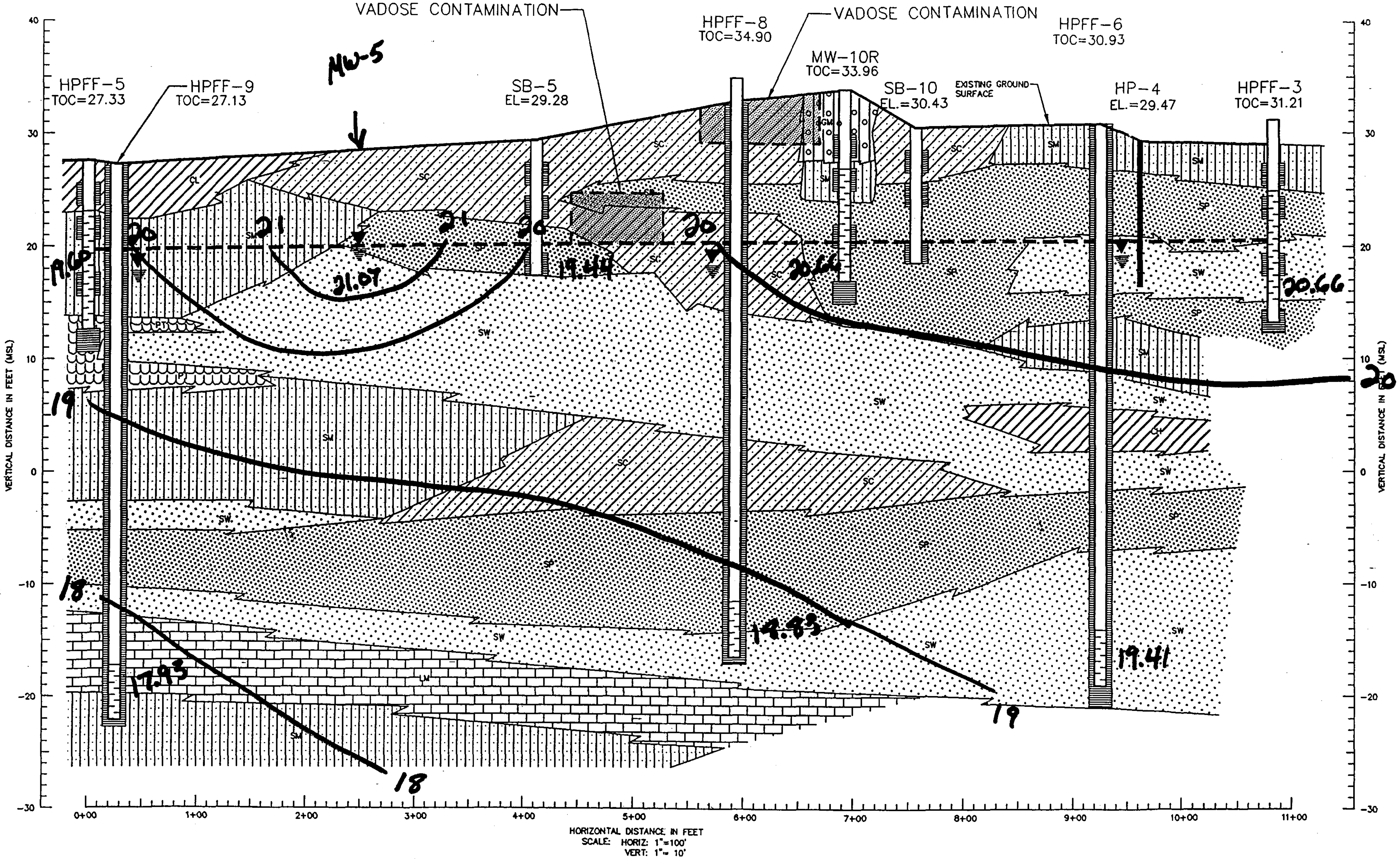
Figure 5 -- Hydrologic Cross-section B-B'



LEGEND

NOTE: CONTACTS REPRESENT GRADATIONAL CHANGES BETWEEN SEDIMENTS AND ARE APPROXIMATE.

SW	WELL GRADED SANDS OR GRAVELLY SANDS, LITTLE OR NO FINES
SP	POORLY GRADED SANDS OR GRAVELLY SANDS, LITTLE OR NO FINES
SM	SILTY SANDS, SAND-SILT MIXTURES
SC	CLAYEY SANDS, SAND-CLAY MIXTURES
GM	SILTY GRAVELS, GRAVEL-SAND-SILT MIXTURES
ML	INORGANIC SILTS AND VERY FINE SANDS, ROCK FLOUR, SILTY OR CLAYEY FINE SANDS OR CLAYEY SILTS WITH SLIGHT PLASTICITY
PT	PEAT AND OTHER HIGHLY ORGANIC SOILS
LM	WEATHERED LIMESTONE
CL	INORGANIC CLAYS OF LOW TO MEDIUM PLASTICITY, GRAVELLY CLAYS, SANDY CLAYS, SILTY CLAYS, LEAN CLAYS
CH	INORGANIC CLAYS OF HIGH PLASTICITY, FAT CLAYS

WATER TABLE ELEVATION IN FEET AS OF 11/29/95

SOIL SAMPLE INTERVAL

SCREEN INTERVAL

TOC TOP OF CASING ELEVATION IN FEET

EL ELEVATION IN FEET

AREA OF VADOSE CONTAMINATION AT LEVELS ABOVE NCDEHNR ACTION LEVELS

FIGURE 5

TITLE: CROSS SECTION B - B'

SCALE: AS NOTED | DRAWN BY: WRW | CHECKED BY: TW.

PROJECT: HADNOT POINT FUEL FARM, MARINE CORPS BASE, CAMP LEJEUNE, N.C.

JOB NO. 95093CSA | DATE: DEC. 1995

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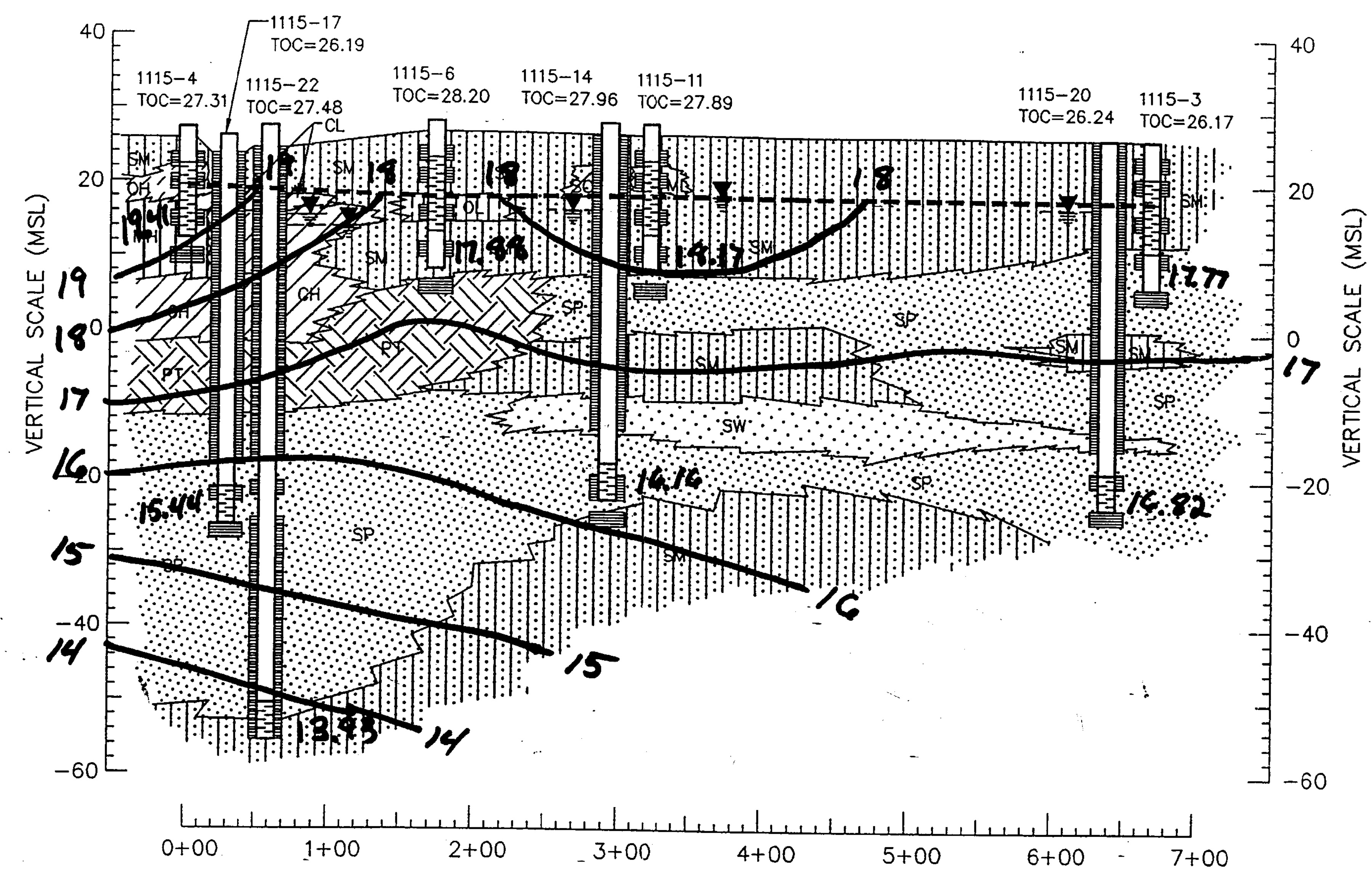
DESIGNED BY:
DRAWN BY:
CHECKED BY:
APPROVED BY:
DATE:

NO.	DESCRIPTION REVISIONS	BY	DATE

C

Figure 6 -- Hydrologic Cross-section C-C'

C'



VERTICAL SCALE 1"=20'
HORIZONTAL SCALE IN FEET 1"=100'

NOTE: CONTACTS REPRESENT GRADATIONAL CHANGES BETWEEN UNITS AND ARE APPROXIMATE.

LEGEND

PT	PEAT AND OTHER HIGHLY ORGANIC SOILS
SW	WELL GRADED SANDS OR GRAVELLY SANDS, LITTLE OR NO FINES
SP	POORLY GRADED SANDS OR GRAVELLY SANDS, LITTLE OR NO FINES
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OL	ORGANIC SILTS AND ORGANIC SILTY CLAYS OF LOW PLASTICITY
MH	INORGANIC SILTS, MICACEOUS OR DIATOMACEOUS FINE SANDY OR SILTY SOILS, ELASTIC SILTS
CH	INORGANIC CLAYS OF FINE PLASTICITY, FAT CLAYS
OH	ORGANIC CLAYS OF MEDIUM TO HIGH PLASTICITY, ORGANIC SILTS
CL	INORGANIC CLAYS OF LOW TO MEDIUM PLASTICITY, GRAVELLY CLAYS, SANDY CLAYS, SILTY CLAYS, LEAN CLAYS

SOIL SAMPLE INTERVAL

SCREEN INTERVAL

TOC TOP OF CASING ELEVATION IN FEET (MSL)

GROUND WATER ELEVATION AS OF 7/18/95

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ENVIRONMENTAL ENGINEERS AND HYDROGEOLOGISTS RC&A
WILMINGTON, NC CHARLESTON, SC ATLANTA, GA MOORESVILLE, NC

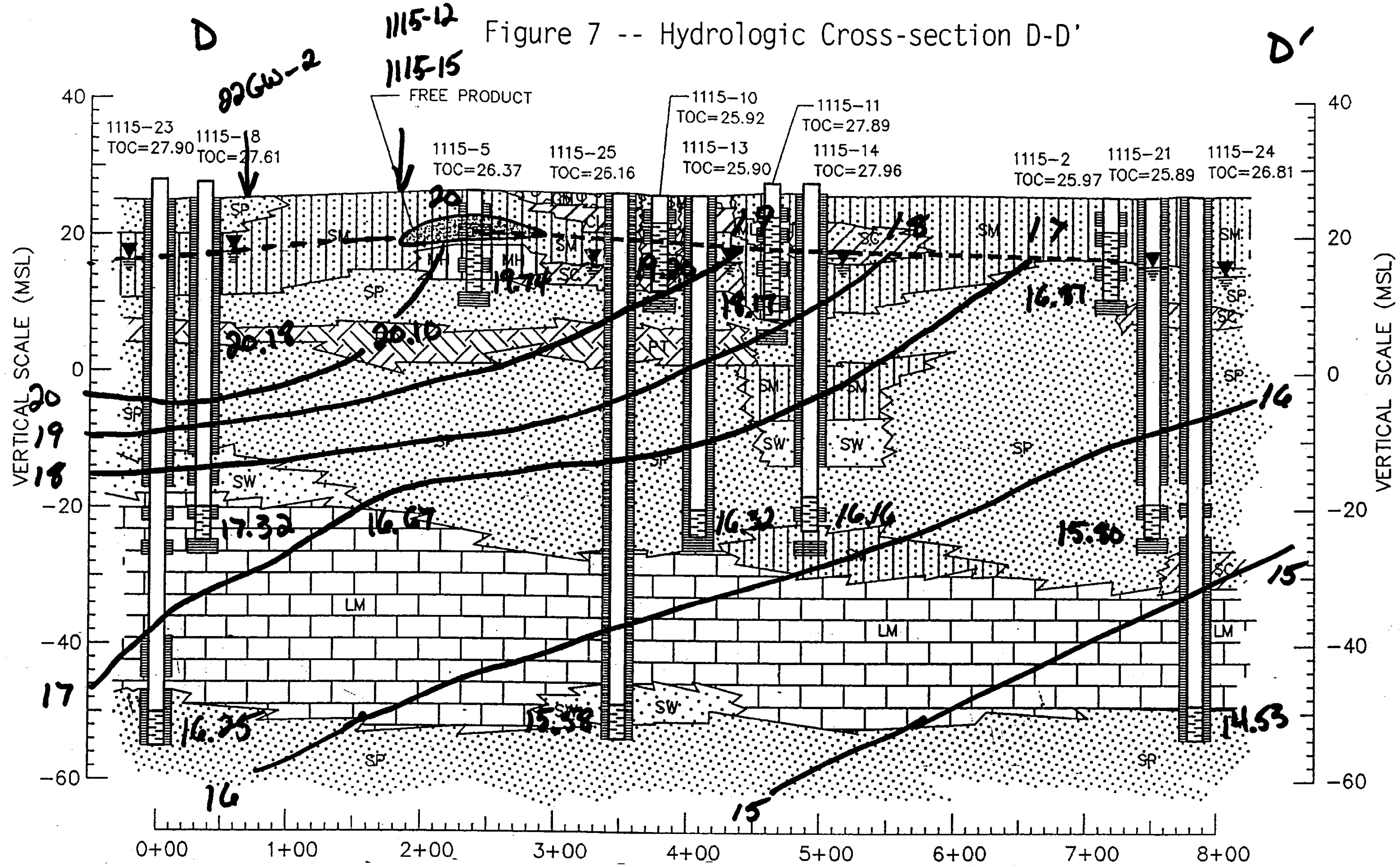
PROJECT: BUILDING 1115 LANTDIV NAVFACENGCOM CAMP LEJEUNE, N.C.

TITLE: CROSS SECTION C-C'

FIGURE 6

JOB NO. 93126ADD | DATE: 1 JUL 95 | SCALE: 1"=100' | DRAWN BY: WW SB | CHECKED BY: TP

Figure 7 -- Hydrologic Cross-section D-D'



VERTICAL SCALE 1"=20'
HORIZONTAL SCALE IN FEET 1"=100'

NOTE: CONTACTS REPRESENT GRADATIONAL CHANGES BETWEEN UNITS AND ARE APPROXIMATE.

LEGEND

PT	PEAT AND OTHER HIGHLY ORGANIC SOILS
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OL	ORGANIC SILTS AND ORGANIC SILTY CLAYS OF LOW PLASTICITY
MH	INORGANIC SILTS, MICACEOUS OR DIATOMACEOUS FINE SANDY OR SILTY SOILS, ELASTIC SILTS
CH	INORGANIC CLAYS OF FINE PLASTICITY, FAT CLAYS
OH	ORGANIC CLAYS OF MEDIUM TO HIGH PLASTICITY, ORGANIC SILTS
CL	INORGANIC CLAYS OF LOW TO MEDIUM PLASTICITY, GRAVELLY CLAYS, SANDY CLAYS, SILTY CLAYS, LEAN CLAYS
LM	WEATHERED LIMESTONE
GM	SILTY GRAVELS, GRAVEL-SAND-SILT MIXTURES
	FREE PRODUCT
	SOIL SAMPLE INTERVAL
	SCREEN INTERVAL
TOC	TOP OF CASING ELEVATION IN FEET (MSL)
▼	GROUND WATER ELEVATION AS OF 7/18/95

Richard Catlin & Associates, Inc. ENVIRONMENTAL ENGINEERS AND HYDROGEOLOGISTS RC&A WILMINGTON, NC CHARLESTON, SC ATLANTA, GA MOORESVILLE, NC	PROJECT: BUILDING 1115 LANTDIV NAVFACENGCOM CAMP LEJEUNE, N.C.	TITLE: CROSS SECTION D-D'	FIGURE 7
JOB NO. 93126ADD	DATE: 1 JUL 95	SCALE: 1"=100' DRAWN BY: WW SB	CHECKED BY: TP

Figure 8 -- Maximum Product Thickness 1988-1991

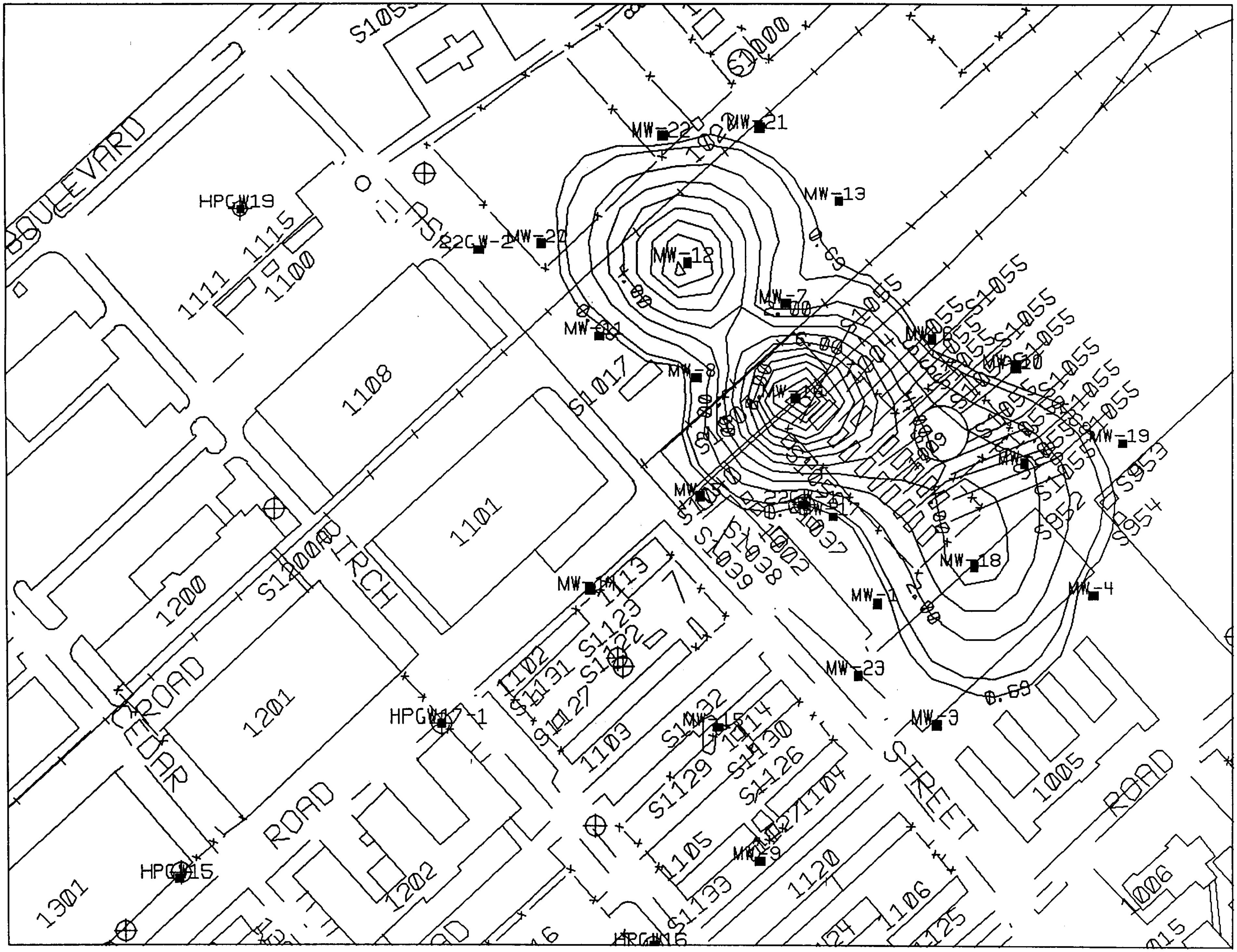


Figure 9 -- Maximum Product Thickness 1995-1996

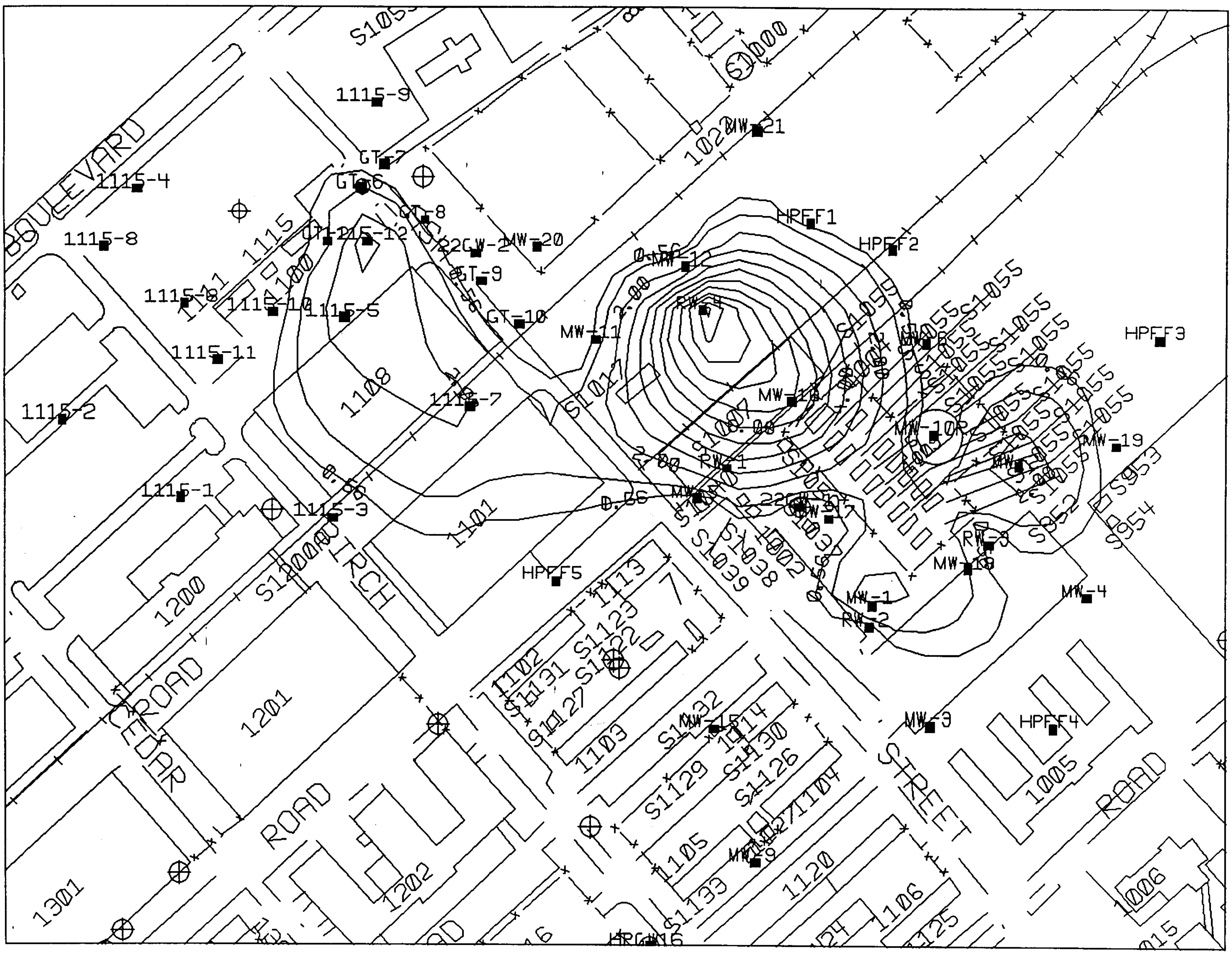


Figure 10 -- Product Thickness versus Time in MW-1

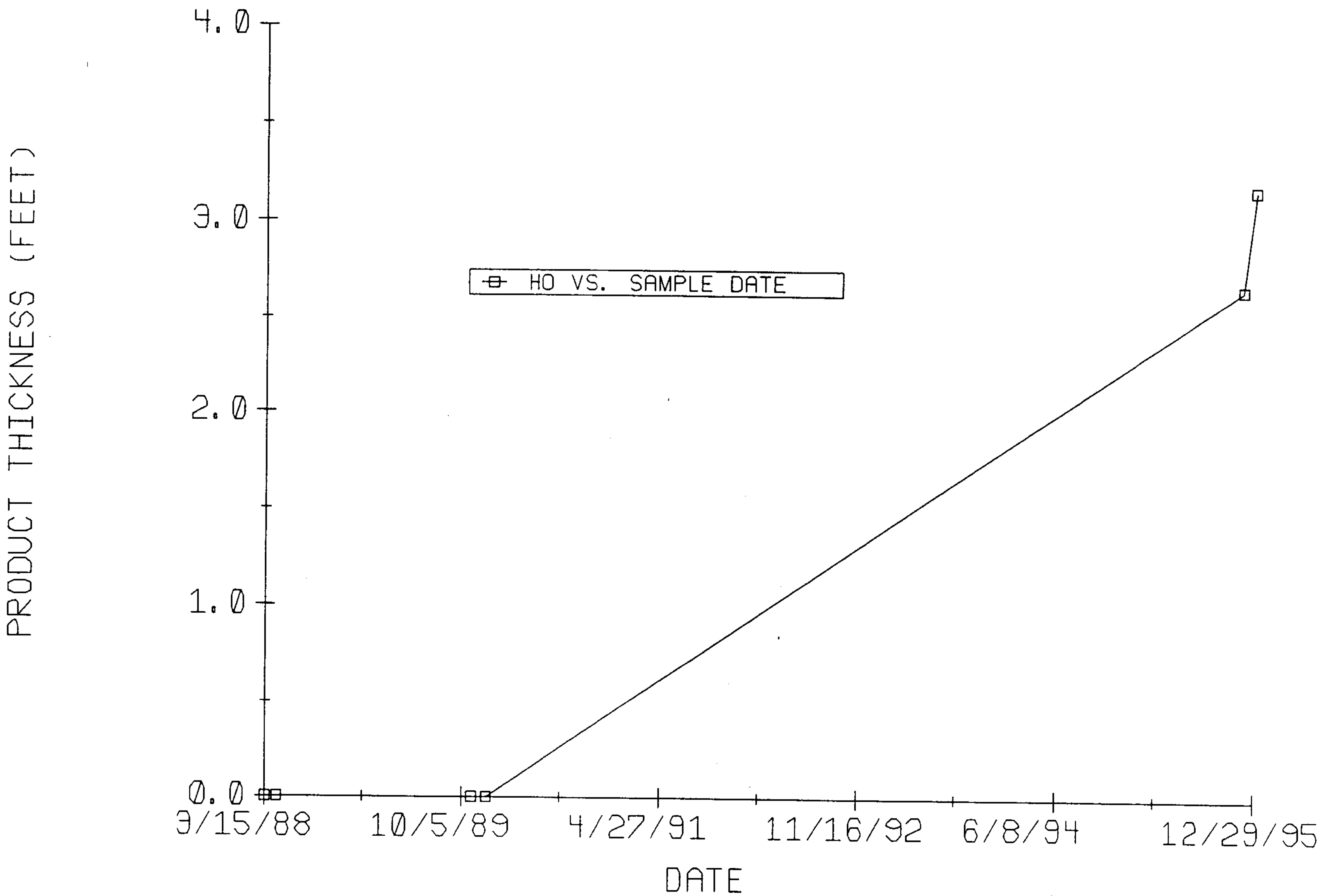


Figure 11 -- Product Thickness versus Time in MW-2

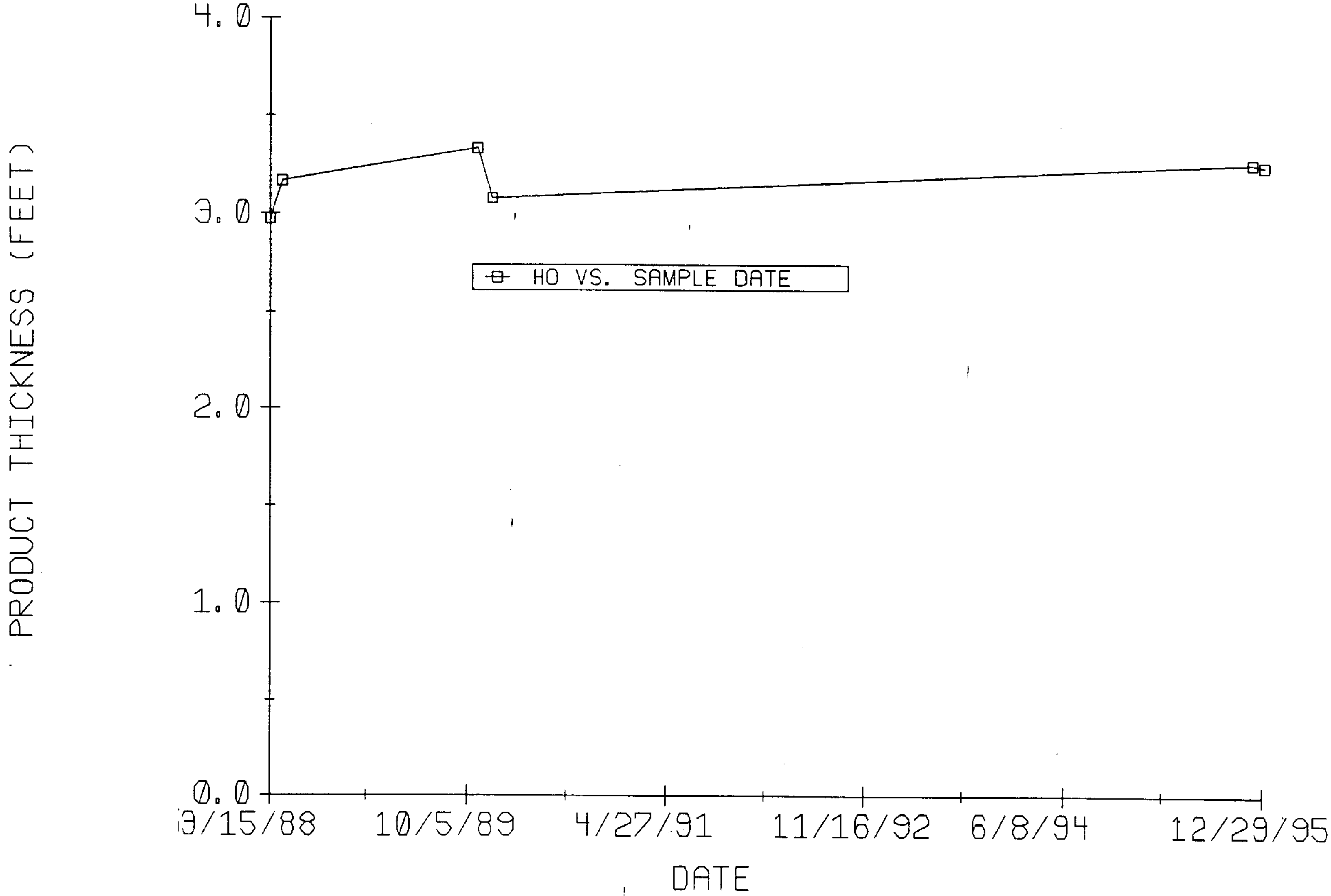


Figure 12 -- Product Thickness versus Time in MW-12

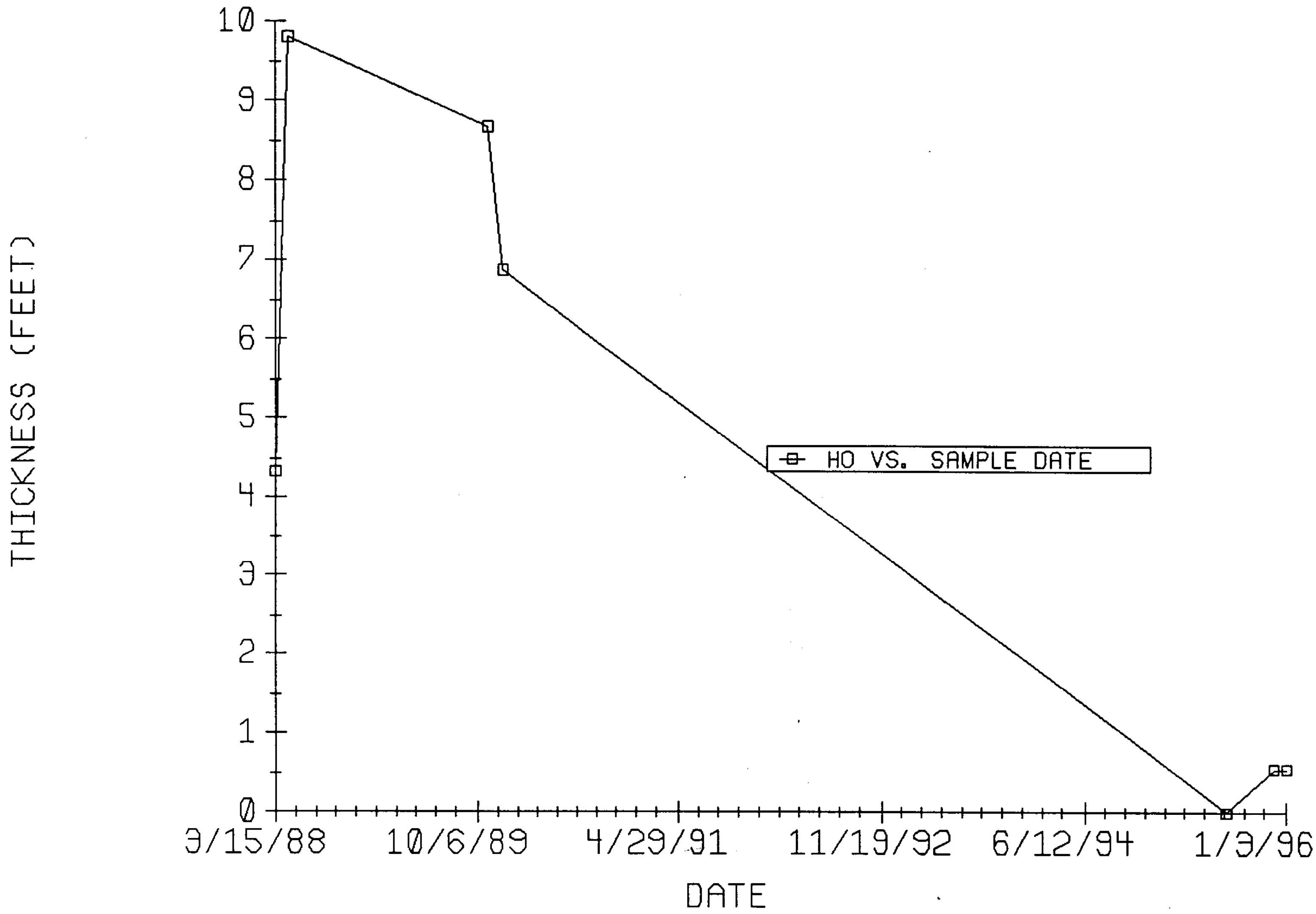


Figure 13 -- Product Thickness versus Time in MW-16

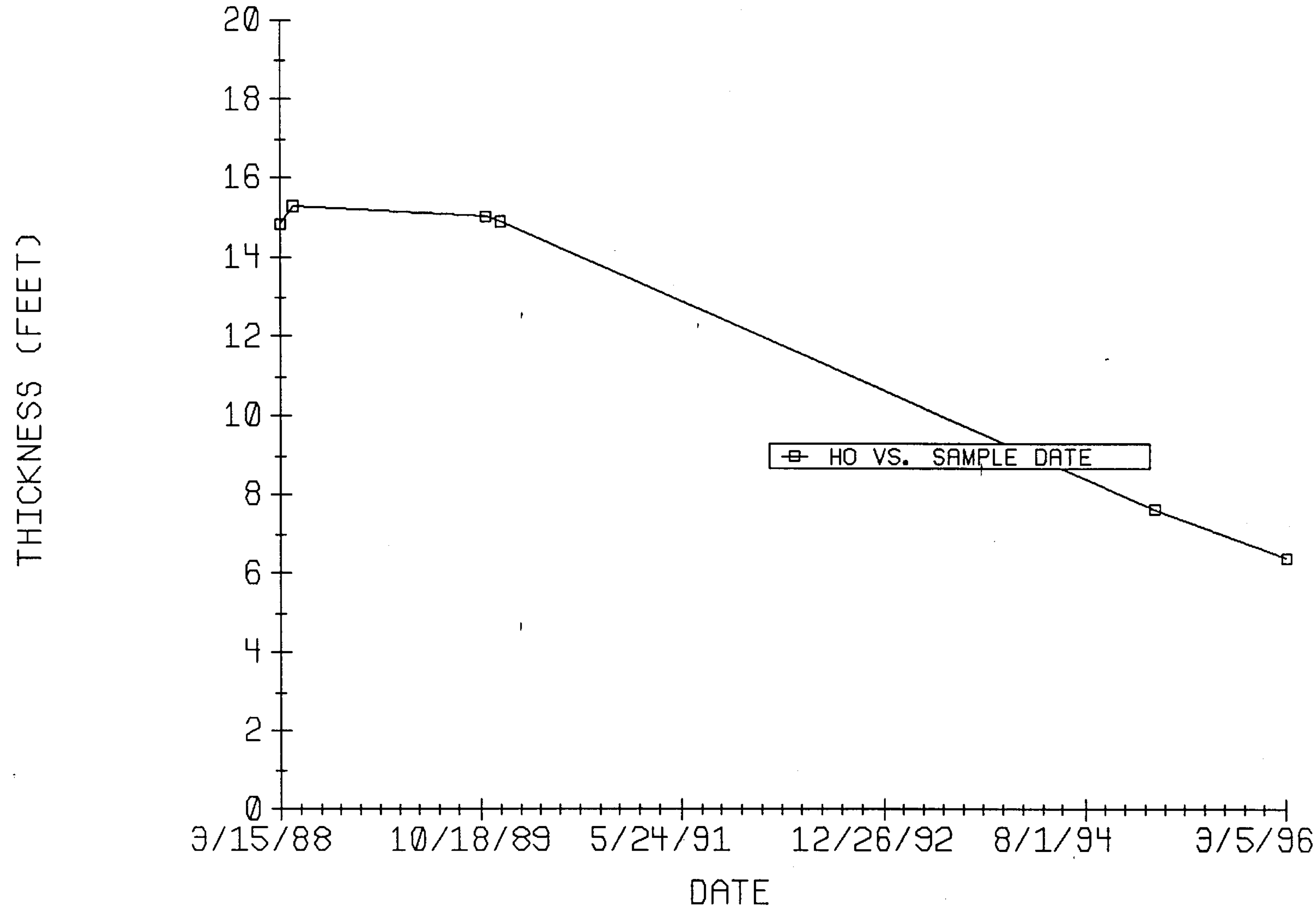


Figure 14 -- Product Thickness versus Time in MW-18

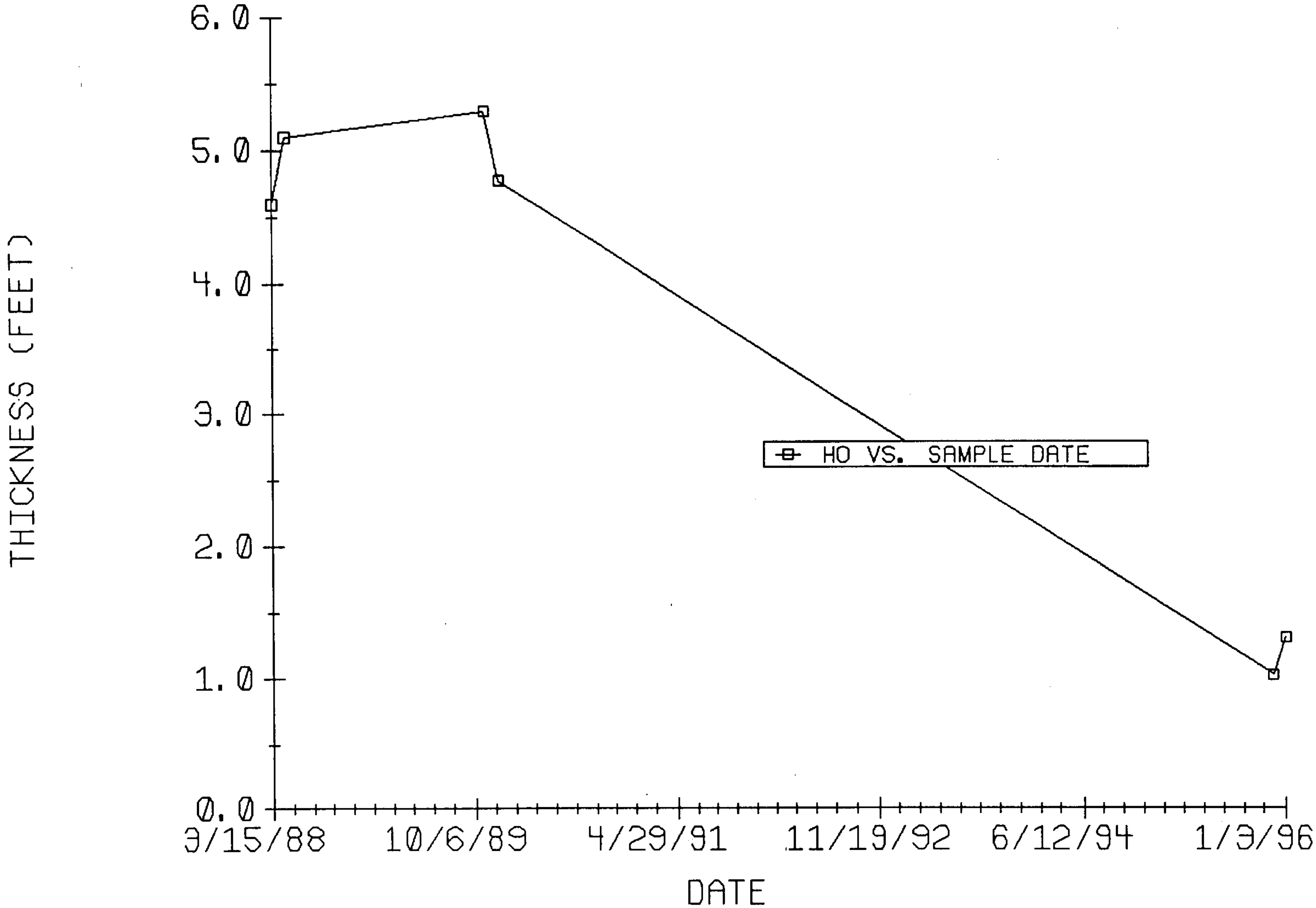


Figure 15 -- Shallow Benzene 1988-1991

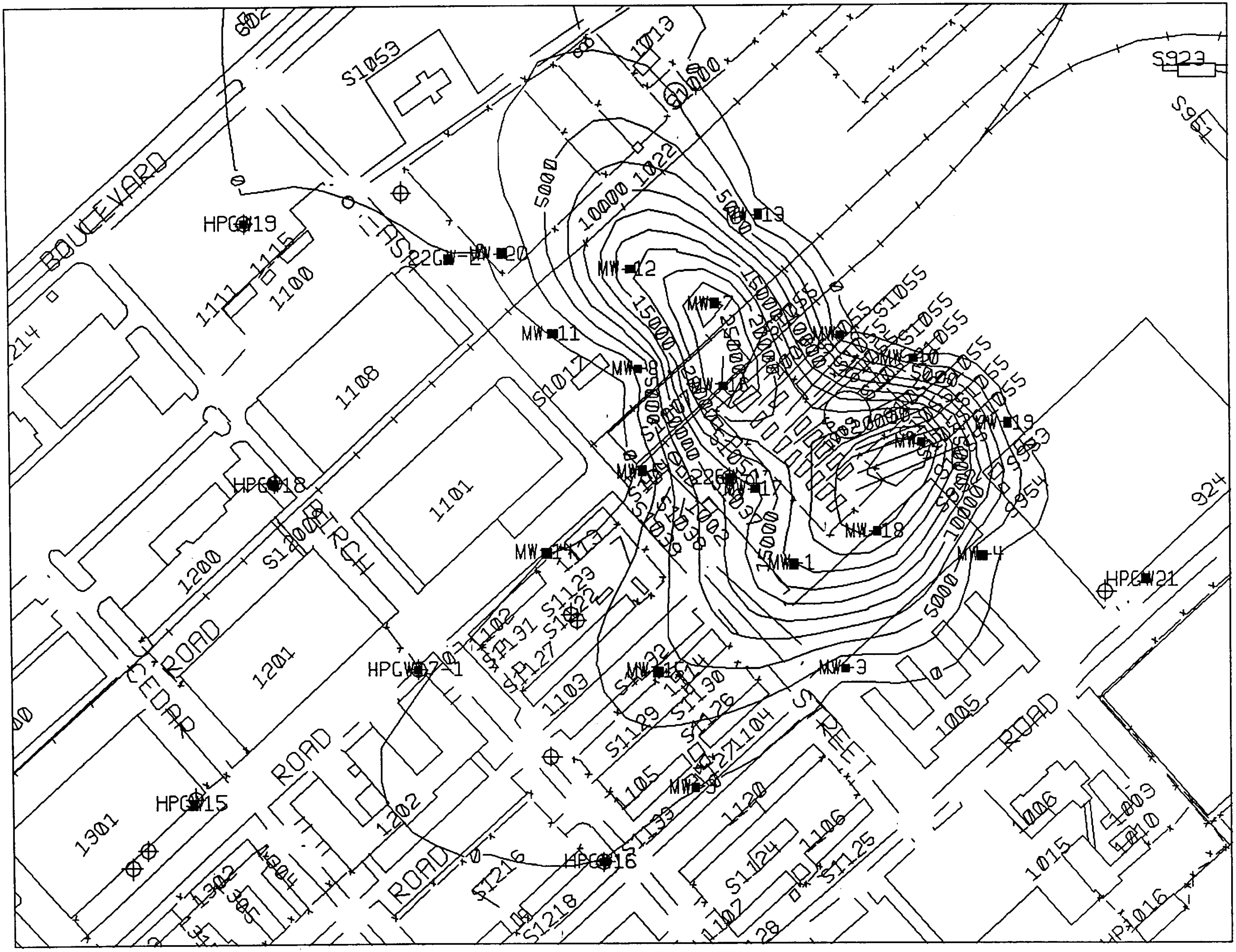


Figure 16 -- Shallow Benzene 1993-1995

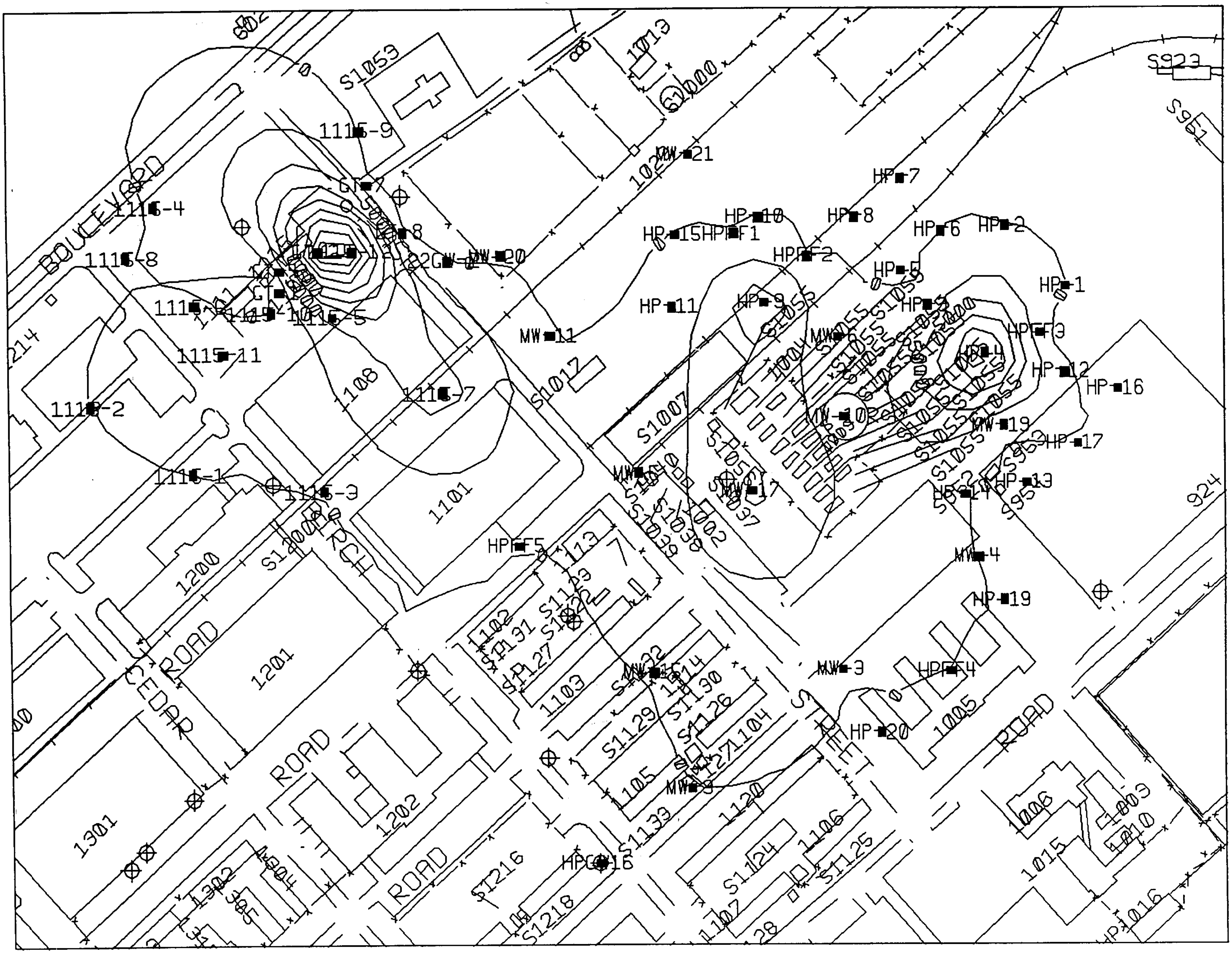


Figure 17 -- Deep Benzene 1993-1995

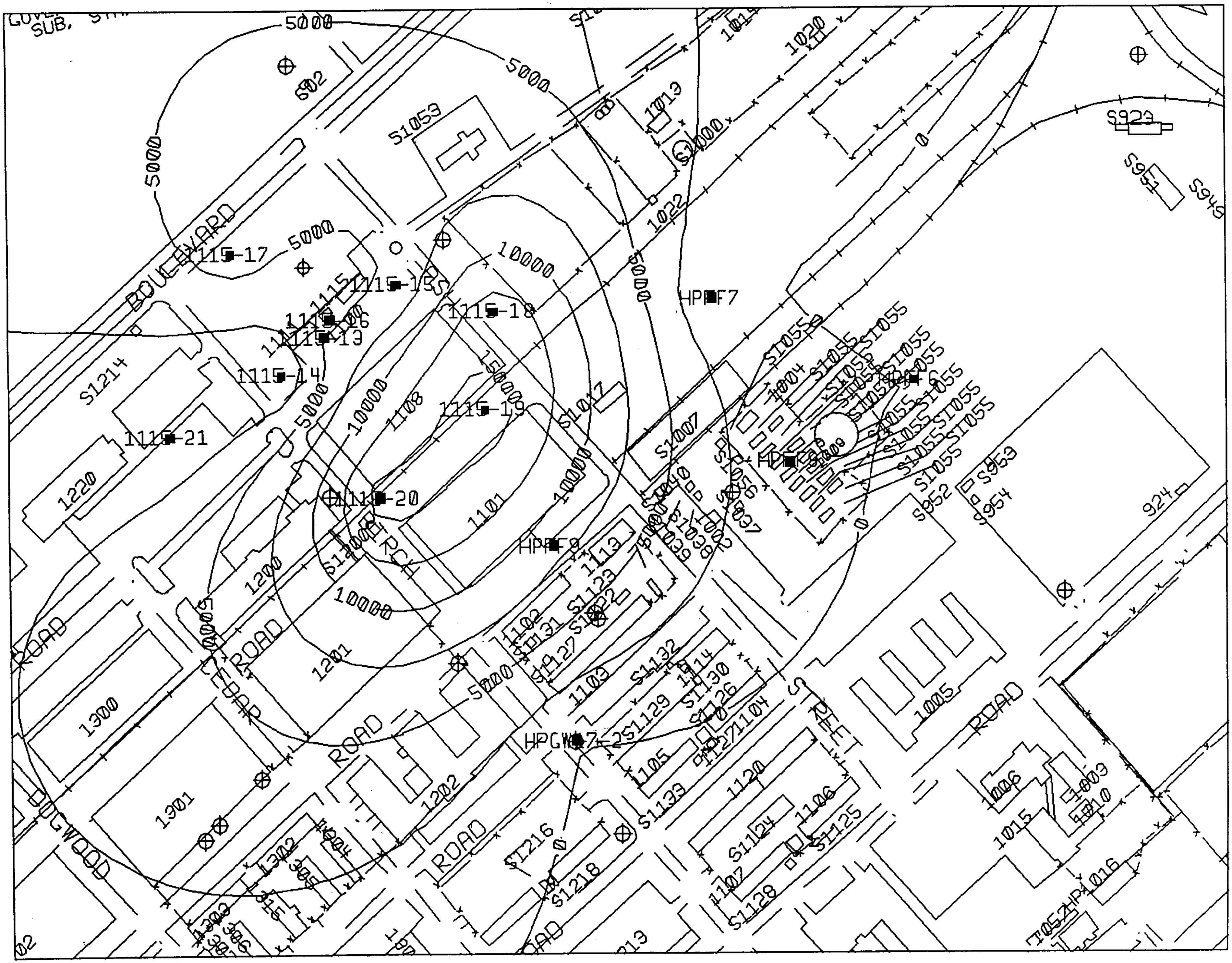


Figure 18 -- Deep Groundwater Elevations 1995 1996

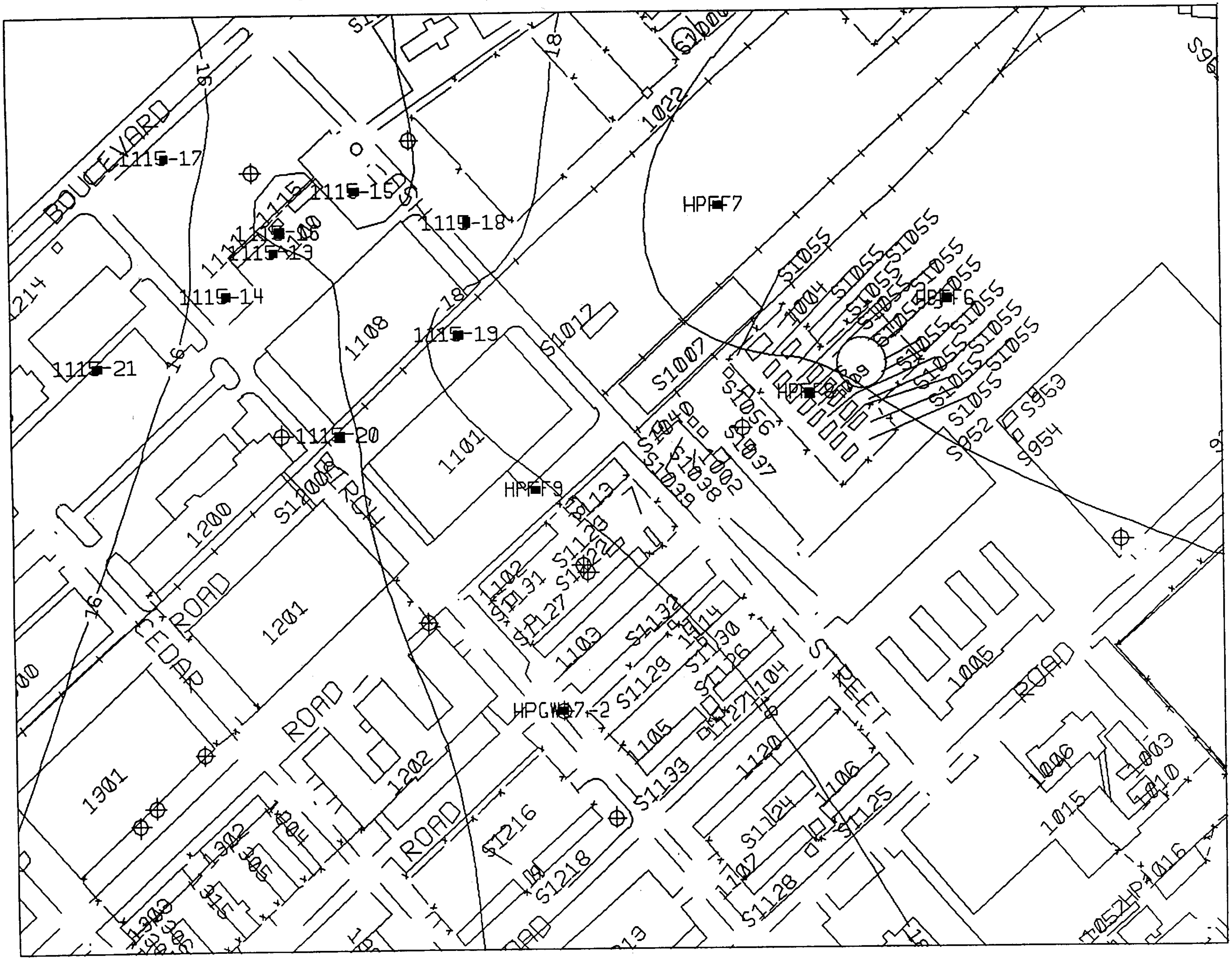
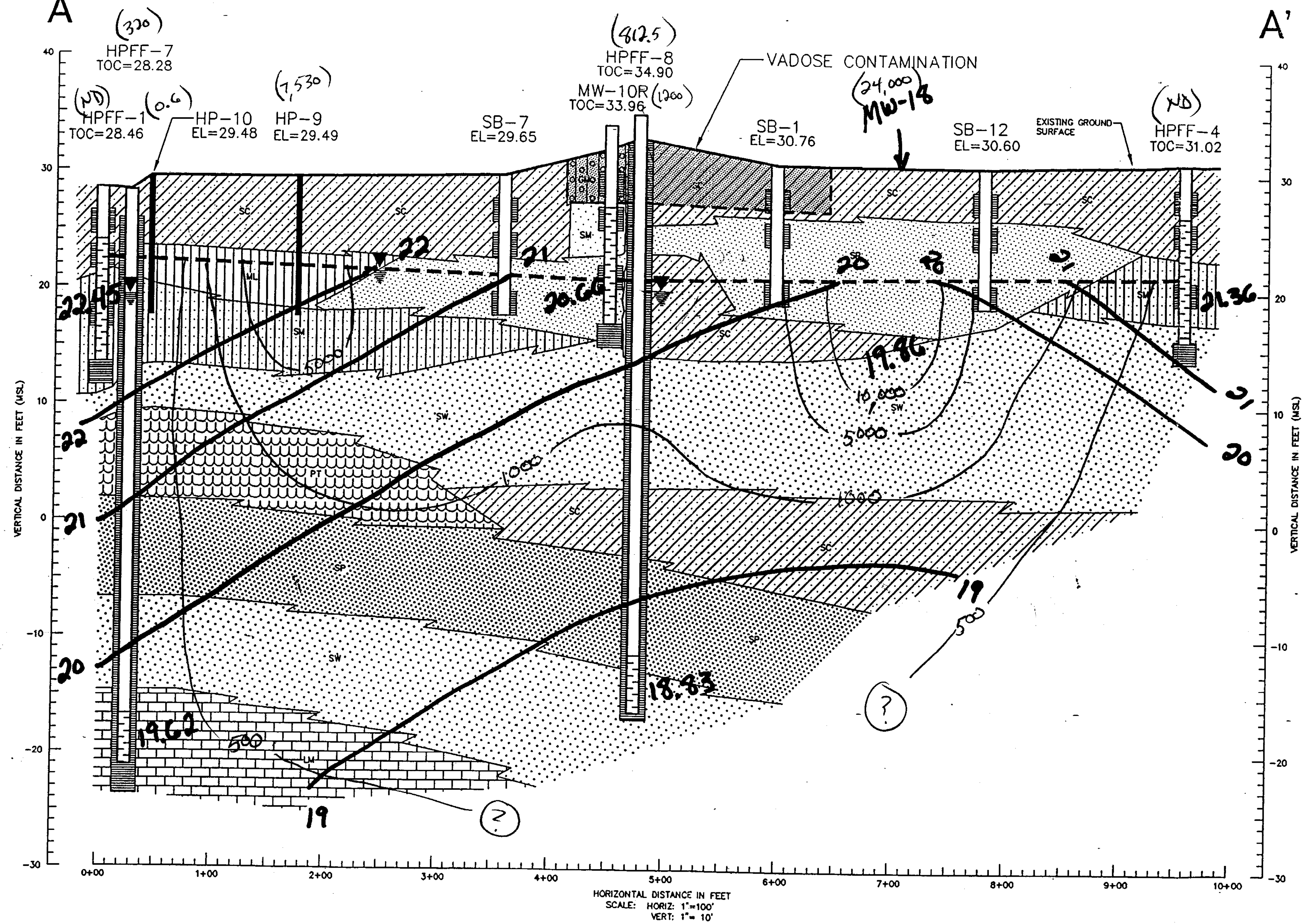


Figure 19 -- Hydrogeochemical Cross-section A-A'



LEGEND

NOTE: CONTACTS REPRESENT GRADATIONAL CHANGES BETWEEN SEDIMENTS AND ARE APPROXIMATE.

SW	WELL GRADED SANDS OR GRAVELLY SANDS, LITTLE OR NO FINES
SP	POORLY GRADED SANDS OR GRAVELLY SANDS, LITTLE OR NO FINES
SM	SILTY SANDS, SAND-SILT MIXTURES
SC	CLAYEY SANDS, SAND-CLAY MIXTURES
GM	SILTY GRAVELS, GRAVEL-SAND-SILT MIXTURES
ML	INORGANIC SILTS AND VERY FINE SANDS, ROCK FLOUR, SILTY OR CLAYEY FINE SANDS OR CLAYEY SILTS WITH SLIGHT PLASTICITY
PT	PEAT AND OTHER HIGHLY ORGANIC SOILS
LM	WEATHERED LIMESTONE
TOC	TOP OF CASING ELEVATION IN FEET
EL	ELEVATION IN FEET

WATER TABLE ELEVATION IN FEET ABOVE MEAN SEA LEVEL AS OF 11/29/95

SOIL SAMPLE INTERVAL

SCREEN INTERVAL

AREA OF VADOSE CONTAMINATION AT LEVELS ABOVE NCDEHNR ACTION LEVELS

Richard Catlin & Associates, Inc. ENVIRONMENTAL ENGINEERS AND HYDROGEOLOGISTS RC&A
WILMINGTON, NC CHARLESTON, SC ATLANTA, GA CHARLOTTE, NC

PROJECT: HADNOT POINT FUEL FARM MARINE CORPS BASE CAMP LEJEUNE, N.C.

TITLE: CROSS SECTION A - A'

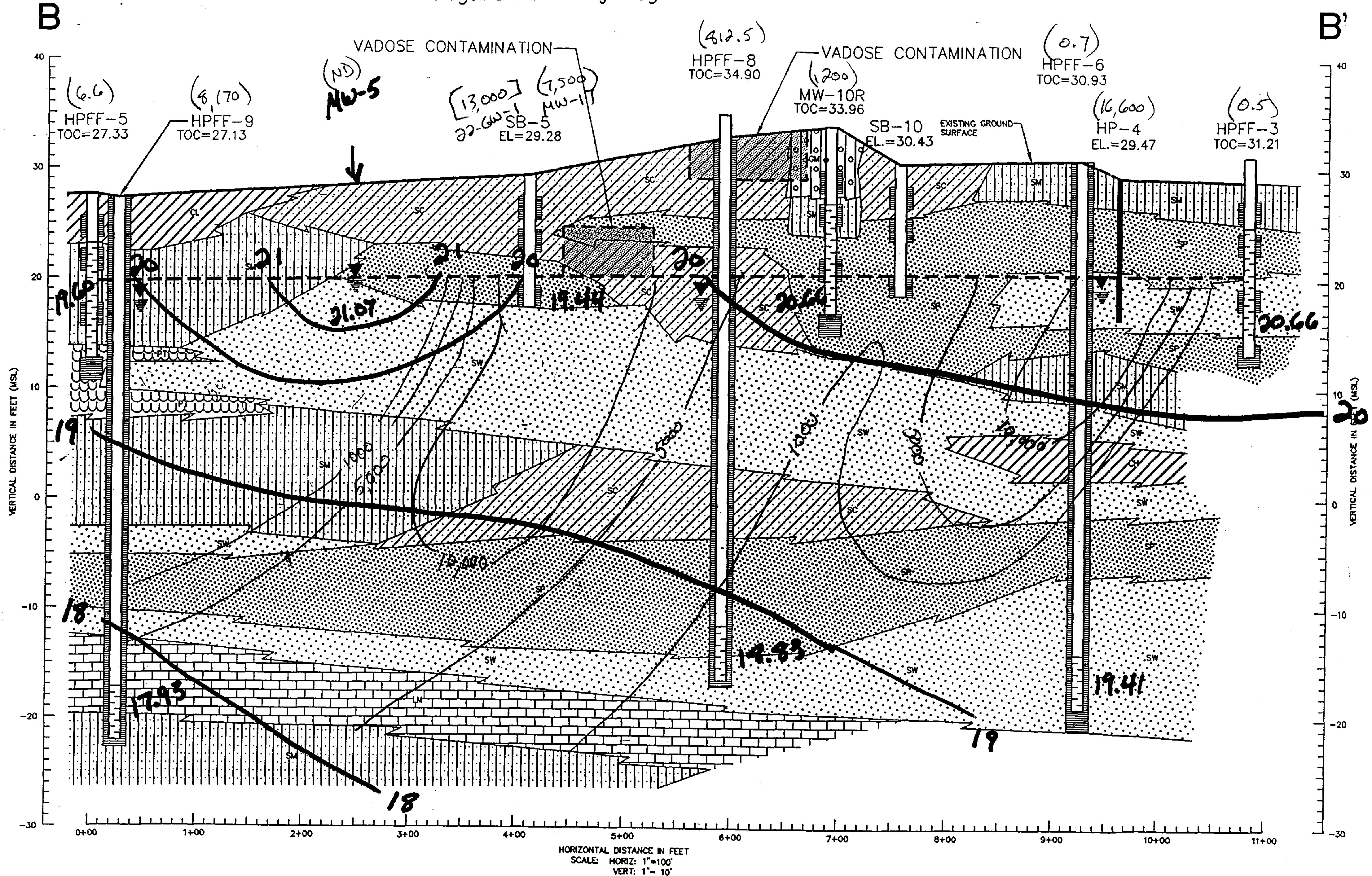
FIGURE 19

JOB NO. 95083CSA | DATE: DEC. 1995 | SCALE: AS NOTED | DRAWN BY: WHW | CHECKED BY: TW

DESIGNED BY: | DRAWN BY: | CHECKED BY: | APPROVED BY: | DATE:

NO.	DESCRIPTION REVISIONS	BY	DATE

Figure 20 -- Hydrogeochemical Cross-section B-B'



LEGEND

NOTE: CONTACTS REPRESENT GRADATIONAL CHANGES BETWEEN SEDIMENTS AND ARE APPROXIMATE.

SW	WELL GRADED SANDS OR GRAVELLY SANDS, LITTLE OR NO FINES
SP	POORLY GRADED SANDS OR GRAVELLY SANDS, LITTLE OR NO FINES
SM	SILTY SANDS, SAND-SILT MIXTURES
SC	CLAYEY SANDS, SAND-CLAY MIXTURES
GM	SILTY GRAVELS, GRAVEL-SAND-SILT MIXTURES
ML	INORGANIC SILTS AND VERY FINE SANDS, ROCK FLOUR, SILTY OR CLAYEY FINE SANDS OR CLAYEY SILTS WITH SLIGHT PLASTICITY
PT	PEAT AND OTHER HIGHLY ORGANIC SOILS
LM	WEATHERED LIMESTONE
CL	INORGANIC CLAYS OF LOW TO MEDIUM PLASTICITY, GRAVELLY CLAYS, SANDY CLAYS, SILTY CLAYS, LEAN CLAYS
CH	INORGANIC CLAYS OF HIGH PLASTICITY, FAT CLAYS
	WATER TABLE ELEVATION IN FEET AS OF 11/29/95
	SOIL SAMPLE INTERVAL
	SCREEN INTERVAL
TOC	TOP OF CASING ELEVATION IN FEET
EL	ELEVATION IN FEET
	AREA OF VADOSE CONTAMINATION AT LEVELS ABOVE NCDEHNR ACTION LEVELS

FIGURE 20

TITLE: CROSS SECTION B – B'

SCALE: AS NOTED | DRAWN BY: WHW | CHECKED BY: TWL

PROJECT: HADNOT POINT FUEL FARM, MARINE CORPS BASE, CAMP LEJEUNE, N.C.

JOB NO. 95093CSA | DATE: DEC. 1995

Richard Catlin & Associates, Inc. — ENVIRONMENTAL ENGINEERS AND HYDROGEOLOGISTS — RC&A

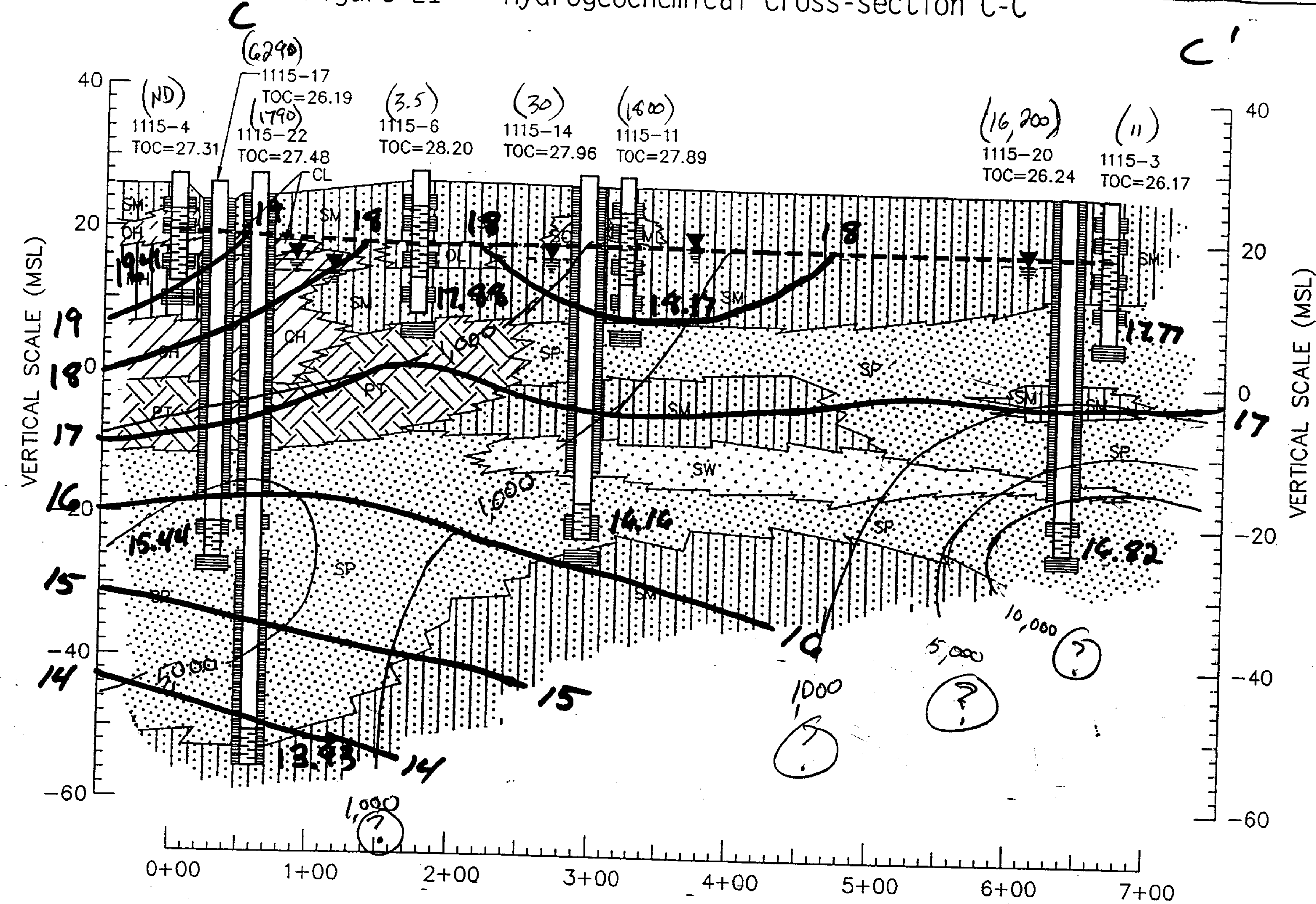
WILMINGTON, NC CHARLESTON, SC ATLANTA, GA CHARLOTTE, NC

DESIGNED BY: ___ DRAWN BY: ___ CHECKED BY: ___ APPROVED BY: ___ DATE: ___

NO.	DESCRIPTION	BY	DATE

REVISIONS

Figure 21 -- Hydrogeochemical Cross-section C-C'



VERTICAL SCALE 1"=20'
HORIZONTAL SCALE IN FEET 1"=100'

NOTE: CONTACTS REPRESENT GRADATIONAL CHANGES BETWEEN UNITS AND ARE APPROXIMATE.

LEGEND

PT	PEAT AND OTHER HIGHLY ORGANIC SOILS
SW	WELL GRADED SANDS OR GRAVELLY SANDS, LITTLE OR NO FINES
SP	POORLY GRADED SANDS OR GRAVELLY SANDS, LITTLE OR NO FINES
SM	SILTY SANDS, SAND-SILT MIXTURES
SC	CLAYEY SANDS, SAND-CLAY MIXTURES
ML	INORGANIC SILTS AND VERY FINE SANDS, ROCK FLOUR, SILTY OR CLAYEY FINE SANDS OR CLAYEY SILTS WITH SLIGHT PLASTICITY.
OL	ORGANIC SILTS AND ORGANIC SILTY CLAYS OF LOW PLASTICITY
MH	INORGANIC SILTS, MICACEOUS OR DIATOMACEOUS FINE SANDY OR SILTY SOILS, ELASTIC SILTS
CH	INORGANIC CLAYS OF FINE PLASTICITY, FAT CLAYS
OH	ORGANIC CLAYS OF MEDIUM TO HIGH PLASTICITY, ORGANIC SILTS
CL	INORGANIC CLAYS OF LOW TO MEDIUM PLASTICITY, GRAVELLY CLAYS, SANDY CLAYS, SILTY CLAYS, LEAN CLAYS

SOIL SAMPLE INTERVAL
SCREEN INTERVAL

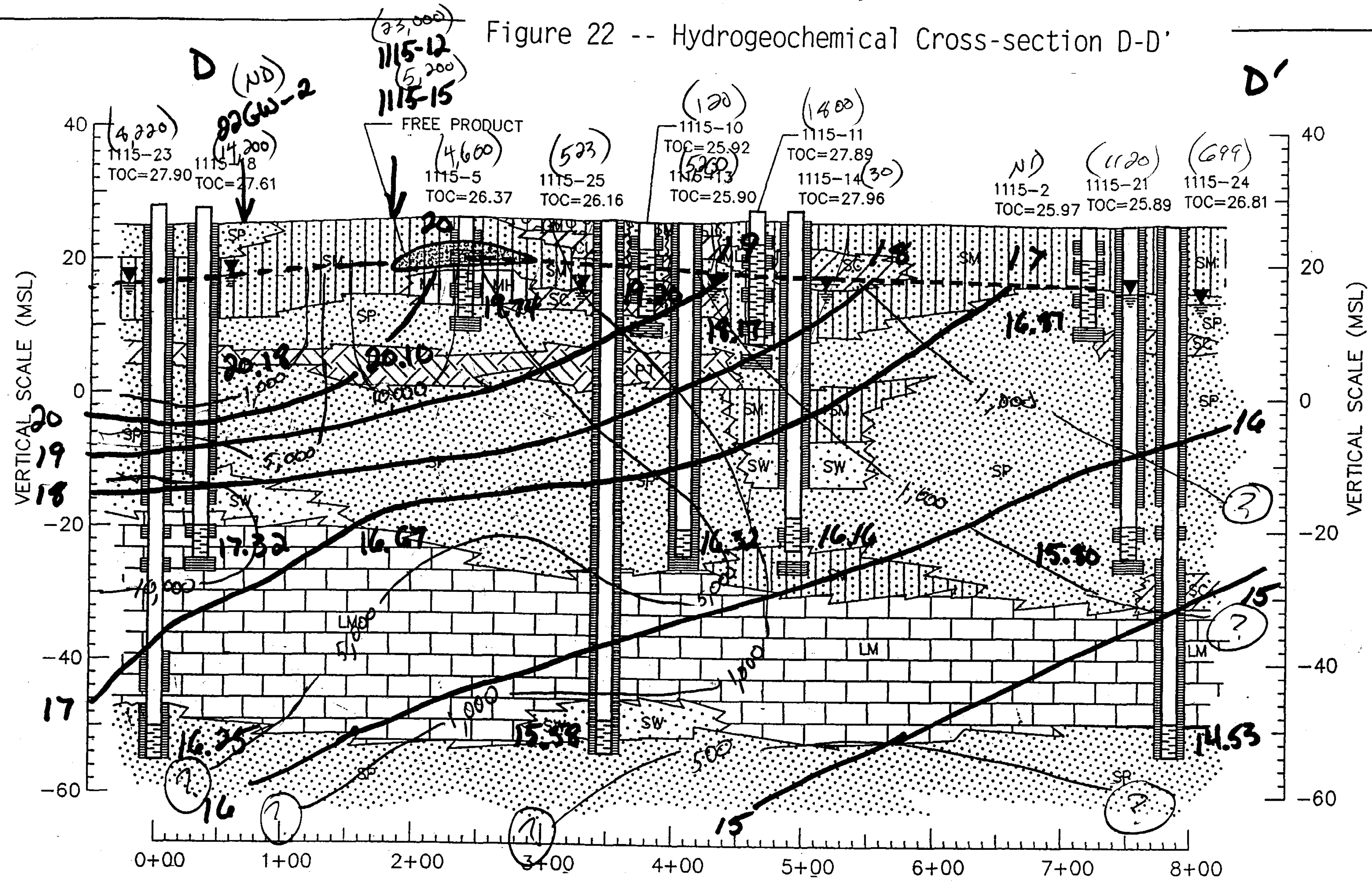
TOC TOP OF CASING ELEVATION IN FEET (MSL)

GROUND WATER ELEVATION AS OF 7/18/95

Richard Catlin & Associates, Inc.
ENVIRONMENTAL ENGINEERS AND HYDROGEOLOGISTS RC&A
WILMINGTON, NC CHARLESTON, SC ATLANTA, GA MOORESVILLE, NC

PROJECT	TITLE	FIGURE
BUILDING 1115 LANTDIV NAVFACENGCOM CAMP LEJEUNE, N.C.	CROSS SECTION C-C'	21
JOB NO. 93126ADD DATE: 1 JUL 95	SCALE: 1"=100' DRAWN BY: WW SB CHECKED BY: TP	

Figure 22 -- Hydrogeochemical Cross-section D-D'



VERTICAL SCALE 1"=20'
HORIZONTAL SCALE IN FEET 1"=100'

NOTE: CONTACTS REPRESENT GRADATIONAL CHANGES BETWEEN UNITS AND ARE APPROXIMATE.

LEGEND

PT	PEAT AND OTHER HIGHLY ORGANIC SOILS
SW	WELL GRADED SANDS OR GRAVELLY SANDS, LITTLE OR NO FINES
SP	POORLY GRADED SANDS OR GRAVELLY SANDS, LITTLE OR NO FINES
SM	SILTY SANDS, SAND-SILT MIXTURES
SC	CLAYEY SANDS, SAND-CLAY MIXTURES
ML	INORGANIC SILTS AND VERY FINE SANDS, ROCK FLOUR, SILTY OR CLAYEY FINE SANDS OR CLAYEY SILTS WITH SLIGHT PLASTICITY.
OL	ORGANIC SILTS AND ORGANIC SILTY CLAYS OF LOW PLASTICITY
MH	INORGANIC SILTS, MICACEOUS OR DIATOMACEOUS FINE SANDY OR SILTY SOILS, ELASTIC SILTS
CH	INORGANIC CLAYS OF FINE PLASTICITY, FAT CLAYS
OH	ORGANIC CLAYS OF MEDIUM TO HIGH PLASTICITY, ORGANIC SILTS
CL	INORGANIC CLAYS OF LOW TO MEDIUM PLASTICITY, GRAVELLY CLAYS, SANDY CLAYS, SILTY CLAYS, LEAN CLAYS
LM	WEATHERED LIMESTONE
GM	SILTY GRAVELS, GRAVEL-SAND-SILT MIXTURES
	FREE PRODUCT
	SOIL SAMPLE INTERVAL
	SCREEN INTERVAL
TOC	TOP OF CASING ELEVATION IN FEET (MSL)
	GROUND WATER ELEVATION AS OF 7/18/95

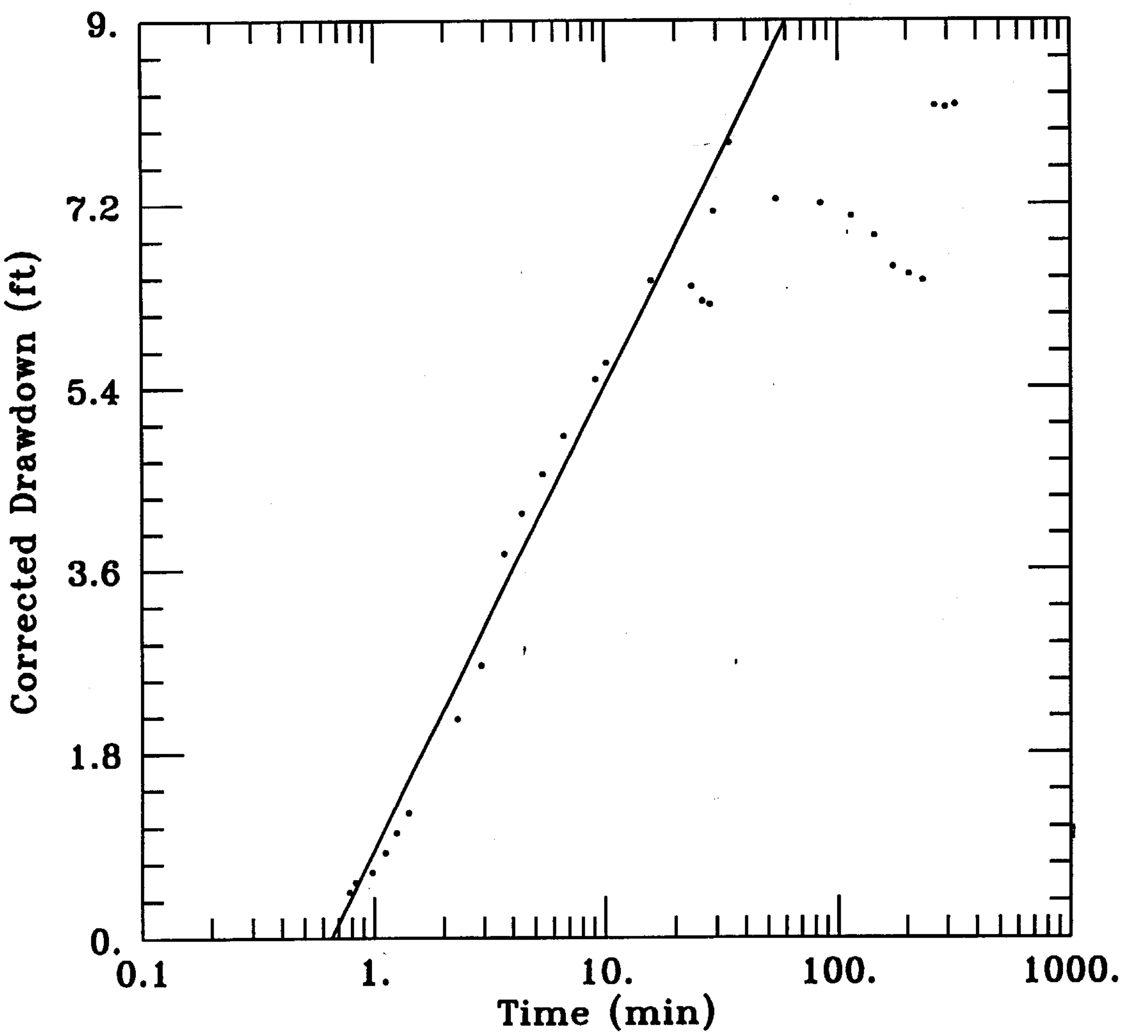
Richard Catlin & Associates, Inc. ENVIRONMENTAL ENGINEERS AND HYDROGEOLOGISTS RC&A WILMINGTON, NC CHARLESTON, SC ATLANTA, GA MOORESVILLE, NC	PROJECT BUILDING 1115 LANTDIV NAVFACENGCOM CAMP LEJEUNE, N.C.	TITLE CROSS SECTION D-D'	FIGURE 22
	JOB NO. 93126ADD DATE: 1 JUL 95	SCALE: 1"=100' DRAWN BY: WW SB CHECKED BY: TP	

Appendix A -- Re-evaluated Pumping Test Results for RW-1 and RW-2

Figure A-1 -- Cooper-Jacob Straight-Line Solution for RW-1 Drawdown Data

Client: **LANTDIV**	Company: **Baker Environmental, Inc.**
Location: **Site 22 Hadnot Pt. Fuel Farm**	Project: **62470-140**

RW-1 - Site 22 - Hadnot Point Fuel Farm



DATA SET:
RW-1.DAT
05/01/96

AQUIFER MODEL:
Unconfined

SOLUTION METHOD:
Cooper-Jacob

PROJECT DATA:
test date: December 15, 1989
test well: RW-1
obs. well: RW-1

TEST DATA:
Q = 3. gal/min
r = 0. ft
r_c = 0.25 ft
r_w = 0.5 ft
b = 22. ft

PARAMETER ESTIMATES:
T = 23.08 ft^2/day
S = 0.09414

$K = T/b = 23/22'$

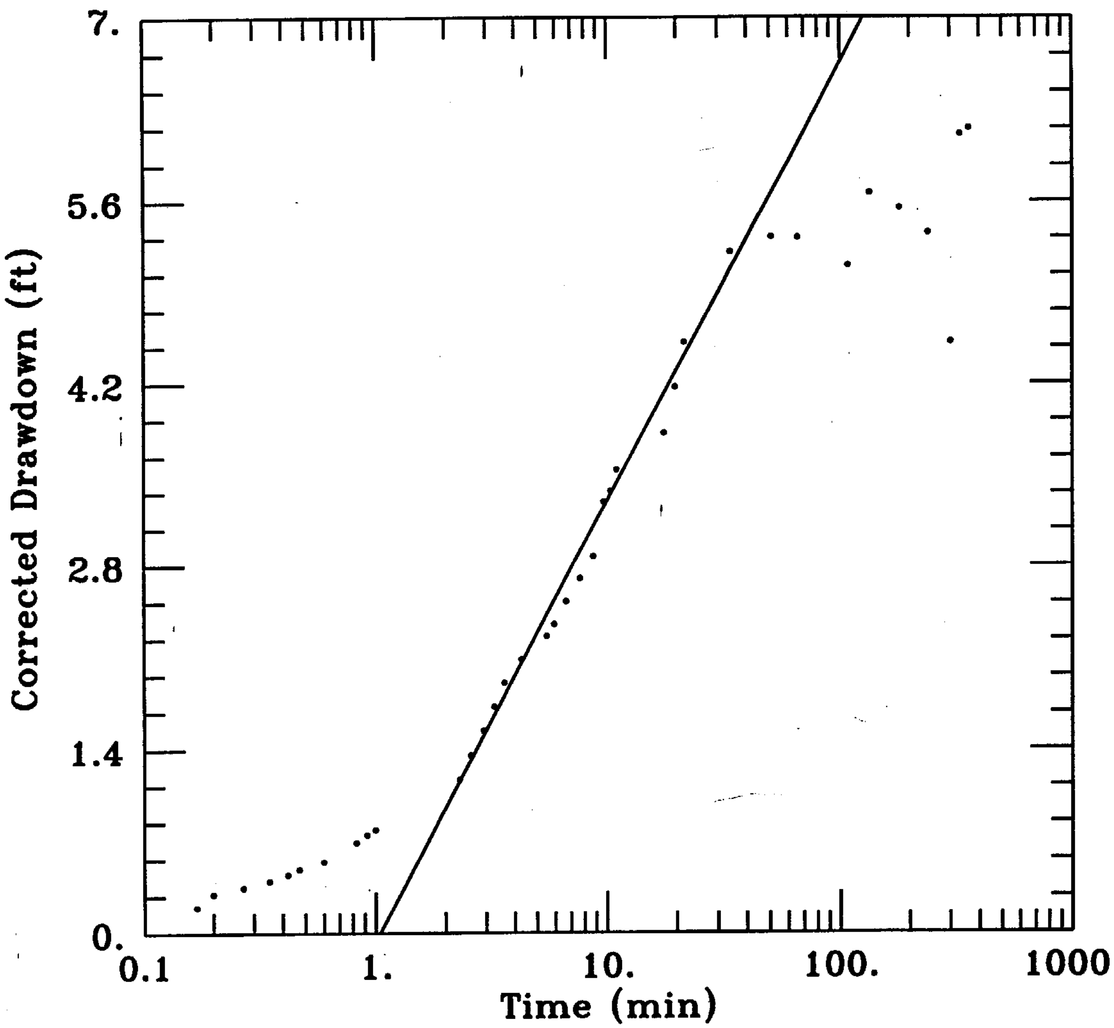
$= 1.0$ ft/day

AQTESOLV

Figure A-2 -- Cooper-Jacob Straight-Line Solution for RW-2 Drawdown Data

Client: **LANTDIV**	Company: **Baker Environmental, Inc.**
Location: **Site 22 Hadnot Pt. Fuel Farm**	Project: **62470-140**

RW-2 - Site 22 - Hadnot Point Fuel Farm



DATA SET:
RW-2.DAT
05/01/96

AQUIFER MODEL:
Unconfined

SOLUTION METHOD:
Cooper-Jacob

PROJECT DATA:
test date: December 15, 1989
test well: RW-2
obs. well: RW-2

TEST DATA:
Q = 2. gal/min
r = 0. ft
r_c = 0.25 ft
r_w = 0.5 ft
b = 21. ft

PARAMETER ESTIMATES:
T = 21.02 ft^2/day
S = 0.1367

$K = 21/21' = 1.0$ ft/day
$= T/b$

AQTESOLV