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THEA FOSS WATERWAY

Round 3 Data Evaluation and Pre-Design Evaluation Report Thea Foss and Wheeler-Osgood Waterways Tacoma, Washington Appendices R - Z

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APPENDIX R
ST. PAUL WATERWAY SUPPLEMENTAL DATA

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APPENDIX R
ST. PAUL WATERWAY SUPPLEMENTAL DATA

This appendix describes supplemental field investigations and hydrogeologic modeling performed in support of evaluating the suitability of the St. Paul Waterway CDF site.

R.1 Supplemental Geotechnical Investigation

This section summarizes supplemental field explorations, sampling, and laboratory tests conducted to support geotechnical engineering analyses of the St. Paul Waterway CDF (as discussed in Section 4.4). These activities were performed in accordance with Attachment A of the Work Plan for the St. Paul Waterway Nearshore Confined Disposal Facility, dated January 8, 1999.

R.1.1 Geotechnical Borings

Eight hollow-stem auger borings were drilled in and adjacent to the St. Paul Waterway between February 19 and March 2, 1999. The boring locations are shown on Figure 5-14, the Confirmed Sample Location Plan for St. Paul Waterway.

Samples of soil and sediment were collected for geotechnical evaluation and testing. Three of the borings were drilled onshore, adjacent to the edge of the waterway. The remaining five borings were drilled offshore, within the waterway. The borings were designated as follows:

General Location	Boring Designations	Range of Depths in Feet below Mudline
Offshore (within waterway)	HC-1, HC-2, HC-3, HC-7, HC-8	58.5 to 90.5
Onshore (adjacent to waterway)	HC-4, HC-5, HC-6	119.5 to 120.5

Boring logs are presented on Figures R-2 through R-8 and Figure R-10. Monitoring well RD3-UMW10 was installed inside boring HC-6. The log for boring HC-6 appears on Figure R-10, with the well installation diagram. Boring HC-8 was collocated with sediment core number B4.

Borings were advanced using a 3-3/8-inch inside diameter hollow-stem auger and a truck-mounted drill rig subcontracted by Hart Crowser. The drill rig was positioned on the SeaHorse barge platform operated by Marine Science Services for the in-water explorations and truck-mounted for upland

explorations. Drilling was continuously observed by an engineer or geologist from Hart Crowser. Observations were recorded in detailed field logs. Using the Standard Penetration Test (SPT) split-spoon sampler, samples were collected at 2-1/2- to 5-foot-depth intervals. Samples were classified in the field according to the methods presented on Figure R-1, Key to Exploration Logs.

Shelby Tube Sampling. To obtain a relatively undisturbed sample for classification and testing of fine-grained sediments and/or sediment deposits, a 3-inch-diameter, thin-walled steel (Shelby) tube sampler was pushed hydraulically below the bottom of the augers during drilling. Shelby tube samples were obtained at a variety of depths in each boring when drilling was determined to be in fine-grained soil deposits. The tubes were sealed in the field and taken to the Hart Crowser sediments laboratory for extrusion and physical testing. The depths at which Shelby tubes were obtained are indicated on the boring logs.

Sample recovery at several locations was hampered by the presence of non-cohesive sediments (i.e., sandy materials). Selected Shelby tube samples were extruded in the laboratory, visually classified, then tested for a variety of geotechnical parameters, as described in Section R.1.2.

Standard Penetration Test (SPT) Procedures. This test is an approximate measure of sediment/soil density and consistency. To be useful, the results must be used with engineering judgment in conjunction with other tests. The SPT (as described in ASTM D 1586) was used to obtain subsurface samples from specific depth intervals. This test employed a standard 2-inch outside diameter split-spoon sampler. Using a 140-pound hammer, free-falling 30 inches, the sampler was driven into the sediment for 18 inches. The number of blows required to drive the sampler the last 12 inches is the Standard Penetration Resistance. This resistance, or "blow count", measures the relative density of granular sediments and the consistency of cohesive sediments or soils. The blow counts were plotted on the boring logs at their respective sample depths.

Sediment/soil samples were recovered from the split-barrel sampler, field classified, and placed into water tight jars. They were then taken to Hart Crowser's laboratory for further testing.

Occasionally very dense materials precluded driving the total 18-inch interval. When this happened, the penetration resistance was entered on logs as follows:

- **Penetration less than six inches.** The log indicated the total number of blows over the number of inches of penetration.
- **Penetration greater than six inches.** The blow count noted on the log was the sum of the total number of blows completed <u>after</u> the first six inches of

penetration. This sum was expressed over the number of inches driven that exceed the first 6 inches. The number of blows needed to drive the first six inches were not reported. For example, a blow count series of 12 blows for 6 inches, 30 blows for 6 inches, and 50 (the maximum number of blows counted within a 6-inch increment for SPT) for 3 inches would be recorded as 80/9.

R.1.2. Laboratory Testing

A laboratory testing program was performed on selected representative samples to evaluate the basic index and geotechnical engineering properties of the site soils. Both disturbed and relatively undisturbed samples were tested. The following tests were performed on all or selected sediment samples:

- Soil Classification;
- Water Content Determinations;
- Grain Size Analysis;
- Atterberg Limits;
- Specific Gravity;
- Consolidation Tests;
- Triaxial Consolidated Undrained (TCU);
- Triaxial Unconsolidated Undrained (TUU); and
- Falling-Head Permeability.

Additionally, the engineering analysis of St. Paul Waterway capacity, and the determination of the time rate of settling and consolidation of Thea Foss Waterway dredged sediments within the waterway, required laboratory tests performed on samples from the Thea Foss Waterway dredge prism. A single composite sample obtained previously during Round 3 activities, labeled LC-01/12, was slurried at a 6:1 water to solids ratio, allowed to settle for 14 days, and the overlying clear supernatant was removed. The resulting resettled sample was used for the following tests:

- Water Content Determinations;
- Grain Size Analysis;
- Atterberg Limits;
- Specific Gravity;
- Consolidation Tests;
- Triaxial Consolidated Undrained (TCU);
- Triaxial Unconsolidated Undrained (TUU); and
- Falling-Head Permeability.

The test procedures that were followed are outlined below.

Visual Observations. Soil samples from the explorations were visually classified in the field and then taken to Hart Crowser's laboratory where the classifications were verified in a relatively controlled laboratory environment. Field and laboratory observations include density/consistency, moisture condition, and grain size and plasticity estimates.

Classifications were made in general accordance with the Unified Soil Classification (USC) System, ASTM D 2487, as presented on Figure R-11. The classifications of selected samples were checked by laboratory tests such as Atterberg limits determinations and grain size analyses, as described in the following sections.

Water Content Determinations. As soon as possible following their arrival in the Hart Crowser laboratory, water contents were determined for surface and subsurface sediment samples in general accordance with ASTM D 2216. Water contents were routinely determined for samples subjected to other physical and chemical testing and as part of the grain size analyses, and were not determined for large gravel contents would result in values considered unrepresentative. The results of the water content determinations are shown at the respective sample depths on the exploration logs.

Grain Size Analysis (GS). Grain size distribution was analyzed on 12 representative samples from the borings, and on one sample of the resettled Thea Foss Waterway sediment sample. Sieve analysis conducted in general accordance with ASTM D 422 was used to determine the grain size distribution greater than the U.S. No. 200 mesh sieve for all samples, and for 12 of the 13 samples, the size distribution for particles smaller than the No. 200 mesh sieve was determined by the hydrometer method. Percent fines (the sum of the silt and clay fractions) is defined as that fraction less than 0.075 mm.

The results of the grain size tests are graphically presented as curves on Figures R-12 through R-22, which plot percent finer by weight versus grain size.

Atterberg Limits (AL). Hart Crowser determined Atterberg limits for ten selected fine-grained soil samples from the borings, and for the resettled Thea Foss Waterway sediment sample. The liquid limit and plastic limit were determined in general accordance with ASTM D 4318-84. The results of the Atterberg limits analyses and the plasticity characteristics are summarized in the Liquid and Plastic Limits Test Reports, Figures R-23 through R-26. These relate the plasticity index (liquid limit minus the plastic limit) to the liquid limit. The results of the Atterberg limits tests are also shown graphically on the boring logs.

Specific Gravity. Specific gravity was determined for the resettled Thea Foss Waterway sediment. Specific gravity is a measure of the density of the soil solids, and is expressed as a multiple of the density of water (62.4 pcf). The specific gravity was determined in general accordance with ASTM D 854-91. The result was a specific gravity of 2.59 for sample LC-01/12.

Consolidation Tests. The one-dimensional consolidation test provides data for estimating settlement. Four tests were performed on selected Shelby tube samples from the St. Paul Waterway, and three tests were conducted on the resettled Thea Foss Waterway sediment sample. Consolidation tests were performed in general accordance with ASTM D 2435. For Shelby tube samples, a relatively undisturbed, fine-grained sample was carefully trimmed and fit into a rigid ring with porous stones placed on the top and bottom of the sample to allow drainage. The resettled Thea Foss Waterway sediment material was carefully placed in the ring using a small spoon and spatula. Vertical loads were then applied incrementally to the sample in such a way that the sample was allowed to consolidate under each load increment. Measurements were made of the compression of the sample (with time) under each load increment. Rebound was measured during the unloading phase. In general, each load was left in place until the completion of 100 percent primary consolidation, as computed using Taylor's square root of time method. The next load increment was applied soon after attaining 100 percent primary consolidation. The test results plotted in terms of axial strain and coefficient of consolidation versus applied load (stress) are presented on Figures R-27 through R-33.

Triaxial Consolidated Undrained (TCU) Test. The triaxial consolidated undrained compression test with pore pressure measurement estimates the effective strength of the soil at various stress levels. A relatively undisturbed fine-grained sample was trimmed to a length of about 6 inches, encased in a rubber membrane, and placed in the triaxial cell. With the sample in the triaxial test cell, an all-around pressure was applied hydraulically. The sample was allowed to consolidate under the applied pressure with drainage occurring through porous stones through slotted filter paper placed around the sample. When consolidation was completed, drainage lines from the sample were closed, a back pressure was applied to saturate the sample, and the sample was loaded to failure under undrained conditions by application of increasing axial load at a constant strain rate.

During loading, we recorded the magnitude of excess pore water pressure developed. From the data, an effective stress plot was developed to illustrate the variation in effective shear strength with varying consolidation (or overburden) pressures. The data are plotted using shear stress versus principal stress as Mohr's circles. The tangent to the Mohr's circles for a test series represents the

effective angle of internal friction (ϕ'). The intercept along the vertical axis is the apparent cohesion (c'). The test results are shown on Figure R-34.

Triaxial Unconsolidated Undrained (TUU) Tests. The triaxial unconsolidated undrained compression test estimates the undrained shear strength of the soil. This test was performed in general accordance with ASTM D 2850. A relatively undisturbed fine-grained sample was trimmed to a length of about 6 inches, encased in a rubber membrane, and placed in the triaxial cell. An all-around confining pressure was applied hydraulically, but the sample was not allowed to consolidate, and no back pressure was applied. An axial load was then applied at a constant strain rate to the sample without allowing drainage from the specimen. The stress-strain behavior was recorded until failure occurred.

The failure stress was generally taken as the maximum load on the sample or the load recorded at 20 percent strain, whichever was greater. The test results plotted in terms of axial strain versus deviator stress are presented on Figures R-35 and R-36. The shear strength is considered to be one-half the maximum stress difference based on the $\phi = 0$ concept and a total stress analysis.

Permeability Tests. Our laboratory determined the permeability for two samples via flexible-wall permeability tests, in accordance with ASTM D 5084-90. The flexible-wall permeability test involves measuring the rate of flow through a cylindrical sample which has been consolidated under a given pressure. The sample is wrapped in a flexible, impermeable membrane and consolidates under the controlled pressure of a surrounding fluid medium. The top and bottom of the sample are connected to porous stones and hydraulic lines which provide routes for inflow and outflow. A gradient is imposed on the sample by controlling the pressures in these lines, and the volume of the outflow is measured over a given time period. This allows the sample's permeability to be calculated.

In addition, the permeability was determined for two resettled samples from the Thea Foss Waterway using fixed-wall permeability tests, in general accordance with ASTM D 2434-68. The fixed-wall permeability test involves measuring the rate of flow through a cylindrical sample which is held in a rigid cylinder. The top and bottom of the sample are connected to porous stones and hydraulic lines which provide routes for inflow and outflow. A column of water is added on the top of the sample, and the volume of the outflow is measured as water flows through the sample, reducing the head over a given time period. This test is also known as a "falling head" permeability test.

Test results are presented in Table R-1.

R.2 Supplemental Hydrogeologic Investigation

This section summarizes monitoring well installation procedures, groundwater and surface water field parameter measurements, and a 72-hour tidal monitoring study performed at the St. Paul Waterway. Field activities discussed in this section were completed between February 22 and March 8, 1999.

R.2.1 Groundwater Monitoring Well Installation and Development

Two monitoring wells (RD3-UMW9 and RD3-UMW10) were installed between February 22 and 27, 1999, by McDonald Drilling. Well borings were advanced using a truck-mounted hollow-stem auger drill rig. A Hart Crowser geologist observed the drilling and recorded the soil lithology and stratigraphy of the borings. RD3-UMW9 was drilled to a depth of 16 feet and completed with a screened interval of 6 to 16 feet below ground surface. RD3-UMW10, which was installed in boring HC-6, was drilled to a depth of 119.5 feet and completed with a screened interval of 89 to 99 feet below ground surface. The wells consist of 2-inch-diameter schedule 40 PVC riser, with 10 feet of 2-inch-diameter 20-slot screen and a 10/20 Colorado Silica sand pack. The wells were installed with flush-mount monuments and fitted with locking well caps.

Following monitoring well installation, the wells were developed using a submersible pump and/or stainless steel bailer to reduce turbidity and increase hydraulic connection with the surrounding aquifer. Turbidity in the discharge water was monitored during development. When the discharge water became clear, the pump head or bailer was moved up and down within the well casing to create a surging action and complete development.

R.2.2 Measurement of Field Parameters

Groundwater and surface water quality field parameters were measured by Hart Crowser at RD3-UMW5, RD3-UMW8, RD3-UMW9, RD3-UMW10, and in St. Paul Waterway on March 5, 1999. Electrical conductivity (EC), pH, temperature, and oxidation-reduction potential (eH) were measured using a YSI 3560 meter with a flow-through cell. Percent salinity and turbidity were measured using a Horiba U-10 Water Quality Checker.

Prior to measuring field parameters at each well, total well depth and depth to water were measured and recorded. This information was used to calculate the volume of water within the well casing. The well was then purged using a Whale submersible electric pump. A minimum of three casing volumes were purged, and purging continued until all field parameter measurements had stabilized (i.e.,

±10 percent between removal of successive casing volumes). Final, stable field parameter measurements are presented in Table R-2.

Salinity measurements in RD3-UMW5 and RD3-UMW10 were approximately 10 and 50 percent that of sea water, indicating some mixing between fresh water from the groundwater flow system and sea water from the adjacent waterways. Salinity measurements at RD3-UMW8 and RD3-UMW9 were essentially zero, indicating that sea water does not intrude inland to these wells. These measurements were consistent with salinities reported by Parametrix (1998).

R.2.3 Tidal Monitoring Study

To evaluate tidal effects on the groundwater flow system, a 72-hour tidal monitoring study was conducted between March 5 and 8, 1999. Pressure transducers with automated data loggers were used to monitor water levels in the waterway and in wells RD3-UMW5, RD3-UMW8, RD3-UMW9, and RD3-UMW10.

As the pressure transducers were installed at each of the monitoring locations, the time, depth to water, and head in feet above the transducer were recorded, so that transducer readings could later be converted to groundwater elevations. Water levels in the monitoring wells and in the St. Paul Waterway were measured and recorded electronically at 15-minute intervals by the data loggers during the study. Plots of data from the water level monitoring study are shown on Figure R-37.

Using 71 consecutive hourly water level measurements, the average water level elevation at each monitoring location was calculated using the method described by Serfes (1991). Table R-3 presents the minimum, maximum, and average water levels collected by Hart Crowser in March 1999, as well as water levels collected by Parametrix in September 1997.

Average water levels in the wells monitored during both studies (RD3-UMW5 and RD3-UMW8) were higher during the wet season (i.e., March) than during the dry season (i.e., September). Additionally, the seasonal change in water level was greater at RD3-UMW5, which is located in an unpaved area and is more sensitive to changes in precipitation.

Average water level elevations were corrected for salinity-induced density variations as described in Todd (1959) to calculate a fresh water equivalent head. Fresh water equivalent head is calculated by multiplying the height to which saline water would rises in a piezometer at the point of interest by a density correction term. Specifically,

$$h_f = \frac{\rho_s}{\rho_f} h_s - \frac{\rho_s - \rho_f}{\rho_f} Z$$

where:

h_f is the fresh water equivalent head;
ρ_s and ρ_f are the densities of the saline and fresh water, respectively;
h_s is the water level of the saline water; and
Z is the elevation of the measurement point with respect to a specified datum (e.g., MLLW).

R.3 Groundwater Flow Modeling Analysis

R.3.1 Site Hydrogeology

The location of the proposed St. Paul Waterway CDF site is shown on Figure 5-14. Net groundwater flow is toward the waterway from uplands areas. Groundwater flow in sediments adjacent to the waterway is periodically reversed due to tidal fluctuations. There is an assumed shallow groundwater divide to the east of the site, between St. Paul Waterway and the Puyallup River. A second shallow groundwater divide exists between Middle and St. Paul Waterways on the southwest side of the site. Deep groundwater flow is generally toward Commencement Bay. A more detailed discussion of site hydrogeology is presented in Section 5.3.

R.3.2 Pre-Construction Groundwater Flow Model Development

A three-dimensional numeric groundwater flow model simulating existing conditions in sediments adjacent to and underlying St. Paul Waterway was developed using the USGS MODFLOW code. The model was calibrated using the March 1999 water level data.

MODFLOW Groundwater Flow Model Description. The groundwater flow models used to simulate current and possible future conditions at the St. Paul Waterway were developed using the USGS MODFLOW code (McDonald and Harbaugh, 1988) with Waterloo Hydrogeologic's Visual MODFLOW pre- and post-processor. MODFLOW is a quasi-3-dimensional, block-centered finite difference code capable of simulating steady-state and transient groundwater flow in a range of aquifer types and configurations. A variety of features, such as time varying boundary conditions and heterogeneous aquifer hydraulic properties, are incorporated into MODFLOW by the use of different packages

or modules. In MODFLOW, the horizontal area of the aquifer to be modeled is discretized into a rectangular grid, which is further subdivided by vertical layers. The resulting 3-dimensional rectangular blocks are termed cells. Within each cell, aquifer properties such as hydraulic conductivity and storage are assigned a constant value. Heterogeneity is simulated by varying aquifer properties between cells. Typically, smaller cells are used in areas where greater detail is required and larger cells are used in areas where less detail is required.

Grid Design. Figure R-38 shows a plan view of the pre-construction model grid superimposed on a site map of the St. Paul Waterway. The model domain is 3,600 feet in the northwest-southeast direction and 1,800 feet in the northeast-southwest direction. Vertically the model extends from elevation 20 to -100 feet MLLW. The model is discretized into 65 rows, 128 columns, and 7 layers. Model cell sizes range from 20 by 20 feet within the CDF site to 50 by 50 feet in the southeastern upland areas and Commencement Bay.

Boundary Conditions. Hydrogeologic boundary conditions are shown on Figure R-38. The waterways and Commencement Bay are represented by inactive cells, except where they are in contact with the aquifer, where they are represented by constant head boundary conditions. The northeast and southwest sides of the model are bounded by no flow boundary conditions, representing the approximate locations of groundwater flow divides. The top layer of the southeast side of the model is bounded by a no flow condition, representing a shallow groundwater divide. The lower layers along the southeast side contain constant head boundaries. The bottom of the model contains constant head boundaries, with values based on water levels measured at RD3-UMW10. Recharge due to precipitation is applied to the top layer of the model.

Flow Model Calibration and Verification. Model calibration consists of systematically adjusting model input parameters, such as hydraulic conductivity, so that a given model output approaches some known set of values. In model verification, the calibrated model is run with a second set of data, and if it still reproduces field measurements it is considered verified. For this work, we first calibrated using a 24-hour set of tidal data and water level measurements from monitoring wells, then verified using a subsequent 48-hour set of tide and water level data.

The hydraulic parameters used in flow model calibration were K_x, K_z, S_s or S_y, recharge rate, and hydraulic head at the constant head boundaries. Initial estimates for conductivity were based on slug test results and laboratory measured permeabilities. Estimates of S_s ad S_y were taken from literature values and knowledge of site geology. The waterway constant head boundary values were taken from measured tide levels, adjusted for density. The constant head

boundary at the bottom layer of the model was based on the average water level measured in well RD3-UMW10. Recharge rates were based on total rainfall for the previous two months. Recharge in paved upland areas was initially assumed to be 10 percent of precipitation, while recharge on the unpaved peninsula was assumed to be 50 percent of precipitation. Table R-4 shows the initial estimated and measured hydraulic parameters used in the model.

The calibration targets for this model were hydraulic heads measured in monitoring wells RD3-UMW5, RD3-UMW8, and RD3-UMW9. The initial estimates for recharge, K_x, K_z, S_s, and Sy, as well as the upland constant head boundary conditions were varied until the root mean squared (RMS) error was minimized. The RMS error for a given observation point is expressed as

$$RMS = \left[1/n \sum_{i=1}^{n} (h_m - h_c)_i^2 \right]^{0.5}$$

where:

h_m is the field measured head;
h_c is the model calculated head; and
n is the number of measurements at the observation point.

The calibration data consisted of 24 hourly head measurements at each monitoring well measured on March 5 to 6, 1999. Verification data consisted of the next 48 hours of water level data. Figure R-39 shows the calculated and measured water levels in the monitoring wells for the entire 72-hour monitoring period, along with the associated RMS errors. Table R-5 shows the final calibrated input parameters for the groundwater flow model.

Flow Model Sensitivity Analysis. A sensitivity analysis was performed by individually varying model input parameters and evaluating their effects on model output. The RMS was calculated for each sensitivity run, and a percent change in RMS from the calibrated model was determined. The model was evaluated for its sensitivity to changes in recharge rate, as well as K_x, K_z, and storage. Table R-6 summarizes results of the sensitivity analysis. Model sensitivity is classified as low, moderate, or high depending on the percent change in RMS error from the calibrated model.

The model is primarily sensitive to decreases in the horizontal conductivity of the two Upland Fill units, and to changes in the recharge rate. The model is moderately sensitive to changes in the storage coefficient, vertical hydraulic conductivity, and increases in the horizontal conductivity in the fill on the

peninsula. The model is relatively insensitive to changes in the horizontal conductivity of the Deltaic/Marine unit and to increases in the horizontal conductivity of the fill in the east and south areas of the model.

R.3.3 Post-Construction Groundwater Flow Model Development

The following sections discuss the development and results of the post-construction groundwater flow model at the St. Paul Waterway CDF site. The calibrated pre-construction flow model was modified to represent likely post-construction conditions. The post-construction model was run to determine the expected water levels within the CDF.

Model Modifications and Assumptions. For this evaluation it was assumed that construction at the site will consist of excavating existing sediments to an elevation of approximately -80 feet MLLW, and filling with sediments from Thea Foss Waterway to an elevation of 9 feet MLLW. The site will be capped with a further 9 feet of clean fill. A berm will be constructed at the mouth of the waterway. The base of the berm will consist of dredged St. Paul Waterway sediments, while the top of the berm will be constructed using structural fill material. The seaward face of the berm will be covered with habitat fill, again derived from St. Paul Waterway sediments. A more detailed discussion of construction activities is presented in Section 4.0.

Tidal channel habitat restoration work in the Middle Waterway will also alter the existing conditions at the site. A portion of the peninsula between Middle and St. Paul Waterways is expected to be removed from the Middle Waterway side. Most of the post-construction land surface elevation in the restoration area will be between elevation -2 and 5 feet (MLLW).

Changes made to the flow model to simulate the post-construction conditions consist of the following:

- Replacing Recent and Deltaic/Marine deposits in the waterway with Thea Foss Waterway sediments to an elevation of -80 feet MLLW. A 2H:1V slope for the dredge prism walls was assumed. Based on permeability tests, a horizontal and vertical conductivity of 1 and 0.01 ft/day (3.4×10^{-4} and 3.4×10^{-6} cm/sec), respectively, was assigned to the Thea Foss Waterway sediments.

- Constructing the lower portion of the berm with a 6H:1V slope on the inland side and a 12H:1V slope for the habitat fill on the seaward side. Hydraulic parameters for the lower berm and habitat fill were based on

values for St. Paul Waterway Marine/Deltaic sediments from the calibrated pre-construction flow model.

- Constructing the upper portion of the berm with a 2H:1V slope using structural fill. Fill material was assumed to be a fine to medium sand, with a horizontal hydraulic conductivity of 28 ft/day (0.01 cm/sec).

- Moving waterway and Commencement Bay constant head boundary conditions to coincide with the new shoreline. St. Paul Waterway boundary conditions were moved north, into Commencement Bay. The Middle Waterway boundary condition along the southwestern edge of the peninsula was moved inland to reflect the planned tidal channel habitat restoration work.

- The recharge rate for the filled areas of the waterway was assumed to be equal to the calibrated recharge rate in other paved upland areas.

Other hydrogeologic conditions were assumed to be unaffected by the changes discussed above. Figure R-40 shows, in plan view, the post-construction hydraulic conductivity distribution and boundary conditions at the site.

Post-Construction Flow Model Results. The post-construction flow model was run under steady-state conditions to evaluate average water levels within the CDF. Figure R-41 shows predicted steady-state water table elevations. Water levels within the CDF range from 9.1 feet near the edge of the berm to over 13 feet along the inland edge.

To evaluate tidal response in the CDF, the post-construction model was run under transient conditions with tidally varying constant head boundary conditions along the shoreline. Figure R-42 shows the tide elevation specified at the boundary and the resultant response in the fill at the edge of the berm and in the southwest corner of the CDF, near the narrowest section of the peninsula. At both locations, tidal response in the fill is minimal and water level elevations remain above 9 feet MLLW.

R.4 Groundwater Transport Analysis

Two cross sectional groundwater flow and transport models were developed to evaluate the potential for contaminant movement to Middle Waterway and Commencement Bay. Contaminant transport of five constituents was simulated at each cross sectional model. The constituents considered were copper, lead, mercury, zinc, and benzo(a)anthracene. This section discusses model development, assumptions, and results for the contaminant transport models.

R.4.1 MT3D Contaminant Transport Model Description

Groundwater contaminant transport at St. Paul Waterway was simulated using the MT3DMS computer code (Zheng and Wang, 1998), an extension of the MT3D code (Zheng, 1990). MT3DMS is a 3-dimensional solute transport model capable of simulating advection, dispersion, and chemical reactions in groundwater flow. It is designed to be used in conjunction with a finite difference flow model, such as MODFLOW. The procedure is to first determine the groundwater flow field using MODFLOW. Then MT3DMS simulates solute transport by tracking particles representing the solute plume through the flow field. Features such as dispersion and chemical reactions can be turned on or off as the situation requires. Different values for the parameters defining the dispersion and reaction terms in the model can be assigned to different model regions, allowing simulation of heterogeneous physical and chemical conditions. The contaminant transport model assumes that any changes in solute concentration have minimal effects on fluid density and therefore do not alter the flow field.

R.4.2 Development of Cross Sectional Models

Two cross sectional groundwater flow and contaminant transport models were developed. One model simulates conditions along a flow path through the containment berm at the mouth of the waterway, and the other model simulates conditions along a flow path through the peninsula between Middle and St. Paul Waterways.

Flow Path Determination. The location of the two cross sectional models was determined by performing a particle tracking analysis with the post-construction model to determine groundwater flow paths out of the CDF. Particles were placed along the outer edge of the fill and tracked forward in time to determine the shortest flow paths across the berm and through the peninsula. These flow paths are shown on Figure R-41 as Cross Sections A-A′ and B-B′. The two cross sectional transport models were constructed along these two flow paths.

Model Grid Design and Hydraulic Parameters. Figures R-43 and R-44 show model grid designs, hydraulic boundary conditions, and hydraulic conductivity distributions for Cross Sections A-A′ and B-B′. The model domain at Cross Section A-A′ is 1,000 feet long by 120 feet deep and is discretized into 67 columns and 10 layers. Cell sizes range from 2 feet wide by 5 feet high in the seaward side of the berm to 20 feet wide by 20 feet high further away from the berm face. Constant head boundary conditions along the bottom and

upgradient edges of the model were taken from the post-construction groundwater flow model.

The model domain at Cross Section B-B′ is 1,000 feet long by 120 feet deep and is discretized into 71 columns and 9 layers. Cell sizes range from 2 feet wide by 5 feet high along the seaward edge of the peninsula to 20 feet wide by 20 feet high. Constant head boundary conditions are based on head values from the post-construction groundwater flow model.

Effective Dispersivity Analysis. The periodic reversal of groundwater flow direction in sediments adjacent to the waterways and bay due to changing tide elevations effectively acts to increase the dispersion of contaminants by mixing with surface water and increasing the flow path length. Running a contaminant transport model for a series of constituents with a tidally varying head would be computationally inefficient. Instead, we determined an effective dispersivity for the transport models, such that the solute distribution predicted using a steady-state flow field with the effective dispersivity matched the solute distribution produced using a transient, tidally varying flow field. The procedure used in determining the effective dispersivity is outlined in the remainder of this section.

Each cross sectional model was run for a period of 2,500 days using a tidally varying flow field. Cells representing the waterways were assigned a constant concentration of zero. Cells representing the contaminated fill material were assigned a constant concentration of 1.0. A small dispersivity of 2 feet was assigned to the entire model. The concentration distribution at the end of this period was recorded. Each cross sectional model was then run again for a period of 2,500 days using a steady-state flow field. Dispersivity values were changed until the concentration output of the steady-state model matched that of the tidally varying model, as shown on Figures R-45 and R-46.

This procedure resulted in an effective dispersivity of 12 feet, extending 80 feet inland from the shoreline, at Cross Section A-A′. The dispersivity for the rest of the model remained at 2 feet. An effective dispersivity of 7 feet, extending 23 feet inland from the shoreline, was determined for Cross Section B-B′. The dispersivity for the rest of the model remained at 2 feet.

Salinity Distribution Analysis. Chemical partitioning coefficients (K_ds) are dependent in part on groundwater salinity. Therefore, to simulate transport of chemically reactive constituents, we needed to predict the post-construction salinity distribution. We ran the two cross sectional models using the effective dispersivities determined previously to estimate the salinity distribution in groundwater. Cells representing the waterways were assigned a constant relative concentration of 1.0, indicating pure sea water. The models were then

run until the groundwater concentration distributions approached steady-state conditions. Results of these models at Cross Sections A-A′ and B-B′ are shown on Figures R-47 and R-48, respectively. The inland migration of saline water was relatively minor. Relative salinity values decreased below 0.5 within approximately 10 feet horizontally and 20 feet vertically from the waterways at Cross Sections A-A′ and B-B′. It is important to note that this model does not account for density effects of salinity on groundwater flow, which would tend to extend the saline zone deeper and further inland.

Partitioning Coefficients. Partitioning coefficients used in these analyses are presented in Table R-7. Partitioning coefficients for metals were assigned based on the salinity distribution and degree of water level fluctuation in unconfined portions of the aquifer. In areas where the salinity was greater than or equal to 0.5 times sea water, or unconfined water level fluctuations were greater than 1 foot, it was assumed that relatively oxidizing conditions exist. In these cases the oxic K_ds from the BET analyses were used. Where the salinity was less than 0.5 times sea water, and unconfined water level fluctuations were less than 1 foot, the freshwater K_d was used.

Partitioning coefficients for benzo(a)anthracene were assigned based on salinity. However, they were also adjusted to reflect the lower organic carbon content of the berm materials. The Thea Foss Waterway dredge material, the St. Paul Waterway dredge material, and the structural fill materials have different organic carbon contents. As a result, there are four distinct zones with different K_ds for benzo(a)anthracene: freshwater Thea Foss fill; freshwater select fill; freshwater St. Paul berm material; and saltwater St. Paul berm material. These K_ds are presented in Table R-7.

Constant Concentration Boundaries. As fresh groundwater flushes saline water out of the fill material, the contaminant concentration leaving the fill will vary with time. This concentration variability will have a direct impact on groundwater concentrations entering the waterway either through the berm or across the peninsula.

The concentration in the fill material was modeled using time varying constant concentration boundary conditions. The concentration values assigned to the boundary conditions were based on the TCLT results. The TCLT analyses report effluent contaminant concentration in terms of number of pore volumes flushed through the column. Using particle tracking we determined the time required to flush one pore volume along each flow path. We then used these pore volume times to convert the TCLT data into fill effluent concentrations at given times, which were assigned to the constant concentration boundaries.

Figures R-49 and R-50 show the constant concentration boundary concentrations used for the four modeled constituents for Cross Sections A-A' and B-B', respectively.

Transport Model Sensitivity Analysis. Sensitivity analyses were performed for the solute transport models to determine the effects of changes in the input parameters on discharge concentrations to the waterway and Commencement Bay. Input parameters evaluated for model sensitivity were:

- Partitioning coefficient;
- Effective porosity;
- Dispersivity; and
- Time to flush one pore volume through the given cross section.

The model was run twice for each input parameter under consideration - once using twice the initial value, and once using one half the initial value. Each parameter that was considered was changed uniformly throughout the model, while all other parameters were held at their initial values.

Tables R-9 and R-10 summarize sensitivity analysis results at Cross Sections A-A' and B-B', respectively. All constituents show essentially no sensitivity to effective porosity. Overall the models show similar levels of sensitivity to partitioning coefficient, dispersivity, and pore volume flushing time. Increases in the partitioning coefficient or dispersivity resulted in decreases in peak concentration, while decreases in these parameters resulted in increased concentration. Increases in pore volume flushing time resulted in increased concentration, and decreases in flushing time resulted in decreased concentration.

R.4.3 Contaminant Transport Analysis Results

Each cross sectional model was run for the equivalent of 40 pore volumes, or 730 and 410 years at Cross Sections A-A' and B-B', respectively. Figures R-51 and R-52 present predicted contaminant concentration versus time in the model cells adjacent to the waterway showing the highest peak concentration. Table R-8 shows the peak breakthrough time and concentrations for Cross Sections A-A' and B-B'. Figures R-53 through R-62 show the concentration distribution for each constituent at the peak breakthrough time.

At Cross Section A-A', zinc concentrations remain below applicable surface water quality criteria (WQC) at all times. Lead concentrations exceed the chronic marine water quality standards beginning at approximately 540 years, with a peak concentration of 12.9 μg/L (1.6 times the WQC) at 750 years.

Mercury concentrations exceed the standards beginning at approximately 550 years, with a peak concentration of 0.049 µg/L (2 times the WQC) at 860 years. Copper begins to exceed water quality standards at about 1,400 years and continues to gradually rise past 2,000 years when it has a value of 3.5 µg/L (1.1 times the WQC). Because the K_ds for the organic constituents are two to three orders of magnitude greater than those for the metals, the leading edge of the benzo(a)anthracene plume does not reach the waterway within the modeled time period and is not shown on Figure R-51.

At Cross Section B-B', the concentrations of the four metals remain below applicable surface water quality criteria at all times. As was the case at Cross Section A-A', the leading edge of the benzo(a)anthracene plume does not reach the waterway within the modeled time period and is not shown on Figure R-52.

R.5 References for Appendix R

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Parametrix and Anchor Environmental, 1998. Technical Memorandum, Physical/Chemical Characterization Data, St. Paul Peninsula Environmental Improvement and Industrial Redevelopment Project. April 1998.

Serfes, M.E., 1991. Determining Mean Hydraulic Gradient of Groundwater Affected by Tidal Fluctuations. Ground Water. V. 29, No. 4, July-August, 1991.

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Zheng, C., 1990. MT3D, A Modular Three-Dimensional Transport Model for Simulation of Advection, Dispersion, and Chemical Reactions of Contaminants in Groundwater Systems, Report to the Kerr Environmental Research Laboratory, US Environmental Protection Agency, Ada, OK.

Zheng, C. and P.P. Wang, 1998. MT3DMS, A Modular Three-Dimensional Transport Model, Technical Report, US Army Corps of Engineers Waterways Experiment Station, Vicksburg, Miss.

407225/Round3/AppendixR.doc

Table R-1 - Results of Permeability Tests

Flexible-Wall Permeability Tests

Sample	Depth in Feet	Confining Pressure in psi	Permeability in cm/sec
HC-4, S-18	88 - 90.5	33	3.8×10^{-7}
HC-6, S-17	60 - 62	27	1.7×10^{-5}

Fixed-Wall Permeability Tests

Sample	Initial Water Content in %	Permeability in cm/sec
LC-01/12-S.1	127	7.0×10^{-3}
LC-01/12-S.2	122	4.4×10^{-3}

407225/Round3/AppendixR.doc

Table R-2 - St. Paul Waterway Tidal Study - Field Parameters

Location	Salinity in ppt	Conductivity in mS/cm	Temperature in ° Celcius	pH	Redox in mV
RD3-UMW5	2.6	4.98	11.8	7.3	140
RD3-UMW8	0.2	0.511	12.6	6.3	210
RD3-UMW9	0.3	0.79	12.7	6.4	190
RD3-UMW10	14.3	22.6	12.6	7.5	20
Waterway	26.5	42.2	9.3	8.2	280

407225/Round3/AppendixR.xls - Table R-2

Table R-3 - Minimum, Maximum, and Average Calculated Groundwater and Tide Elevations
St. Paul Waterway Tidal Studies

	September 14 to September 17, 1997			March 5 to March 8, 1999		
	Head in Feet above MLLW			Head in Feet above MLLW		
Well	Minimum	Maximum	Average	Minimum	Maximum	Average
RD3-UMW5	8.49	9.36	9.01	9.98	10.72	10.28
RD3-UMW6	8.84	8.98	8.94	NM	NM	NM
RD3-UMW7	9.01	9.08	9.07	NM	NM	NM
RD3-UMW8	9.39	11.21	10.31	10.54	10.84	10.68
RD3-UMW9	NM	NM	NM	10.14	10.79	10.41
RD3-UMW10	NM	NM	NM	8.92	11.29	10.16
Waterway	0.37	~12.5	~ 7.5	2.48	11.97	7.44

Notes:
NM - Not measured
1997 data collected and reported by Anchor Environmental and Parametrix (1998)
1999 data collected by Hart Crowser

Table R-4 - Initial Estimated Hydraulic Parameters

Geologic Unit	Horizontal Hydraulic Conductivity in ft/day	Vertical Hydraulic Conductivity in ft/day	Storage Coefficient	Recharge in inches/month
Uplands Fill (1)	28	2.8	0.1	0.6
Uplands Fill (2)	14	1.4	0.1	3
Deltaic/Marine	2.8	0.28	0.0001	NA
Recent Sediments	0.01	0.001	0.001	NA

407225/Round3/AppendixR.xls - Table R-4

Table R-5 - Calibrated Groundwater Flow Model Input Parameters

Geologic Unit	Horizontal Hydraulic Conductivity in ft/day	Vertical Hydraulic Conductivity in ft/day	Storage Coefficient	Recharge in inches/month
Uplands Fill (1)	28	2.8	0.01	1.25
Uplands Fill (2)	14	1.4	0.01	6
Deltaic/Marine	2.8	0.28	0.0001	NA
Recent Sediments	0.01	0.001	0.001	NA

(1) Fill unit at east and south portions of model.
(2) Fill unit on peninsula between St. Paul and Middle Waterways.
NA: Not applicable.

407225/Round3/AppendixR.xls - Table R-5

Table R-6 - Sensitivity Analysis Results for Groundwater Flow Model

Hydrogeologic Unit	Parameter	Units	Calibrated Value	Value Used for Sensitivity Analysis	Percent Change in RMS Error	Sensitivity
Upland (1)	K_x	ft/day	28	140	-67 to 53	Low
				5.6	3 to 565	High
	K_z	ft/day	2.8	14	-24 to 249	Moderate
				0.56	-30 to 242	Moderate
	S_y	–	0.01	0.05	1 to 160	Moderate
	Recharge	in/month	1.25	0.625	191 to 900	High
Upland (2)	K_x	ft/day	21	105	0 to 315	Moderate
				4.2	1 to 500	High
	K_z	ft/day	1.4	7	3 to 158	Moderate
				0.28	-1 to 121	Moderate
	S_y	–	0.01	0.05	1 to 210	Moderate
	Recharge	in/month	6	3	191 to 900	High
Deltaic/Marine	K_x	ft/day	2.8	14	-5 to 89	Low
				0.56	3 to 95	Low
	K_z	ft/day	0.028	0.14	56 to 431	Moderate
				0.0056	-2 to 144	Moderate

407225/Round3/AppendixR.xls - Table R-6

Table R-7 - Contaminant Transport Model K_d Values

Constituent	Location and K_d in L/Kg					
	Oxic Conditions	Anoxic Conditions	Saline St. Paul Berm	Freshwater St Paul Berm	Freshwater Structural Berm	Freshwater Thea Foss Fill
Metals			NA	NA	NA	NA
Copper	2,240	10	NA	NA	NA	NA
Lead	49	7	NA	NA	NA	NA
Mercury	575	6	NA	NA	NA	NA
Zinc	18,000	10	NA	NA	NA	NA
Organics						
Benzo(a)anthracene	NA	NA	17,686	4,861	1,870	11,217

NA - K_ds for these locations are not applicable for the given constituent.

Table R-8 - Comparison of Peak Breakthrough Concentrations to Water Quality Screening Criteria

Constituent	Surface Water Screening Criteria in µg/L	Cross Section A-A' Time of Peak in Years (1)	Cross Section A-A' Concentration of Peak in µg/L (1)	Cross Section B-B' Time of Peak in Years (1)	Cross Section B-B' Concentration of Peak in µg/L (1)
Metals					
Copper	3.1	>2,000	3.5	>2,000	0.094
Lead	8.1	750	12.9	320	4.6
Mercury	0.025	860	0.049	1610	0.0137
Zinc	81	>2,000	1.2	>2,000	0.00012
Organics					
Benzo(a)anthracene	0.031	>2,000	<0.001 (2)	>2,000	<0.001 (2)

Notes:
(1) >2,000 indicates peak concentration has not been reached after 2,000 years. Reported concentration in this case is value at 2,000 years.
(2) <0.001 indicates leading edge of benzo(a)anthracene plume has not reached face of berm after 2,000 years.

Table R-9 - Sensitivity Analysis Results for Transport Model at Cross Section A-A'

Constituent	Base Case Peak Concentration in mg/L	Parameter Varied	Percent Change in Parameter	Percent Change in Peak Concentration	(Change in Concentration)/(Change in Parameter)
Benzo(a)anthracene	<0.001	Partitioning Coefficient	100	-90	-0.90
			-50	180	-3.60
		Effective Porosity	100	0	0.00
			-50	0	0.00
		Dispersivity	100	-6	-0.06
			-50	40	-0.80
		Pore Volume Time	100	0	0.00
			-50	0	0.00
Copper	3.5	Partitioning Coefficient	100	-61	-0.61
			-50	57	-1.15
		Effective Porosity	100	0	0.00
			-50	0	0.00
		Dispersivity	100	-38	-0.38
			-50	24	-0.47
		Pore Volume Time	100	53	0.53
			-50	-24	0.47
Lead	12.9	Partitioning Coefficient	100	-43	-0.43
			-50	44	-0.88
		Effective Porosity	100	0	0.00
			-50	0	0.00
		Dispersivity	100	-46	-0.46
			-50	58	-1.16
		Pore Volume Time	100	41	0.41
			-50	-37	0.74
Mercury	0.049	Partitioning Coefficient	100	-43	-0.43
			-50	60	-1.21
		Effective Porosity	100	0	0.00
			-50	0	0.00
		Dispersivity	100	-45	-0.45
			-50	47	-0.94
		Pore Volume Time	100	58	0.58
			-50	-41	0.81
Zinc	1.2	Partitioning Coefficient	100	-80	-0.80
			-50	129	-2.58
		Effective Porosity	100	0	0.00
			-50	0	0.00
		Dispersivity	100	-16	-0.16
			-50	-16	0.33
		Pore Volume Time	100	39	0.39
			-50	-22	0.44

407225/Round3/AppendixR.xls - Table R-9

Table R-10 - Sensitivity Analysis Results for Transport Model at Cross Section B-B'

Constituent	Base Case Peak Concentration in mg/L	Parameter Varied	Percent Change in Parameter	Percent Change in Peak Concentration	(Change in Concentration)/(Change in Parameter)
Benzo(a)anthracene	<0.001	Partitioning Coefficient	100	-96	-0.96
			-50	269	-5.39
		Effective Porosity	100	0	0.00
			-50	0	0.00
		Dispersivity	100	-100	-1.00
			-50	158	-3.17
		Pore Volume Time	100	0	0.00
			-50	0	0.00
Copper	0.094	Partitioning Coefficient	100	-99	-0.99
			-50	1428	-28.57
		Effective Porosity	100	0	0.00
			-50	0	0.00
		Dispersivity	100	33	0.33
			-50	-31	0.62
		Pore Volume Time	100	30	0.30
			-50	-25	0.49
Lead	4.6	Partitioning Coefficient	100	-16	-0.16
			-50	111	-2.21
		Effective Porosity	100	0	0.00
			-50	0	0.00
		Dispersivity	100	-45	-0.45
			-50	66	-1.33
		Pore Volume Time	100	150	1.50
			-50	-40	0.81
Mercury	0.014	Partitioning Coefficient	100	-57	-0.57
			-50	70	-1.40
		Effective Porosity	100	0	0.00
			-50	0	0.00
		Dispersivity	100	-44	-0.44
			-50	66	-1.32
		Pore Volume Time	100	187	1.87
			-50	-1	0.02
Zinc	0.00012	Partitioning Coefficient	100	-93	-0.93
			-50	1157	-23.15
		Effective Porosity	100	0	0.00
			-50	0	0.00
		Dispersivity	100	58	0.58
			-50	-11	0.22
		Pore Volume Time	100	20	0.20
			-50	-20	0.39

407225/Round3/AppendixR.xls -Table R-10

Key to Exploration Logs

Sample Description

Classification of soils in this report is based on visual field and laboratory observations which include density/consistency, moisture condition, grain size, and plasticity estimates and should not be construed to imply field nor laboratory testing unless presented herein. Visual-manual classification methods of ASTM D 2488 were used as an identification guide.

Soil descriptions consist of the following:
Density/consistency, moisture, color, minor constituents, MAJOR CONSTITUENT, additional remarks.

Density/Consistency

Soil density/consistency in borings is related primarily to the Standard Penetration Resistance.
Soil density/consistency in test pits is estimated based on visual observation and is presented parenthetically on the test pit logs.

SAND or GRAVEL Density	Standard Penetration Resistance (N) in Blows/Foot	SILT or CLAY Consistency	Standard Penetration Resistance (N) in Blows/Foot	Approximate Shear Strength in TSF
Very loose	0 – 4	Very soft	0 – 2	<0.125
Loose	4 – 10	Soft	2 – 4	0.125 – 0.25
Medium dense	10 – 30	Medium stiff	4 – 8	0.25 – 0.5
Dense	30 – 50	Stiff	8 – 15	0.5 – 1.0
Very dense	>50	Very stiff	15 – 30	1.0 – 2.0
		Hard	>30	>2.0

Moisture

Dry	Little perceptible moisture
Damp	Some perceptible moisture, probably below optimum
Moist	Probably near optimum moisture content
Wet	Much perceptible moisture, probably above optimum

Minor Constituents

	Estimated Percentage
Not identified in description	0 – 5
Slightly (clayey, silty, etc.)	5 – 12
Clayey, silty, sandy, gravelly	12 – 30
Very (clayey, silty, etc.)	30 – 50

Legends

Sampling Test Symbols

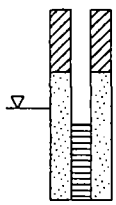
BORING SAMPLES

- ☒ Split Spoon
- ⧅ Shelby Tube
- ▥ Cuttings
- ◫ Core Run
- * No Sample Recovery
- P Tube Pushed, Not Driven

TEST PIT SAMPLES

- ☒ Grab (Jar)
- ⧄ Bag
- ⧅ Shelby Tube

Groundwater Observations



Surface Seal

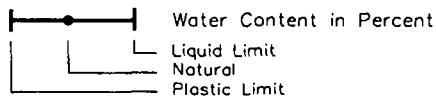
Groundwater Level on Date (ATD) At Time of Drilling

Observation Well Tip or Slotted Section

Groundwater Seepage (Test Pits)

Test Symbols

NS	No Sheen
SS	Slight Sheen
MS	Moderate Sheen
HS	Heavy Sheen
TCD	Triaxial Consolidated Drained
QU	Unconfined Compression
DS	Direct Shear
K	Permeability
PP	Pocket Penetrometer Approximate Compressive Strength in TSF
TV	Torvane Approximate Shear Strength in TSF
CBR	California Bearing Ratio
MD	Moisture Density Relationship
AL	Atterberg Limits
PID	Photoionization Detector Reading
CA	Chemical Analysis
DT	In Situ Density Test



HARTCROWSER

J-4072-25 6/99

Figure R-1

BORING.DWG

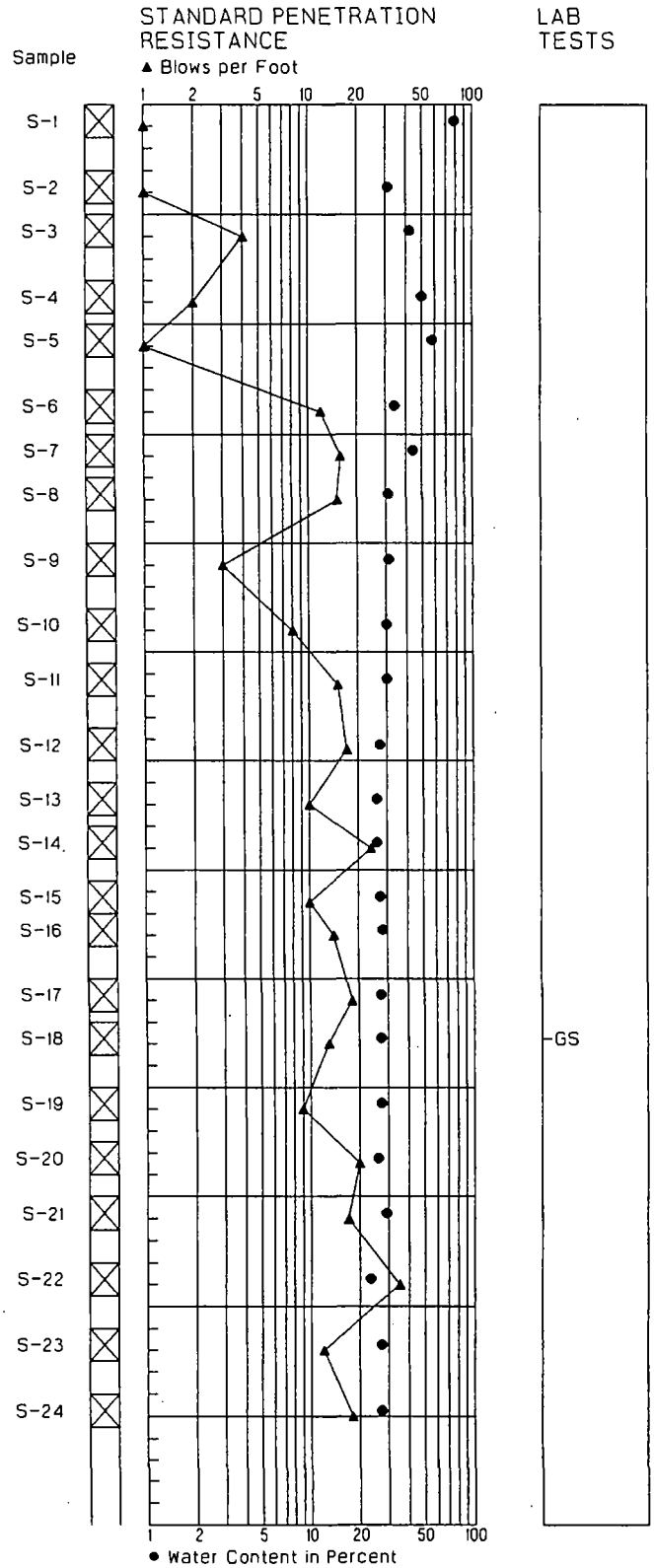
1=1

Boring Log HC-1

Soil Descriptions

Ground Surface Elevation in Feet: -23.0

Soil Description	Depth in Feet
Very soft, wet, black, sandy SILT with organics.	0
Very loose, wet, black, silty SAND with thin interbedded layers of very soft to soft, sandy SILT and SILT.	5, 10
Medium dense, wet, black, non-silty to silty SAND with scattered organics.	15
Soft to medium stiff, wet, dark gray, slightly clayey SILT.	20
Grades to very stiff.	25
Medium dense, wet, dark gray, silty SAND.	30, 35, 40
Medium dense, wet, black, very silty SAND with interbedded layers of stiff, very sandy SILT.	45
Medium dense to dense, wet, black, slightly silty SAND.	50
Stiff to very stiff, wet, black, sandy to very sandy SILT.	55
Bottom of Boring at 60.5 Feet. Completed 2/28/99.	60, 65



1. Refer to Figure R-1 for explanation of descriptions and symbols.
2. Soil descriptions and stratum lines are interpretive and actual changes may be gradual.
3. Groundwater level, if indicated, is at time of drilling (ATD) or for date specified. Level may vary with time.

HARTCROWSER

J-4072-25 2/99

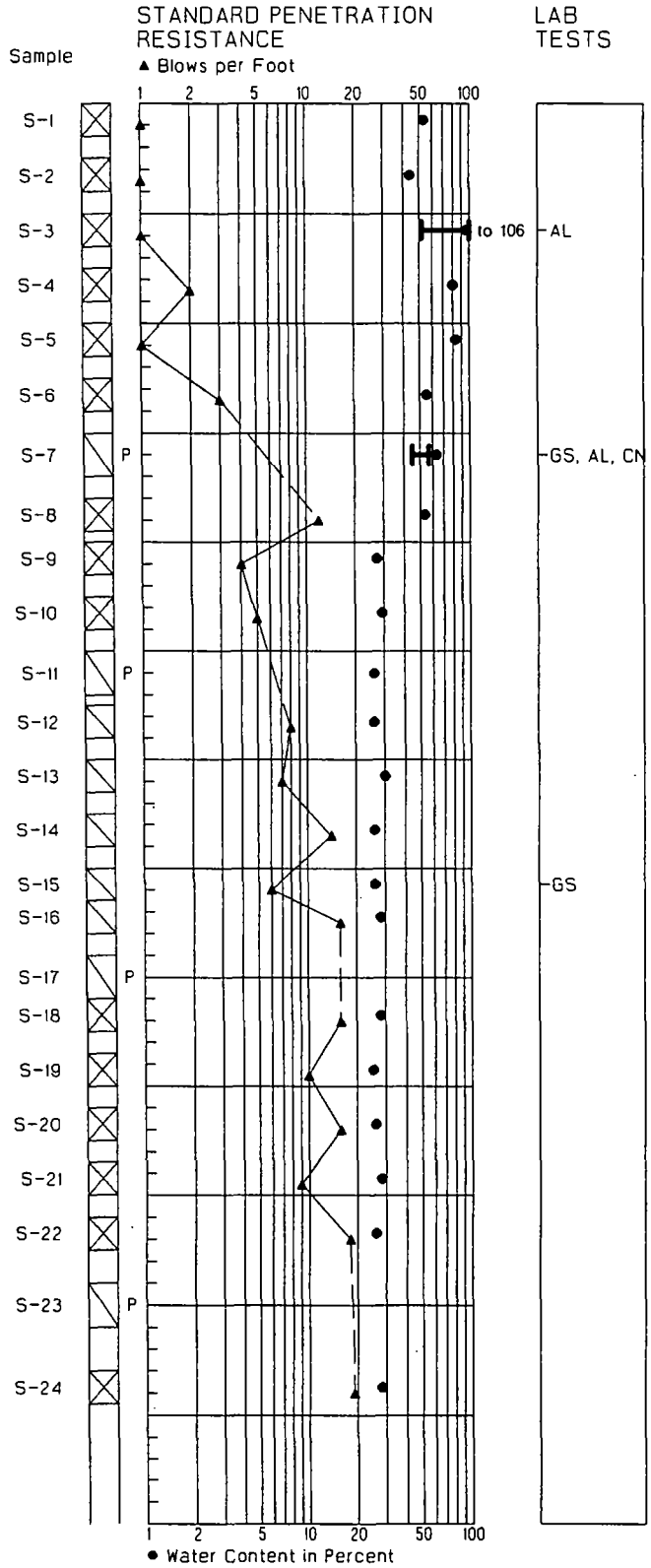
Figure R-2

Boring Log HC-2

Soil Descriptions

Ground Surface Elevation in Feet: -17.2

Soil Description	Depth in Feet
Very loose, wet, black SAND.	0
Very soft, wet, brown, slightly sandy, clayey SILT with organics.	5, 10
Soft, wet, brown, clayey, sandy SILT with organics.	15
Medium dense to loose, wet, black SAND.	20
Medium stiff, wet, dark gray, sandy SILT.	25
Loose to medium dense, wet, dark gray, silty, fine SAND with interbedded layers of medium stiff to stiff, very sandy SILT.	30, 35
Medium dense, wet, black SAND.	40
Thin interbedded layers of SILT.	45
Medium dense, wet, black, silty SAND.	50, 55
Bottom of Boring at 59.5 Feet. Completed 2/25/99.	60, 65



1. Refer to Figure R-1 for explanation of descriptions and symbols.
2. Soil descriptions and stratum lines are interpretive and actual changes may be gradual.
3. Groundwater level, if indicated, is at time of drilling (ATD) or for date specified. Level may vary with time.

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Figure R-3

Boring Log HC-3

Soil Descriptions

Ground Surface Elevation in Feet: -23.3

Loose, wet, black SAND with scattered wood.

Grades to medium dense.

Soft, wet, dark gray, slightly sandy, clayey SILT with scattered wood.

Loose wet, black, silty SAND with scattered wood.

Grades to medium dense.

Grades to soft, slightly, clayey, sandy SILT.

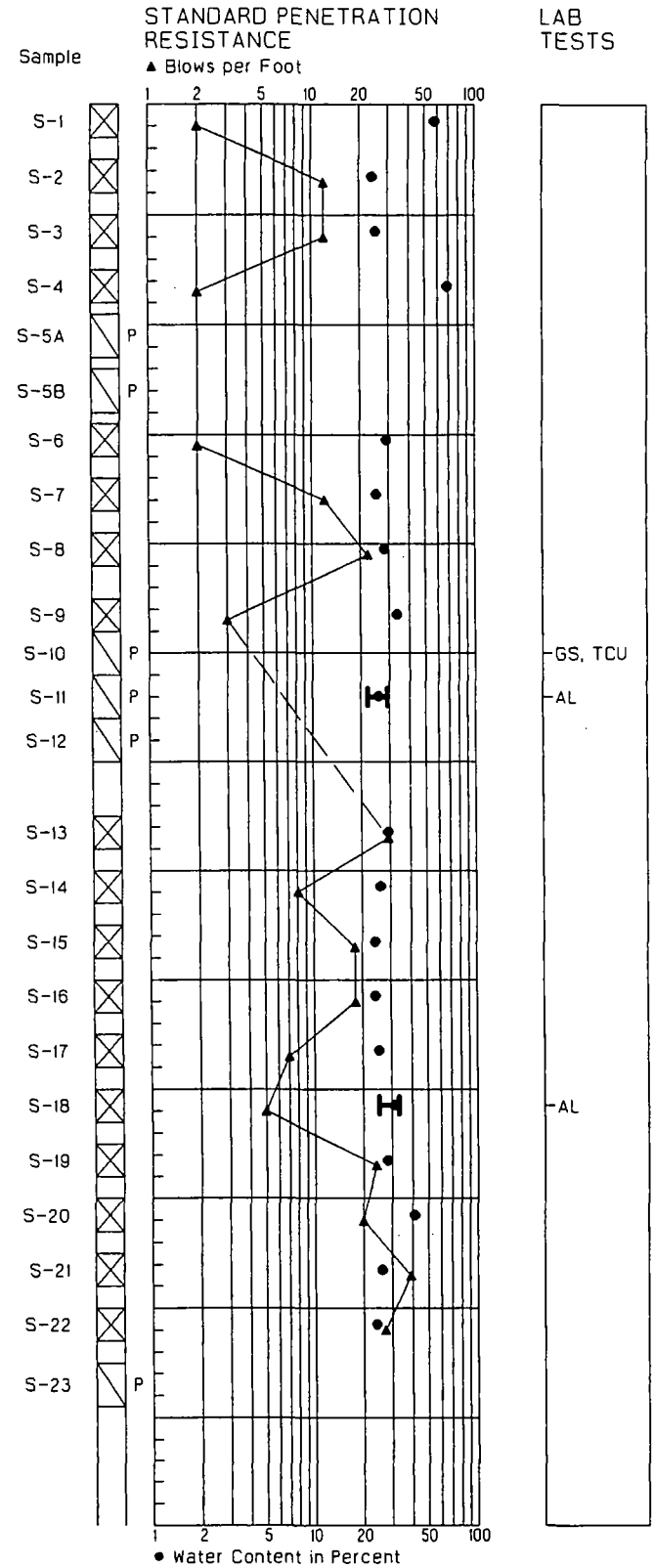
Medium dense, wet, black, silty SAND.

Loose, wet, black, very silty SAND.

Medium stiff, wet, black, sandy SILT.

Medium dense to dense, wet, black, very silty SAND.

Bottom of Boring at 59.5 Feet.
Completed 2/23/99.



1. Refer to Figure R-1 for explanation of descriptions and symbols.
2. Soil descriptions and stratum lines are interpretive and actual changes may be gradual.
3. Groundwater level, if indicated, is at time of drilling (ATD) or for date specified. Level may vary with time.

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Figure R-4

Boring Log HC-4

Soil Descriptions

Ground Surface Elevation in Feet: 18.5

Medium dense, wet, black SAND with trace silt.

Grades to very silty.

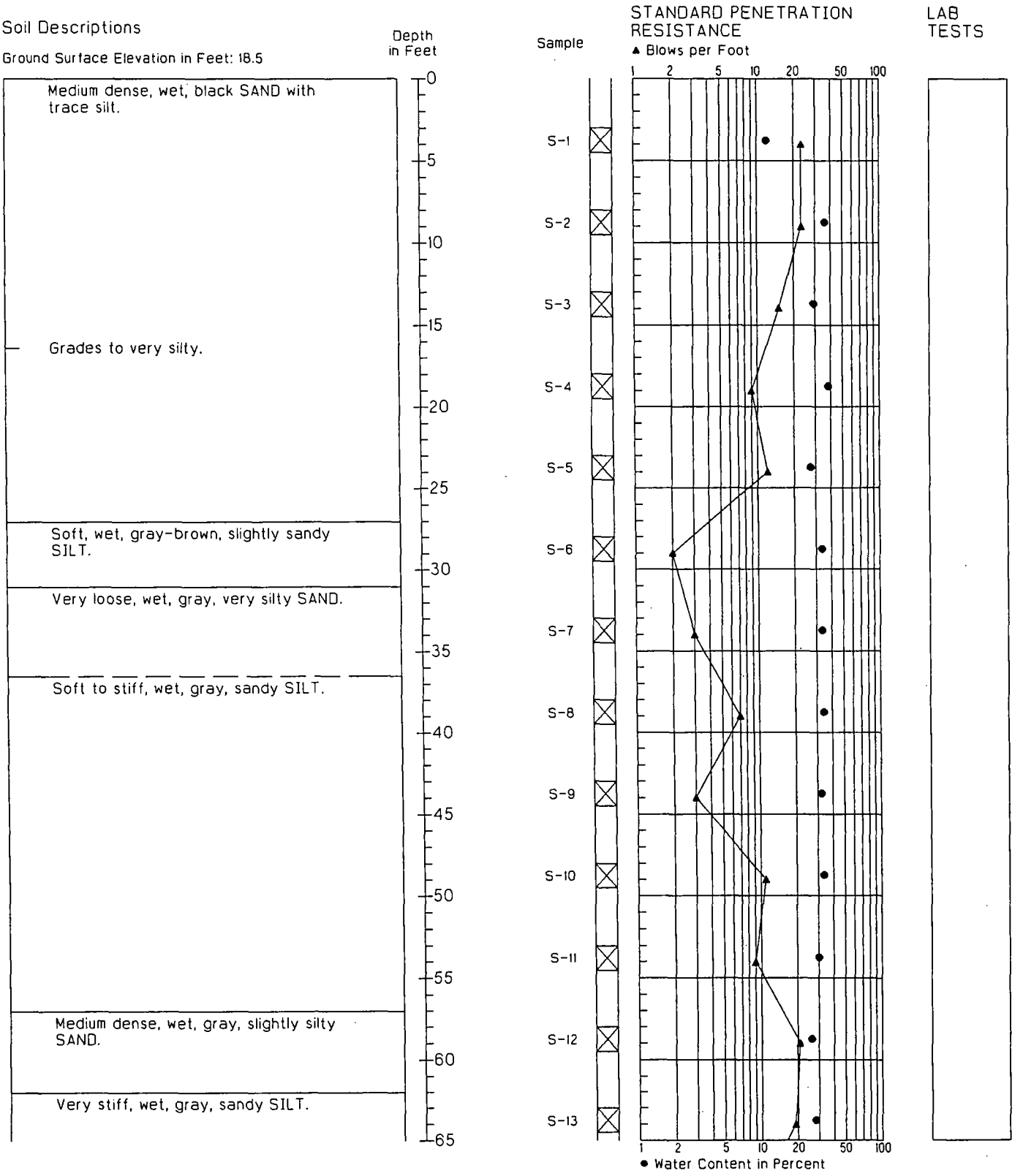
Soft, wet, gray-brown, slightly sandy SILT.

Very loose, wet, gray, very silty SAND.

Soft to stiff, wet, gray, sandy SILT.

Medium dense, wet, gray, slightly silty SAND.

Very stiff, wet, gray, sandy SILT.



1. Refer to Figure R-1 for explanation of descriptions and symbols.
2. Soil descriptions and stratum lines are interpretive and actual changes may be gradual.
3. Groundwater level, if indicated, is at time of drilling (ATD) or for date specified. Level may vary with time.

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Figure R-5 1/2

Boring Log HC-4

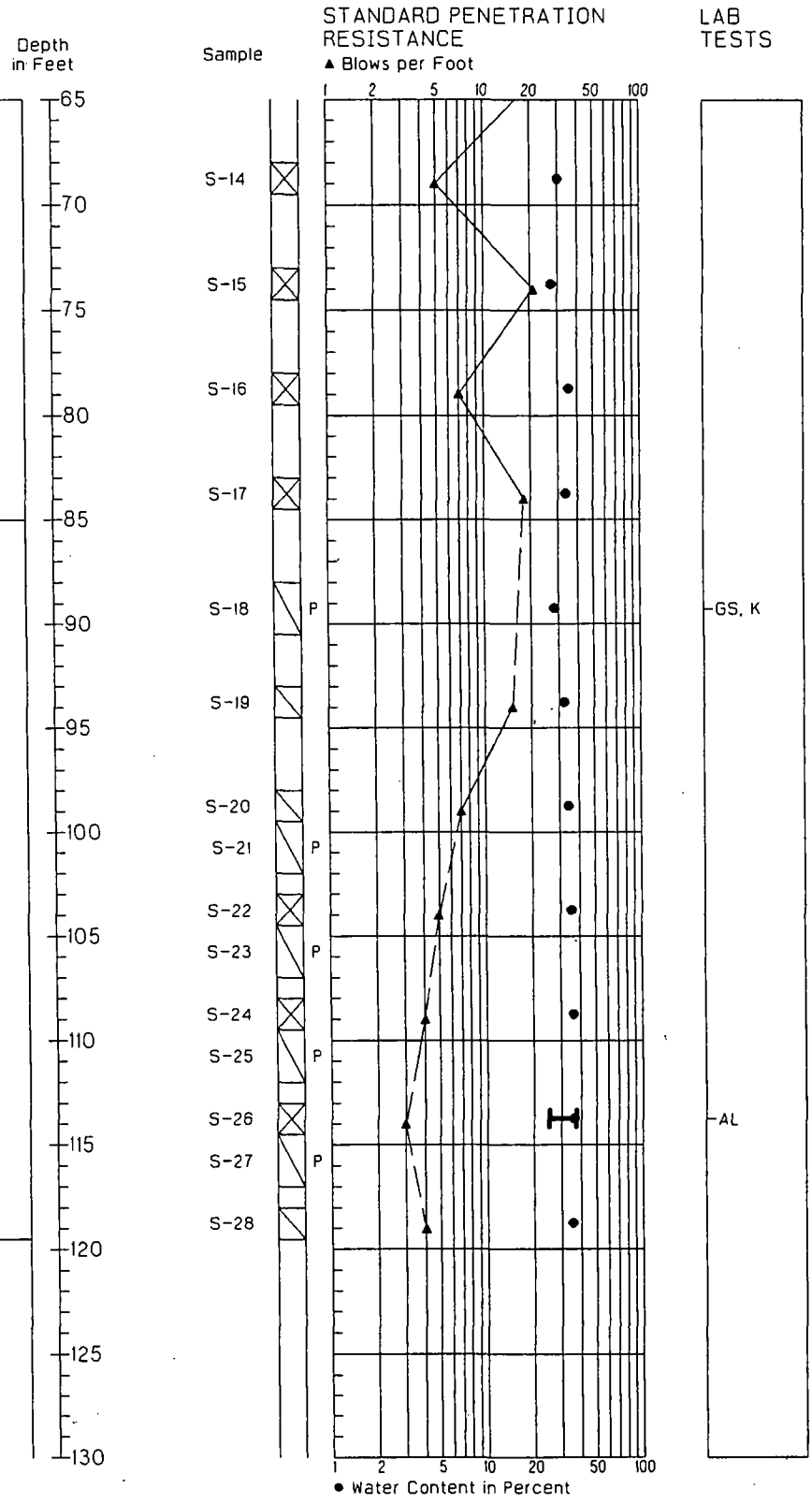
Soil Descriptions

Ground Surface Elevation in Feet: 18.5

Loose to medium dense, wet, gray, slightly silty to silty SAND with scattered organics.

Soft to stiff, wet, gray, slightly sandy to sandy, clayey SILT with interbedded layers of silty SAND.

Bottom of Boring at 119.5 Feet. Completed 2/19/99.



1. Refer to Figure R-1 for explanation of descriptions and symbols.
2. Soil descriptions and stratum lines are interpretive and actual changes may be gradual.
3. Groundwater level, if indicated, is at time of drilling (ATD) or for date specified. Level may vary with time.

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Figure R-5 2/2

Boring Log HC-5

Soil Descriptions

Ground Surface Elevation in Feet: 17.3

5 inches of Asphalt.

Slightly sandy GRAVEL.

Loose, moist, dark gray SAND.

Wood debris from 8 to 16 feet depth. S-2 blowcount may be artificially increased.

Soft, wet, light gray SILT.

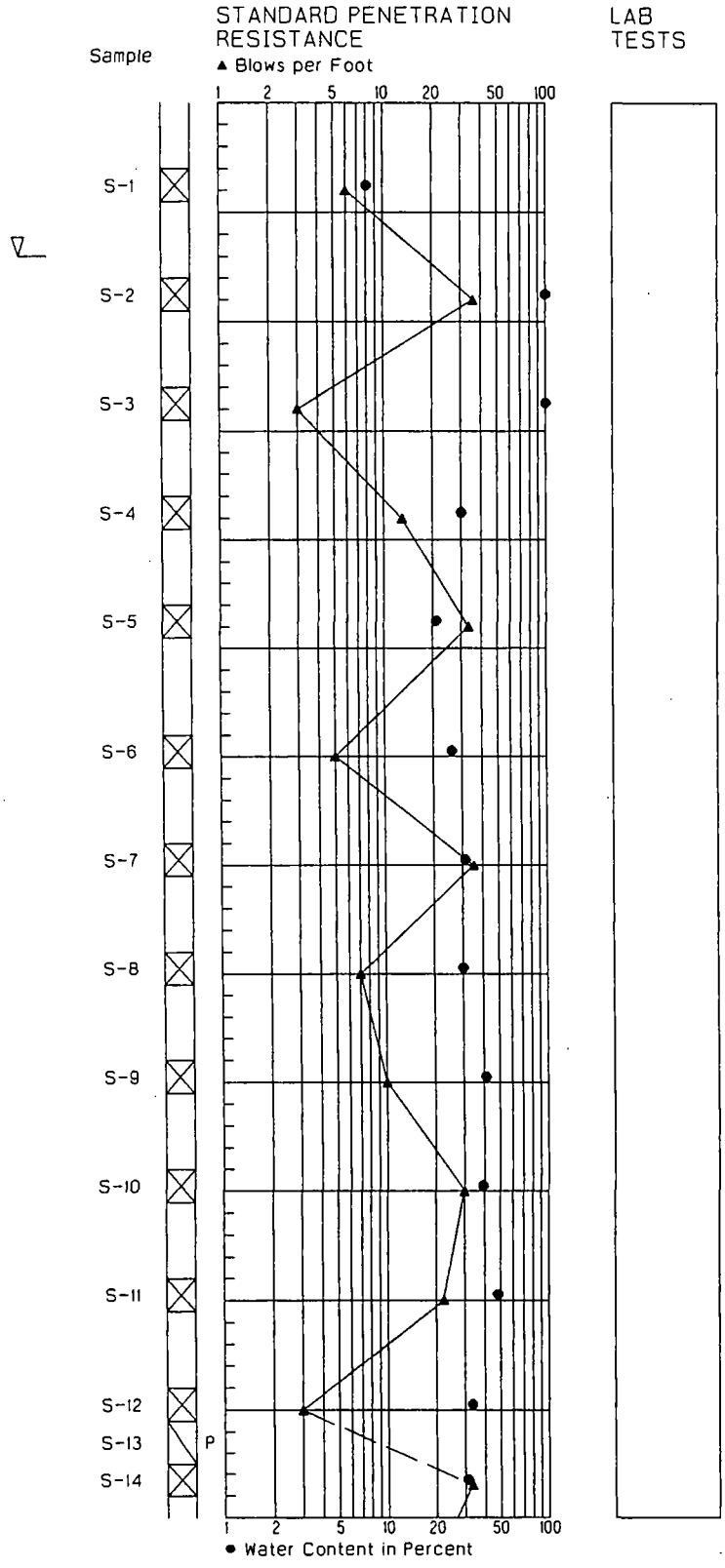
Medium dense to dense, wet, dark gray SAND with trace organics.

Loose to medium dense, wet, dark gray, silty SAND with trace organics.

S-7 blow count may be artificially increased due to the sampler driving on wood.

Interbedded, medium stiff to stiff SILT layers.

Medium stiff to very stiff, wet, dark gray, sandy SILT and SILT with interbedded layers of loose to medium dense, silty SAND.



1. Refer to Figure R-1 for explanation of descriptions and symbols.
2. Soil descriptions and stratum lines are interpretive and actual changes may be gradual.
3. Groundwater level, if indicated, is at time of drilling (ATD) or for date specified. Level may vary with time.

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Figure R-6 1/2

Boring Log HC-5

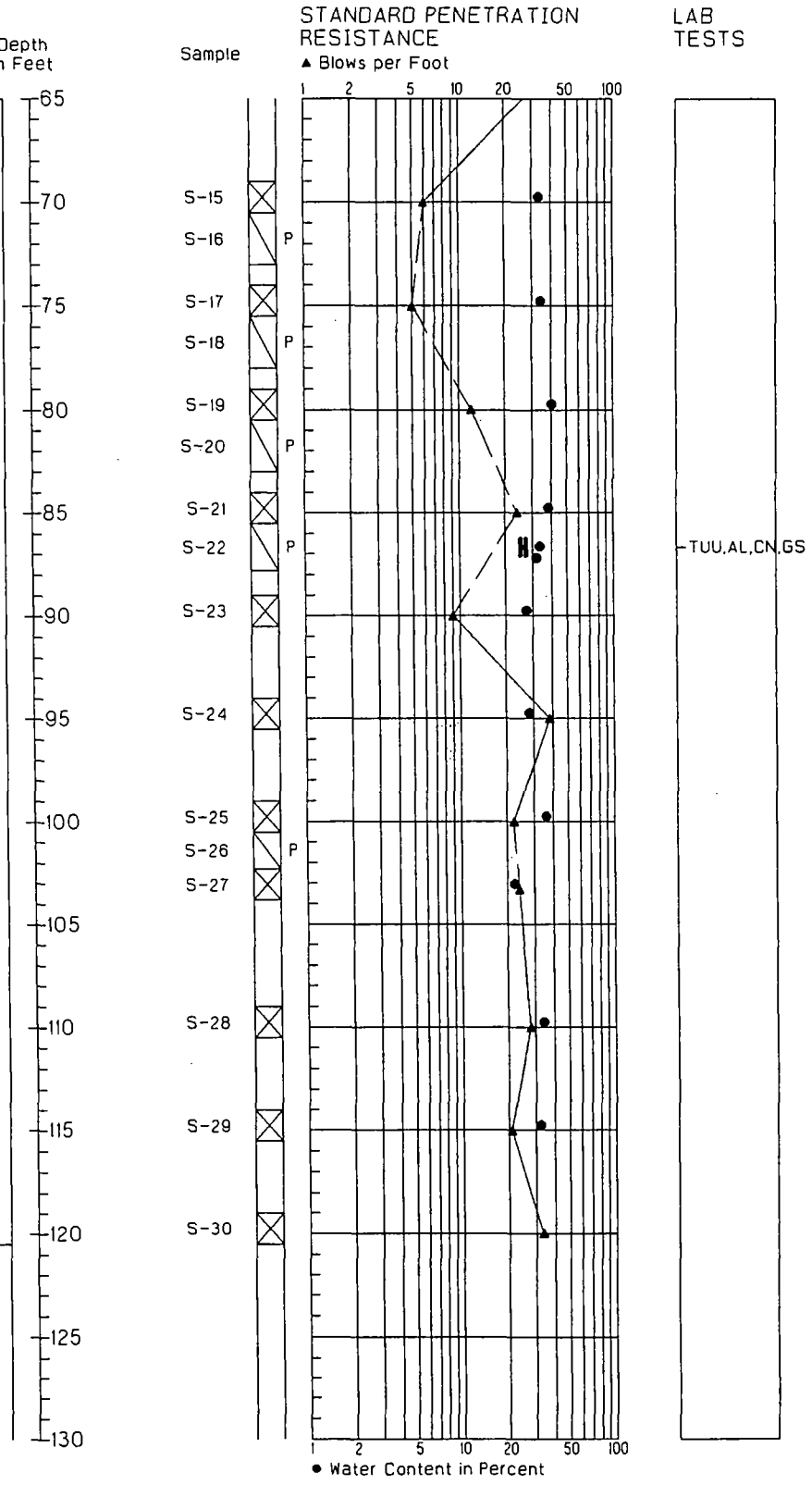
Soil Descriptions

Ground Surface Elevation in Feet: 17.3

Medium stiff to very stiff, wet, dark gray, clayey, sandy SILT with interbedded layers of loose to medium, dense, silty SAND.

S-24 blow count may be artificially increased due to the sampler driving on wood.

Bottom of Boring at 120.5 Feet.
Completed 3/2/99.



1. Refer to Figure R-1 for explanation of descriptions and symbols.
2. Soil descriptions and stratum lines are interpretive and actual changes may be gradual.
3. Groundwater level, if indicated, is at time of drilling (ATD) or for date specified. Level may vary with time.

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Figure R-8 2/2

Boring Log HC-7

Soil Descriptions

Ground Surface Elevation in Feet: -2.5

Soft, wet, dark gray, sandy SILT with abundant wood chips.

Loose to medium dense, wet, black SAND with scattered wood chips.

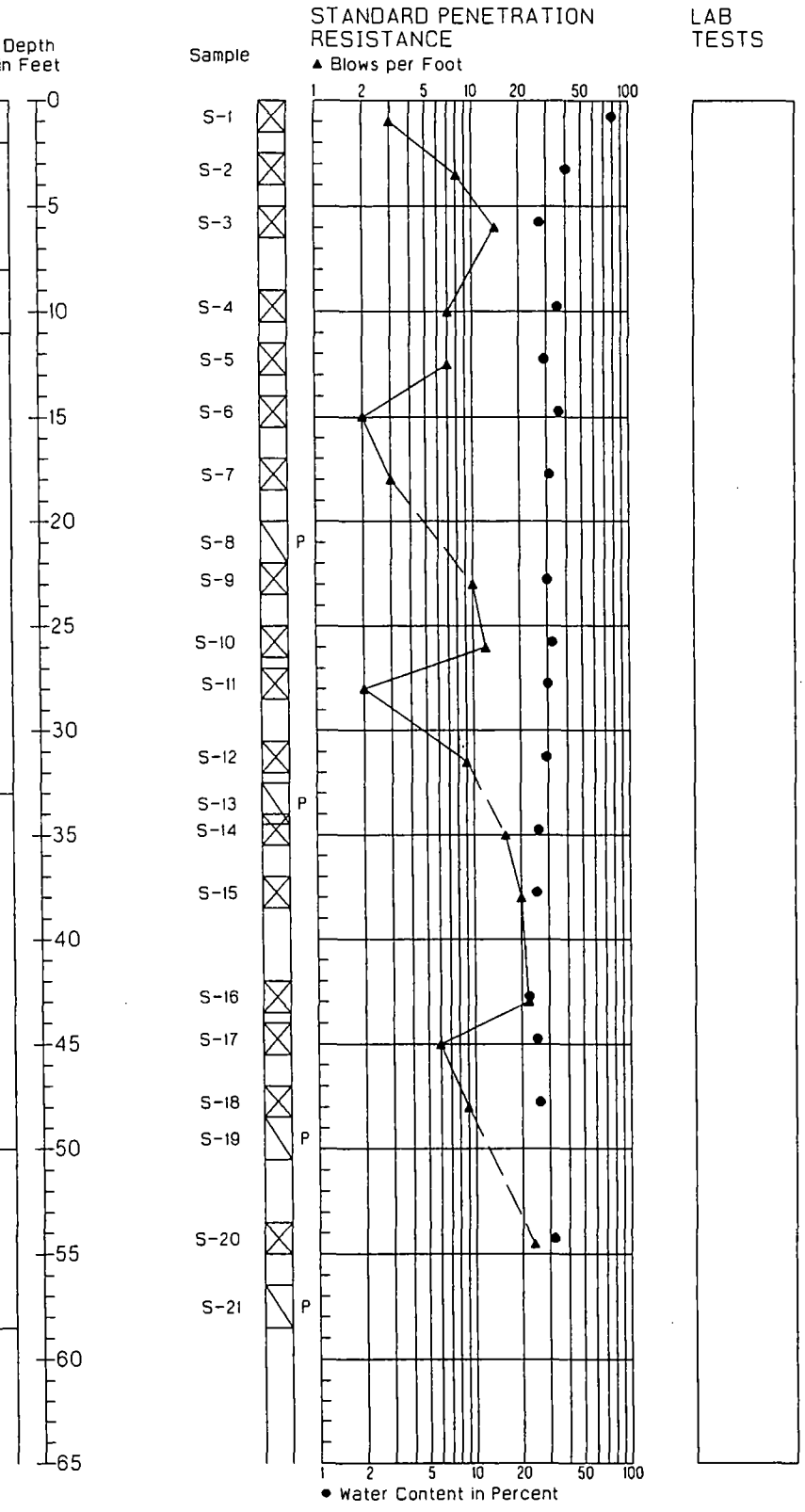
Medium stiff, wet, brown, sandy SILT with trace organics.

Very loose to loose, wet, dark gray, silty to very silty SAND.

Loose to medium dense, wet, dark gray, non-silty to silty SAND.

Very stiff, wet, black, slightly sandy SILT.

Bottom of Boring at 58.5 Feet. Completed 2/26/99.



1. Refer to Figure R-1 for explanation of descriptions and symbols.
2. Soil descriptions and stratum lines are interpretive and actual changes may be gradual.
3. Groundwater level, if indicated, is at time of drilling (ATD) or for date specified. Level may vary with time.

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Figure R-7

Boring Log HC-8

Soil Descriptions

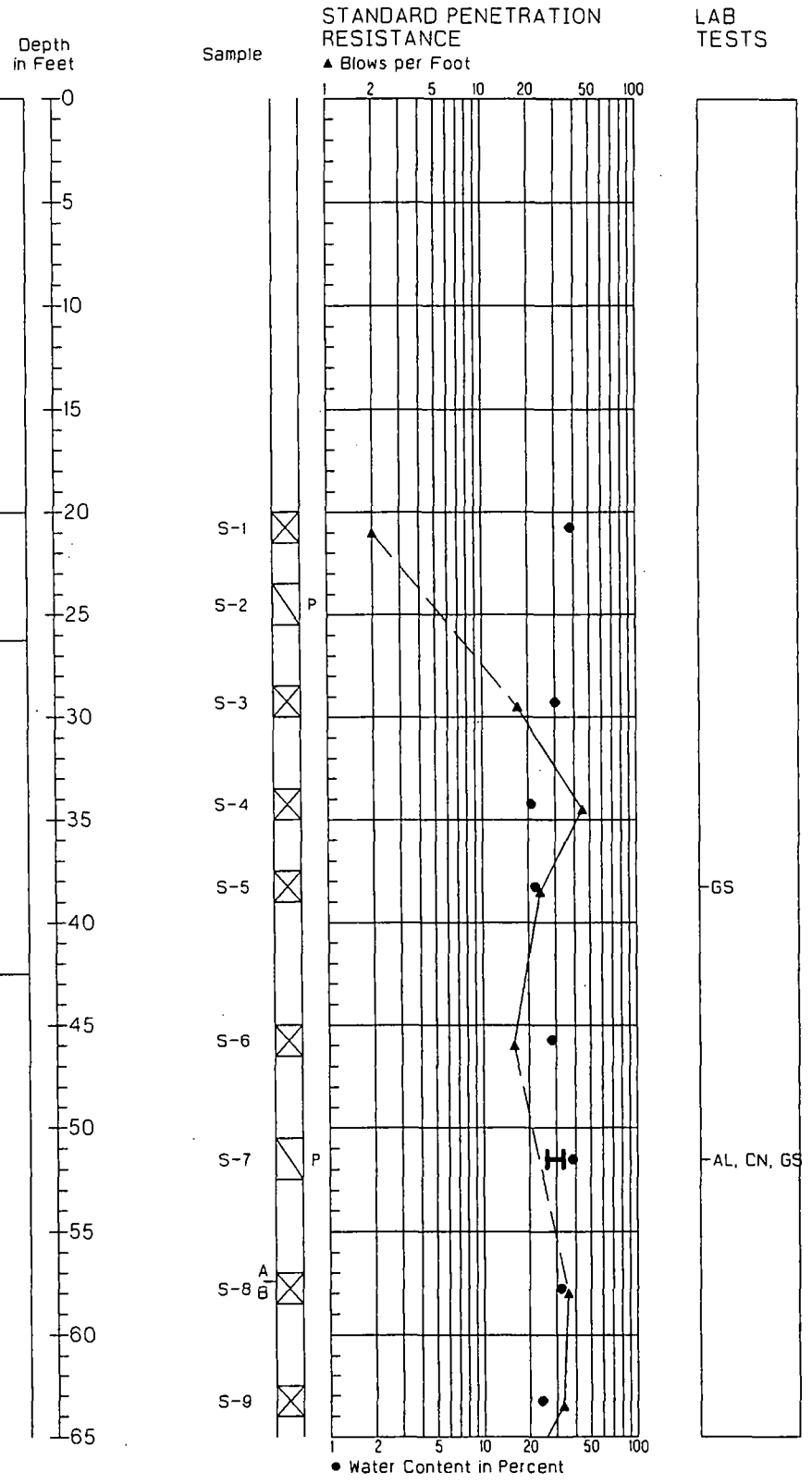
Ground Surface Elevation in Feet: -6.4

Drilled without sampling to 20 feet.

Very soft, wet, black, sandy SILT with trace wood.

Medium dense to dense, wet, black, slightly clayey, silty SAND.

Interbedded layers of medium dense, wet, black, silty SAND and medium stiff to stiff, clayey SILT.



1. Refer to Figure R-1 for explanation of descriptions and symbols.
2. Soil descriptions and stratum lines are interpretive and actual changes may be gradual.
3. Groundwater level, if indicated, is at time of drilling (ATD) or for date specified. Level may vary with time.

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Figure R-8 1/2

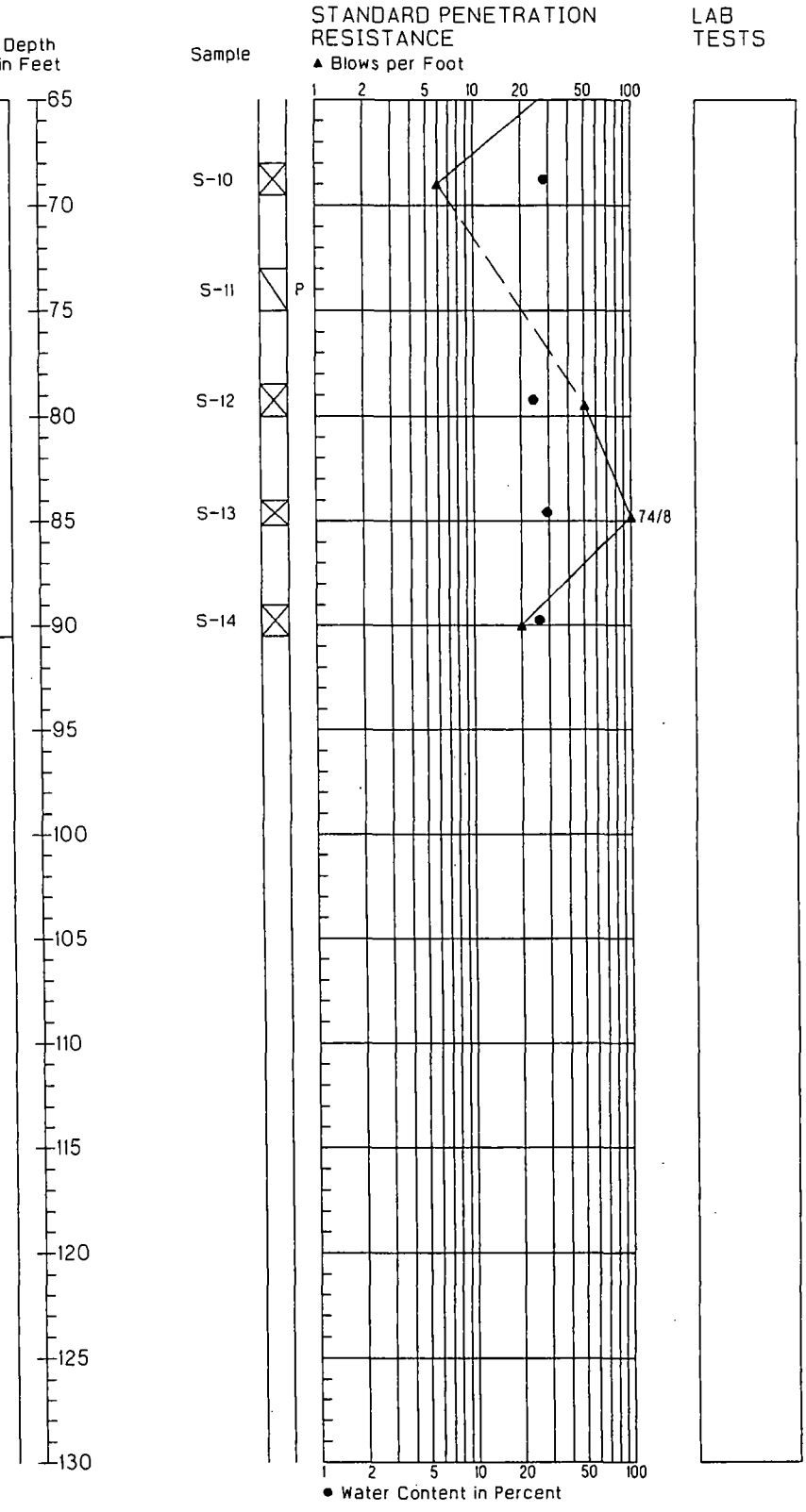
Boring Log HC-8

Soil Descriptions

Ground Surface Elevation in Feet: -6.4

Interbedded layers of medium dense, wet, black, silty SAND and medium stiff to stiff, clayey SILT.

Bottom of Boring at 90.5 Feet.
Completed 2/26/99.



1. Refer to Figure R-1 for explanation of descriptions and symbols.
2. Soil descriptions and stratum lines are interpretive and actual changes may be gradual.
3. Groundwater level, if indicated, is at time of drilling (ATD) or for date specified. Level may vary with time.

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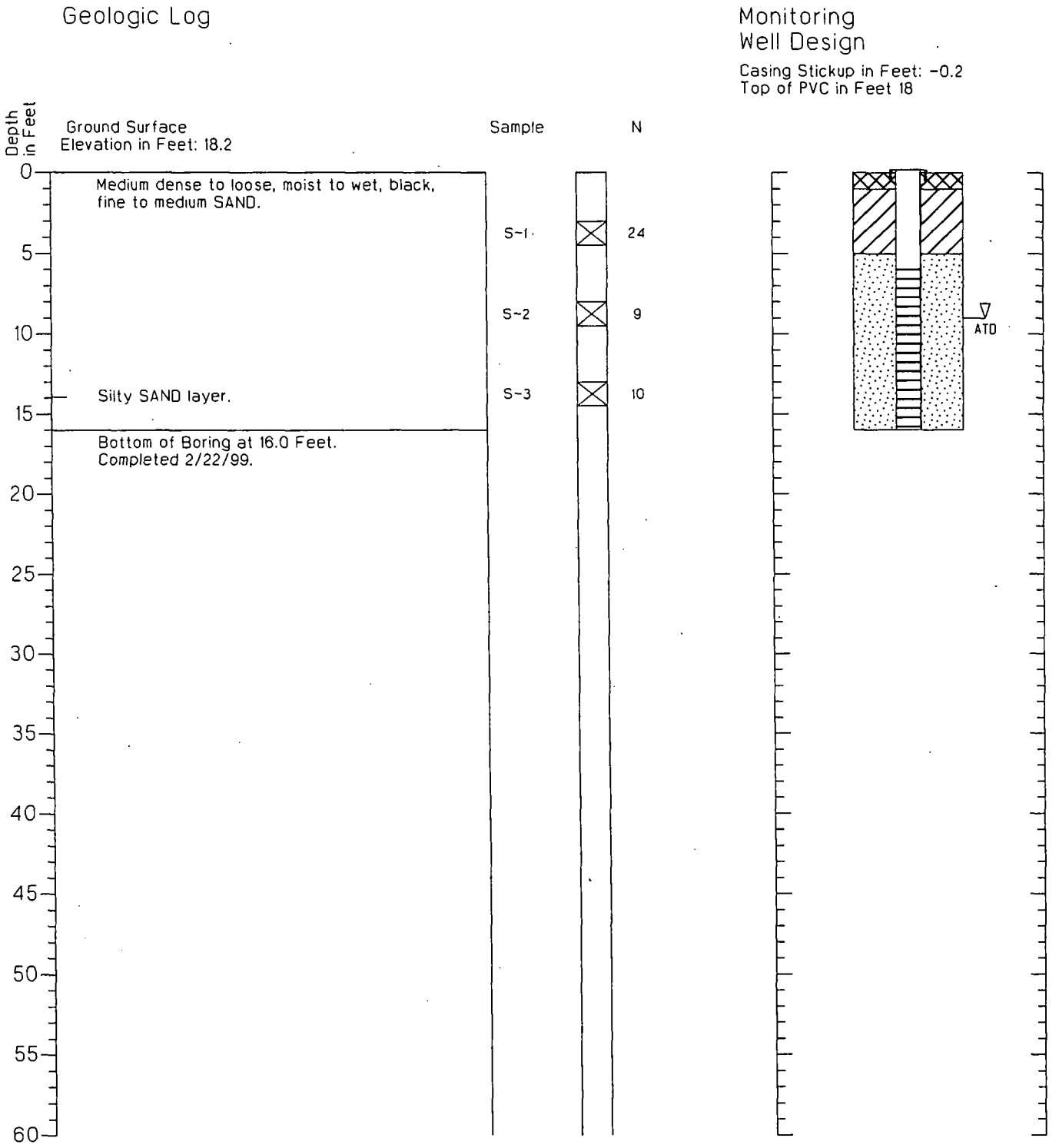
Figure R-8 2/2

Boring Log and Construction Data for Monitoring Well RD3-UMW9



1. Refer to Figure R-1 for explanation of descriptions and symbols.
2. Soil descriptions and stratum lines are interpretive and actual changes may be gradual.
3. Ground water level, if indicated, is at time of drilling (ATD) or for date specified. Level may vary with time.

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Figure R-9

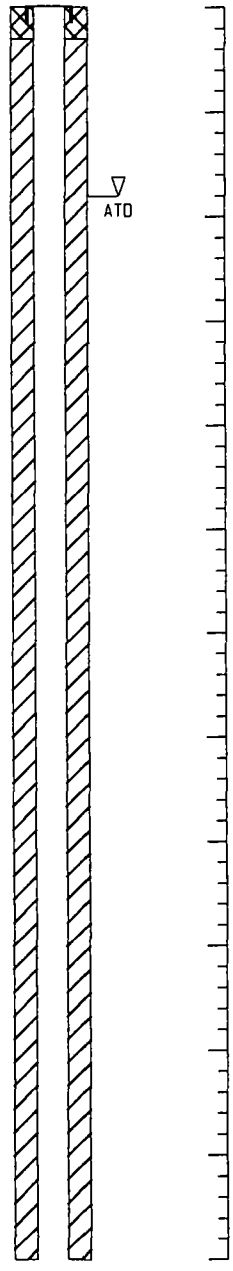
Boring Log and Construction Data for Monitoring Well RD3-UMW10 and Boring Log HC-6

Geologic Log

Monitoring Well Design

Ground Surface Elevation in Feet: 18.6

Depth in Feet	Geologic Log	Sample	N	Lab Tests
0	GRAVEL with wood chips.			
	Medium dense, moist, gray, slightly silty SAND with scattered wood.	S-1	33	
5				
	Grades to very loose.	S-2	3	
10				
	WOOD CHIPS.			
		S-3	10	
15				
		S-4	5	
20	Medium dense, wet, black SAND.			
		S-5	12	
25				
	Scattered wood.	S-6	11	
30				
	Soft, wet, gray, sandy SILT.	S-7	3	
35		S-8	P	
	Medium dense, wet, gray, silty SAND.	S-9	12	
40				
	Very loose, wet, gray, very silty SAND with interbedded layers of soft, non-clayey to clayey, sandy to very sandy SILT.	S-10	3	GS
45		S-11	P	
		S-12	2	
50		S-13	P	
		S-14	2	
55		S-15	P	GS, TCU
		S-16	3	
60				



1. Refer to Figure R-1 for explanation of descriptions and symbols.
2. Soil descriptions and stratum lines are interpretive and actual changes may be gradual.
3. Ground water level, if indicated, is at time of drilling (ATD) or for date specified. Level may vary with time.

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Figure R-10 1/2

Boring Log and Construction Data for Monitoring Well RD3-UMW10 and Boring Log HC-6

Geologic Log

Monitoring Well Design

Depth in Feet

Ground Surface Elevation in Feet: 18.6

Depth	Description	Sample	N	Lab Tests
60		S-17	P	GS, K
65		S-18	4	
		S-19	2	
70		S-20	P	TUU ,AL CN, GS
	Medium dense, wet, gray, very silty SAND.	S-21	13	
75				
	Stiff, wet, gray, very sandy SILT.	S-22	9	
80		S-23	P	
		S-24	12	
85				
		S-25	14	
90		S-26	P	
		S-27	10	
95				
	Medium dense to dense, wet, gray, silty to very silty SAND.	S-28	39	
100				
		S-29	20	
105				
	Stiff, wet, gray, very sandy SILT.	S-30	9	
110				
		S-31 A/B	41	
115	Medium dense to dense, wet, gray, silty to very silty SAND.			
		S-32	21	
120	Bottom of Boring at 119.5 Feet. Completed 2/25/99.			

1. Refer to Figure R-1 for explanation of descriptions and symbols.
2. Soil descriptions and stratum lines are interpretive and actual changes may be gradual.
3. Ground water level, if indicated, is at time of drilling (ATD) or for date specified. Level may vary with time.

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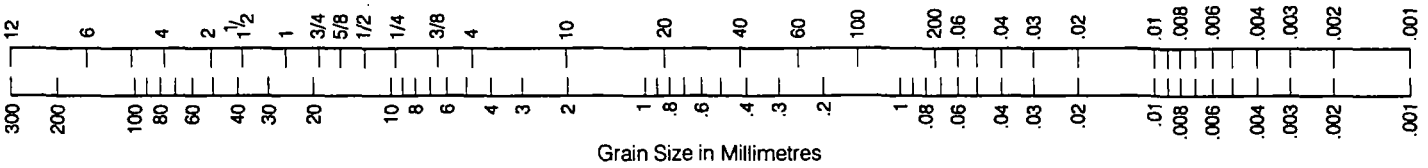
Figure R-10 2/2

Unified Soil Classification (USC) System

Soil Grain Size

Size of Opening In Inches	Number of Mesh per Inch (US Standard)	Grain Size in Millimetres



COBBLES	GRAVEL	SAND	SILT and CLAY
Coarse-Grained Soils			Fine-Grained Soils

Coarse-Grained Soils

G W	G P	G M	G C	S W	S P	S M	S C
Clean GRAVEL <5% fines	*	GRAVEL with >12% fines		Clean SAND <5% fines	*	SAND with >12% fines	
GRAVEL >50% coarse fraction larger than No. 4				SAND >50% coarse fraction smaller than No. 4			
Coarse-Grained Soils >50% larger than No. 200 sieve							

G W and S W $\left(\frac{D_{60}}{D_{10}}\right) > 4$ for G W, $\left(\frac{D_{60}}{D_{10}}\right) > 6$ for S W & $1 \leq \left(\frac{(D_{30})^2}{D_{10} \times D_{60}}\right) \leq 3$

G P and S P Clean GRAVEL or SAND not meeting requirements for G W and S W

G M and S M Atterberg limits below A line with PI <4

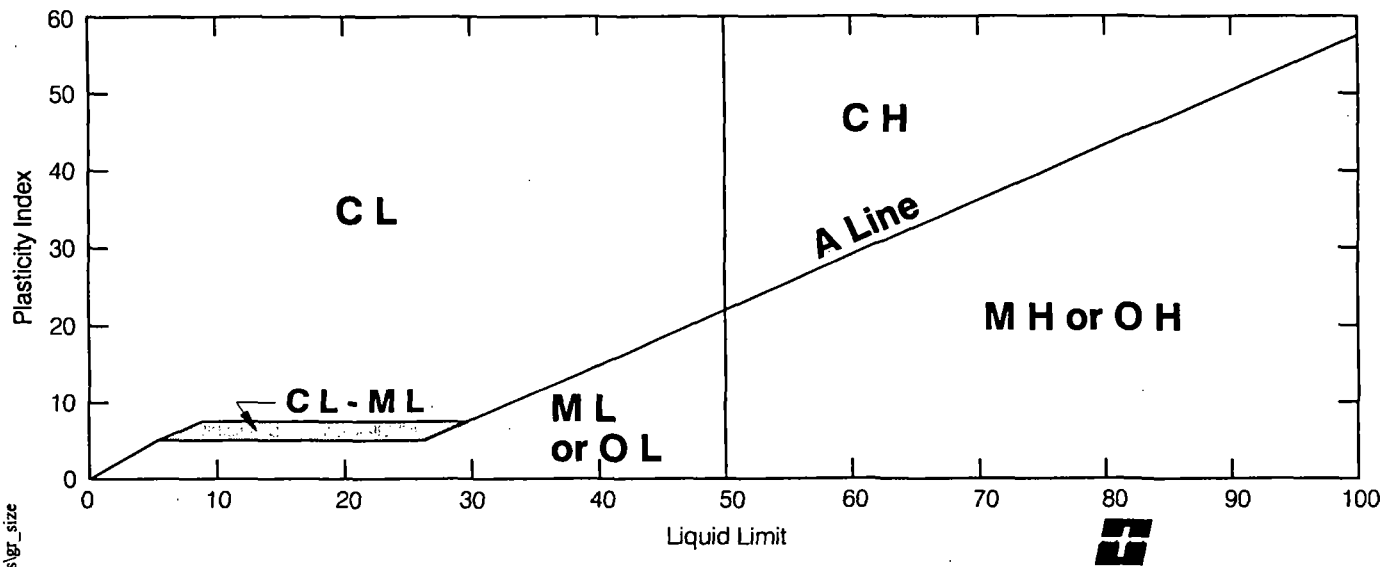
G C and S C Atterberg limits above A Line with PI >7

* Coarse-grained soils with percentage of fines between 5 and 12 are considered borderline cases required use of dual symbols.

D_{10}, D_{30}, and D_{60} are the particles diameter of which 10, 30, and 60 percent, respectively, of the soil weight are finer.

Fine-Grained Soils

M L	C L	O L	M H	C H	O H	Pt
SILT	CLAY	Organic	SILT	CLAY	Organic	Highly Organic Soils
Soils with Liquid Limit <50%			Soils with Liquid Limit >50%			
Fine-Grained Soils >50% smaller than No. 200 sieve						



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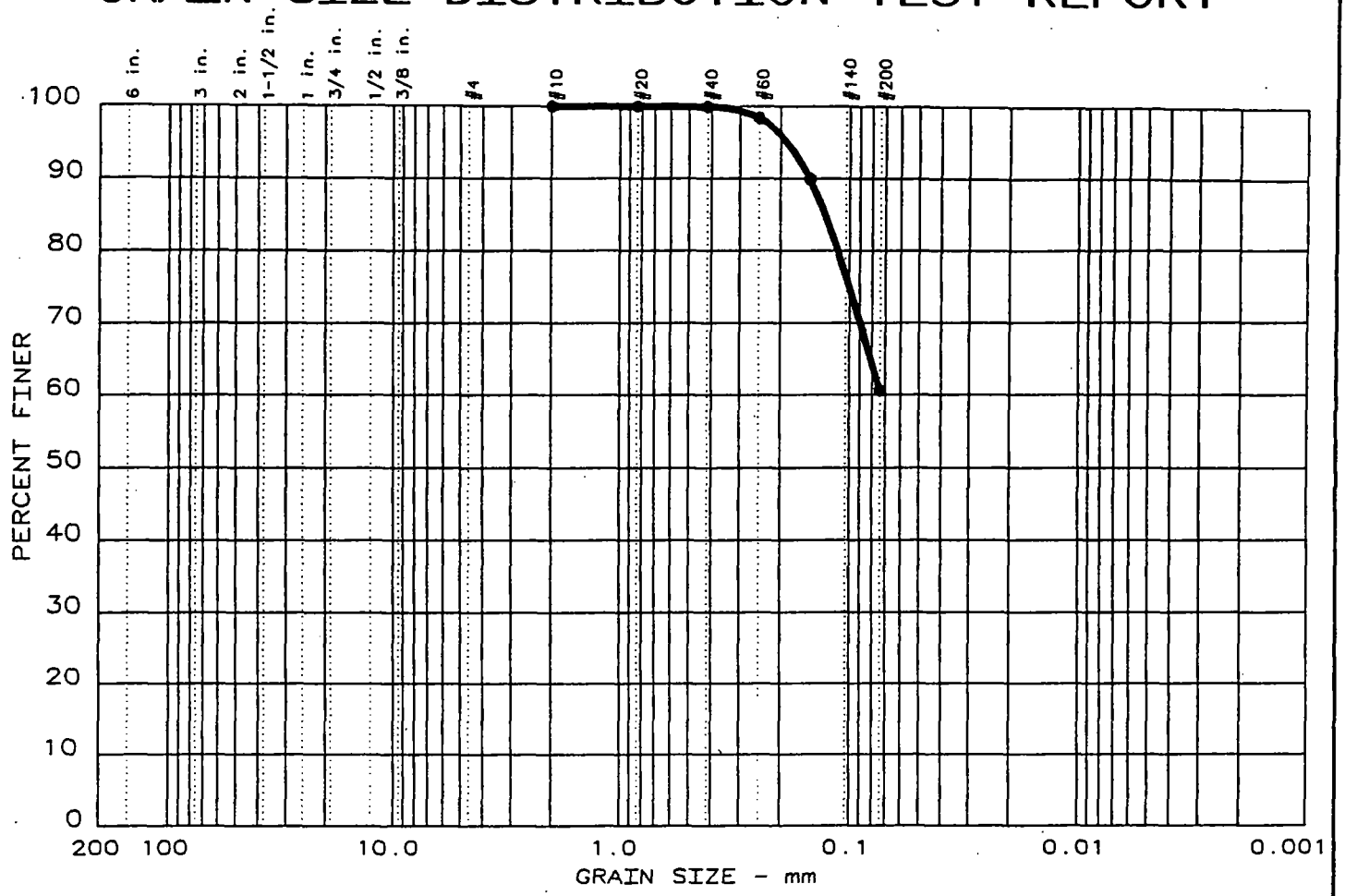
J-4072-25 6/99

Figure R-11

GRAIN SIZE DISTRIBUTION TEST REPORT



	%+75mm	% GRAVEL	% SAND	% SILT	% CLAY
●	0.0	0.0	39.4	60.6	

	LL	PI	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
●			0.13							

MATERIAL DESCRIPTION	USCS	NAT. MOIST.
● Very sandy SILT	ML	27%

Remarks:

Project: St. Paul Waterway

● Location: HC-1, S-18

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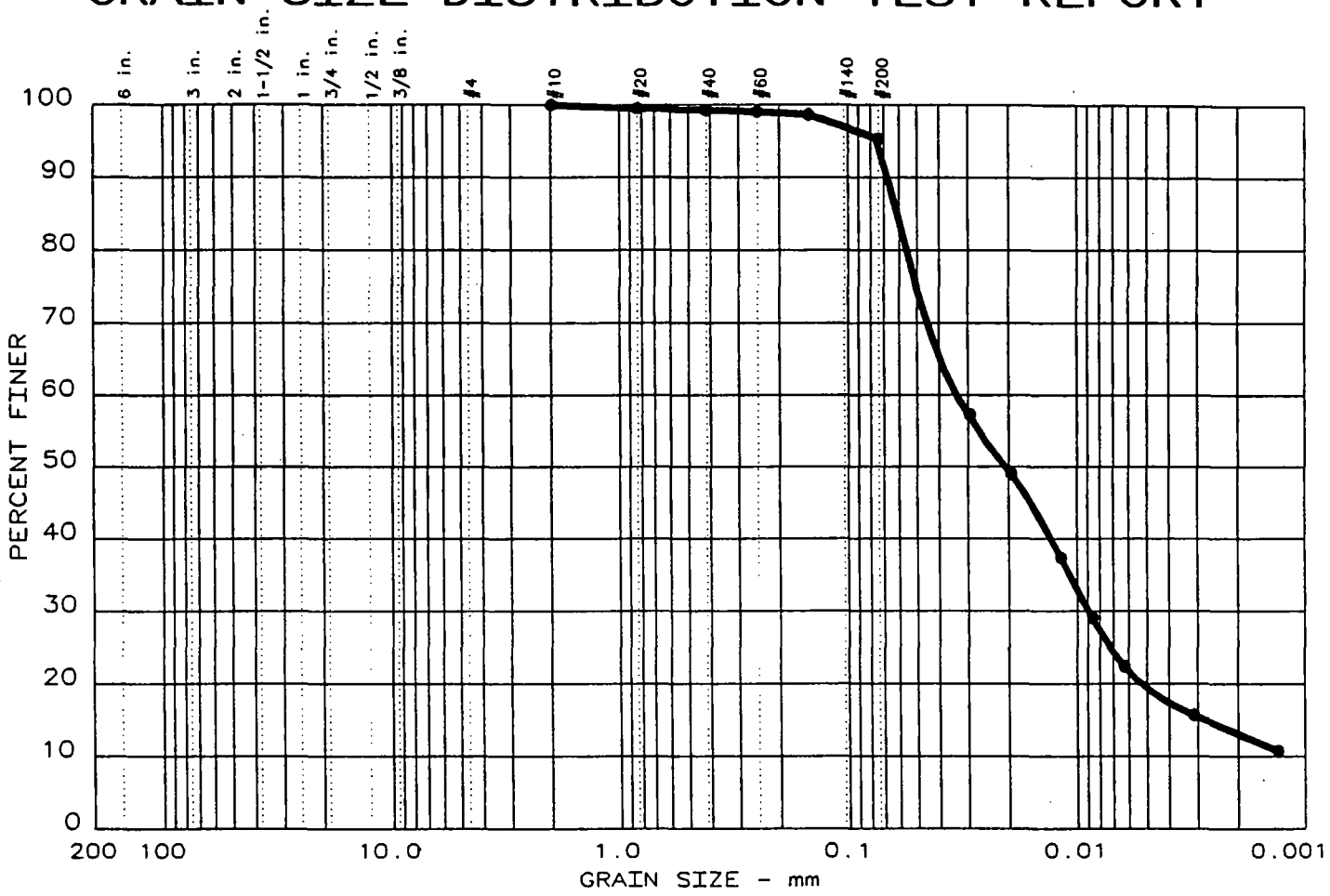
Figure R-12

GRAIN SIZE DISTRIBUTION TEST REPORT



	%+75mm	% GRAVEL	% SAND	% SILT	% CLAY
●	0.0	0.0	4.7	75.9	19.4

	LL	PI	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
●	57	12			0.02	0.009	0.0028			

MATERIAL DESCRIPTION	USCS	NAT. MOIST.
● Clayey SILT	MH	63%

Remarks:

Project: St. Paul Waterway

● Location: H-2, S-7, Depth 15 to 17 feet

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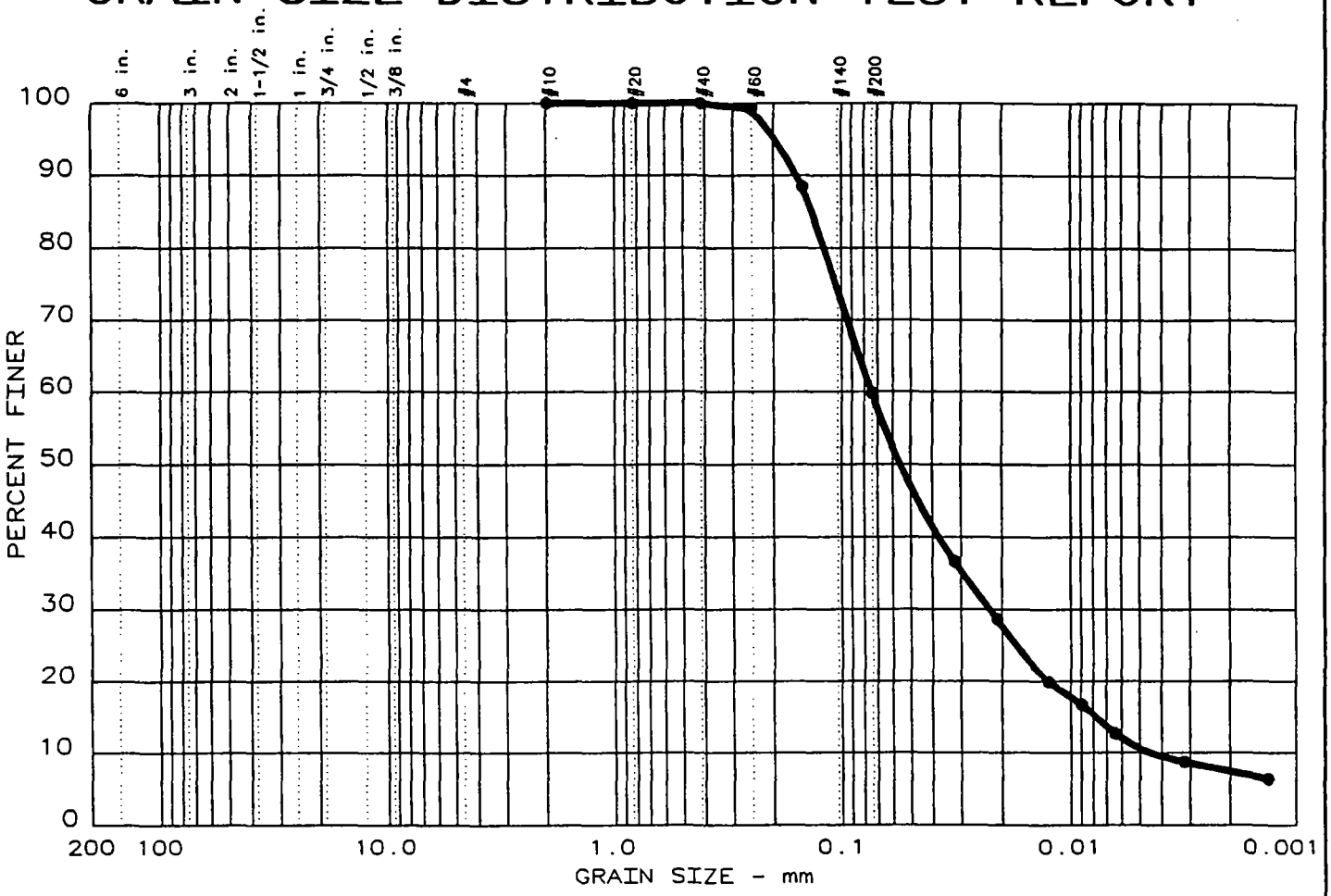
Figure R-13

GRAIN SIZE DISTRIBUTION TEST REPORT



	%+75mm	% GRAVEL	% SAND	% SILT	% CLAY
●	0.0	0.0	40.2	49.2	10.6

	LL	PI	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
●			0.13	0.07	0.06	0.022	0.0078	0.0045	1.51	16.6

MATERIAL DESCRIPTION	USCS	NAT. MOIST.
● Slightly clayey, very sandy SILT	ML	26%

Remarks:

Project: St. Paul Waterway

● Location: HC-2, S-15

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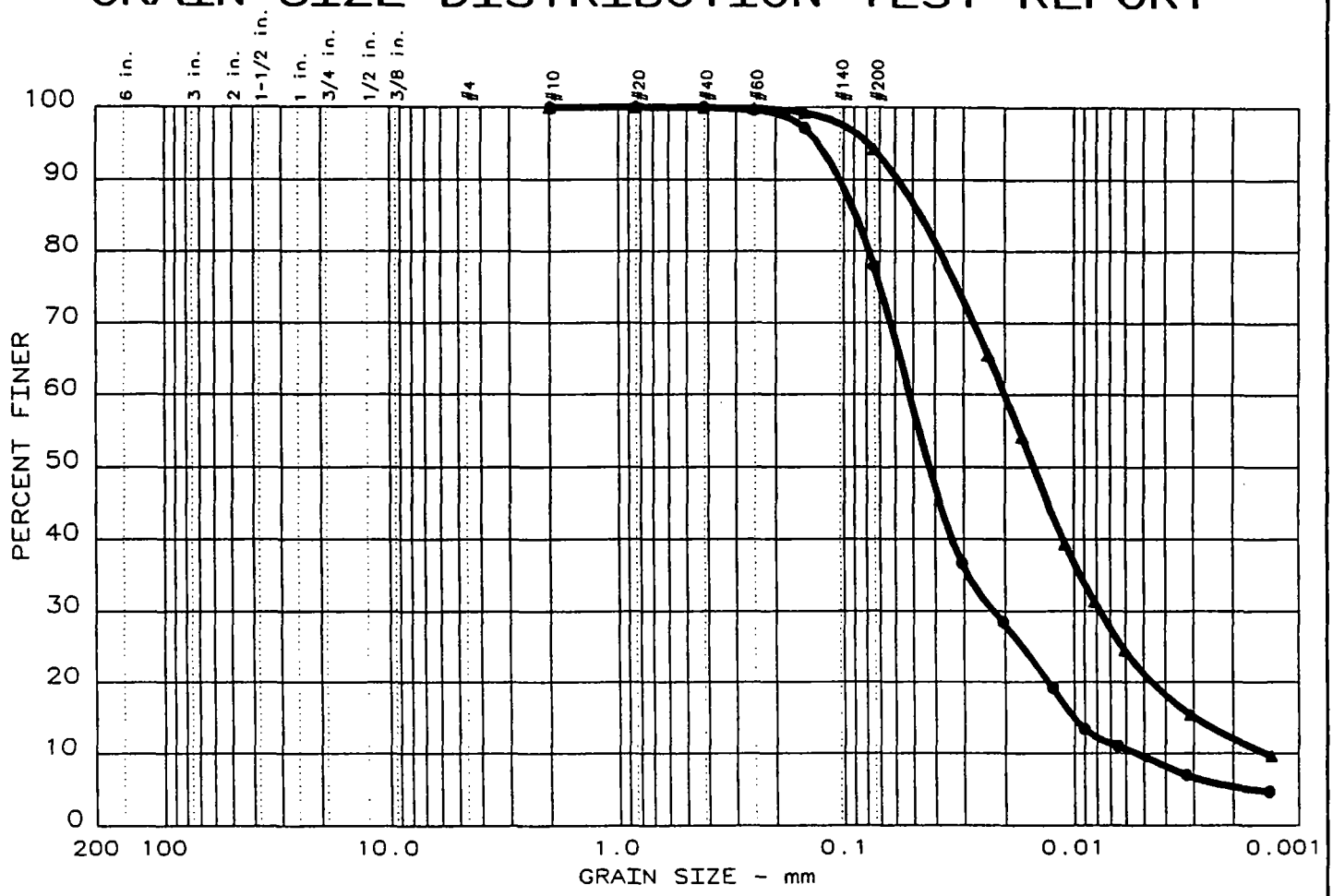
Figure R-14

GRAIN SIZE DISTRIBUTION TEST REPORT



	%+75mm	% GRAVEL	% SAND	% SILT	% CLAY
●	0.0	0.0	22.1	68.3	9.6
▲	0.0	0.0	5.8	73.1	21.1

	LL	PI	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
●	29	1	0.09		0.04	0.022	0.0101	0.0053	1.80	9.7
▲	33	6			0.01	0.008	0.0030	0.0014	2.14	14.1

MATERIAL DESCRIPTION	USCS	NAT. MOIST.
● Slightly clayey, sandy SILT	ML	33%
▲ Slightly sandy, clayey SILT	ML	38%

Remarks:

Project: St. Paul Waterway
● Location: HC-3, S-10, Depth 24 to 26 feet
▲ Location: HC-6, S-15, Depth 54.5 to 56.5 fee

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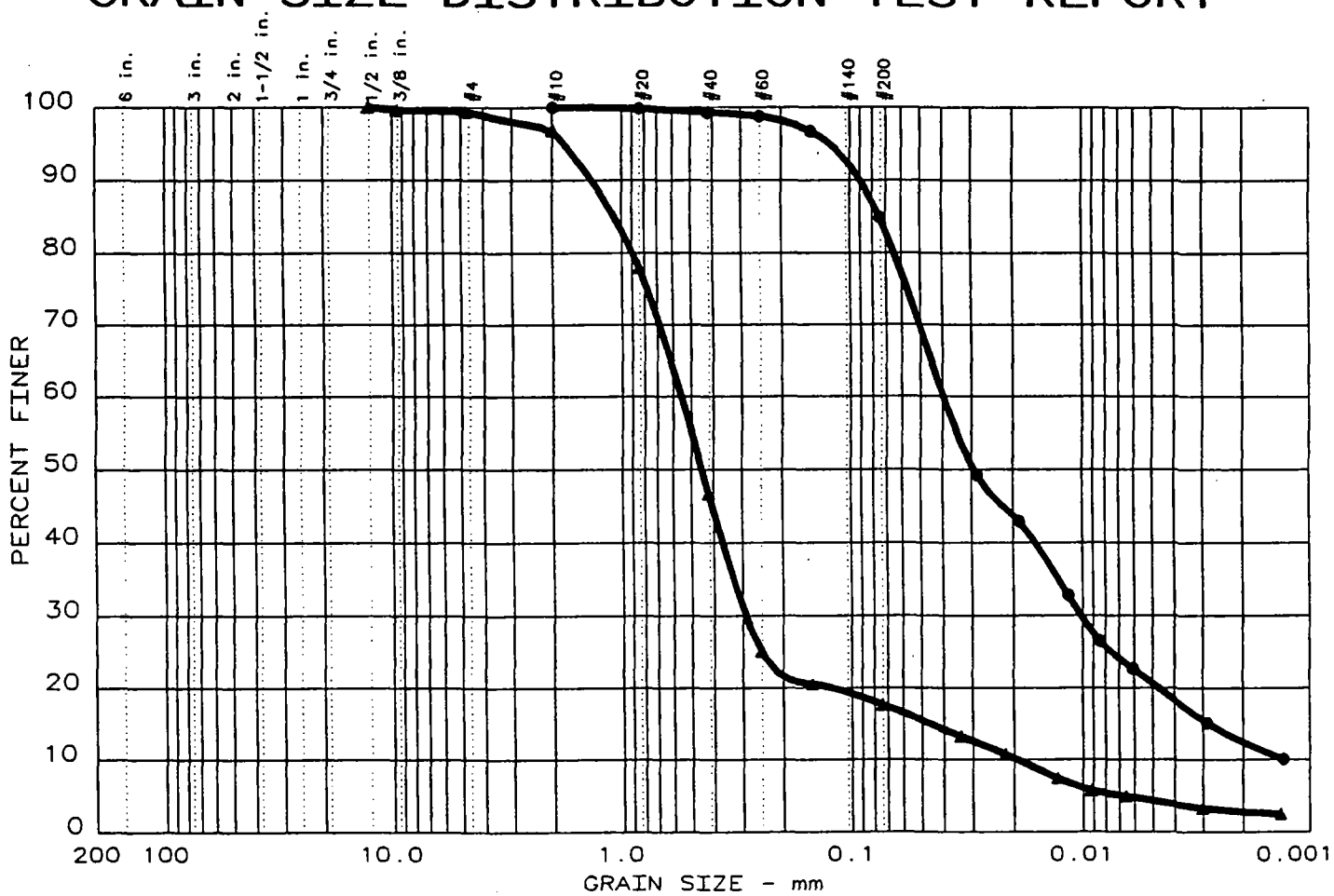
Figure R-15

GRAIN SIZE DISTRIBUTION TEST REPORT



	%+75mm	% GRAVEL	% SAND	% SILT	% CLAY
●	0.0	0.0	15.1	64.2	20.7
▲	0.0	0.6	81.7	13.3	4.4

	LL	PI	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
●			0.07		0.03	0.010	0.0028			
▲			1.07	0.55	0.45	0.292	0.0457	0.0193	8.04	28.5

MATERIAL DESCRIPTION	USCS	NAT. MOIST.
● Sandy, clayey SILT	ML	38%
▲ Silty SAND	SM	22%

Remarks:

Project: St. Paul Waterway
● Location: HC-18, S-4, Depth 88 to 90.5 feet
▲ Location: HC-6, S-17, Depth 60 to 62 feet

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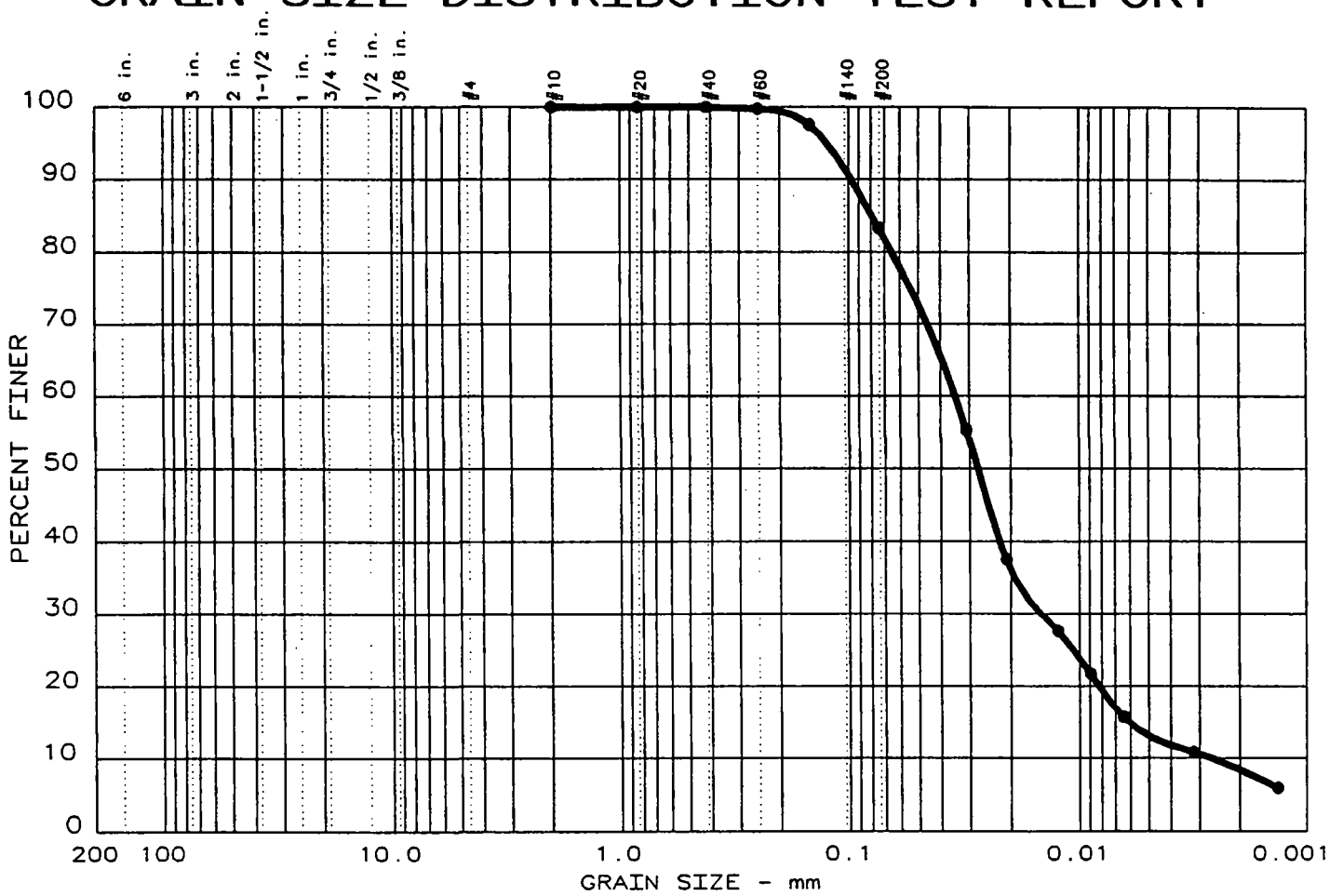
Figure R-16

GRAIN SIZE DISTRIBUTION TEST REPORT



	%+75mm	% GRAVEL	% SAND	% SILT	% CLAY
●	0.0	0.0	16.7	70.2	13.1

	LL	PI	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
●	27	2	0.08		0.03	0.015	0.0061	0.0026	2.37	13.1

MATERIAL DESCRIPTION	USCS	NAT. MOIST.
● Clayey, sandy SILT	ML	31%

Remarks:

Project: St. Paul Waterway

● Location: HC-5, S-22, Depth 85.5 to 87.8 fee

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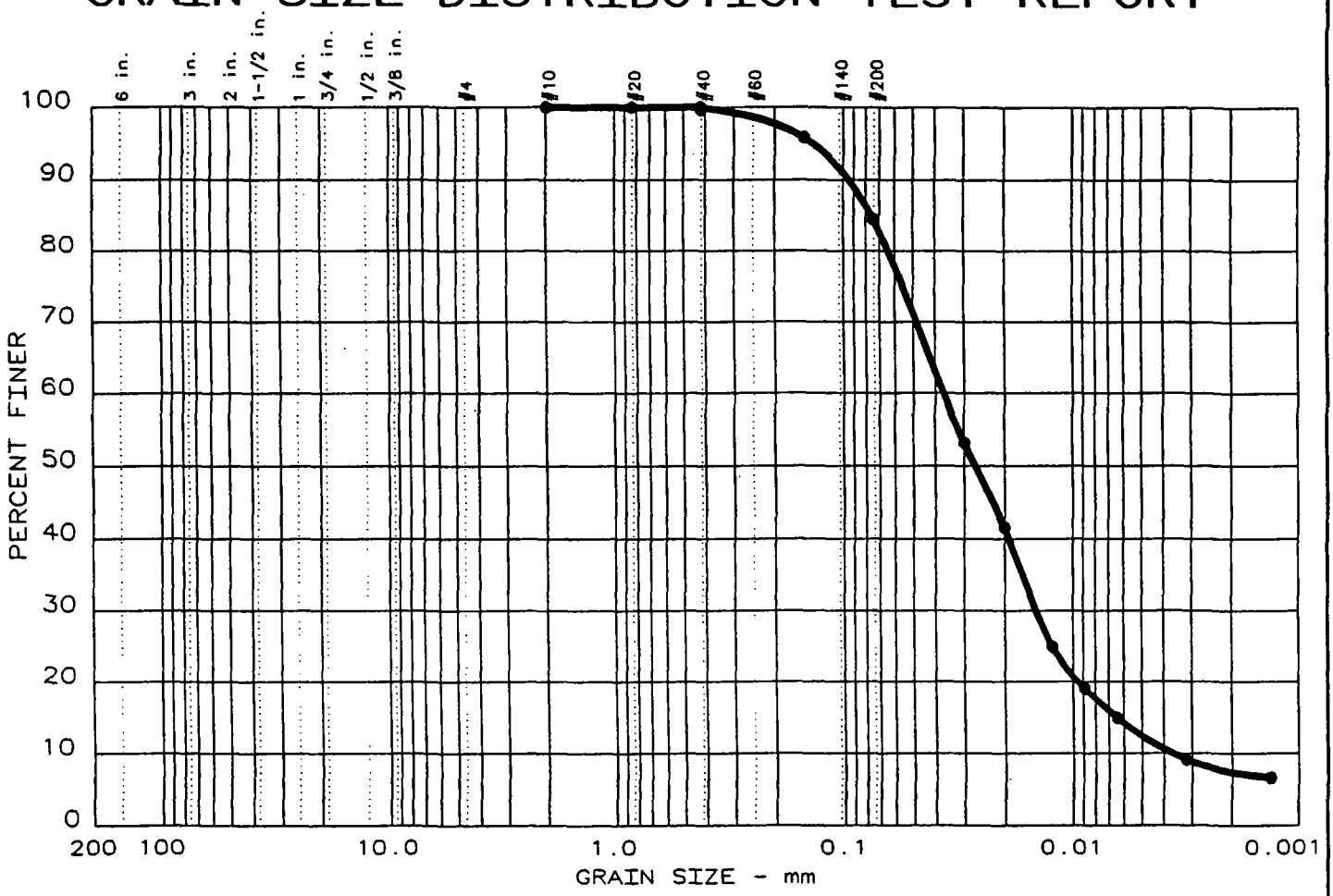
Figure R-17

GRAIN SIZE DISTRIBUTION TEST REPORT



	%+75mm	% GRAVEL	% SAND	% SILT	% CLAY
●	0.0	0.0	15.5	72.1	12.4

	LL	PI	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
●			0.07		0.03	0.015	0.0064	0.0037	1.56	9.9

MATERIAL DESCRIPTION	USCS	NAT. MOIST.
● Clayey, sandy SILT	ML	35%

Remarks:

Project: St. Paul Waterway

● Location: HC-6, S-10

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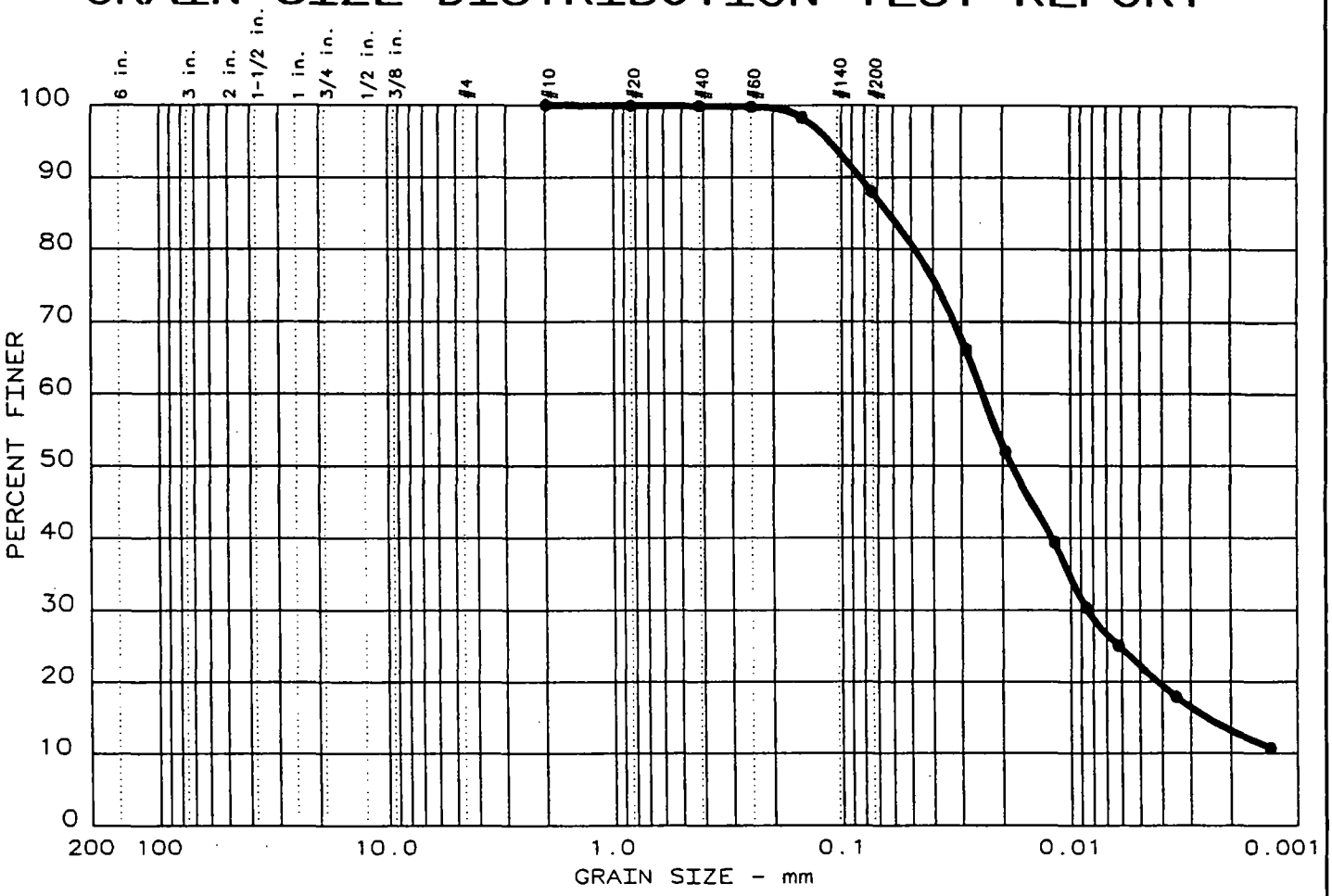
Figure R-18

GRAIN SIZE DISTRIBUTION TEST REPORT



	%+75mm	% GRAVEL	% SAND	% SILT	% CLAY
●	0.0	0.0	12.0	65.8	22.2

	LL	PI	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
●	31	8			0.02	0.008	0.0025			

MATERIAL DESCRIPTION	USCS	NAT. MOIST.
● Sandy, clayey SILT	ML	32%

Remarks:

Project: St. Paul Waterway

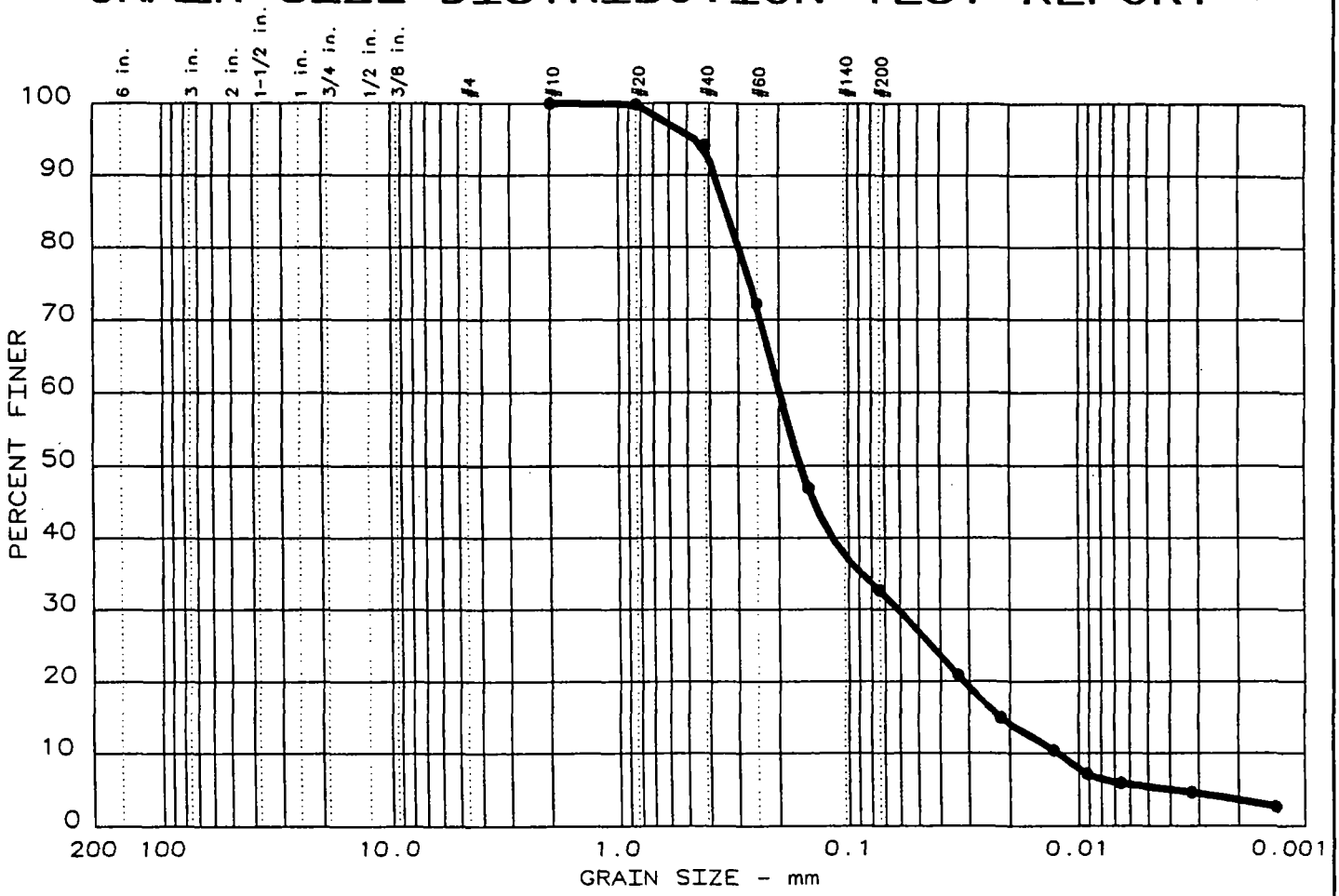
● Location: HC-6, Depth 70 to 72 feet
S-20

HARTCROWSER

J-4072-25 3/21/99

Figure R-19

GRAIN SIZE DISTRIBUTION TEST REPORT



	%+75mm	% GRAVEL	% SAND	% SILT	% CLAY
●	0.0	0.0	67.3	27.3	5.4

	LL	PI	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
●			0.33	0.20	0.16	0.061	0.0217	0.0123	1.53	16.1

MATERIAL DESCRIPTION	USCS	NAT. MOIST.
● Slightly clayey, silty SAND	SM	22%

Remarks:

Project: St. Paul Waterway

● Location: HC-8, S-5

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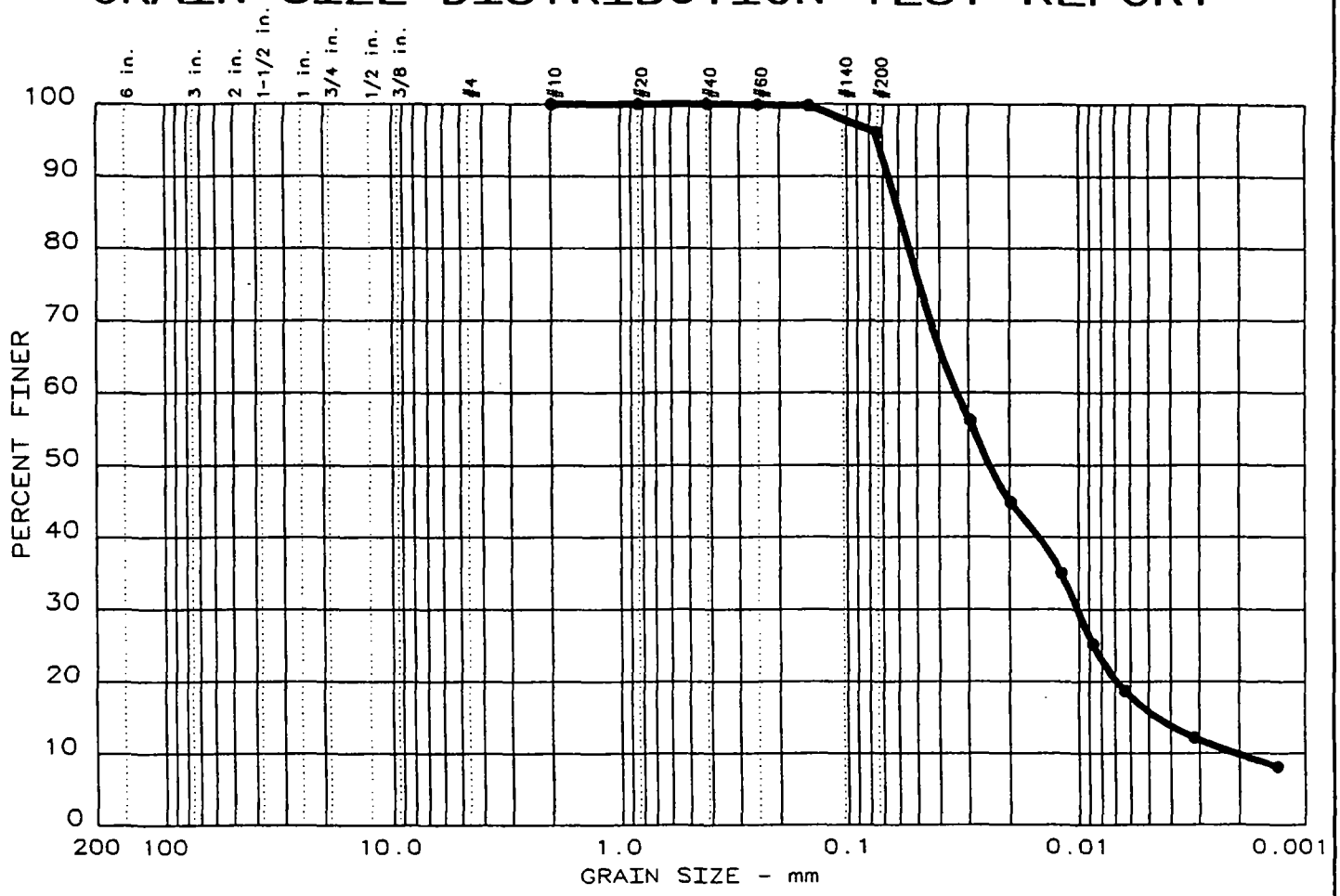
Figure R-20

GRAIN SIZE DISTRIBUTION TEST REPORT



	%+75mm	% GRAVEL	% SAND	% SILT	% CLAY
●	0.0	0.0	3.9	80.3	15.8

	LL	PI	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
●	33	7			0.02	0.010	0.0046	0.0020	1.52	16.9

MATERIAL DESCRIPTION	USCS	NAT. MOIST.
● Clayey SILT	ML	38%

Remarks:

Project: St. Paul Waterway

● Location: HC-8, S-7, Depth 50.5 to 52.5 feet

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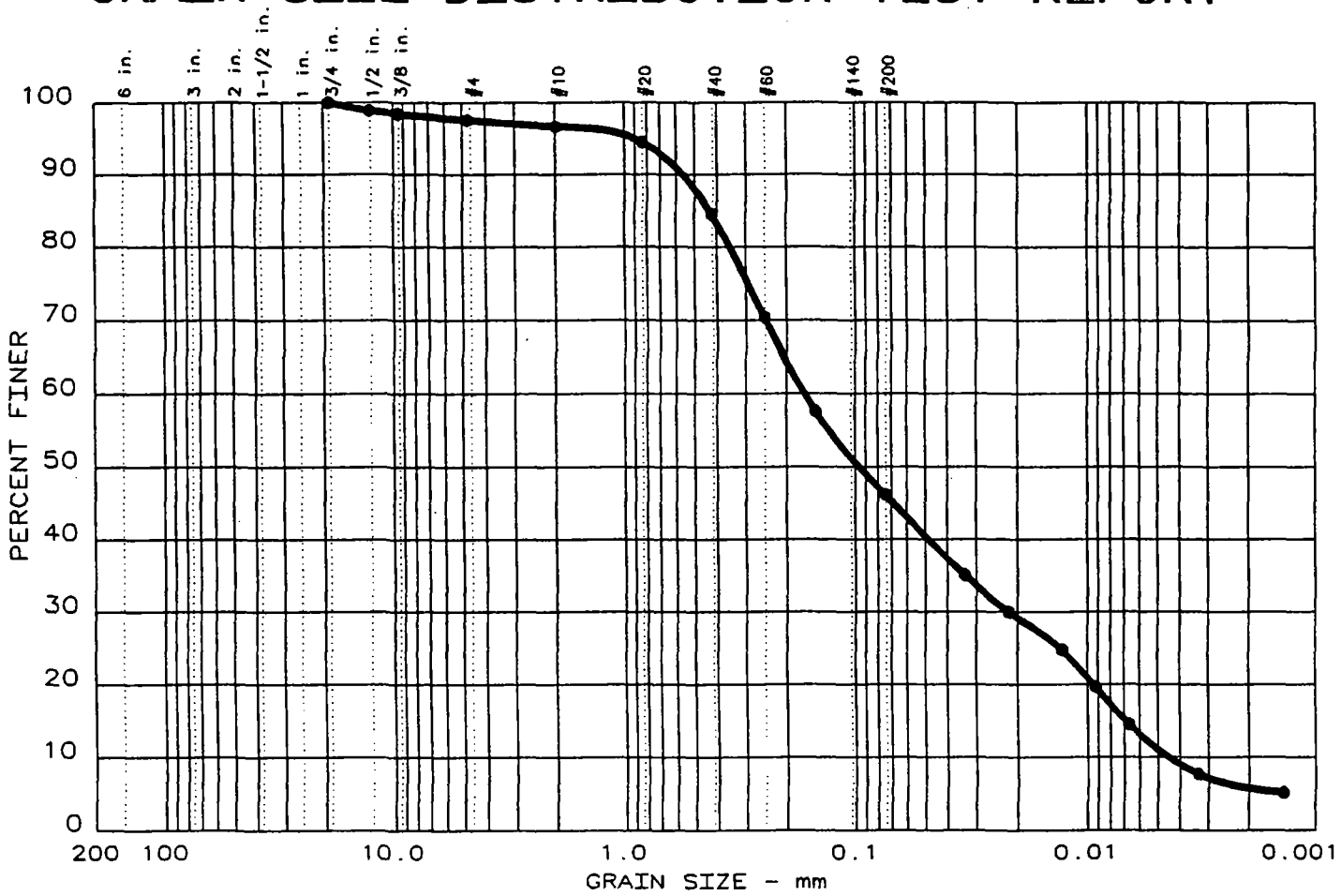
Figure R-21

GRAIN SIZE DISTRIBUTION TEST REPORT



	%+75mm	% GRAVEL	% SAND	% SILT	% CLAY
●	0.0	2.5	51.4	35.1	11.0

	LL	PI	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
●			0.43	0.17	0.10	0.022	0.0068	0.0045	0.65	37.2

MATERIAL DESCRIPTION	USCS	NAT. MOIST.
● Slightly clayey, very silty SAND	SM	62%

Remarks:

Project: St. Paul Waterway
● Location: LC-01/12

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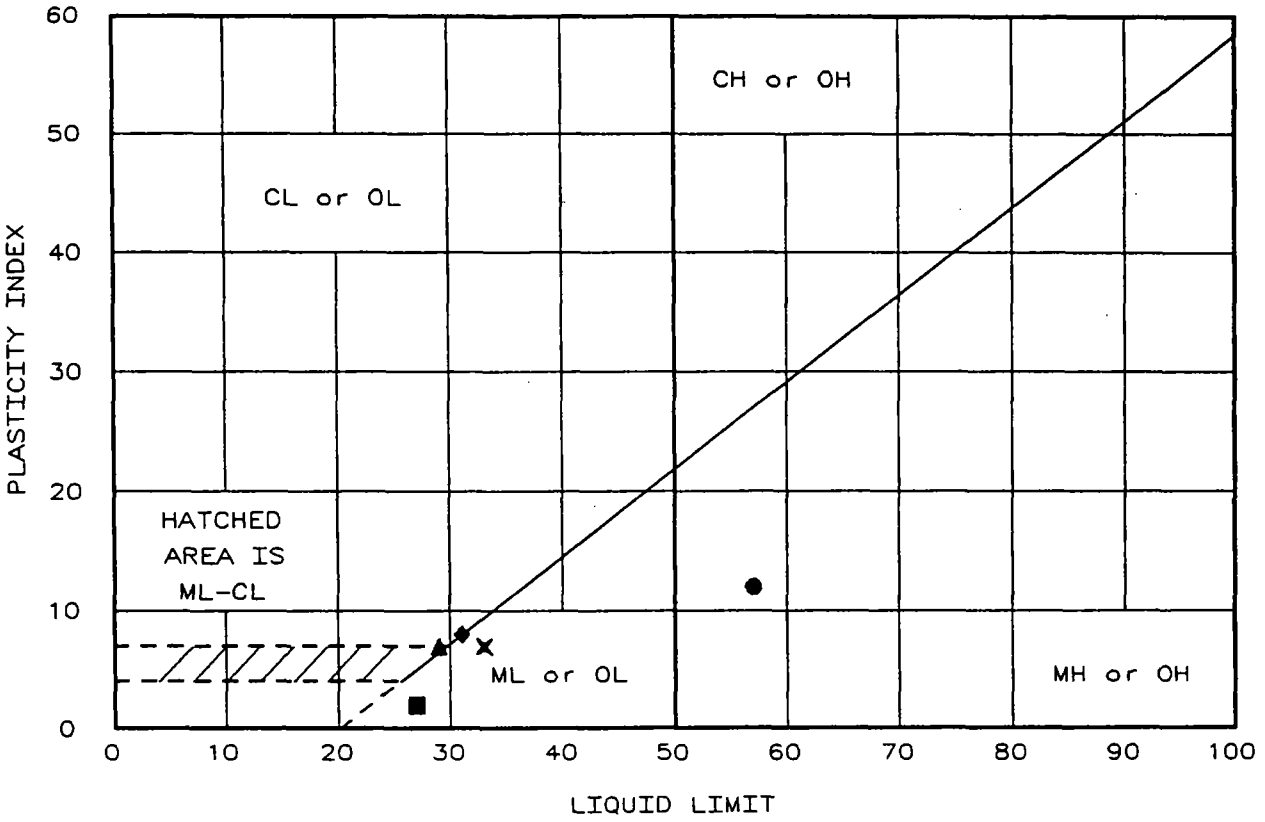
J-4072-25 3/25/99

Figure R-22

LIQUID AND PLASTIC LIMITS TEST REPORT



	Location + Description	LL	PL	PI	-200	ASTM D 2487-90
●	HC-2, S-7 Depth 15 to 17 feet	57	45	12		
▲	HC-3, S-11 Depth 26 to 28 feet	29	22	7		
■	HC-5, S-22 Depth 85.5 to 87.8 feet	27	25	2		
◆	HC-6, S-20 Depth 70 to 72 feet	31	23	8		
×	HC-8, S-7 Depth 50.5 to 52.5 feet	33	26	7		

Remarks:

Project: St. Paul Waterway

Client:

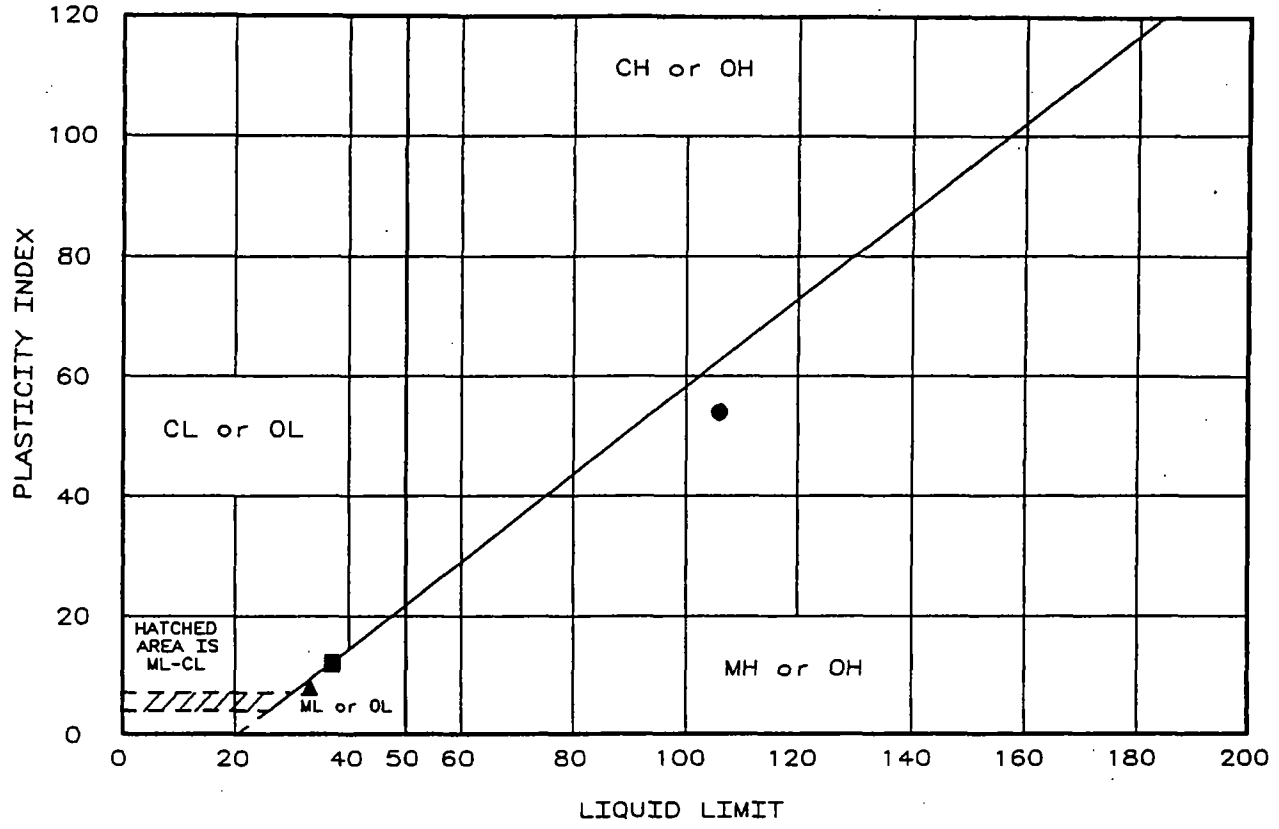
Location: Tacoma, Washington

HARTCROWSER

J-4072-25 3/17/99

Figure R-23 .

LIQUID AND PLASTIC LIMITS TEST REPORT



	Location + Description	LL	PL	PI	-200	ASTM D 2487-90
●	HC-2, S-3 Depth 5 to 6.5 feet	106	52	54		
▲	HC-3, S-18 Depth 47 to 49 feet	33	25	8		
■	HC-4, S-26 Depth 113 to 114.5 feet	37	25	12		

Remarks:

Project: St. Paul Waterway

Client:

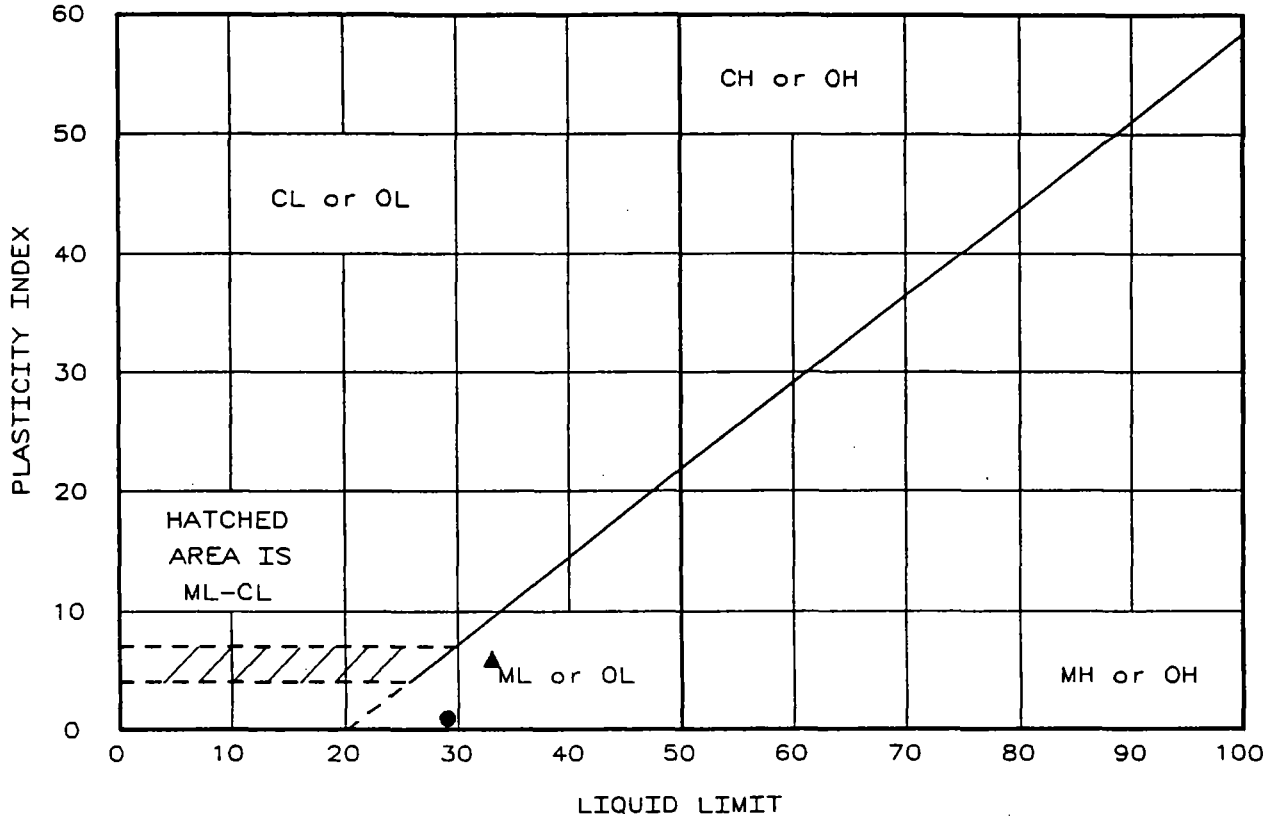
Location: Tacoma, Washington

HARTCROWSER

J-4072-25 3/23/99

Figure R-24

LIQUID AND PLASTIC LIMITS TEST REPORT



	Location + Description	LL	PL	PI	-200	ASTM D 2487-90
●	HC-3, S-10 Depth 24 to 26 feet	29	28	1		
▲	HC-6, S-15 Depth 54.5 to 56.5 feet	33	27	6		

Remarks:

Project: St. Paul Waterway

Client:

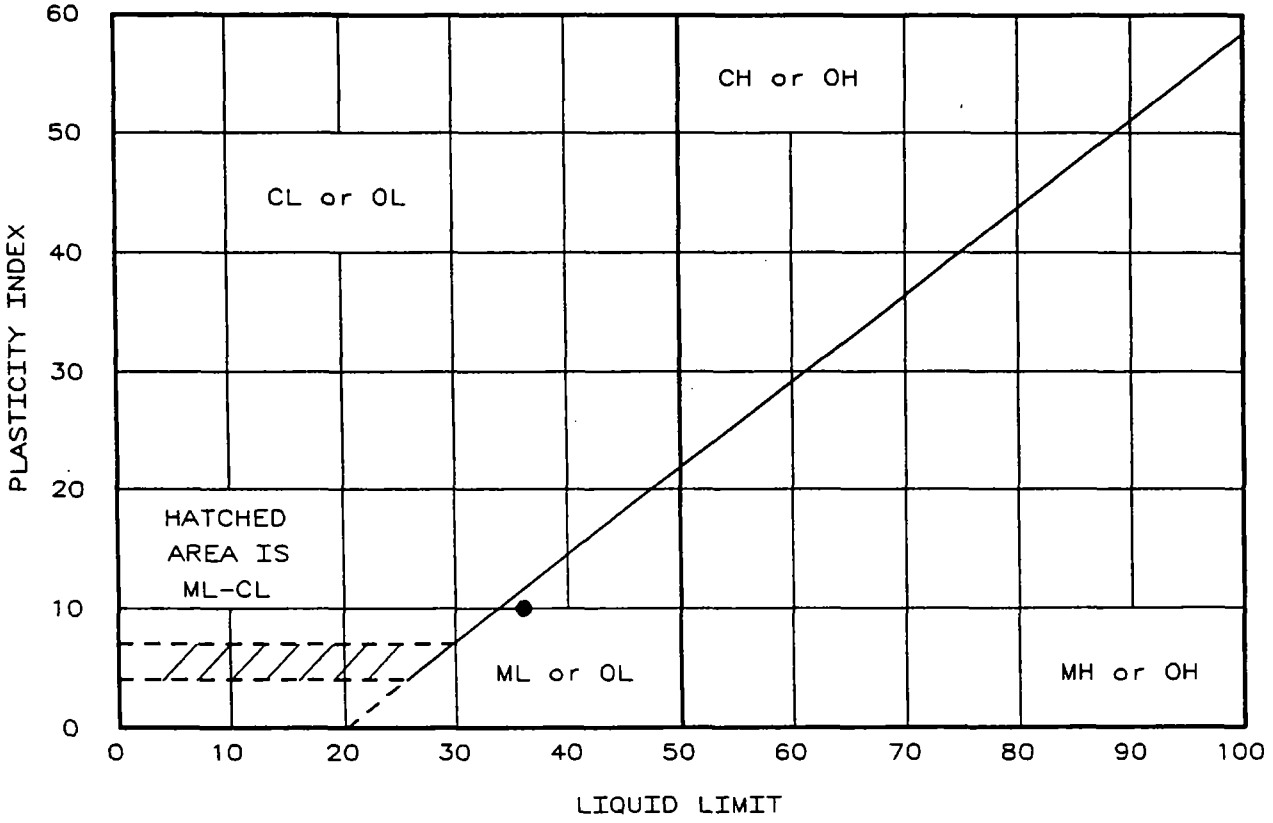
Location: Tacoma, Washington

HARTCROWSER

J-4072-25 5/11/99

Figure R-25

LIQUID AND PLASTIC LIMITS TEST REPORT



Location + Description	LL	PL	PI	-200	ASTM D 2487-90
● LC-01/12	36	26	10		

Remarks:

Project: St. Paul Waterway

Client:

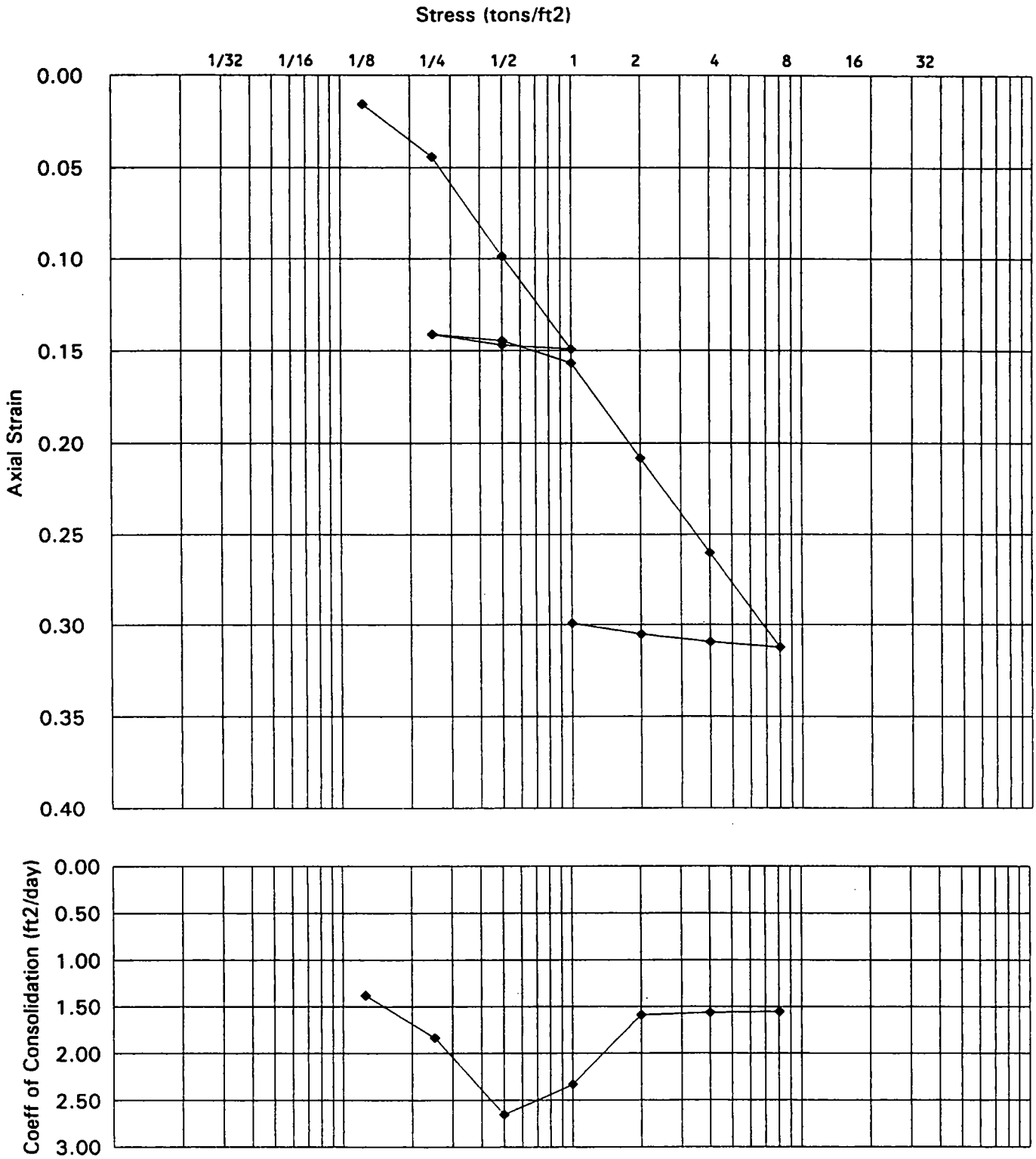
Location: Tacoma, Washington

HARTCROWSER

J-4072-25 3/26/99

Figure R-26

CONSOLIDATION TEST RESULTS



Expl. No.	Sample No.	Depth (ft)	W.C. % Before	W.C. % After	Atterberg Limit LL	Atterberg Limit PL	Atterberg Limit PI	Wet Wt (pcf)	USC	Description
HC-2	S-7	16	63%	44%	57	45	12	87 pcf	MH/OH	SILT and ORGANICS

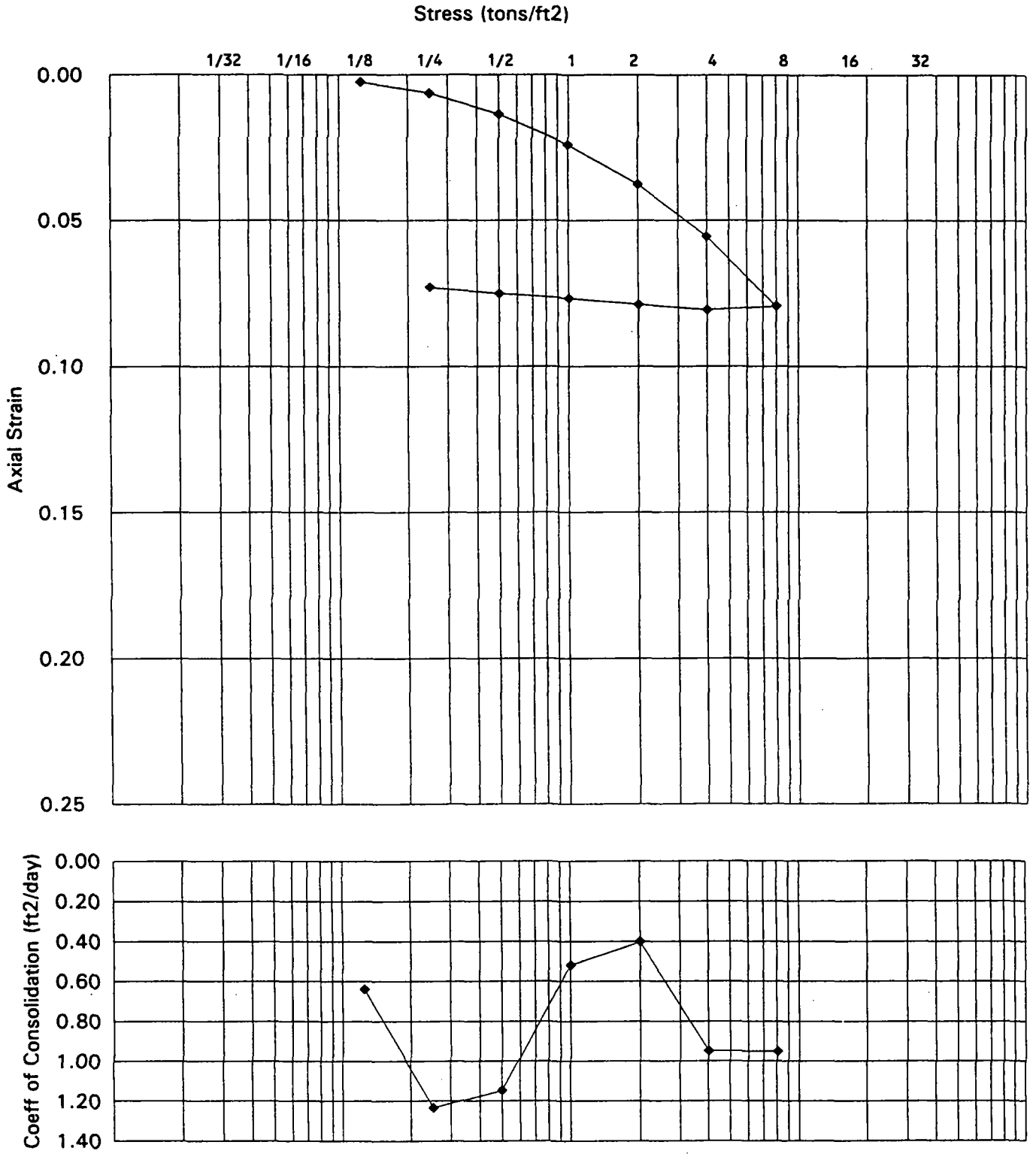
Remarks:

HARTCROWSER

3/17/99

Figure R-27

CONSOLIDATION TEST RESULTS



Expl. No.	Sample No.	Depth (ft)	W.C. % Before	W.C. % After	Atterberg Limit LL	Atterberg Limit PL	Atterberg Limit PI	Wet Wt (pcf)	USC	Description
HC-5	S-22	87	33%	32%	27	25	2	113 pcf	ML	SILT

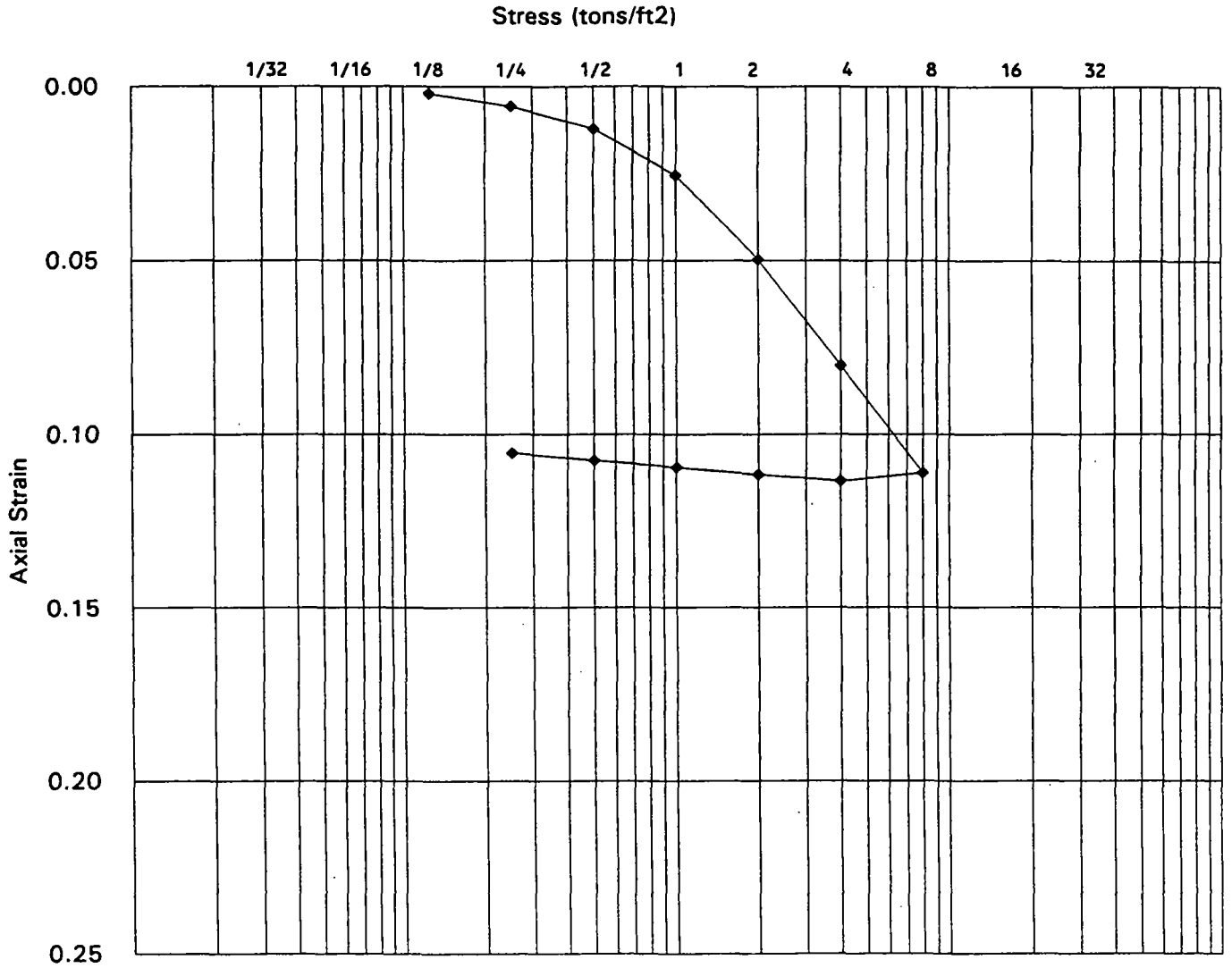
Remarks:

HARTCROWSER

3/17/99

Figure R-28

CONSOLIDATION TEST RESULTS



Expl. No.	Sample No.	Depth (ft)	W.C. %		Atterberg Limit			Wet Wt (pcf)	USC	Description
			Before	After	LL	PL	PI			
HC-6	S-20	71	33%	30%	31	23	8	113 pcf	ML	SILT

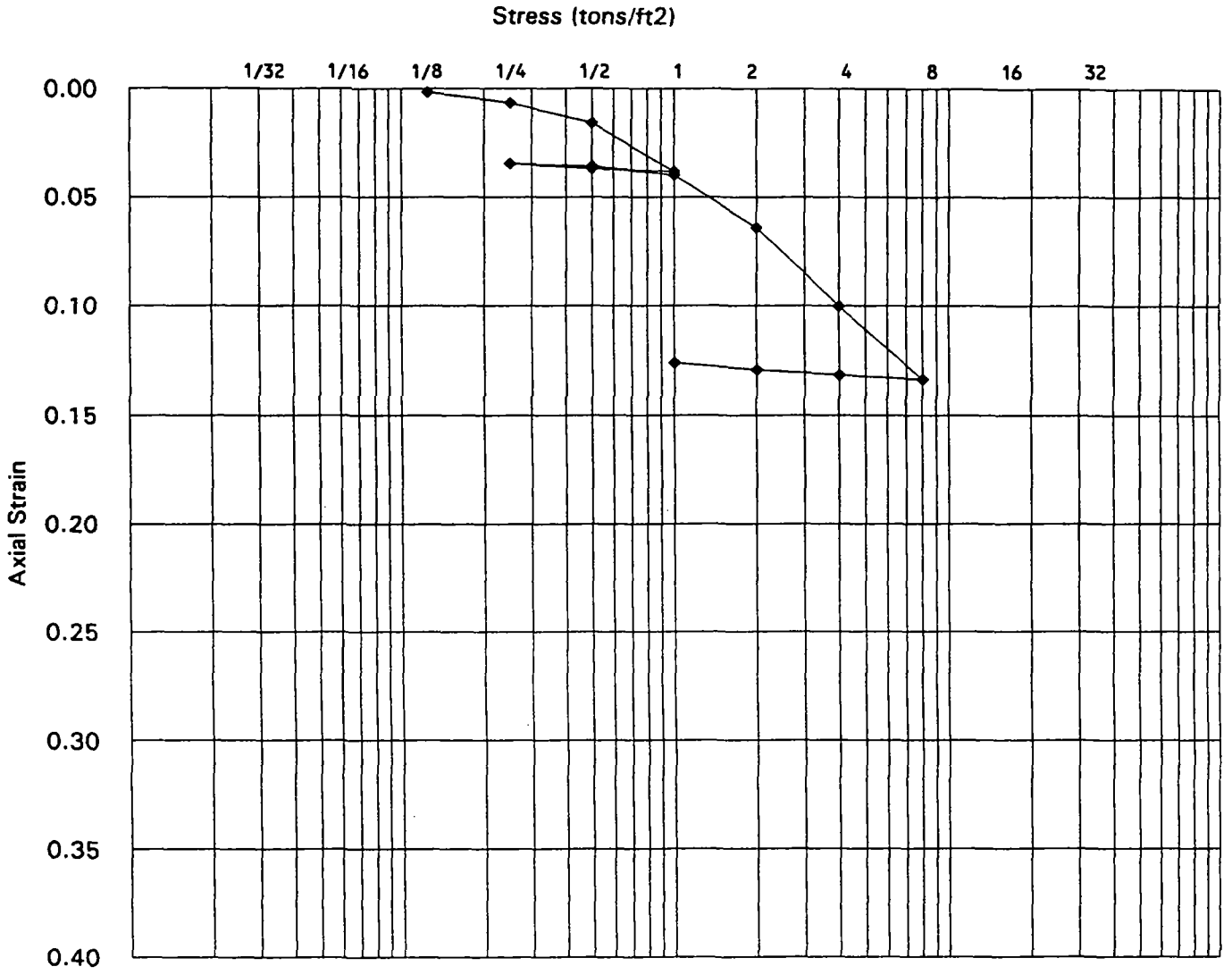
Remarks:

HARTCROWSER

3/17/99

Figure R-29

CONSOLIDATION TEST RESULTS



Expl. No.	Sample No.	Depth (ft)	W.C. % Before	W.C. % After	Atterberg Limit LL	Atterberg Limit PL	Atterberg Limit PI	Wet Wt (pcf)	USC	Description
HC-8	S-7	52	38%	34%	33	26	7	110 pcf	ML	SILT

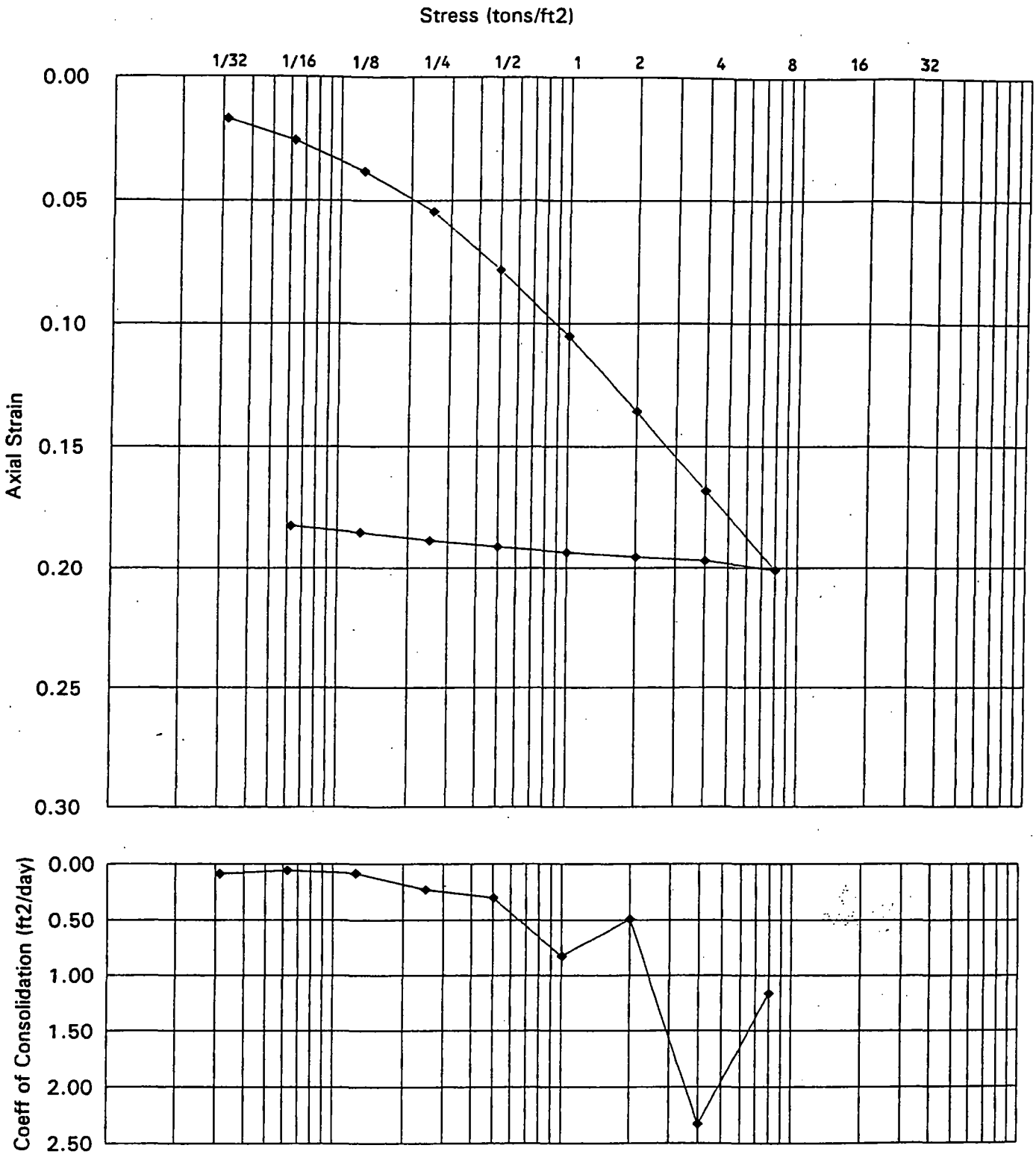
Remarks:

HARTCROWSER

3/17/99

Figure R-30

CONSOLIDATION TEST RESULTS



Expl. No.	Sample No.	Depth (ft)	W.C. %		Atterberg Limit			Wet Wt (pcf)	USC	Description
			Before	After	LL	PL	PI			
*	LC-01/12	*	40%	25%	36	26	10	112 pcf	ML	*

Remarks: The sample tested was in reduced moisture condition

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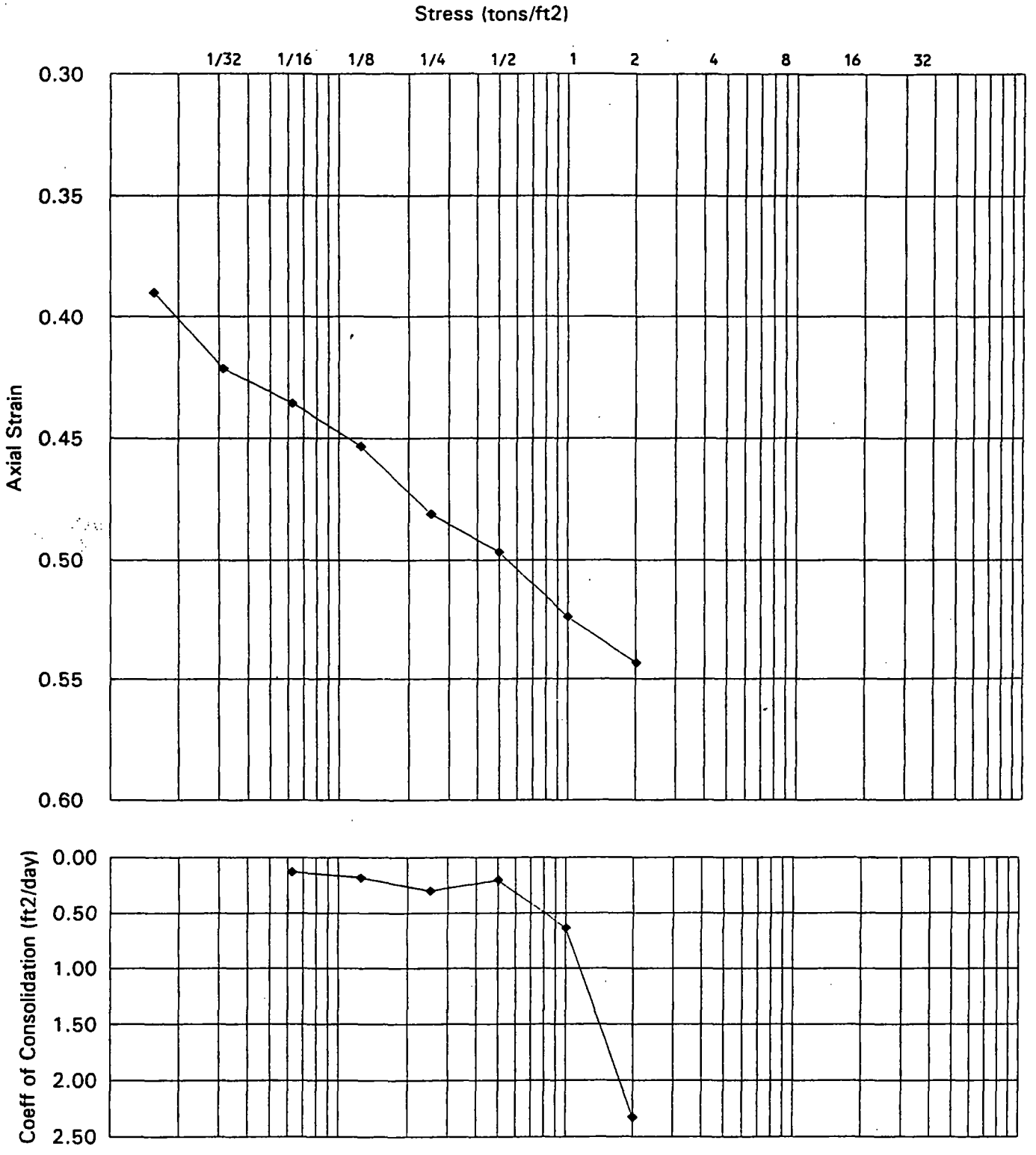
J-4072-25 4/2/99

Figure R-31

CONSOLIDATION TEST RESULTS



Expl. No.	Sample No.	Depth (ft)	W.C. % Before	W.C. % After	Atterberg Limit LL	Atterberg Limit PL	Atterberg Limit PI	Wet Wt (pcf)	USC	Description
*	LC-01/12	*	128%	37%	*	*	*	88 pcf	ML	*

Remarks: The sample tested was in slurry condition

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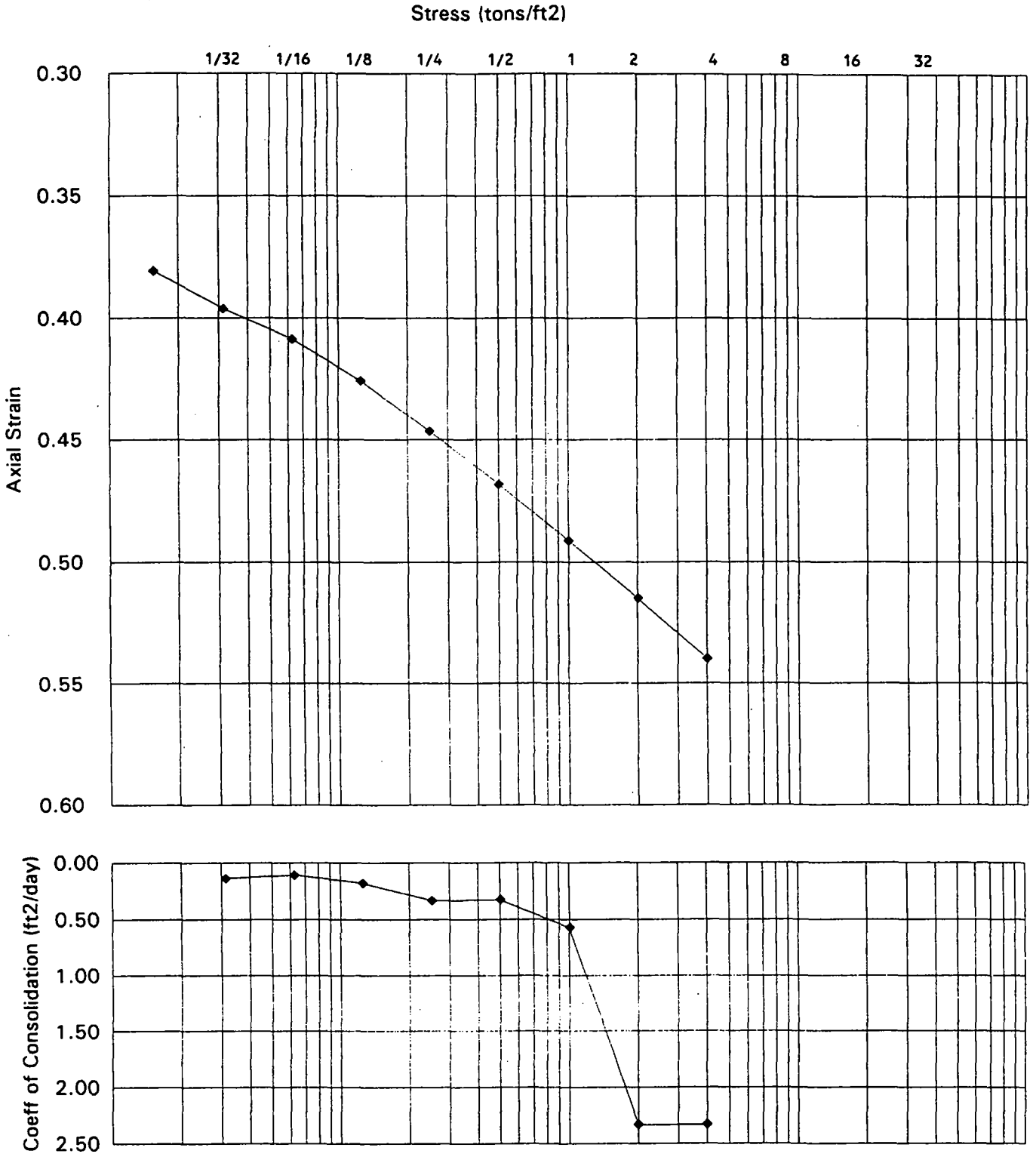
J-4072-25 5/20/99

Figure R-32

CONSOLIDATION TEST RESULTS



Expl. No.	Sample No.	Depth (ft)	W.C. % Before	W.C. % After	Atterberg Limit LL	Atterberg Limit PL	Atterberg Limit PI	Wet Wt (pcf)	USC	Description
*	LC-01/12	*	113%	32%	*	*	*	88 pcf	ML	*

Remarks: The sample tested was in slurry condition

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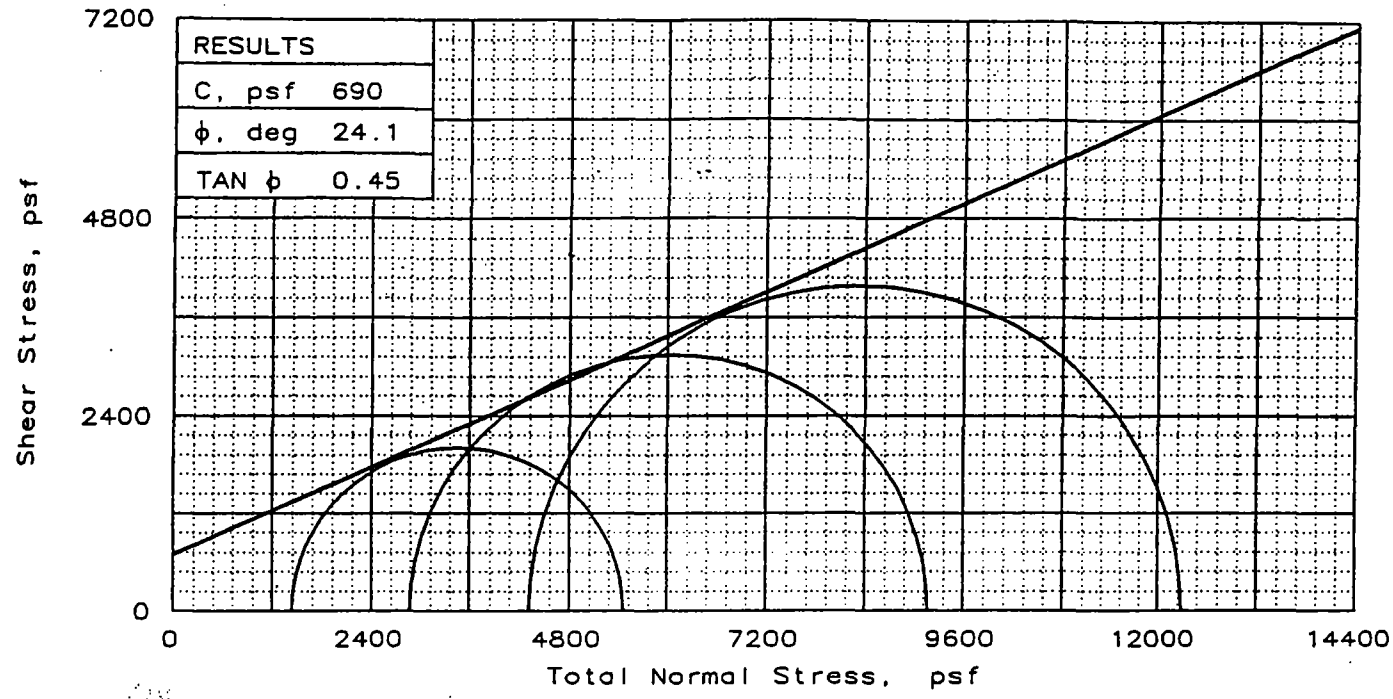
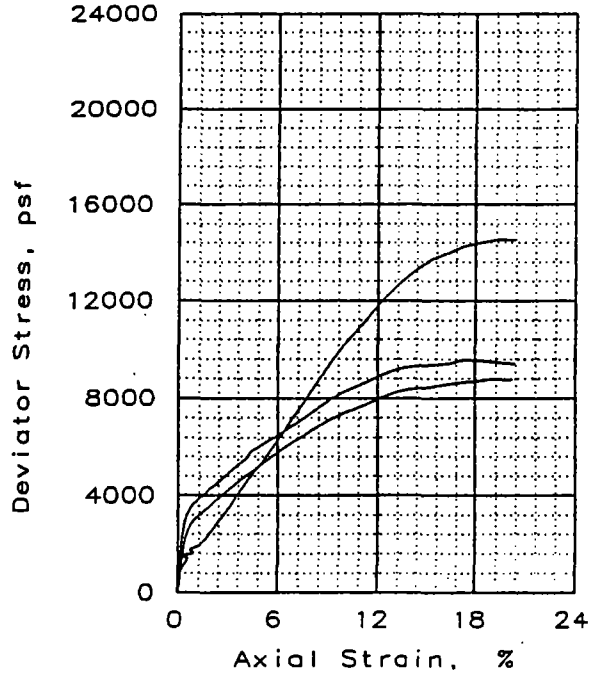
J-4072-25 6/18/99

Figure R-33





SAMPLE NO.		1	2	3
INITIAL	WATER CONTENT, %	34.8	36.6	36.7
	DRY DENSITY, pcf	85.2	82.2	82.5
	SATURATION, %	98.0	95.7	96.6
	VOID RATIO	0.941	1.013	1.006
	DIAMETER, cm	7.25	7.25	7.25
	HEIGHT, cm	15.24	15.24	15.24
AT TEST	WATER CONTENT, %	31.1	31.4	31.4
	DRY DENSITY, pcf	89.7	84.3	86.8
	SATURATION, %	97.5	86.3	91.8
	VOID RATIO	0.845	0.963	0.907
	DIAMETER, cm	7.13	7.19	7.13
	HEIGHT, cm	14.99	15.11	14.99
BACK PRESSURE, psf		4320	4320	4320
CELL PRESSURE, psf		5760	7200	8640
FAILURE STRESS, psf		4019	6296	7973
PORE PRESSURE, psf		4766	5443	6221
STRAIN RATE, %/min.		1.333	1.333	1.333
ULTIMATE STRESS, psf		4019	6296	7973
PORE PRESSURE, psf		4766	5443	6221
$\bar{\sigma}_1$ FAILURE, psf		5012	8053	10393
$\bar{\sigma}_3$ FAILURE, psf		994	1757	2419

TYPE OF TEST:
CU with pore pressures
SAMPLE TYPE: Shelby Tube
DESCRIPTION:

LL= PL= PI=
SPECIFIC GRAVITY= 2.65
REMARKS: The tested samples were obtained from two different borings

CLIENT:

PROJECT: St. Paul Waterway

SAMPLE LOCATION: HC-3,S-10 and HC-6,S-15

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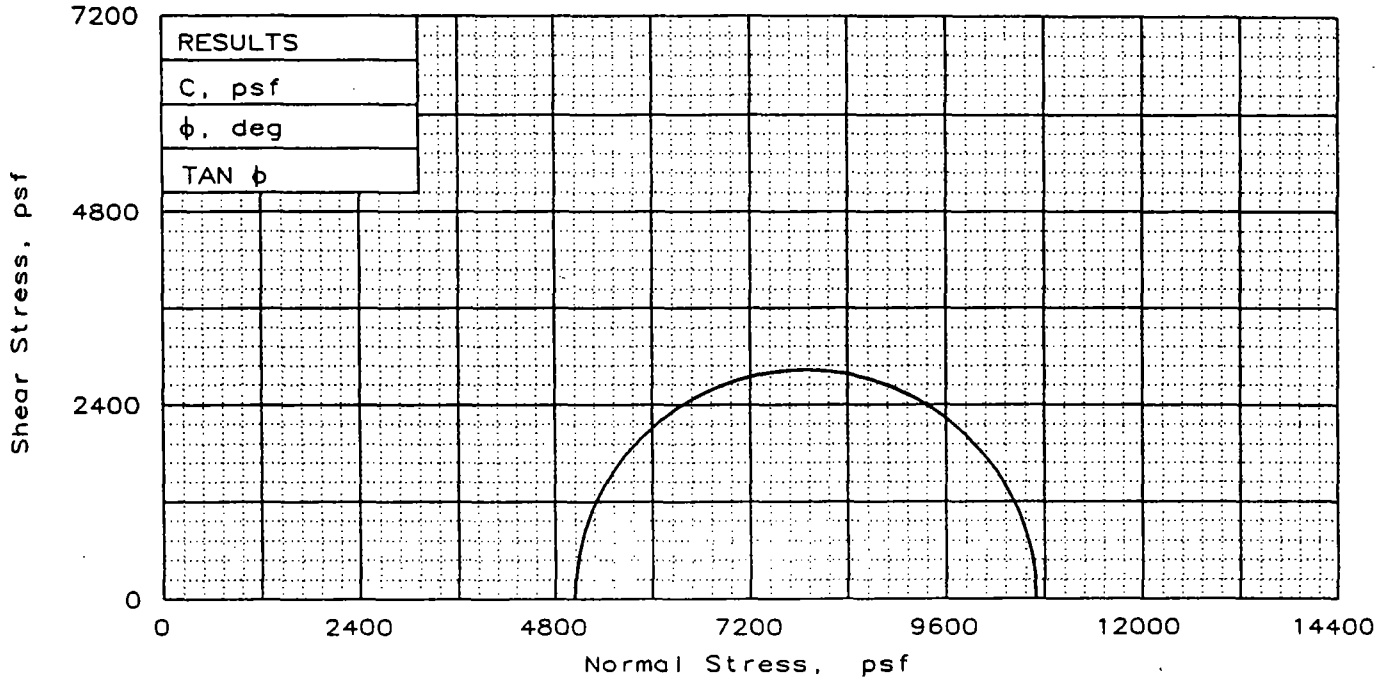
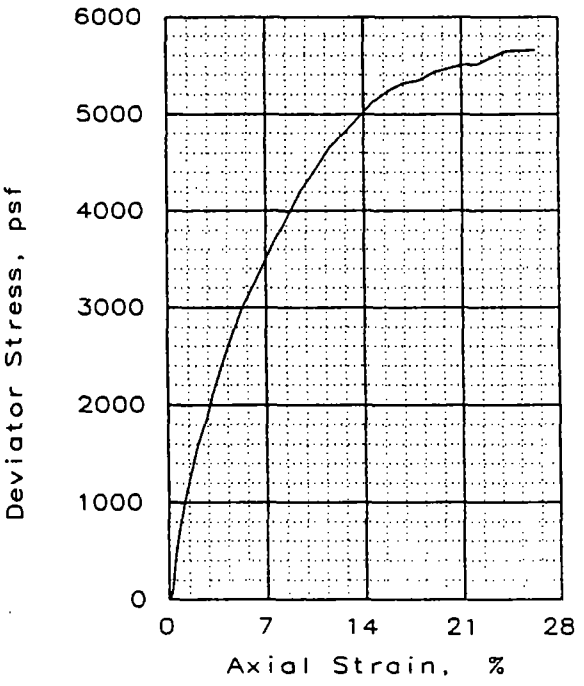
4072-25 5/10/99

Figure R-34





SAMPLE NO.		1
INITIAL	WATER CONTENT, %	31.1
	DRY DENSITY, pcf	91.1
	SATURATION, %	101.1
	VOID RATIO	0.816
	DIAMETER, cm	7.25
	HEIGHT, cm	13.84
AT TEST	WATER CONTENT, %	31.0
	DRY DENSITY, pcf	96.3
	SATURATION, %	114.3
	VOID RATIO	0.719
	DIAMETER, cm	7.12
	HEIGHT, cm	13.59
BACK PRESSURE, psf		0
CELL PRESSURE, psf		5040
FAILURE STRESS, psf		5658
PORE PRESSURE, psf		
STRAIN RATE, %/min.		1.000
ULTIMATE STRESS, psf		
PORE PRESSURE, psf		
σ_1 FAILURE, psf		10698
σ_3 FAILURE, psf		5040

TYPE OF TEST:
Unconsolidated undrained
SAMPLE TYPE:
DESCRIPTION:

LL= 27 PL= 25 PI= 2.0
SPECIFIC GRAVITY= 2.65
REMARKS:

CLIENT:

PROJECT: St. Paul Waterway

SAMPLE LOCATION: HC-5, S-22

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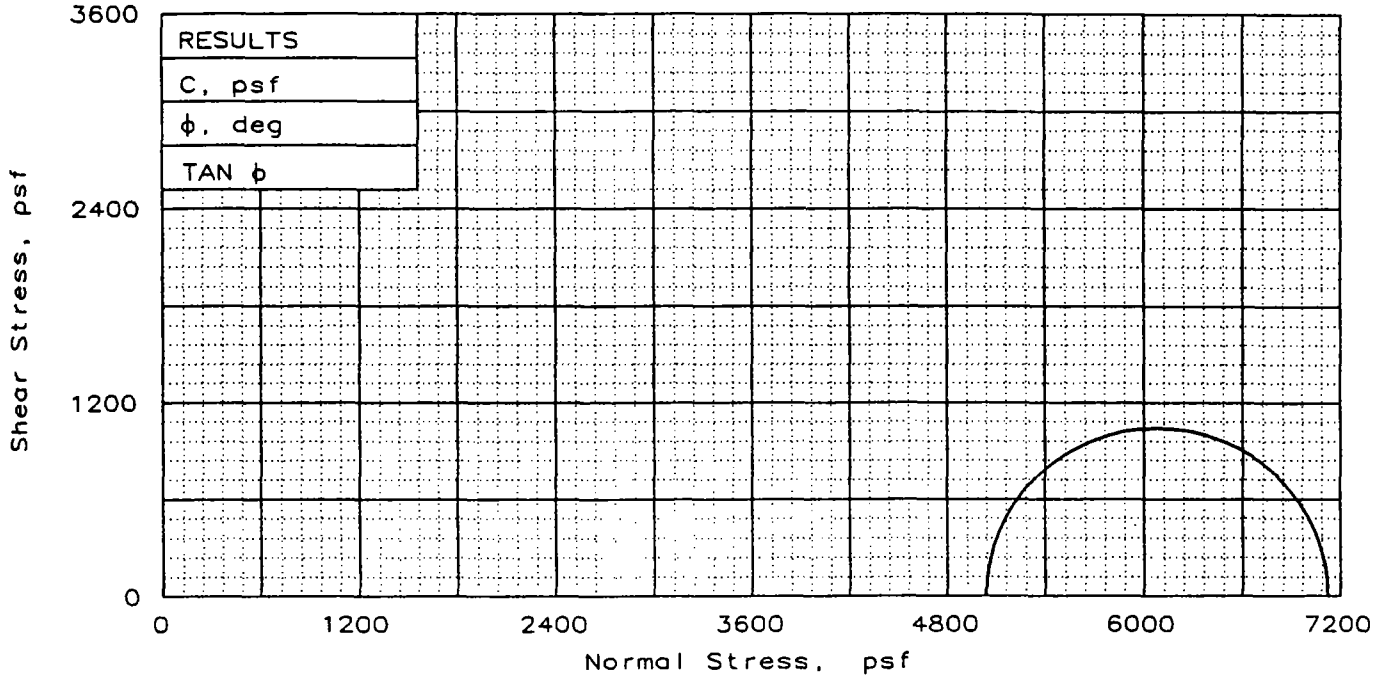
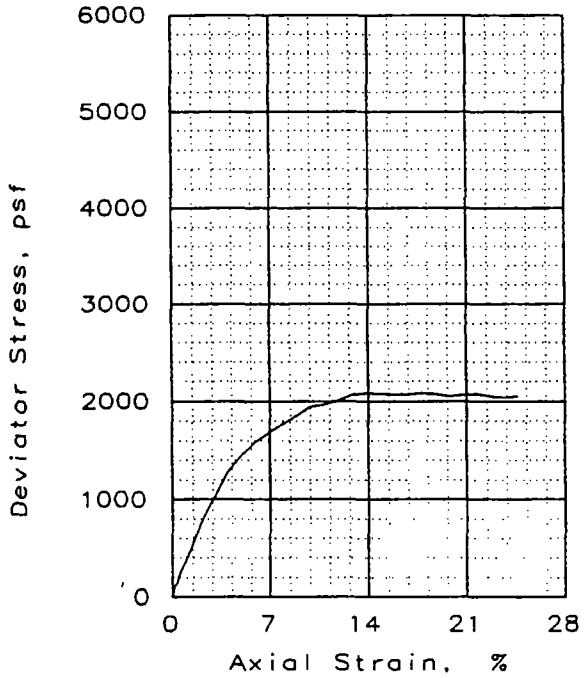
4072-25 3/18/99

Figure R-35





SAMPLE NO.		1
INITIAL	WATER CONTENT, %	31.8
	DRY DENSITY, pcf	92.1
	SATURATION, %	105.8
	VOID RATIO	0.796
	DIAMETER, cm	7.23
	HEIGHT, cm	14.80
AT TEST	WATER CONTENT, %	32.3
	DRY DENSITY, pcf	97.0
	SATURATION, %	121.2
	VOID RATIO	0.706
	DIAMETER, cm	7.11
	HEIGHT, cm	14.55
BACK PRESSURE, psf		0
CELL PRESSURE, psf		5040
FAILURE STRESS, psf		2081
PORE PRESSURE, psf		
STRAIN RATE, %/min.		1.000
ULTIMATE STRESS, psf		
PORE PRESSURE, psf		
σ_1 FAILURE, psf		7121
σ_3 FAILURE, psf		5040

TYPE OF TEST:
Unconsolidated undrained
SAMPLE TYPE:
DESCRIPTION:

LL= 31 PL= 23 PI= 8.0
SPECIFIC GRAVITY= 2.65
REMARKS:

CLIENT:

PROJECT: St. Paul Waterway

SAMPLE LOCATION: HC-6, S-20

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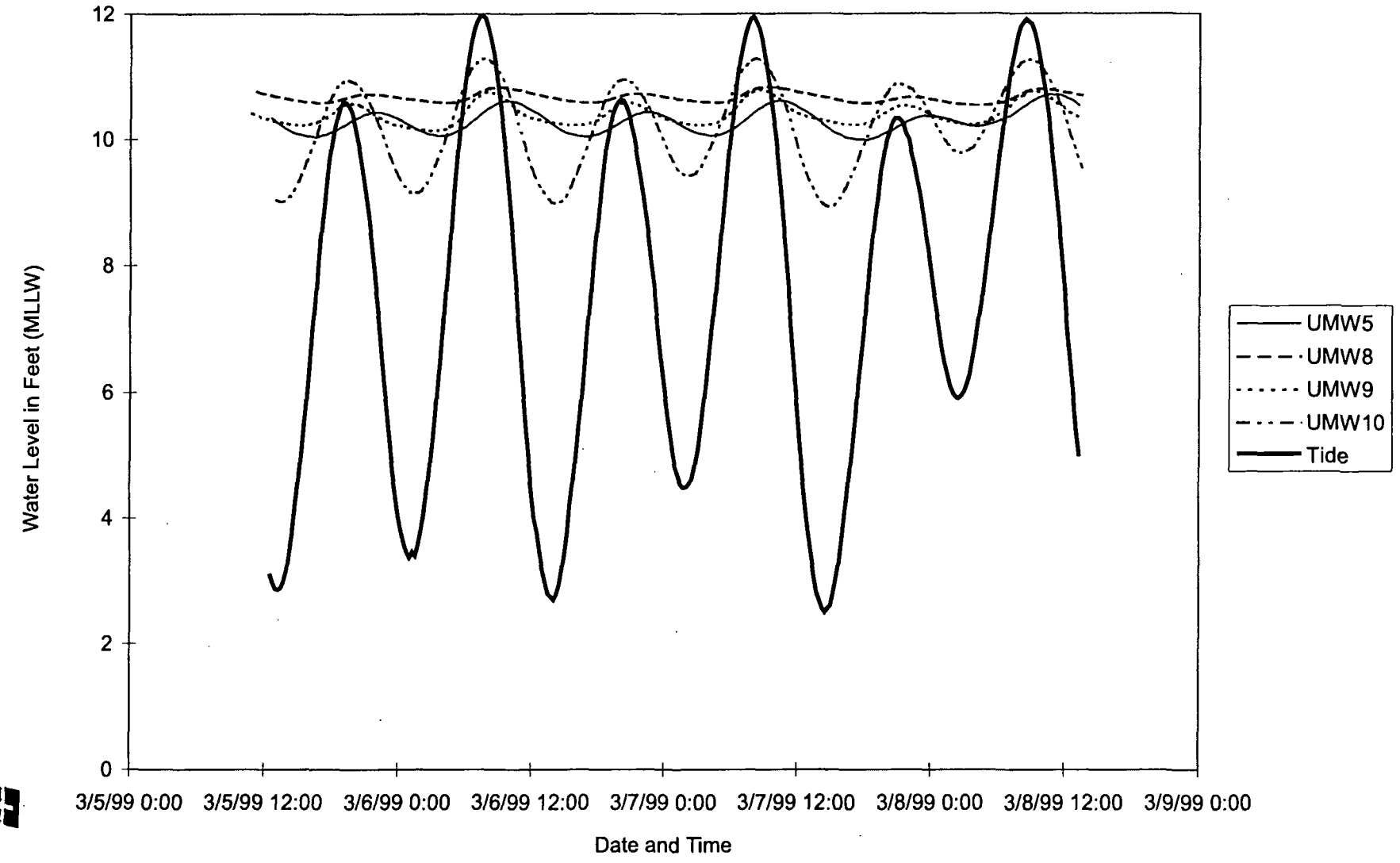
4072-25 3/18/99

Figure R-36

Measured Groundwater and Tide Elevations



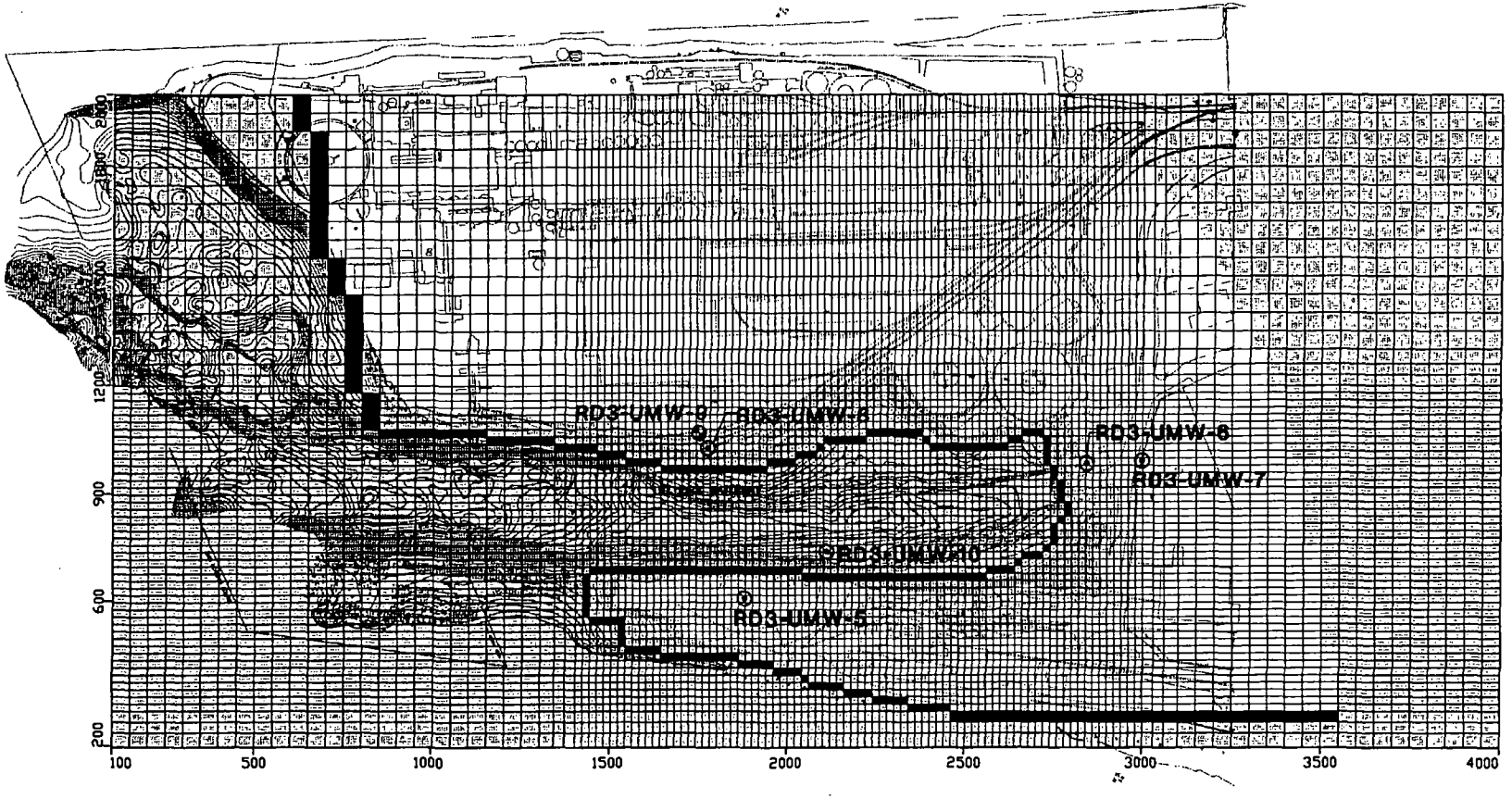
HARTCROWSER
J-4072-25 6/99
Figure R-37

407223\COREL\TIDE ELEVATIONS

CVD 7/7/99 I=[illegible]DSTK-B.PC2 XREF=BASE23 40722554

Site Map with Model Grid

Pre-Construction



Monitoring Well Location and Number

⊙RD3-UMW-5 Monitoring Well Installed by Parametrix, 1997

⊙RD3-UMW-9 Monitoring Well Installed by Hart Crowser, 1999

No Flow Cell

Constant Head Boundary

N

0 500 1000

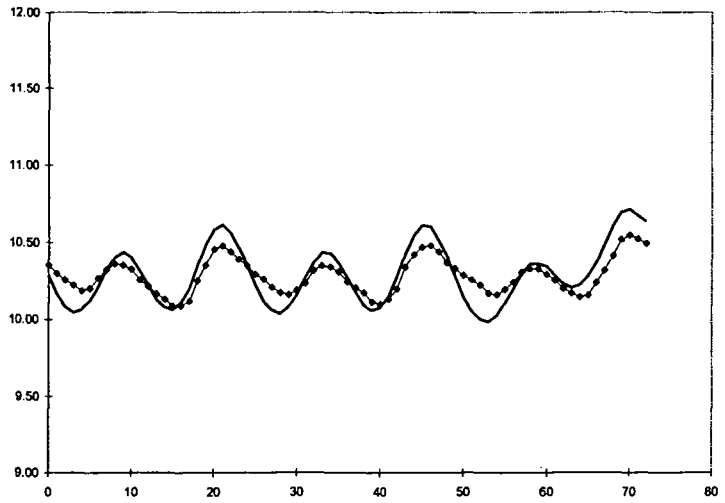
Scale in Feet

HARTCROWSER

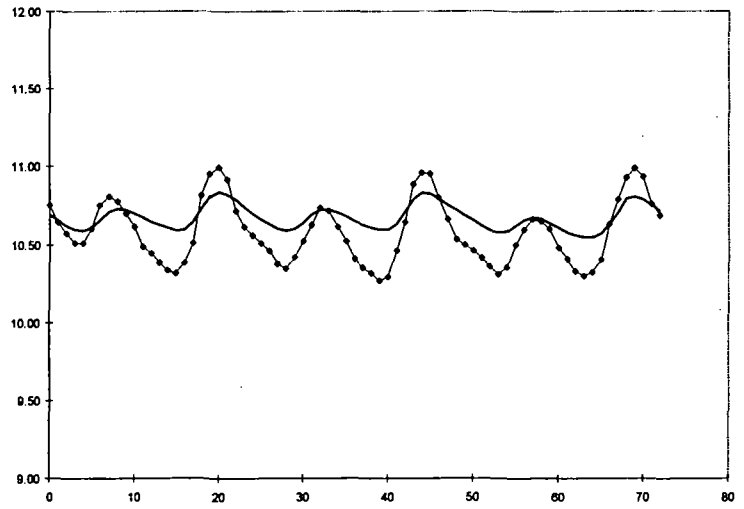
J-4072-25 7/99

Figure R-38

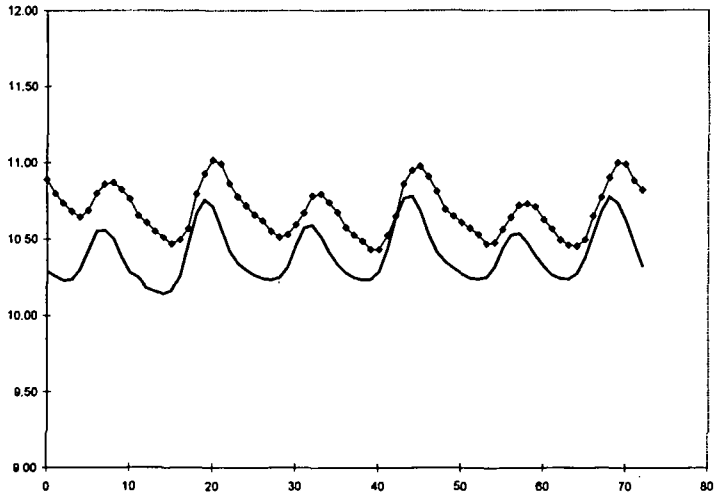
Pre-Construction Groundwater Flow Model Calibration Results



RD3-UMW5



RD3-UMW8



RD3-UMW9

Measured

Predicted

Root Mean Squared Errors

Well	RMS in Feet
RD3-UMW5	0.10
RD3-UMW8	0.16
RD3-UMW9	0.31

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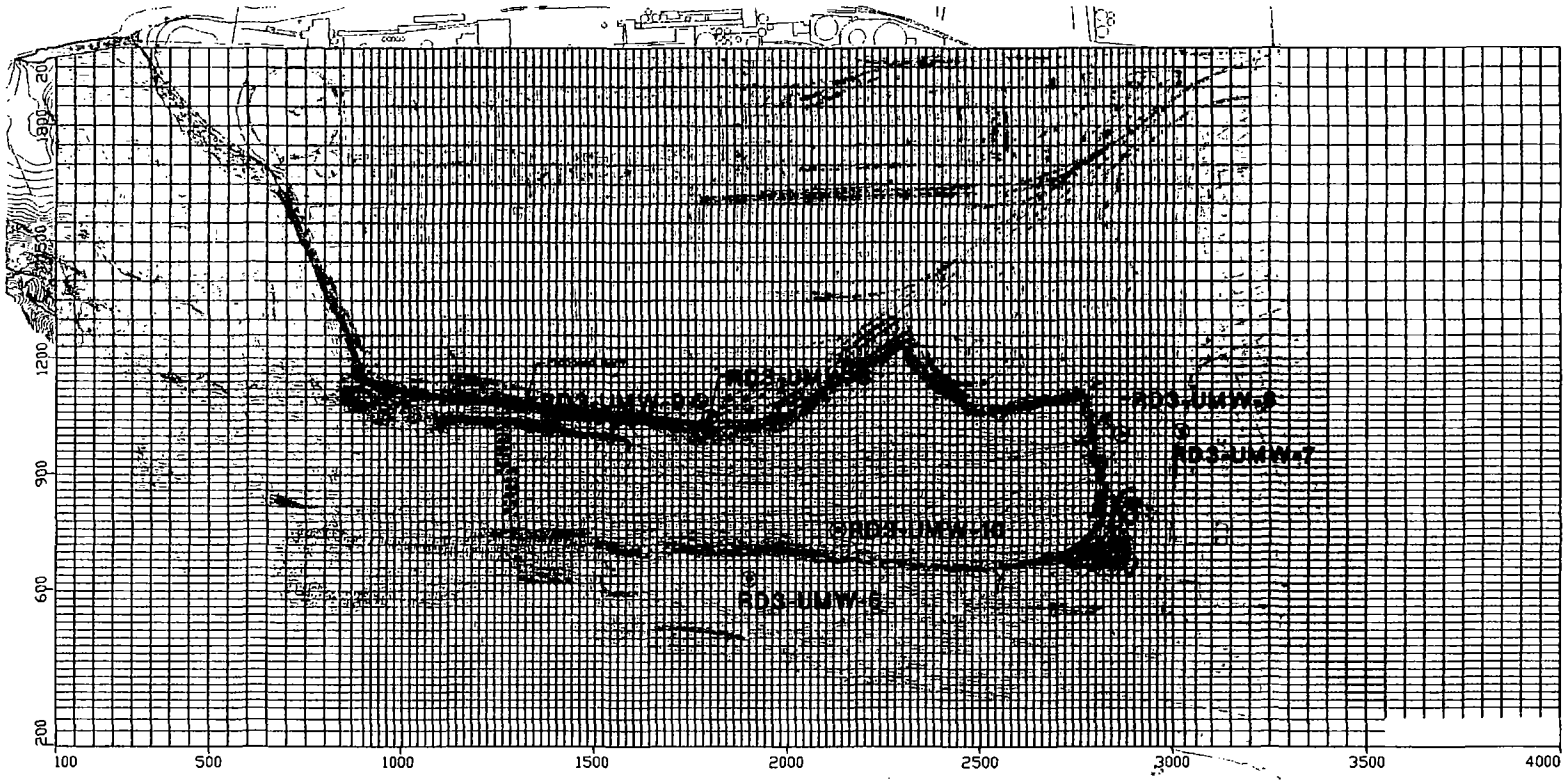
Figure R-39

407223\COREL\FLOW MODEL

CVD 7/7/99 1=1 XREF=BASE23 COLOR.PC2 40722555

Site Map with Model Grid

Post-Construction



Monitoring Well Location and Number

⊙ **RD3-UMW-5** Monitoring Well Installed by Parametrix, 1997

⊕ **RD3-UMW-9** Monitoring Well Installed by Hart Crowser, 1999

Upland Fill (1)

Thea Foss Waterway Sediments

Constant Head Boundary

Upland Fill (2)

St. Paul Waterway Berm Material

Structural Fill Berm Material

N

0 500 1000

Scale in Feet

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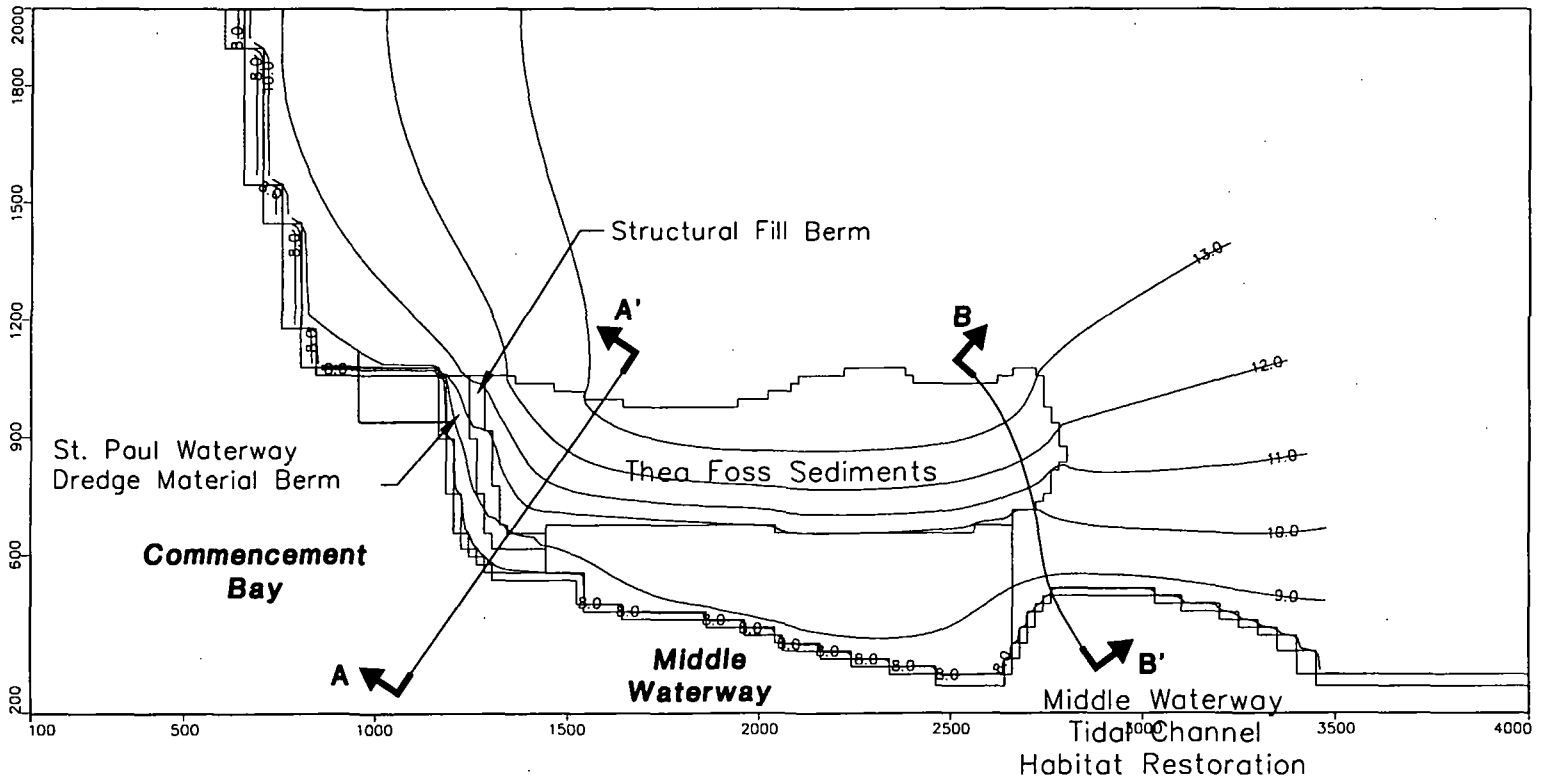
Figure R-40

CVD 7/1/99 1=500 Woodstck-8.pc2 40722551

Predicted Average Post-Construction Groundwater Levels



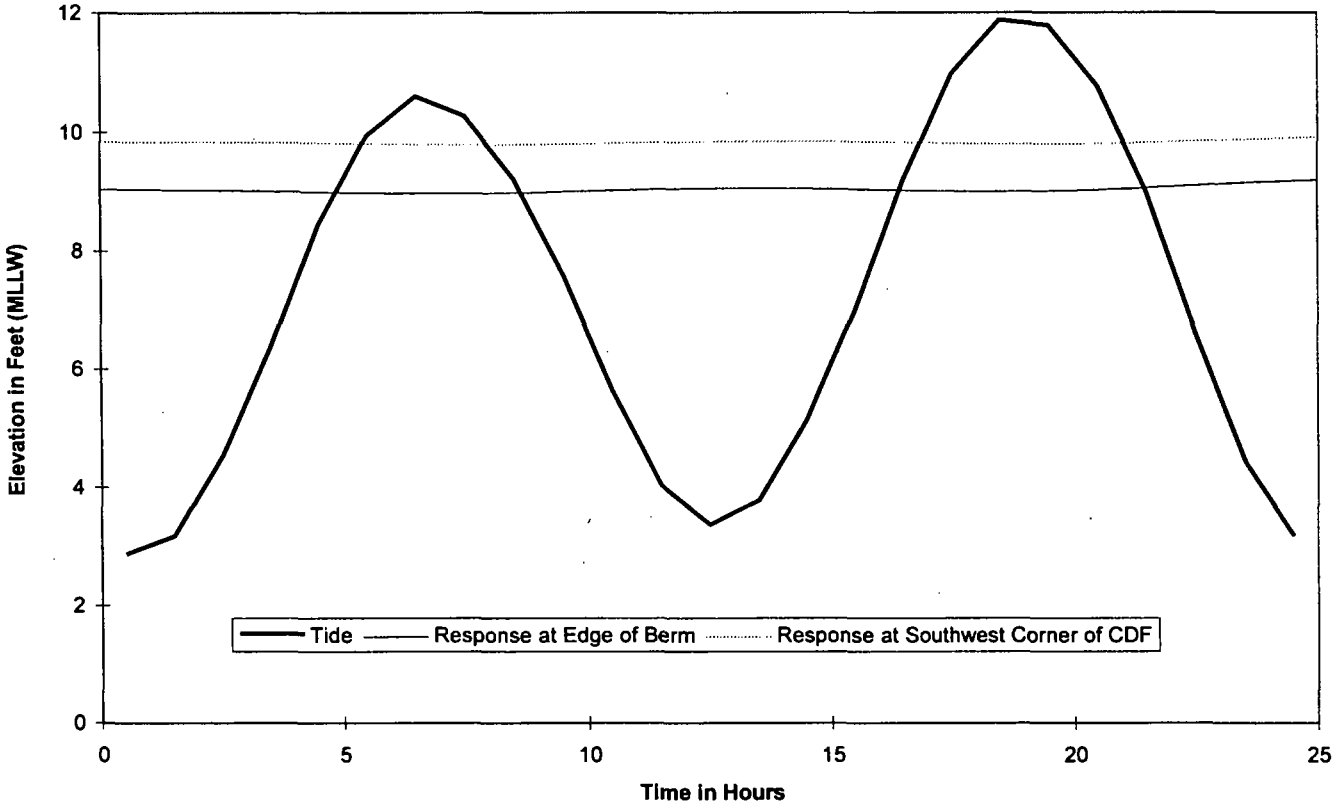
0 500 1000
Scale in Feet

AA' Model Grid Cross Section Location and Designation

10.0 Predicted Groundwater Level Elevation in Feet

HARTCROWSER
J-4072-25 7/99
Figure R-41

Tidal Response in St. Paul Waterway CDF



407225\Corel\RESPONSE

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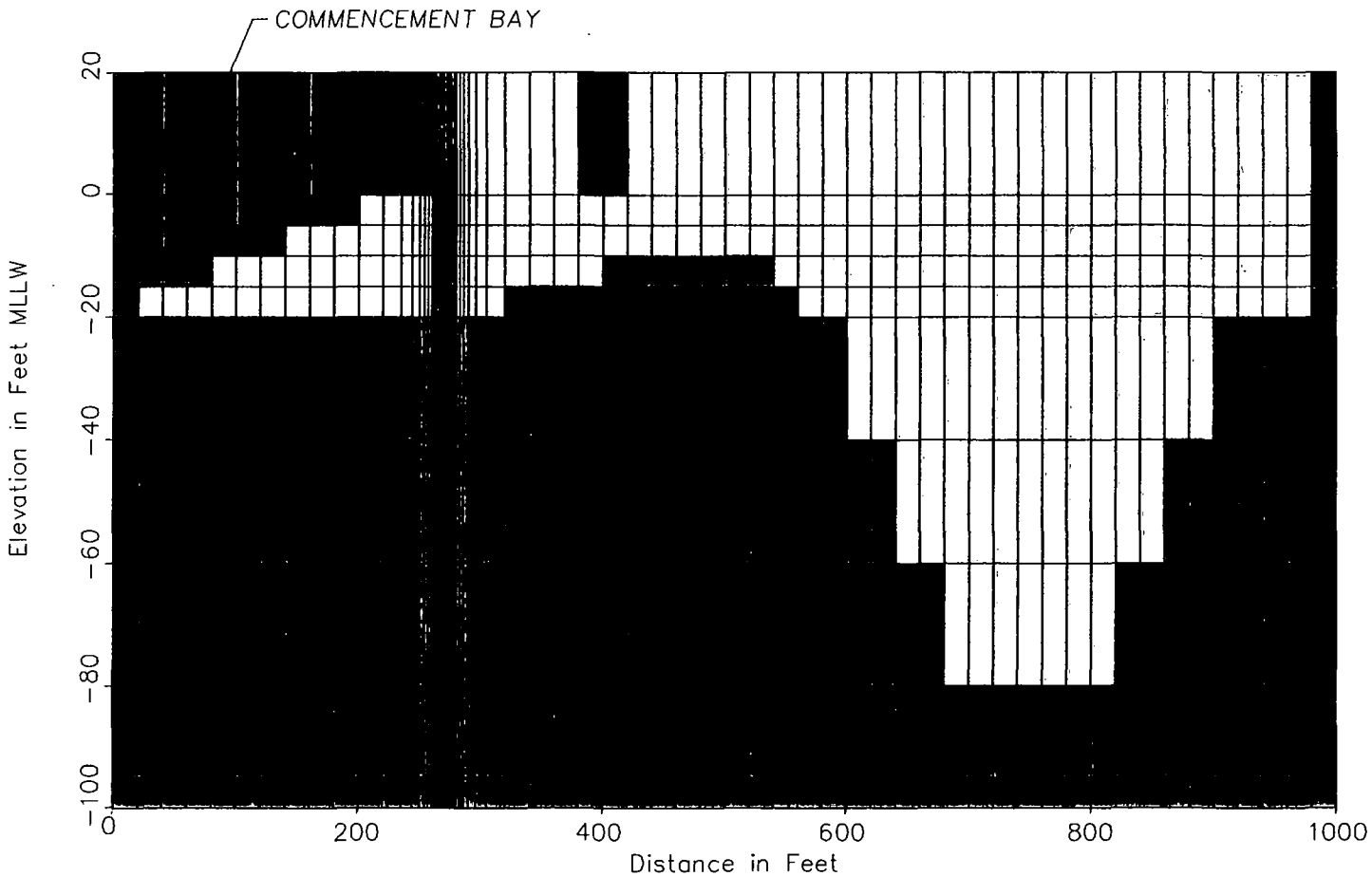
J-4072-25 7/99

Figure R-42

CVD 7/7/99 1=150 COLOR.PC2 40722550

Cross Section A-A' Model Grid



Horizontal Scale in Feet
0 150 300
0 30 60
Vertical Scale in Feet
Vertical Exaggeration x 5

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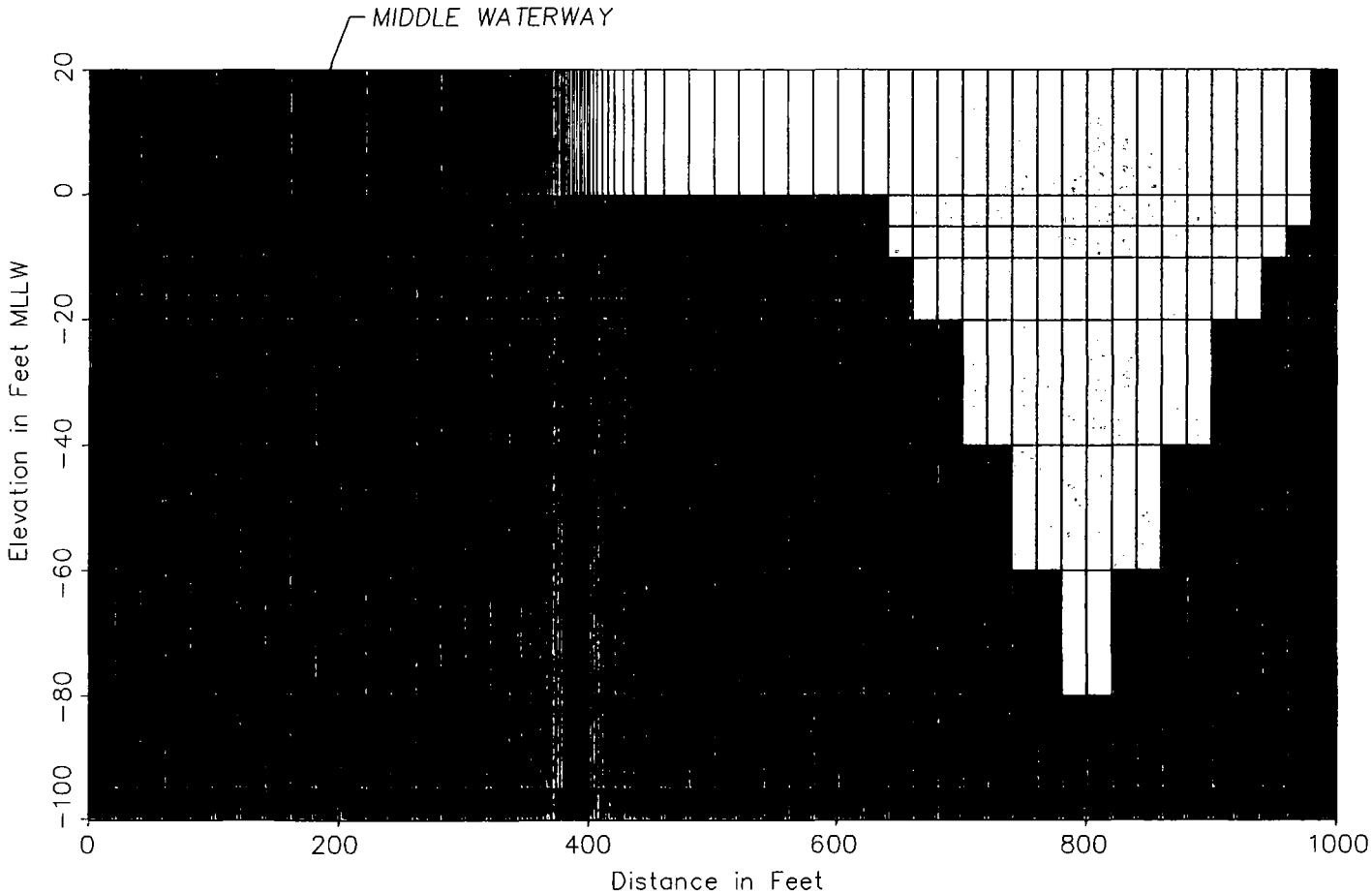
J-4072-25 7/99
Figure R-43

CVD 7/7/99 1=150 COLOR PC2 40722552

Cross Section B-B' Model Grid



Horizontal Scale in Feet
0 150 300
0 30 60
Vertical Scale in Feet
Vertical Exaggeration x 5

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Figure R-44

Comparison of Transient Dispersion and Steady-State with Effective Dispersivity

Transport Section A-A'

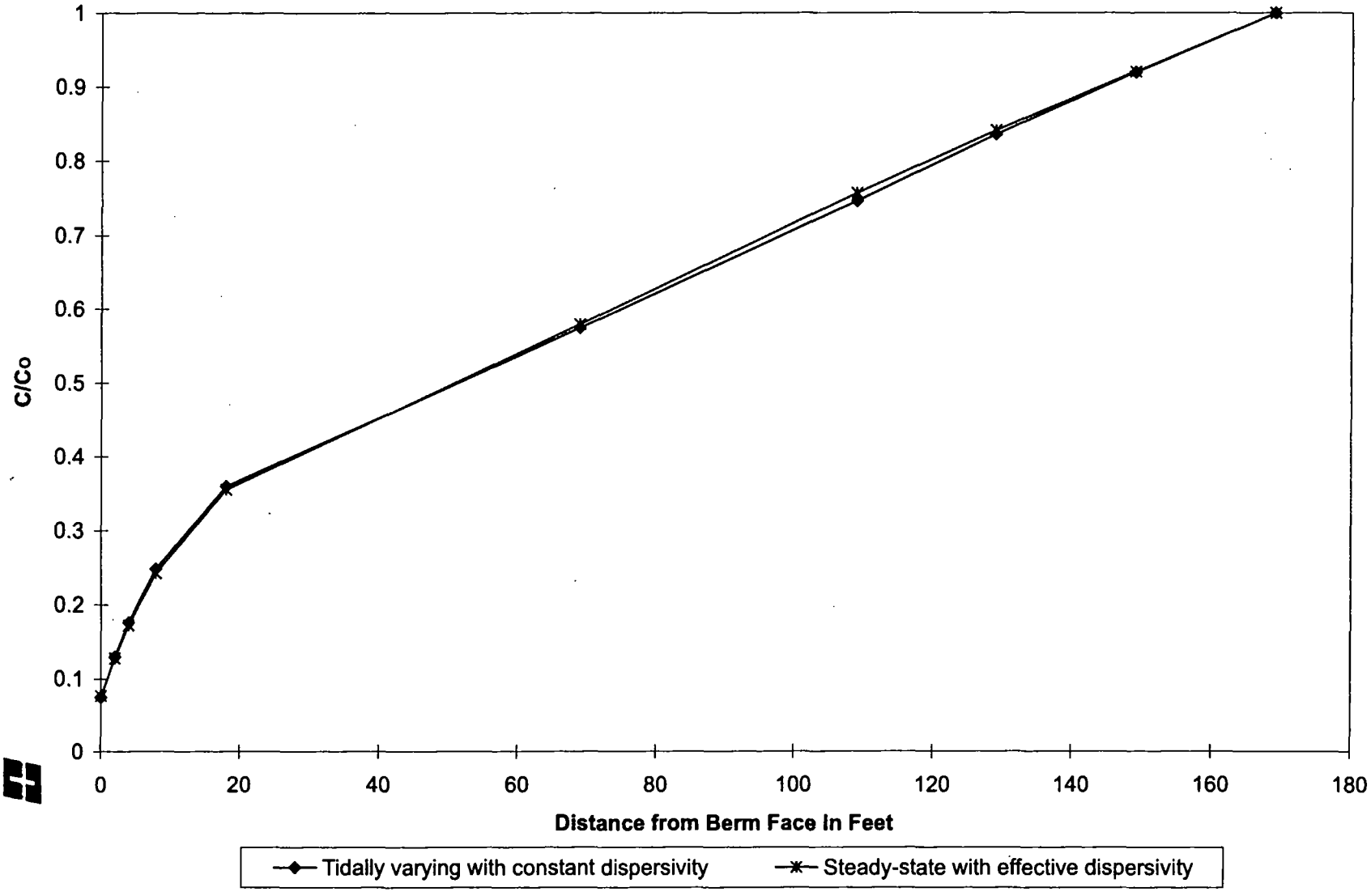

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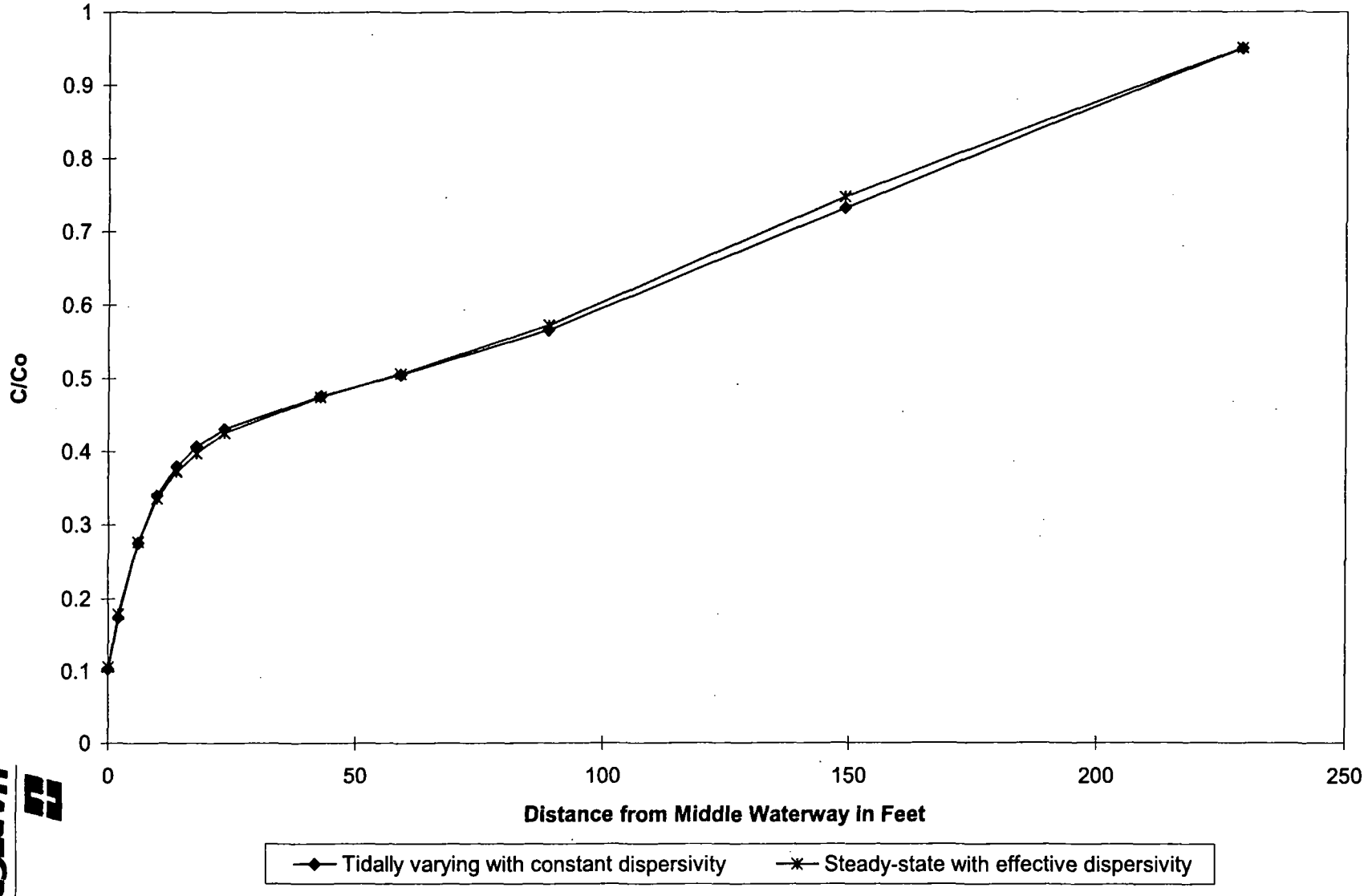
Figure R-45

407225\core\TRANSIENT (App-R.xls)

Comparison of Transient Dispersion and Steady-State with Effective Dispersivity

Transport Section B-B'



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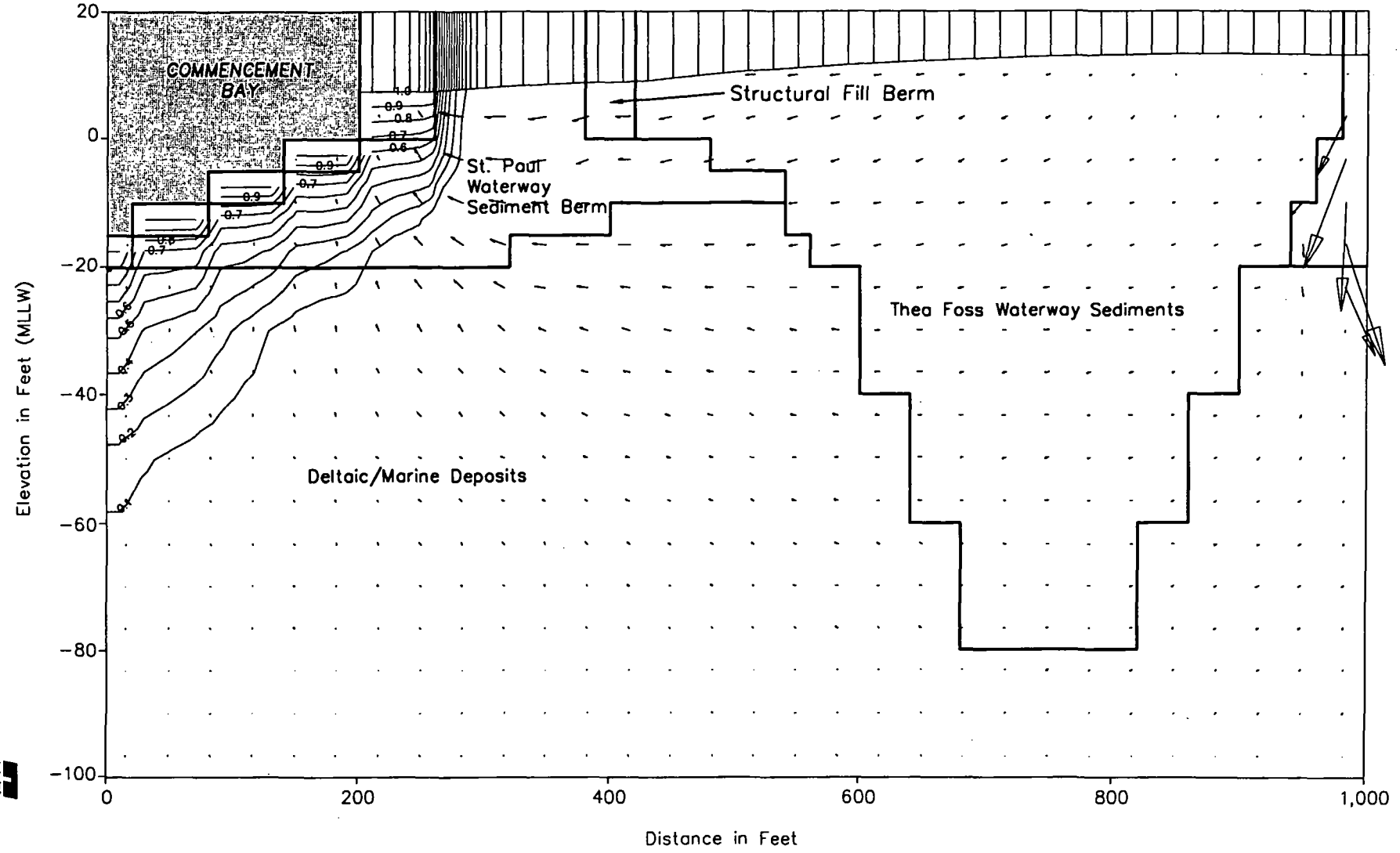
J-4072-25
Figure R-46
7/99

407225\core\TRANSIENT 2
(App-R.xls)

Predicted Relative Salinity Distribution and Steady-State Flow Vectors at Cross Section A-A'



0.1 Relative Salinity Concentration

Groundwater Flow Vector

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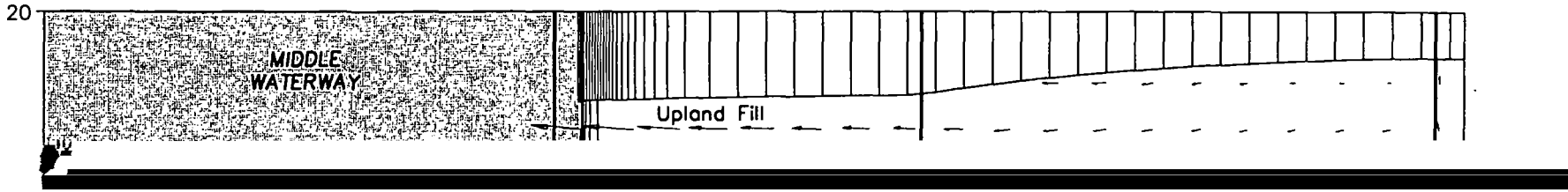
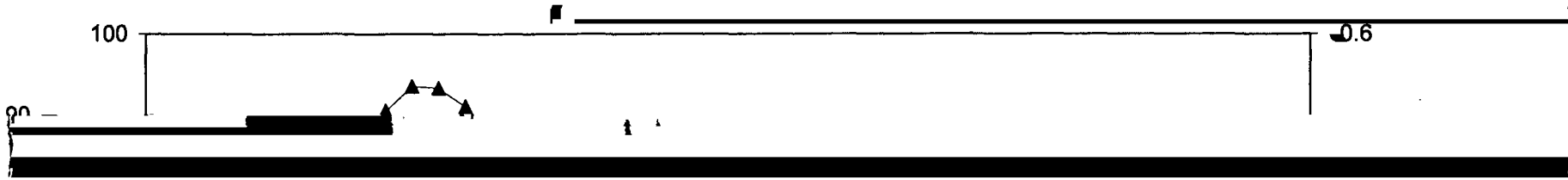
Figure R-47

Predicted Relative Salinity Distribution and Steady-State Flow Vectors at Cross Section B-B'





Predicted Concentrations at Point of Discharge

Cross Section A-A'

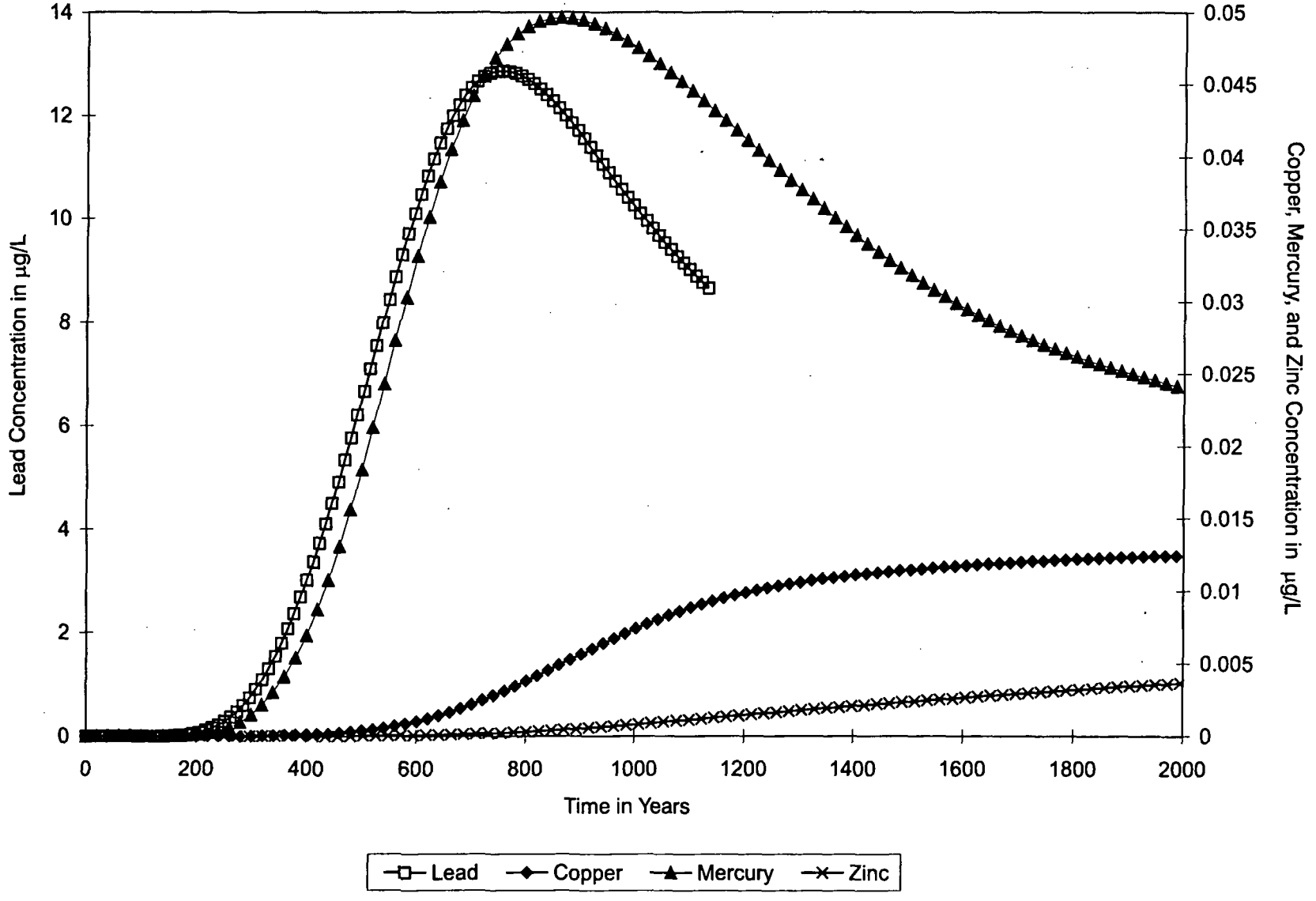


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Figure R-51

407225\corel\BREAKTHROUGH AA
(App-R.xls)

Predicted Concentrations at Point of Discharge

Cross Section B-B'

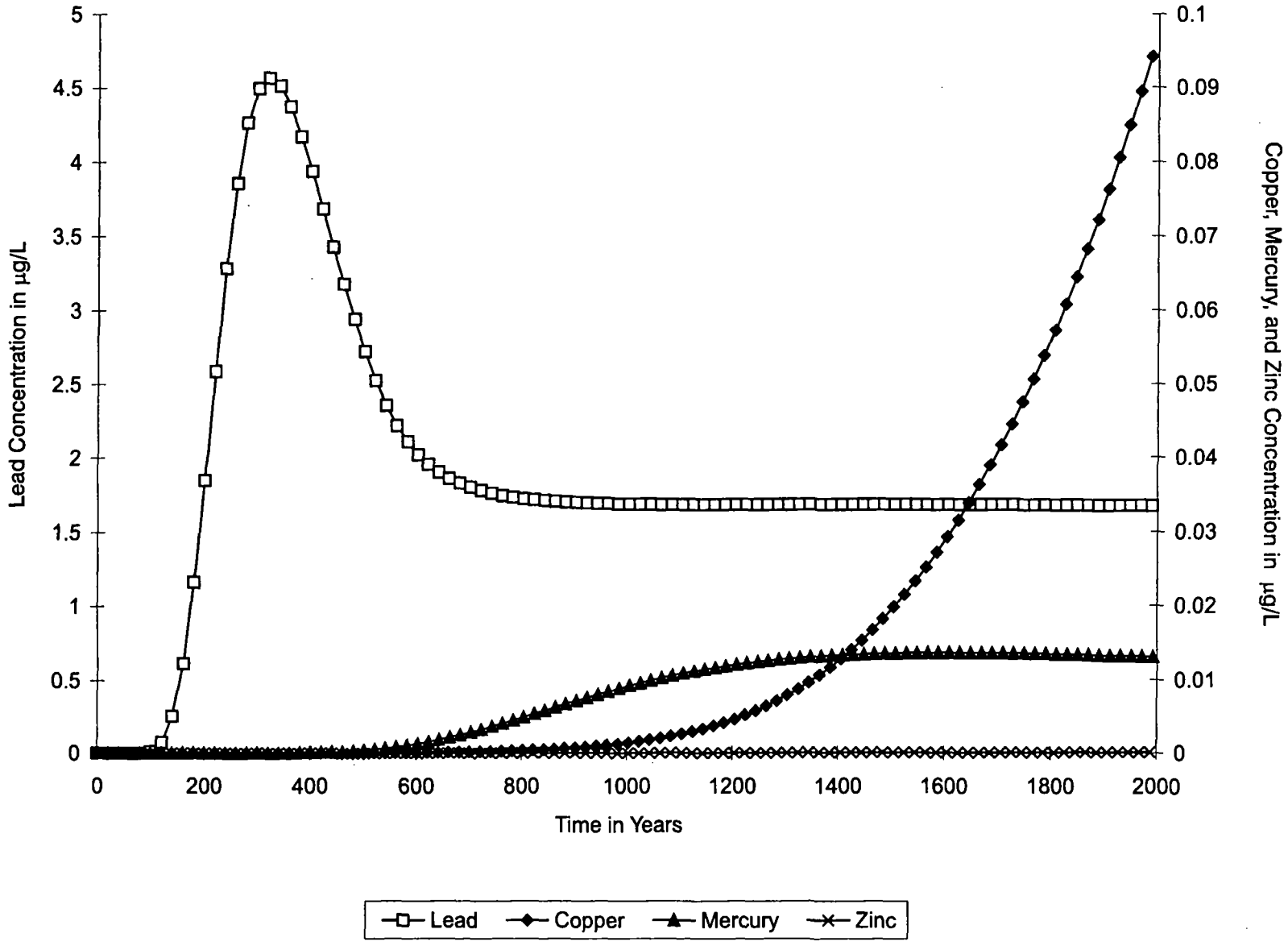

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Figure R-52

407225\core\BREAKTHROUGH BB (App-R.xls)

Maximum Predicted Copper Concentration Distribution

Cross Section A-A'

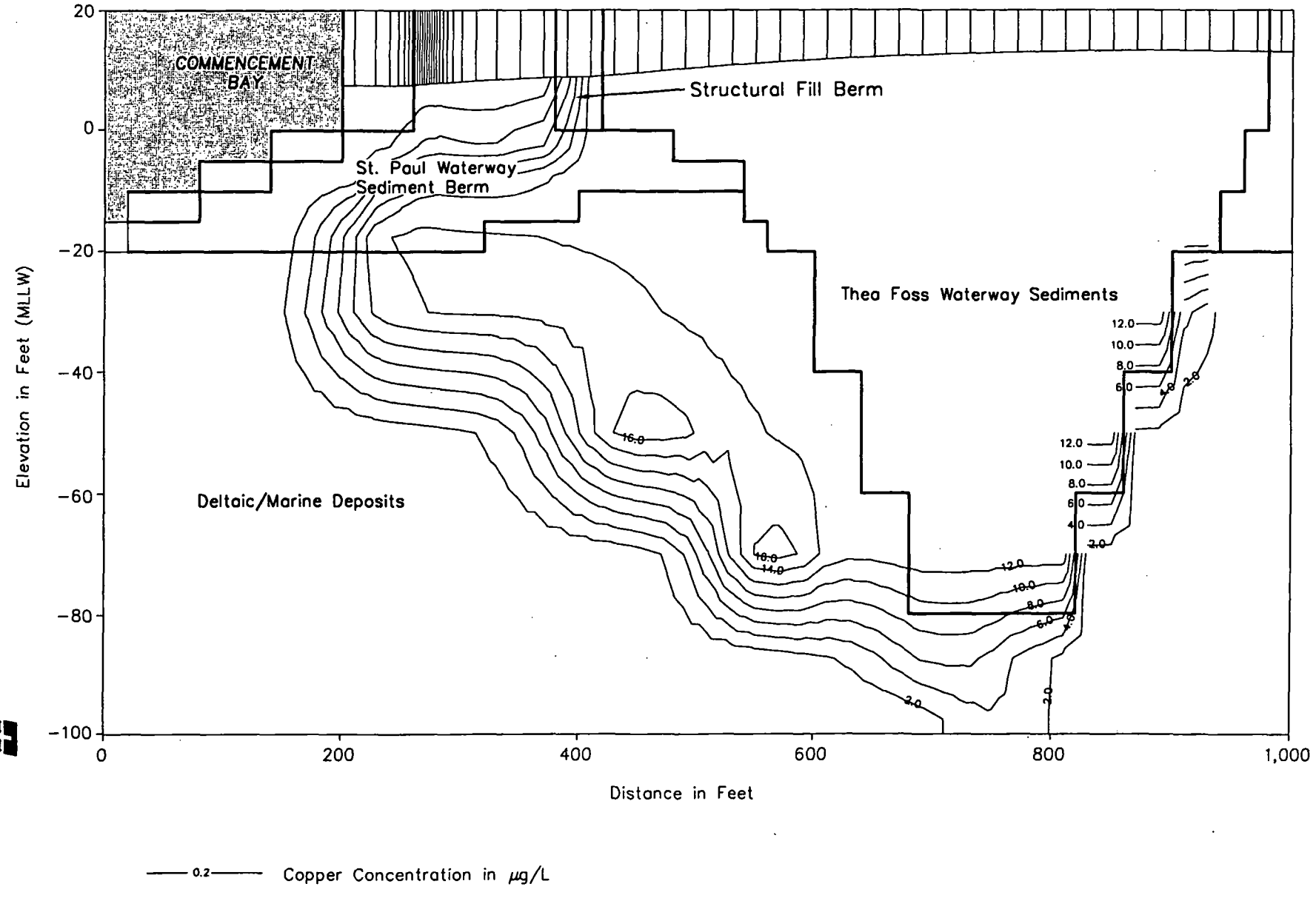

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Figure R-53

Maximum Predicted Lead Concentration Distribution Cross Section A-A'

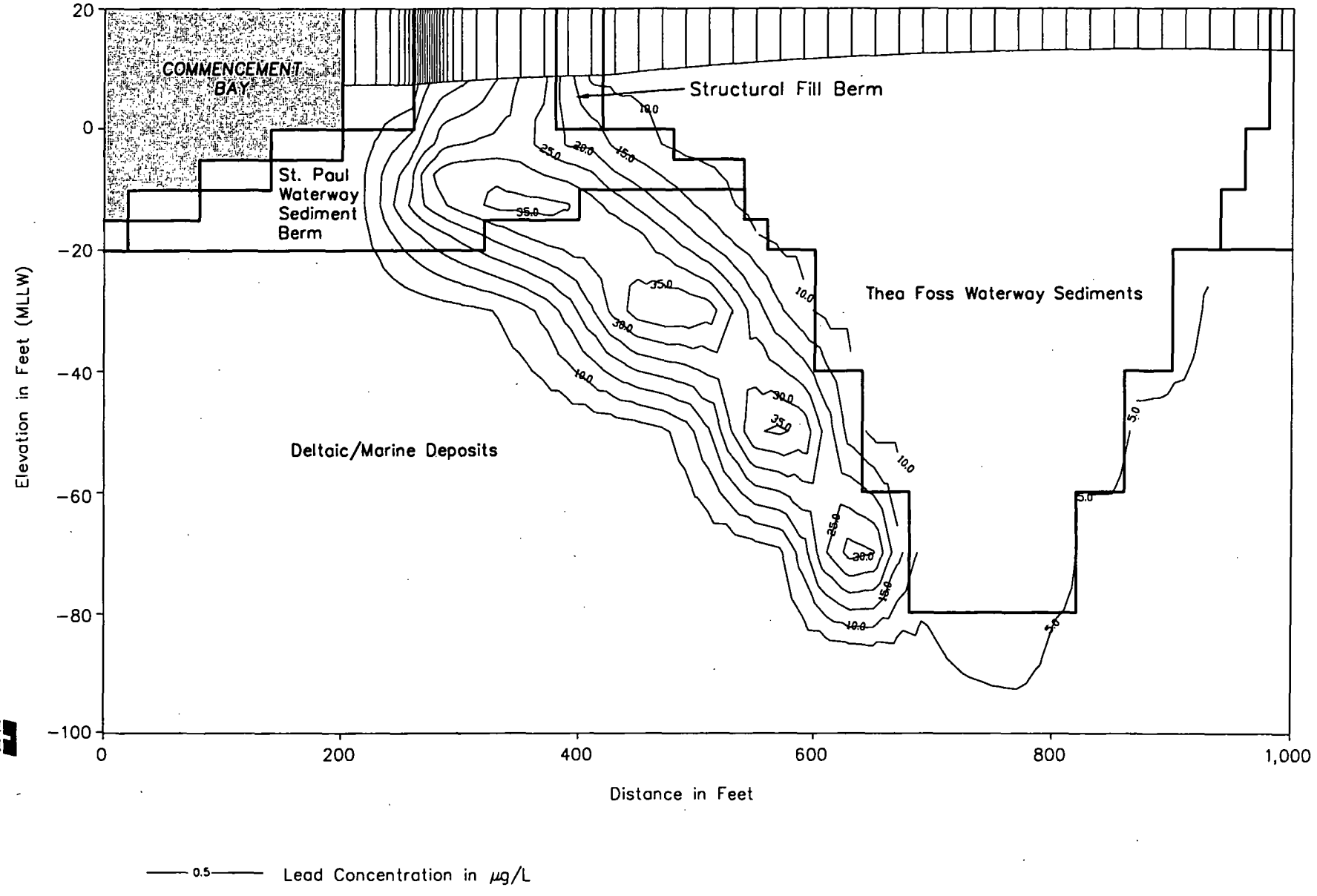

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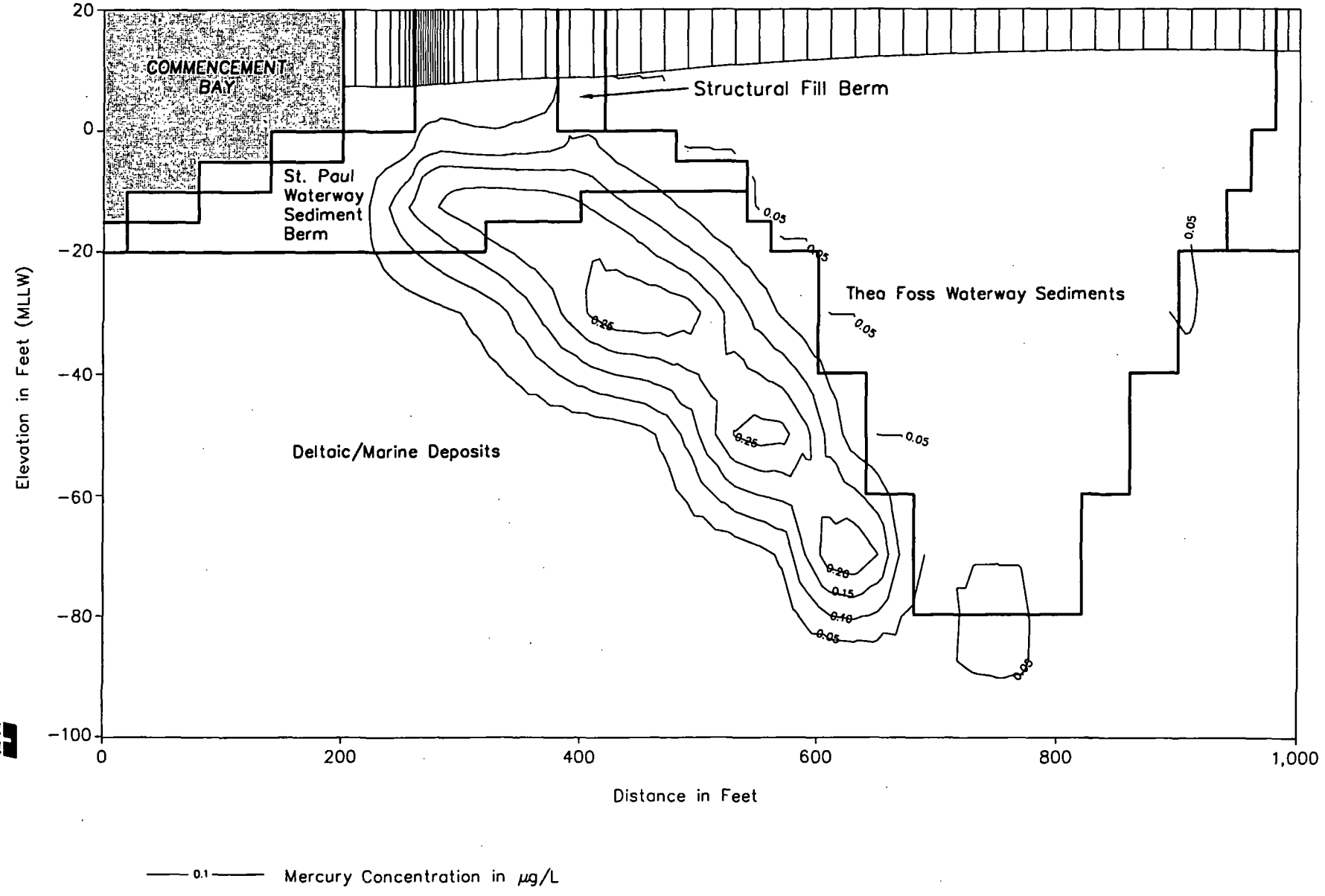
Figure R-54

CVD 7/2/99 1=120 MDSTK-8.PC2 40722576

Maximum Predicted Mercury Concentration Distribution

Cross Section A-A'



HARTCROWSER
J-4072-25 7/99
Figure R-55

CVD 7/2/99 1=120 WDSTK-8.PC2 40722577

Maxiumu Predicted Zinc Concentration Distribution

Cross Section A-A'

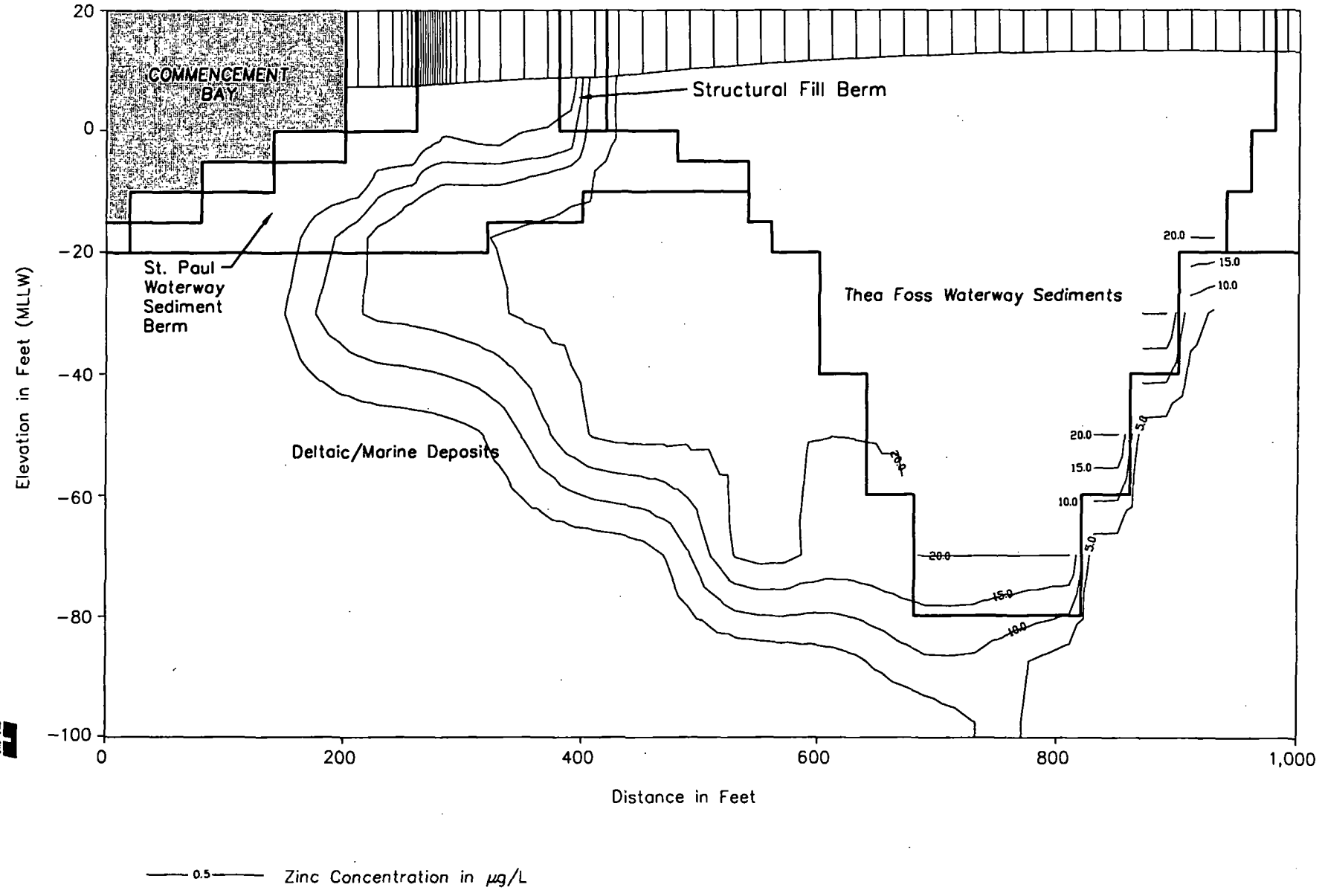


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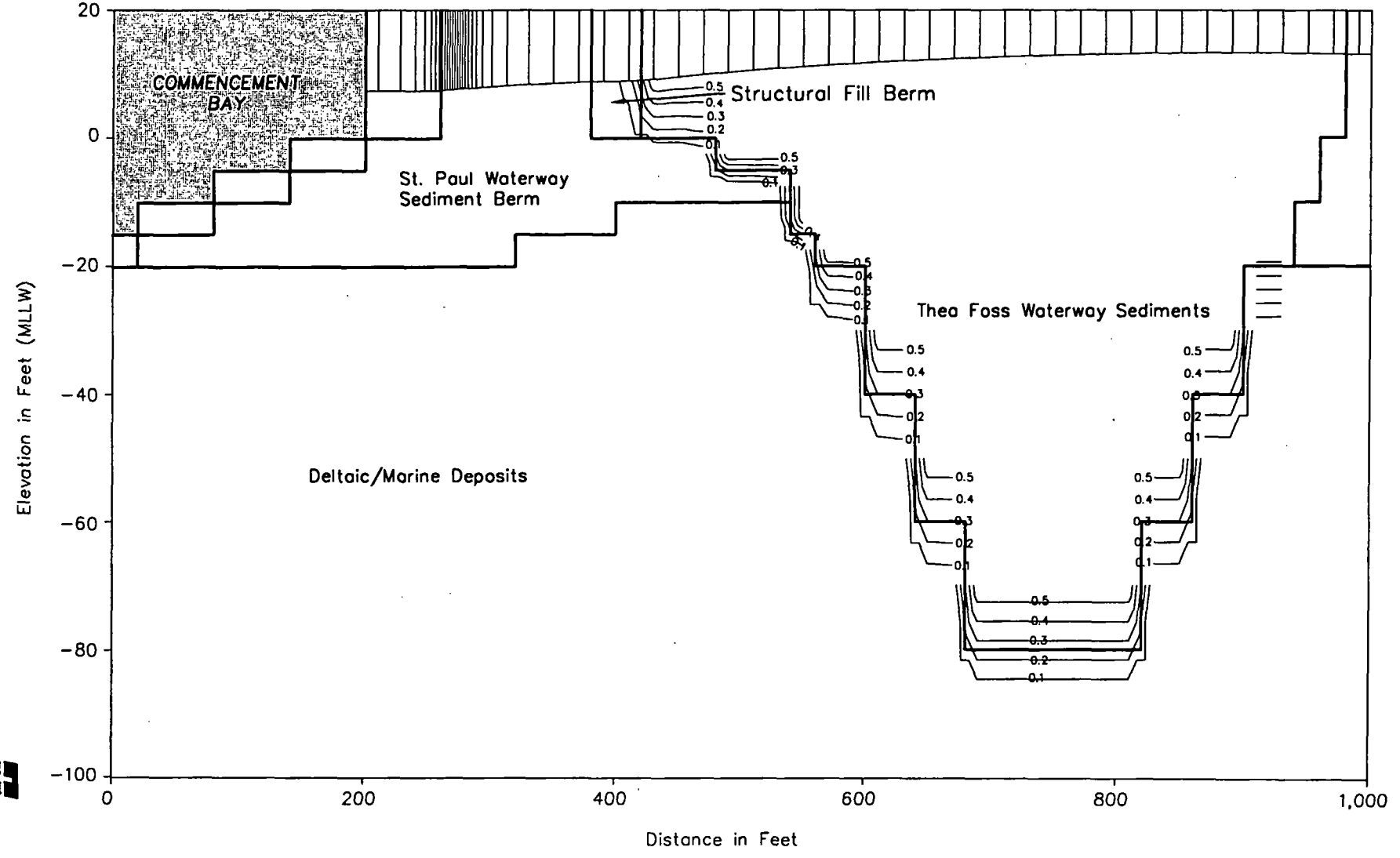
Figure R-56

Maximum Predicted Benzo(a)anthracene Concentration Distribution

Cross Section A-A'



0.1 Benzo(a)anthracene Concentration in µg/L

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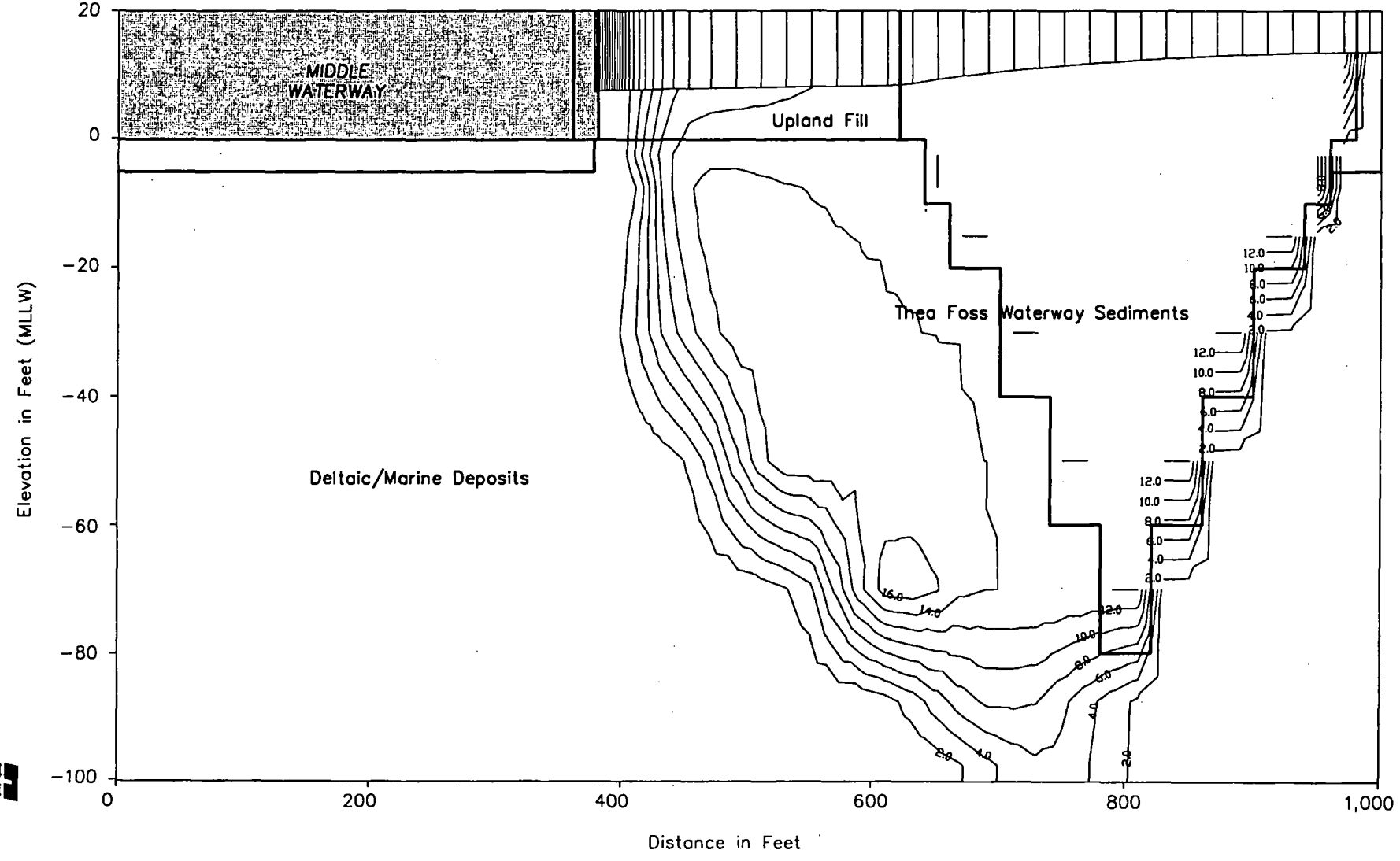
Figure R-57

CVD 7/2/99 1=12 DSTK-8.PC2 40722579

Maximum Predicted Copper Concentration Distribution

Cross Section B-B'



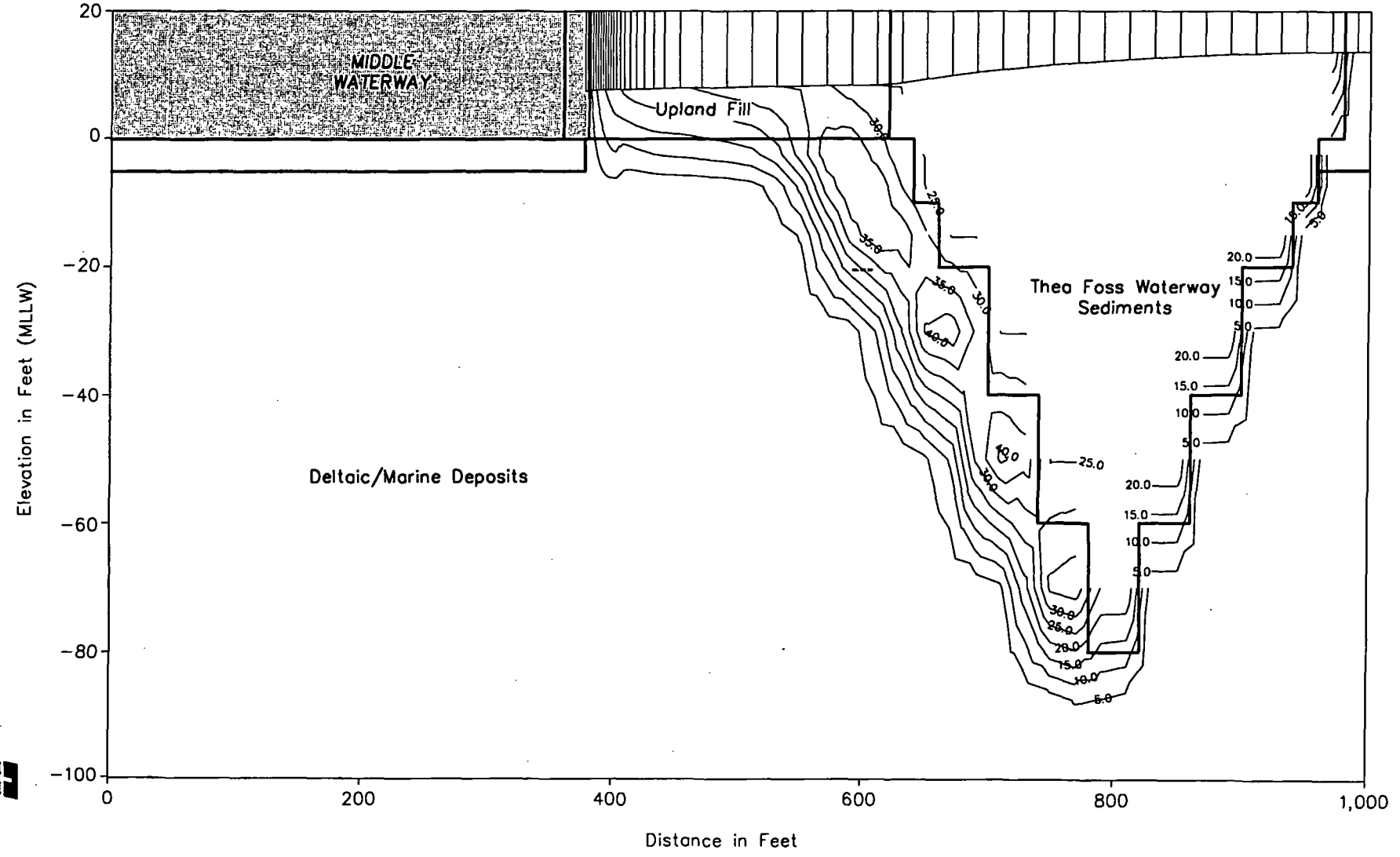
0.1 Coppper Concentration in µg/L

HARTCROWSER
J-4072-25 7/99
Figure R-58

CVD 7/2/99 1=1 DSTK-8.PC2 407225B0

Maximum Predicted Lead Concentration Distribution

Cross Section B-B'

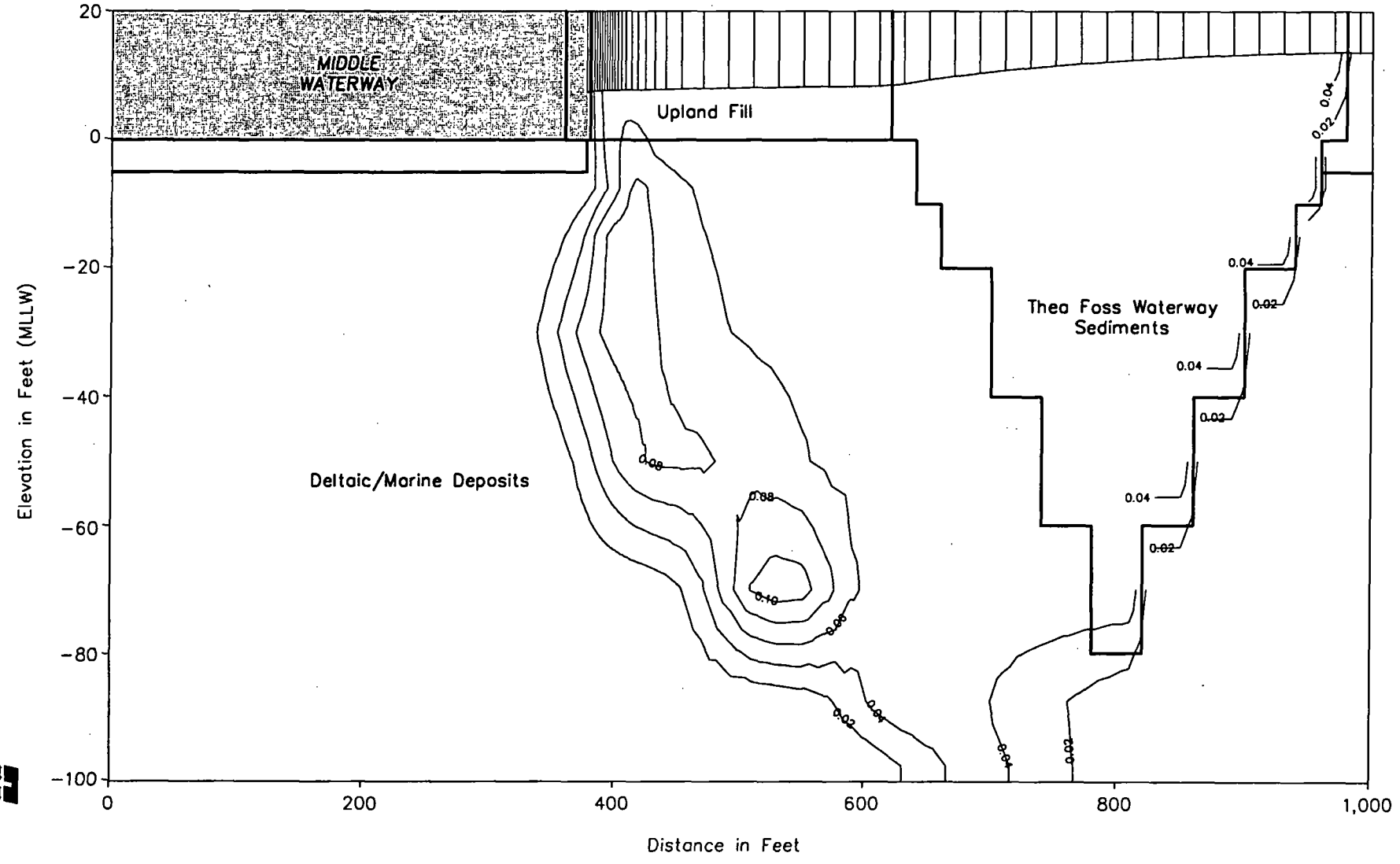


2.0 Lead Concentration in µg/L

HARTCROWSER
J-4072-25 7/99
Figure R-59

Maximum Predicted Mercury Concentration Distribution

Cross Section B-B'

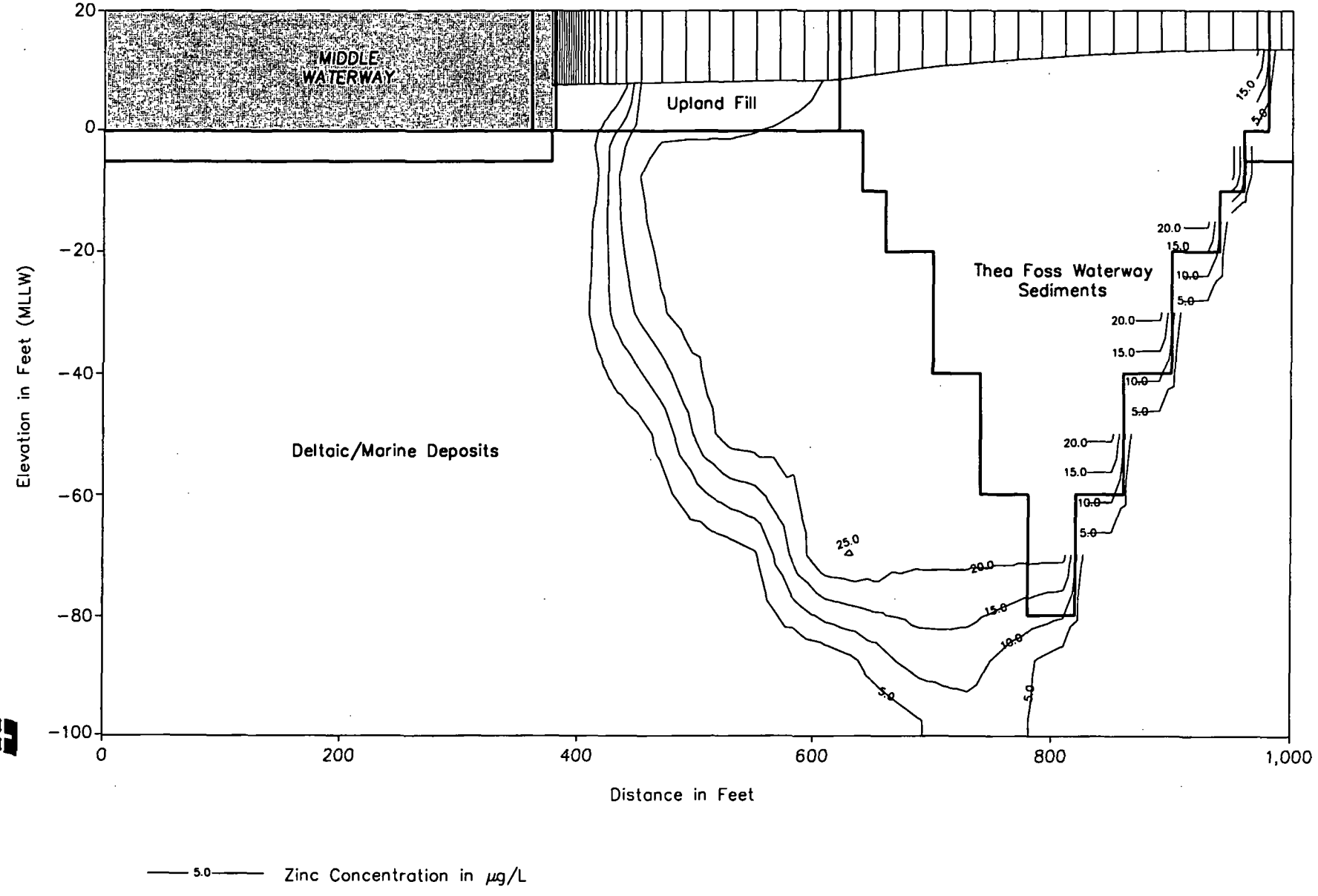


2.0 Mercury Concentration in µg/L

HARTCROWSER
J-4072-25 7/99
Figure R-60

Maximum Predicted Zinc Concentration Distribution

Cross Section B-B'

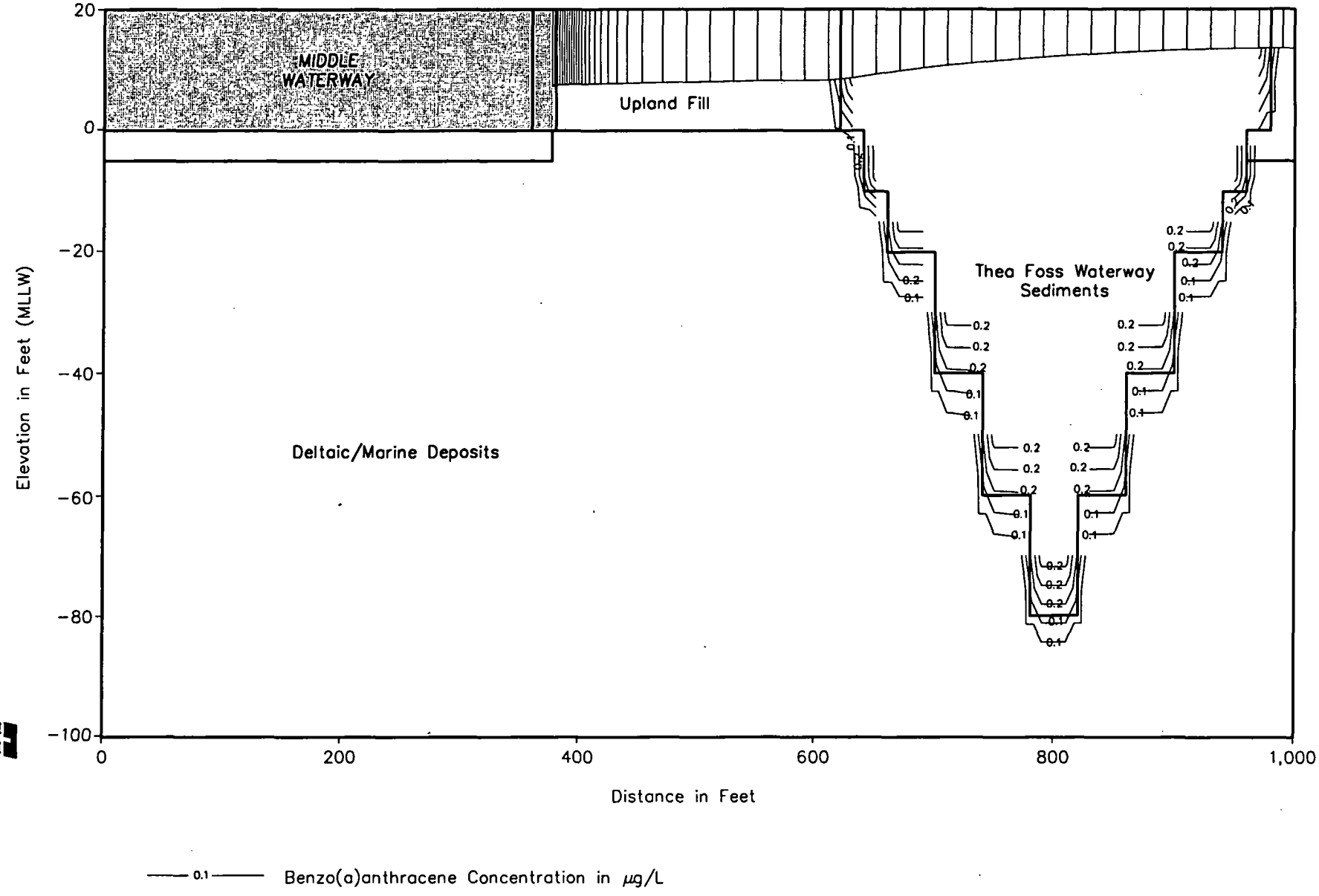


HARTCROWSER
J-4072-25 7/99
Figure R-61

CVD 7/2/99 1=120 WDSTK-8.PC2 40722583

Maximum Predicted Benzo(a)anthracene Concentration Distribution

Cross Section B-B'



HARTCROWSER
J-4072-25 7/99
Figure R-62