REPORT OF PHASE 3 HYDROGEOLOGIC SERVICES
FORMER BARGE WASTE DISPOSAL SITE
VANCOUVER, WASHINGTON
FOR
COLUMBIA MARINE LINES

GeoEngineers
Incorporated

GeoEngineers Incorporated

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Consulting Geotechnical
Engineers and Geologists

April 14, 1986

Crowley Environmental Services Corporation
3400 East Marginal Way South
Seattle, Washington 98134

Attention: Mr. Pat Sanborn

Gentlemen:

We are pleased to submit four copies of our Phase 3 hydrogeologic report for the former Columbia Marine Lines barge waste disposal site near Vancouver, Washington. Our scope of services for the Phase 3 studies is listed in our confirming agreement dated January 13, 1986.

We appreciate the opportunity to be of service on this project. Please call if you have questions regarding this report or if we may be of further assistance in data evaluation.

Yours very truly,

GeoEngineers, Inc.

James A. Miller

James A. Miller
Associate

JAM:da

File No. 698-03

cc: Columbia Marine Lines
Attn: Mr. Ray Jubitz

Kennedy/Jenks/Chilton
Attn: Mr. Nathan Graves

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REPORT OF PHASE 3 HYDROGEOLOGIC SERVICES
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INTRODUCTION

The results of our Phase 3 hydrogeologic studies at the former barge waste disposal site operated most recently by Columbia Marine Lines (CML) are presented in this report. This report has been prepared for CML to partially fulfill Order No. DE 85-591, dated August 19, 1985, as issued by the Washington Department of Ecology (WDOE).

This report is the third in a series of hydrogeologic studies conducted by GeoEngineers, Inc. at the former disposal area. Previous Phase 1 and Phase 2 hydrogeologic reports are dated November 28, 1983 and April 9, 1985. Mr. Patrick H. Wicks, Hazardous Materials Management Consultant, submitted a report on soil and ground water quality at the former disposal area in April 1985. Mr. Wicks' report was based on data included in our Phase 1 and Phase 2 hydrogeologic reports. A subsurface floating hydrocarbon recovery system was installed at the site in July 1985. A letter report regarding that installation was submitted by our firm on September 12, 1985.

PURPOSE AND SCOPE

The purpose of this report is to further define the extent of subsurface contamination surrounding the former barge waste disposal area and to provide a basis for a comprehensive environmental-risk assessment. A copy of this report will be submitted to Kennedy/Jenks/Chilton for review and incorporation into the risk assessment. Our Phase 3 scope of services includes:

1. Installation of six "shallow" ground water monitor wells.
2. Installation of one "deep" ground water monitor well.
3. Collection and logging of soil samples from each monitor well boring.
4. Conducting "slug tests" for each soil unit encountered in the deep well boring.
5. Developing each of the Phase 3 well screens.

6. Obtaining ground water samples with a stainless steel bailer from Monitor Wells MW-2, MW-13 and each of the Phase 3 monitor wells.
7. Measuring the pH of ground water samples collected from each Phase 3 monitor well and existing wells MW-2 and MW-13.
8. Measuring the temperature and electrical conductivity of ground water in all wells at the site.
9. Determining the casing rim elevation of each Phase 3 monitor well.
10. Measuring ground water levels and the thickness of floating hydrocarbons in all wells at the site.
11. Analysis of slug test data to provide an estimate of hydraulic conductivity for the sandy soil units encountered in the deep well boring.
12. Laboratory testing of one soil sample obtained from the deep well boring to determine the vertical hydraulic conductivity of that sample.
12. Grain-size testing of two sand samples from the deep well boring.
13. Interpretation of static ground water levels, preparation of a water table contour map and analysis of ground water flux.

SUBSURFACE CONDITIONS

GENERAL

A total of 21 monitor well borings have been drilled at the former disposal site during the Phase 1, 2, and 3 hydrogeologic explorations. Details of the drilling programs for MW-1 through MW-14, including boring logs, are given in the Phase 1 and Phase 2 reports. Details of the Phase 3 field exploration program and logs for MW-15 through MW-21 are presented in the appendix to this report. Monitor well locations are indicated on the Site Plan, Figure 1.

SOIL CONDITIONS

The uppermost soil unit at the site is dredge material from the nearby Columbia River. The dredge fill consists of relatively clean fine to medium sand. The sand ranges from less than a few feet thick to as much as 19 feet thick at Boring MW-17.

Columbia River flood plain deposits comprised of silty fine sand, silt, and clay underlie the dredge fill. In deep Boring MW-20, the composite thickness of these soils is about 20 feet. Boring MW-20 is the only exploration at the site that penetrated the base of the flood plain deposits.

A unit of dense fine-grained sand was encountered beneath the flood plain deposits in Boring MW-20. The base of this sand unit was not encountered in our explorations. The thickness of the unit exceeds 47 feet at Boring MW-20.

Subsurface conditions at the site are shown on the Subsurface Sections, Figures 3 through 5. Grain-size curves for soil samples obtained from the dredge fill and underlying fine sand unit are shown graphically on Figure 6.

GROUND WATER CONDITIONS

General: Subsurface explorations by GeoEngineers encountered three "hydrostratigraphic units" at the site. These three hydrostratigraphic units (surficial dredge fill sand, silty flood plain deposits and underlying fine sand) govern the flow of ground water at relatively shallow depths. Studies by Robinson & Noble, Inc. at the nearby Alcoa Plant encountered two additional hydrostratigraphic units below the depths explored by GeoEngineers at the CML facility. These two additional units include the Troutdale Formation and a silty gravel which overlies the Troutdale. General characteristics of these five hydrostratigraphic units are summarized in Table 1.

Description of the field and laboratory procedures used for estimating hydraulic conductivities of the dredge fill, flood plain sediments and fine sand deposits are presented in the appendix. For this report, the terms "permeability" and "hydraulic conductivity" are considered synonomous.

Dredge Fill Aquifer: Ground water within the dredge fill aquifer in the former disposal area is unconfined and is recharged by direct precipitation and by runoff from the adjacent paved parking area. Our analyses of slug test data and soil grain-size gradation indicates that the dredge fill aquifer has a moderate permeability. However, the saturated thickness of the aquifer is relatively small. Ground water levels within the dredge fill appear to decrease to near the base of this aquifer during periods of seasonally low precipitation. In our opinion, the dredge fill aquifer is unsuitable for potable use based on the shallow depth to the water table and limited saturated thickness.

Water table contours for the dredge fill aquifer based on site measurements made on February 14, 1986, are indicated on Figure 2. These contours show the drawdown due to ongoing pumping from the hydrocarbon recovery gallery and a ground water mound around the water disposal gallery.

A secondary mound on the water table within the dredge fill in the vicinity of MW-18 is believed to be a temporary response to heavy precipitation that occurred in late January and early February 1986. Ongoing monitoring by CML personnel should help determine if this ground water mound is caused by a combination of precipitation and infiltration or by leakage from the Alcoa pipeline and/or ponds.

Ground water flow in areas outside of the limits of influence of the hydrocarbon recovery system is semi-radial away from the former disposal site. This ground water appears to eventually discharge to the Columbia River and to the field located north of the former disposal site.

Flood Plain Aquitard: The flood plain deposits act as an aquitard because of their low hydraulic conductivity. Ground water levels within the dredge fill aquifer are about 14 feet higher than the water level in MW-20, which is completed in the underlying fine sand aquifer. The difference in water levels demonstrates that the flood plain deposits which separate the dredge fill and underlying fine sand aquifer have a low hydraulic conductivity and restrict the flow of ground water between the two aquifers.

The low permeability of the flood plain deposits is further indicated by the fact that a rapid uphole flow of flammable gas was encountered at a depth of 32 feet while drilling boring MW-20. The gas was encountered immediately below the base of the flood plain deposits. The drillers were able to drive the casing through the gas-bearing zone and the flow of gas ceased at a depth of 36 feet. In our opinion, the gas encoutnered in MW-20 was naturally occurring methane. The flood plain deposits act as a stratigraphic trap that prevents the upward migration of methane. The ability of the flood plain deposits to restrict the upward migration of gas is a result of their low vertical permeability.

Our laboratory testing of a soil sample from the flood plain deposits indicated a low vertical hydraulic conductivity and confirmed our field observations.

The flood plain deposits appear to be continuous across the former disposal site and surrounding area. The channel of the Columbia River may breach the flood plain deposits and allow direct hydraulic communication between the underlying fine sand aquifer and the Columbia River.

Fine Sand Aquifer: Ground water within the fine sand aquifer is confined by the overlying flood plain deposits. The water level in MW-20 (deep well) on February 14, 1986 was about 13 feet above the base of the flood plain deposits. Analyses of slug test data and soil grain-size data indicate that the fine sand aquifer has a moderate permeability.

Ground water probably discharges from the fine sand aquifer into the Columbia River during normal river stage conditions. However, flow reversal may occur during periods of high river stage.

Ground Water Flux: The former disposal area experiences approximately 40 inches of precipitation per year. A portion of this precipitation is lost to direct runoff and to evapotranspiration. The remaining portion infiltrates the ground to recharge the dredge fill aquifer. Additional ground water recharge to the dredge fill aquifer is provided by runoff from the paved and unpaved areas located east of the former disposal area. A portion of the recharge to the dredge fill aquifer flows semi-radially away from the disposal area through the dredge fill sand, and the remainder flows vertically downward through the flood plain deposits into the fine sand aquifer.

Our analyses indicate that, on an average annual basis, approximately 2-million gallons of water recharges the dredge fill aquifer within the 2.4-acre area indicated as having hydrocarbon contamination on Figure 2. The volume of ground water seepage from the dredge fill aquifer into the underlying fine sand aquifer is estimated at approximately 2.6 percent of the total recharge (53,500 gallons per year). The remainder of the total recharge flows semi-radially away from the former disposal area within the dredge fill aquifer.

The low permeability of the flood plain deposits severely restrict the rate of seepage into the fine sand aquifer. We estimate a ground water travel time of approximately 58 years for ground water to flow downward through the flood plain deposits into the fine sand aquifer.

Field Measurements of Ground Water Quality: We measured the temperature and electrical conductivity of water in all of the monitor wells during our Phase 3 studies. These measurements were made with a probe that was lowered to the base of each monitor well (except MW-20 because the length of cable was not sufficient to reach the base of that well). We also measured the pH of all water samples collected during the Phase 3 study. The temperature, conductivity and pH data are presented in Table 2. The data indicate relatively large variations in ground water temperature across the site, modest variations in electrical conductivity and relatively constant pH.

In our opinion, monitor wells listed on Table 2 with ground water temperatures less than 11°C probably are located in areas where precipitation infiltrates the ground relatively rapidly. Those shallow wells with water temperatures higher than 13°C are considered anomalous and may indicate areas of ground warming due to possible leakage of warm water from Alcoa's process water pipeline.

The electrical conductivity of water is generally correlative with the concentrations of dissolved ions in the water. In our opinion, variations in the conductivity of ground water at this site are primarily a result of variation in the concentration of dissolved solids in the aquifers. The well that resulted in the highest electrical conductivity value, MW-13, is screened almost entirely in flood plain deposits. This suggests that ground water within the finer-grained flood plain deposits may be significantly higher in suspended solids than ground water in the dredge fill aquifer and the fine sand aquifer.

Hydrocarbon Contamination: Floating hydrocarbons have been measured in Wells MW-1, MW-2, MW-5, MW-6, MW-7, MW-8 and MW-19. The well screen for MW-5 and MW-6 is set too low to detect floating hydrocarbons during periods of heavy precipitation and high ground water levels. However, these well screens can detect floating hydrocarbons during periods of normal to low ground water levels.

In addition to measuring the thickness of floating hydrocarbons in the monitor wells, we used an explosimeter to detect flammable gases in the annulus of the well casings. The flammable gas measurements generally give a good indication of soil contamination by hydrocarbons. Although free hydrocarbons and flammable gases were not detected in MW-18, hydrocarbon contamination of the soil was observed while drilling that boring. A summary of floating hydrocarbon thickness and flammable gas measurements is presented in Table 3. It is possible that the exposimeter was detecting both methane and hydrocarbon vapor during our field measurements.

The approximate limit of hydrocarbon contaminated subsurface soil, based on our measurements and observations, is indicated on Figure 2. The floating hydrocarbon plume occupies only a portion of the contaminated area indicated on Figure 2.

FLOATING HYDROCARBON RECOVERY PROGRAM

A floating hydrocarbon recovery system was installed at the disposal site by CES during July 1985. A description of the installation of the recovery system is presented in our report of September 12, 1985.

Water table depression in the hydrocarbon recovery well and trench commenced on August 6, 1985 and continued to September 2, 1985. The recovery system was temporarily shut down on September 2, 1985 when seasonal ground water levels decreased to about 9 inches above the intake of the water level depression pump. Floating hydrocarbons were not recovered between August 6 and September 2, 1985. The low ground water level during that time period appears to have restricted the development a cone of depression around the recovery trench and prevented the recovery of floating hydrocarbons.

Following a recommendation by the Washington Department of Ecology, Crowley Environmental Services Corp. (CES) installed an oil/water separator between the water table depressant pump and the water disposal gallery in December 1985. Hydrocarbon recovery operations with the in-line oil/water separator commenced on January 3, 1986. CES indicates that 510 gallons of hydrocarbon product were recovered by the system between January 3 and February 28. An additional 15 gallons was recovered from the recovery well between March 1 and March 4.

Hydrocarbons were also removed intermittently from MW-8 with a vacuum truck. CES estimates that 10 to 20 gallons of hydrocarbons were removed from MW-8 between mid-February and mid-April.

The capacity of the water disposal gallery was exceeded in February, as evidenced by the presence of water on the ground surface above the gallery. The disposal gallery was reconstructed and lengthened between March 4 and March 17. No problems with acceptance of water by the gallery have been observed after the system was put back into operation on March 18 (up to the date of this report).

Less than one gallon of hydrocarbon product was recovered from the recovery well between March 17 and April 10. This suggests that most of the floating product at the site has now been removed by pumping and supports the fact that our site measurements on February 14 found very little floating hydrocarbons in the monitor wells (see Table 3).

Based on the low rate of product recovery and small thickness of floating hydrocarbons in the monitor wells, we recommend that the recovery system be shut down until the winter of 1986/1987. Measurements of site monitor wells should be made at that time, and the recovery program should be resumed if floating hydrocarbons are present in thicknesses of 0.1 feet or greater in two or more wells at the site.

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We appreciate the opportunity to be of service. Please call if you have questions regarding this report.

Respectfully submitted,

GeoEngineers, Inc.

James A. Miller
Associate

SEW:JHB:JAM:da

TABLE 1

SUMMARY OF HYDROSTRATIGRAPHIC UNITS

Unit Number	Typical Upper Elevation(1)	Typical Base Elevation(1)	Character	Hydraulic Conductivity (Feet/minute)	Comments
1	28	17	Unconfined aquifer	0.045(2)	Dredge sand
2	17	-3	Aquitard	0.00000022(3)	Flood plain deposits
3	-3	-70	Confined aquifer	0.031(2)	Fine sand
4	-70	-85	Aquitard	-	Silty gravel
5	-85	-115	Confined aquifer	4.6+(4)	Regional aquifer, Troutdale Formation

Notes:
1. Mean Sea Level Datum.
2. Based on field slug test in MW-20 and laboratory grain-size analyses.
3. Based on laboratory permeability test of silt sample from MW-20.
4. From studies by Robinson & Noble, Inc. at Alcoa Plant.

TABLE 2

GROUND WATER ELEVATION, TEMPERATURE, CONDUCTIVITY, AND PH DATA

As Measured on 2/14/86

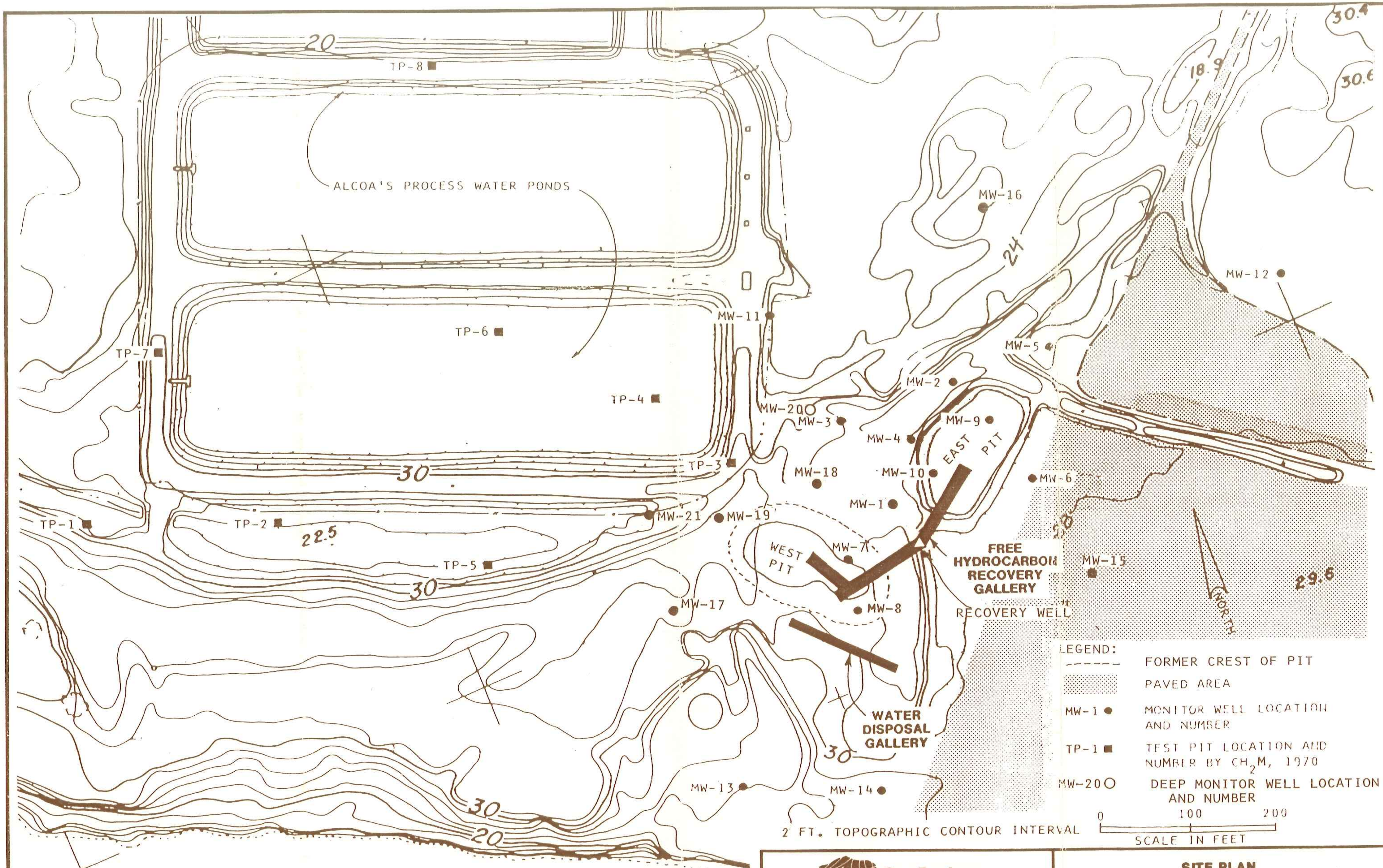
Well No.	Rim Elev. (ft)	Ground Water Elevation (ft)	Temperature °C	Conductivity mmhos/cm	(1)pH
1	31.80	(2)23.23	13.1	500	-
2	34.12	21.26	13.5	385	7.0
3	31.03	23.40	13.0	690	-
4	28.54	19.88	14.0	580	-
5	23.51	20.98	12.1	720	-
6	26.59	21.30	11.1	600	-
7	33.50	20.36	14.0	280	-
8	33.64	(2)24.97	9.7	395	-
9	26.54	21.16	10.4	680	-
10	26.01	23.38	4.0	124	-
11	26.03	20.76	11.1	318	-
12	28.40	21.91	10.0	152	-
13	22.91	14.72	11.7	1020	7.1
14	26.40	19.37	10.9	200	-
15	26.41	21.08	11.8	208	7.0
16	31.29	20.63	12.0	810	7.2
17	34.11	20.52	13.0	283	7.0
18	33.34	25.28	11.0	253	-
19	34.16	(2)20.29	15.0	810	6.7
20	30.53	8.30	(3)13.0	(3)610	6.7
21	30.21	20.38	10.0	240	6.9
Columbia River	-	-	3.5	280	-

NOTES:
(1) pH measured 2/5/85
(2) Corrected for the presence of free hydrocarbon fluid using a specific gravity of 0.88 for hydrocarbons
(3) Measured at a depth of 47 feet

TABLE 3

FREE HYDROCARBON THICKNESS AND FLAMMABLE GAS MEASUREMENTS

Monitor Well No.	12/12/84 Product Thickness	12/12/84 %LEL	1/23/85 Product Thickness	1/23/85 %LEL	7/26/85 Product Thickness	7/26/85 %LEL	9/18/85 Product Thickness	9/18/85 %LEL	10/24/85 Product Thickness	10/24/85 %LEL	11/8/85 Product Thickness	11/8/85 %LEL	2/14/86 Product Thickness	2/14/86 %LEL
1	0	-	0	5	0	0	0	-	0	-	0	-	0.05	3
2	0	-	0	0	0.17	100+	-	-	0	-	0	-	0	5
3	0	-	0	0	0	0	0	-	0	-	0	-	0	7
4	0	-	0	0	0	0	0	-	0	-	0	-	0	0
5	0	-	0	0	0	100+	0.22	-	0.02	-	0.01	-	0	4
6	0	-	0	20	0.08	100+	0.21	-	0	-	0	-	0	10
7	0.20	-	0.46	100+	0.13	100+	0.43	-	0.11	-	0.01	-	0	12
8	6.62	-	6.22	100+	5.52	100+	8.17	-	7.29	-	7.33	-	0.03	30
9	0	-	0	0	0	0	0	-	0	-	0	-	0	14
10	0	-	0	5	0	0	-	-	0	-	0	-	0	0
11	0	-	0	0	0	0	-	-	0	-	0	-	0	0
12	0	-	0	0	0	0	0	-	0	-	0	-	0	0
13	0	-	0	0	0	0	0	-	0	-	0	-	0	0
14	0	-	0	0	0	0	0	-	0	-	0	-	0	0
15	-	-	-	-	-	-	-	-	-	-	-	-	0	0
16	-	-	-	-	-	-	-	-	-	-	-	-	0	0
17	-	-	-	-	-	-	-	-	-	-	-	-	0	0
18	-	-	-	-	-	-	-	-	-	-	-	-	0	0
19	-	-	-	-	-	-	-	-	-	-	-	-	0.12	5
20	-	-	-	-	-	-	-	-	-	-	-	-	0	0
21	-	-	-	-	-	-	-	-	-	-	-	-	0	0



REFERENCE:
BASE MAP: U.S. ARMY ENGINEERS, PORTLAND DISTRICT, COLUMBIA RIVER BASIN
VANCOUVER LAKE AREA, PROPOSED IMPROVEMENTS-FLOOD PROTECTION, 1972.

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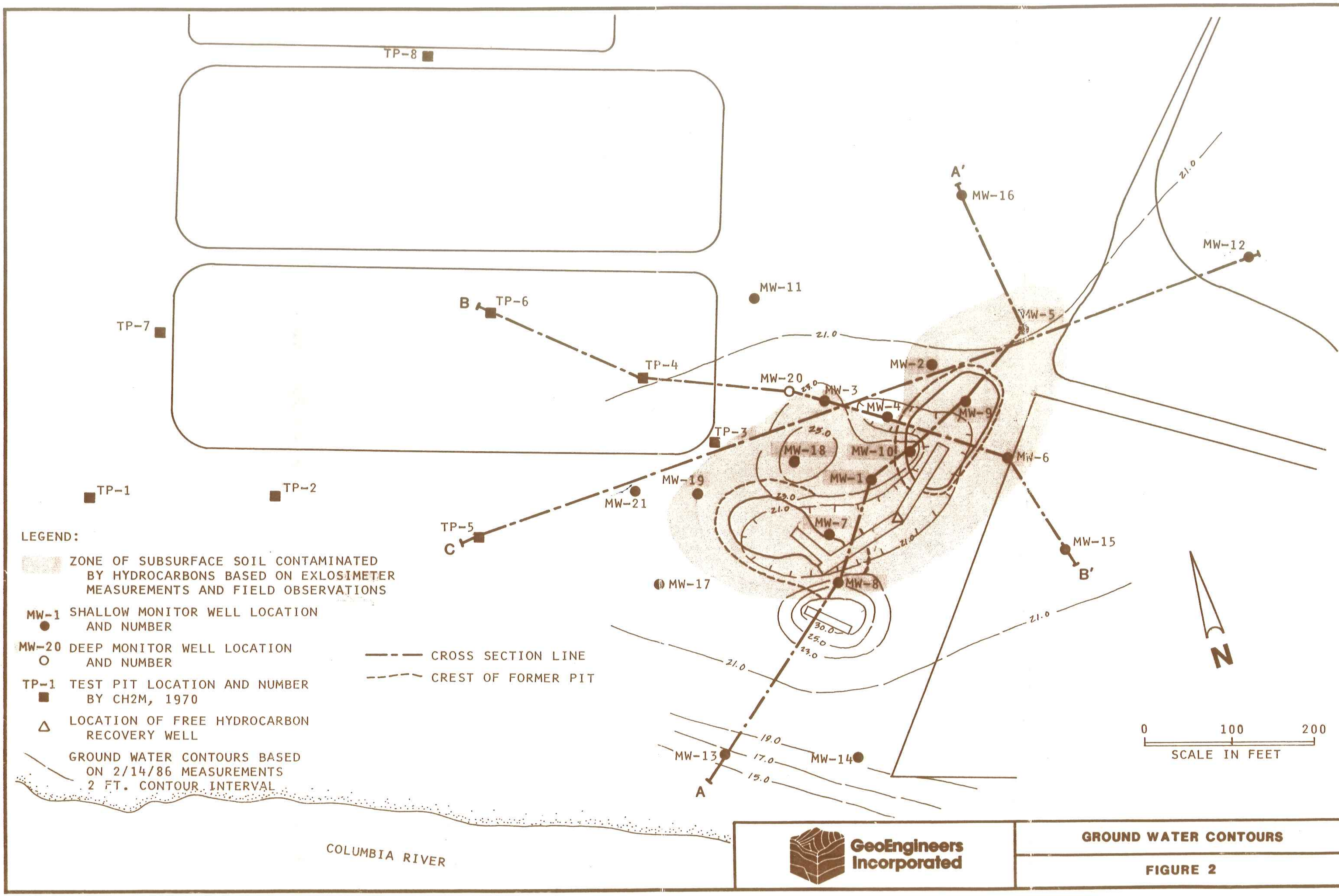
SITE PLAN

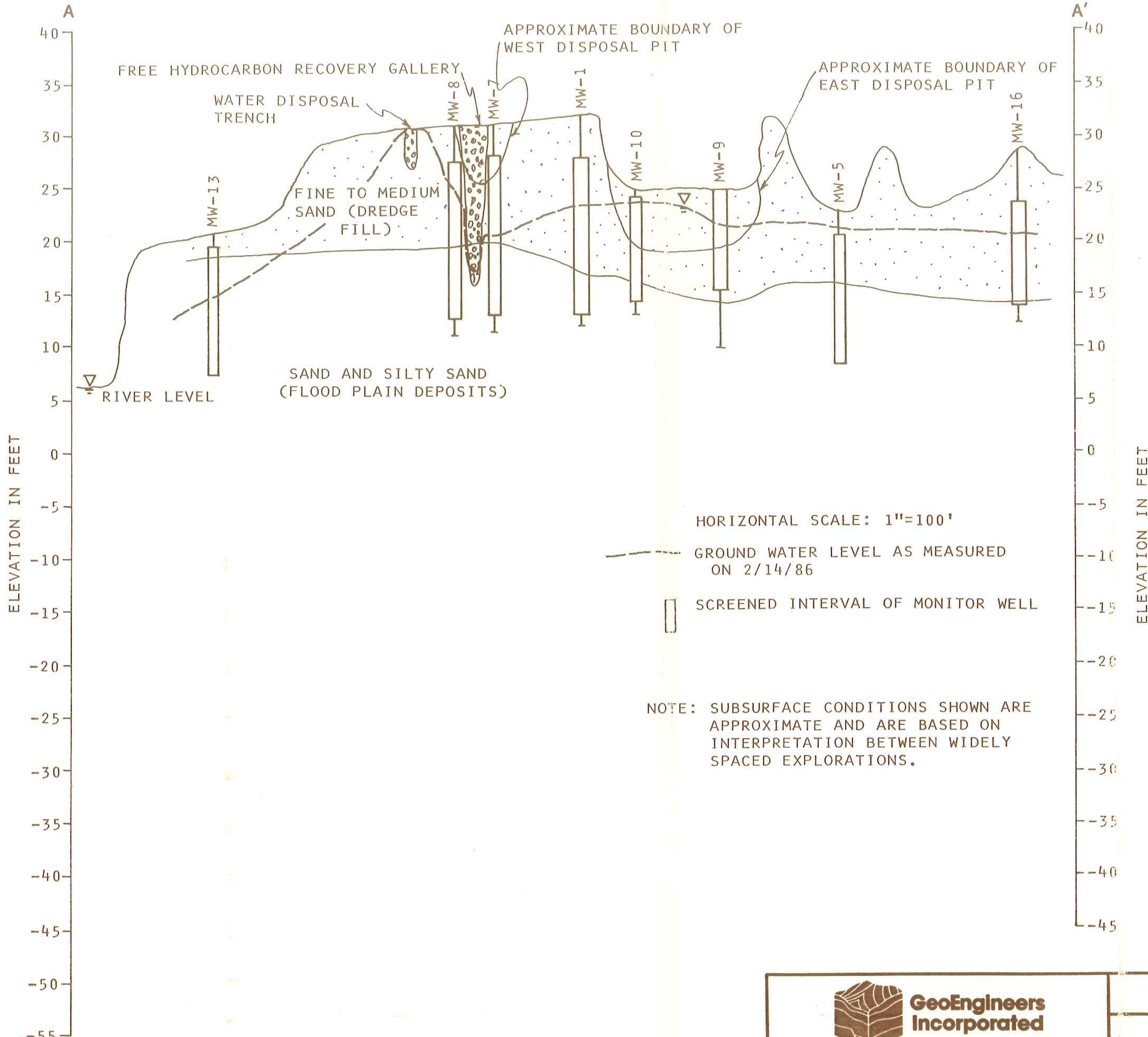
FIGURE 1

JOB # 698-03 SW:WJ 3/5/86



GROUND WATER CONTOURS

FIGURE 2



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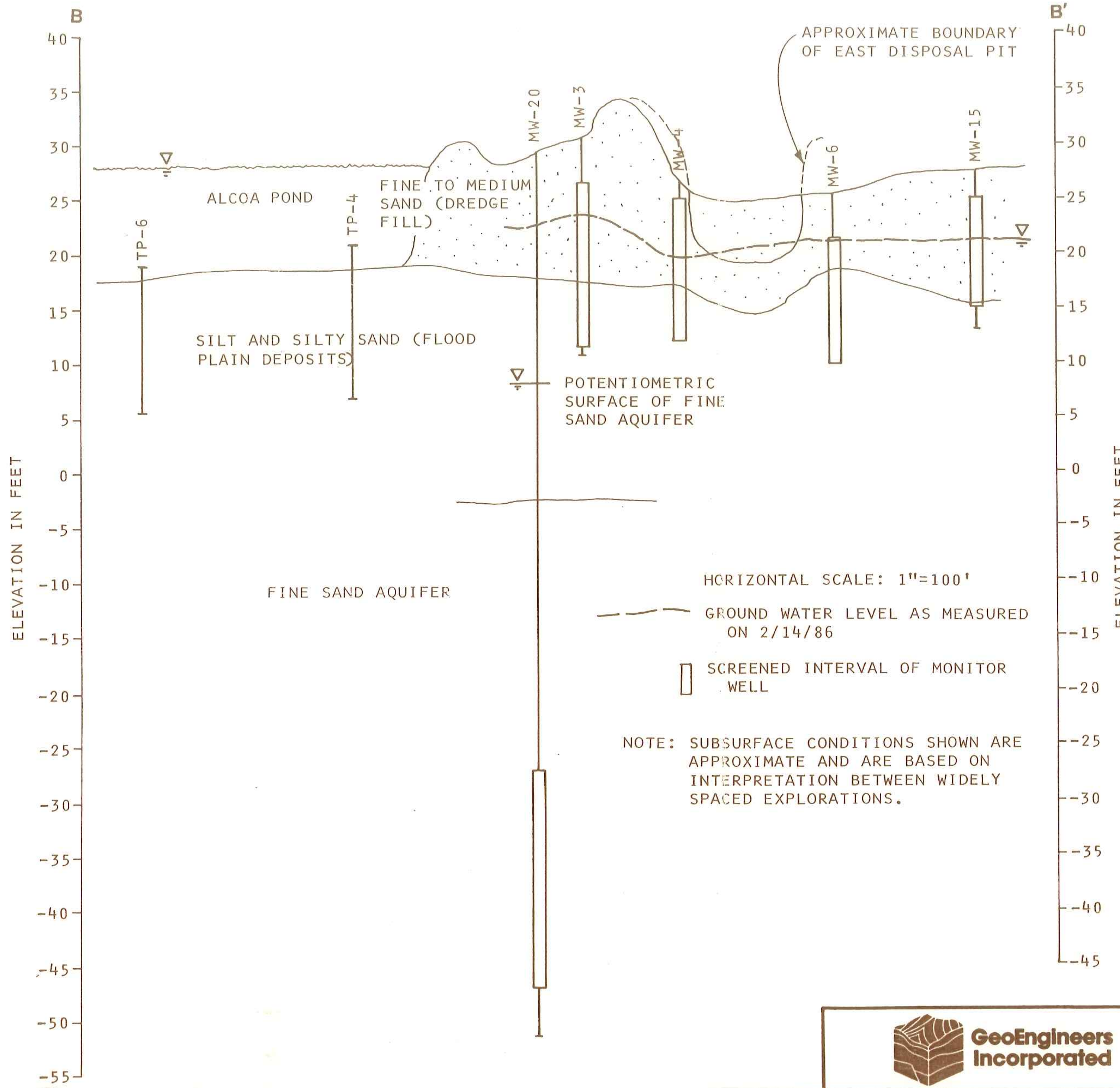
CROSS-SECTION A-A'

FIGURE 3

JOB # 698-03 SW: WJ 3/7/86



JOB # 698-03 SW WJ 3/7/86

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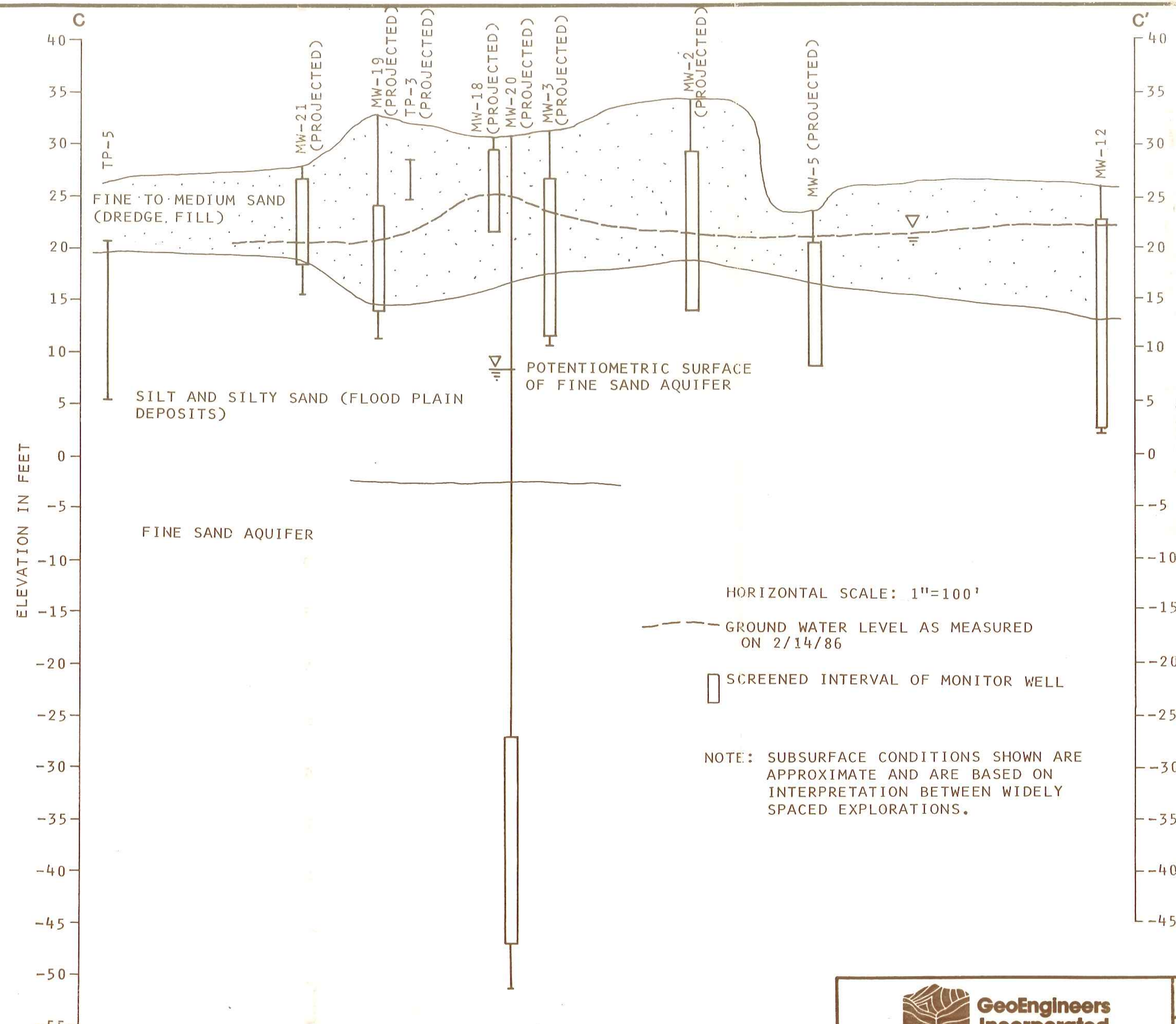
CROSS-SECTION B-B'

FIGURE 4



JOB # 698-03 SW:WJ 3/7/86

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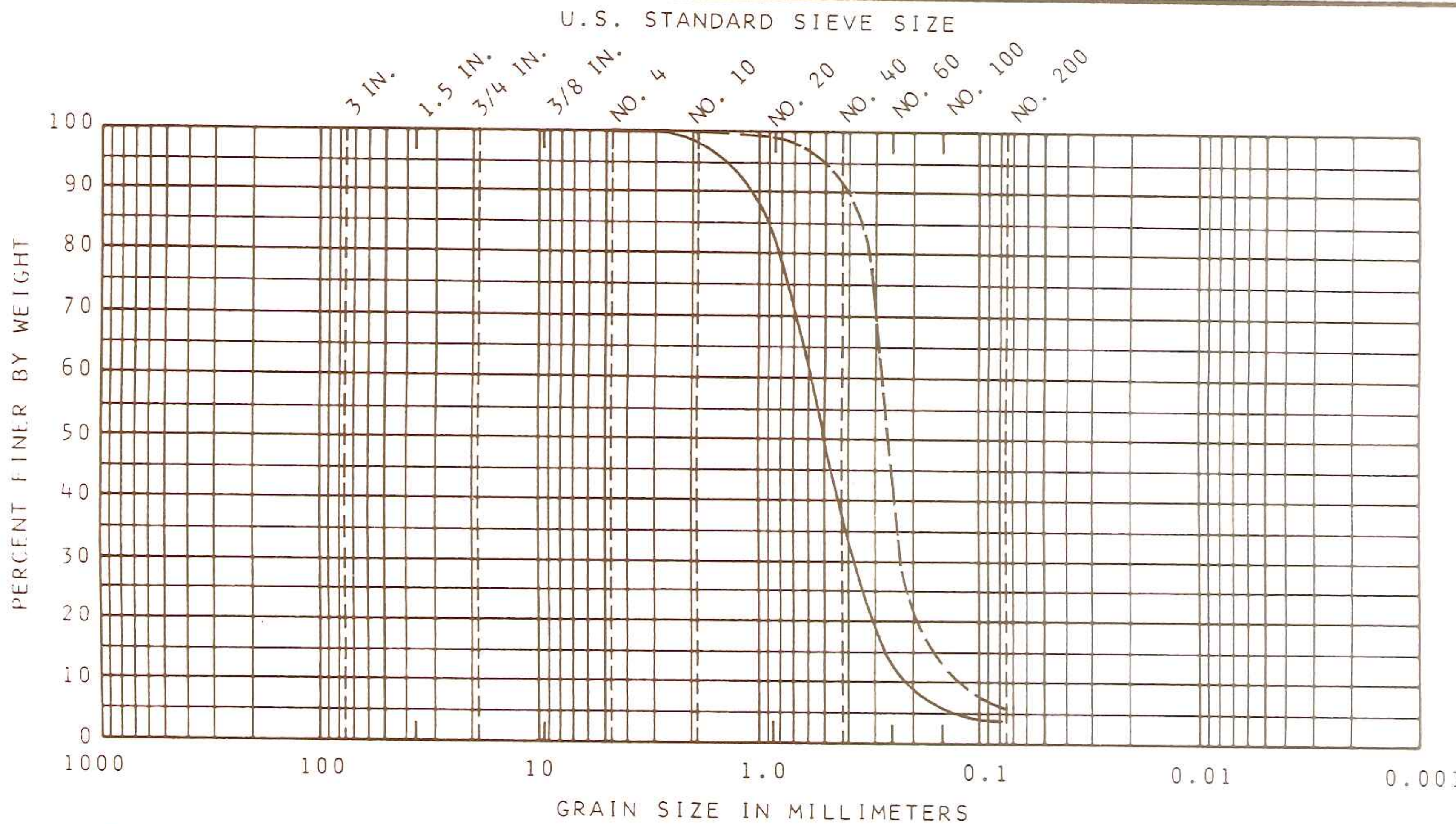
CROSS-SECTION C-C'

FIGURE 5

698-0



COBBLES	GRAVEL		SAND			SILT OR CLAY
	COARSE	FINE	COARSE	MEDIUM	FINE	

SYMBOL	EXPLORATION NUMBER	SAMPLE DEPTH	SOIL DESCRIPTION
———— (solid)	MW 20	8'	FINE TO MEDIUM SAND (SP)
— — — (dashed)	MW 20	68'	FINE SAND (SP)

GeoEngineers Incorporated

GRADATION CURVES

FIGURE 6

APPENDIX

FIELD EXPLORATIONS

DRILLING AND SOIL SAMPLING PROGRAM

Borings MW-15 through MW-21 were completed during the Phase 3 exploration at the approximate locations indicated on Figure 1. Borings MW-15 through 19 and MW-21 were drilled to depths ranging from 9 to 23 feet and Boring MW-20 was drilled to a depth of 79 feet using a Bucyrus-Erie Model 22-W cable tool rig.

A hydrogeologist from our staff determined boring locations, examined and classified the soils encountered, and prepared a detailed log of each boring. Soils encountered were classified visually in accordance with ASTM D-2487-83, which is described in Figure A-1. An explanation of the boring log symbols is presented in Figure A-2. The boring logs are given in Figures A-3 through A-9.

Relatively undisturbed soil samples were obtained from each boring using a Dames & Moore split barrel sampler (2.4-inch-ID). The sampler was driven 18 inches by a 300-pound weight falling a vertical distance of 30 inches.

A total of 21 soil samples which were obtained from the borings were retained by Kennedy/Jenks/Chilton for analytical testing. Sample numbers are indicated on the boring logs, Figures A-3 through A-9. GeoEngineers retained three soil samples from Boring MW-20 for laboratory estimation of permeability.

Drilling and sampling equipment was steam cleaned prior to drilling each boring and prior to leaving the site.

The drilling and sampling programs during our Phase 1 and Phase 2 explorations are described in our 1983 and 1985 reports, respectively.

MONITOR WELL CONSTRUCTION

Two-inch-diameter, Schedule 40 PVC pipe was installed in each boring at the completion of drilling. The PVC pipe was steam cleaned prior to installation. The lower 10 to 20 feet of PVC pipe is machine slotted (0.02 inch slot width to allow entry of water and/or floating hydrocarbons into the well casings. The screen in MW-5 and MW-6 may not extend above the water table during periods of high water levels. Coarse sand was placed in the borehole annulus to approximately one foot above the slotted portion of the wells. A bentonite seal was placed above the sand backfill, followed by native soil to the surface. Monitor well construction is indicated in Figures A-3 through A-9.

Monitor Wells 15 through 21 were developed by surging with compressed air and bailing until the water which entered the casing was relatively clean and sand-free.

Elevations of the well casings were determined to the nearest 0.01 foot with an engineers level by GeoEngineers during February 1986.

GROUND WATER SAMPLING PROGRAM

Ground water samples were collected by GeoEngineers from MW-2, MW-13, and MW-15 through MW-21 on February 5, 1986. Ground water samples were collected with a stainless steel bailer after a minimum of three well volumes of water was removed from the well casing. Ground water samples collected for volatile analysis were siphoned from the bailer with teflon tubing.

The bailer was cleaned prior to each sampling attempt with a fresh water rinse, tri-sodium phosphate wash, and a second fresh water rinse which was followed by a distilled water rinse. A new length of teflon tubing and bailer cord was used during each sampling attempt.

GROUND WATER AND HYDROCARBON ELEVATIONS

The elevation of the ground water table and hydrocarbon product were measured from the monitor well casing rim using a weighted fiberglass tape and water finding paste on February 14, 1986. Ground water elevations have been adjusted for the presence of floating hydrocarbons, when present.

GROUND WATER TEMPERATURE, CONDUCTIVITY, AND PH

The temperature and conductivity of ground water in MW-1 through MW-21 was measured with YSI Model 33 Temperature-Conductivity Meter on February 14, 1986. Temperature-conductivity measurements were conducted near the base of each well with the exception of MW-20 where measurements were conducted at a depth of about 47 feet.

The pH of ground water from MW-2, MW-13, and MW-15 through MW-21 was measured with a Corning Model pH103 meter on February 5, 1986. The pH measurements were conducted during the ground water sampling program after the water samples were withdrawn from the monitor wells.

EXPLOSIVE VAPOR CONCENTRATION

Explosive vapor concentration was measured in each monitor well at a point about one foot above the water table on February 14, 1986. Vapor concentrations in percent of the lower explosive limit (LEL) were measured with a Bacharach Model L Explosimeter, which is calibrated to hexane.

SOIL PERMEABILITY

In-Situ Soil Permeability: Slug tests were conducted while drilling boring MW-20 at depths of 10.5, 16 and 48 feet within the dredge fill aquifer, flood plain deposit and underlying fine sand aquifer, respectively. Water was removed from the drill casing and the rate of rise of the water level was measured. Soil permeability was estimated based on the variable head method (U.S. Navy Bureau of Yards and Docks, 1961) and the time lag method (U.S. Corps of Engineers, Hvorslev, 1951).

Based on the analysis of the slug test data, the permeability of the dredge fill aquifer and underlying fine sand aquifer is estimated to be 0.049 ft/min and 0.054 ft/min, respectively.

Slug test data for the flood plain deposits appears to have been affected by leakage around the drill casing. Hydraulic conductivity of the flood plain deposits is estimated based on a fixed head permeameter test, as reported below.

Soil Laboratory Testing: A fixed head permeameter test was conducted on a sample of the flood plain deposits from a depth of 28 feet in boring MW-20. The permeability of the silty flood plain deposits is estimated to be 0.00000022 ft/min based on the permeameter test.

Soil grain-size gradation of two samples from boring MW-20 was determined by wet sieving. The soil samples were obtained from depths of 8 and 68 feet within the dredge fill sand and lower fine sand aquifers. Soil permeability was estimated based on a relationship between the D_{20} soil grain size and permeability. The permeability of the dredge fill sand and lower fine sand units is estimated to be 0.043 ft/min and 0.018 ft/min, based on soil grain-size data.

Summary: Reported permeabilities of the dredge fill (0.045 ft/min) and fine sand (0.031 ft/min) aquifers are based on a geometric mean of the in-situ (slug tests) and laboratory (grain-size) test results. The reported permeability of the flood plain deposits is based on the permeameter test.

SOIL CLASSIFICATION SYSTEM

MAJOR DIVISIONS			GROUP SYMBOL	GROUP NAME
COARSE GRAINED SOILS MORE THAN 50% RETAINED ON NO. 200 SIEVE	GRAVEL MORE THAN 50% OF COARSE FRACTION RETAINED ON NO. 4 SIEVE	CLEAN GRAVEL	GW	WELL-GRADED GRAVEL, FINE TO COARSE GRAVEL
			GP	POORLY-GRADED GRAVEL
		GRAVEL WITH FINES	GM	SILTY GRAVEL
			GC	CLAYEY GRAVEL
	SAND MORE THAN 50% OF COARSE FRACTION PASSES NO. 4 SIEVE	CLEAN SAND	SW	WELL-GRADED SAND, FINE TO COARSE SAND
			SP	POORLY-GRADED SAND
		SAND WITH FINES	SM	SILTY SAND
			SC	CLAYEY SAND
FINE GRAINED SOILS MORE THAN 50% PASSES NO. 200 SIEVE	SILT AND CLAY LIQUID LIMIT LESS THAN 50	INORGANIC	ML	SILT
			CL	CLAY
		ORGANIC	OL	ORGANIC SILT, ORGANIC CLAY
	SILT AND CLAY LIQUID LIMIT 50 OR MORE	INORGANIC	MH	SILT OF HIGH PLASTICITY, ELASTIC SILT
			CH	CLAY OF HIGH PLASTICITY, FAT CLAY
		ORGANIC	OH	ORGANIC CLAY, ORGANIC SILT
HIGHLY ORGANIC SOILS			PT	PEAT

NOTES:

1. Field classification is based on visual examination of soil in general accordance with ASTM D2488-83.
2. Soil classification using laboratory tests is based on ASTM D2487-83.
3. Descriptions of soil density or consistency are based on interpretation of blowcount data, visual appearance of soils, and/or test data.

SOIL MOISTURE MODIFIERS:

Dry - Absence of moisture, dusty, dry to the touch

Moist - Damp, but no visible water

Wet - Visible free water or saturated, usually soil is obtained from below water table

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SOIL CLASSIFICATION SYSTEM

FIGURE A-1

LABORATORY TESTS:

AL	Atterberg limits
CP	Compaction
CS	Consolidation
DS	Direct shear
GS	Grain-size analysis
HA	Hydrometer analysis
K	Permeability
M	Moisture content
MD	Moisture and density
SP	Swelling pressure
TX	Triaxial compression
UC	Unconfined compression

SOIL GRAPH:

Soil Group Symbol (See Note 1)

Distinct contact between Soil Strata

Gradual Change between Soil Strata

Water Level

Bottom of Boring

BLOW-COUNT/SAMPLE DATA:

Blows required to drive sampler 12 inches or other indicated distances using 300 pound hammer falling 18 inches.

"P" indicates sampler pushed with weight of hammer or hydraulics of drill rig.

22 ■	Location of relatively undisturbed sample
12 ☒	Location of disturbed sample
P □	Location of sampling attempt with no recovery
10 ◪	Location of sample attempt using Standard Penetration Test procedures

NOTES:

1. Soil classification system is summarized in Figure A-1.
2. The reader must to the discussion in the report text as well as the exploration logs for a proper understanding of subsurface conditions.

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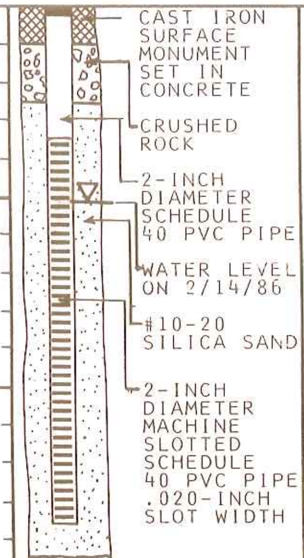
KEY TO BORING LOG SYMBOLS

FIGURE A-2

MONITOR WELL NO. 15

WELL SCHEMATIC
Casing Elevation: 26.41
Casing Stickup: −0.2



DESCRIPTION
Surface Elevation: 26.2

Depth in Feet	Sample Number	Group Symbol	Description
0		GM	BROWN SILTY GRAVEL WITH SAND (MEDIUM DENSE, MOIST)
		SP	GRAY FINE TO MEDIUM SAND (MEDIUM DENSE, MOIST)
	■		GRADES TO DARK GRAY IN COLOR
	⊠		
	15-1 ■	ML	LIGHT GRAY FINE SANDY SILT (SOFT, WET)
15			BORING COMPLETED AT 14.5 FEET ON 1/30/86

DEPTH IN FEET: 0, 5, 10, 15, 20, 25, 30, 35, 40

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Note: See Figure A-2 for Explanation of Symbols

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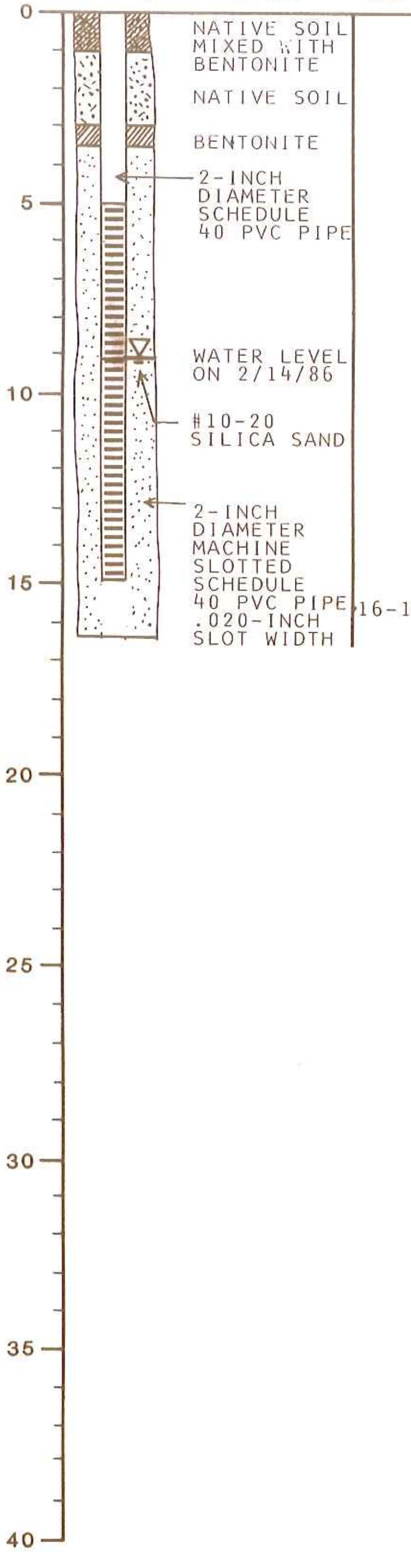
LOG OF MONITOR WELL

FIGURE A-3

MONITOR WELL NO. 16

WELL SCHEMATIC
Casing Elevation: 31.29
Casing Stickup: 2.6



Sample Number	Group Symbol	DESCRIPTION (Surface Elevation: 28.7)
	SP	GRAY FINE TO MEDIUM SAND (MEDIUM DENSE, MOIST)
	SP-SM	GRAY FINE SAND WITH SILT (SOFT, WET)
16-1	ML	LIGHT GRAY SILT (SOFT, WET)

BORING COMPLETED AT 16.5 FEET ON 1/31/86

Note: See Figure A-2 for Explanation of Symbols

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LOG OF MONITOR WELL

FIGURE A-4

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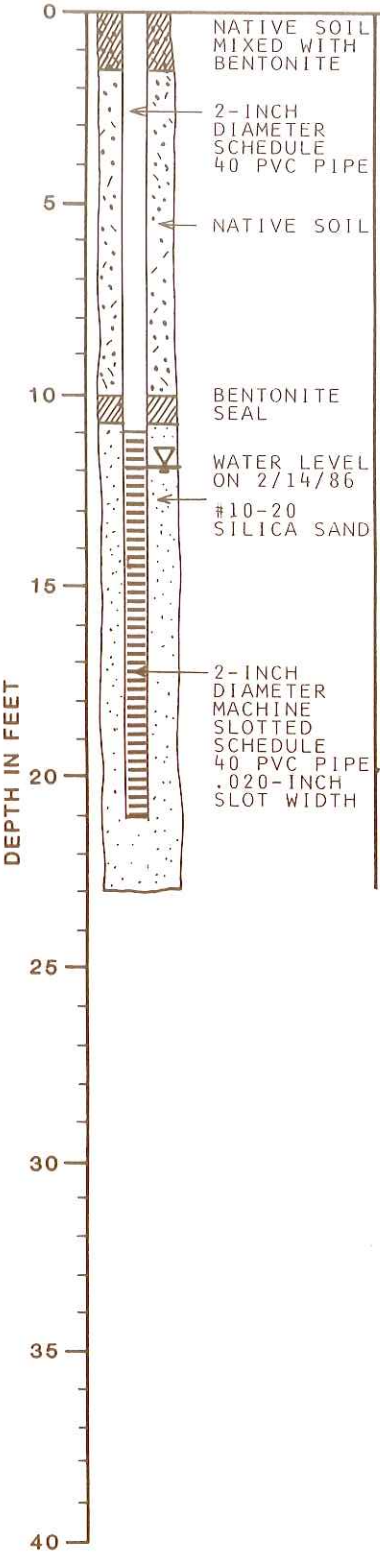
MONITOR WELL NO. 17

WELL SCHEMATIC
Casing Elevation: 34.11
Casing Stickup: 1.6



Sample Number	Group Symbol	DESCRIPTION Surface Elevation: 32.5
	SP	GRAY FINE TO MEDIUM SAND (MEDIUM DENSE, MOIST)
17-1	ML	MOTTLED BROWN AND LIGHT GRAY SILT WITH OCCASIONAL PIECES OF ORGANIC MATTER (SOFT, WET)

BORING COMPLETED AT 23 FEET ON 1/31/86

Note: See Figure A-2 for Explanation of Symbols

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LOG OF MONITOR WELL

FIGURE A-5

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MONITOR WELL NO. 18

WELL SCHEMATIC
Casing Elevation: 33.34
Casing Stickup: 2.7

Depth (feet)	Sample Number	Group Symbol	DESCRIPTION Surface Elevation: 30.6
0		SP	BROWN FINE TO MEDIUM SAND (MEDIUM DENSE, DRY)
	18-1		
5			STRONG HYDROCARBON ODOR AT 7 FEET
		SP	GRAY FINE TO MEDIUM SAND WITH OCCASIONAL FRAGMENTS OF ORGANIC MATTER (MEDIUM DENSE, MOIST)
	18-2		
			BORING COMPLETED AT 9 FEET ON 2/1/86

DEPTH IN FEET: 0, 5, 10, 15, 20, 25, 30, 35, 40

Note: See Figure A-2 for Explanation of Symbols

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LOG OF MONITOR WELL

FIGURE A-6

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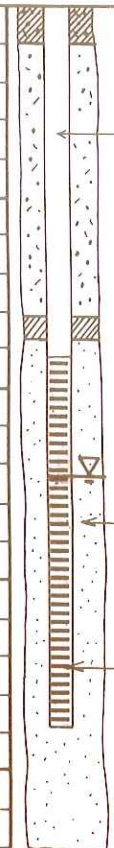
MONITOR WELL NO. 19

WELL SCHEMATIC Casing Elevation: 34.16 Casing Stickup: 1.1	Sample Number	Group Symbol	DESCRIPTION Surface Elevation: 33.1



Depth in feet: 0–40

		Sample Number	Group Symbol	Description
0	BENTONITE MIXED WITH NATIVE SOIL		SP	BROWN FINE TO MEDIUM SAND (MEDIUM DENSE, MOIST TO WET)
	2-INCH DIAMETER SCHEDULE 40 PVC PIPE	19-1		
	BENTONITE	19-2		
	WATER LEVEL ON 2/14/86			STRONG HYDROCARBON ODOR AT 12 FEET
	#20 SILICA SAND	■		
	2-INCH DIAMETER MACHINE SLOTTED SCHEDULE 40 PVC PIPE .020-INCH SLOT WIDTH	19-3		
		19-4	ML	
22				BORING COMPLETED AT 22 FEET ON 2/1/86

DEPTH IN FEET

Note: See Figure A-2 for Explanation of Symbols

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LOG OF MONITOR WELL

FIGURE A-7

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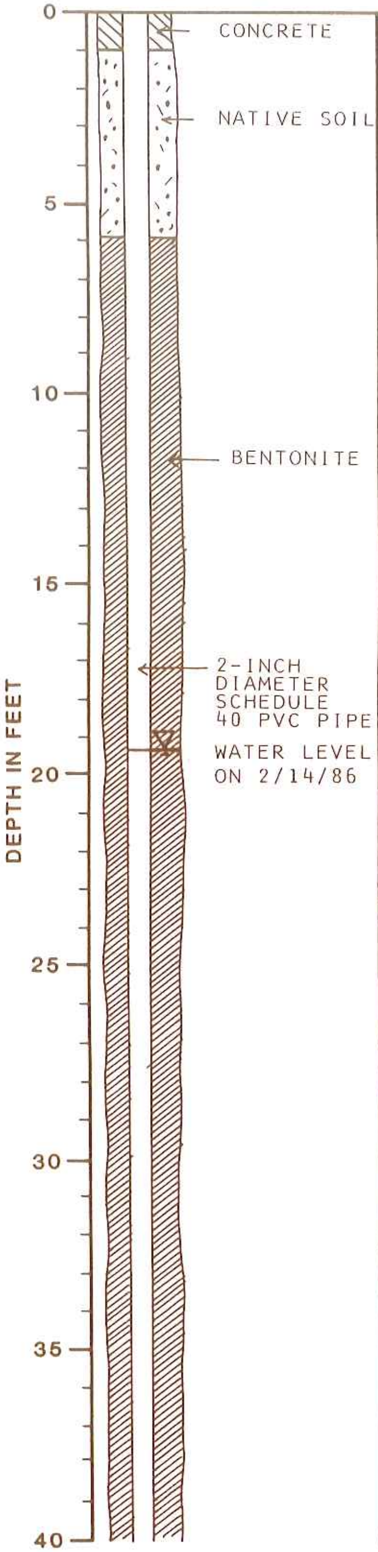
MONITOR WELL NO. 20

WELL SCHEMATIC
Casing Elevation: 30.53
Casing Stickup: 2.8

DESCRIPTION
Surface Elevation: 27.7



Sample Number	Group Symbol	Description
20-1	SP	BROWN FINE TO MEDIUM SAND (MEDIUM DENSE, MOIST)
20-2		GRADES TO GRAY IN COLOR
20-3	SM	LIGHT GRAY SILTY FINE SAND WITH OCCASIONAL PIECES OF ORGANIC MATTER (SOFT, WET)
20-4	ML	LIGHT GRAY SILT WITH OCCASIONAL PIECES OF ORGANIC MATTER (STIFF, WET)
20-5		
20-6		GRADES TO CLAYEY SILT AT 28 FEET
	CL	BLUE-GREEN CLAY (STIFF, WET)
		STRONG UPHOLE FLOW OF NATURALLY OCCURING GAS (METHANE?) FROM 32 FEET
20-7	SM-SP	GRAY FINE SAND WITH SILT AND A TRACE OF ORGANIC MATTER (MEDIUM DENSE, WET)
20-8	SP	DARK GRAY FINE SAND (DENSE, WET)

Note: See Figure A-2 for Explanation of Symbols

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LOG OF MONITOR WELL

FIGURE A-8

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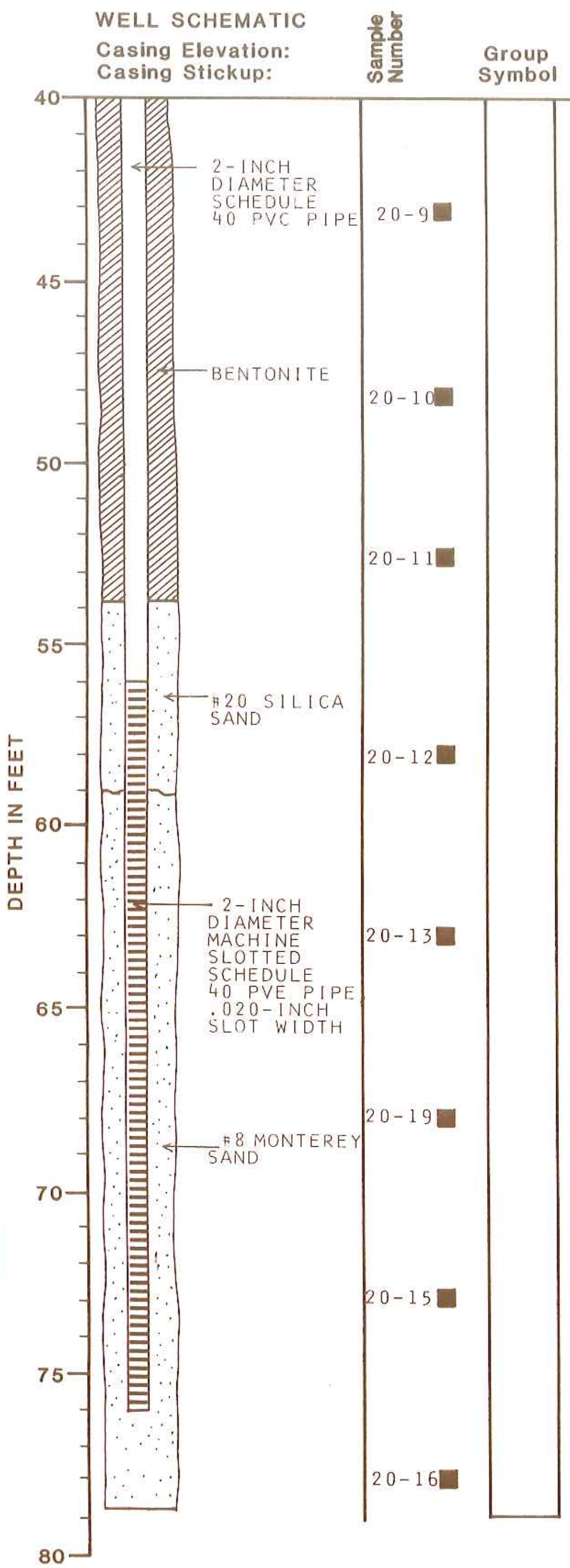
MONITOR WELL NO. 20 (CONTINUED)



DESCRIPTION

Surface Elevation:

GRADES TO VERY DENSE AT 49 FEET

DARK GRAY FINE SAND (VERY DENSE, WET)

BORING COMPLETED AT 79 FEET ON 2/3/86

Note: See Figure A-2 for Explanation of Symbols

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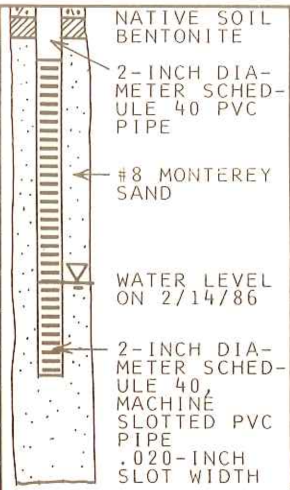
LOG OF MONITOR WELL

FIGURE A-9

MONITOR WELL NO. 21

WELL SCHEMATIC
Casing Elevation: 30.21
Casing Stickup: 2.5



Depth in Feet	Sample Number	Group Symbol	DESCRIPTION Surface Elevation: 27.7
0		SP	BROWN FINE TO MEDIUM SAND (MEDIUM DENSE, MOIST)
	21-1 ■		
5			
	□		
10	21-2 ■	SM	GRAY SILTY FINE SAND WITH A TRACE OF ORGANIC MATTER (MEDIUM DENSE, WET)
	21-3 ■	ML	GRAY FINE SANDY SILT (MEDIUM STIFF, WET)
			BORING COMPLETED AT 12.5 FEET ON 2/4/86
15			
20			
25			
30			
35			
40			

Note: See Figure A-2 for Explanation of Symbols

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LOG OF MONITOR WELL

FIGURE A-10