GW - 1

REPORTS

YEAR(S):

1989

RESPONSE TO NMOCD COMMENTS ON "REPORT ON SOIL VAPOR SURVEY, WELL INSTALLATION, AND HYDROCARBON RECOVERY SYSTEM, BLOOMFIELD REFINING COMPANY"

COMMENT	RESPONSE
1a.	Ground elevations at boreholes drilled by GCL were incorrectly reported on the corresponding lithologic logs as TOP elevations. The ground elevations were corrected by subtracting the length of pipe 'stick-up' from the TOP elevations and the revised values were listed on the new set of lithologic logs presented in Appendix B. There does not appear to be any basis for assuming that Nacimiento elevations supplied by Engineering-Science are incorrect. ok
1b.	A revised Plate 3 showing corrected Nacimiento Formation bedrock elevations has been constructed. All bedrock elevations reported by Engineering-Science were retained. The revised bedrock structural contour map shows evidence of a bedrock "high" south of Sullivan Road that extends into the area of hydrocarbon recovery and that may constrain southward movement of hydrocarbons. Southward migration of hydrocarbons in the unconsolidated surficial aquifer would be inhibited by structural highs in the Nacimiento Formation because the decreased saturated thickness and transmissivity of the surficial aquifer caused by these bedrock highs would tend to deflect movement of ground water and hydrocarbons into thicker, more transmissive alluvial deposits north and northwest of the recovery area under anisotropic flow conditions.
2.	Plates 5 and 7 have been recontoured using only water-level measurements observed at recovery wells, piezometers, and monitor wells MW-11 and MW-13 on January 16 and February 15, 1989. Water levels at all other wells were assumed to be located sufficiently far from the recovery area to be minimally impacted by recovery operations. Water levels were measured for all monitor wells, recovery wells and piezometers on June 15, 1989. The water level contour map for June 15th's measurements is enclosed as plate number 7. Recovery well MW-4 was not operational at the time the measurements were made and it is not known how long the well was out of service.

COMMENT	RESPONSE
3.	Water levels in the eastern part of the refinery tend to decrease between September and January, as evidenced by 1986 water-level data supplied by Engineering-Science. Thus, use of September water levels to reflect initial, pre-recovery conditions resulted in calculated water-level declines that are likely due, at least in part, to natural ground water recession in response to the end of the irrigation season. However, if the rate of loss of ground water from the recovery area to western reaches of Hammond Ditch during recession periods is significantly larger than the rate of recovery-well capture, downgradient flexures would likely be evident in the Kriged water table. Revised 12-day and 42-day recovery water table maps show evidence of upgradient flexures in the recovery area, particularly near recovery well RW-3, suggesting that ground water capture is more dominant than loss of ground water to Hammond Ditch in the area of recovery. Pre-recovery water levels were obtained on January 4, 1989 at all recovery wells, piezometers, and monitor well MW-11 immediately prior to the onset of recovery. The pre-recovery water table shown in Plate 4 has been redrafted to reflect the true pre-recovery conditions. Due to problems associated with quantifying water-level declines attributed to ground water recession, Plates 6 and 8 have been omitted from the report. ok ok ok good!
4.	If water-level declines in recovery wells were primarily generated by ground water recession, greater declines would be observed in wells located closest to Hammond Ditch and the spray irrigation area. Inspection of water-level declines listed in Table 3-1 indicate that proximity to recovery wells instead governs the magnitude of water level declines in piezometers. Although this pattern does not conclusively demonstrate that the recovery system is effectively capturing ground water and hydrocarbons, it is not entirely clear how the data 'introduces serious doubts as to whether the system can work as designed'. Given the large specific yields typical of coarse-grained deposits, the effectiveness of recovery can not be judged on the basis of 42 days worth of data. true

COMMENT	RESPONSE
5.	The statement that the soil-vapor concentration of toluene found at MW-11 is 'roughly equal to background' has been omitted from the text. The distribution of toluene suggests that, like benzene, soil-vapor concentrations decrease to background west and south of well MW-11 and 300 feet east of well MW-11. Refer to the revised text on page 45 for a discussion of the probable extent of hydrocarbon plumes beneath BLM land. Soil-vapor concentrations of all hydrocarbons increase abruptly near sample point 17, where additional sampling may be required to further define the magnitude and extent of hydrocarbons released to the subsurface due to loading and degreasing activities.
6.	The map shown in Figure 3-7 has been correctly relabelled as 1,2 dichloroethane. The occurrence of very small concentrations of DCA in wells RW-2 and MW-11 during October sampling and the absence of DCA in these wells during sampling the following April may be due to analytical error attributed to the small concentrations. OK

FINAL REPORT ON SOIL VAPOR SURVEY, WELL INSTALLATION, AND HYDROCARBON RECOVERY SYSTEM BLOOMFIELD REFINING COMPANY

August 3, 1989

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FINAL REPORT ON SOIL VAPOR SURVEY, WELL INSTALLATION, AND HYDROCARBON RECOVERY SYSTEM BLOOMFIELD REFINING COMPANY

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1.0 EXECUTIVE SUMMARY

A soil vapor survey was conducted during the week of July 18, 1988 on U.S. Bureau of Land Management (BLM) property south of the Bloomfield Refining Company (BRC) facility in order to determine if solvents are present in ground water and to assess the extent of dissolved or floating petroleum product migration in the subsurface. Survey results suggest that the underlying Nacimiento Formation may inhibit movement of volatile organic compounds (VOCs) in ground water towards BLM land. Based on this information, installation of recovery wells on Bloomfield Refining Company property was expected to be sufficient to capture most of the dissolved and immiscible hydrocarbons in perched ground water beneath the refinery and some hydrocarbons from beneath BLM property.

Two recovery wells were installed on BRC property between August 29 and September 2, 1988. These wells, in addition to existing well MW-10, comprise the hydrocarbon recovery system. Based on a numerical ground-water flow model, these three wells are considered to be sufficient to capture hydrocarbons from beneath refinery property. Four piezometers have also been installed to assess the hydraulic impacts of recovery operations on the perched alluvial aquifer. After 42 days of recovery, significant hydraulic capture of ground water and hydrocarbons was evident. Operation of the recovery system over longer periods of time is expected to further increase the extent and rate of hydraulic capture in the perched alluvial aquifer.

2.0 SOIL VAPOR SAMPLING

2.1 GOALS AND OBJECTIVES

A soil vapor survey was conducted during the week of July 18, 1988 on U.S. Bureau of Land Management (BLM) property in order to determine if halogenated hydrocarbons are present in ground water and to assess the extent of dissolved or floating petroleum product migration in the subsurface from beneath Bloomfield Refining Company (BRC) property. Soil vapor surveys have proven effective in identifying the extent of volatile organic compounds (VOCs) in ground water. The purpose of the survey was to assist in the identification of the source of hydrocarbons observed in ground water south of the refining facility and to better define the areal extent of these hydrocarbons. Results of the survey were also used to assist in determining the location of on-site ground-water recovery wells.

2.2 TECHNICAL APPROACH

The vapor survey was not conducted on refinery property due to anticipation of significant chemical interference from normal refinery operations. However, soil vapor samples were collected at monitor well locations where concentrations of organic constituents in ground water were known. A grid initially constructed on 300-foot centers was used to perform the soil vapor survey on BLM property. The large distance between grid centers was chosen in order to avoid the influence of small-scale heterogeneities that might affect vapor migration in the subsurface. The original grid, which extended southward from Sullivan Road and westward from the edge of the terminal area, was oriented parallel and perpendicular to the general direction of westward ground-water flow in the perched alluvial aquifer. Grid spacing was continuously redefined on the basis of the vapor concentration observed at the most recently sampled grid point. A total of 25 points included 3 vapor samples collected on BRC property and 22 vapor samples collected on BLM land. Approximate locations of the soil vapor sample points are shown in Figure 2-1.

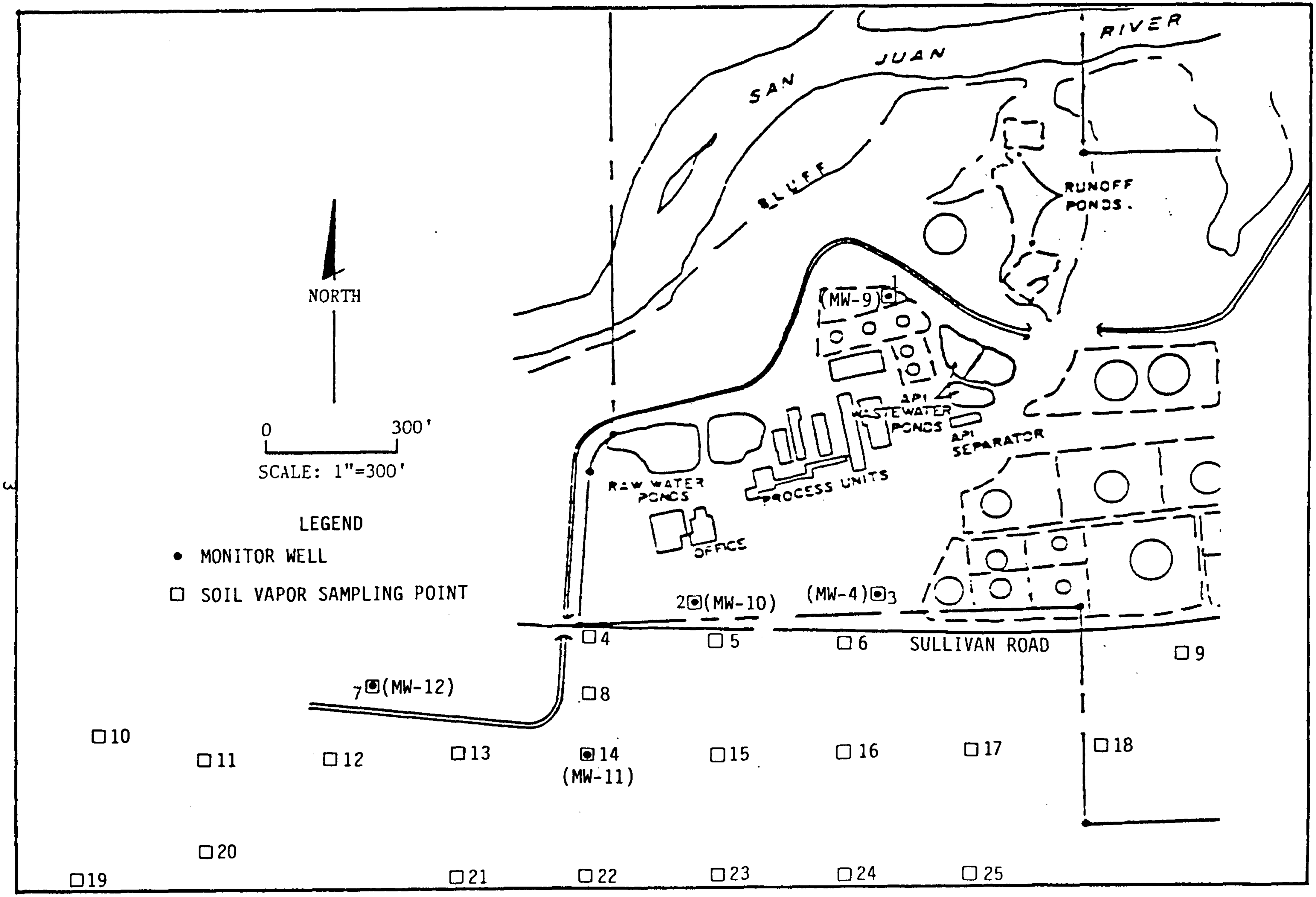

FIGURE 2-1

LOCATIONS OF SOIL VAPOR SAMPLING POINTS

Soil vapor sampling was performed pursuant to guidelines presented in the GCL Standard Operating Procedures for Soil Vapor Sampling and Analysis (Appendix A). Prior to sampling on the grid, soil vapor samples were obtained near monitor wells at which concentrations of VOCs were known. This permitted estimation of the degree of correlation between VOC soil vapor concentrations and observed concentrations of VOCs in ground water.

The sampling system employed driven 3/4-inch diameter hollow steel probes and a Photovac 10S50 gas chromatograph (GC). Analysis of soil vapor grab samples extracted from the shallow subsurface at depths of 5 feet helped to identify the presence of VOCs in the soil and underlying ground water. Analyses made at each sample point consisted of:

- Benzene
- Toluene
- Ethylbenzene
- Xylenes
- Trichloroethylene (TCE)
- Tetrachloroethylene (PCE)

Table 2-1 lists the physical properties of these volatile organic compounds. All VOCs sampled during the soil vapor survey were characterized by Henry's law constants in excess of 5×10^{-4} atm·m^3/mole and vapor pressures of at least 1 mmHg, and were therefore considered suitable for soil-vapor sampling (Marrin, 1988). Quality control of the analyses included daily calibrations, air blanks, equipment blanks, and retention time checks for all constituents of interest. Calibration standards, analyzed to ±2%, were supplied by Scotty Specialty Gases. Based upon analysis of concentrations of "background" VOCs located 1140 feet southwest of the refinery, a significant level of aromatic or halogenated hydrocarbons was considered to exist if:

- Total hydrocarbons in soil vapor were found to exceed 50,000 µg/l (50 ppm),
- Either benzene or toluene in soil vapor was found to exceed 1500 µg/l (1.5 ppm), or

TABLE 2-1

PHYSICAL PROPERTIES OF VOLATILE ORGANIC CONSTITUENTS OBSERVED AT BLOOMFIELD REFINING COMPANY

	Solubility in Water (20-25°C) (mg/l)	Vapor Pressure (14-32°C) (mmHg)	Henry's Law Constant (atm·m^3/mole)	Log of Octanol/ Water Partition Coefficient
Benzene	1780-1800	95.2	5.55×10^{-3}	2.13
Toluene	535	28.7	5.93×10^{-3}	2.69
Ethylbenzene	206	7	6.44×10^{-3}	3.15
Xylenes	insoluble	10(O-Xylene)	6.12×10^{-3}	----
Tetrachloroethylene (PCE)	150	14	28.7×10^{-3}	2.88
Trichloroethylene (TCE)	1100	57.9	11.7×10^{-3}	2.29
1,2-Dichloroethane (DCA)	6300-8300	61-200	$(1.10\text{-}5.32) \times 10^{-3}$	1.48
Phenol	67000	insignificant	1.3×10^{-6}	1.46

Source: U.S. EPA, 1981.

- The concentration of PCE in soil vapor exceeded 10,000 µg/l (10 ppm).

2.3 RESULTS AND CONCLUSIONS

Interpretation of soil vapor survey results should account for source location, soil moisture content, organic carbon content, and volatility and solubility of the VOC under investigation. The primary transport mechanism for VOCs in unsaturated soil is by upward diffusion from the underlying saturated zone through air- and gas-filled voids. The presence of soil moisture tends to inhibit transport of vapors by reducing the volume of open voids through which volatile organic vapors can diffuse, but has less influence on highly-volatile VOCs than on compounds characterized by low volatility. The presence of organic matter may also inhibit diffusion through physical sorption of VOCs. Silka (1988) has shown that sorption in soils containing as little as 0.1% organic carbon can act as a significant sink for VOC vapors. Since soil moisture and organic matter act as sinks for VOC vapors and inhibit free movement of vapors from the ground water to the overlying soil, use of soil vapor concentrations to define the extent of hydrocarbons dissolved in underlying ground water is especially well-suited to coarse-grained, freely-draining deposits that do not contain significant amounts of organic material.

As indicated by lithologic logs of boreholes recently drilled on or near refinery property, the upper 10 to 20 feet of deposits underlying the site are comprised of partially-saturated silt and clay. These fine-grained deposits tend to trap infiltrating moisture and thereby inhibit upward diffusion of organic vapor that partitions out of the underlying ground water. The deposits might include minor amounts of organic matter that can easily adsorb organic vapors. Since the shallow clay layer appears to extend continuously across the site north of Sullivan Road, the diffusion-inhibiting effects of the clay would be expected to be roughly uniform across refinery property. Thus, it can be assumed that soil vapor concentrations observed north of Sullivan Road are reliable indicators of the extent of dissolved hydrocarbon plumes in the underlying ground water, especially when overall trends in the soil vapor plumes for a number of constituents are consistent with each other. The relative concentrations of soil vapors are also useful for identifying source areas where hydrocarbons are likely to have been released into the subsurface. Since the shallow clay layer appears to be absent from at least a portion of BLM property, soil vapor concentrations would be expected to be higher beneath BLM land for a given ground-water concentration.

Concentrations of benzene, toluene, ethylbenzene, total xylenes, tetrachloroethylene (PCE) and trichloroethylene (TCE) observed in the vapor samples are listed in Table 2-2. Plots of vapor concentrations and the logarithms of concentrations are shown in Figures 2-2 through 2-13. The distribution of log concentration is useful when vapor concentrations vary over several orders of magnitude because the logged concentration data are less subject to averaging during machine contouring than raw concentration data. The Golden Software "Surfer" graphics package was used to perform kriging of the data over a 1000-foot search radius, a procedure that tended to smooth the data with respect to space. X- and y-coordinates used for plotting were referenced to monitor well MW-11. Locations of the monitoring wells relative to the vapor sample points are approximate and can be more accurately defined by means of a topographic survey of well head locations.

The largest concentrations of benzene, toluene, total xylenes, and PCE were observed at sample point 1 (well MW-9). Although the area near well MW-9 is not considered to be the sole source of hydrocarbons, it appears to have been the site of significant hydrocarbon release during the history of the refinery. An air blank analysis was performed at point 1 because of the strong odor evident at this sample point. Results of the air blank analysis, which are presented in Table 2-2, indicate the presence of toluene, ethylbenzene, total xylenes, and TCE in the ambient air. However, the observed air concentrations are not sufficient to explain the high subsurface concentrations of these constituents beneath

TABLE 2-2

BLOOMFIELD REFINING COMPANY
SOIL VAPOR SURVEY RESULTS

Point or Sample	x(ft)[a]	y(ft)[b]	Concentration (ppm)					
			Benzene	Toluene	Ethylbenzene	Total Xylenes	PCE	TCE
1(MW-9)	600	1070	2995	4655	ND	634	110	ND
2(MW-10)	150	350	38.2	11.9	74.5	ND	ND	ND
3(MW-4)	570	350	ND	710	102	20.6	78	ND
4	0	300	ND	1025	ND	10195	ND	ND
5	300	300	0.062	0.149	ND	0.071	0.011	ND
6	600	300	ND	0.041	ND	0.006	ND	0.086
7(MW-12)	-610	150	ND	0.285	ND	ND	ND	ND
8	0	150	ND	1.95	ND	25.58	ND	6.49
9	1200	150	ND	0.448	0.349	0.442	0.513	0.380
10	-1200	0	ND	0.085	ND	0.038	ND	0.034
11	-900	0	ND	0.125	ND	0.430	ND	2.14
12	-600	0	ND	0.130	ND	0.037	ND	ND
13	-300	0	ND	0.100	ND	0.042	ND	0.037
14(MW-11)	0	0	0.560	10.9	ND	9.70	ND	ND
15	300	0	0.230	1.24	ND	0.126	ND	ND
16	600	0	0.072	0.584	0.146	ND	ND	ND
17	900	0	ND	1.88	9.27	0.979	ND	23.8
18	1200	0	ND	0.143	ND	0.107	0.003	0.082
19	-1200	-300	ND	0.061	ND	0.028	0.002	0.003
20	-900	-200	ND	0.060	ND	0.033	0.004	0.072
21	-300	-300	ND	0.088	ND	0.127	ND	0.033
22	0	-300	ND	0.044	ND	0.016	ND	ND
23	300	-300	ND	0.925	ND	0.661	ND	ND
24	600	-300	ND	0.979	ND	0.310	ND	ND
25	900	-300	0.014	0.107	ND	0.055	0.006	0.067
Air Blank	-----	----	ND	0.049	0.008	0.091	ND	0.074
Soil Blank	-700	-600	0.016	0.547	ND	0.037	ND	ND

ND = not detected
a approximate distance east from well MW-11
b approximate distance north from well MW-11

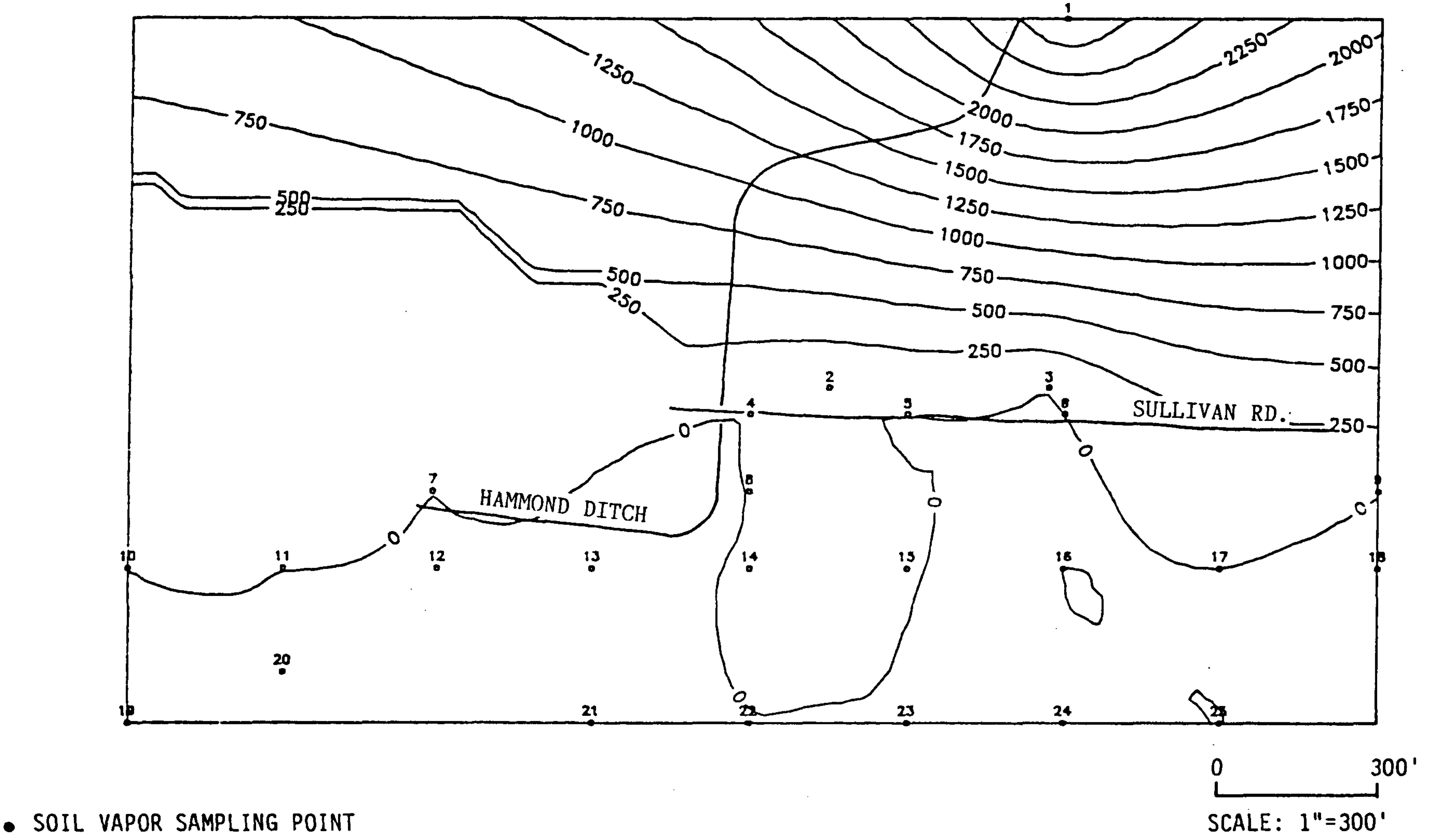

FIGURE 2-2
BENZENE VAPOR CONCENTRATION (ppm)

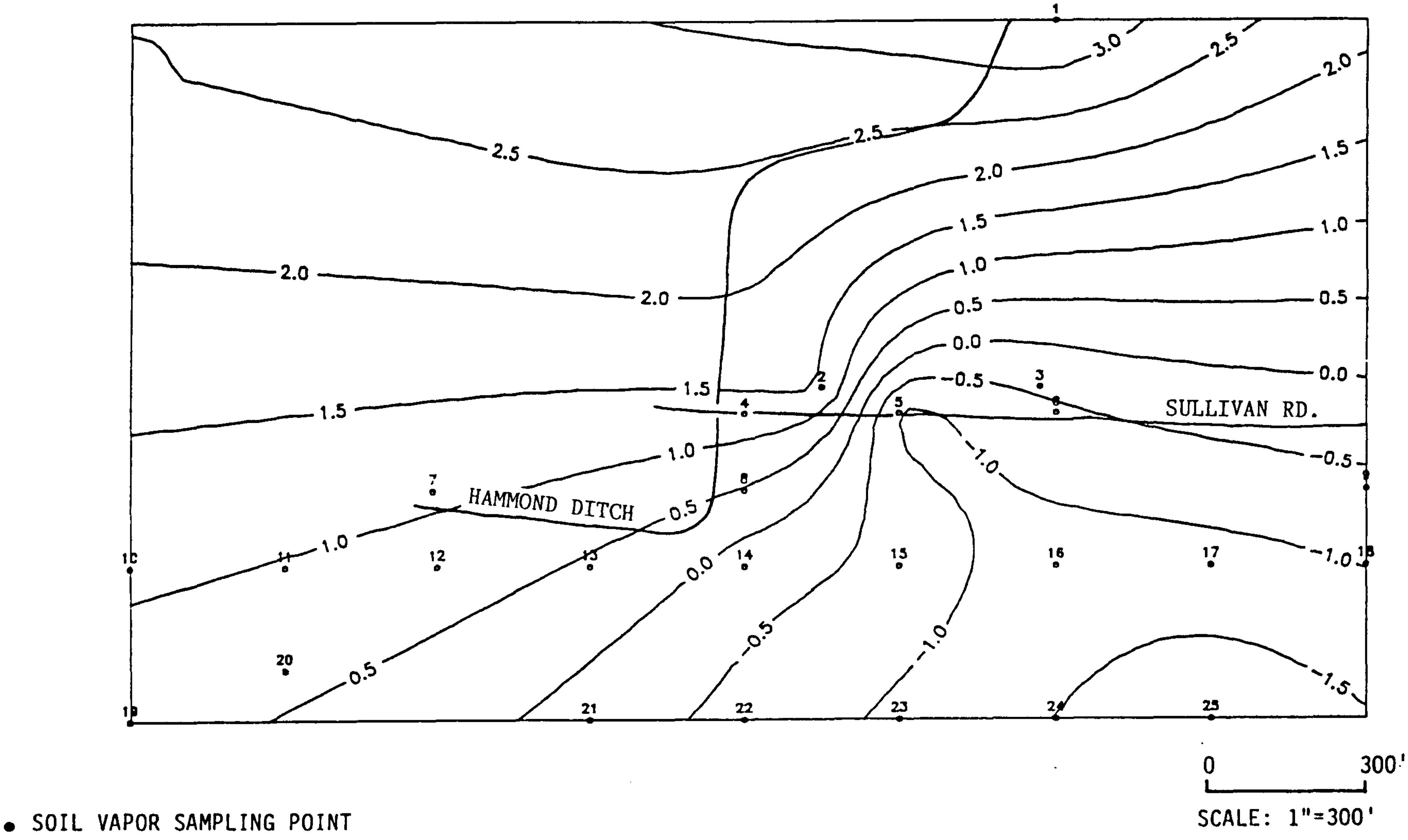

FIGURE 2-3
BENZENE VAPOR LOG CONCENTRATION (LOG ppm)

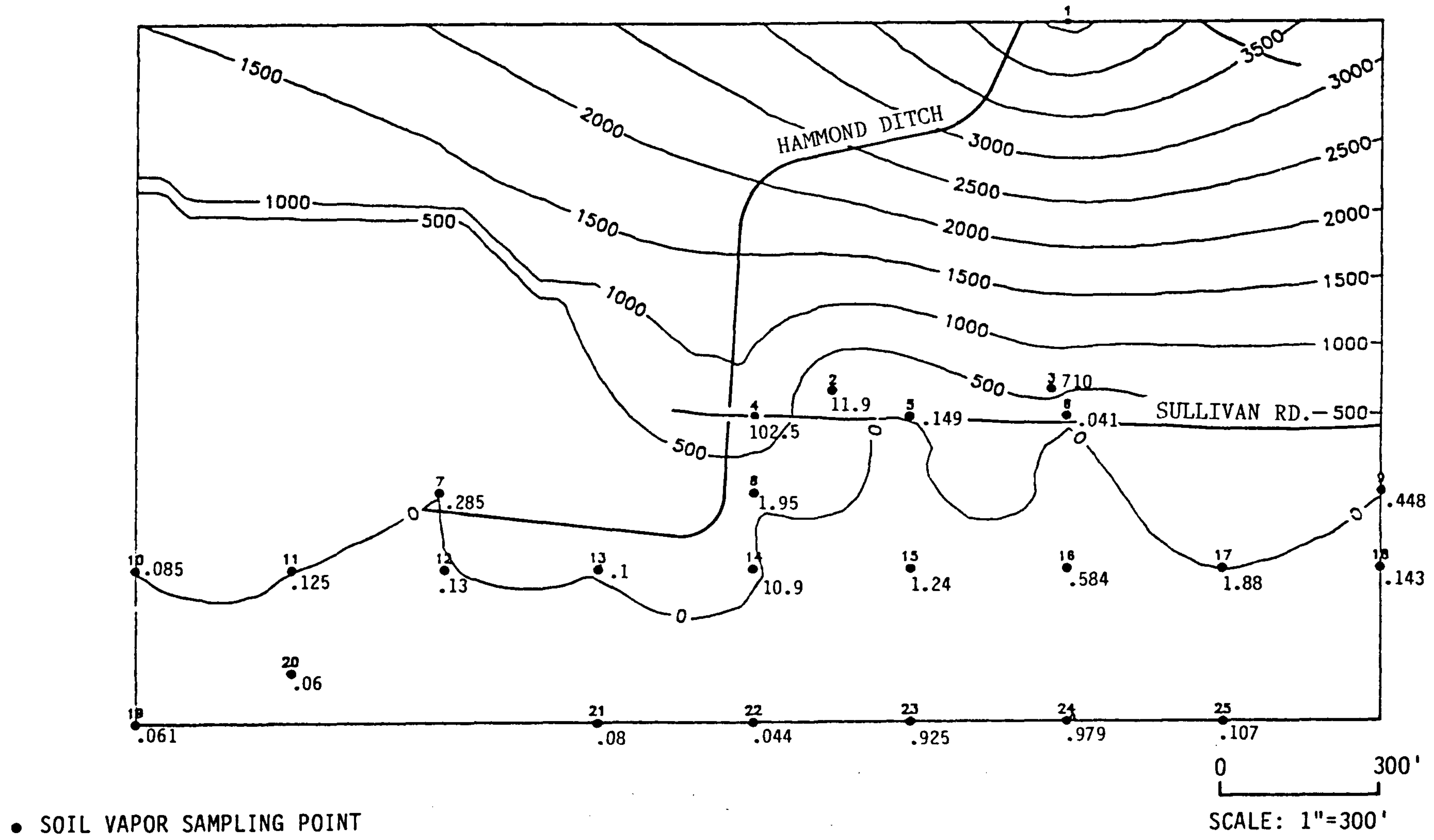

FIGURE 2-4
TOLUENE VAPOR CONCENTRATION (ppm)

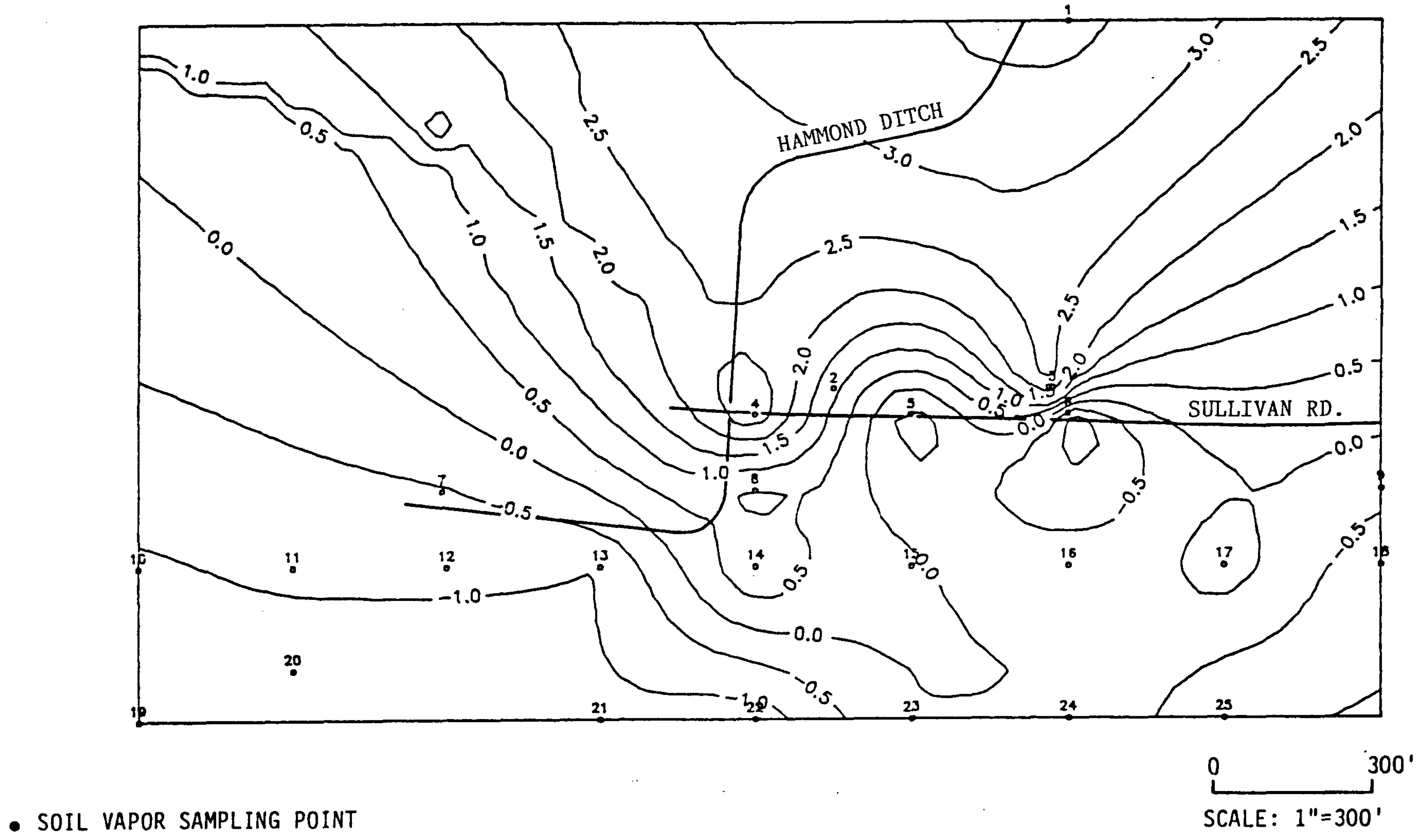

FIGURE 2-5
TOLUENE VAPOR LOG CONCENTRATION (LOG ppm)

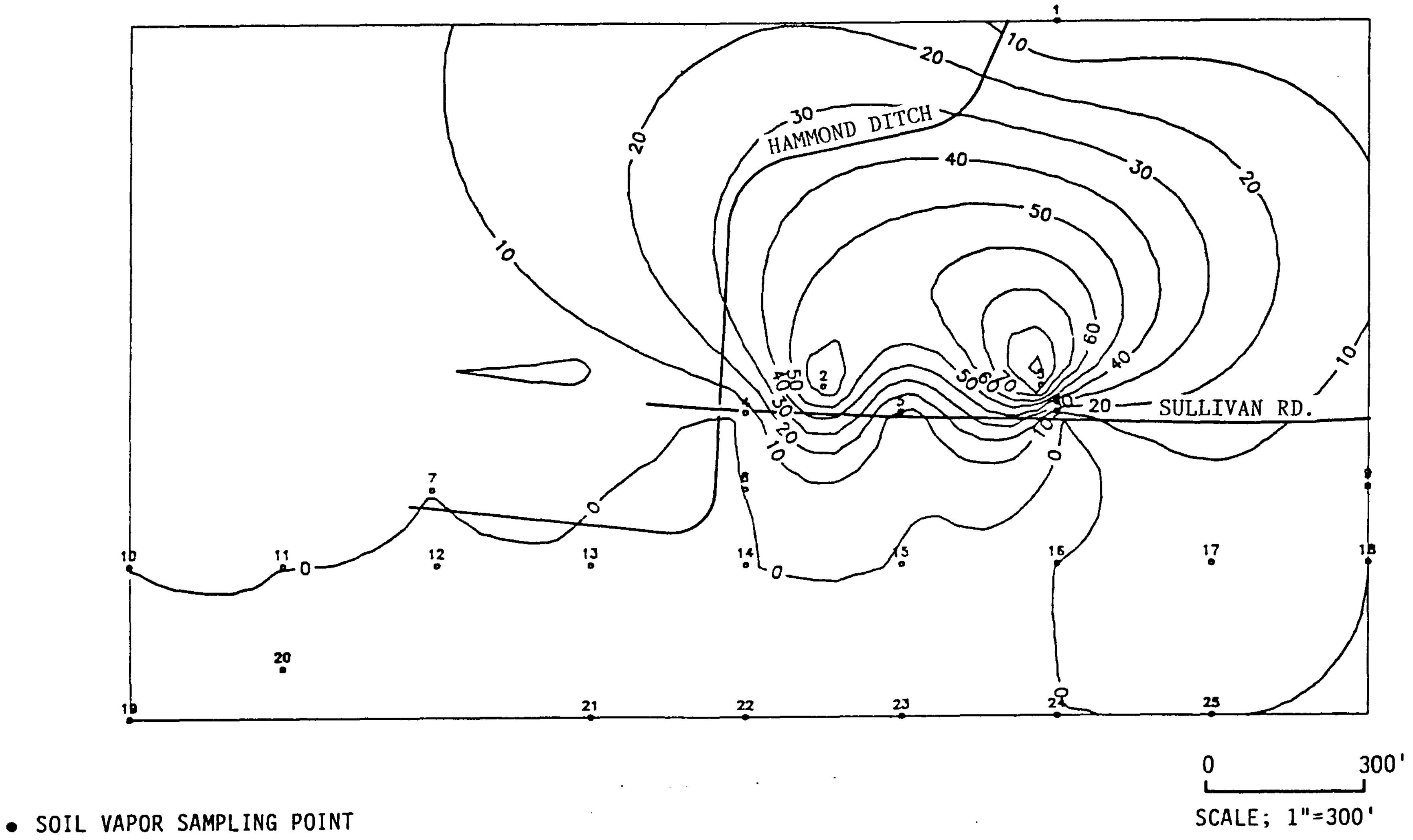

FIGURE 2-6
ETHYLBENZENE VAPOR CONCENTRATION (ppm)

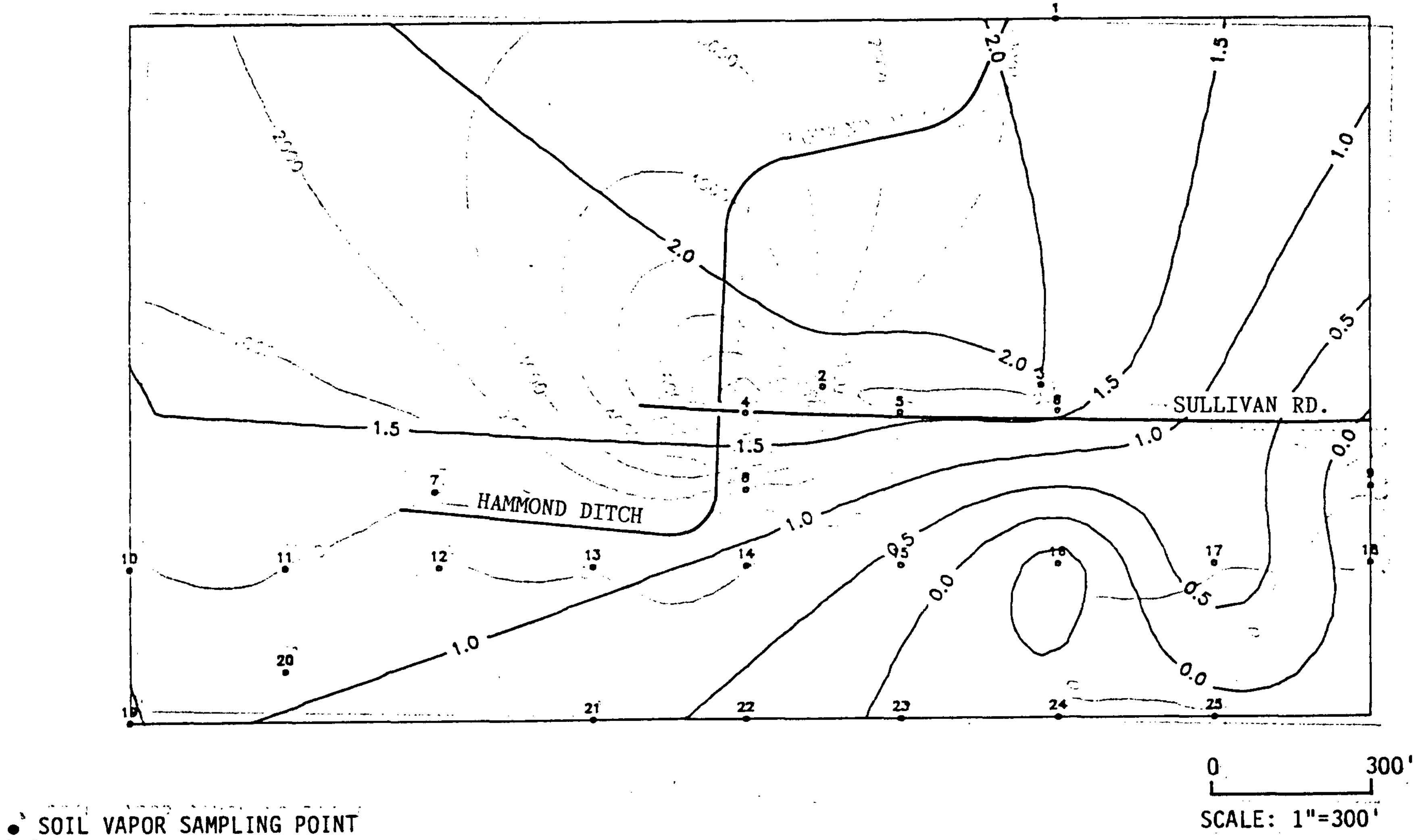

FIGURE 2-7
ETHYLBENZENE VAPOR LOG CONCENTRATION (LOG ppm)

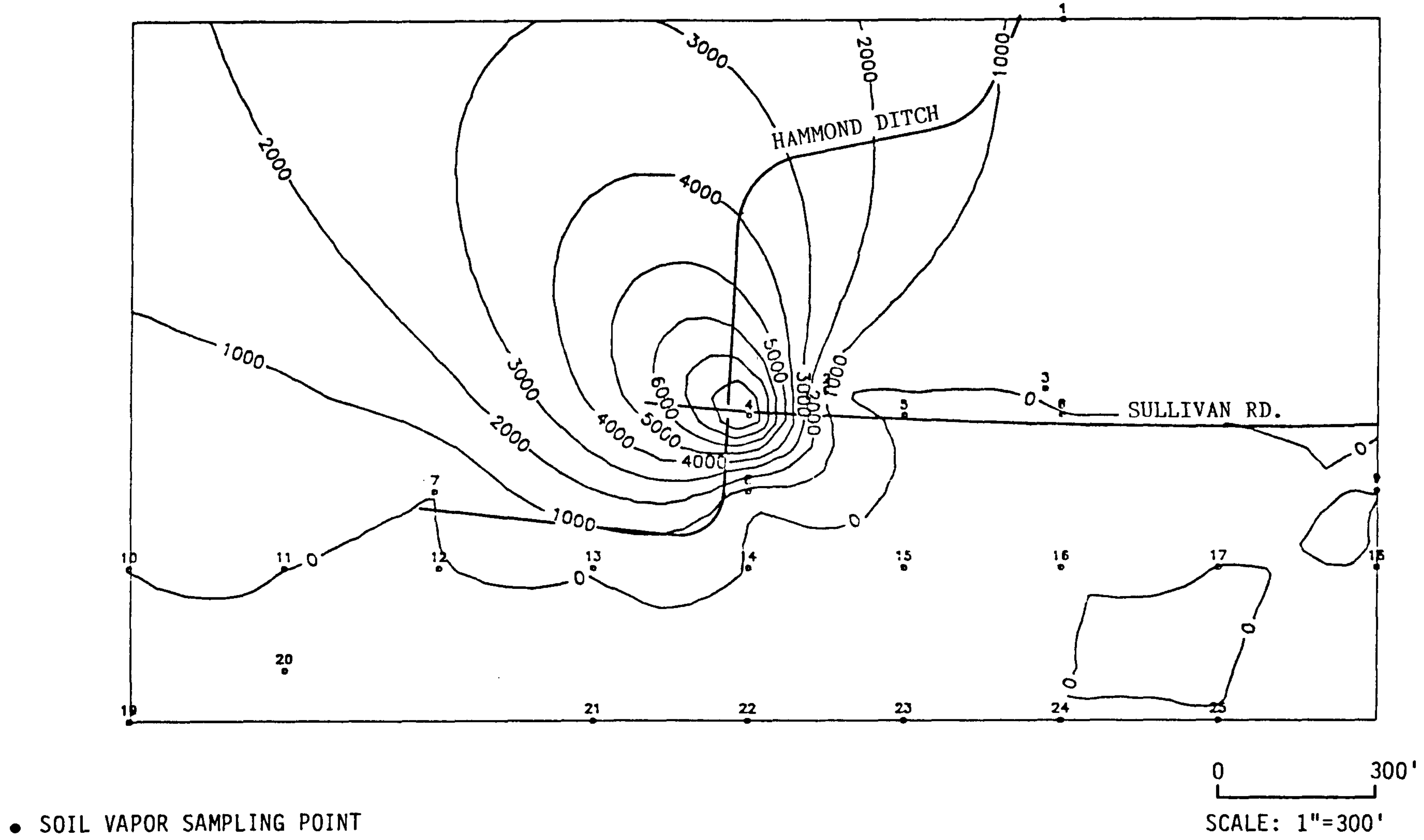

FIGURE 2-8
XYLENE VAPOR CONCENTRATION (ppm)

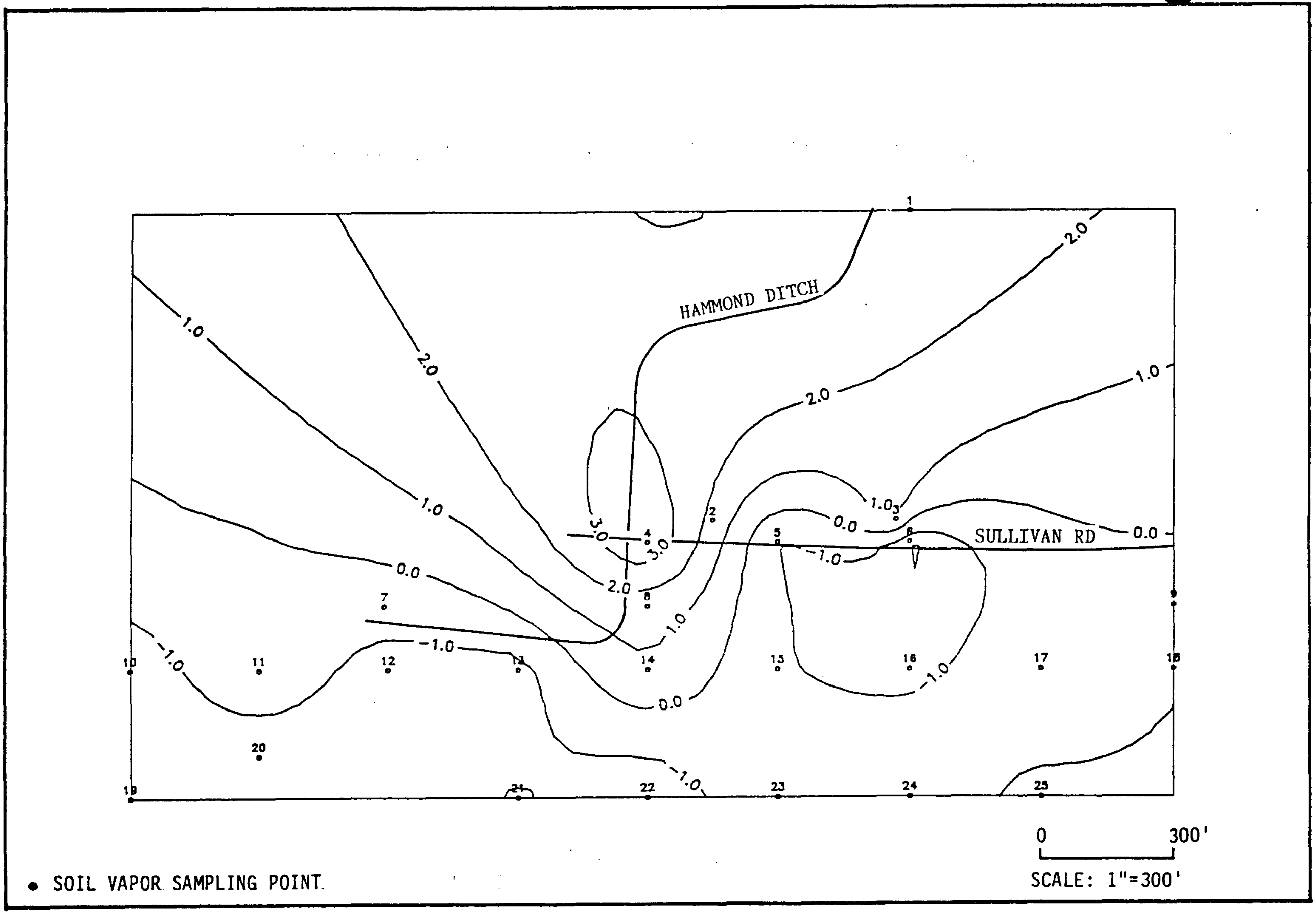

FIGURE 2-9

XYLENE VAPOR LOG CONCENTRATION (LOG ppm)

PCE VAPOR CONCENTRATION (PPM)

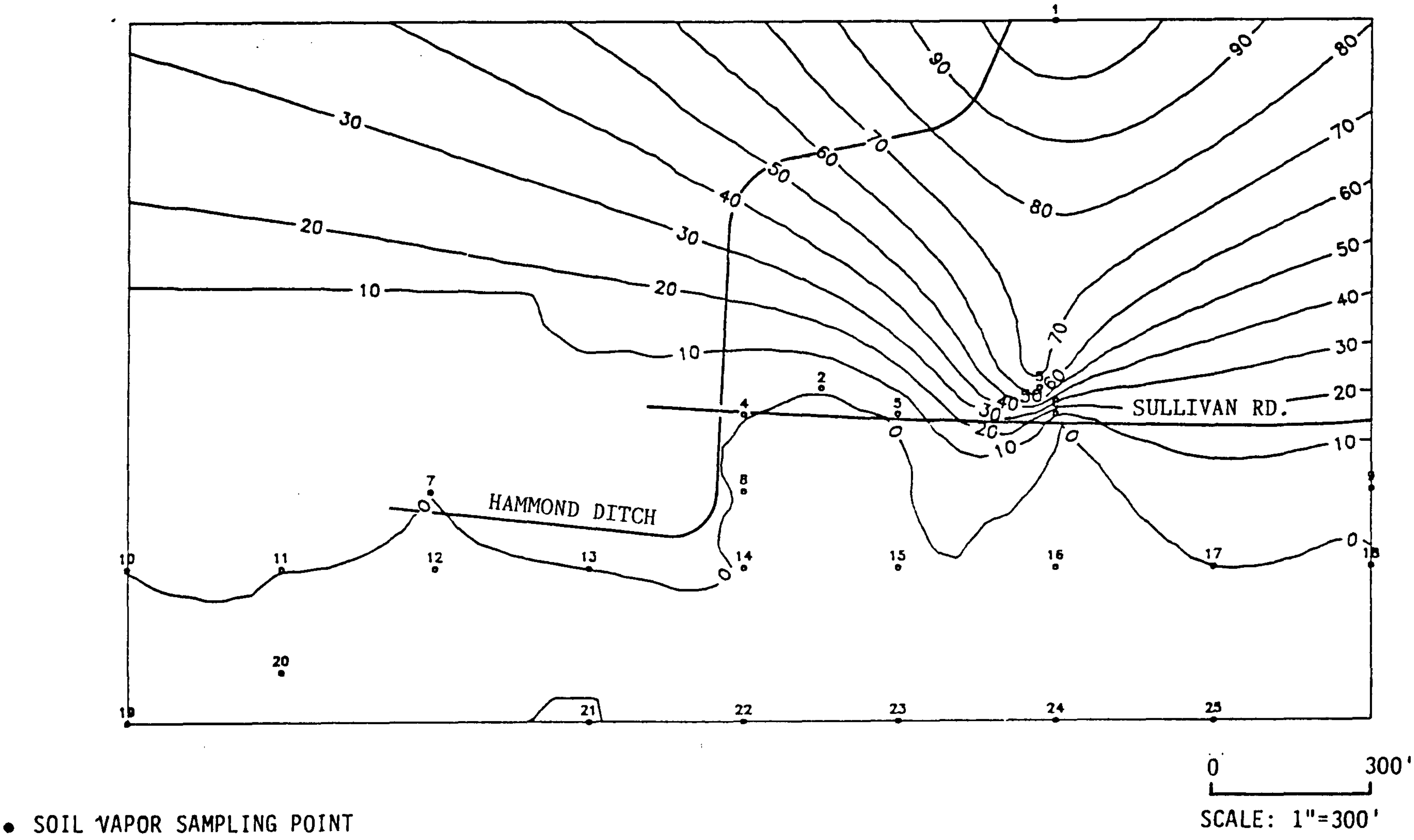

FIGURE 2-10
PCE VAPOR CONCENTRATION (ppm)

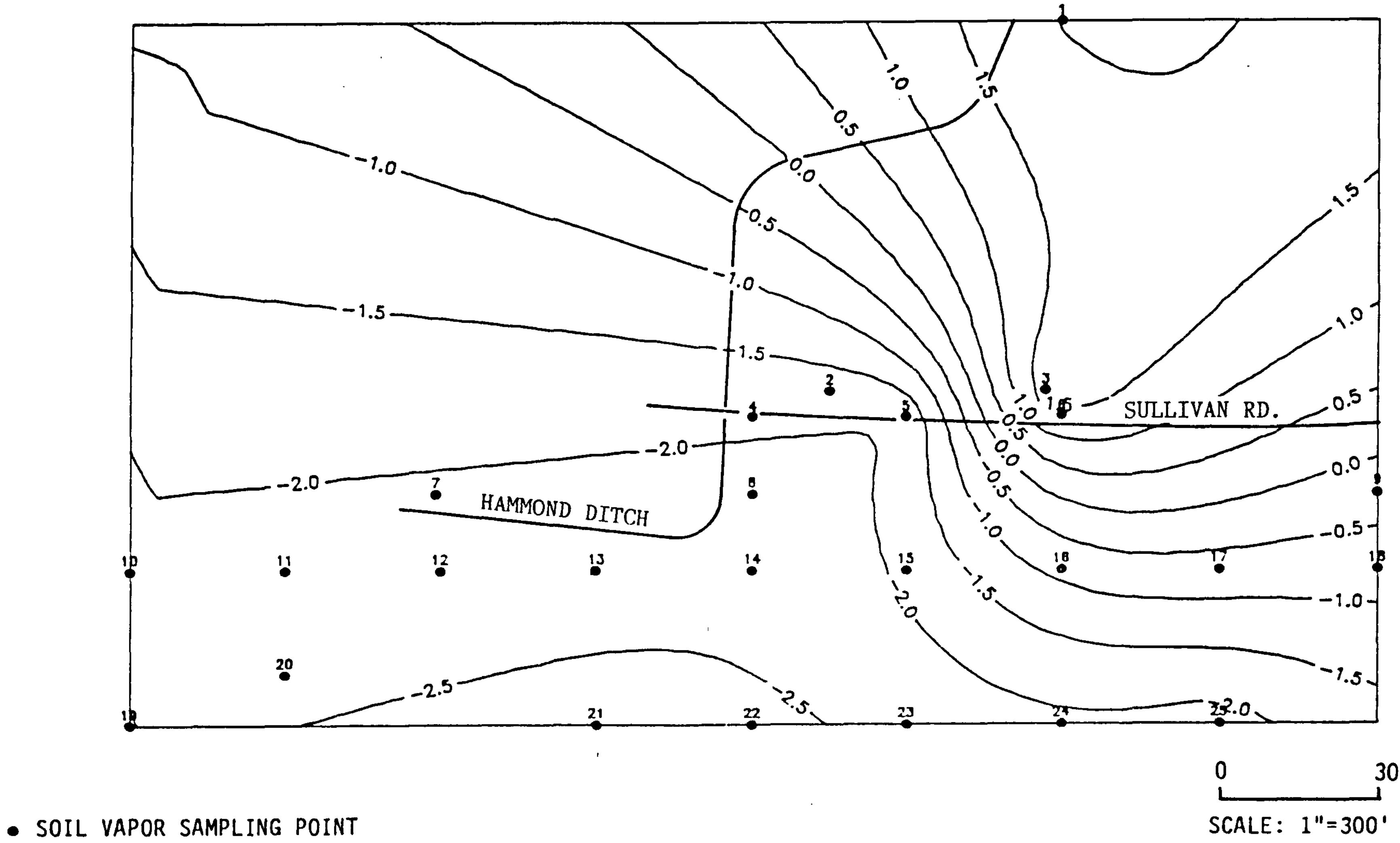

FIGURE 2-11
PCE VAPOR LOG CONCENTRATION (LOG ppm)

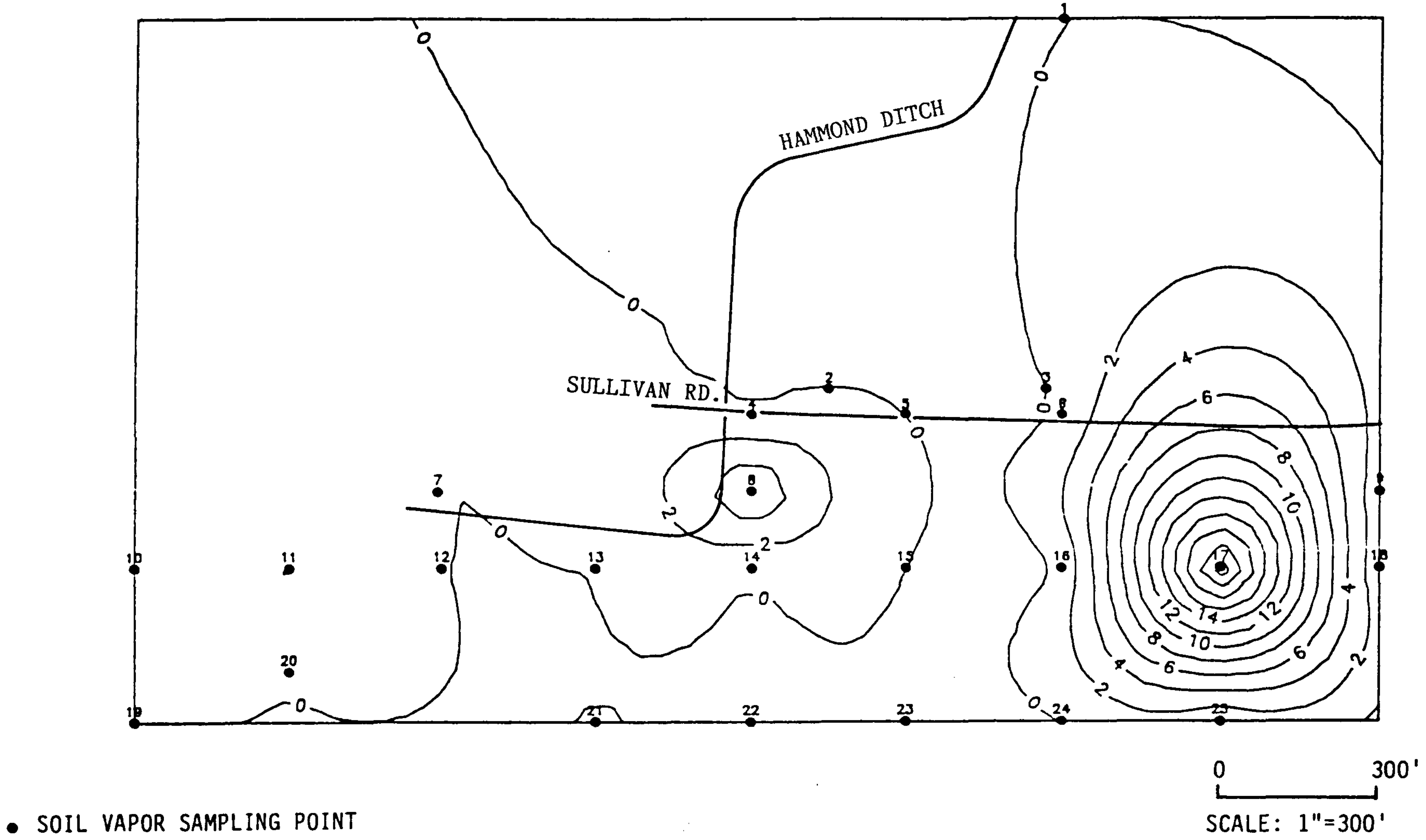

FIGURE 2-12
TCE VAPOR CONCENTRATION (ppm)

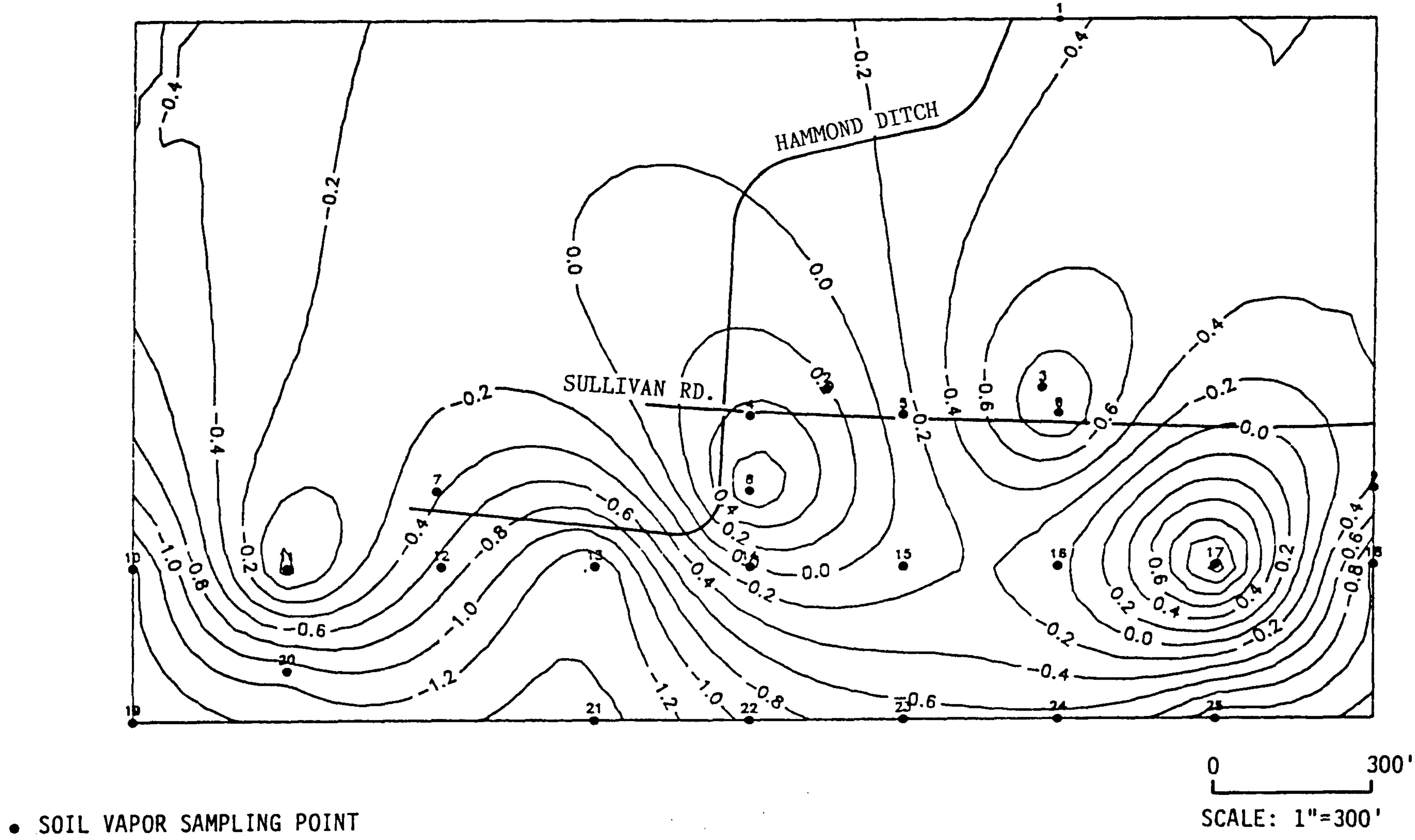

FIGURE 2-13
TCE VAPOR LOG CONCENTRATION (LOG ppm)

the site. It is assumed that the source of high vapor concentrations of these VOCs is hydrocarbons in ground water beneath the site or in the unsaturated zone overlying the perched water table.

Analysis of a soil blank sample collected on BLM land at a point 700 feet west and 600 feet south of well MW-11 indicates the presence of benzene, toluene, and xylenes at elevated concentrations in the subsurface (see Table 2-2). The location of the soil blank is outside of the area of hydraulic influence associated with the perched system underlying the site. Background concentrations of 0.02 ppm, 0.55 ppm, and 0.36 ppm for benzene, toluene, and xylenes were defined on the basis of these soil blank concentrations. The occurrence of elevated concentrations of VOCs outside of the area potentially impacted by BRC operations is attributed to the large amount of oil-field activity in the area and to the presence of a natural gas pipeline east and hydraulically-upgradient of the soil-blank sampling point.

Concentrations of VOCs in soil vapor depend on local geology, moisture conditions, the pH-redox environment in the subsurface, and the unique physical characteristics of the organic compound. The concentration distributions presented in Figures 2-2 to 2-13 suggest that hydrocarbons in the subsurface occur primarily beneath the site and do not extend more than a few hundred feet south of the refinery beneath BLM property. The tendency for vapor concentrations to decrease from north to south is related to the large concentrations observed at sample point 1 (MW-9) and the absence of data in an east-west direction through the center of the site, where samples were not collected because of chemical interference from normal refinery operations. In general, concentrations less than or of the same order of magnitude as background were observed west and south of well MW-11 and at sample points 15 and 16 located between well MW-11 and the terminal area. The consistent tendency for VOCs in soil vapor to rapidly decrease to background levels west and south of MW-11 and at sample points 15 and 16 may be evidence that geologic controls influence the presence of soil vapor beneath BLM property, that the edge of the perched system occurs in the area south and west of well MW-11, that lateral recharge from Hammond Ditch flushes hydrocarbons from the perched aquifer or prevents upward diffusion of vapor by saturating the deposits overlying the water table west of well MW-11, and that hydrocarbons accidentially released from the terminal area as a result of loading and degreasing activities have not extensively migrated onto BLM land.

Table 2-3 compares volatile organic vapor and ground-water concentrations at locations where both sets of data are available between July and September, 1988. Only toluene vapor concentrations exhibit a systematic relation to toluene ground-water concentrations. Soil vapor and ground water concentrations of toluene show strong correlation when the order of magnitude of the concentrations is considered. Toluene ground-water concentrations in milligrams per liter of water are, with the exception of the concentration at MW-13, two orders of magnitude smaller than vapor concentrations in microliters of gas per liter of air, suggesting that a general correlation exists between toluene dissolved in the ground water and toluene vapor in the overlying unsaturated zone. The distribution of toluene concentrations observed in ground water during September of 1988, in fact, shows peak concentrations at approximately the same locations as peak vapor concentrations previously observed in July of that year during the soil vapor survey.

Given that toluene appears to act more like a conservative tracer than other aromatic hydrocarbons, the distribution of toluene vapor is probably most representative of the distribution of dissolved toluene in the ground water and can be used to approximate the extent of dissolved aromatic hydrocarbons in the saturated subsurface in areas where ground-water concentrations are not known. Assuming that this is true, the toluene soil vapor log distribution shown in Figure 2-5 suggests that local aromatic hydrocarbon concentration peaks occur near wells MW-10 and MW-4, the locations of which are shown in Plate 1. High ground-water concentrations of aromatic hydrocarbons have actually been observed in the vicinity of wells MW-4 and MW-10 and have also been observed southwest of the office building, immediately south of well MW-10, and near well MW-11.

TABLE 2-3

CONCENTRATIONS OF VOLATILE ORGANIC COMPOUNDS IN GROUND WATER AND SOIL VAPOR AT MONITOR WELL LOCATIONS

Soil Vapor Point(s)	Well I.D.	Benzene Concentration Water (mg/l)	Benzene Concentration Vapor (ppm)	Toluene Concentration Water (mg/l)	Toluene Concentration Vapor (ppm)	Ethylbenzene Concentration Water (mg/l)	Ethylbenzene Concentration Vapor (ppm)
2	RW-3	12	38.2	0.062	11.9	0.00286	74.5
3	MW-4, P-2, RW-2 (average)	8.23	ND	4.19	710	1.27	102
5	P-3	19.4	0.062	0.00435	0.149	ND	ND
14	MW-11	44.4	0.56	0.840	10.9	0.063	ND
18	MW-13	0.00023	ND	0.00024	0.143	0.00029	ND

[See Plate 1 for locations of recovery wells (RW) and piezometers (P)]

Since there are no source areas at these locations, it is likely that these hydrocarbons originated near the process units, storage tanks, or terminal area and migrated west and southwest under the hydraulic gradients that prevail in the perched alluvial aquifer. Assuming an average hydraulic gradient of 0.003, a hydraulic conductivity of 1.8 x 10^{-4} ft/sec from slug and pump tests performed near well MW-10, and an effective porosity of between 0.10 to 0.20, the average linear groundwater velocity could range from 2.7 to 5.4 x 10^{-6} ft/sec. If dissolved aromatic hydrocarbons move primarily under advective transport mechanisms, hydrocarbons originating in the storage area and currently observed near well MW-10 would have migrated through the western edge of the storage area under a predominantly westward flow direction between 4½ and 9 years ago. Similarly, a release that is presently evident at MW-4 as a peak concentration may have originated from the western edge of the tank storage area between 2 and 4 years ago. Peak concentrations of aromatic hydrocarbons presently evident at well MW-10, as well as aromatic hydrocarbons observed southwest of the office building, may have originated in the process area and migrated southwestward along a curvilinear flow path caused by southward flow from the northern reaches of Hammond Ditch. If this is the case, and if the hydraulic gradient increases to 0.04 under the influence of Hammond Ditch recharge, hydrocarbons currently arriving southwest of the office building could have been released from the process area between 4 and 8 years ago. Hydrocarbons presently at well MW-10 may have been released from the process area 5 to 10 years ago. Similar calculations can be made with respect to times of release from the terminal area.

The occurrence of below-detection levels of tetrachloroethylene (PCE) and trichloroethylene (TCE) at the soil blank location and the presence of large concentrations of these halogenated hydrocarbons near MW-4 and beneath the terminal area, respectively, is an indication that PCE and TCE may be limited to the subsurface directly beneath the site or near the site boundary. Although high concentrations of TCE are evident near well MW-11, the TCE observed near MW-11 probably originated in the terminal area, as evidenced by high TCE concentrations observed at soil-vapor sample point 17. High TCE concentrations between Sullivan Road and MW-11 could represent a slug of TCE that has migrated westward from the terminal area at some time during the history of the refinery. Both PCE and TCE were presumably released from solvents used for degreasing equipment in the terminal area or, perhaps, at off-site locations.

The absence of elevated concentrations of volatile organic constituents at soil vapor sample points located along Hammond Ditch, including a point at MW-12 where no organic constituents have previously been observed in the perched ground water, suggests either that lateral recharge from the Ditch is very effective in flushing out organic compounds that may have migrated through the alluvial ground-water system beneath BLM land or that recharge from the Ditch in partially-unsaturated to the saturated alluvial deposits is inhibiting the upward diffusion of vapor.

Given the limited extent of organic compounds in soil vapor underlying BLM property and the significant correlation between vapor and ground-water concentrations with respect to at least one compound, recovery wells installed north of Sullivan Road will probably be adequate for effective capture of organic constituents in the underlying ground water. The southern extent of the capture zones induced by operation of recovery wells north of Sullivan Road will be the determining factor when deciding the need for additional recovery of ground water near well MW-11, where elevated soil vapor and ground-water concentrations of benzene, toluene and xylene have been detected. Hydraulic head and water quality data observed at a piezometer located south of Sullivan Road will be used to estimate the effectiveness of the proposed recovery system with respect to capture of hydrocarbons currently present beneath BLM land.

3.0 INSTALLATION OF RECOVERY WELLS AND PIEZOMETERS

3.1 GOALS AND OBJECTIVES

The perched alluvial aquifer underlying the Bloomfield Refining Company is primarily recharged along upstream reaches of Hammond Ditch and beneath the spray irrigation area in the southeastern part of the facility property, as evidenced by the peak water levels observed beneath the spray irrigation area and the addition of a southward ground-water flow component to the otherwise northwestward direction of ground-water flow along northern reaches of the Ditch. Minor amounts of recharge may occur through the bottoms of the raw water and evaporation ponds. The aquifer is underlain by the Nacimiento Formation, which acts as a barrier to significant downward movement of ground water and dissolved hydrocarbons. Perched ground water containing hydrocarbons is, however, migrating laterally from the spray irrigation area and from the areas adjacent to upstream northern and northeastern reaches of Hammond Ditch towards BLM property and to downstream western reaches of the Ditch. A recovery strategy has been formulated to intercept ground water containing hydrocarbons that would otherwise migrate into the downstream reaches of the Ditch or beneath BLM property.

Due to the moderately-large hydraulic conductivity and 8-foot average saturated thickness of the alluvial aquifer, it was expected that broad, shallow cones of depression would develop during hydrocarbon recovery operations. Because of the anticipated shallow capture zones, at least two recovery wells, in addition to existing monitor/recovery well RW-3 (previously referred to as MW-10), were believed to be needed to ensure capture of all hydrocarbons originating from the refinery site. Monitor/recovery well RW-2 was installed near existing well MW-4, which was constructed with torch-slotted casing and was not considered suitable as a recovery well. Recent observations of hydrocarbon seepage into western reaches of Hammond Ditch suggest that a recovery well would be needed west of the office building and southwest of the raw water ponds. An additional monitor/recovery well (RW-1) was therefore installed east of Hammond Ditch and west of the office building to capture ground water that was not expected to be intercepted by upgradient recovery well RW-3.

The location of this well was selected based upon results of the numerical flow model previously developed to define a remedial-action strategy, and modified to reflect conditions during non-irrigation seasons when water from Hammond Ditch would not be available to contain ground water on BRC property. A third monitor well MW-13 was installed west of the terminal area within the facility boundary to determine if aromatic or halogenated hydrocarbons observed under BLM land could have migrated from this area as a consequence of refinery loading and degreasing activities.

Simulated steady-state hydraulic head during recovery at the three recovery wells, shown in Plate 2, indicates that long-term recovery of 3, 1.5, and 1.5 gpm at wells RW-1, RW-2, and RW-3, respectively, should be sufficient to capture on-site hydrocarbons and a portion of hydrocarbons present on BLM property. In order to demonstrate that the recovery system is effectively capturing flow from the refinery, several piezometers were also installed. The locations of these piezometers were selected to provide hydraulic head data critical for assessing the hydraulic impacts of recovery well operation. A minimum of three piezometers was considered necessary to assess the effectiveness of the proposed recovery system north of Sullivan Road.

Piezometer P-2 was located between well RW-2 and existing well RW-3 in order to assess the well losses associated with recovery well operation. Since this piezometer is sufficiently far from recovery wells to not be significantly influenced by well losses, it should give a true indication of the depth of the hydraulic "trough" induced by pumping at the line of recovery wells north of Sullivan Road. A second piezometer P-3, located south of Sullivan Road, will be used to measure the effectiveness of the recovery system north of the Road with respect to capture of ground water from BLM land or prevention of ground water originating on-site from migrating towards BLM land. A third piezometer P-1 was placed immediately west of the RW-1 well located east of Hammond Ditch and west of the office building. Water level measurements obtained from this piezometer are to be used to determine whether the recovery well located between the Ditch and the office building is effective in capturing westward-moving ground water during non-irrigation periods when there is no water in the Ditch to help contain hydrocarbons on BRC property. Locations of all existing and new wells and piezometers are shown in Plate 1.

Installation of monitor/recovery wells and piezometers, in addition to supplying a means of remediating the ground water beneath the refinery, also made it possible to further assess the extent and magnitude of hydrocarbons in the perched alluvial aquifer underlying the site. Samples of ground water collected from the alluvial wells and piezometers were used to define the extent of the hydrocarbon plume in the alluvial aquifer and will also be critical for tracing changes in hydrocarbon concentrations induced by remedial clean-up operations. These samples, along with measurements of hydraulic head observed in the wells and piezometers, will make it possible to determine the need for additional recovery wells and to evaluate the effectiveness of the recovery strategy.

3.2 TECHNICAL APPROACH

Two monitor/recovery wells and four piezometers were drilled and installed by Beeman Brothers Drilling Company between August 20 and September 2, 1988 using an air-rotary casing-driver drill rig. The depth of the boreholes were selected by GCL's on-site geologist based on the depth to water observed in each borehole during drilling. A conventional rotary drill bit was advanced while cuttings were simultaneously blown upward and out of the borehole with compressed air. An in-line air filter ensured that hydrocarbons were not introduced into the borehole from the compressor during drilling operations. After a selected depth was reached with the rotary drill bit, 8-inch diameter steel casing was hammered into the borehole around the drill rods to the same depth as the drill bit using a hydraulic casing driver attached to the drill rig. This process was repeated until the target depth of each borehole was reached. Samples of the drill cuttings were collected at approximately 5-foot intervals and logged by the on-site geologist.

After the target depth of each borehole was attained and the temporary casing advanced to the total depth of the borehole, recovery of ground water was monitored until a static level could be estimated and a total depth for the well casing selected. Four-inch screen and well casing were then installed in the borehole through the temporary steel casing. The casing is comprised of schedule 40 polyvinyl chloride (PVC) or stainless steel, with parts of the well casing that are in contact with ground water composed of stainless steel. The top of the screen was set 5 feet above the static water level in the well to allow for sampling near the water table during the irrigation season. A filter pack and bentonite seal were subsequently inserted into the borehole through the annulus of the temporary casing as it was retrieved from the borehole. The borehole was then grouted above the bentonite seal using a neat cement slurry with 5% bentonite. After the grouting was completed, a concrete pad was constructed, complete with locking guard pipe. Recovery-well completion diagrams, including the diagram for existing well RW-3, are shown in Figures B-1 to B-3 in Appendix B. Piezometers were constructed similarly to the monitor/recovery wells using 4-inch PVC instead of stainless steel casing below the water table. Piezometer completion diagrams are presented in Figures B-4 to B-7.

After the grout in the borehole cured, the wells were developed utilizing a 4-inch submersible pump. Wells with stainless steel screens were bailed prior to installation of the submersible pump. The wells were pumped until produced water was clear and free of sand. The developed water was stored in 55-gallon drums at each well head. After the water level in each well had recovered to static conditions, a water sample was collected and analyzed in the field for pH in order to identify potential invasion of the filter pack by emplaced grout.

Following installation and development of the recovery wells and piezometers, all wells and piezometers were sampled by Bloomfield Refinery Company personnel for New Mexico WQCC parameters.

3.3 RESULTS AND CONCLUSIONS

3.3.1 Lithology

Based on lithologic logs of the boreholes shown in Figures B-8 to B-14 (Appendix B), the subsurface geology appears to be dominated by three lithologies: an uppermost clayey silt, a sandy gravel unit and the underlying Nacimiento shale of Early Tertiary age. As indicated in the stratigraphic sections presented in Figures B-15 and B-16 of Appendix B, the uppermost clayey silt is present throughout the site except between holes P-3 and MW-11, where this unit has probably been removed by erosion or where a localized bedrock high occurs. This unit ranges in thickness from 0 feet in P-3 and MW-11 to 27 feet in P-4. In boreholes located on refinery property, this unit is at least partly composed of fill dirt.

Underlying the uppermost silt are coarse-grained gravel and sand deposits of the ancestral San Juan River. This unit is poorly sorted, with moderately-rounded gravel up to two inches in diameter. In all boreholes drilled, the lowermost portion of the gravel unit is water-saturated and under unconfined conditions. The unit appeared to be lithologically homogeneous over the site and ranges in thickness from 14 to 18.5 feet. However, borehole P-4 showed some variation from the typical lithology of this unit. In this borehole, a distinctive, relatively well-sorted three-foot thick orange sand overlies the gravel unit. Additionally, a two-foot thick clay horizon was encountered near the base of gravel unit. This clay unit was not encountered in other boreholes and is presumably restricted to the southeastern portion of the site.

The lowermost unit encountered in the boreholes was the Nacimiento Shale of Paleocene age. This unit consists primarily of a fine-grained dusky yellow to olive-gray shale, and acts as an aquitard beneath the facility. Boreholes were drilled into this unit to accommodate the silt trap at the base of each well. Once again, borehole P-4 showed variation from the typical Nacimiento Formation in the project area. In this borehole, the top of the Nacimiento consisted of weathered bluish well-sorted, fine-grained clayey sand. This sand unit was not encountered in other boreholes and is presumed to be of limited areal extent.

Plate 3 shows the structural contours of the Nacimiento Formation obtained from data collected by Engineering-Science (1986) and GCL. The contour map shows an overall decrease in the elevation of bedrock from southeast to northwest towards the San Juan River. There is some evidence that a local bedrock high occurs in the extreme southwestern part of the site. This bedrock high may influence the distribution of VOCs in the subsurface by inhibiting further westward and southwestward migration of organic compounds in this area, causing the observed "tongues" of benzene and toluene soil vapor beneath BLM land evident in Figures 2-2 and 2-5.

3.3.2 Well Yield

Each well was developed following installation using a submersible pump. The largest yield was obtained from piezometer P-4, which was pumped for one hour at a rate of slightly less than 13.5 gallons/minute. Recovery wells RW-1 and RW-2 sustained rates of approximately 3 and 8 gpm, respectively. Based on a previous pump test performed at the refinery, the sustainable yield of well RW-3 was estimated to be 1.5 gpm.

3.3.3 Pre-Recovery Water Table and Saturated Thickness

Table 3-1 lists and Plate 4 shows the distribution of pre-recovery water levels observed at all recovery wells, piezometers and well MW-11 on January 4, 1989. In the absence of ground-water recovery and under isotropic flow conditions, it is clear that ground water and dissolved contaminants migrate westward and southwestward into Hammond Ditch and beneath BLM property. Flow may locally deviate from these directions in response to changes in saturated thickness and transmissivity caused by variation in bedrock elevation. The three recovery wells are located in an area where up to 10 feet of saturated thickness was initially available for propagating recovery stresses into adjacent portions of the aquifer.

3.3.4 Water Quality

Table 3-2 lists the results of the September, 1988 BRC sampling effort. Neither TCE or PCE were above detection limits in any of the ground-water

TABLE 3-1

WATER LEVEL AND PRODUCT THICKNESS AT RECOVERY WELLS AND PIEZOMETERS (FEET)

	Pre-Recovery (Jan. 4, 1988)		12-Day Recovery (Jan. 16, 1989)		42-Day Recovery (Feb. 15, 1989)	
Well or Piezometer	Water Level	Product Thickness	Corrected Water Level	Product Thickness	Corrected Water Level	Product Thickness
RW-1	5498.34	0	5498.44	0	5497.51	0.17
RW-2	5499.66	0	5498.46	0.21	5498.39	0.042
RW-3	5498.08	0	5497.09	0	5496.51	0
P-1	5498.19	0	5498.16	0	5497.36	0.04
P-2	5499.60	0	5499.25	0	5498.41	0
P-3	5498.17	0	5498.10	0	5496.62	0
MW-13	5500.46	0	5500.27	0	5499.07	0
MW-11	5496.89	0	5496.84	0	5496.37	0

TABLE 3-2

SUMMARY OF
BLOOMFIELD REFINING COMPANY
GROUND-WATER QUALITY

Parameter	Units	Detection Limit	New Mexico Standards 3-103 (A)	6-3-88 MW-4	9-9-88 RW-2	9-9-88 P-2
Benzene	mg/l	0.0002	0.01	8.9	11.000	4.80
Ethylbenzene	mg/l	0.0002	0.75	--	2.900	0.900
Toluene	mg/l	0.0002	0.75	0.93	10.200	1.430
M-Xylene	mg/l	0.0002	0.62	--	17.700	4.500
O-Xylene	mg/l	0.0002	0.62	--	4.900	1.460
P-Xylene	mg/l	0.0002	0.62	--	6.200	1.570
1,2-Dichloroethane	mg/l	0.001	0.01	--	0.0016	ND
Trans 1,2-Dichloroethene	mg/l	0.001	--	--	ND	ND
Nitrate as N	mg/l	0.01	10.0	0.14	<0.01	--
Phenol	mg/l	0.001	0.005	0.069	0.13	--
Sulfate	mg/l	1	600.	3	<1	--
TDS	mg/l	10	1000	1820	1980	--

TABLE 3-2 (Continued)

Parameter	Units	Detection Limit	New Mexico Standards 3-103 (A)	9-9-88 RW-3	9-9-88 P-3	9-9-88 RW-1	9-9-88 P-1	9-9-88 MW-11	9-9-88 MW-13
Benzene	mg/l	0.0002	0.01	12.000	19.400	6.400	102.200	44.400	0.00023
Ethylbenzene	mg/l	0.0002	0.75	0.00286	ND	0.540	0.00143	0.063	0.00029
Toluene	mg/l	0.0002	0.75	0.062	0.00435	0.070	0.034	0.840	0.00024
M-Xylene	mg/l	0.0002	0.62	3.500	22.800	4.800	0.483	2.600	0.00065
O-Xylene	mg/l	0.0002	0.62	0.103	3.600	8.300	0.061	0.061	0.00056
P-Xylene	mg/l	0.0002	0.62	1.800	8.700	1.700	0.322	0.745	0.00035
1,2-Dichloroethane	mg/l	0.001	0.01	ND	ND	ND	ND	0.0022	0.0156
Trans 1,2-Dichloroethene	mg/l	0.001	--	ND	ND	ND	0.0015	ND	ND
Nitrate as N	mg/l	0.01	10.0	<0.01	--	<0.01	--	0.06	13.1
Phenol	mg/l	0.001	0.005	0.05	--	0.34	--	0.06	0.03
Sulfate	mg/l	1	600.	9.5	--	4.5	--	30.	728.
TDS	mg/l	10	1000	3250	--	3130	--	1900	3220

samples. These VOCs may have degraded to daughter-product trans 1,2-dichloroethene (DCE), a biological transformation that can be completed within a matter of a few years (Vogel, 1987). Figures 3-1 to 3-9 show the areal distributions of aromatic and halogenated hydrocarbons in September, 1988.

In the majority of cases, maximum aromatic VOC concentrations in ground water occur beneath the portion of the refinery located north of Sullivan Road or just south of the road at piezometer P-3, with moderately high concentrations of VOC's in well MW-11. Peak halogenated hydrocarbon concentrations occur north of Sullivan Road or in well P-4 located within the terminal area. The occurrence of peak VOC concentrations beneath the site or near facility boundaries suggests either that hydrocarbon release from the unsaturated zone is ongoing or that previous releases from the tank storage area, process units, or terminal area have yet to migrate completely off the site. These results tend to be supported by the soil vapor survey data, which indicate that hydrocarbons are generally confined to beneath the refinery site, with some hydrocarbons evident south of Sullivan Road on BLM property.

The concentration distributions presented in Figures 3-1 to 3-9 show that a single plume configuration can explain the observed water-quality data for the case of each VOC. However, it is possible that hydrocarbons occurring in well MW-11 have migrated south of Sullivan Road along a flowpath that differs from the pathway associated with movement of hydrocarbons observed north of Sullivan Road. Hydrocarbons originating in the terminal area may have migrated towards well MW-11 under the influence of radial flow from the spray irrigation area. Despite anisotropic flow influences caused by variations in bedrock elevation, which would tend to deflect ground-water flow towards the northwest near the bedrock high evident in the southwest corner of the site, the radial flow forces may have been sufficiently dominant to cause VOCs from the terminal loading/degreasing area to appear in well MW-11.

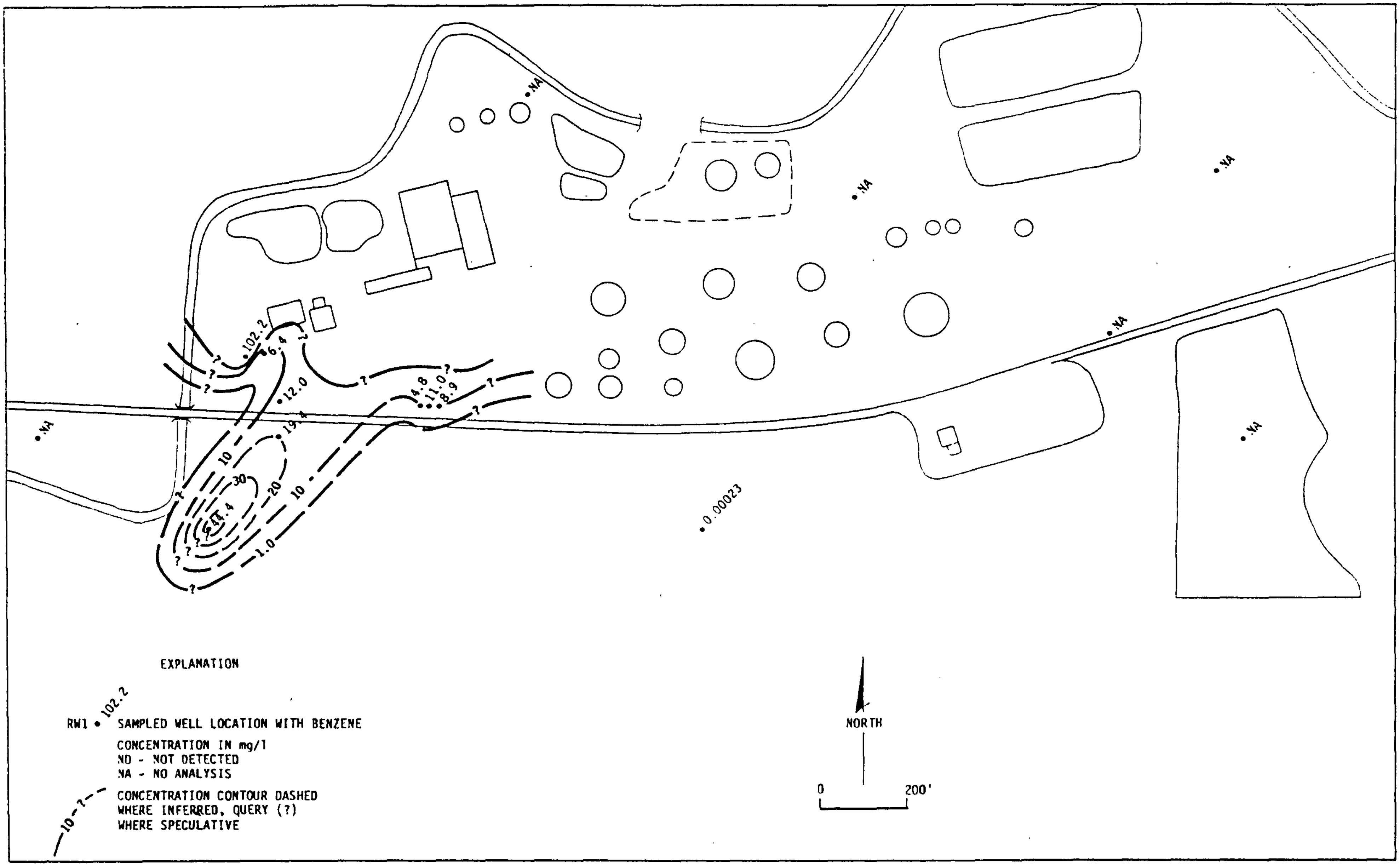

FIGURE 3-1

BENZENE CONCENTRATION IN GROUND WATER SEPTEMBER 1988 BLOOMFIELD REFINING COMPANY

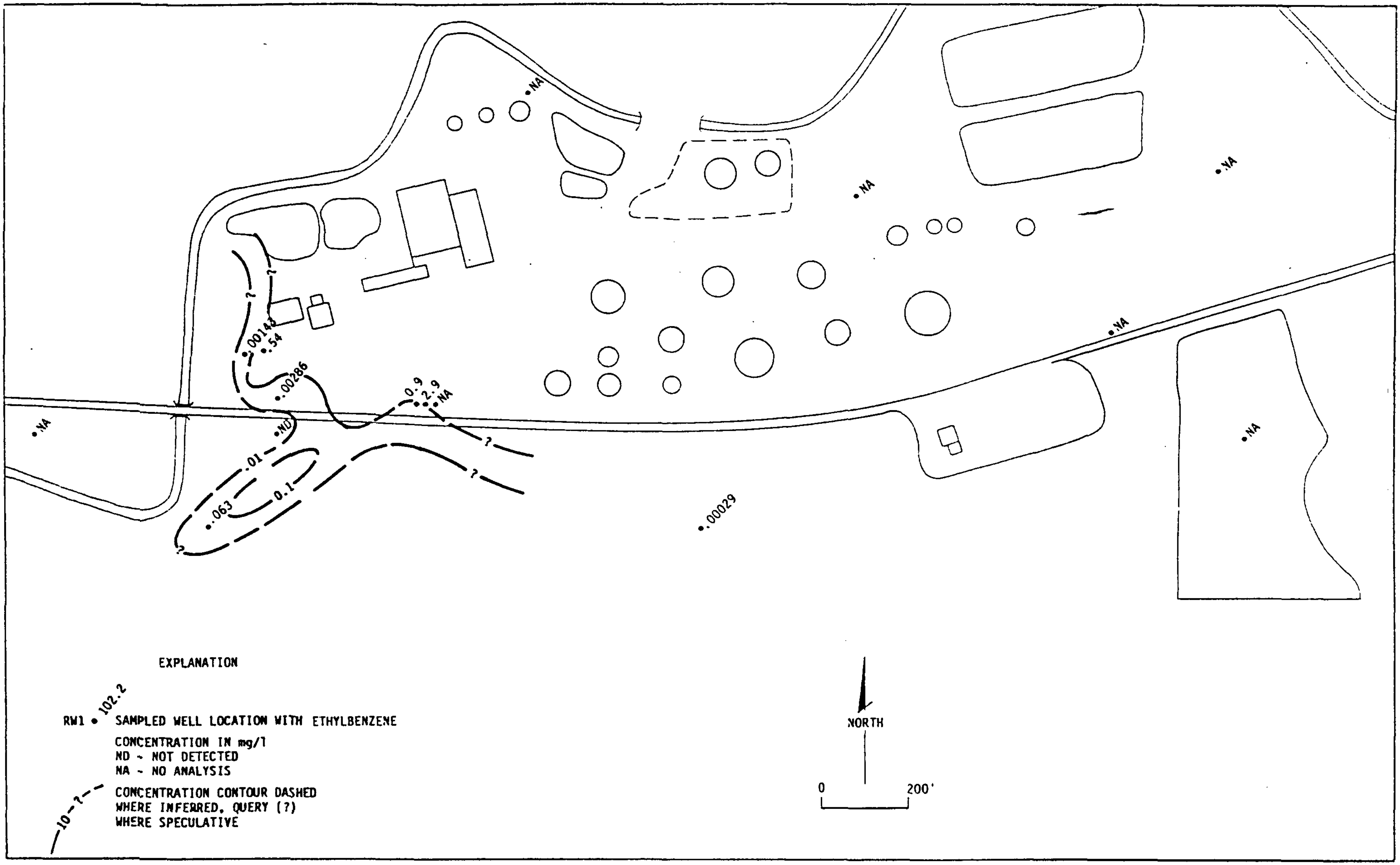

FIGURE 3-2

ETHYLBENZENE CONCENTRATION IN GROUND WATER SEPTEMBER 1988 BLOOMFIELD REFINING COMPANY

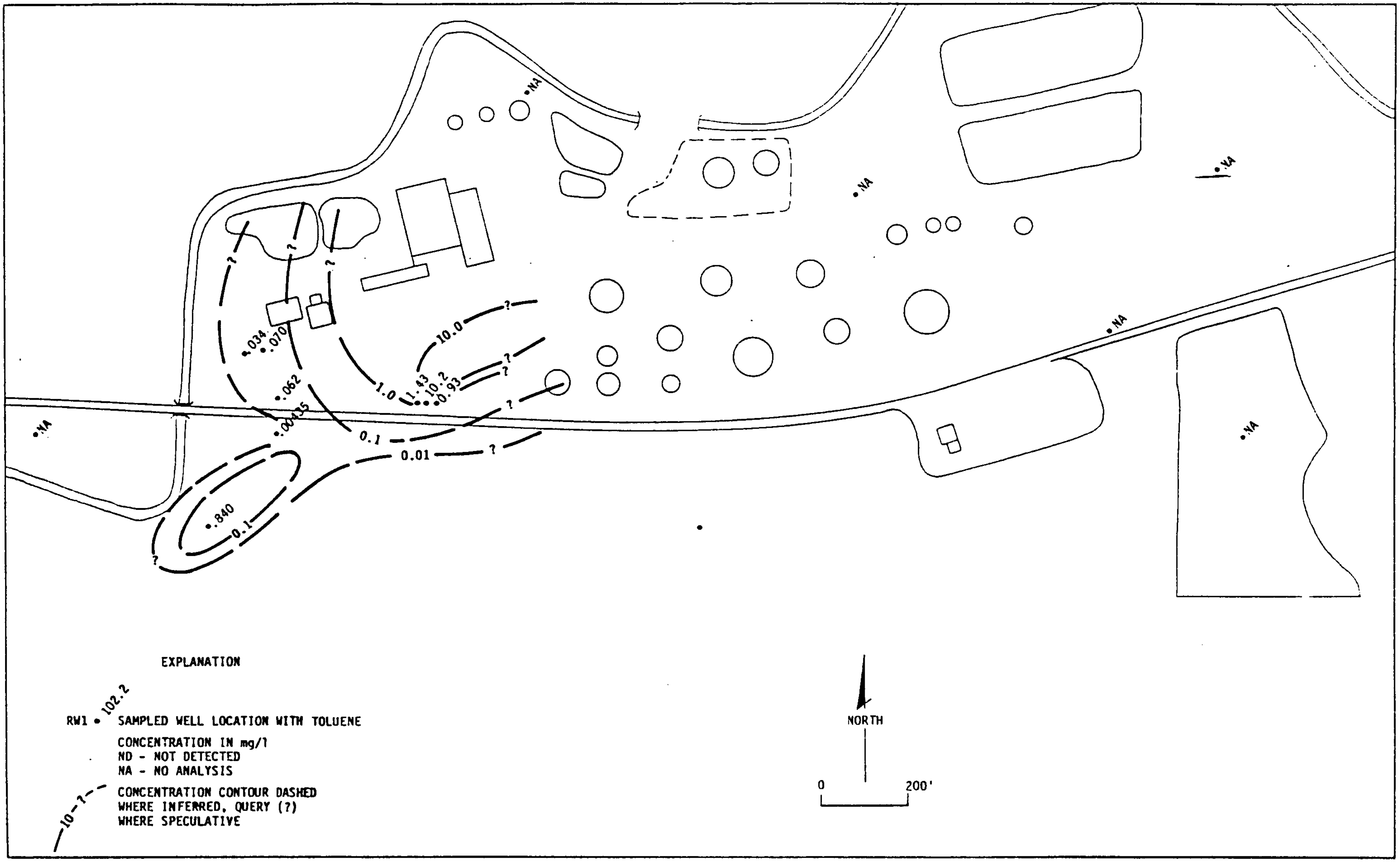

FIGURE 3-3

TOLUENE CONCENTRATION IN GROUND WATER SEPTEMBER 1988 BLOOMFIELD REFINING COMPANY

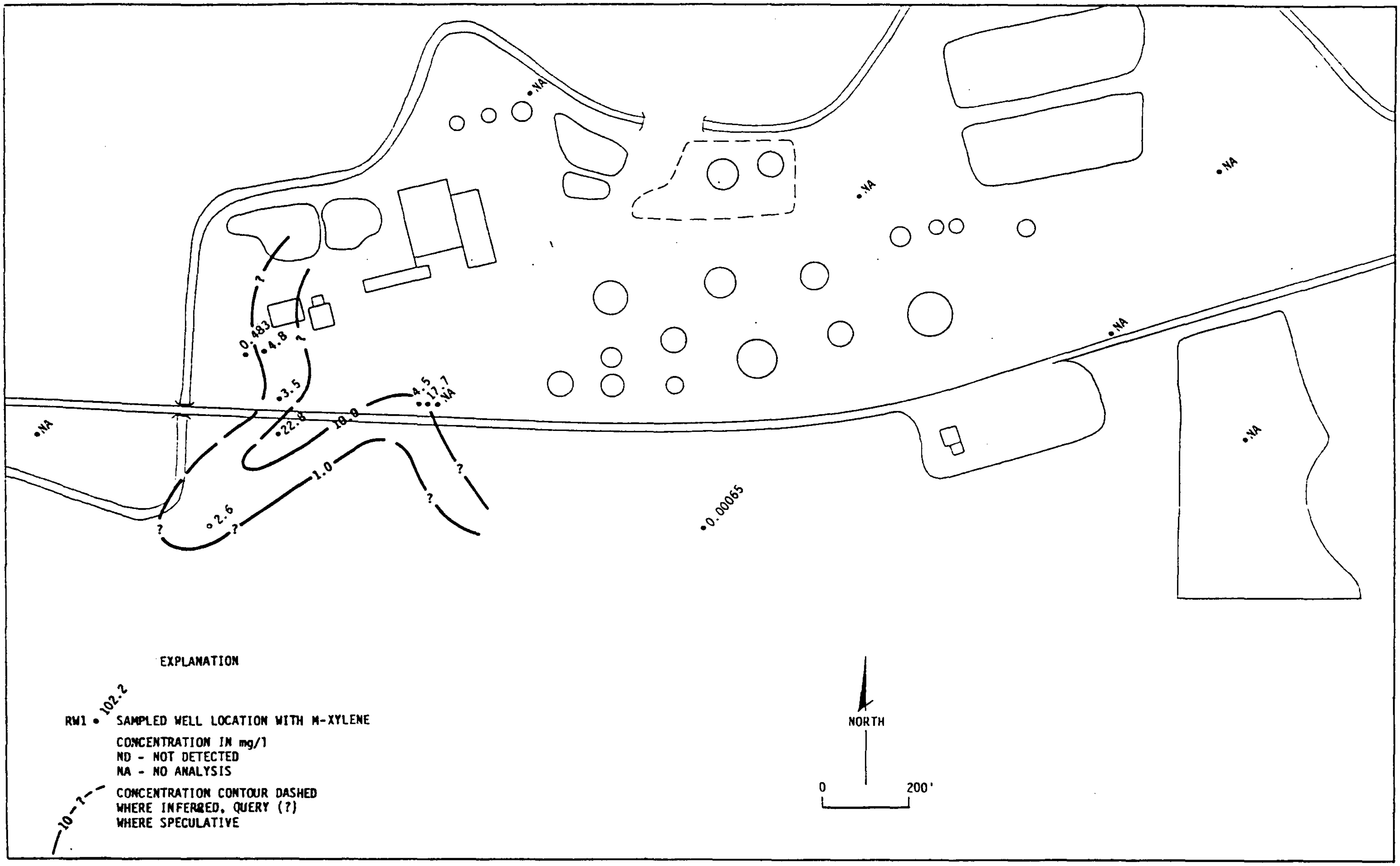

FIGURE 3-4

M-XYLENE CONCENTRATION IN GROUND WATER SEPTEMBER 1988 BLOOMFIELD REFINING COMPANY

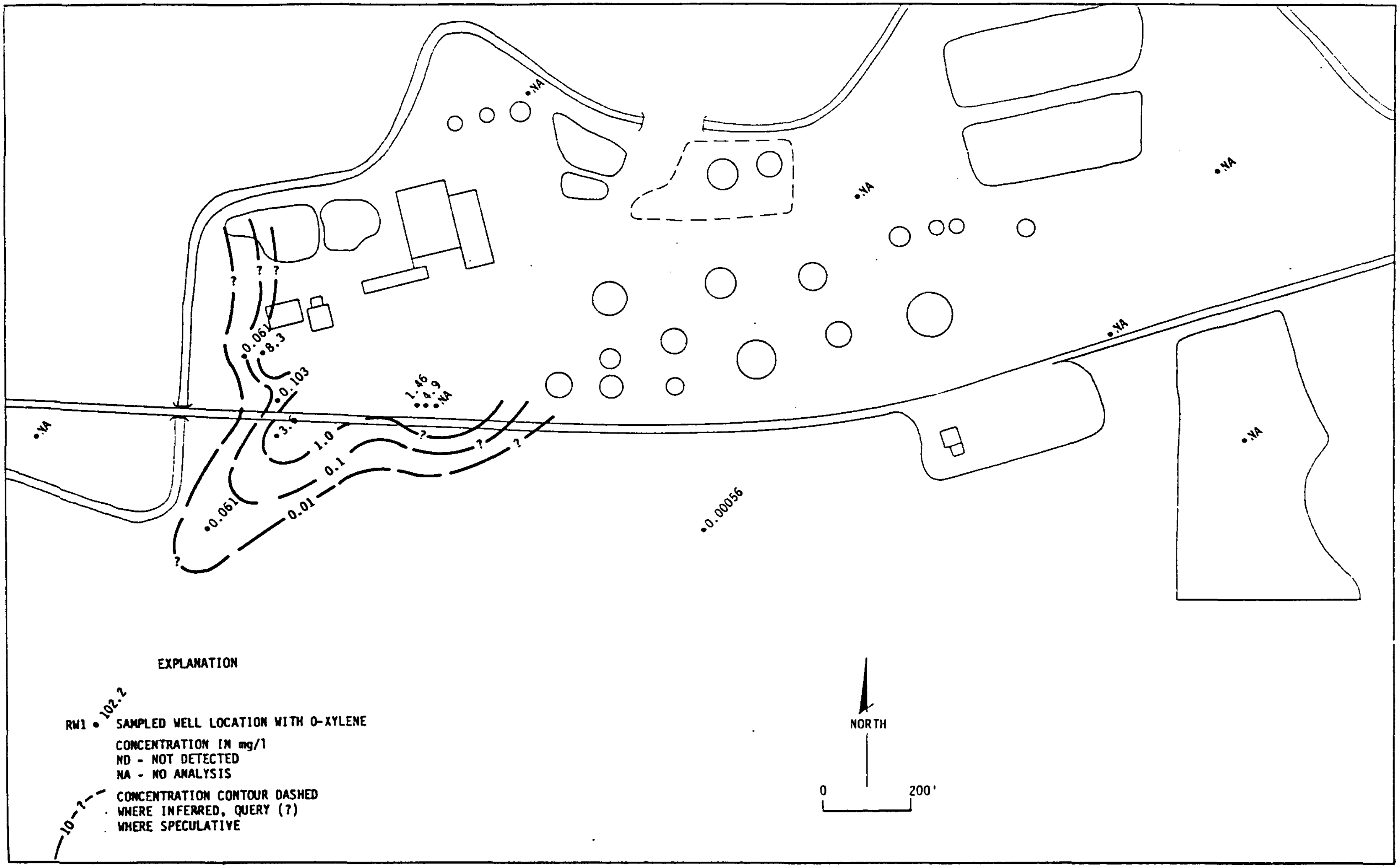

FIGURE 3-5

O-XYLENE CONCENTRATION IN GROUND WATER SEPTEMBER 1988 BLOOMFIELD REFINING COMPANY

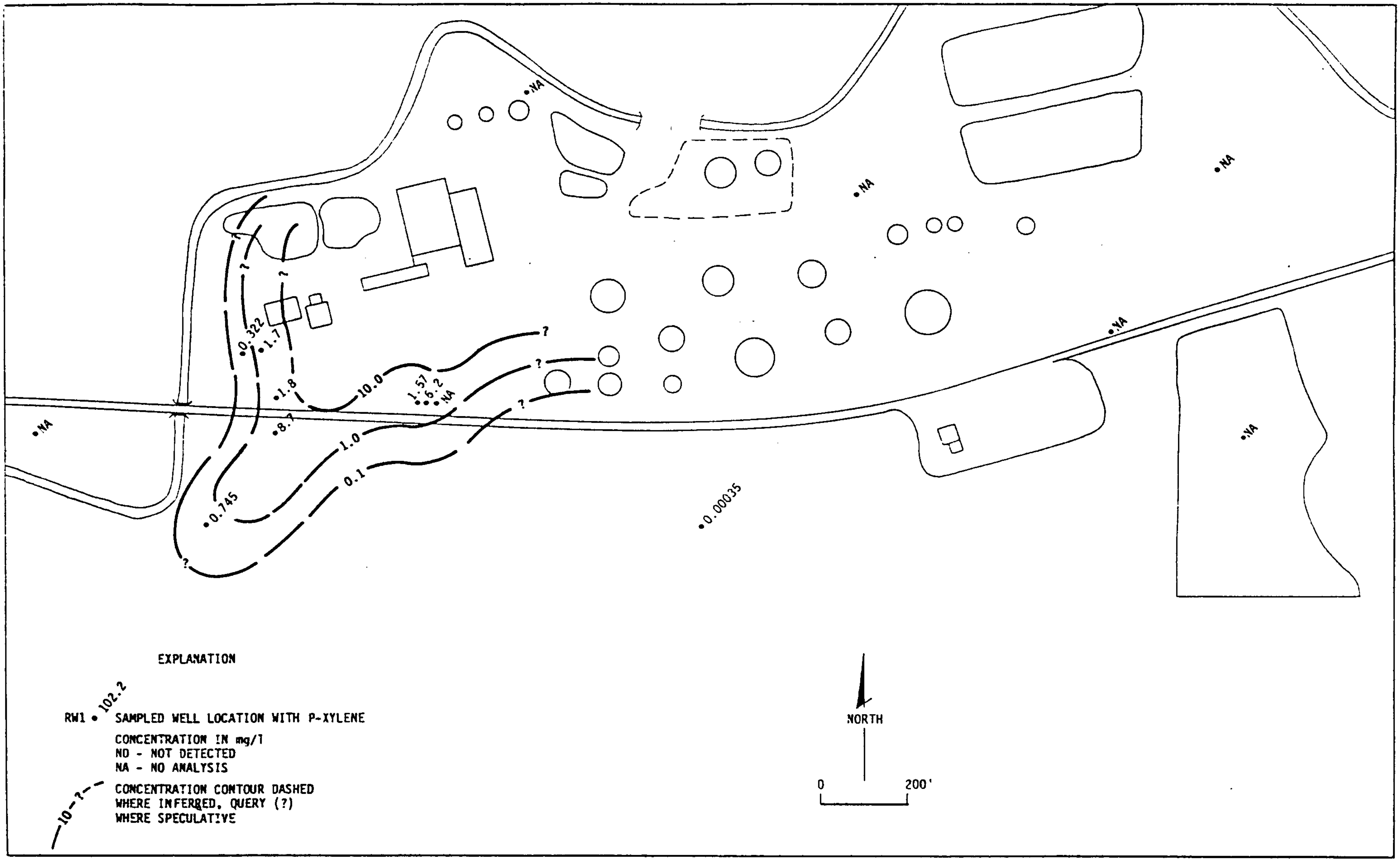

FIGURE 3-6

P-XYLENE CONCENTRATION IN GROUND WATER SEPTEMBER 1988 BLOOMFIELD REFINING COMPANY

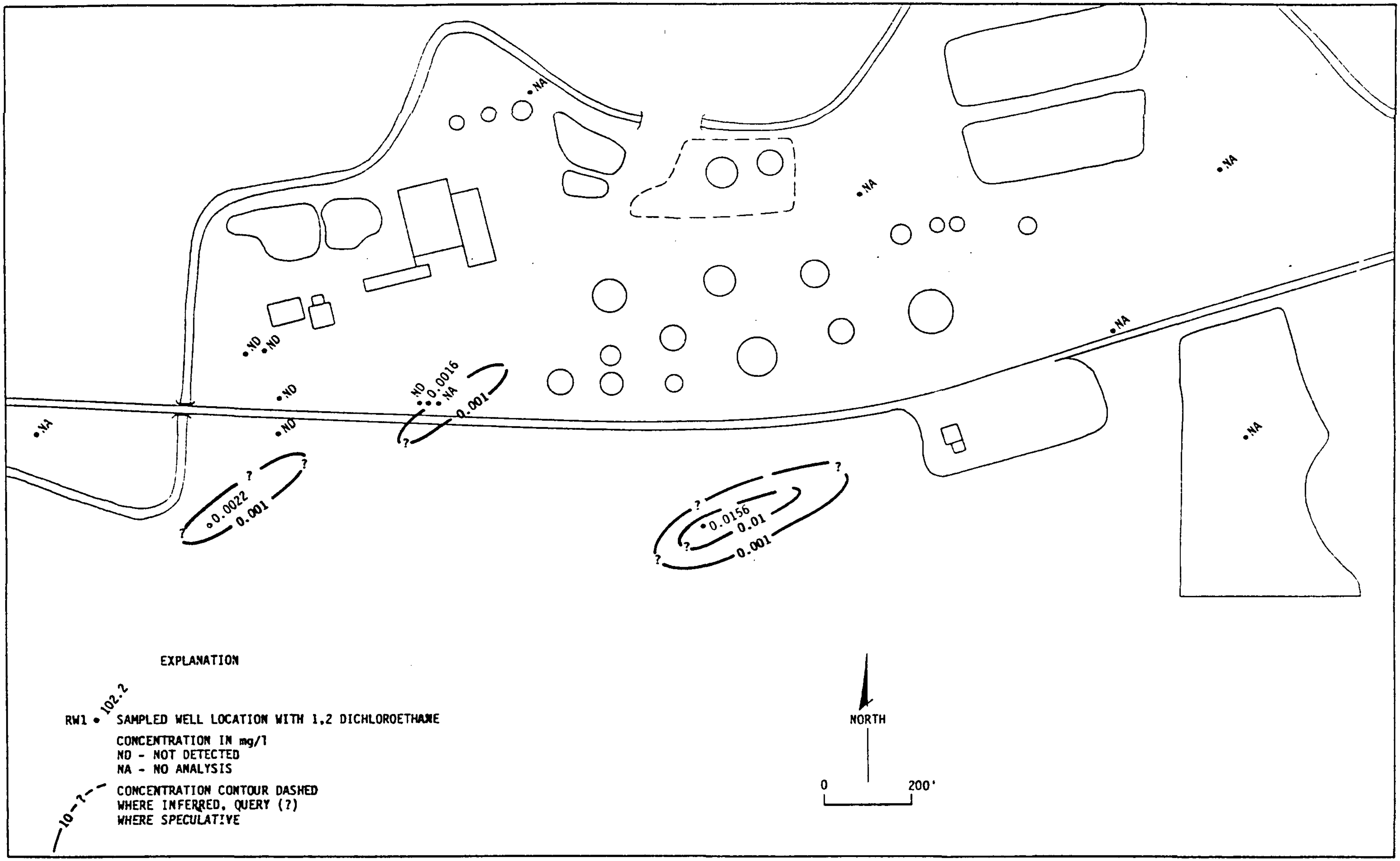

FIGURE 3-7

1,2 DICHLOROETHANE CONCENTRATION IN GROUND WATER SEPTEMBER 1988 BLOOMFIELD REFINING CO.

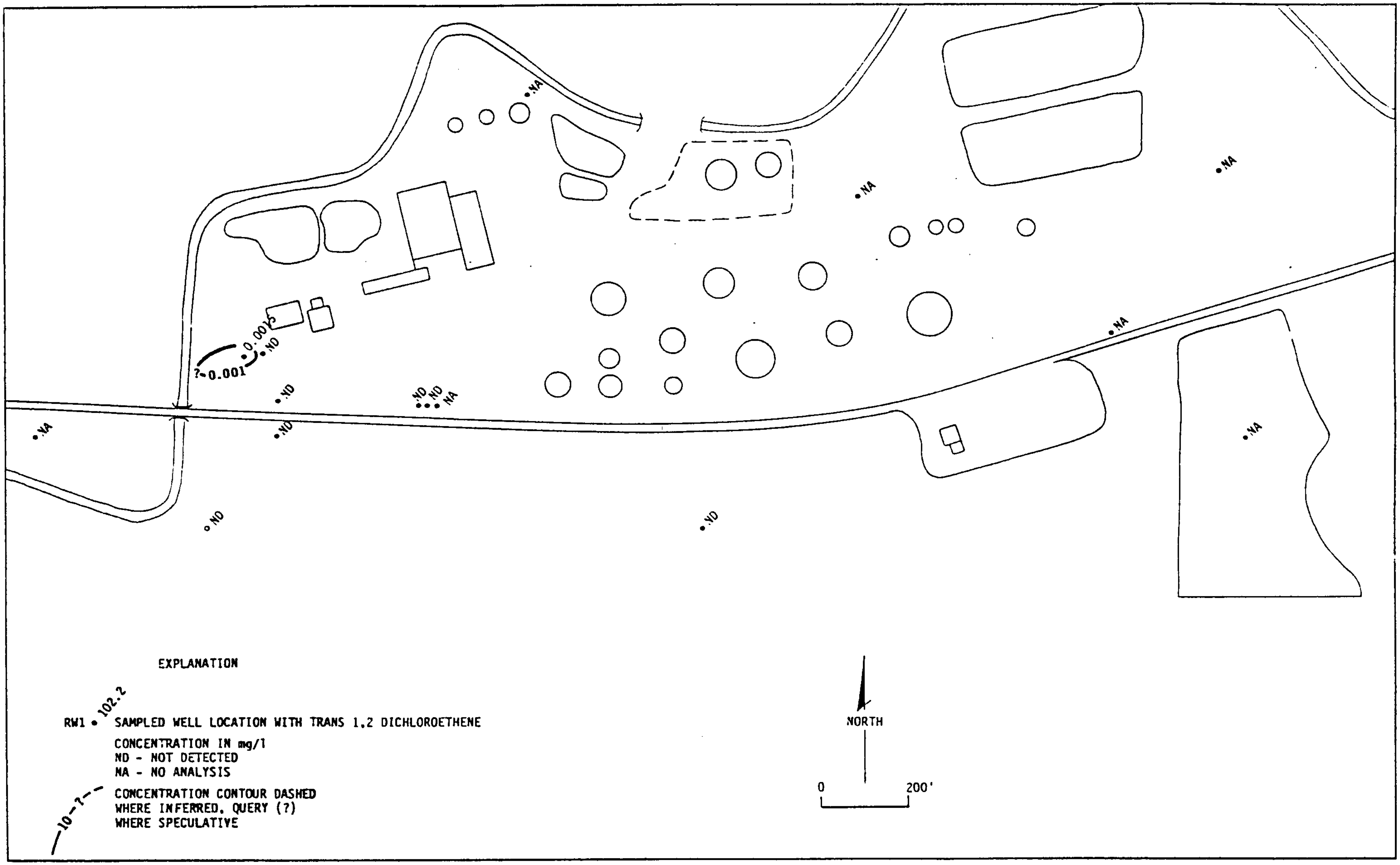

FIGURE 3-8

TRANS 1,2 DICHLOROETHENE CONCENTRATION IN GROUND WATER SEPT. 1988 BLOOMFIELD REFINING CO.

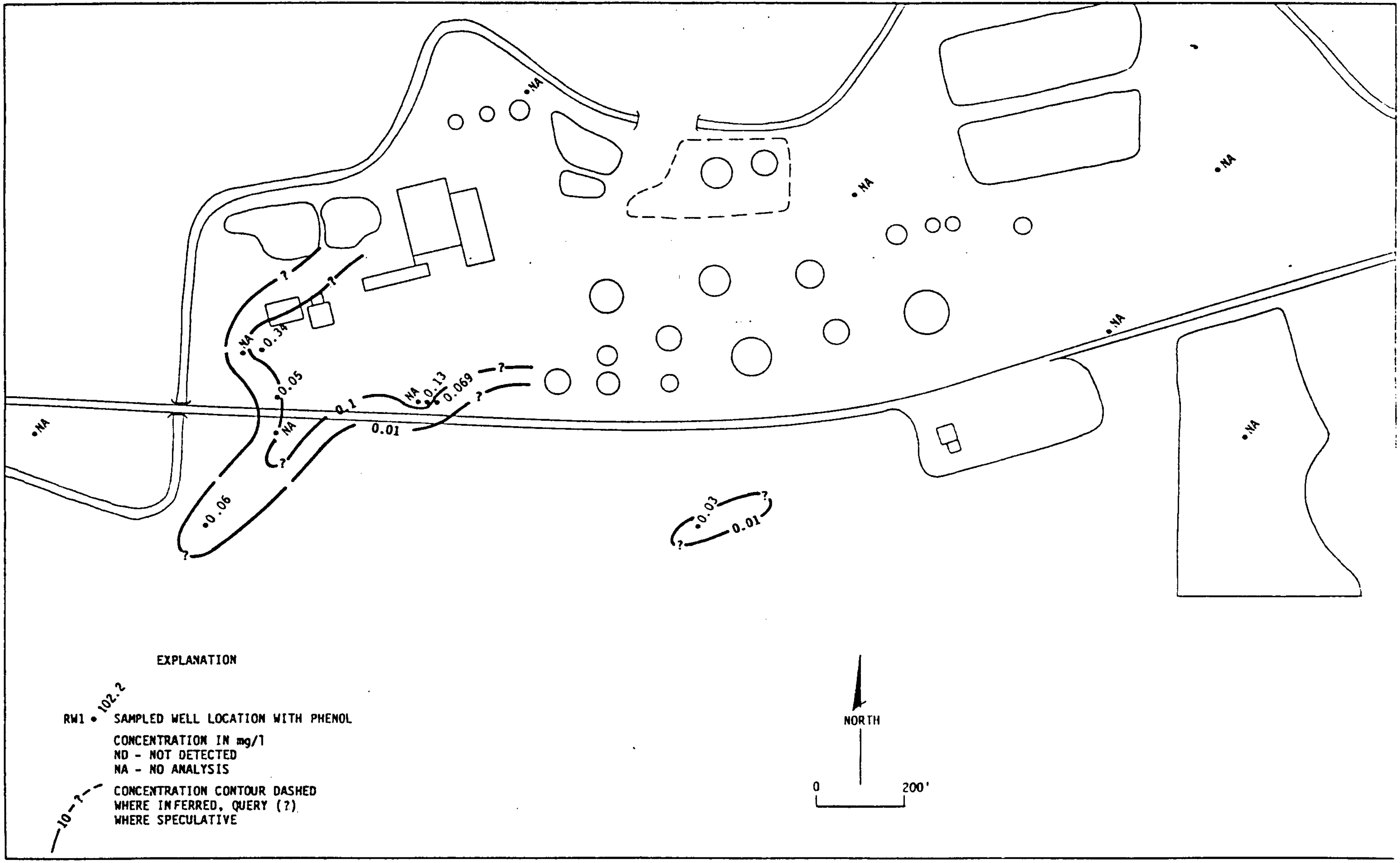

FIGURE 3-9

PHENOL CONCENTRATION IN GROUND WATER 1988 BLOOMFIELD REFINING COMPANY

Regardless of the origin of hydrocarbons observed beneath and near the refinery, it is likely that the perched system does not extend large distances onto BLM land and that the potential for widespread migration of VOCs onto BLM property is limited. Since the sources of perched water are located on refinery property, the hydrologic impacts of the system will diminish with distance towards BLM land, as indicated by the map of pre-recovery saturated thickness shown in Plate 5. With less than 4 feet of saturated thickness occurring southwest of well MW-11 in the direction of ground-water flow, the resulting low transmissivity will tend to constrain the rate and extent of VOC movement beneath BLM land. Assuming that saturated thickness decreases linearly over BLM land, the saturated part of the aquifer would pinch out to zero at a point located roughly 570 feet southwest of well MW-11, suggesting that the maximum extent of contamination may be located 650 feet southwest of Sullivan Road in a direction roughly parallel to the direction of the pre-recovery hydraulic gradient.

Considering the small amount of precipitation that occurs in the area, it is likely that a portion of the hydrocarbons that were released several years ago have been retained in the unsaturated zone above the water table and act as an intermittent source of dissolved or immiscible hydrocarbons to the ground water during the late summer and early fall when rainfall is at a maximum. Regardless of whether the hydrocarbons have been entirely released to the saturated zone, the three-well recovery system is expected to intercept hydrocarbons that would otherwise migrate beneath off-site property.

4.0 INSTALLATION AND OPERATION OF HYDROCARBON RECOVERY SYSTEM

4.1 GOALS AND OBJECTIVES

The overall goal associated with operation of the hydrocarbon recovery system is capture and remediation of ground water in the perched alluvial system underlying the refinery. Remediation of ground-water quality is being implemented through operation of three hydrocarbon recovery wells and treatment of recovered water in the refinery wastewater treatment system. Wastewater treatment involves separation of immiscible petroleum product from ground water in API separator tanks, volatilization of remaining VOCs in evaporation ponds, and spray irrigation of the treated water to the land surface. This type of treatment is considered the most efficient and cost-effective method of removing dissolved and immiscible hydrocarbons from ground water. If concentrations of VOCs in treated wastewater exceed discharge plan requirements, an air-stripper may be used to further reduce levels of these volatile organic constituents.

4.2 TECHNICAL APPROACH

4.2.1 Installation of Hydrocarbon-Recovery Pumps

The pumps that have been installed at the Bloomfield Refinery are air-operated skimmer pumps designed to remove floating product and ground water from the upper portion of the aquifer. They are made primarily of stainless steel and are 3 feet long, with an outside diameter of 2-3/8 inches. Each pump fills from the top by gravity in order to provide the skimming action. When a pump becomes full of liquid, a float switch inside the pump activates the pumping cycle and compressed air is applied to the pump, forcing the liquid to the surface. The pump then rests until it becomes full again and the pumping cycle repeated. In this manner, the pump can be set near the water surface to skim off hydrocarbons while withdrawing a relatively small amount of clean water.

Pump intakes were set several feet below the water table. An air-supply hose of 1/4-inch inside diameter and a product return hose of 3/8-inch inside diameter, both comprised of oil-resistant rubber, were connected to each pump through a control box installed on supports close to each well head. These hoses were then connected to the main pump discharge line. A check valve was installed in each product line to prevent liquid from flowing back into the well and a flow indicator was provided for visual inspection of pump operation.

Air is presently being supplied to each recovery pump from the refinery's central compressed-air system at a constant air-pressure of 50 psi maintained by the control box. A 10,000-gallon above-ground tank stores pumped liquids until they can be discharged to the refinery's wastewater treatment system at appropriate times. Air lines, product lines and electrical cable serving each control box are buried in a single trench approximately 2 feet deep. Both air lines and product lines are wrapped with electrical heat tape and insulated wherever they are exposed in order to protect the lines from freezing.

A cycle counter has been installed inside each control box for the purpose of determining the quantity of liquid pumped at each location. Each cycle produces approximately 1/2 gpm. Therefore, the number of gallons pumped equals 1/2 the number of cycles indicated on the counter. Operation of recovery pumps began on January 4, 1989.

4.2.2 Operation and Maintenance of Hydrocarbon-Recovery Pumps

Output per cycle from each pump should be measured periodically to verify the cycle capacity. The pump cycle is determined by the timer module located in the control box and is initiated by the float switch inside the pump, with its duration dictated by the setting of the timer dial. Optimal cycling is determined by gradually increasing the time until all liquid is ejected from the pump followed by a burst of air. It is recommended that air be allowed to follow the water in order to completely flush particulates through the discharge line. This prevents plugging of the lines with sediment and also reduces the potential for freezing of the lines.

The pumps should be inspected weekly and a log kept of weekly counter readings and other observations. In addition, the flow indicator should be inspected to make sure that liquid is flowing in only one direction. If liquid appears to flow back toward the well, the check valve at the well head must be cleaned or replaced.

4.3 RESULTS AND CONCLUSIONS

Table 3-1 lists water levels observed at the recovery wells and piezometers immediately prior to the onset of recovery and following 12 and 42 days of recovery-well operation. Although no floating petroleum product was encountered in any of the wells or piezometers prior to recovery, operation of the recovery pumps caused development of depressions in the water table that tended to accumulate low-density product over time. In cases where a layer of floating petroleum product was encountered, water levels were corrected for confining pressures caused by the hydrocarbon layer by subtracting product thickness times the relative density of diesel fuel, assumed to be equal to 0.8, from measured depth to water. Only well RW-2 contained floating product after the first 12 days of recovery. The hydrocarbon recovery pump in well RW-1, which froze several days after the onset of pumping, was not operative until January 16, 1989. After 30 days of recovery at well RW-1, both well RW-1 and piezometer P-1 began to show evidence of floating product. Product thickness at well RW-2 decreased dramatically between the 12th and 42nd day of recovery, presumably due to flushing of product from the aquifer. Up to 1.6 feet of water-level decline was recorded at the recovery wells during the 42-day period ending on February 15, 1989, part of which may be related to ground-water recession during the non-irrigation season.

Plate 6 shows the hydraulic impacts associated with operation of the hydrocarbon recovery system for 12 days. The water table contours presented in Plate 6 were generated by Kriging, a method that uses the autocovarionce structure of the hydraulic head field to compensate for scarce water-level data. Recovery pumps in wells RW-2 and RW-3 were operating at average rates of 0.94 and 0.73 gpm, respectively, throughout this 12-day period. These rates were estimated on the basis of 32713 and 25367 recovery cycles at wells RW-2 and RW-3, with a recovery volume of

0.5 gal/cycle and a total elapsed recovery time of 17352 minutes. Comparison of the pre-recovery water table presented in Plate 4 with the 12-day recovery water table shows clear evidence that, under isotropic flow conditions, intermittent pumping of recovery wells RW-2 and RW-3 at average rates of 0.94 and 0.73 gpm during the first 12 days of recovery resulted in capture of some of the ground water that normally flows off-site to the west and southwest. Although water-level declines attributed to ground-water recession may have occurred during the first 12 days, local upgradient flexures in the water table show that some ground water was captured during this time. If ground-water losses to the western reaches of Hammond Ditch were dominant relative to rates of recovery pumping, downgradient flexures in the water table would likely be evident in Kriged water table contours throughout the recovery area. Anisotropic influences caused by variations in saturated thickness and consequent changes in transmissivity may have resulted in a smaller capture zone after 12 days than is otherwise indicated in Plate 6, but it is evident that significant hydraulic stresses were being propagated through the alluvial aquifer during early stages of recovery.

The Kriged distribution of hydraulic head following 42 days of recovery at all three recovery wells is shown in Plate 7. Average pumping rates of 1.2, 0.50, and 0.42 gpm were estimated from a cumulative total of 103991, 60917, and 50251 cycles recorded at wells RW-1, RW-2, and RW-3 during the 60550 minutes comprising the 42-day period. Average rates of withdrawal at wells RW-2 and RW-3 during the entire 42-day recovery operation decreased relative to rates calculated for the first 12 days of recovery because residual hydraulic stresses from prior pumping helped to maintain water levels at the pump intakes at lower discharge rates. Intermittent pumping of ground water at these average pumping rates throughout this period resulted in the development of a more extensive capture zone around the recovery area than was evident after 12 days of pumping. The 42-day recovery water table appears to be minimally impacted by discharge at well RW-2, due either to the low rate of discharge at this well, to the larger transmissivity associated with the larger saturated thickness near this well, or to some combination of these two influences. Again, the existence of upgradient flexures in the water table is evidence that capture is occurring despite ground-water recession, which would tend to produce downgradient flexures in the recovery area. Anisotropic flow would somewhat alter the 42-day capture zone from the zone otherwise indicated by water table contours shown in Plate 7.

Plate 7 suggests that ground water and hydrocarbons beneath BLM property were not being captured after 42 days of recovery operations. However, comparison of Plates 6 and 7 indicates that recovery stresses are propagating further beneath BLM land as the impacts of pumping are transmitted through the high-storativity alluvial system. Until steady-state conditions are approximately attained, these stresses will continue to migrate southward and westward towards off-site property. The high specific yield typically characteristic of the coarse-grained deposits encountered beneath the site and adjacent areas will require long periods of recovery before the effectiveness of ground water capture is fully realized. Based on the water table observed after 42 days of recovery, the predominant upgradient flexure in the water table surface occurs near recovery well RW-3. It thus appears that recovery well RW-3 will play an important role with respect to capture of hydrocarbons from both on-site and off-site portion of the perched alluvial aquifer.

5.0 REFERENCES

Engineering-Science, 1986, A Final Report on Section 3013 Administrative Order Work Elements.

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Silka, L.R., 1988, 'Simulation of Vapor Transport Through the Unsaturated Zone - Interpretation of Soil-Gas Surveys', Groundwater Monitoring Review, Spring, p. 115-123.

U.S. Environmental Protection Agency, 1981, Treatability Manual, Volume I. Treatability Data, Office of Research and Development, Washington, D.C.

Vogel, T.M., C.S. Criddle and P.L. McCarty, 1987, 'Transformations of Halogenated Aliphatic Compounds', Environmental Science and Technology, v. 2, n. 8, p. 722.

APPENDIX A

GCL STANDARD OPERATING PROCEDURES FOR SOIL VAPOR SAMPLING AND ANALYSIS

PROCEDURES FOR SOIL VAPOR SAMPLING AND ANALYSIS

1.0 PURPOSE

To describe and illustrate the methods and procedures used in sampling and analyzing shallow subsurface soil vapor for various contamination evaluations.

2.0 SCOPE

A shallow soil-vapor survey is commonly a rapid and cost-effective method for roughly delineating the areal extent of a known spill involving hydrocarbons or other volatile constituents. Shallow soil-vapor investigations are also used to determine the presence or absence of specific constituents in the subsurface at sites where spills or leaks are possible but have not been identified.

3.0 PROCEDURES

3.1 EQUIPMENT AND SUPPLIES

A. Necessary equipment at all sites will include:

- Probes (3/4" I.D. steel pipe, schedule 20 or similar)
- Drive Points
- Adapters
- Floor jack (2-ton capacity)
- Pipe clamp
- Pipe wrenches
- Pipe cutter
- Pipe reamer
- Portable gas chromatograph (GC) (Photovac), syringes and other necessary GC supplies (kit)
- Calculator
- Internal tank filling adapter
- Vacuum pump (battery operated)
- Slide hammer
- Duct tape
- Teflon tubing
- Black inert rubber hose
- Battery pack for GC
- Zero-grade air cylinders

B. Optional equipment and supplies needed at some sites:

- Rotary hammer with bit
- Extension cords
- Generator
- Brunton compass and tape measure
- Steam cleaner
- Metal detector
- Sand and asphalt or concrete patching material

C. Safety Equipment for Persons Driving Probes:

- Hard Hats
- Coveralls
- Gloves
- Safety Glasses
- Steel-toed Boots

3.2 Define the area to be surveyed. This may include an entire gas station, a large area of property, or as small as the area around a single tank.

3.3 Divide the survey area into a grid or other appropriate pattern, and number each location on the grid. Grid spacing may vary depending on the size of the survey area, site conditions and the level of detail required. 20 to 50 foot grid spacing is generally used for a survey at a service station. Note: One may want to number points as field work progresses, so expansion of the grid will be consistently numbered.

3.4 Be sure all sampling equipment, including probes, vacuum adapters, points, and slide hammer (inside and outside) is thoroughly steam cleaned prior to use.

3.5 Prior to soil sampling, an "air sample" of the ambient air should be analyzed with the GC. Be sure the air sample is collected a distance away from or upwind from any running vehicle or other source of hydrocarbon emissions (20-30 feet is sufficient).

3.6 Next, collect a "system blank" to be analyzed prior to sampling. The vacuum pump should be attached to a clean probe with point attached, via an adapter, and a sample collected. This will provide background data of ambient air passing through a probe.

3.7 If it is necessary to drill through concrete or asphalt, start the generator (make sure it is positioned downwind of probes) or plug an extension cord into an available electrical outlet. Locate the rotary hammer over the hole and drill through the concrete or asphalt to underlying soil. Remove drill.

3.8 Insert the drive point into base of probe. Tape point loosely with duct tape to probe (so it won't fall out during insertion into hole).

3.9 Remove lift plate (white) from floor jack, and place hole in lifting arm of the jack over the drilled hole.

3.10 Insert the probe through the hole in the jack's lifting arm, and into the drilled hole or the soil surface.

3.11 Place slide hammer over the top of the probe and drive to the target depth. Generally, a target depth of 5 feet is used, except for vertical profiles. Remove the slide hammer.

3.12 Promptly after driving the probe, place an adapter over it and connect it to the vacuum pump.

3.13 Place pipe clamp around probe at the lifting arm of the jack. Tighten clamp. Turn jack handle clockwise to activate hydraulics. Use jack to retract probe 1-3 inches immediately before sampling.

3.14 When the chemist is ready to take the sample, activate the vacuum pump. It is necessary to evacuate approximately 5 probe volumes of soil vapor prior to sampling. This can be approximated by the vacuum reading on the pump.

VACUUM PUMP GAGE READING (Inches Hg)	EVACUATION TIME (Seconds)
2 - 5	30
5 - 10	45
10 - 15	60
15 - 17	90

Note: Vacuum pressures above 17 in. Hg. suggest either a clogged probe, a very tight formation, or water. If there is a possibility of shallow ground water, be sure water is not evacuated and passed into the vacuum pump. Above 17 in. Hg. the pump will not collect a good soil vapor sample and the problem should be investigated.

3.15 After the evacuation time is satisfied, insert a clean syringe (equipped with a mini-enert valve) through the flexible latex (self-sealing) tubing at the top of the adapter. Flush the syringe 3 times with the soil vapor while the evacuation pump is running. Turn the evacuation pump off and immediately withdraw a 2cc sample and close the mini-enert valve on the syringe.

3.16 Analyze the sample by gas chromatography. This task will be performed by a person experienced in GC operations.

3.17 With the pipe clamp still tightened around the probe, extract the probe. The jack can be reset by turning the handle counterclockwise. This will allow the lifting arm to drop, and the pipe clamp can be loosened and lowered.

3.18 After extraction, the used probe and adaptor should be set aside in a designated area so as to prevent confusion with clean probes or adapters.

3.19 For each soil vapor point, record in log book the following items:

SITE LOCATION
WEATHER JOB #

	TIME	POINT #	DEPTH	VACUUM	EVAC TIME	REMARKS
Example	10:00	# 5	5′	3" Hg	30 Sec.	
	10:30	# 7	5′	18" Hg	-	Probe clogged removed, cleaned redrove to 6′

3.20 Steam clean all probes and adapters prior to re-use.

3.21 After QA/QC of field data, results should be submitted to Data Management for processing and mapping.

Prepared By: ______________________________

Reviewed By: ______________________________

APPENDIX B

LITHOLOGIC LOGS AND STRATIGRAPHIC SECTIONS

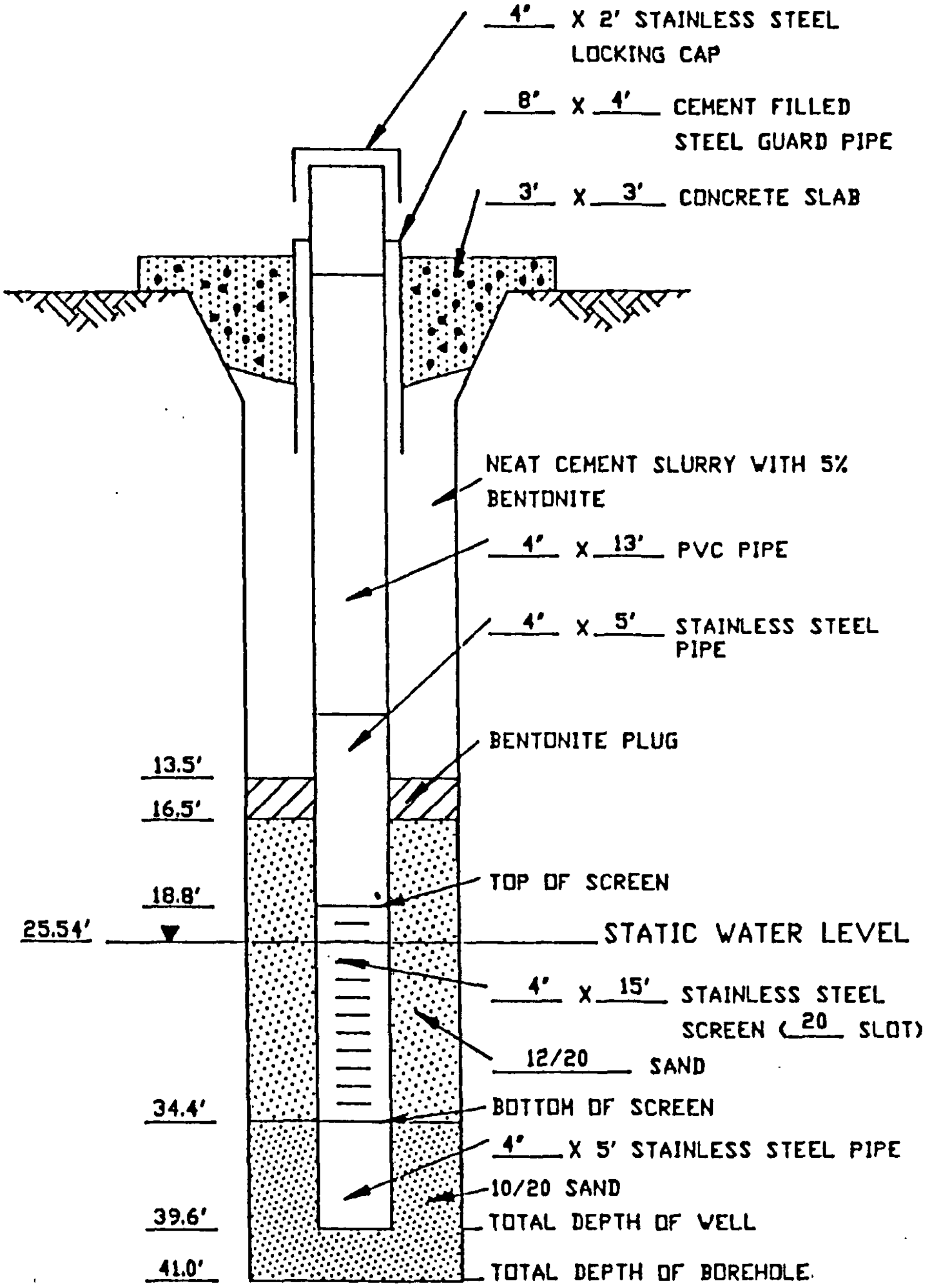


FIGURE B-1

COMPLETION DIAGRAM

RECOVERY WELL RW-1

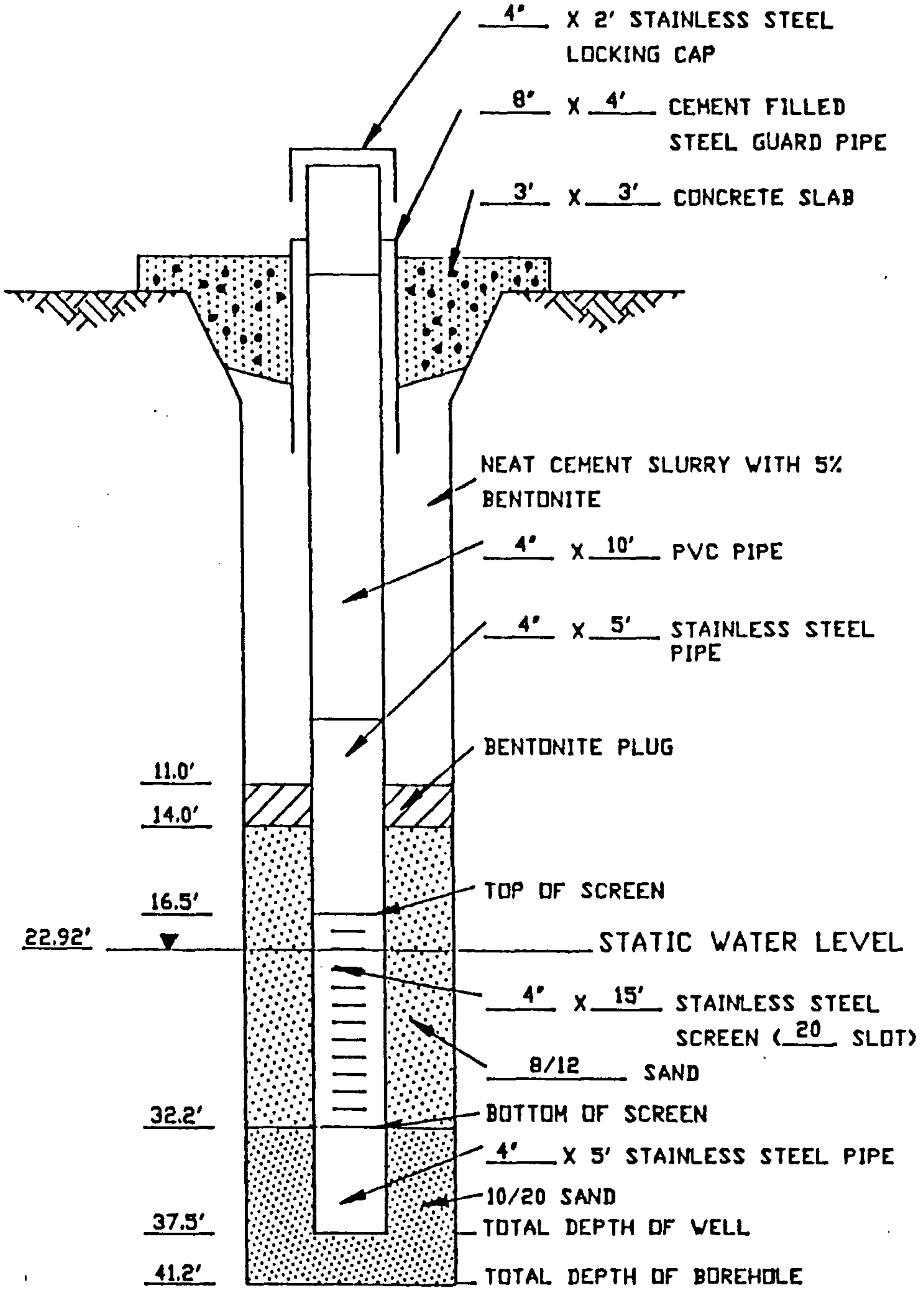


FIGURE B-2

COMPLETION DIAGRAM

RECOVERY WELL RW-2

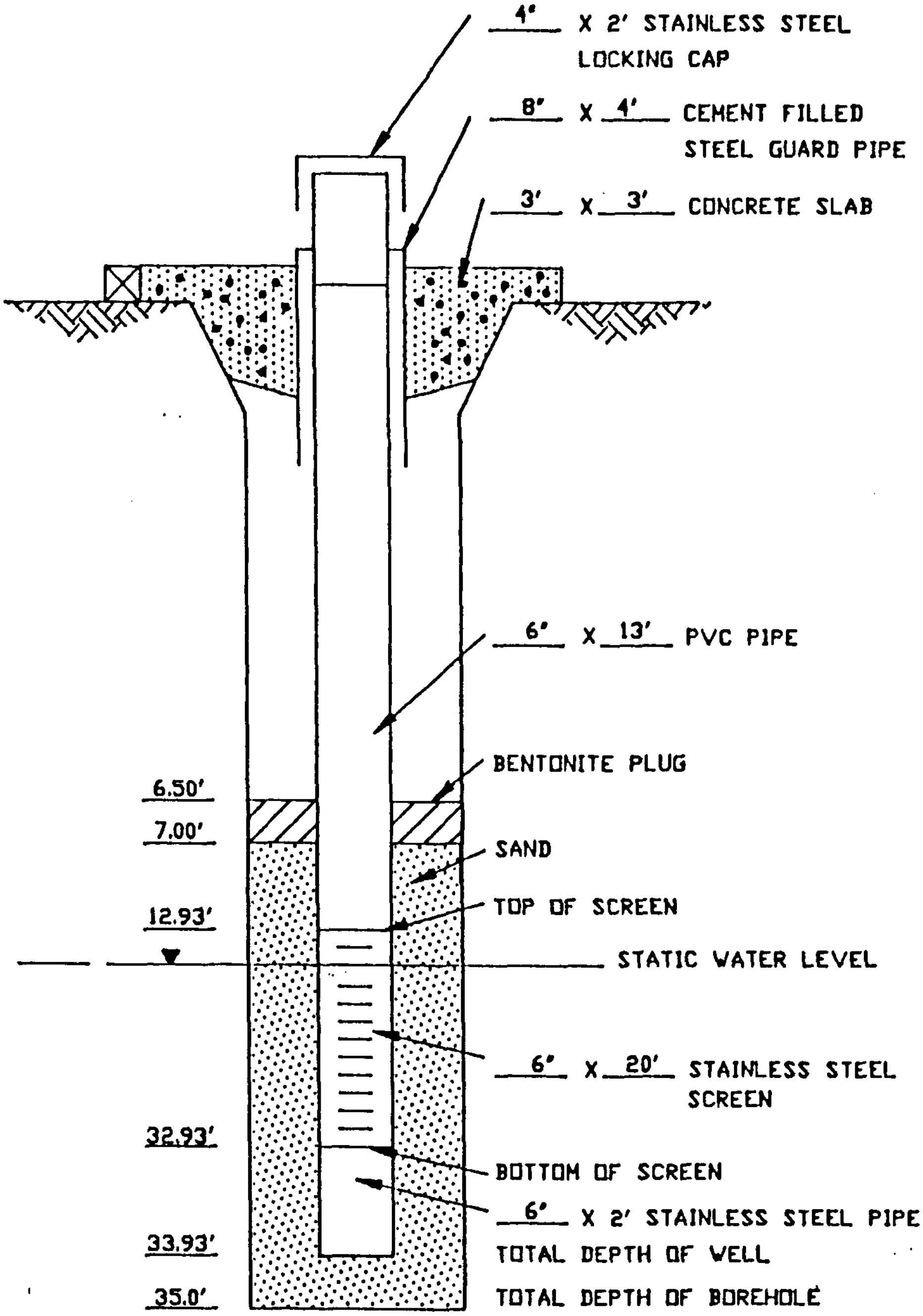


FIGURE B-3

COMPLETION DIAGRAM
RECOVERY WELL MW-10 (RW-3)
(RECONSTRUCTED FROM VERBAL DESCRIPTION
SUPPLIED BY ENGINEERING-SCIENCE, 1987)

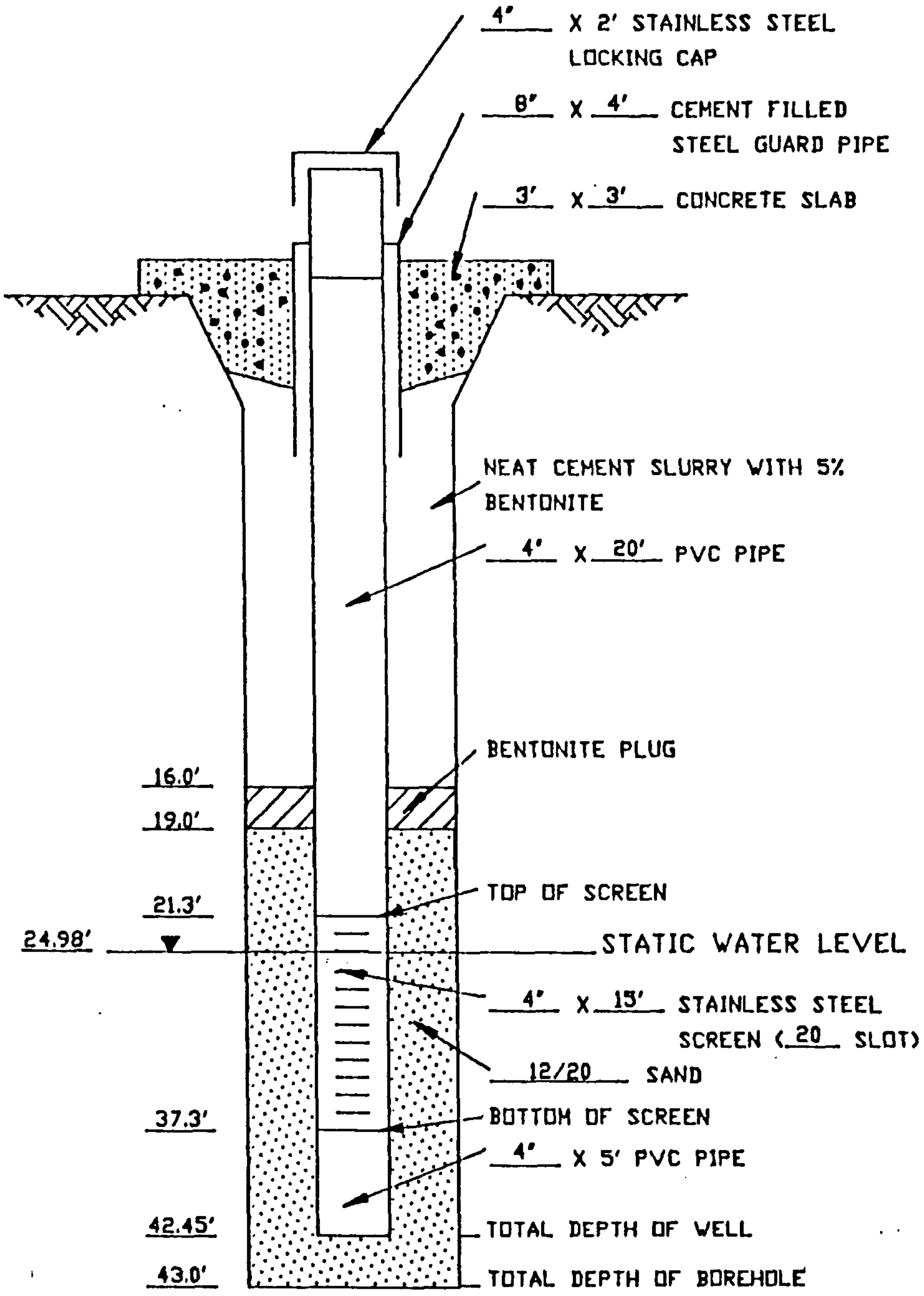


FIGURE B-4

COMPLETION DIAGRAM
PIEZOMETER P-1

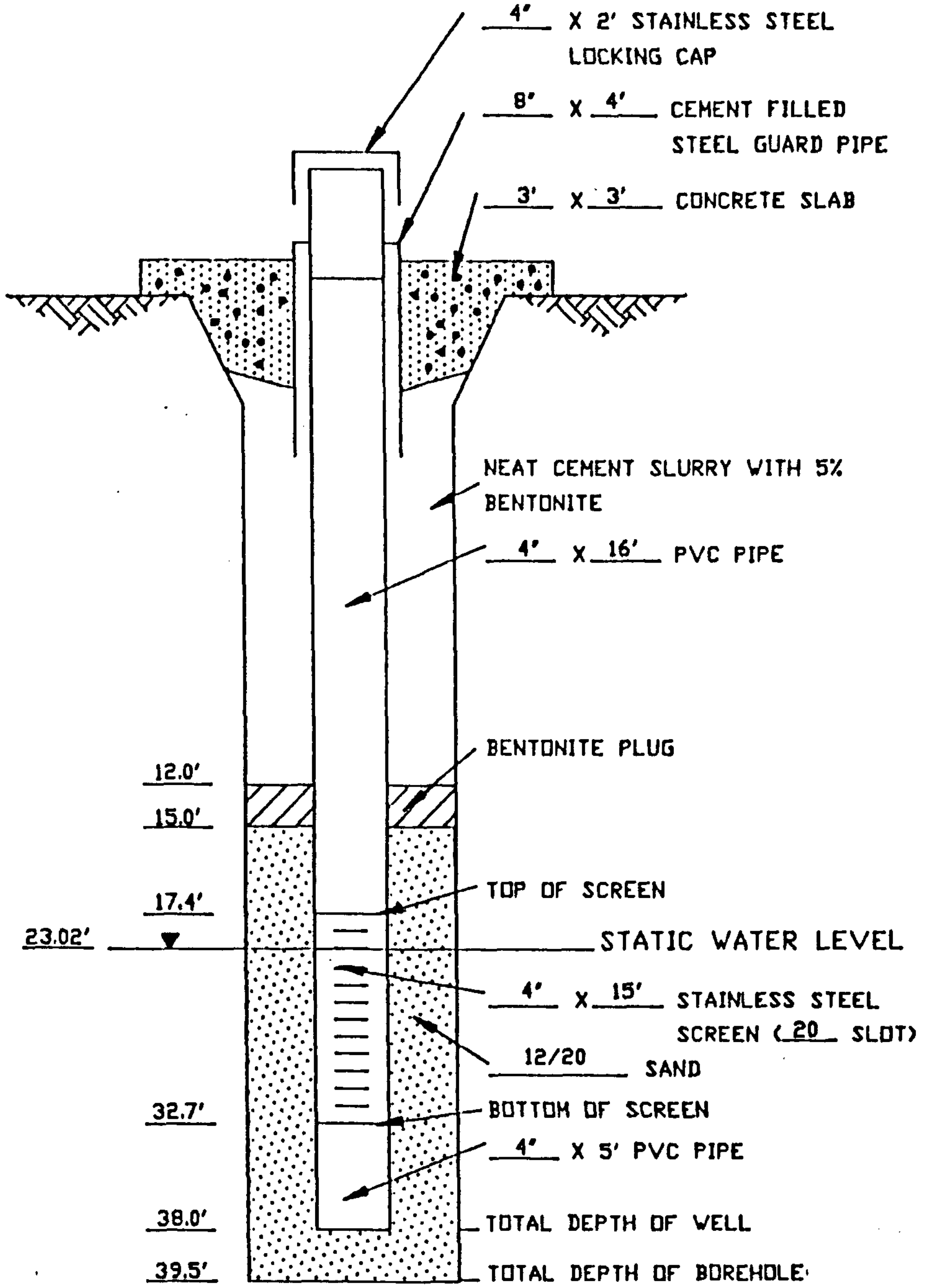


FIGURE B-5

COMPLETION DIAGRAM
PIEZOMETER P-2

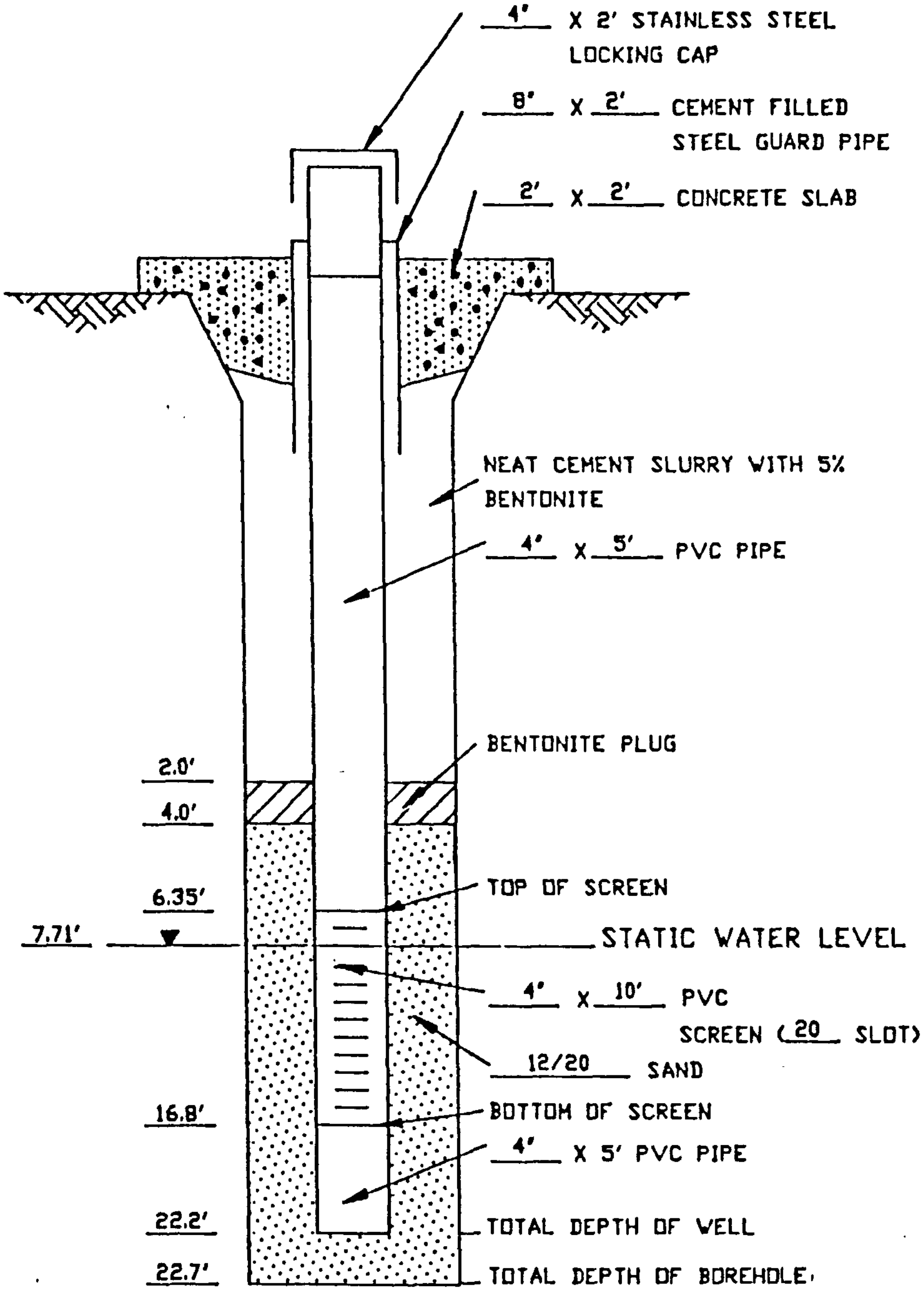


FIGURE B-6
COMPLETION DIAGRAM
PIEZOMETER P-3

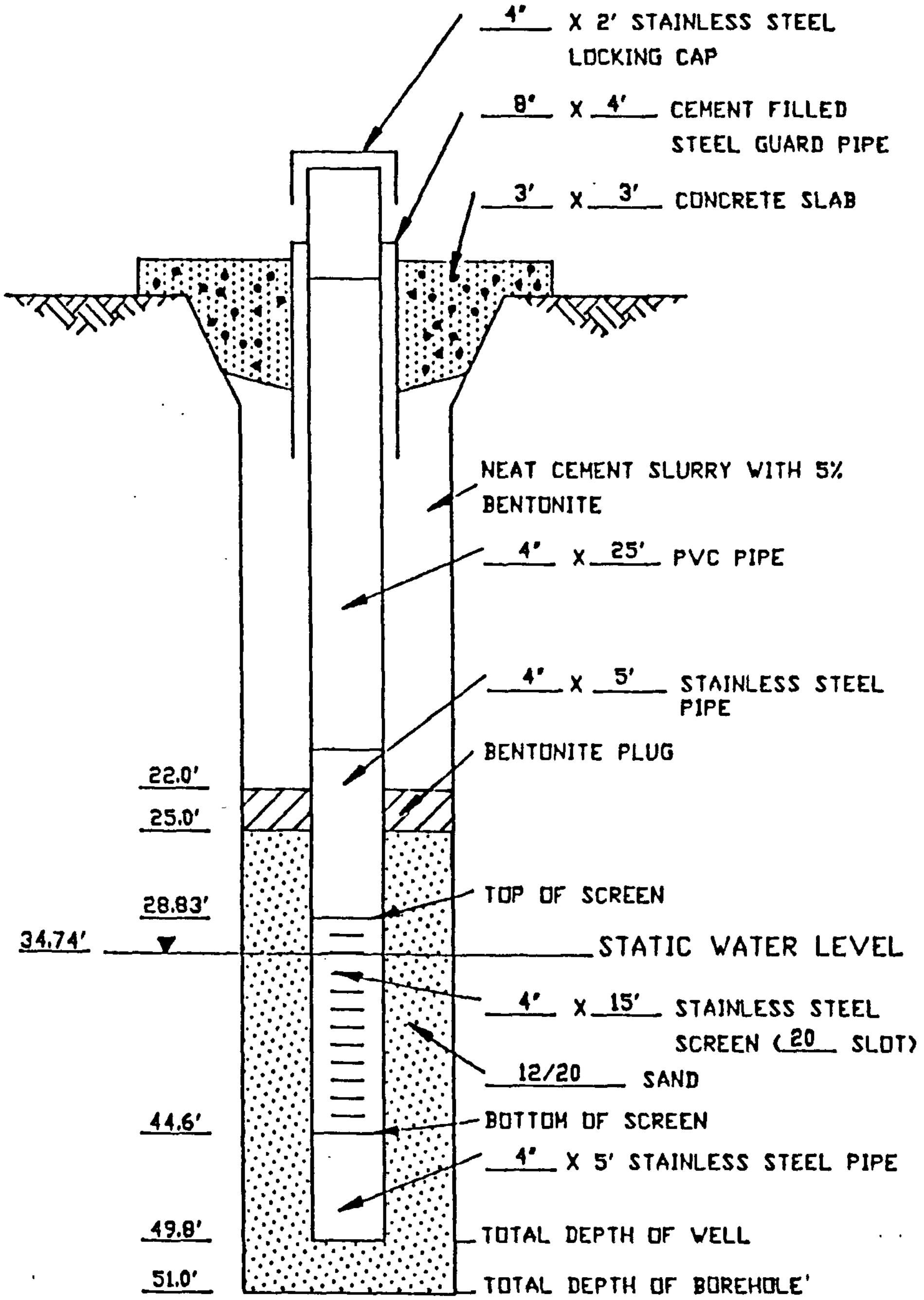


FIGURE B-7

COMPLETION DIAGRAM
PIEZOMETER P-4

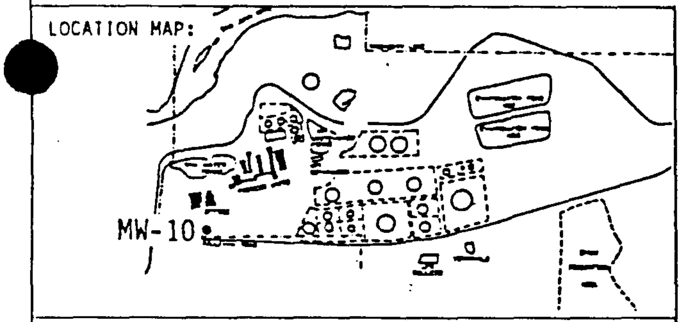
FIGURE B-10

LITHOLOGIC LOG (SOIL)

RECOVERY WELL MW-10 (RW-3)

Page 1 of 1

LOCATION MAP:



____1/4 ____1/4 ____1/4 ____1/4 S____ T____ R____

SITE ID: BRC LOCATION ID: MW-10 (RW-3)
SITE COORDINATES (ft.):
N E
GROUND ELEVATION (ft. MSL): 5515.46
STATE: New Mexico COUNTY: San Juan
DRILLING METHOD: Auger
DRILLING CONTR.: Earl & Sons, Inc.
DATE STARTED: 4 March 1986 DATE COMPLETED: 4 March 1986
FIELD REP.: Engineering-Science, Inc.
COMMENTS:

LOCATION DESCRIPTION:

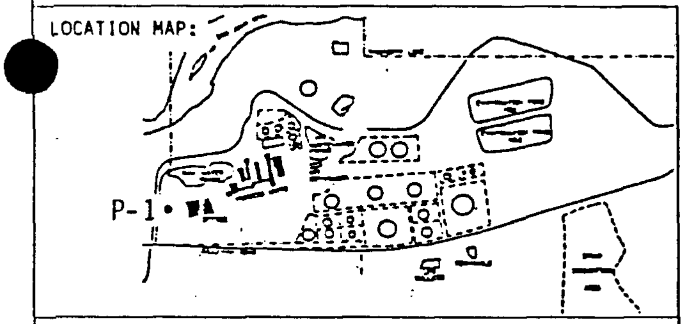
Depth	Visual %	Lith	Drilling Time Scale:	Sample Type and Interval	Lithologic Description
					0'-5' Topsoil, Roadbase, Sandy Clay
5					5'-10' Silty, Sandy Clay
10					10'-15' Cobbles and Pebbles
15					15'-20' Gravel, Cobbles, and Pebbles
20					20'-30' Green Clay: Nacimiento Formation
25					30'-35' Nacimiento Formation - Yellow-green to blue-gray.
30					
35		T.D. 35'			
40					
45					
50					

FIGURE B-11

LITHOLOGIC LOG (SOIL)
PIEZOMETER P-1

Page 1 of 1

LOCATION MAP:



____1/4 ____1/4 ____1/4 ____1/4 S____ T____ R____

SITE ID: BRC LOCATION ID: P-1
SITE COORDINATES (ft.):
N E
GROUND ELEVATION (ft. MSL): 5523.82
STATE: New Mexico COUNTY: San Juan
DRILLING METHOD: Casing Driver
DRILLING CONTR.: Beeman Brothers
DATE STARTED: 30 August 1988 DATE COMPLETED: 30 August 1988
FIELD REP.: W.S. Dubyk
COMMENTS: This well replaced by P-1a on August 31, 1988.

LOCATION DESCRIPTION:

Depth	Visual %	Lith	Drilling Time Scale:	Sample Type and Interval	Lithologic Description
					0'-20' Silt and Clay - Dark yellowish brown (10 YR 4/2) to grayish brown (5 YR 3/2). Weak hydrocarbon odor.
5			1135		
10			1140		
15			1145		
20			1200		20'-36.5' Sand and Gravel - Dark gray (N3) to grayish black (N2). Sand is fine to very coarse grained, subangular to rounded. Gravel is subangular to well rounded, to 2" diameter. Very strong to intense hydrocarbon odor.
25			1205		
30			1210		
35			1220		36.5'-42.0' Shale - Nacimiento Formation - Dusky yellow (5 Y 6/4) to olive gray (5 Y 3/2) shale.
40			1225 1240		
		T.D. 42'			
45					
50					

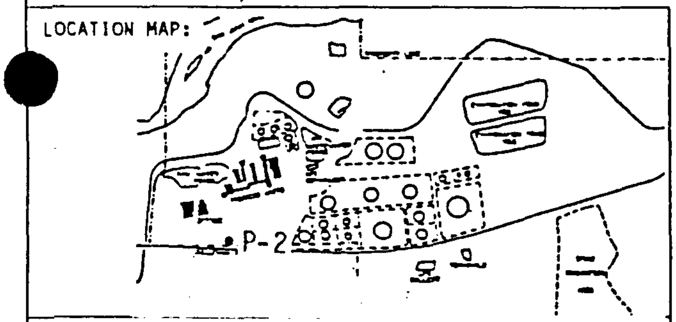
FIGURE B-12

LITHOLOGIC LOG (SOIL)

PIEZOMETER P-2

Page 1 of 1

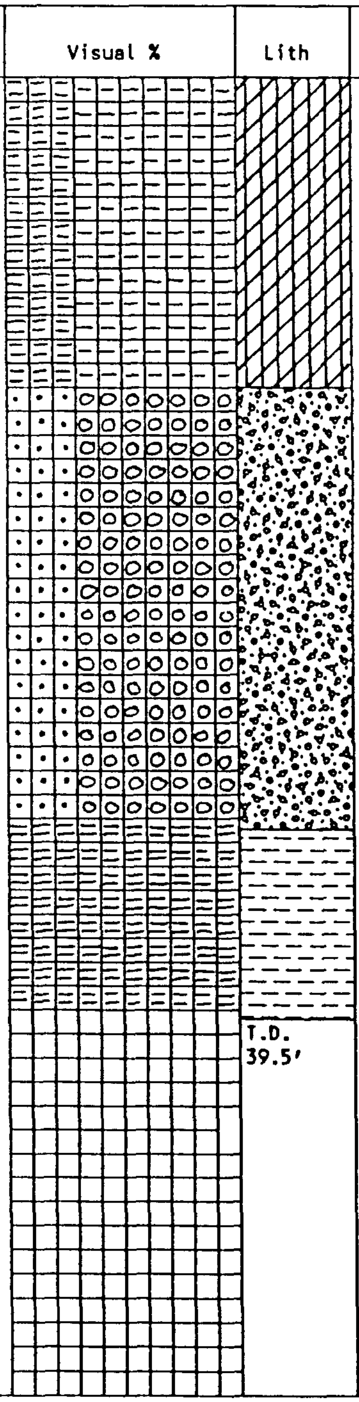
LOCATION MAP:



____1/4 ____1/4 ____1/4 ____1/4 S____ T____ R____

SITE ID: BRC LOCATION ID: P-2
SITE COORDINATES (ft.):
N E
GROUND ELEVATION (ft. MSL): 5522.93
STATE: New Mexico COUNTY: San Juan
DRILLING METHOD: Casing Driver
DRILLING CONTR.: Beeman Brothers
DATE STARTED: 29 August 1988 DATE COMPLETED: 29 August 1988
FIELD REP.: W.S. Dubyk
COMMENTS: This well replaced by P-2a. Static on September 2, 1988: 23.75 from TOC.

LOCATION DESCRIPTION:



Depth	Drilling Time Scale:	Sample Type and Interval	Lithologic Description
			0'-13' Silty and Clay - Dark gray (N3) to grayish black (N2) to dark yellowish brown (10 YR 4/2). Intense hydrocarbon odor.
5	1650		
10	1656		
15	1710		13'-31.5' Sand and Gravel - Moderate yellowish brown (10 YR 5/4) to medium gray (N5). Sand is medium to very coarse grained, subangular to subrounded. Gravel is subangular to well rounded, to 2" diameter. Strong hydrocarbon odor below 25'.
20	1720		
25	1730		
30	1734		31.5'-39.5' Shale - Nacimiento Formation - Dusky yellow (5 Y 6/4) to olive gray (5 Y 3/2).
35	1752		
40	1808		
45			
50			

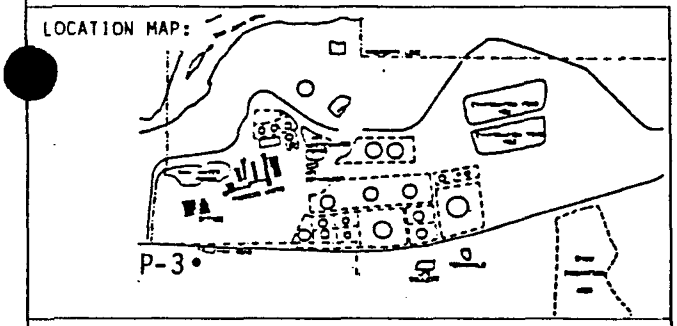
FIGURE B-13

LITHOLOGIC LOG (SOIL)

PIEZOMETER P-3

Page 1 of 1

LOCATION MAP:



____1/4 ____1/4 ____1/4 ____1/4 S____ T____ R____

SITE ID: BRC LOCATION ID: P-3
SITE COORDINATES (ft.):
N E
GROUND ELEVATION (ft. MSL): 5506.40
STATE: New Mexico COUNTY: San Juan
DRILLING METHOD: Casing Driver
DRILLING CONTR.: Beeman Brothers
DATE STARTED: 1 September 1988 DATE COMPLETED: 1 September 1988
FIELD REP.: W.S. Dubyk
COMMENTS: Static on September 2, 1988: 8.30' from TOC.

LOCATION DESCRIPTION:

Depth	Visual %	Lith	Drilling Time Scale:	Sample Type and Interval	Lithologic Description
					0'-14' Sand and Gravel - Medium gray (N5) to dark gray (N3). Sand is medium to coarse grained, subangular to subrounded. Gravel is subrounded to rounded, to 2" diameter. Strong hydrocarbon odor.
5			0902		
10			0913		
15			0920		14'-22.7' Shale: Nacimiento Formation - Dusky yellow (5 YR 6/4) to light olive gray (5 Y 6/1) shale.
20			0925		
		T.D.22.7'	1000		
25					
30					
35					
40					
45					
50					

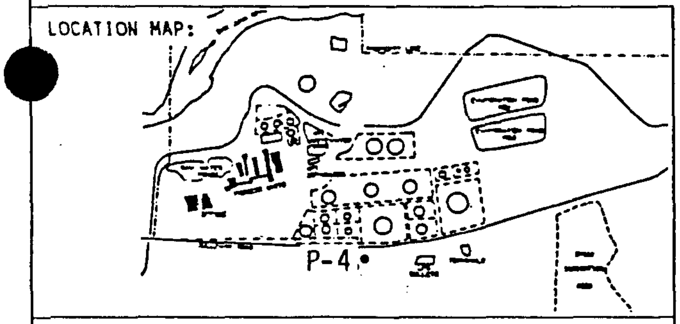
FIGURE B-14

LITHOLOGIC LOG (SOIL)

PIEZOMETER P-4

Page 1 of 1

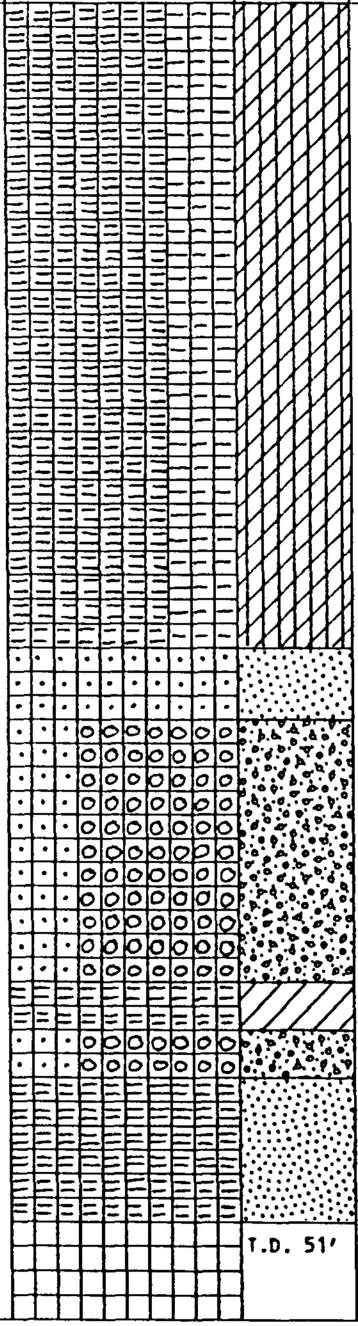
LOCATION MAP:



____1/4 ____1/4 ____1/4 ____1/4 S____ T____ R____

SITE ID: BRC LOCATION ID: P-4 (MW-13)
SITE COORDINATES (ft.):
N ____ E ____
GROUND ELEVATION (ft. MSL): 5535.12
STATE: New Mexico COUNTY: San Juan
DRILLING METHOD: Casing Driver
DRILLING CONTR.: Beeman Brothers
DATE STARTED: 2 September 1988 DATE COMPLETED: 3 September 1988
FIELD REP.: W.S. Dubyk
COMMENTS: Static on September 9, 1988: 37.91' from TOC.

LOCATION DESCRIPTION:



Depth	Visual %	Lith	Drilling Time Scale:	Sample Type and Interval	Lithologic Description
					0'-27' Silt and Clay - Moderate brown (5 YR 4/4) to light brown (5 YR 5/6).
5					
10					
15					
20					
25			1233		
					27'-30' Sand - Very pale or (5 YR 8/2) fine to coarse grained, angular to subangular predominantly quartz.
30					30'-40' Gravel and Sand - Light gray (N7). Sand is medium to coarse grained, subrounded to rounded. Gravel is subangular to rounded, up to 3" diameter.
35					
40			1415		41'-43' Clay - Pale olive (10 Y 6/2), plastic.
					43'-45' Gravel and Sand - As above.
45			1420		45'-51' Sand : Nacimiento Formation -light bluish grey (5B7/1) Fine grained, silty.
50					
		T.D. 51'	1455		

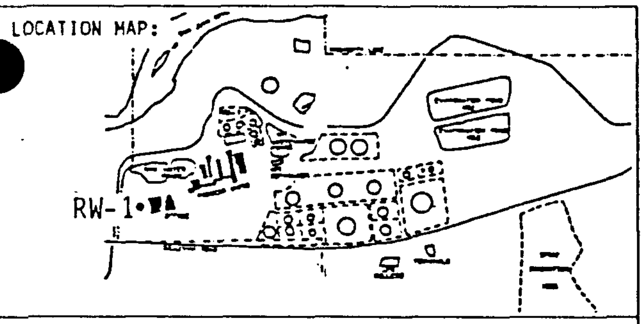
FIGURE B-8

LITHOLOGIC LOG (SOIL)

RECOVERY WELL RW-1

Page 1 of 1

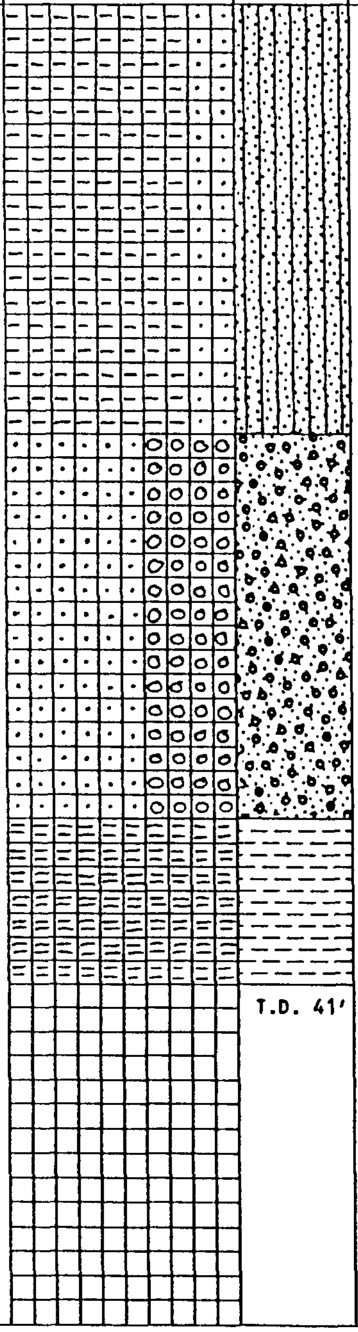
LOCATION MAP:



___1/4 ___1/4 ___1/4 ___1/4 S___ T___ R___

SITE ID: BRC LOCATION ID: RW-1
SITE COORDINATES (ft.):
N E
GROUND ELEVATION (ft. MSL): 5524.52
STATE: New Mexico COUNTY: San Juan
DRILLING METHOD: Casing Driver
DRILLING CONTR.: Beeman Brothers
DATE STARTED: 30 August 1988 DATE COMPLETED: 31 August 1988
FIELD REP.: W.S. Dubyk
COMMENTS: Static on September 2, 1988: 26.65 from TOC.

LOCATION DESCRIPTION:



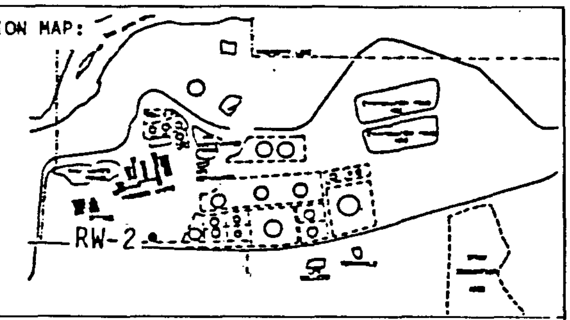
Depth	Visual %	Lith	Drilling Time Scale:	Sample Type and Interval	Lithologic Description
					0'-18' Silt and Sand - Dark yellowish brown (10 YR 4/2) to grayish brown (5 YR 3/2). Minor to strong hydrocarbon odor.
5			1642		
10			1646		
15			1710		
20			1720		18'-34' Sand and Gravel - Medium dark gray (N4). Sand is medium to very coarse grained, subangular to subrounded. Gravel is subrounded to well rounded, to 2" diameter. Strong hydrocarbon odor.
25			1725		
30			1730		
35			1738		34'-41' Shale - Nacimiento Formation - Dusky yellow (5 YR 6/4) to light olive gray (5 Y 6/1) shale.
40			1758		
45					
50					

FIGURE B-9

LITHOLOGIC LOG (SOIL)
RECOVERY WELL RW-2

Page 1 of 1

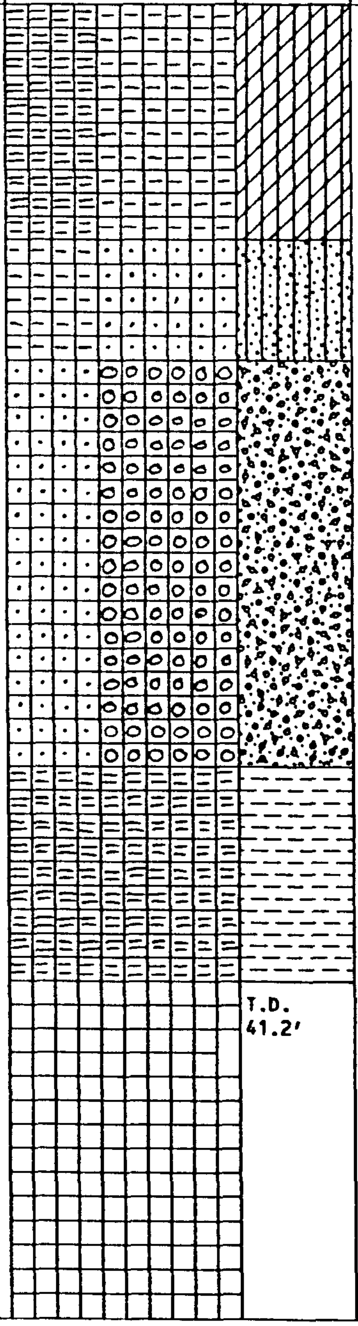
LOCATION MAP:



____1/4 ____1/4 ____1/4 ____1/4 S____ T____ R____

SITE ID: BRC LOCATION ID: RW-2
SITE COORDINATES (ft.):
N E
GROUND ELEVATION (ft. MSL): 5522.98
STATE: New Mexico COUNTY: San Juan
DRILLING METHOD: Casing Driver
DRILLING CONTR.: Beeman Brothers
DATE STARTED: 29 August 1988 DATE COMPLETED: 29 August 1988
FIELD REP.: W.S. Dubyk
COMMENTS: Static on September 2, 1988: 23.42 from TOC.

LOCATION DESCRIPTION:



Depth	Visual %	Lith	Drilling Time Scale:	Sample Type and Interval	Lithologic Description
					0'-10' Silt and Clay - Medium dark gray (N4) to brownish gray (5 YR 4/1). Slightly effervescent in HCl. Faint hydrocarbon odor.
5			0948		
10			0953		10'-15' Sand and Silt - Moderate brown (5 YR 4/4), very fine grained and well sorted.
15			0958		15'-32' Sand and Gravel - Olive gray (5 Y 4/1) to brownish gry (5 YR 4/1). Sand is medium to very coarse grained, subangular to subrounded. Gravel is subangular to well rounded, to 2" diameter. Noticeable hydrocarbon odor below 25'.
20			1024		
25			1029		
30			1033		
					32'-41.2' Shale - Nacimiento Formation - Dusky yellow (5 Y 6/4) to olive gray (5 Y 3/2).
35			1050		
40					
		T.D. 41.2'	1100		
45					
50					

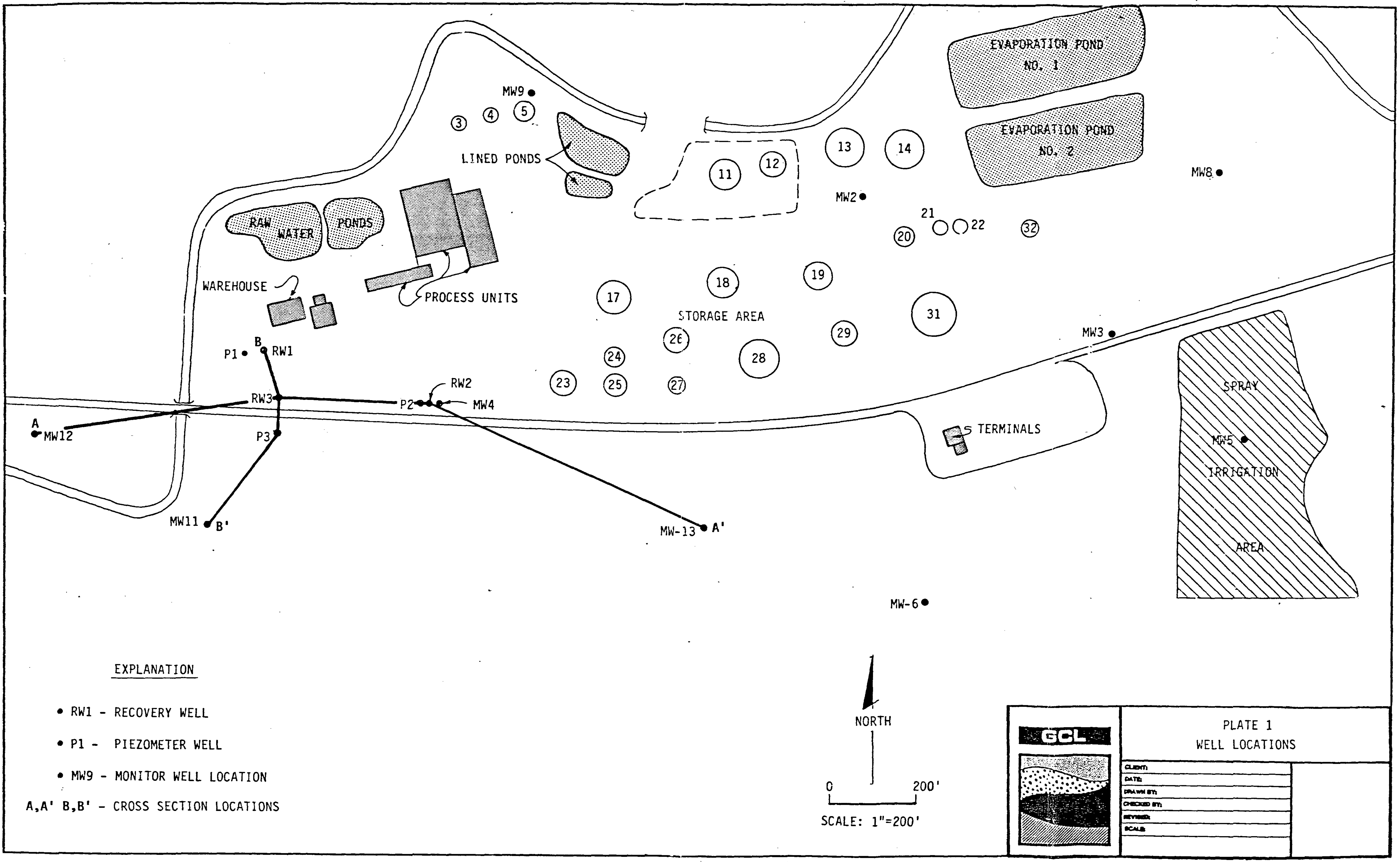


PLATE 1
WELL LOCATIONS

EXPLANATION

- ● RW1 - RECOVERY WELL
- ● P1 - PIEZOMETER WELL
- ● MW9 - MONITOR WELL LOCATION
- A,A' B,B' - CROSS SECTION LOCATIONS

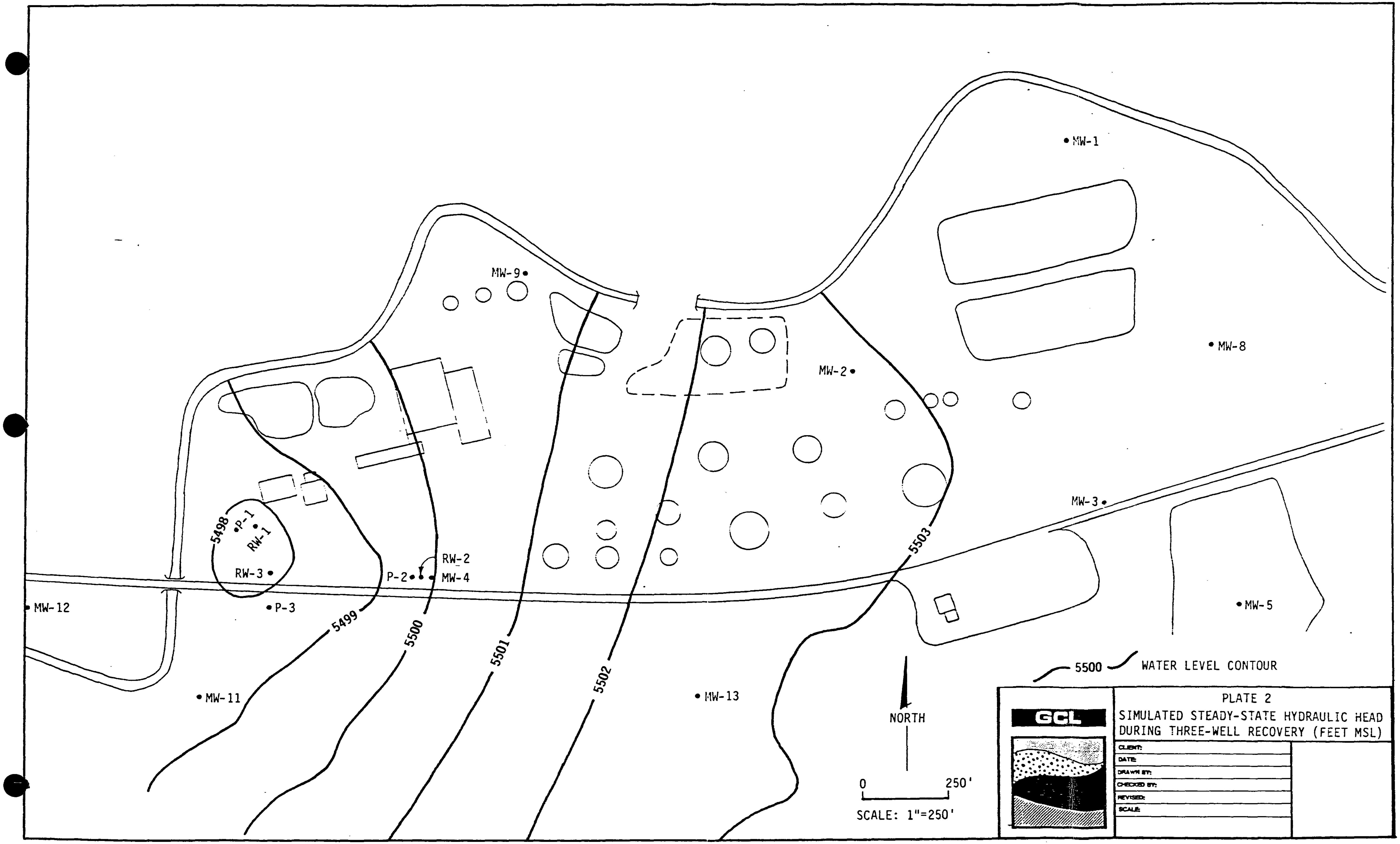


PLATE 2

SIMULATED STEADY-STATE HYDRAULIC HEAD DURING THREE-WELL RECOVERY (FEET MSL)

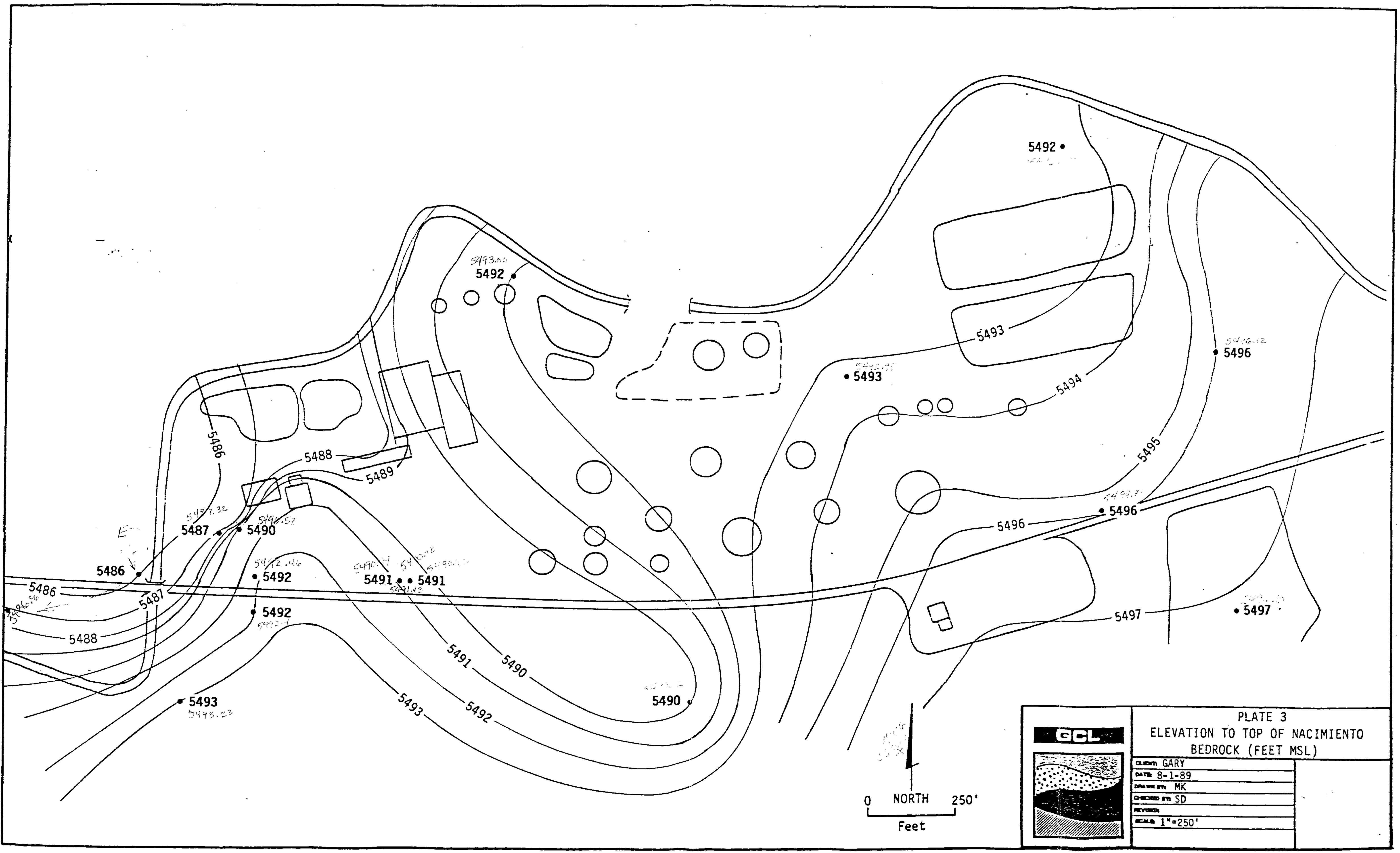
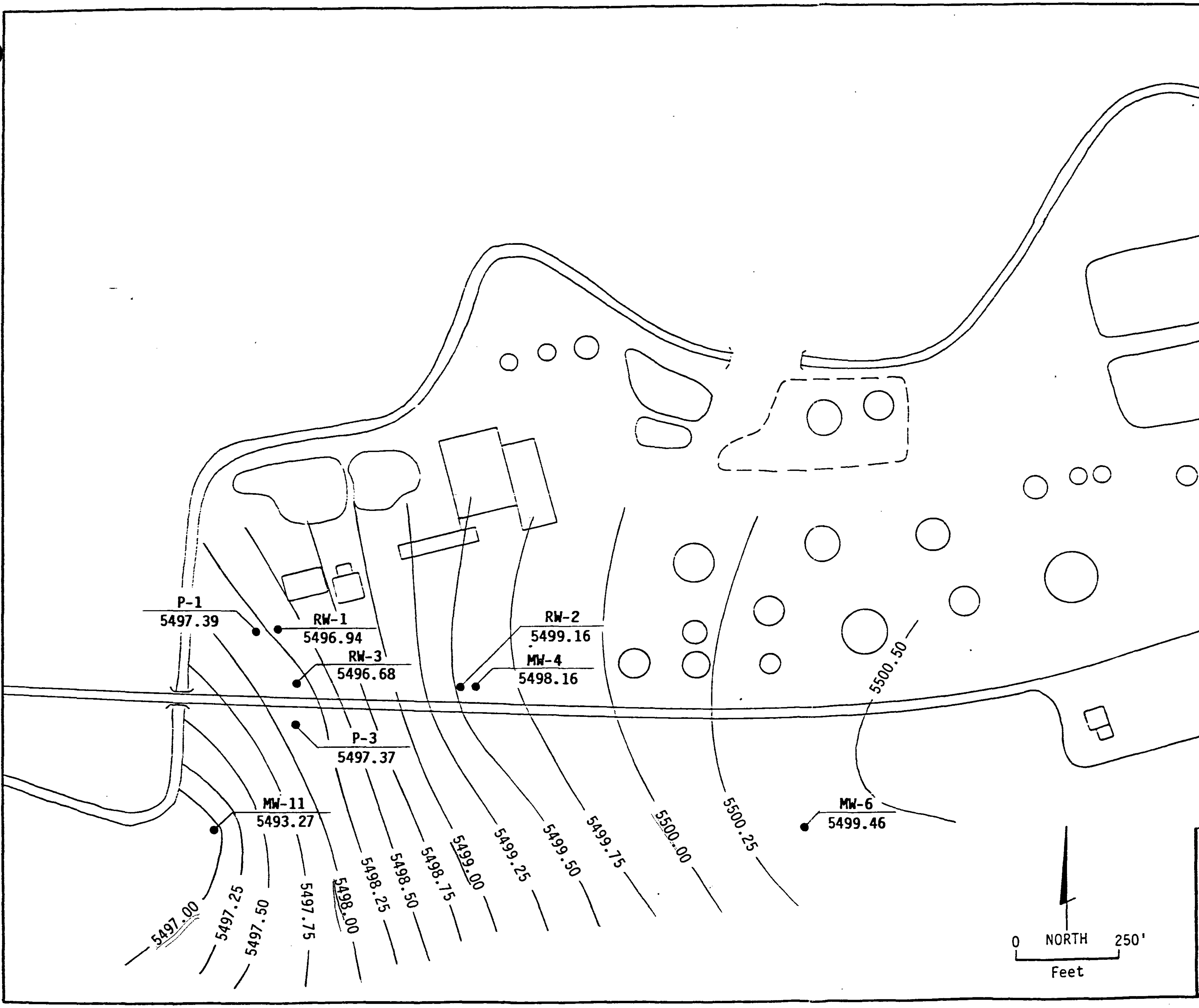


PLATE 3
ELEVATION TO TOP OF NACIMIENTO BEDROCK (FEET MSL)

CLIENT: GARY
DATE: 8-1-89
DRAWN BY: MK
CHECKED BY: SD
REVISED:
SCALE: 1"=250'

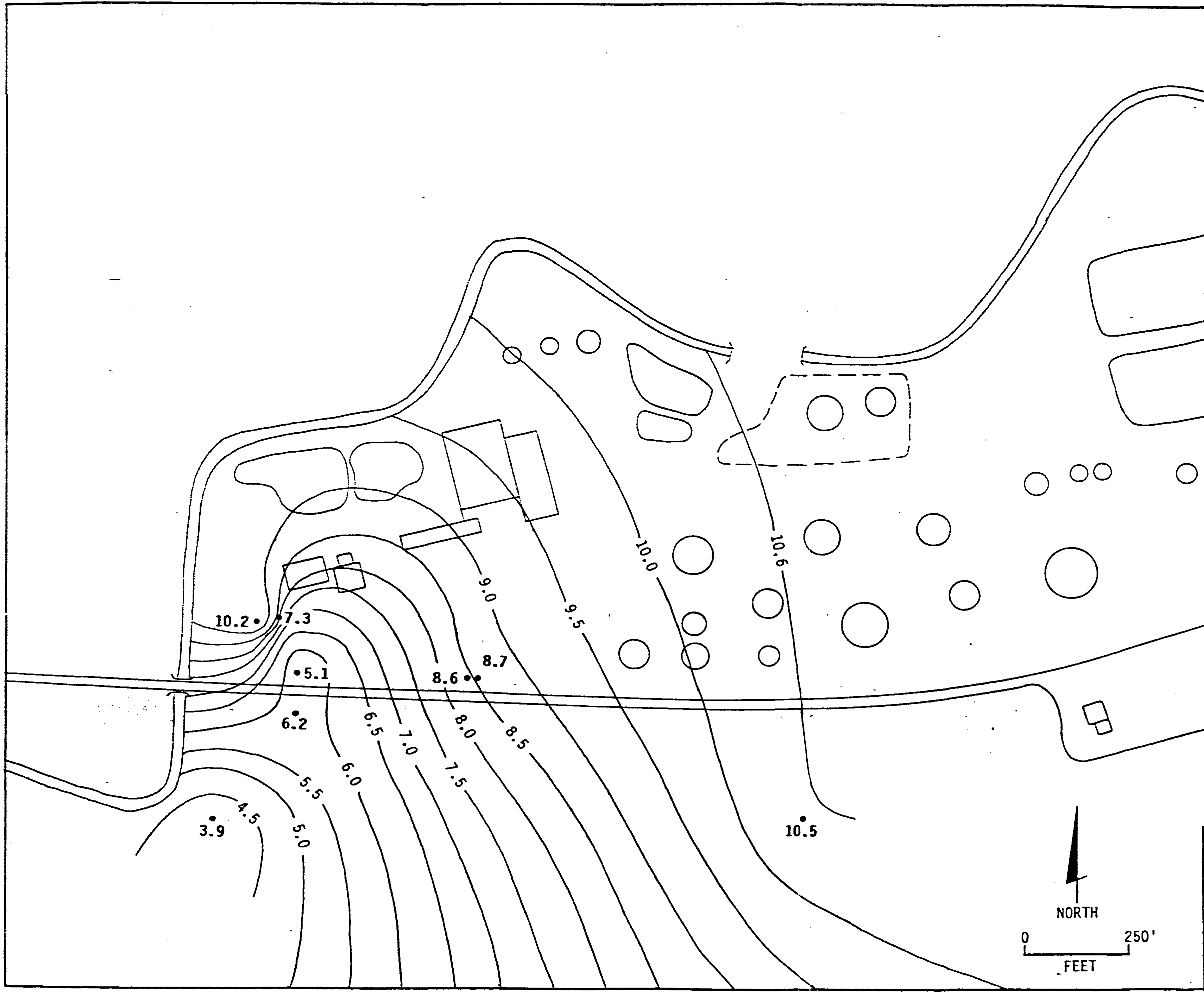


GCL

PLATE 4

PRE-RECOVERY WATER TABLE OBSERVED
ON JANUARY 4, 1989 (FEET MSL)

CLIENT: GARY
DATE: 8-1-89
DRAWN BY: MK
CHECKED BY: SD
REVISED:
SCALE: 1"=250'



GCL

PLATE 5
PRE-RECOVERY SATURATED THICKNESS OBSERVED ON JANUARY 4,1989 (FEET MSL)

CLIENT:
DATE:
DRAWN BY:
CHECKED BY:
REVISED:
SCALE:

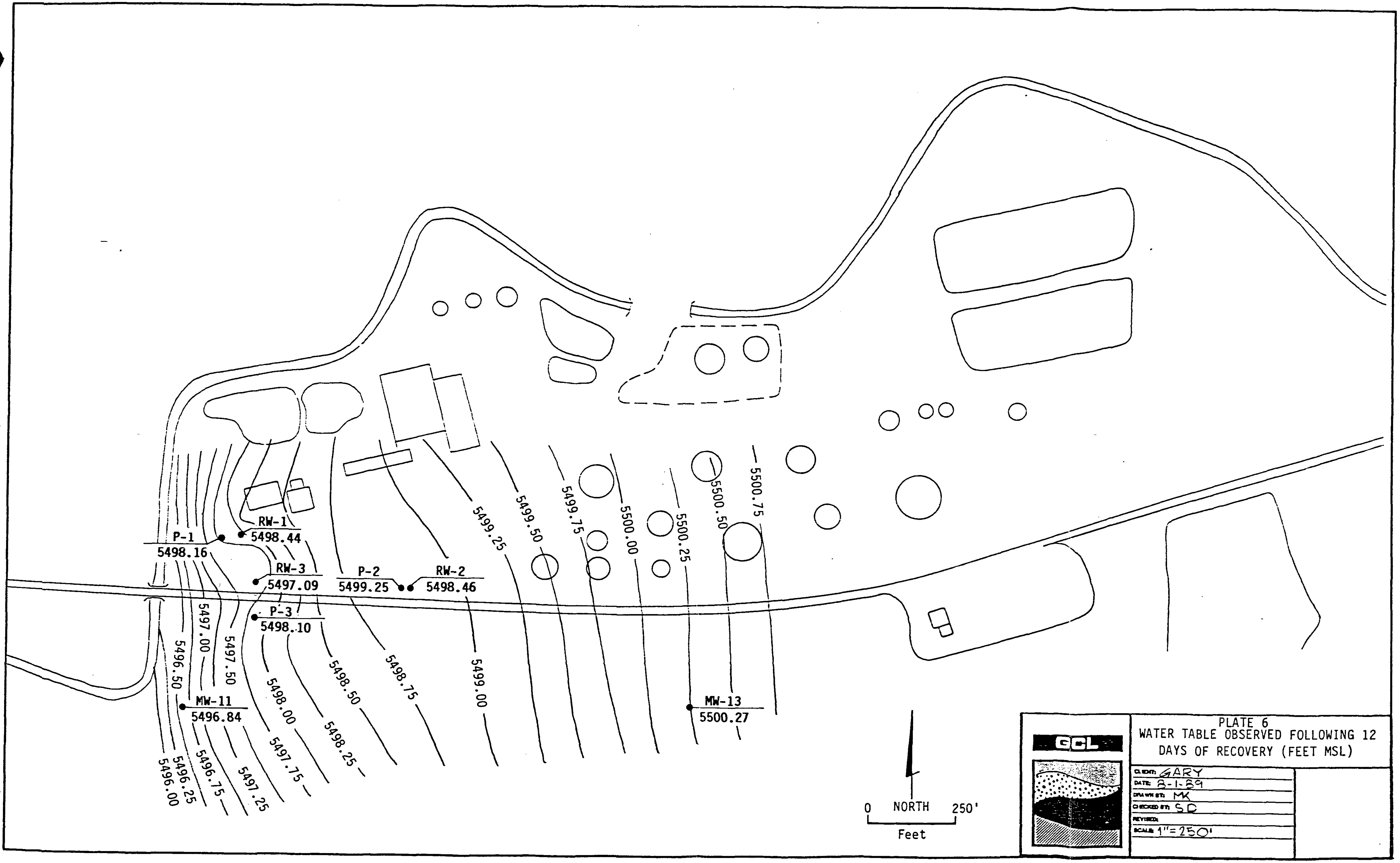


PLATE 6
WATER TABLE OBSERVED FOLLOWING 12
DAYS OF RECOVERY (FEET MSL)

CLIENT: GARY
DATE: 8-1-89
DRAWN BY: MK
CHECKED BY: SD
REVISED:
SCALE: 1"=250'

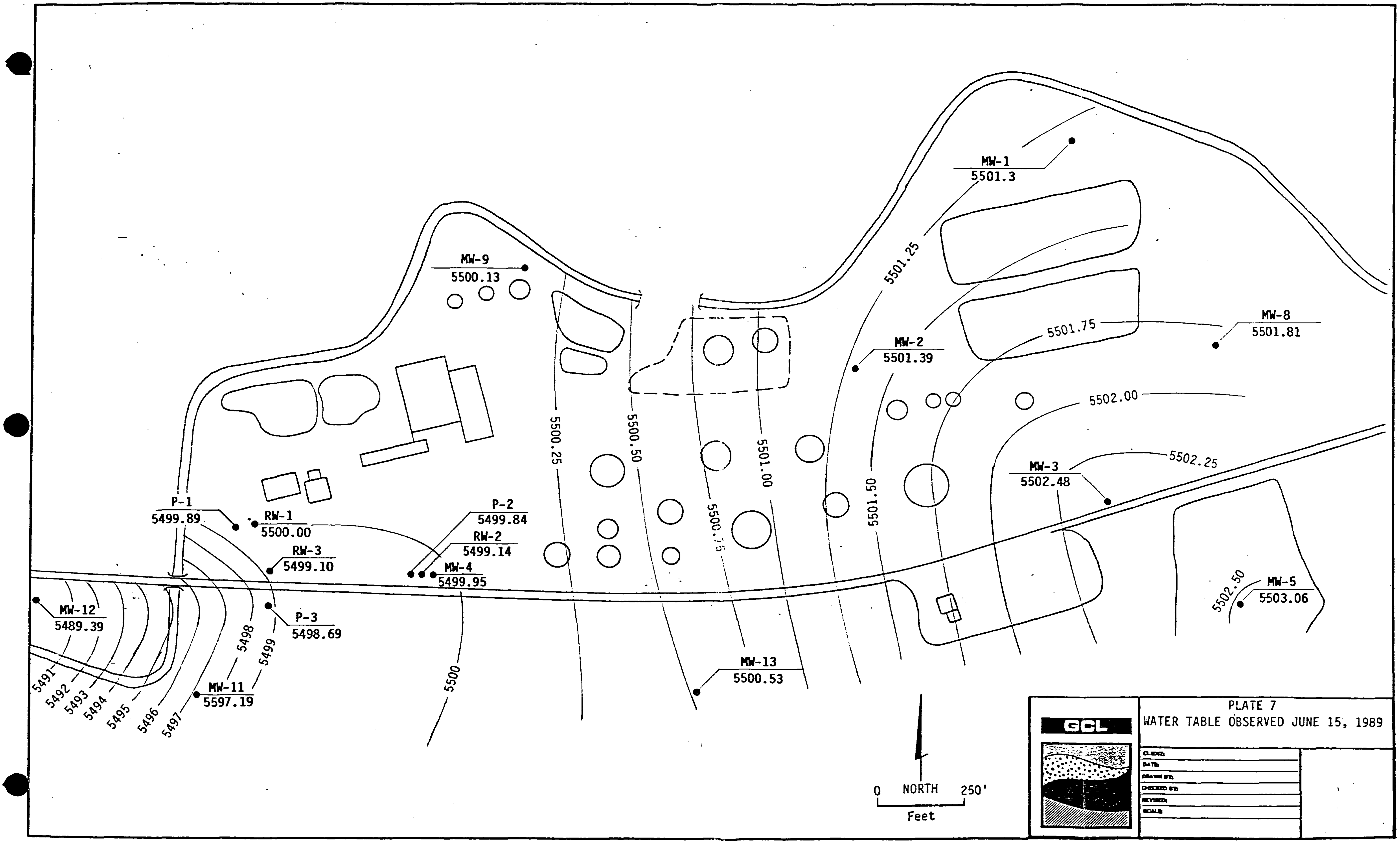


PLATE 7
WATER TABLE OBSERVED JUNE 15, 1989

CLIENT:
DATE:
DRAWN BY:
CHECKED BY:
REVISED:
SCALE: