United States
Environmental Protection
Agency

Office of Emergency and
Remedial Response
Washington DC 20460

EPA/540/2-89/054b
October 1989

Superfund

EPA

Evaluation of Ground-Water Extraction Remedies:

Volume 2. Case Studies 1-19

Interim Final

EPA/540/2-89/054b
October 1989

Evaluation of Ground-Water Extraction Remedies

Volume 2, Part 1
Case Studies 1-10

Interim Final
October 1989

Office of Emergency and Remedial Response
U.S. Environmental Protection Agency
Washington, D.C 20460

Notice

Development of this document was funded by the United States Environmental Protection Agency in part under contract No. 68-W8-0098 to CH2M HILL SOUTHEAST. It has been subjected to the Agency's review process and approved for publication as an EPA document.

The policies and procedures set out in this document are intended solely for the guidance of response personnel. They are not intended, nor can they be relied upon, to create any rights, substantive or procedural, enforceable by any party in litigation with the United States. The Agency reserves the right to act at variance with these policies and procedures and to change them at any time without public notice.

VOLUME 2

INTRODUCTION

This volume was prepared as part of an evaluation of ground-water extraction remedies completed under EPA Contract No. 68-W8-0098. It presents 19 case studies of individual sites where ground-water extraction systems have been implemented. These case studies present site characteristics and discuss factors that have influenced the success of the remedial activities.

Volume 1 is the summary report presenting the general conclusions and observations of the study. It is based on a review of general information for 112 sites where ground-water extraction systems are in various stages of planning or implementation and on the 19 more detailed case studies presented in this volume. Volume 1 describes the methodology of the study, the factors that influence the effectiveness of ground-water extraction systems, and the data requirements for the design of extraction systems.

Volume 3 presents general information on 112 sites where ground-water extraction is either planned or already in use. It includes information on the location, the geologic setting, the contamination, and the administrative status of each site.

Each of the 18 case studies written as part of this investigation is presented in two sections, the first describing the general background characteristics of the site, and the second describing the remediation. The general outline of the reports is as follows:

A. BACKGROUND OF THE PROBLEM

1. Introduction
2. Site History
3. Geology
4. Hydrogeology
5. Waste Characteristics and Potential Sources

B. REMEDIATION

1. Selection and Design of the Remedy
2. Evaluation of Performance
3. Summary of Remediation

The information in the first seven sections of each case study is presented as it was described by the authors of the source documents. Conclusions reached as a result of the review of the source documents in this study are presented in the final section summarizing the remediation.

The final case study, prepared by the Environmental Ministry of Quebec, describes the Ville Mercier site in Quebec, Canada. It does not follow the same format as the first 18 case studies.

WDCR13/036.50

LIST OF CASE STUDIES

1. Amphenol Corporation
2. Black & Decker, Inc.
3. Des Moines TCE
4. DuPont-Mobile Plant
5. Emerson Electric Company
6. Fairchild Semiconductor Corporation
7. General Mills, Inc.
8. GenRad Corporation
9. Harris Corporation
10. IBM-Dayton
11. IBM-San Jose
12. Nichols Engineering
13. Olin Corporation
14. Ponders Corner
15. Savannah River Plant A/M-Area
16. Site A
17. Utah Power & Light
18. Verona Well Field
19. Ville Mercier

WDCR13/036.50

CASE STUDY 1

Amphenol Corporation
Sidney, New York

CASE STUDY FOR THE AMPHENOL CORPORATION SITE

BACKGROUND OF THE PROBLEM

The Amphenol Corporation (formerly Bendix Corp.) operates an electrical-connector manufacturing plant in the village of Sidney, Delaware County, New York (see Figure 1). Between 1971 and 1985, wastewater from Amphenol's electroplating operations was piped to a pair of surface impoundments near the Susquahanna River, about half a mile north of the plant, where metal hydroxides were removed by precipitation. In 1983, the soil and ground water around the lagoons was found to be contaminated with several volatile organic compounds (VOCs), of which trichloroethylene was the most prevalent. After closure of the treatment lagoons and remediation of the contaminated soils, a ground-water extraction system was put into operation in January 1987 to control the migration of contaminants and restore aquifer quality. Operation and monitoring of the system, as required by the Resources Conservation and Recovery Act (RCRA), is continuing under the regulatory authority of the New York State Department of Environmental Conservation (NYSDEC).

SITE HISTORY

In 1981, Amphenol implemented a ground-water monitoring program in the area of the waste treatment lagoons to satisfy the requirements of RCRA. Figure 2 shows the location of the lagoons with respect to the river, the current monitoring-well network, and the facilities belonging to the village of Sidney. The initial round of ground-water samples, taken from wells 1 through 4 in January 1982, was analyzed for inorganics and did not indicate a problem.

In June of 1982, consultants completed a preliminary evaluation of the hydrogeologic conditions around the lagoons. This included the installation of several additional wells. A more extensive ground-water monitoring program initiated in 1983 revealed the presence of several VOCs of which trichloroethylene was the most common.

In response to the findings of this and other more recent investigations, Amphenol installed a new electroplating waste-treatment system at the main plant site and discontinued the use of the lagoons. In 1985, work on lagoon closure was initiated with removal of the accumulated precipitate sludge. It was sent to the onsite facility for treatment. The sludge was processed through a filter press and sent to a secure landfill.

In December 1985, a soil boring and sampling program was begun at the deactivated treatment lagoons to determine the degree of soil remediation that would be required. The soil boring program was completed in May 1986. Soil borings were drilled at 44 locations to an average depth of 5 to 6 feet. The resulting samples were analyzed for VOCs and metals, but only the VOCs were found to be a problem.

Soil remediation under the former lagoon areas was begun in July 1986. Soils in the areas that had been found to be contaminated with VOCs were excavated and exposed to the air to release the adsorbed volatiles. When VOC concentrations were reduced to levels that had been determined to be acceptable, the soils were returned to the lagoon area for backfilling. The soil remediation program was completed in late 1986.

In August 1986, consultants for Amphenol, submitted a corrective action plan (ERM, 1986b) calling for two recovery wells to control the migration of the contaminant plume and remove VOC contamination from the ground water. By January 1987, the wells had been installed and the ground-water remediation began. Since then, the wells have been sampled quarterly and two annual reports on the progress of the cleanup have been submitted to the NYSDEC (ERM, 1988 and ERM, 1989).

GEOLOGY

The area surrounding the Amphenol lagoons is underlain by a sequence of recent fluvial deposits and Pleistocene-age glacial and glaciofluvial deposits with a total thickness between 100 and 200 feet. The geologic logs of the wells illustrated in Figure 2 were used to create the fence diagram shown in Figure 3, which illustrates the degree of stratigraphic complexity across the site. The unconsolidated materials include silt, sand, and gravel deposits of both alluvial and glacial origin. They are generally underlain by a glacial till composed of dense silt and gravel, which lies on shale bedrock.

The thickness of these different deposits varies across the site but in general, the entire sequence of unconsolidated sediments thickens towards the river. Although none of the wells constructed for the study penetrated the entire thickness of sediments, deeper wells outside of the study area have shown the presence of a relatively flat bedrock surface at approximately 200 feet below grade.

HYDROGEOLOGY

The principal geologic unit of concern at the site is a 100- to 200-foot thick sequence of alluvial materials and underlying glaciofluvial sands and gravels. These sands and gravels comprise the aquifer from which the village of Sidney draws its potable water, using production well No. 1, shown on Figure 2.

Ground water at the site occurs under unconfined conditions in the overburden flow system. The water table is approximately 10 to 12 feet below the land surface. Forty monitoring wells, including several groups of multilevel piezometers, were installed as part of the site investigation. Data gathered from these wells indicate that flow in the system is principally horizontal.

The direction of ground-water flow is influenced by water level differences between the aquifer and the Susquehanna River, by the topography of the river's flood plain, and by pumping from the village of Sidney's production well. Because of slight differences in the response of the shallow and deep monitoring wells to pumping from the Sidney production well, a distinction is made between the shallow and deep flow zones of the aquifer. Wells that monitor the shallow zone are generally screened at depths between 10 and 20 feet. Deep zone monitor wells are screened at a depth of more than 65 feet below ground surface.

The most common ground-water flow pattern in the shallow zone is shown in Figure 4. It occurs when the water levels in the river are higher than in the aquifer and the Sidney production well is in operation. Under these conditions, increased recharge from the river near well No. 16 causes a ground-water mound to form under the former lagoon area. South of the lagoon area is a ground-water divide. East of the divide, water is drawn into the Sidney production well. West of the divide, ground-water flow follows the natural gradients to the west and northwest downstream along the Susquahanna River floodplain.

A less common flow pattern that has been observed in the shallow zone occurs when abundant recharge causes the water table to rise. The water levels in the river and the aquifer are then more nearly equal and production from the Sidney well has less influence. Shallow ground-water flow is then topographically controlled and is directed to the northwest parallel to the river. Figure 5 shows an example of such a flow pattern.

Flow in the deep zone of the aquifer may be less sensitive to seasonal variations in water level. Water levels measured during simultaneous test pumping of the Sidney production well No. 1 and the Sidney test well in January 1986, indicated that the capture zone of the production well extends farther toward the lagoon area in the deep zone than it does in the shallow zone. Figures 6 and 7 show the flow patterns generated in the shallow and deep zones, respectively, after 72 hours of pumping. The production well was pumped at 400 gallons per minute (gpm) and the test well at 800 gpm. Figure 8 shows the natural flow patterns in the deep zone, which are very similar to the normal flow in the shallow zone illustrated in Figure 4.

The results of the aquifer test conducted in January 1986 indicated transmissivities varying from 51,800 gallons per day per foot (gpd/ft) to 252,700 gpd/ft, depending on which observation well was used. This wide range of transmissivities confirms the heterogeneity of the aquifer illustrated in the fence diagram of Figure 3.

WASTE CHARACTERISTICS AND POTENTIAL SOURCES

The soil and ground-water contamination at the Amphenol site originated from leaks in the asphalt lining of the two waste-treatment lagoons. Most of the leakage occurred in the southern portion of the east lagoon. The soil under the lagoon in this area had total VOC concentrations ranging from 25 to over 1,000 parts per million (ppm). VOC concentrations beneath the other lagoon areas were generally less than 25 ppm.

The soil remediation program conducted in 1986 was designed to ensure that future leaching of VOCs from the soil would not result in VOC concentrations of greater than 5 parts per billion (ppb) in the ground water. This ground-water concentration limit was interpreted as a depth-averaged concentration for a 15-foot thickness of the aquifer. The VOC concentrations that were allowed to remain in the contaminated soil were based on laboratory partitioning experiments using soil samples taken from beneath the lagoons and a mass-balance analysis of leachate mixing in the aquifer. By these methods it was determined that total VOC concentrations in the soil had to be remediated to less than .5 ppm.

The ground water beneath and around the lagoon area was also found to be contaminated with VOCs. Figure 9 shows the contaminant plume in the shallow zone of the aquifer, as determined from measurements taken in 1985. The maximum concentration of total VOCs was 329 ppb in well 17-S. (The individual wells in the multi-well clusters are distinguished by the suffixes S for shallow, I for intermediate, and D for

deep.) Table 1 shows the concentrations of the individual volatile organics found in well 17-S in the July 1985 sample.

Table 1
VOC CONCENTRATIONS IN WELL 17-S, JULY 12, 1985

Volatile Organic Compound	Concentration (ppb)
Chloroform	125
Methylene Chloride	3
Dichlorobromomethane	5
Tetrachloroethylene	7
Trichloroethylene	192

Figure 10 is an isoconcentration map of the deep zone based on samples from the deep monitoring wells taken in 1985. The contaminant plume is a three-dimensional entity whose different parts migrate in response to the locally varying flow patterns of the ground water. As shown in Figure 10, it appears that migration in the lower portion of the plume has been primarily to the southeast toward the Sidney production well. The concentrations in the deeper zone of the plume are generally lower than in the shallower zone.

Figures 11 and 12 present cross-sectional isoconcentration maps illustrating the vertical variation of total VOCs. The locations of the cross sections are shown on Figure 9. Cross section A-A' in Figure 11 shows that the highest levels of groundwater contamination are in the shallow zone. In Figure 12, cross section B-B' shows the elongation of the plume toward the Village of Sidney's production well in the deeper part of the aquifer. There is no indication that VOC contamination has yet reached the production well in measurable concentrations.

Because of the variations observed in the sample concentrations, the highest concentration at each sample point was used to construct the plume maps shown in Figures 9 through 12. They, therefore, represent a worst-case estimate of the plume configuration.

REMEDIATION

SELECTION AND DESIGN OF THE REMEDY

Objectives of Remediation

The principal goal of the ground-water remediation system was to restore water quality in the aquifer to total VOC concentrations of less than 5 ppb. However, if experience should prove this to be impossible, Amphenol has reserved the right to petition the NYSDEC for an alternative concentration limit. A second goal of the ground-water remediation is to protect the Sidney's production wells from contamination originating at the site. Currently, the village of Sidney is operating production well No. 1, but another production well has been installed near the test well shown in Figure 2. This new well is scheduled to start operating in late 1989 (Amphenol, 1989).

System Configuration

A ground-water extraction system consisting of two recovery wells was designed to achieve the goals of the ground-water remediation. The locations of these wells, and the water levels observed in the shallow zone of the aquifer on June 27, 1988, are shown in Figure 13. Well RW-1 has a 20-foot screen set directly above the glacial till layer, which is approximately 120 feet below ground surface in that area (see Figure 12). It is intended to pump primarily from the deep zone of the aquifer and is operated at a withdrawal rate of 150 gpm. Well RW-2 is approximately 25 feet deep and is intended to capture the more highly contaminated ground water in the shallow zone of the aquifer. Its withdrawal rate has averaged around 57 gpm.

The locations and pumping rates of the two extraction wells were selected with the help of analytical computer models of ground-water flow in the aquifer. Flow models were set up and calibrated to match the observed potentiometric head distributions in the aquifer. The results of the January 1986 aquifer test were used to guide the assignment of aquifer properties in the model. Computer simulation of the aquifer test was also performed as a means of verifying the model setup. The calibrated model was then used to predict the capture zones of proposed recovery wells under differing operating conditions of the village of Sidney production wells.

The ground-water flow models were also used to estimate the time required for aquifer remediation. This was done without contaminant transport modeling by calculating the approximate travel time along streamlines connecting the

recovery wells to the hydraulically most remote edges of the contaminant plume. The effects of contaminant sorption were accounted for by assuming that removal of several pore volumes in the outer reaches of the plume, and more than 10 pore volumes in the high-concentration areas, would be necessary to reduce VOC concentrations to less than 5 ppb. The estimated duration of the recovery period was 5 to 10 years.

The contaminated water produced by the extraction system is treated by air stripping before being discharged to the Susquahanna River.

The progress of the ground-water remediation system is monitored quarterly by sampling selected monitoring wells. During 1987, the first year of ground-water extraction, 17 monitoring wells were included in the quarterly sampling program. However, several of these wells consistently showed concentrations below detection limits, and in 1988 only 12 wells were sampled quarterly.

EVALUATION OF PERFORMANCE

Within a few days after the startup of the ground-water extraction wells in January 1987, ground-water divides had been established in both the shallow and deep zones of the aquifer. An essential element of the extraction system design was to position these flow divides to prevent migration of the contaminant plume to the Sidney production wells. Quarterly water-level monitoring conducted since the system has been in operation has shown that the location of the ground-water divides moves in response to changes in recharge and fluctuation of the river water levels. Most monitoring rounds have shown the divides to be located between the plume and the production wells, as intended. Figures 13 and 14 show the water levels measured in the shallow and deep zones, respectively, on June 27, 1988. Comparison with the plume maps in Figures 9 and 10 suggests that the desired control over plume migration was being achieved at that time. No plume maps have been presented showing the location of the contaminant plume since 1985. However, the analytical results for ground-water samples taken in 1987 and 1988 indicate that the VOC concentrations in the vicinity of the flow divides are below detection limits.

Figures 15, 16, and 17 show the history of total VOC concentrations in three monitoring wells in the shallow aquifer zone. Also shown on these figures are the approximate times when the lagoons were drained, the soil remediation was completed, and the extraction was begun. For all three of these wells, the highest VOC concentrations were measured

while the lagoons were still in use. Before the start of ground-water extraction, the concentrations exhibited strong fluctuations. The time series data suggest that these fluctuations may be seasonal, but sampling has not been frequent enough to allow this to be firmly established. After the start of extraction, the concentrations appear to fluctuate much less.

In general, there has been a considerable decrease in concentrations over the period of record. In wells 1-S and 17-S, the beginning of the decline seem to have coincided with the closure of the lagoons. In well 2, there seems to be a systematic decline in the VOC concentrations even before the lagoon closure, but this may be just a reflection of the natural changes in ground-water flow directions. Since the completion of soil remediation and the start of ground-water extraction, the decline in concentrations has continued. In all three wells there was a sharp reduction in concentrations near, or shortly after, the start of extraction. This sharp reduction was followed by a more gradual decrease in the concentration in each well. Well 1, which is located nearest to the origin of the plume showed the slowest rate of concentration decline. The total VOC concentration at well 2 was reduced below the remediation goal of 5 ppb in October 1987, and the well was then dropped from the monitoring program.

Figure 18 shows the record of total VOC concentrations for well 1-D, which is screened in the deep zone of the aquifer. VOC concentrations in the other monitoring wells in the deep zone have either been reduced below detection limits or are fluctuating at levels close to the cleanup goal. Since the closure of the lagoons in late-1985, the concentration record for well 1-D has been characterized by a general declining trend punctuated by an occasional slight increase.

SUMMARY OF REMEDIATION

The ground-water extraction system has been in operation at the Amphenol site since January 1987. The system was designed to prevent migration of the contaminant plume to the Sidney wells and to restore aquifer quality by reducing total VOC concentrations to less than 5 ppb. It was estimated that aquifer restoration would require 5 to 10 years.

Water level monitoring indicates that the two extraction wells do seem to capture the contaminant plume under most conditions. However, the flow patterns in the aquifer are strongly influenced by river levels and seasonal recharge rates. There may be limited periods during the year when these influences modify the capture zones of the extraction wells so that the plume is not hydraulically controlled.

These periods are probably short enough so that no appreciable amount of contamination migrates away from the long-term capture zone.

The records of total VOC concentration in the monitoring wells close to the former contaminant source show a general decline toward the aquifer restoration goal. Much of this decline took place before ground-water extraction was started. The removal of wastewater from the treatment lagoons in late 1985 seems to have initiated the decline in concentrations. Remediation of the contaminated soils and the start of ground-water extraction coincided with a temporary acceleration of concentration reduction in early 1987. Since then, the rate of decline has decreased. The concentration records appear to be consistent with the initial projection of a 5- to 10-year remediation period.

BIBLIOGRAPHY

Amphenol. May 22, 1989. Personal communication with Mr. Wayne Barto, P.E., of Amphenol Corporation.

Environmental Resources Management (ERM). February 19, 1985(a). Letter to Henry Mitchell of Bendix Corp.

ERM. November 1985(b). Preliminary Report: Groundwater Assessment at Amphenol Wastewater Treatment Lagoons for Amphenol Products--Bendix Connector Operations, Sidney, NY.
ERM. June 1986(a). Addendum Report: Groundwater Assessment at Amphenol Wastewater Treatment Lagoons for Amphenol Products--Bendix Connector Operations, Sidney, NY.

ERM. August 27, 1986(b). Corrective Action Plan for the Amphenol Wastewater Treatment Lagoons, for Amphenol Products--Bendix Connector Operations, Sidney, NY.

ERM. June 13, 1988. Annual Groundwater Monitoring Report for 1987, Amphenol Corporation, Bendix Connector Operations, Sidney, NY.

ERM. March 22, 1989. Annual Groundwater Monitoring Report for 1988, Amphenol Corporation, Bendix Connector Operations, Sidney, NY.

United States Geological Survey. 1982. Sidney Quadrangle, 7.5 minute topographic series.

WDCR435/013.50

CASE STUDY 2

Black & Decker
Brockport, New York

CASE STUDY FOR THE BLACK & DECKER SITE

BACKGROUND OF THE PROBLEM

The former Black & Decker industrial facility is located in Brockport, Monroe County, New York. The manufacturing plant produced appliances, generating as by-products, electroplating sludges and metal-plating wastewaters. Until 1985, treated wastewaters were discharged to onsite surface impoundments for removal of solid materials by settling. Settled solids were transferred to a sludge drying bed for further dewatering (see Figure 1). Interim status monitoring wells were installed to meet Resource Conservation and Recovery Act (RCRA) requirements. After volatile organic compounds (VOCs) were found in several of the monitoring wells, a ground water quality assessment program was conducted at the facility in 1985 and 1986. As a result of the assessment, a volatile organic plume was identified within the bedrock aquifer, which underlies 15 feet of glacial till. Investigations revealed the source of contamination to be chlorinated organic solvents used in degreasing activities. The corrective action involves ground-water recovery from a single well located in an artificially-produced fracture zone. The first phase of the program, initiated in March 1987, involved the creation and testing of the fracture zone. Long-term remediation was initiated in May 1988. However, due to system control problems, continuous operation of the extraction and treatment system did not begin until October 1988. It has been operating on a nearly continuous basis since that time.

SITE HISTORY

The Black and Decker facility is a RCRA treatment, storage, and disposal facility (TSDF) operating under interim status regulations. In compliance with RCRA requirements, groundwater wells were installed under the direction of the New York State Department of Environmental Conservation to monitor for heavy metals contamination. Monitoring data indicated that no heavy metal contamination had occurred. However, statistical analyses of collected data indicated a probability of ground-water contamination. In response to this statistical prediction, additional ground-water monitoring was conducted in 1985 and 1986. The new monitoring data revealed the existence of a volatile organic contamination plume in the bedrock aquifer. Further investigations determined that the chlorinated organic compounds used in degreasing activities were the cause of the contamination.

GEOLOGY

The topography of the site and the surrounding area has minimal relief. It slopes gently to the north, toward a barge canal. Unconsolidated deposits in the study area consist of 5 to 20 feet of Lake Woodfordian sandy glacial till overlying approximately 50 feet of consolidated Medina sandstone (Grimsby member) of early Silurian age (see Figure 2). Underlying the sandstone are several hundred feet of Upper Ordovician Queenston shale. The regional bedrock dip is toward the south at approximately 50 feet per mile.

HYDROGEOLOGY

The water table is typically 4 to 8 feet below ground surface. The ground-water flow system consists of two hydraulically interconnected aquifers--an unconsolidated overburden aquifer and a deeper sandstone bedrock aquifer. These two aquifers are composed of different geologic material and have different ground-water flow properties.

Ground-water flow is predominantly to the northwest across the site toward the New York State Barge Canal with an increasing gradient to the north in response to the topography. There is generally a downward gradient between the two aquifers and within the bedrock. Based on in situ permeability tests performed at the site, the average hydraulic conductivity of each of the aquifers is approximately the same, 0.8 ft/day (2.8×10^{-4} cm/sec). In this relatively flat area, localized reversals in the direction of ground-water flow have been observed as a result of variations in recharge and evapotranspiration rates. Examples of these reversals have been observed between Wells GEB-6S and GEB-4S and between Wells GEB-18S and GEB-9S (see Figure 1).

Ground-water flow within the overburden is assumed to be predominantly through intergranular pores. Based on hydraulic conductivity values, water-level data, and an estimated effective porosity of 10 to 20 percent, the average linear rate of ground-water flow within the overburden aquifer ranges from 0.04 to 0.26 ft/day. The overburden flow system is more variable in the southern portion of the site, primarily because of the distribution of recharge, which is controlled by site features such as building, paved areas, slopes, and vegetation. Figure 3 shows ground-water elevation contours for the overburden aquifer.

Ground-water flow within the Medina sandstone occurs predominantly through secondary porosity openings such as fractures, joints, and bedding planes. Intergranular flow is judged to be minimal. Because of the nature of fracture flow in the sandstone, the ground-water flow rate varies

considerably between individual fractures, making accurate calculations of flow velocities and travel times almost impossible. Definition of the nature of ground-water flow in the bedrock has required more monitoring wells than in the overburden, including monitoring well clusters. Based on hydraulic conductivity values, water-level data, and an estimated effective porosity of 5 to 15 percent, the average linear rate of ground-water flow within the bedrock aquifer is expected to range from 0.043 to 0.31 ft/day. Figure 4 shows the ground-water elevation contours for the bedrock aquifer.

Several studies were performed to more fully understand the nature of ground-water flow within the bedrock. These studies included: fracture trace analysis using historic aerial photographs, joint orientation and frequency analysis based on a nearby outcrop, correlation of onsite rock core data, and the evaluation of geologic data collected from tunnels located approximately 20 miles from the site. Two major sets of nearly vertical fractures were found to exist within the Medina sandstone: a northwest-trending set and a northeast-trending set. Site-specific data were insufficient to determine the spacing and hydrogeologic characteristics of the fractures and bedding planes. In addition, no major fractures for recovery well installation were identified through these studies.

WASTE CHARACTERISTICS AND POTENTIAL SOURCES

Significant concentrations of two compounds were identified in the ground water. They include trichloroethylene (TCE) and 1,1,1-trichloroethane, and their degradation by-products, 1,2-dichloroethlyene and vinyl chloride. Contaminant levels were highest in the bedrock aquifer, with TCE concentrations detected at levels far exceeding those of other contaminants.

Primary consulting engineers have stated that it is not possible to calculate the actual release of the contaminants to ground water based on existing site records. However, to comply with a request from the New York State Department of Environmental Conservation (NYSDEC), an estimate was calculated based on previously prepared iso-concentration maps. The primary consulting engineers described the numbers they generated as "meaningless" for evaluating the ground-water corrective action measures. Table 1 lists the consulting engineers' estimates of the dissolved mass of the contaminants.

Table 1
ESTIMATES OF CONTAMINANT MASS DISSOLVED IN GROUND WATER

	Overburden Aquifer	Bedrock Aquifer	Total Dissolved Mass
TCE	66 lb (5.4 gal)	1,300 lb (106 gal)	1,366 lb (111 gal)
1,2-DCE	69 lb (6.5 gal)	150 lb (14 gal)	219 lb (20.5 gal)
Vinyl Chloride	16.5 lb*	0.46 lb*	17 lb*
1,1,1-TCA	1.19 lb(0.105 gal)	19 lb (1.7 gal)	20 lb (1.8 gal)

*Vinyl chloride is a gas at room temperature.

Figure 5 shows a contour map of TCE concentrations prior to the startup of the extraction system. The primary consulting engineers have cautioned that this figure is a generalized simplification of average TCE concentrations. It does not account for variations in concentration within individual fractures. Individual fracture data was thought to be too difficult to obtain.

The ground water was contaminated by releases from the waste management area, located southeast of the manufacturing plant. This unit consists of six surface impoundments, for separating solids from process wastewaters, and one sludge drying bed for dewatering of the settled solids. Operations at the waste management area stopped in 1986 and 1987. Other disposal practices thought to contribute to organic contamination were terminated by 1987. The contaminant plume is migrating toward the northwest in accordance with ground-water flow.

Although supporting documentation is lacking, there may have been secondary releases to ground water that contributed to contaminant levels in the bedrock. These secondary releases include: release of contaminated wastewater through a sump liner which was excavated into bedrock; seepage of contaminants through leaking floor drains and associated piping located near the existing and former degreasers; spills during handling of drums of solvent stored behind the manufacturing building; and leakage of cooling fluids used for industrial air conditioning.

REMEDIATION

SELECTION AND DESIGN OF THE REMEDY

Objectives of Remediation

The primary objective of the remediation is to restore water quality in the overburden and sandstone bedrock aquifers to health-based standards. Cleanup criteria for the contaminants detected in the ground water were developed based on New York state standards (Title 6, Chapter X, Part 703.5) or federal Safe Drinking Water Act (SDWA) Maximum Concentration Limits (MCL), whichever was more stringent. The following table lists the cleanup levels for the four contaminants of concern.

Table 2
REMEDIATION TARGET CONCENTRATIONS

Compound	Limit	Source
TCE	5 ug/l	SDWA MCL
1,2-DCE	50 ug/l	NYS guidance value
Vinyl chloride	2 ug/l	SDWA MCL
1,1,1-TCA	200 ug/l	SDWA MCL

In conjunction with this primary objective, an additional requirement of the extraction system is that it be capable of effecting hydraulic capture of the ground water within the contaminated region.

Testing of the Initial Recovery Well

A recovery well system was initially selected as the remedial alternative. A 72-hour aquifer test was performed in March 1987 prior to the design of the recovery system. This test was performed to further investigate the hydrogeologic characteristics of the bedrock aquifer.

For the test, a recovery well, Well RW-1A was positioned downgradient of the facility in the centerline of the plume (see Figure 1 for location). It was installed 25 feet into bedrock at a total depth of 40 feet. Ground water was pumped at a set rate of 3.4 gpm, treated using an air stripper and carbon adsorption unit, and discharged to the canal north of the site.

Test data revealed that delineation of the capture zone would be extremely difficult, and that the installation of additional recovery wells would not be a cost-effective approach to creating a well-designed capture zone. Irregular responses of individual wells were observed within clusters 31 and 32 (see Figure 1 for location). This irregularity was thought to be a result of the complexity of the three-dimensional capture zone created by pumping within the fractured bedrock aquifer. Observations revealed that individual bedrock monitoring wells generally were hydraulically poorly interconnected. No response to pumping was observed in any monitoring well located upgradient of Recovery Well RW-1A. The single recovery well that was installed and tested was found to be inadequate to prevent further migration of the contaminant plume.

System Configuration

Several options for creating an effective capture zone were explored. The first approach was to increase the number of fractures intersected by individual recovery wells either by angle drilling or by artificial fracturing of the rock. On-site and regional data indicated that the fracture geometry necessary to support angle drilling did not exist at the Black and Decker site. In addition, the shallow overburden at the site could not support conventional hydraulic or explosive fracture production techniques.

The second option was to interconnect all the fractures transporting the contaminants by creating a single, artificial fracture oriented perpendicular to the direction of ground-water flow, and then extracting the contaminated ground water in this artificial fracture using one or more extraction wells. The primary consulting engineers postulated that this artificial fracture method, produced by the controlled use of explosives, would prevent further migration of the plume and draw back contaminated ground water downgradient of the zone. However, there was concern that a single fracture might not produce complete interconnection across the path of ground-water flow. Also, there was doubt that the fracture aperture would be sufficient to produce the yield necessary for complete plume capture.

To overcome these concerns, a method was designed to create a thoroughly fractured zone several feet wide within the upper 25 feet of rock. There were several advantages to creating an enhanced fracture zone. First, verification of contaminant capture would become easier because the recovery wells would be directly connected to fractures along the entire cross section of the fracture zone. Verification would thus be reduced to assessing the extent of the capture zone downgradient and on either end of the fracture zone.

Second, there would be substantial savings in operation and maintenance costs because fewer wells would be required to achieve remedial goals. Last, the method would permit higher pumping rates which could result in a faster aquifer remediation.

The fracture zone was positioned perpendicular to the direction of ground-water flow and centered near the leading edge of the contaminant plume. Fracturing was restricted to the upper 25 feet of rock because contamination was not detected below that depth. Shot holes for the explosives were spaced 4 to 5 feet apart. In May 1987, the charges were detonated progressively from the bottom of the holes upwards. Ground water spouted from the previously blasted holes for several seconds after each blast. This spouting demonstrated the high degree of hydraulic interconnection that had been created between blast holes. Fractures were not expected below the bottom of the shot holes because of the positioning of the explosives and the detonating sequence.

A 72-hour aquifer test was performed in Well RW-1A in June 1987, one month after the blasting program was completed. For comparative analyses, efforts were made to simulate, as closely as possible, the conditions of the pre-fracturing aquifer test.

For the test, ground water was pumped at 18.5 gpm, compared with 3.4 gpm in the prefracture, 72-hour aquifer test. The water level in the recovery well dropped a total of 11.2 feet during the 72-hour pumping period. To verify the continuity of the induced fracture zone, three observation wells were installed at the ends of the zone. Two of these wells, OW-1 and OW-2, were installed at the east end of the fracture, with OW-1 screened in the upper half of the fracture zone and OW-2 screened in the lower half of the fracture zone. The pair of wells was necessary to verify that the entire vertical section of the rock was thoroughly fractured. Well OW-3, located in the western edge of the fracture zone, was installed to monitor the drawdown at the opposite end of the fracture.

Nearly identical drawdowns were observed in Wells OW-1, OW-2, and OW-3. Final drawdown elevations differed by less than 0.4 feet between the recovery well and the three observation wells in the fractured zone. The fact that elevations were similar in all observation wells confirmed the high degree of interconnection created by the fracturing. More than 3 feet of drawdown occurred in 12 of the 15 observation wells. Post-fracturing drawdowns ranged from a minimum of 1.6 feet in Well GEB-28BS to a maximum of 11.2 feet in Well GEB-31BD. In contrast, during the prefracturing aquifer test, only three of those same 15 wells exhibited

drawdowns of more than 3 feet. At the conclusion of this test, the consulting engineers determined that only one recovery well, Well RW-1A, was required to accomplish remedial goals using this technique.

EVALUATION OF PERFORMANCE

The long-term ground-water extraction and treatment system operated from May through October 1988 on an irregular basis as a result of start-up system testing and problems associated with the recovery well controls. The control problems were corrected in October 1988 and the system has been operating on a nearly continuous basis since that time.

Hydraulic Capture

Water levels obtained in March 1988 and November 1988 are considered representative of pre- and post-pumping conditions, respectively. Potentiometric surface maps for the overburden and bedrock aquifers have been prepared for these two dates and are presented in Figures 6, 7, 8, and 9. It is interesting to note from Figures 6 and 7 that the artificial fracture zone did not lead to any perturbations in the contour lines, as might be expected near a highly transmissive zone at an angle to prevailing gradients.

As shown in Figures 8 and 9, the ground-water flow in the overburden and bedrock aquifers has been distinctly altered as a result of pumping. By dewatering the upper section of the bedrock in the area of the fracture zone, downward flow has been induced from the overlying overburden aquifer. Figures 7 and 9 show the potentiometric head in the bedrock aquifer prior to and after testing in March 1988 and November 1988, respectively. In the March 1988 bedrock aquifer contour map (see Figure 7), a component of flow to the east was evident in the vicinity of the surface impoundments and sludge drying bed (waste management area). Primary consulting engineers speculated that the eastern component of flow may have been caused by higher recharge to the bedrock aquifer in a localized area near the closed waste management area. This accelerated recharge would create a potentiometric head mound in this area and cause ground water to flow radially outward from this mound. This condition may be the cause of the contamination observed in GEB-24B and 25B. Black & Decker's engineers anticipated that this mounding condition would be affected by changes in ground-water flow in this area due to ground-water extraction. This eastward component of flow was not observed in the November 1988 contour map (see Figure 9). The shallow depth to bedrock in this area may be partially responsible for the increased bedrock recharge. It has not been determined if long-term pumping at the fracture zone will affect the

presence of the eastern component of ground-water flow observed within the bedrock.

An unusually low overburden water level is depicted in Figure 8 at Well GEB-20S. This low water level affects the potentiometric surface contour map. Although unexplained, this well has displayed similarly low water levels on previous occasions, including during pre-pumping conditions.

The rate of ground-water flow within the overburden aquifer increased from a range of 0.047 to 0.093 ft/day during pre-pumping tests in March 1988, to a range of 0.13 to 0.26 ft/day during post-pumping testing in November 1988. This increase is caused by higher hydraulic gradients. The rate of ground-water flow in the bedrock aquifer under pumping conditions was expected to be similar to the rate under pre-pumping conditions. However, higher velocities were observed in the vicinity of the fracture zone, which acts as a discharge zone, because of increased hydraulic gradients.

Contaminant Plume Reduction

The extent of the capture zone that was created in the overburden is difficult to assess because only two overburden wells, GEB-30S and GEB-32S, are located in the immediate vicinity of the fracture zone (see Figure 8). The capture zone created by pumping in the bedrock at Recovery Well RW-1A appears to extend a significant distance on both sides (northwest and southwest) of the fracture zone (see Figure 9). Monitoring Well GEB-28BS is the only one of the 15 bedrock wells that is not responding significantly to pumping (see Figure 9). Well GEB-28BS monitors the lateral extent of contamination. It is the most contaminated well within its cluster. As a result of Well GEB-28BS's poor response, Black & Decker is in the process of confirming if the well was properly completed or the width of the capture zone has been defined adequately.

Water-level measurements obtained at the intermediate bedrock (BI) and deep bedrock (BD) wells in clusters GEB-28, GEB-29, GEB-30, GEB-31, and GEB-32 demonstrate a greater response to pumping than the shallow bedrock wells portrayed in Figure 9. At these greater depths, the primary consulting engineers concluded that the capture zone is expected to extend well beyond these wells.

Reductions in Mass and Concentration of Contaminants

Ground water samples were collected four times in 1988 to analyze for changes in ground-water quality: March 1988, June 1988, August 1988, and November 1988. The samples were analyzed for VOCs by EPA Method 601. For each sampling

event, a core group of 15 wells was sampled. Five wells represent the areas of poorest ground-water quality in the bedrock without regard to depth. These monitoring wells are located immediately downgradient of, or lateral to, the fracture zone. The other ten wells were positioned at a variety of locations for general site coverage. In all cases, sampling levels were recorded as the maximum concentrations detected in a particular well cluster.

According to the primary consulting engineers, no significant changes in VOC concentrations have been observed at the site, and no further expansion of the plume is believed to have occurred since implementing remedial measures. The concentrations of the VOCs of concern at the site were found to be typical of concentrations observed during pre-pumping conditions. Results from the wells assessing the lateral extent of contamination--GEB-12B and GEB-15B--continued to show low levels of VOCs with no trend toward higher concentrations. Wells monitoring the eastern extent of contamination--GEB-24B and GEB-25B--have demonstrated no increase in VOC concentrations. The primary consulting engineers reported that wells monitoring the centerline of the plume--GEB-18S, GEB-18B, GEB-23S and GEB-23B--have similarly demonstrated no increase in VOC concentrations (see Figure 10). However, sampling data indicate some decrease in absolute concentration levels (see Figures 11 and 12). No VOCs were detected in Well GEB-26B, the background well for the bedrock aquifer. Sporadic low levels of VOCs were observed in Well GEB-21S (see Figure 8 for location), the background well for the overburden aquifer.

Wells GEB-28BS, GEB-29BD, GEB-30BI, and GEB-31BI represent the most contaminated wells of their respective clusters. As such, these wells are used to evaluate the effectiveness of the pumping program. VOC concentrations at many of these wells decreased markedly during 1988 as a result of the pumping. Several of these wells experienced an increase in VOC concentrations as a result of the fracture interconnection achieved by the blasting process. As expected, reductions in VOC concentrations were noted after a relatively short period of continuous pumping. A summary of the effects of pumping on the concentrations of TCE in a well downgradient of the recovery well is presented in Figure 13.

A change in chemical ratios has been observed at Wells GEB-32BD, GEB-28BI, and GEB-28BD (see Figure 9). At each of these wells, decreases in TCE concentrations have been coupled with increases in DCE. A definitive explanation for this occurrence has not been presented by Black & Decker's consulting engineers.

SUMMARY OF REMEDIATION

Preliminary remedial investigations revealed the presence of a fractured bedrock system contaminated with volatile organics, primarily TCE and 1,1,1-TCA. Recovery of ground water in this type of fractured system is difficult because of the inability to adequately characterize the discrete fractures through which the contaminants may be migrating. Difficulties also arise in properly positioning wells and verifying the performance of the system.

An artificial fracture system that increased the interconnection between natural fractures was produced using explosives. The fracture zone was oriented perpendicular to the direction of ground-water flow. Contaminated ground water is withdrawn from the fracture zone using one extraction well. This fracture zone is thought to be preventing further migration of the plume and to be drawing back ground water downgradient of the fracture zone. Problems associated with verification of the capture zone are minimized using this technique. The verification method requires that only the extent of the capture zone downgradient and on either end of the fracture zone be assessed. Remedial cost savings were realized based on the primary consulting engineer's findings that only one recovery well would be required to attain cleanup criteria for the site.

The long-term ground-water extraction and treatment system, although initiated in May 1988, did not begin continuous operations until October 1988. Black & Decker's consulting engineers concluded in March 1989 that no significant changes in VOC concentration have been observed, and that no further expansion of the plume has occurred to date. They recommended a follow-up report on contaminant reduction in March 1990.

BIBLIOGRAPHY

Begor, K., M. Miller, and R. Sutch. February 1989. Creation of an Artificially-Produced Fracture Zone to Prevent Contaminated Ground-Water Migration. Ground Water. Volume 27, No. 1.

Dunn Geoscience Corporation. Interim Status Period Ground-Water Monitoring Data.

Dunn Geoscience Corporation. 1988. Remedial System Performance Monitoring Plan.

Dunn Geoscience Corporation. March 1988. RCRA Annual Ground-Water Monitoring Report.

WDCR25/013.50

CASE STUDY 3

Des Moines TCE
Des Moines, Iowa

CASE STUDY FOR THE DES MOINES TCE SITE

BACKGROUND OF THE PROBLEM

The Des Moines TCE Superfund Site is located in south central Des Moines, Iowa, in an industrial area bordering the Raccoon River. The site encompasses the Des Moines Water Works (DMWW) plant, a meander of the Raccoon River, and the facilities of the DICO Corporation (see Figure 1). The site is referred to as the Des Moines TCE site in recognition of its primary contaminant, trichloroethylene (TCE).

The Des Moines Water Works is the major source of municipal water for the City of Des Moines and surrounding communities. As such, it serves a population of over 260,000 people. The DMWW is surrounded on its east, north, and west sides by a loop of the meandering Raccoon River. The facility draws 12 to 15 million gallons per day from a production system consisting of 3 to 5 miles of horizontal infiltration galleries running roughly parallel to the Raccoon River both north and south of the DMWW. The contamination originating from the DICO plant has forced the shutdown of part of the north gallery system, but the south gallery remains in operation. The site is administered by the EPA under the Superfund program.

SITE HISTORY

A contamination problem at this site was first detected in 1974 when a sample of ground water at the DMWW was found to contain TCE. It was later determined that the contaminated water was entering the system through the north gallery, but pumping of the north gallery continued pending further study. In 1978, a sample of ground water taken from a DICO well contained 2,400 ppb TCE. In response to this, the EPA installed a system of six well points west of the DICO buildings in 1978, and continued to sample these well points through 1980. Because these well points consistently showed the presence of volatile organic compounds, an EPA Field Investigation Team study was conducted from 1980 to 1983 during which 11 monitoring wells were installed in the surficial aquifer. In 1984, the site was listed on the National Priority List. The DMWW ceased pumping from the north gallery in April 1984. A remedial investigation/ feasibility study took place from 1984 to 1986 to further assess the areal extent and seriousness of contamination at the site and to suggest possible remedies. In response to the Operable Unit Feasibility Study finalized in 1986, a system of seven recovery wells located west and northwest of the DICO facility was installed in 1987. Full operation of the remediation system began on December 17, 1987.

GEOLOGY

The study area is underlain by 40 to 60 feet of unconsolidated silts, clays, sands, and gravel of glacio-fluvial origin deposited during the last million years. These surficial deposits can be divided into two layers. The upper layer consists of an average of 10 feet of silt and clay overbank deposits of river origin. These sediments are underlain by the second layer consisting of very fine to fine sands and gravel. The percentage of silts and clays in the second layer is less than 10 percent (AWARE, November 1988). It is this layer of unconsolidated sands and gravels that is contaminated with organic solvents, particularly in the lowest 10 feet. Both surficial layers are laterally extensive throughout the site.

These surficial layers are underlain by the consolidated shale, siltstone, and sandstone layers of the Cherokee Group of Pennsylvania age. The Cherokee Group is 380 feet thick at the site.

Below the Cherokee Group are Mississippian to Cambrian age consolidated formations of limestone, dolostone, sandstone, and shale. These formations are over 1,500 feet thick.

HYDROGEOLOGY

There are three main aquifer systems in the consolidated Mississippian to Cambrian bedrock formations mentioned above. These systems, in order of decreasing depth, are: (1) Cambrian to Ordovician formations, including the St. Peter sandstone, the Prairie du Chien dolostone, and the Jordan sandstone; (2) Devonian limestone; and (3) Mississippian limestone and dolostone formations. The Cambrian to Ordovician aquifers are important water producers in this area. The regional flow direction of these three systems is south to southeast. Each of these three major aquifer systems is separated by a shale aquiclude and all contain ground water under confined conditions. The vertical hydraulic gradients between the bedrock aquifers are moderate and would tend to induce downward flow. However, the presence of the thick, low permeability shales ($K=5.2 \times 10^{-9}$cm/sec) of the Cherokee Group make it highly unlikely that the bedrock aquifers will be contaminated by the shallow contamination at the Des Moines TCE site.

The water level in the unconfined surficial sand and gravel aquifer ranges from about 10 to 25 feet below the land surface at the site, depending on location and conditions. In the absence of pumping, the regional gradients and directions of flow are south to southeast. The Raccoon River and

the surficial aquifer are hydrologically interconnected. The relative direction of flow between the river and the aquifer is variable and depends on river flood stage and ground-water elevations. The natural ground-water flow directions are strongly influenced by the pumping of the DMWW horizontal infiltration galleries and by pumping of the recovery wells that have been operating since December 1987 as part of the site remediation. The hydraulic conductivity of the surficial aquifer has been estimated by aquifer tests to be 3,000 to 5,000 gpd/ft^2, which is high enough to allow for pumping effects to be felt at comparatively large distances (AWARE, 1986). Vertical gradients in the surficial aquifer are generally insignificant.

WASTE CHARACTERISTICS AND POTENTIAL SOURCES

In addition to TCE, investigations at the site have also shown the ground water to be contaminated with trans-1,2-dichloroethylene (trans-1,2-DCE), and vinyl chloride, which are degradation products of TCE, and other halogenated hydrocarbons. TCE, trans-1,2-DCE, and vinyl chloride are all volatile organic compounds. No other contaminants were consistently found in the ground water at concentrations that exceed federal standards. TCE and trans-1,2-DCE were found in soils between the DICO facility and the Raccoon River to the west at concentrations up to 3,000 ppb and 3,800 ppb, respectively. The maximum concentrations of these compounds in ground-water samples were also from this same area of the site. The maximum ground-water concentrations were 8,467 ppb for TCE, 2,000 ppb for trans-1,2-DCE, and 95 ppb for vinyl chloride. These concentrations were measured in the sand and gravel aquifer. These concentrations are high compared to the maximum contaminant level (MCL) in drinking water of 5 ppb for TCE and 2 ppb for vinyl chloride and the proposed maximum contaminant level goal (PMCL) of 70 ppb for trans-1,2-DCE under the Safe Drinking Water Act.

Based on historical data and the results of past site investigations, the primary source of the volatile organics contaminating the ground water at the site is the contaminated soil west of the DICO plant. Degreasing solvents, including TCE, are used in the manufacture of steel wheels and rubber products at the DICO plant. In past years, about 100 to 200 gallons of waste solvent sludge left over from the manufacturing process were applied to road and parking surfaces at the plant each year to control dust. Once this sludge was applied to the road and parking lot surfaces of the plant, it was free to migrate by surface runoff into open soil areas and eventually leach downward to the underlying aquifer. A sample of the sludge was found to contain

3,000,000 ppb of TCE during a 1982 EPA/FIT study, a concentration 1,000 times greater than the maximum concentration found in soils.

REMEDIATION

SELECTION AND DESIGN OF THE REMEDY

The objectives of the remediation are to clean up the contaminated ground water to federal health-based standards on the Des Moines Water Works property adjacent to the north gallery and to capture and treat contaminant plumes east and north of the Raccoon River across from the gallery. These objectives are to be accomplished through ground-water pumping.

The recovery well system in place as of December 1987 consists of seven wells oriented roughly north-south between the Raccoon River and the DICO facility (see Figure 2). These wells are each pumped at 150 to 225 gpm for a total system pumpage of about 1300 gpm. The positions and rates of pumping of the seven wells were determined through field investigations and computer modeling. Figure 2 also shows the March 1988 limit of the north plume that has been drawn south by the recovery system.

The hydrodynamic performance of the recovery system is monitored by a network of about 60 wells and piezometers, including the recovery wells and the 40 monitoring wells and piezometers installed from 1982 to 1984 (see Figure 3). Six of the piezometers are equipped with continuous water level meters. The water levels in the remaining wells and piezometers are measured monthly. Water quality is monitored by analysis of monthly samples taken from 36 wells and piezometers. These samples are analyzed for 34 volatile organic compounds.

EVALUATION OF PERFORMANCE

The recovery system has had a significant effect on potentiometric head distribution in the surficial aquifer at the site. Figure 4 shows a June 1988 contour map of the trough of depression that has developed along the line of recovery wells. An analogous map from March 1988 is almost identical indicating that the system was at or near steady state 3 months after startup. The system has created an inward flow pattern extending beyond the known areal limits of the targeted contamination. The system appears to be effective in achieving its objective of inducing a flow pattern that will capture the targeted solvent plumes over time. Figure

4 shows evidence of discharge from the Raccoon River to the aquifer in the area west of the recovery well system.

There is evidence that the remediation is improving the water quality at the site. Figures 5 and 6 show the contour maps of TCE concentration for December 1987 and June 1988, respectively. The areas enclosed by the 1000 ppb and 100 ppb contours have decreased significantly over the first 6 months of operation. Note that the position of the 100 ppb contour in June 1988 was roughly equal to the position of the 1000 contour of December 1987.

This observation of reduced concentrations east of the Raccoon River was also supported by concentration data from individual wells in the southern part of the site. Figures 7 and 8 show a time series plot of three volatile organics for recovery well 8 (ERW-8; see Figure 2) and monitoring well NW-23, respectively. Well ERW-8 is southeast of the largest DICO building while well NW-23 is at the northwest corner of the large DICO building to the south. Both wells showed considerable concentration decreases over the first 10 months of pumping. The concentrations in well NW-23 seem to show a declining trend over the entire 300 days of record. The concentrations in well ERW-8 seem to have stabilized at about 200 ppb for TCE and 100 ppb for trans-1,2-DCE after 150 days of pumping. This is not necessarily an indication of reduced system effectiveness. At these concentrations and at a pump rate of 175 gpm, well ERW-8 continues to extract 5.7 kg of TCE and 2.9 kg of trans-1,2-DCE per month even though it is not in the area of greatest contamination.

There is also evidence that concentrations west of the Raccoon River have decreased, particularly in the area northwest of the main DICO building. In well NW-25 in this area, initial concentrations of 93 and 7 ppb for TCE and trans-1,2-DCE, respectively, were below detection levels for the entire period of pumping. Concentrations of TCE in well NW-21, to the south of well NW25, decreased from their pre-pumping levels but varied during the period of pumping and did not show a continuously declining trend (see Figure 9). The reason for this variability is unclear but may be due to sampling or laboratory error.

One interesting development during the first 6 months of operation was a plume of high trans-1,2-DCE concentration that entered the study area from the north and migrated south under the influence of pumping. Because flow in the area of this northern plume was southward to westward in the past, the source of this contamination must be north of the DICO facility.

Further evidence of cleanup progress is shown by the decline in contaminant concentrations in the air stripper influent. Figure 10 shows that the TCE concentration has declined to one third of its original concentration over the first 6 months of pumping. A mass balance calculation of the influent and effluent concentrations and flow rates for the first 6 months of operation shows that 560 gallons of TCE and 120 gallons of 1,2-Trans-DCE and vinyl chloride have been removed from the aquifer during the first 6 months of remediation.

SUMMARY OF REMEDIATION

- The contamination at this site is in a highly permeable (K= 3,000-5,000 gpd/ft^2) unconfined aquifer adjacent to the main water source for the City of Des Moines, Iowa.

- In the first 6 months of pumping from a system of seven recovery wells, a hydraulic zone of capture extending beyond the limits of the targeted contamination was established.

- Concentrations of the volatile organic contaminants were reduced to one third or less of initial concentrations in the area east of the Raccoon River. The high permeability of the contaminated zone and the high pump rate of the system both favor extraction of contaminants at this site.

- The primary source of contaminants is the soil in the vicinity of the DICO plant. The soil was contaminated by sludge applied to the parking lot surface. Because the source of contaminants in the vadoze zone may still remain, the recovery system may have to be operated for many years before the aquifer area east of the river is restored.

- There is no evidence of a contaminant source west of the Raccoon River. The contamination present to the west of the river was drawn there by pumping from the north gallery of the Des Moines Water Works system. However, the plume seems to be reduced west of the river suggesting that the city may soon be able to resume pumping portions of the north gallery.

- The moderate to very high mobility of these volatile organic compounds in water (see Volume 1, Appendix A) favors their removal with the extracted groundwater. The low percentage (<10 percent)

of silts and clays in the contaminated aquifer also favors mobility and disfavors retention.

- The recovery wells are close together in a line that is centrally located with respect to the plume. Consequently, the recovery wells produce a groundwater flow pattern that is uniformly inward throughout most of the plume. Zones of stagnation are reduced and mobility is enhanced because all of the wells induce flow in the same general direction.

BIBLIOGRAPHY

1. AWARE, Inc. November, 1986. Groundwater Model Calibration and Conceptual Design Report, Des Moines TCE Site, Des Moines, Iowa.

2. AWARE, Inc. April 1988. Performance Evaluation Report No. 2 (December 1987 through March 1988) Groundwater Recovery and Treatment System, Des Moines TCE Site, Des Moines, Iowa.

4. Dula et al. 1988. Site Investigation Report, Des Moines TCE-North Plume, Ecology and Environment/FIT, TOD No. F-07-8807-009.

5. Ecology & Environment. December 1985. Final Remedial Investigation Report, Vol. 1 of 4, Remedial Investigation/Feasibility Study, Des Moines TCE Site, Des Moines, Iowa, WA 99-7L25.0.

6. ICF. 1985. Draft, Superfund Health Assessment Manual, U.S. Environmental Protection Agency, Contract No. 68-01-6872, Washington, D.C.

WDCR312/041.50

CASE STUDY 4

Du Pont Mobile Plant
Axis, Alabama

CASE STUDY FOR THE DU PONT MOBILE SITE

BACKGROUND OF THE PROBLEM

The E.I. Du Pont de Nemours & Company, Mobile plant is located on approximately 510 acres of land about 25 miles north of Mobile, in the town of Axis, Alabama. The site, as shown in Figure 1, is adjacent to the Mobile River and is bounded on the north by the property of Courtauld's North-American Ltd. The plant manufactures agricultural products, including herbicides and insecticides. A ground-water extraction system has been operating at the site since 1985, with the primary objective of preventing offsite migration of contaminated ground water. The system is operated under the jurisdiction of the RCRA program.

SITE HISTORY

The manufacturing facilities at the site were constructed, beginning in 1968, by Shell Oil Company on land that was previously undeveloped. Initially, only two agricultural insecticides were produced. However, during the 1970s and 1980s the manufacturing processes were modified and expanded to include other insecticides, soil fumigants, epoxy resins, resin curing agents, and various catalysts. In 1986, the facility was purchased by Du Pont, which continues to manufacture these products at the site.

Before 1980 three waste management units were in operation at the site: (1) a landfill in the southern part of the property, (2) a surface impoundment, called Six Acre-Foot Pond, and (3) a smaller surface impoundment near the Mobile River, called Four Acre-Foot Pond (see Figure 2). All three units were closed as part of a corrective action program initiated by Shell Oil Company in 1977. The closures were completed in 1980.

Sludges and drummed liquid wastes were buried in the onsite landfill from 1969 through 1974. The specific nature, volume, and location of the wastes were not documented during disposal operations. However, they are known to have included drummed insecticides, liquids containing trichlorobenzene, and sludges from various sump areas. The total quantity of wastes and contaminated soils excavated during the closure of the landfill in 1980 was 4,000 cubic yards. The amount of contaminated soils excavated was controlled by the requirement that all soils remaining in place must have contaminant concentrations below "action levels" based on the standard RCRA leaching test. Monitoring wells installed during landfill closure did not indicate ground-water contamination. However, it was later found that they had been

installed on the upgradient side of the landfill because the direction of ground-water flow had been misinterpreted.

The Six Acre-Foot pond was constructed in 1976 to store liquids generated during the manufacture of insecticide. It was composed of four adjacent rectangular impoundments, or ponds, that were constructed by scraping earth from their centers to form berms around their edges. Each pond was approximately 46 feet wide by 230 feet long by 6 feet deep. The ponds were lined with 1/4 inch of asphalt sprayed over 4 inches of compacted clay, underlain by 3 inches of lime. Three of the ponds also had synthetic membrane liners. All four ponds were covered with fiberglass roofing. During the closure of the Six Acre-Foot Pond the liquid contents and liner materials were removed and disposed of offsite. Soil samples were collected from depths of 4 to 7 feet, and contaminant concentrations were found to be below action levels. The area was then regraded.

The Four Acre-Foot Pond was constructed in 1968 near the bank of the Mobile River to provide temporary storage and surge protection for the NPDES discharge from the plant. The discharge permit required daily sampling of pH, sodium chloride, methylene chloride extractibles, and pesticides. Closure of this pond consisted of drainage of the pond liquids, removal of the accumulated sludge for offsite disposal, and regrading. No soil or ground-water samples were collected as part of the closure program.

In 1983, a Facility Assessment was conducted on the site by Shell Oil Company, and a plume of ground water contaminated with insecticides and a variety of organic compounds was found. Starting in 1985, a system of ground-water extraction and monitoring wells was installed in the upper part of the Alluvium Aquifer (Unit B) to deal with this problem. In 1987, Du Pont was issued a RCRA (Part B) permit to operate a hazardous waste storage facility and a hazardous and a waste incinerator at the site. In compliance with this permit, Du Pont conducted a second Facility Assessment in 1988 covering the three closed waste management units and the associated ground-water contamination.

GEOLOGY

The site is located in the Piney Meadows physiographic province and borders the Mobile River. The province is developed on Pleistocene and Holocene age terrace, flood plain, and beach deposits. It is underlain by unconsolidated sediments that thicken to the south-southwest at a rate of 10 to 50 feet per mile. The coastal plains sediments range from pre-Jurassic to Holocene and consist of alternating layers of sand, shale, clay, and limestones in complex layers.

The three prominent stratigraphic units identified at the site are: Unit A--surficial clay, Unit B--sand, and Unit C--blue clay. Unit A is a surficial clay layer that ranges from 5 to 50 feet thick and is covered, in a few locations, with several feet of fill material. Unit B is a sand layer directly underlying Unit A that ranges in thickness from 65 to 90 feet. The sand is apparently hydraulically continuous across the site despite the existence of some clay lenses. Unit C is a relatively thick clay layer that extends vertically from approximately 90 feet to approximately 600 feet below the ground surface. It is an effective barrier separating Unit B sand from the lower aquifers. Figure 3 shows a north-south cross-section that passes through the landfill area. It should be noted that the Unit C blue clay was only observed in two borings for process wells (DW-1 and DW-3) at elevations of -54 and -70, as well as in soil test borings drilled in 1967.

HYDROGEOLOGY

The unit B sand comprises an aquifer that is known in the Mobile River Valley as the Alluvium Aquifer. The upper portion of this aquifer is a fine clayey sand that grades downward into coarse sand and gravel interbedded with clay lenses. The capacities of wells completed in the Alluvium Aquifer range from 50 to 800 gallons per minute. A test run in the aquifer at the Du Pont site in 1987 indicated a transmissivity of 250,000 gallons per day per foot. This corresponds to an average hydraulic conductivity of 484 feet per day, or 0.17 centimeters per second. The hydraulic conductivity in the Unit B sand is thought to increase with depth, because the materials have been observed to be coarser in the deeper portions of the unit. However, no tests have been done specifically to quantify this observation.

In its natural state, the Unit B Alluvium Aquifer at the site was confined by the Unit A clay, and the direction of ground-water flow was eastward toward the Mobile River. This has been altered by heavy industrial water-supply pumping (8,000 gpm) at the neighboring Courtauld's North-American property to the north. The ground-water levels near this withdrawal have dropped 20 to 40 feet such that the Unit B aquifer at the Du Pont site is now unconfined and the flow is toward the north. The water levels at the Du Pont site are currently 40 to 50 feet below the ground surface. Because of this local change in the flow regime, the Mobile River is now a recharge source to the aquifer (see Figure 4). An average hydraulic gradient calculated from monitoring wells on the Du Pont site in December 1986 was 0.007 feet per foot toward the north. This, combined with the estimated hydraulic conductivity of 484 feet per day and

an assumed effective porosity of 0.2, yields an interstitial ground-water velocity of 17 feet per day.

The hydraulic conductivity of the Unit A clay was measured by a constant head permeameter and found to range from 10^{-6} cm/s to 10^{-8} cm/s. Assuming a median value of 10^{-7} cm/s and an effective porosity of 0.45, the estimated vertical interstitial velocity in the clays is about 0.15 feet per year.

WASTE CHARACTERISTICS AND POTENTIAL SOURCES

The ground-water contamination found at the site is thought to be primarily due to leaching of contaminants from the landfill. The principal contaminants found in the landfill waste pits during the closure operations in 1980 included:

1. Pentachloroacetophenone (PCAP)
2. Trichlorobenzene (TCB)
3. Trichloroethylene (TCE)
4. Trimethylphosphate (TMPO)
5. Dichloroacetic acid (DCAA)
6. RABON® -2-chloro-1(2,4,5-trichlorophenyl)vinyl dimethyl phosphate
7. VAPONA* -2,2-dichlorovinyl dimethyl phosphate
8. DIBROM* -1,2 dibromo-22,-dichlorodimethyl phosphate
9. Hexane
10. Carbon tetrachloride (CBT)
11. Chloroform (CRF)

During closure of the landfill in 1980, soil samples were taken from 47 borings ranging in depth from 2 to 20 feet. The samples were analyzed using the standard RCRA leaching test and compared to the action levels that had been established for the site. Table 1 shows the maximum leaching test concentrations found from these samples and the corresponding action levels for each compound.

Table 1
MAXIMUM CONTAMINANT LEVELS IN LEACHATE FROM SOIL SAMPLES TAKEN DURING LANDFILL CLOSURE, WITH CORRESPONDING ACTION LEVELS
(Concentrations in mg/l)

Compound	Maximum Soil Leachate Concentration	RCRA Soil Leachate Action Level
PCAP	12.6	3.0
TCB	5.8	42.0
TCE	0.07	280.0
TMPE	<4.0	47.0
DCAA	<200.0	156.0
VAPONA*	<0.5	--
DIBRON*	<1.0	24.0
CRF	0.3	45.0
CBT	28.0	1.0
Hexane	6.9	--

Source: Du Pont, 1988. Table 5-9.

It can be seen from Table 1 that the maximum standard leaching concentration for PCAP (12.6 mg/l) was higher than the accepted action level. A review of the complete list of soil leaching data reveals that this high concentration was limited to a single sample taken from a depth of 15 to 16 feet below the waste pits. The other samples showed PCAP leaching concentrations that were well below the action level of 3.0 mg/l.

No explanation is given in the Facility Assessment Report of the rationale behind the action levels listed in Table 1. The development of the action level values is listed as one of the initial tasks in the 1980 closure program.

The partition coefficients for adsorption of these organic constituents to the soils of the Unit A clay and the Unit B sands can be predicted on the basis of the organic content of the soils. Measurements of organic carbon content were not made at the Du Pont Mobile site. However, the Facility Investigation report states that the soils underlying the site are not high in organic carbon, so adsorption is not expected to have a pronounced effect on contaminant migration in the ground water. This may be true for the Unit B sands; however, it is likely that the less mobile constituents, such as TCB, CBT, and, to a lesser extent,

TCE, do sorb to the materials in the overlying Unit A clay. These sorbed contaminants would represent a potential source of continued leaching to the underlying aquifer that could persist for many years.

The ground-water monitoring program was initiated at the site in 1983, and additional wells were added to the system in 1984 and 1985. Table 2 lists the maximum concentrations of the various contaminants that have been found in ground-water samples from these wells. From this table, CBT, CRF, TCE, and TCB are notable as contaminants with the highest ground-water concentrations. Of these, CBT, CRF, and TCE were used, to a limited extent, as indicator compounds. TCB was not used as an indicator of contaminant migration because it has relatively low mobility. Table 2 also lists the soil-water partition coefficients, K_{oc}, and the health-based regulatory standards for the ground-water contaminants found. High values of K_{oc} indicate low aqueous mobility.

Figure 5 shows the distribution of total organic halide (TOX) concentrations in July 1984. The landfill, the 6-acre-foot pond, and the area near well 24 all appear to be source areas or areas of high contaminant concentrations. The northern extent of contamination was not defined by the monitoring well system in July 1989.

No multi-level, or nested, wells have been installed to determine the vertical distribution of contaminants in the Alluvium Aquifer. However, the two production wells, DW-1 and DW-2, are screened near the bottom of the aquifer, while the monitoring wells are typically screened near the water table. The only priority pollutant that has been detected in the production wells is acrolein, which was found in one sample taken from Well DW-2 in 1984 at a concentration of 144 ppb. This has been taken as an indication that the contaminants are limited to the upper portion of the Alluvium Aquifer. However, reference to Figure 5 shows that DW-1 and DW-2 are outside the 100 ppb TOX contour even in the upper portion of the Alluvium Aquifer so the absence of contamination in the lower portion of the aquifer is not anomalous.

REMEDIATION

SELECTION AND DESIGN OF THE REMEDY

Objectives of Remediation

The objective of the ground-water remediation program at this site is to prevent offsite migration of the contaminated ground water. Removal of contaminants from the

aquifer is acknowledged as a secondary benefit of the remedial efforts. However, because the contaminated soils beneath the former landfill remain a continuing source of ground-water contamination, no projections of the time required for aquifer restoration have been made.

System Configuration

The ground-water extraction system consists of a line of four barrier wells, Wells E-1 through E-4, along the northern boundary of the Du Pont property (see Figure 6). These locations were probably chosen to prevent offsite migration to the north. Two wells (E-1 and E-2) were initially constructed in May 1985. They were drilled to a depth of 75 feet and screened with 20 feet of 12-inch-diameter PVC well screen. The screens were set in the upper part of the Alluvium Aquifer where the aquifer materials are relatively fine and less permeable than in the lower part. An explanation for this choice of the screened interval is not provided, but it was probably done in an attempt to minimize the extraction of clean ground water from the lower portion of the aquifer.

The first two extraction wells became operational on December 10, 1985. The pumping rate selected for these two wells was initially 62.5 gallons per minute (gpm) each. This selection was made by using the Thiem-Dupuit equation for steady flow in an unconfined aquifer to predict the radius of influence, and thereby the hydraulic capture radius, of the wells. The actual hydraulic effectiveness of the wells in capturing the contaminant plume was observed by measuring the drawdown in neighboring monitoring wells. As a result of this hydraulic monitoring, a third well (E3) was added to the system in 1986 to increase the capture effectiveness of the system. Also in 1986, the casing of Well E-2 experienced structural failure, and a replacement well (E-4) was installed.

The extracted ground water is treated in the plant's industrial biotreater and then discharged to the Mobile River under the existing NPDES permit for the plant.

EVALUATION OF PERFORMANCE

The effectiveness of the ground-water recovery program is assessed in three ways: (1) isopleth map and trend analysis, (2) hydraulic analysis of plume capture, and (3) percent recovery of TOX in the ground-water plume.

The analysis of ground-water contaminant isopleths is conducted under the assumption that the contaminant plume has

reached a quasi-steady state in which continued leaching from the former landfill area replaces the contaminants extracted by the recovery system. Figures 6 and 7 show the distribution of TOX concentrations in June 1986 and June 1988, respectively. These two figures can be compared to Figure 5 to show the cleanup progress over time. In the 4-year period between July 1984 and June 1988, the contaminant plume has been reduced both in area and in maximum concentration.

The concentrations in the central part of the plume, however, have not shown a consistent decrease with time. Figure 8 shows the variation of TOX concentration with time in wells 24 and 32--two monitoring wells located in the central part of the plume between the former landfill and the extraction wells. Well 24, which is located slightly off the centerline of the plume and fairly close to the extraction wells, shows a strong TOX concentration peak after more than a year of remediation but an overall decline from July 1984 to June 1988. By contrast, the TOX concentration in well 32 began to increase at approximately the same time as the concentration in well 24 but continued to show an increasing trend until at least mid-1988.

Figure 9 shows the variations of TOX concentrations with time in the extraction wells. In general, the TOX concentrations are highly variable and do not show a long-term declining trend. Concentrations rose markedly in the wells E-1 and E-2 shortly after the commencement of extraction. However, after 400 days they had fallen off again to approximately the pre-extraction levels. The TOX concentrations in wells E-3 and E-4 showed a highly variable increasing trend over the period of pumping. This is not typical behavior for an extraction system that is successfully capturing a contaminant plume. Normally, the extraction well concentrations fall off dramatically after the system has established hydraulic control of the plume because clean water from outside the contaminated area is drawn into the wells.

These data suggest a continuing source of contamination. A long-term decrease in concentrations is expected, as the contaminants in the source are exhausted by continuous leaching. However, the rate of decrease has not been projected, and it is not thought that any definite rate can be determined from the monitoring results to date. Instead, the available record of monitoring-well concentrations has been averaged over time to generate a long-term plume configuration, as shown in Figure 10. Comparison of the configuration of the time-averaged plume in Figure 10 to the time-averaged water levels shown in Figure 11 suggests that

the current extraction system generally does induce the flow regime necessary to contain the contaminants.

An attempt has been made to compare the rate of contaminant removal from the extraction wells to the rate of contaminant mass flux through the plume, and thereby to estimate the percent recovery of the system. The results of this comparison contradict the conclusion that the extraction system captures the TOX plume, however. The long-term average rate of contaminant removal by the wells was estimated to be 490 grams per day. The mass flux rate through the plume was estimated by numerically integrating the product of TOX concentration and ground-water discharge velocity along the line A-A1 shown on Figure 10. This resulted in a long-term estimate of 998 grams per day passing through the plume. The removal efficiency was then estimated as the quotient of these two figures, or 49 percent.

No explanation has been given for the fate of the remaining 51 percent of the contaminants that are not removed by the system. Evidently, either the contamination escapes the site by passing between, around, or under the extraction wells or the calculations of mass flux are inaccurate.

SUMMARY OF REMEDIATION

The ground-water extraction system at the Du Pont Mobile site is intended to provide hydraulic containment of the plume of contaminated ground water. Aquifer restoration is not a primary objective.

Four years of extraction has significantly reduced the area of the contaminant plume as measured by the system of onsite monitoring wells. The maximum concentrations in the contaminant plume have also been reduced. However, the concentration of the extraction system influent has not decreased over time, suggesting that a continuing source of contamination is present at the site.

Comparison of time-averaged distributions of TOX concentrations and water levels suggests that the extraction system is capturing the contaminant plume. However, mass flux calculations suggest that only half of the TOX mass flowing past the extraction system is captured. However, these mass flux calculations are based on the assumption that porosity, saturated thickness, and ground-water flow velocity are rarely uniform and that the measured concentrations are characteristic of the entire saturated thickness. These assumptions may lead to an overestimate of mass flux. Nonetheless, it is possible that some contamination is escaping

the extraction system at depth or to the north of the extraction wells, where the limit of the contaminant plume has not been characterized.

BIBLIOGRAPHY

E.I. Du Pont de Nemours & Company, Inc., November 1988. Status Report, Tas 9.2 of the Solid Waste Management Unit Investigation Plan, Agricultural Products Department, Mobile Chemical Plant, Axis, Alabama.

WDCR426/019.50

CASE STUDY 5

Emerson Electric Company
Altamonte Springs, Florida

CASE STUDY FOR THE EMERSON ELECTRIC COMPANY SITE

BACKGROUND OF THE PROBLEM

This case study summarizes the remediation efforts at the Emerson Electric Company site in Altamonte Springs, Florida. The site is in Seminole County in central Florida near the city of Orlando. The Electronic and Space Division of Emerson Electric operated an electrical component manufacturing and assembly plant at this site from January 25, 1979, to the mid-1980s. The site is bordered on the south by a swampy area and on the north and west by a light industrial park (see Figure 1). Some construction debris was buried south of the site prior to 1979. From January 1980 to November 1981, wastewater from metal filming operations was discharged to a septic tank and tile drain on the southeast side of the main building. Contained in this discharge were chlorinated and non-chlorinated solvents, xylene, ketones, and other contaminants.

In response to ground-water contamination discovered during the site investigation, a remediation system consisting of five extraction wells was operated from December 1984 to June 1987. The concentrations of the contaminants in composite samples taken from the extraction system declined to below goal concentrations during this period. As a result, remediation of this site was considered complete and the site was removed from the State Action Site list. The Emerson Electric site has been administered by the Florida Department of Environmental Regulation (FDER).

SITE HISTORY

A possible contamination problem at Emerson Electric was first discovered during an October 20, 1981, site inspection by representatives of the FDER. The inspectors found that wastewater from metal filming operations was being discharged to a septic tank without pre-treatment. On October 21, 1981, the FDER directed Emerson Electric to develop treatment and disposal systems and to study ground-water conditions at the site. Emerson Electric stopped the wastewater discharge on November 17, 1981.

In March 1982, Environmental Science and Engineering (ESE), the consultant hired by Emerson Electric, conducted an electrical conductivity survey to detect possible zones of contamination. Despite interference from buried metal debris, an area of high conductivity indicative of contamination was detected southwest of the main building (see Figure 2). In August 1982, two deep (100 feet) and four shallow (50 feet)

monitoring wells were installed to define the contamination (see Figure 3). Ground water from these wells was sampled and analyzed weekly for 4 weeks following well installation. The two wells north of the plant were grouted and abandoned between mid-September and mid-November 1982.

In mid-September 1982, 30 soil samples were collected south of the plant to detect possible chromium contamination caused by buried paint filters. The paint filters were encountered during drilling and subsequent analyses using EP toxicity procedures showed that the soil was contaminated with up to 2,480 micrograms per liter of dissolved chromium.

On November 2, 1982, the buried paint filters containing leachable chromium were excavated by ESE. In May 1983, sludge from the septic tank was also removed.

On February 1, 1984, ESE presented a remedial action plan for the site to the FDER. This plan was based on the field investigations conducted by ESE and analyses of the six monitoring wells. The plan included installation of four extraction wells in the zone of maximum contamination near well ES4 and extraction of ground water at a combined rate of approximately 30 gallons per minute (gpm). The plan called for the extracted ground water to be discharged directly to the community sanitary sewer system and then to be treated by the Altamonte Springs wastewater treatment plant.

It was projected by ESE that contamination would be reduced to below health-based levels in less than 9 months (ESE, 1984a). A consent order issued by the State of Florida on October 21, 1984, required Emerson Electric to deliver the completed remediation system to the FDER and to pay the FDER and the Altamonte Springs treatment plant the costs associated with operating and maintaining the system for 9 months (ESE, 1984a). After complying with the consent order, Emerson Electric was to be released of legal responsibility for the contamination. Emerson Electric delivered the completed system to the FDER on December 14, 1984, and made the required payments, releasing it of further responsibility. The system began operating in December 1984.

The system was operated by the FDER from December 1984 until the system was shut off in June 1987. Based on the contaminant concentrations found in ground-water samples taken in September 1987 and May 1988, the site was deleted from the State Action Site list in January 1989 at the recommendation of the FDER.

GEOLOGY

The Emerson Electric site is in an area characterized by sand hills and many lakes. This site was once a swampy area but was filled in with 2 to 10 feet of sandy fill material and construction debris prior to the arrival of Emerson Electric in 1979 (see Figure 4). Underlying this fill are 20 to 50 feet of unconsolidated sand. It is this sand layer that is contaminated. Underlying the sand, is the Hawthorne Formation, a layer of interbedded clay and sandy phosphatic limestone with a thickness of 20 to 60 feet. The top of the Hawthorne Formation is 20 to 60 feet below land surface. Underlying the Hawthorne Formation is the Ocala Limestone, which is the upper unit of the Floridan aquifer, an important water producer in this area. The Ocala Limestone is cavernous regionally but appears to be solid at the two deep-well locations at this site.

HYDROGEOLOGY

The shallow sand layer is an unconfined water table aquifer. The depth to water in this shallow aquifer was 0.56 to 2.98 feet below land surface at the four monitoring-well locations in August and September 1982. Figure 5 shows the potentiometric surface of the shallow aquifer as measured on September 2, 1982, from the four fully-screened, shallow, monitoring wells. The flow in the shallow aquifer is to the southwest. The hydraulic conductivity of the shallow aquifer as estimated using slug tests conducted in August 1982, is 2.35×10^{-5} ft/sec. The horizontal ground-water flow velocity in August 1982 was estimated by ESE to be 5.15 ft/year (ESE, 1982b). However, the horizontal ground-water velocity appears to the authors of this case study to be approximately 25 ft/year based on the above conductivity, an assumed porosity of 30 percent, and a horizontal gradient of 0.01 ft/ft taken from the potentiometric surface map.

The deep Floridan aquifer is typically confined by the Hawthorne Formation in this region. However, according to the USGS, this site is within an area where the Floridan aquifer receives over 10 inches of recharge per year. Figure 6 shows the potentiometric surface of the Floridan aquifer on September 2, 1982. The water level in the aquifer was from 31.0 to 35.4 feet below land surface in August and September 1982. Flow in the Floridan aquifer was to the south-southwest during this period. No vertical flow rates were reported but comparison of the two potentiometric surface maps shows that there is a head difference of approximately 30 feet across the 40- to 50-foot thickness of the confining layer. ESE concluded that flow in the surficial aquifer is predominantly downward rather than horizontal (ESE, 1982a),

but comparison of horizontal and vertical flow rates supports the opposite conclusion.

The horizontal hydraulic conductivity of the Floridan aquifer, as measured by August 1982 slug tests, was 3.25 x 10^{-6} ft/sec. This conductivity value seems very low compared to regional values for the Upper Floridan, possibly because the upper 20 feet of the Floridan consists of solid limestone and some clay and because slug tests provide very localized measurements. The velocity of ground-water movement in the Floridan aquifer in August 1982 was estimated by ESE to be 0.4 ft/year (ESE, 1982b). However, the ground-water velocity appears to the authors of this case study to be approximately 3.4 ft/year based on the above conductivity, an assumed porosity of 30 percent, and a horizontal gradient of 0.01 ft/ft, as shown in Figure 6. The vertical hydraulic conductivity of the Hawthorne Formation ranged from 2.0 x 10^{-8} cm/sec to 7.1 x 10^{-6} cm/sec based on falling head permeameter tests of cores taken from wells ED1 and ED2.

WASTE CHARACTERISTICS AND POTENTIAL SOURCES

Two potential sources of contamination at the site are buried construction debris and the wastewater discharged through the plant's septic system. The construction debris was buried in unknown locations south of the plant prior to 1979. The wastewater was discharged to drain fields in the southeast part of the plant. The estimated volume of wastewater released to the septic system from January 25, 1980, to November 17, 1981, was 34,650 gallons (ESE, 1983).

The main contaminants of concern at the Emerson Electric site are acetone, methyl ethyl ketone (MEK), methyl isobutyl ketone (MIBK), toluene, 1,1-dichloroethylene (DCE), 1,1-dichloroethane (DCA), 1,1,1-trichloroethylene (TCE), 1,1,1-trichloroethane (TCA), benzene, and chromium. The concentrations of contaminants observed in early September 1982 in the four shallow monitoring wells are shown in Figure 7. The highest concentrations of contaminants were observed in well ES4 rather than in ES1, the well adjacent to the drain fields.

The consultants hired by Emerson Electric concluded that Emerson Electric could not have been the cause of the contamination found in the area of well ES4. The consultant came to this conclusion because of the lower concentrations of contaminants in well ES1 and because the contaminants could not have migrated in the sand aquifer from the drain field to well ES4 in 2-1/2 years (January 1980 to August 1982) at the estimated ground-water velocity of

5.15 ft/year. Even at the higher flow velocity of 25 ft/year estimated by the authors of this case study, contaminant migration between these two points is not likely in only 2-1/2 years. Well ES4 is directly downgradient from the drain field judging from gradients shown in Figure 5, however. ESE reported that the contamination was probably the result of a single release of approximately 500 gallons of mixed solvents between 1975 and 1978, before Emerson Electric began operations at the site. The buried debris at the site may also have contributed to contamination. The true source of the observed contamination is uncertain.

The contamination in the Floridan aquifer is at much lower concentrations than the contamination in the surficial aquifer. Figure 8 shows the analyses of samples taken from the two deep wells in early September 1982. Wells ED1 and ED2 appear to be contaminated with chromium and toluene at low concentrations. Well ED1 also had low concentrations of DCA but all other contaminants were below detection limits. There are no public or private drinking-water wells within 2,000 feet of the site.

The spatial distribution of contamination at the Emerson Electric site has not been well characterized. The six monitoring wells installed in August 1982 are the only measurement points that have been used to assess the extent and degree of contamination. Because all six wells exhibited some degree of contamination in September 1982, the contaminant plume must have extended outward from the area delineated by the six wells and, therefore, its lateral extent was unknown.

REMEDIATION

SELECTION AND DESIGN OF THE REMEDY

The objective of the remediation was to reduce the concentration of contaminants at the site to below regulated levels. Progress towards this objective was judged solely on the basis of ground water removed by the extraction system near well ES4. The extraction system consisted of well ES4 and four new wells, each pumped at 6 gpm for a total system pumping rate of 30 gpm (see Figure 9). Each well was installed in the surficial aquifer to approximately 50 feet and was screened over the bottom 40 feet. Water extracted by the system was pumped directly into the municipal sanitary sewer network. This water was eventually treated by the Altamonte Springs water treatment plant using normal municipal wastewater treatment methods.

The location of the four additional wells was chosen based on computer modeling of the hydraulic influence of various options. The configuration with the shortest average travel time to the well network from a set of 18 test points was chosen. Figure 10 shows the water levels simulated by modeling the actual extraction well network at an extraction rate of 6 gpm per well. ESE estimated that all contaminant concentrations except those for toluene and ethyl benzene would be reduced to below detection level by extracting eight to nine pore volumes of contaminated ground water. Toluene and ethyl benzene were projected to be reduced to less than 10 percent of the federal regulated standard after nine pore volumes were extracted (ESE, 1984a). At 30 gpm, this volume could be removed in approximately 7 months (ESE, 1984b). This time estimate was the basis for the operation and maintenance payment by Emerson Electric to the FDER and the Altamonte Springs wastewater treatment plant.

The extraction system was monitored by taking composite samples of the water extracted by the five extraction wells from January 1985 to September 1987. In addition, three of the five wells were sampled individually in May 1988. All contaminants in the three wells were found to be below detection limits. The results of the analyses and the standards chosen for the site are shown in Table 1. Concentration data for monitoring wells ES1, ES3, and ED1 were not reported.

EVALUATION OF PERFORMANCE

Little information is available to assess the performance of the remediation system. The effect of remedial pumping on the water levels near the extraction system was not reported. The modeling results shown in Figure 9 are a steady state simulation of the effect of pumping but no actual field measurments of water-level results are available.

Figure 11 is a time series plot of the concentration of the volatile organic compounds TCA, DCA, and DCE. The plot shows steady decreases in concentrations of TCA and DCA, although both compounds were below their respective standards of 200 parts per billion (ppb) and 810 ppb for the duration of remediation. The concentration of DCE also declined but consistently exceeded the standard of 7 ppb during the first 1-1/2 years of operation.

Figure 12 is a time series plot of xylenes, methyl ethyl ketone (MEK), and methyl isobutyl ketone (MIBK). The concentration of xylenes increased sharply after the startup of remediation but then declined sharply from March to April

1985 and declined steadily from April 1985 to June 1987. The concentration of xylenes exceeded the proposed maximum contaminant level (MCLG) of 440 ppb once during the sampling period. The concentration of MEK was above the established standard of 172 ppb for all but two of the sampling events during the first year of operation, but declined to below 10 ppb by May 1988. The concentration of MIBK was variable during most of the period of remediation but declined to below detection by October 1986. No goal concentration was established for MIBK. No estimate of the mass of contaminants removed by the extraction system was reported. However, calculations based on a time-averaged pumping rate of 31 gpm show that approximately 4.0 kg of TCA, 3.8 kg of DCE, and 32 kg of MEK were removed before these contaminants were reduced to below detection limits by the remediation system.

SUMMARY OF REMEDIATION

The surficial sand aquifer in an area adjacent to the Emerson Electric plant was contaminated with volatile organic solvents, ketones, and xylene. The lower Floridan aquifer also appears to be contaminated, although contaminant concentrations are low. The source of the contamination is open to question but Emerson Electric is known to have discharged wastewater containing many of these contaminants from January 1980 to November 1981. The ground-water contamination was first measured directly in August 1982.

A remediation system consisting of five extraction wells was operated from December 1984 to June 1987. ESE, the consultant hired by Emerson Electric, projected that this system would clean up the aquifer to below detection limits for almost all contaminants within 9 months. The actual time required to reduce the contaminant concentrations to the projected levels ranged from 11 months for toluene to 33 months for DCE and DCA. Most contaminants were reduced to below detection limits after 20 to 22 months of remediation. Remediation may have taken longer than projected because of unanticipated retardation effects and because the mass inventory and persistence of the source were underestimated. Because the composite concentration of contaminants extracted by the system declined over the period of remediation to below established standards for all contaminants and two rounds of post-termination monitoring showed no exceedance of the standards, the FDER removed the site from the State Action Site list in January 1989. However, it is difficult to judge the completeness of aquifer restoration because performance monitoring has been limited to samples taken from the extraction wells.

BIBLIOGRAPHY

Environmental Science and Engineering, Inc. May 1982(a). Emerson E&S Division--Orlando, Hydrogeological Data Review and Geophysical Survey for Miller Street Facility. ESE No. 82-206-200.

Environmental Science and Engineering, Inc. November 1982(b). Contamination Assessment at the Miller Street Facility. ESE No. 82-206-300.

Environmental Science and Engineering, Inc. May 1983. Wastewater and Hazardous Waste Audit of the Emerson Miller Street Facility.

Environmental Science and Engineering, Inc. February 1984(a). Effectiveness of Proposed Remedial Action. ESE No. 83-218-0200.

Environmental Science and Engineering, Inc. July 1984(b). Engineering Report for Ground Water Cleanup System for Miller Street Facility. ESE No. 83-218-0700.

Environmental Science and Engineering, Inc. January 1985. Miller Street Facility Cleanup System, Altamonte Springs, Florida.

State of Florida Department of Environmental Regulation. October 1984. Consent Order vs. Emerson Electric Co., OGC File No. 83-0241.

WDCR421/073.50

CASE STUDY 6

Fairchild Semiconductor Corporation
San Jose, California

CASE STUDY FOR FAIRCHILD SEMICONDUCTOR SITE

BACKGROUND OF THE PROBLEM

This case study summarizes the remediation of ground-water contamination at the Fairchild Semiconductor Corporation Plant (Fairchild) in San Jose, California (Figure 1). Manufacturing operations were conducted at the Fairchild facility which required the use, handling, repackaging, and storage of industrial solvents including xylenes, acetone, 1,1,1-trichloroethane (TCA), isopropyl alcohol (IPA), and 1,1,2-trichloro-1,2,2-trifluoroethane (Freon-113).

Fairchild ceased manufacturing activities at this facility in October 1983. The site is currently owned by Schlumberger Technology Corporation (Schlumberger) which is the former parent corporation of Fairchild. Schlumberger has entered into a contract to sell the property to the Koll Company which has plans to develop the property as a shopping center. The objectives of the remediations were aquifer restoration and plume containment.

SITE HISTORY

On November 25, 1981, Fairchild discovered chemical residues in the ground water at the plant. On December 4, 1981, Fairchild determined that an underground waste solvent storage tank had leaked causing the release of organic solvents to the soil and ground water. In response to this discovery, the tank was taken out of service and Fairchild expanded its investigation to determine the extent and degree of contamination in the soil and ground water.

On January 16, 1982, Fairchild began pumping ground water from a water supply well to aid in the offsite hydraulic control of the contaminated ground water. An onsite ground-water recovery program was also initiated in 1982. Since the beginning of the investigation, Fairchild has installed 124 wells in the site area. Of these, 40 were recovery wells. A slurry wall was constructed in 1986 around the periphery of the Fairchild property to the bottom of the second uppermost aquifer to facilitate the remediation (see Figure 2). All of these activities are considered interim responses (IRMs) to the problem. A Remedial Action Plan (RAP) for the final remedial program was prepared in October 1988.

GEOLOGY

The Fairchild facility is located within a hydrologic area designated as the South Bay Drainage Unit by the California Department of Water Resources. This unit consists of a broad, alluvial valley sloping northward into the nearby San Francisco Bay.

The Fairchild site is in the southern Santa Clara Valley in a subarea of the South Bay Drainage Unit known as the Santa Teresa Plain. The Santa Clara Valley was created by tectonic activity and remains tectonically active. The valley floor is underlain by Quaternary alluvium consisting of unconsolidated clays, silts, sands, and gravels. The alluvium is approximately 400 feet thick near the center of the basin and 330 to 360 feet in the study area.

The Santa Teresa Plain is bounded by bedrock outcrops in the surrounding highlands. This bedrock also underlies the Quaternary alluvium at depth within the valley. The bedrock is relatively impermeable compared to the Quaternary alluvium and no significant bedrock aquifers are known to exist within the study area.

HYDROGEOLOGY

Sand and gravel layers interbedded with silt and silty clay layers combine to form four distinct aquifer systems in the alluvial formation. These are referred to as the A, B, C, and D aquifers, in order of increasing depth. The aquifers are separated by silt and silty clay aquitards which range from several feet to approximately 60 feet thick. At some locations in the study area, the aquifers merge or are absent (see Figure 3).

The A aquifer consists of alluvial sands and gravels. It ranges from 15 to 40 feet thick, and is first encountered at depths of 10 to 20 feet below the ground surface. The A aquifer is not continuous offsite and is currently generally dry onsite because of the ongoing remediation. In several locations across the study area, there is no evidence of the existence of the A aquifer. The aquitard between the A and B aquifers is from 5 to 30 feet thick and consists of clay, silty clay, and clayey silt with occasional interbedded sand lenses. This aquitard generally separates the shallow A aquifer from the B aquifer, however, the A and B aquifers are naturally interconnected onsite in the vicinity of the former leaking waste solvent tank.

The B aquifer consists of dense to very dense sands and gravels which are generally located between the depths of 60 and 120 feet below ground surface. The aquitard between the B and C aquifers is up to 60 feet thick and is continuous across the site. In general, it effectively separates the two aquifers.

The C aquifer also consists of dense to very dense sands and gravels. It is areally extensive and is generally found between 150 to 190 feet below ground surface. The B and C aquifers are a primary source of ground water for agricultural and domestic purposes in this area.

The D aquifer is discontinuous, is not areally extensive, and is not a major source of ground water in the site area. The D aquifer also consists of very dense sands and gravels, but generally contains a higher percentage of fine-grained material than do the other aquifers. The D aquifer is located between 220 and 270 feet below ground surface.

Seasonal variations in ground-water levels are typical in the site area, with the low water levels usually occurring between August and December. Water level data obtained in April 1982 indicate that ground-water flow in the B aquifer was in a northwest direction at a gradient of approximately 0.0016 ft/ft onsite and 0.0020 ft/ft offsite. The B aquifer was confined in early 1982 at the beginning of the remediation program. Downward gradients between the B and C aquifers ranged from 0.063 ft/ft to 0.16 ft/ft in 1982.

The ground-water flow in the C aquifer was in a west to northwest direction in April 1982 with a gradient of approximately 0.0006 ft/ft. The C and D aquifers were also confined in early 1982. The net vertical gradient between the D and C aquifers was approximately zero in early 1982 indicating little or no vertical flow. Vertical gradients through the C-D aquitard were upward from the D aquifer to the C aquifer in 1987.

The transmissivities of the B aquifer determined from aquifer tests ranged from 69,000 gpd/ft to over 800,000 gpd/ft. The average hydraulic conductivity of the B aquifer was computed to be 0.33 cm/sec. Transmissivities of approximately 140,000 gpd/ft for the C aquifer, and from 265,000 gpd/ft to 312,000 gpd/ft for the combined C and D aquifers were also determined from aquifer tests.

WASTE CHARACTERISTICS AND POTENTIAL SOURCES

The initial chemical distribution at the Fairchild facility was defined as the distribution that existed on October 31, 1982. Seven indicator chemicals were selected to define the boundaries of the ground-water contamination in order to formulate interim and final remedial measures. The seven compounds were TCA, 1,1-dichloroethylene (1,1-DCE), acetone, IPA, xylenes, Freon-113, and tetrachloroethylene (PCE). The cleanup levels for the site have been specified by the EPA as:

TCA	200 ppb
Xylenes	620 ppb
Acetone	3,500 ppb
IPA	450 ppb
Freon-113	18,000 ppb
1,1-DCE	6 ppb
PCE	2 ppb

The highest concentrations of solvents in onsite ground water were detected prior to November 1982 in the A aquifer wells located within 50 feet of the former leaking waste solvent tank. Maximum concentrations detected were as high as 1,900,000 ppb for TCA, 76,000,000 ppb for xylenes, 99,000,000 ppb for acetone, 45,000,000 ppb for IPA, 45,000 ppb for Freon-113, and 53,000 ppb for 1,1-DCE. Because several of these concentrations are higher than the compounds' solubilities, it can be concluded that the compounds were present in the non-aqueous phase in aquifer A. One well drilled offsite to the same depth as aquifer A in November 1982 was found to be contaminated with 0.3 ppb of TCA. No other compounds were detected. Because the A aquifer is not continuous offsite, it is unlikely that any hydrologic connection exists between this offsite permeable zone and the onsite A aquifer.

The highest concentrations detected in onsite B aquifer wells were measured in 1982 and were 670,000 ppb for TCA, 6,400 ppb for 1,1-DCE, and 7,200 for Freon-113. Prior to October 1982, offsite B aquifer wells contained concentrations of TCA ranging from below detection limits to greater than 1,000 ppb. The highest initial 1,1-DCE concentrations offsite ranged from 47 to 83 ppb. Freon-113 was detected in offsite B aquifer wells at concentrations up to 15 ppb prior to October 1982. Aquifer B concentration contours of TCA, and 1,1-DCE based on the 1982 data are shown by the dashed lines in Figure 4 and 5, respectively.

TCA was the only contaminant detected in onsite wells screened in the C aquifer. The concentrations of TCA in onsite wells were below 7 ppb. No TCA has been detected in the onsite C aquifer since October 1982. Prior to October 1982, offsite TCA concentrations in aquifer C exceeded 1,000 ppb locally. The maximum concentrations of 1,1-DCE and Freon-113 in offsite wells were 3 ppb and 7.1 ppb, respectively. A contour map of C aquifer TCA concentration is shown in Figure 6.

There were no wells completed in the D aquifer onsite. Two wells were completed in the D aquifer offsite. As a result of cross contamination of the well during drilling, installation, and development, IPA and acetone were detected in these wells. The concentrations were reduced to below detection by February 1983. TCA has been detected intermittently with concentrations generally below 1 ppb.

REMEDIATION

SELECTION AND DESIGN OF THE REMEDY

Following the detection of contamination in the ground water beneath the facility, Fairchild implemented a series of interim remedial measures (IRMs). The onsite IRMs included soil removal, ground-water extraction and treatment, a flushing program in the A aquifer, a potential conduit well investigation and well sealing program, installation of a slurry cutoff wall, and an in-situ soil aeration pilot study. Offsite IRMs included ground-water extraction and treatment, and a potential conduit well investigation and sealing program. In October 1988, Fairchild completed the Remedial Action Plan for the final remedy at the site.

Objectives of Remediation

The overall objectives of both the ongoing IRMs and the final remedial actions are to protect the environment and public health. The specific objectives of the IRMs were to:

- Reduce the volume of chemical residues in onsite soil
- Prevent additional migration of chemical residues from the source area
- Prevent further migration of contaminated ground water

- Reduce the extent of contamination in the ground water

System Configuration

During the interim remedial program, Fairchild installed a total of 124 ground-water observation and recovery wells at the site as shown in Figure 2. The letter "A" through "D" following the well number indicates the aquifer in which the well was completed. The letter "M" identifies existing wells screened in multiple aquifers.

There are 40 recovery wells in the system but 4 of these were never activated because hydraulic control was achieved and maintained without pumping these wells. Eight recovery wells were completed in the A aquifer and 14 wells each were completed in the B and C aquifers. In addition, one well was completed in both the A and B aquifers and three existing water supply wells were completed in multiple aquifers. Some of the remaining 36 recovery wells were only pumped for certain periods of time. As of December 30, 1988, there was one active well operating in the onsite ground-water extraction program and 5 in the offsite program. The recovery wells are monitored weekly for pumping rates and sampled biweekly for chemical analysis.

The ground-water extraction and treatment program was initiated in January 16, 1982 with the pumping of approximately 1,260 gpm from well GO-13(M). By November 1982, approximately 5,000 gpm were being extracted. The pumping rate increased steadily until January 1983 when approximately 9,200 gpm were being extracted. Since January 1983, the total flow rate has been gradually and steadily reduced; as of December 1987, the rate was approximately 2,100 gpm. The periods of operation of some of the extraction wells are shown in Table 1.

The pumped ground water was treated either by air stripping or granular activated carbon before being discharged to Canoas Creek via the City of San Jose storm sewer system.

Design Decisions

The slurry wall was installed through the entire thickness of the A and B aquifers to contain the areas of extremely high concentration of contaminants that initially existed at the Fairchild plant. This allowed the pumps operating within the slurry wall to dewater this isolated area by extracting only the water within the boundaries of the slurry wall rather than drawing from a larger, less contaminated, area. This isolation caused onsite ground-

water gradients to be steeper and contaminant withdrawal rates to be quicker than if the slurry wall had not been installed.

Table 1
WELLS PUMPED IN GROUND-WATER EXTRACTION PROGRAM

Well Number	Location	Initial Pumping Date	Final Pumping Date
RW-1(A,B)	On-Site	11-04-82	03-15-86
RW-2(B)	Off-Site	12-10-82	*
RW-3(C)	Off-Site	12-10-82	05-02-88
RW-4(C)	Off-Site	11-29-82	05-02-83
RW-5(C)	Off-Site	11-30-82	06-27-88
RW-7(C)	Off-Site	11-18-82	12-01-82
RW-9(C)	Off-Site	01-05-83	09-06-88
RW-12(B)	Off-Site	04-14-83	07-22-83
RW-14(B)	Off-Site	11-10-83	10-23-84
RW-16(A)	On-Site	01-24-83	01-13-84
RW-19(B)	Off-Site	07-19-83	*
RW-20(B)	Off-Site	04-12-84	10-26-87
RW-22(B)	Off-Site	02-10-84	*
RW-23(A)	On-Site	02-22-84	***
RW-25(B)	Off-Site	06-27-84	*
RW-27(B)	Off-Site	10-30-87	*
WCC-1(B)	On-Site	04-25-84	09-01-87
WCC-2(B)	On-Site	04-30-84	07-30-87
WCC-10(A)	On-Site	05-11-84	12-20-84
WCC-12(A)	On-Site	10-21-82	12-20-84
WCC-18(C)	Off-Site	05-04-82	10-13-84
WCC-20(B)	On-Site	12-83	*
WCC-32(C)	On-Site	05-18-82	09-12-84
WCC-41(A)	On-Site	01-19-82	01-13-84
GO-13(M)	Off-Site	NA**	09-29-86
17N1(C)	Off-Site	NA	04-22-83
17L4(B)	Off-Site	NA	10-03-84
17N11(M)	Off-Site	NA	07-10-87
18J1(M)	Off-Site	NA	07-03-84

* Well remains active in ground-water extraction program as of 12-30-88.
** Private well, not available.
*** Well RW-23(A) was modified for the in-situ soil aeration pilot study and currently pumps intermittently. Well RW-23(A) was most recently active in the ground-water extraction program in November 1984.

Aquifer testing was conducted to aid in the design and evaluation of the hydraulic control system and other remedial actions. These aquifer test results and other data were used to select recovery well locations. The recovery well locations appear to have been chosen to be dispersed throughout the initial contaminant plume in a line running west northwest of the Fairchild plant. Most wells were installed in the B and C aquifers. There is also a line of recovery/observation wells installed parallel to San Ignacio Avenue between Santa Teresa Boulevard and Via de Oro. This line of wells may have been installed to prevent further westward migration of the plume. The pump rates seem to

have been chosen to create a zone of hydraulic capture large enough to include the entire plume. As the plume size decreased, wells were removed from service as detailed in Table 1 and the total pumpage decreased as a result. Three of the six operating wells shown in Table 1 are within the December 1988 10 ppb TCA plume.

Observation wells were installed to evaluate the effectiveness of the IRMs. Water levels in the observation wells were measured on a monthly basis, and the observation wells were sampled and analyzed for contaminants biweekly, monthly, and quarterly.

EVALUATION OF PERFORMANCE

Implementation of the IRMs at the Fairchild facility appear to have changed the ground-water flow patterns. Ground-water pumping operations lowered the water levels in the A, B, and C aquifers, and created cones or troughs of depression around the pumping recovery wells. These cones of depression appear to be creating flow patterns that will eventually capture most of the contaminant plume. Although some stagnation areas are evident, the remediation system seems to be hydraulically successful. A potentiometric surface map of the B aquifer based on water level data collected in December 1987 and December 1988, is shown in Figure 7. It shows a trough in the potentiometric surface that plunges to the northwest. Ground-water flow directions are locally inward towards the trough in the potentiometric surface. There is also evidence that pumping has affected the potentiometric surface in aquifer C west of the Fairchild facility (see Figure 8).

The A aquifer was dewatered in most onsite areas by early 1984. The slurry cutoff wall, constructed by mid-1986, removed the potential for Coyote Creek and the Santa Clara Valley Water District percolation ponds to resaturate the A and B aquifers within the onsite area. The B aquifer system has changed from a confined condition to an unconfined condition and water levels have declined 23 to 38 feet below the April 1982 levels. Water levels in the C aquifer have declined approximately 40 feet below initial levels, but the aquifer remains confined. Vertical gradients in December 1988 were upward from the D aquifer to the C aquifer.

Direct evidence of a reduction in contaminant concentrations in all three aquifers is provided by water quality data. Maps of contaminant contours, time series plots for individual wells, and a comparison of maximum concentration at the site in 1982 and 1987 as shown in Table 2, all suggest progress in restoration of the aquifer system.

Table 2
MAXIMUM SITE CHEMICAL CONCENTRATIONS IN GROUND WATER
1982 VERSUS 1987

	1982 Maximum Chemical Concentrations			1987 Maximum Chemical Concentrations		
Chemical	Concentration (ppb)	Well Number	Date	Concentration (ppb)	Well Number	Date
TCA	1,900,000	WCC-41(A)	06/23/82	100,000	WCC-17(B)	05/13/87
Xylene	76,000,000	WCC-41(A)	06/21/82	16,000	WCC-17(B)	05/13/87
Acetone	99,000,000	WCC-41(A)	06/15/82	88,000	WCC-11(B)	07/08/87
IPA	45,000,000	WCC-41(A)	06/10/82	5,700	WCC-17(B)	05/13/87
Freon-113	46,000	WCC-41(A)	10/12/82	12.0	WCC-20(B)	01/22/87
1,1-DCE	53,000	WCC-41(A)	08/02/82	14,000	WCC-17(B)	05/13/87
PCE	2,700	WCC-41(A)	03/10/83*	330	WCC-17(B)	04/27/87

*Ground water was not tested for PCE in 1982.

Because well WCC-41(A) became dewatered and was last sampled in 1984, a direct comparison of 1982 and 1987 concentrations in WCC-41(A) is not possible. It should be noted, however, that the inability to take a ground-water sample because of aquifer dewatering does not indicate that the aquifer has been restored in the dewatered zone. Some contamination has been retained by the solid phase of the aquifer, and this residual contamination could recontaminate the ground water once the aquifer is resaturated. However, the application of in situ aeration to the A aquifer and the A-B aquitard has substantially decreased the level of chemical residues remaining in the dewatered zone.

Only three wells in the A aquifer have been sampled since February 1986 because of aquifer dewatering. Two of the wells, 82(A) and WCC-4(A), are immediately outside of the slurry cutoff wall near the northeast and southwest corners. TCA was detected in 82(A) well at a concentration of 0.7 ppb in September 1987, versus 24.0 ppb in October 1984. The concentration of TCA in well WCC-4(A) was 4.0 ppb in April

1982. No contaminants were detected when WCC-4(A) was last sampled in September 1986. The third well, 23(A), located approximately 100 feet downgradient of the former leaking waste solvent tank within the slurry wall contained 54 ppb TCA and 46 ppb 1,1-DCE in September 1987. These concentrations were lower than those found in the same well four months earlier.

Because well WCC-41(A) became dewatered and was last sampled in 1984, a direct comparison of 1982 and 1987 concentrations in WCC-41(A) is not possible.

TCA concentrations at the onsite B aquifer well locations have decreased from a maximum of 670,000 ppb in 1982 to a maximum of 220 ppb in 1987, a decrease of about three orders of magnitude since remediation began. As of December 1987, TCA concentrations in offsite B aquifer wells were less than 100 ppb, compared to over 1,000 ppb before startup. The contours of the December 1987 and December 1988 concentrations for TCA at the site are shown in Figure 4 along with 1982 contours. These results show a substantial reduction in the size and concentration of the contaminant plume in the B aquifer when compared to the 1982 concentration contours.

Time series plots of TCA concentrations in aquifer B are shown in Figures 9 through 12, in order of decreasing distance from the Fairchild facility. These individual results show substantial decreases in point concentrations of TCA that support the general observation of plume reduction. Well RW-14 (Figure 9) is a 10-inch pumping well located northwest of the intersection of San Ignacio Ave. and Santa Teresa Blvd. (see Figure 4). The concentration of TCA in well RW-14 declined to below detection limits by early 1985 from an initial concentration of about 9 ppb. Well RW-2 (Figure 10) is a 16-inch pumping well located within 100 feet of Via del Oro on the southwest side. Figure 10 shows that TCA declined from an initial concentration of over 1,000 ppb in 1982 to a December 1988 concentration of about 10 ppb. A decline from over 1000 ppb in 1982 to less than 100 ppb in 1988 is shown in Figure 11 for observation well 78, located about 600 feet southeast of RW-2 along Via del Oro. Well WCC-02 (Figure 12) is a 6-inch pumping well located west of the plant just inward of the slurry wall boundary. The time series plot of well WCC-02

shows peaks in TCA concentration exceeding 3000 ppb in 1982 and 1985, each followed by a decline to under 300 ppb. The reason for the second peak is unclear.

The concentration of 1,1-DCE in onsite B aquifer wells decreased from a maximum of 6,400 ppb to a maximum of 300 ppb from 1982 to 1987. The concentration of 1,1-DCE declined to less than 10 ppb for all offsite wells by December 1987 (see Figure 5). Freon-113 decreased from 7,200 ppb to 7 ppb in onsite wells and is no longer detected in offsite B aquifer wells.

In aquifer C, concentrations of TCA decreased from over 1000 ppb in 1982 to less than 5 ppb in December 1987 (see Figure 6). A time series plot of TCA concentration in observation well 80 completed in the C aquifer west of the intersection of Via del Oro and Great Oaks Blvd. is shown in Figure 13. Concentrations of 1,1-DCE decreased from about 3 ppb in 1982 to below detection levels by 1988. Freon-113 decreased from 7.1 ppb to below detection levels from 1982 to 1987.

Further evidence of the progress of aquifer restoration at the site is shown in Figure 14, a graph of the change in contaminant inventory from 1982 to mid-1987. The total mass of TCA, acetone, IPA, and xylene removed from the subsurface as a result of ground-water extraction from January 1982 through May 1987 for all wells in the system was approximately 90,000 pounds. The total mass of TCA removed and the total volume of ground water extracted from all wells is shown in Figure 15. The initial mass of contaminants present in the aquifer system was not estimated, so an assessment of the percent reduction in contaminant inventory cannot be made.

SUMMARY OF REMEDIATION

The interim remedial measures implemented at the Fairchild site are summarized as follows:

- There are four aquifers beneath the Fairchild site identified as aquifers A, B, C, and D. Aquifers A, B, and C were contaminated with organic solvents before remediation began.

- A slurry wall was constructed in 1986 around the periphery of the Fairchild property down to the bottom of the B aquifer to isolate the area of highest ground-water contamination. This was done to extract contaminated ground water as efficiently as possible by preventing the extraction of clean recharge water originating from nearby streams. As a result of the high withdrawal rate, the A aquifer was dewatered within the slurry wall area and ground-water samples could no longer be collected from most wells. It is important to remember that the inability to take a sample should not be equated with cleanup. Once water levels are allowed to rise back to their natural levels, any contaminants that remain sorbed to the solid phase could recontaminate the ground water. The slurry wall will probably have to be maintained for many years to insure the effectiveness of its containment ability.

- Recovery wells were installed in the A, B, and C aquifers. The first extraction well began pumping on January 16, 1982.

- Seven years of operation have substantially reduced the concentration of contaminants in the A, B, and C aquifers. Time series plots show that chemical concentrations in the A, B, and C aquifers have decreased by as much as three orders of magnitude. The areal extent of the contaminant plumes in all aquifers have been reduced substantially. Almost 90,000 pounds of solvent (TCA, IPA, acetone, and xylene) have been removed from the subsurface.

BIBLIOGRAPHY

Canonie Environmental. October 1988. Revised Draft Report, Remedial Action Plan, Fairchild Semiconductor Corporation, San Jose Facility.

WDCR08/005.50

CASE STUDY 7

General Mills, Inc.
Minneapolis, Minnesota

CASE STUDY FOR GENERAL MILLS SITE

BACKGROUND OF THE PROBLEM

The General Mills site is northeast of downtown Minneapolis on Hennepin Avenue, approximately 1 mile northeast of the Mississippi River (Figure 1). The disposal of solvents from a General Mills research laboratory in a soil absorption pit on the site resulted in the spread of hazardous chemicals, predominantly volatile organic compounds (VOCs), to ground water in two underlying aquifers. In accordance with a Response Order by consent between General Mills and the Minnesota Pollution Control Agency (MNPCA), ground-water extraction was implemented in both aquifers to prevent additional contaminant migration and to restore ground-water quality to acceptable levels. The extraction system has been in continuous operation since late 1985.

SITE HISTORY

General Mills owned and operated the site between 1930 and 1977 as a food research laboratory. In 1947, General Mills began conducting chemical research at the facility in addition to food research. Beginning about 1947 and until about 1962, laboratory solvents from the research operation were discharged to a disposal pit in the southeast corner of the General Mills property. In August 1977, the property was sold to Henkel Corporation, but under Minnesota law, General Mills retained the responsibility for environmental problems arising from its operations at the site.

In 1981, the MNPCA was notified of conditions at the site. At that time, General Mills was conducting an investigation of the pit. Since then, General Mills, in consultation with the MNPCA, has continued to investigate soil and water contamination in the vicinity of the pit.

A Consent Order, specifying installation of a ground-water extraction and treatment system, was signed in October 1984. General Mills retained Barr Engineering as consultants for the design and operation of the system. In January 1985, Barr Engineering submitted a plan for the extraction and treatment system. The system began operating in the fall of 1985 and has been in operation continuously since then, except for brief shutdowns for maintenance and repair. Yearly progress reports have been submitted to the MNPCA, with the latest covering the year 1988.

GEOLOGY

A generalized geologic column for the region is shown in Figure 2. The subsurface materials at the site comprise 30 to 50 feet of unconsolidated alluvial and glacial deposits, underlain by a thick sequence of sandstone, shale, limestone, and dolomite.

A geologic cross-section of the alluvial and glacial deposits in the site vicinity is shown on Figure 3. (The location of the cross-section, A-A', is shown on Figure 4.) The soils near the absorption pit consist of 2 to 8 feet of fill over peat. The fill is mostly silty sand; however, gravel, silty clay, ash, cinders, concrete, brick, and organic soils are also present. The peat thickness ranges from zero to 10 feet. The peat is underlain by 30 to 40 feet of fine-to-medium alluvial sand. Directly below the site surface and to the south and west, the alluvial sand is underlain by up to 10 feet of clay till.

The bedrock beneath the site consists of Cambrian and Ordovician sedimentary rocks of marine origin. In order of increasing depth, the formations of interest are the Decorah Shale, the Platteville Limestone, the Glenwood Shale, and the St. Peter Sandstone. The units underlying the St. Peter Sandstone--the Prairie du Chien Group and the deeper Cambrian sandstones--are not believed to have been contaminated by the site.

HYDROGEOLOGY

As shown in Figure 2, the site is underlain by numerous water-bearing formations. Only the upper four aquifers are of direct concern to the General Mills aquifer remediation. In order of increasing depth, these aquifers are the shallow unconsolidated alluvial and glacial deposits, the Carimona Member of the Plattevile Formation, the Magnolia Member of the Platteville Formation, and the St. Peter Sandstone.

Ground water in the shallow unconsolidated aquifer, also called the glacial drift aquifer, is unconfined and flows southwest toward the Mississippi River. A profile of the water table parallel to the direction of flow is shown in Figure 3. Contours of the water table elevation in the vicinity of the site in March 1984 are shown in Figure 4. The hydraulic conductivity of the alluvial sand has been estimated on the basis of grain-size analysis to be between 2×10^{-3} and 5×10^{-2} centimeters per second (cm/s). An aquifer test performed at well 109 resulted in a hydraulic conductivity estimate of 2.4×10^{-3} cm/s.

The glacial drift aquifer is separated from the underlying bedrock aquifers by a layer of glacial till and by the Decorah Shale, where present. These layers serve hydraulically as aquitards. They impede, but do not entirely prevent, the downward flow of ground water to the lower aquifers. The natural piezometric head in the glacial drift aquifer at the General Mills site is about 10 feet higher than the head in the underlying Carimona Member, indicating the potential for downward flow.

The Carimona Member of the Platteville Formation is 3 to 4 feet thick in the vicinity of the site. It is composed of micrite, an extremely fine-grained limestone. Regionally, the Carimona Member has been found to be highly fractured and weathered. Figure 5 shows the locations of monitoring wells completed in this stratum and the water levels measured in them during an aquifer test conducted in well 108 in January 1984. The results of this aquifer test were difficult to interpret, and no unambiguous estimate of its transmissivity has been made. The aquifer test was apparently used primarily to demonstrate the ability of well 108 to produce drawdown over a considerable area.

The piezometric surface near the site in the Carimona aquifer is relatively flat, with a possible trend toward flow to the southeast. The Carimona Member is separated from the underlying Magnolia Member of the Platteville Formation by a very thin bentonite layer that retards downward flow. The piezometric head in the Carimona Member is generally 4 to 5 feet higher than in the Magnolia Member in the vicinity of the site, indicating the potential for downward flow.

The Magnolia Member of the Platteville Formation is 8 to 9 feet thick near the General Mills site. Flow is toward the northwest, driven by a horizontal component of hydraulic gradient of about 1 foot in 300 feet (0.0033 ft/ft). The hydraulic conductivity of this layer has not been reported. Below the Magnolia Member lie alternating layers of shale, limestone, and dolomite, which act as aquitard layers. The total thickness of these three aquitard layers is 22 to 27 feet. The head difference between the Magnolia Member and the underlying St. Peter Sandstone is approximately 55 feet in the area of the site, with flow in the downward direction.

The St. Peter Sandstone is 150 to 170 feet thick. Flow in this aquifer is to the southwest toward the Mississippi River, with gradients of approximately 1 foot in 135 feet (0.0074 ft/ft). The St. Peter Sandstone is used to a limited extent for water supply, although it is considered a low-yielding aquifer. The major water supply aquifers in

the area are the Prairie du Chien and Jordan Sandstone aquifers.

WASTE CHARACTERISTICS AND POTENTIAL SOURCES

The primary source of the ground-water contamination at the site was a disposal pit located in the southeast corner of the property. The pit is believed to have been constructed from three perforated 55-gallon drums that were stacked on top of one another and buried in the ground, with the bottom of the deepest drum 10 to 12 feet below the ground surface. Laboratory solvents from the chemical research facility were routinely disposed of in the pit between 1947 and 1962. It is estimated that about 1,000 gallons of waste per year may have been poured into the pit.

Soil and ground-water sampling near the disposal pit indicated that the subsurface was contaminated with a variety of chlorinated organic solvents, including trichloroethylene (TCE), tetrachloroethylene (PCE), 1,1,1-trichloroethane (TCA), and various degradation products of these compounds. Total VOC concentrations of up to 2,000 parts per million were found in the soils near the pits (NMPCA, 1989). Benzene, toluene, and xylene were also found but are not the compounds of major concern at the site. The most prevalent compound in the ground water is TCE.

General Mills proposed to excavate approximately 1,200 cubic yards of contaminated soil surrounding the disposal pit. However, this proposal was rejected by the MNPCA, and the contaminated soils remained in place after closure of the pit (MNPCA, 1989).

Ground-water contamination has been detected both in the shallow aquifer and in the Carimona bedrock aquifer. The maximum TCE concentrations that have been found in these aquifers were 1,300 parts per billion (ppb) in the shallow glacial drift aquifer (well 3) and 2,300 ppb in the Carimona aquifer (well WW). The distribution of total VOCs in the shallow aquifer in March 1984 is shown in Figure 4.

TCE has also been found in lower concentrations in the Magnolia Member and the St. Peter Sandstone. The maximum concentration found in the Magnolia was 440 ppb. TCE concentrations of less than 100 ppb have been found in the St. Peter Sandstone.

Based on the method of waste disposal at the site and the high concentrations of VOCs found in the soil, the presence of residual contamination in the form of nonaqueous phase liquids (NAPLs) could be expected. Because the chlorinated organic solvents are more dense than water, they would be

expected to sink through the ground water and form pools in the low areas of the underlying low conductivity layers, if they were discharged to the pit in sufficient quantity. However, there has apparently been no effort to detect the presence of NAPLs at this site.

The adsorptive partitioning of contaminants between the soil and the water in the vicinity of the disposal pit represents another potentially important source of residual contamination. TCE has a soil-water distribution coefficient of 152 milliliters per gram and is considered a moderately mobile compound (Fetter, 1988). In soil with an organic content of 0.3 percent, it would have a retardation coefficient of 4 to 6. The organic carbon content of the soils at the General Mills site have not been reported. However, a peat layer up to 10 feet thick has been reported below the surficial fill materials at the site. Peat is almost totally organic, and if it was present below the disposal pit it could have adsorbed a large percentage of the contaminants and could continue to release them slowly as leachate for a very long time. No mention of contaminant adsorption appear in any of the site documents that have been made available for review.

REMEDIATION

SELECTION AND DESIGN OF THE REMEDY

The remedial action was designed to minimize further migration of volatile organic hydrocarbons, particularly TCE, and to improve the quality of the ground water in the shallow aquifer and the Platteville Formation. To achieve this, separate extraction systems were installed for each aquifer system.

Extraction in the Shallow Aquifer

The cleanup objective for the shallow aquifer is to reduce the TCE concentrations of the ground water to less than 270 ppb and to minimize further downward migration of contaminants. The containment objective of the system is to prevent migration of ground water containing greater than 270 ppb of TCE.

Five extraction wells were installed to achieve the cleanup and containment objectives for the shallow aquifers. The locations and design capture zones are shown in Figure 6. Wells 109 and 110 are in or near the source area. As such, their primary purpose is aquifer restoration.

Wells 111, 112, and 113 are located farther downgradient and are intended to intercept the central part of the contamin-

ant plume, where concentrations are higher than 270 ppb. These wells are located just upgradient of a ridge in the underlying till that partially restricts the southwest flow in the glacial drift aquifer. This location was chosen because the natural gradient is relatively low and the saturated thickness of the glacial drift is great enough to allow significant drawdowns to be developed in the extraction wells. The hydraulic conductivity derived from the aquifer test was used in a two-dimensional analytic element model to study the capture zones that could be produced by these wells. It was estimated that pumping each well at about 50 gallons per minute (gpm) would result in a capture zone extending about 100 feet to either side of the well.

Extraction in the Carimona Aquifer

The cleanup objective for the Carimona aquifer is to reduce the concentration of TCE in the ground water to less than 27 ppb.

The extraction system consists of one well (108), which is open to the full thickness of the Carimona Member of the Platteville Formation (798.8 to 802.3 feet above MSL). A pumping test of this well demonstrated that a pumping rate of 50 gpm would create a capture zone that extended beyond the monitoring network.

The extraction system in the Carimona Member is also expected to induce upward leakage from the Magnolia Member of the Platteville Formation, thus minimizing solvent migration through the Magnolia Member.

Treatment System

Ground water removed from the source area extraction wells--109 and 110 in shallow system and 108 in the bedrock system--is treated by air stripping before being discharged to the Minneapolis storm sewer network. Ground water removed from wells 111, 112, and 113 is discharged directly to the storm sewer.

EVALUATION OF SYSTEM PERFORMANCE

Shallow Aquifer

Since the extraction system started operating in late 1985, the wells have been operated continuously at their maximum sustainable yield. This yield varies among wells, depending on either the pump capacity or the local productivity of the aquifer. The combined average withdrawal rate of wells 109 and 110 in the source area has been about 70 gpm. The

combined average rate for the three downgradient wells, 111, 112, and 113, has been about 300 gpm.

Figure 7 shows the water-level distribution in the shallow aquifer as measured in April 1988. A fairly distinct capture zone can be seen in the vicinity of the three downgradient wells, but the capture zones of the two source-area wells are not so clearly discernable. The operators of the system report that this water table configuration is representative of the flow patterns that were established in the first year of operation and have been maintained ever since (Barr, 1988). The operators feel that the high concentration zones of the plume have been controlled successfully despite the absence of a distinct capture zone near the source-area wells.

Figure 8 shows the distribution of total VOC concentrations measured in the shallow aquifer wells in April 1988. Sampling rounds conducted later in 1988 included fewer wells than in April and may have been less representative because of unusually low water levels caused by a severe drought. The figure shows that high concentrations persist along the central axis of the plume after more than 2 years of extraction. Some of the wells shown in Figure 8 did not exist or were not sampled before the system started, so a comparison between Figures 4 and 8 is difficult. A direct comparison of the 1984 and 1988 total VOC concentrations in several of the shallow aquifer wells is given in Table 1.

Table 1
COMPARISON OF 1984 AND 1988 TOTAL VOC CONCENTRATIONS IN SELECTED SHALLOW AQUIFER WELLS

Well	Concentrations in ppb March 1984	April 1988
Q	56	6.2
S	850	520
T	BDL*	BDL*
V	100	180
W	11	67

*Below detection limit.

Table 1 shows that total VOC concentrations have decreased in some wells and increased in others since the extraction system has been in operation. The major contributor to the total VOC concentrations continues to be TCE. Table 2 lists

the concentrations of individual VOCs measured in the shallow aquifer during 1988. The TCE concentrations in the central portion of the contaminant plume were well above the target level of 270 ppb in April 1988. They appear to have declined considerably later in the year. The effect that the drought in 1988 may have had on these declines is not yet known.

Time-series plots of total VOC concentration in some of the shallow aquifer monitoring wells are shown in Figures 9 and 10. As shown in Figure 9, wells 3 and S appear to show very similar and nearly simultaneous variations in concentration, even though they are approximately 1,000 feet apart. Both wells are located along the centerline of the plume. Well B, located upgradient of the source zone, appears to show a fairly steady reduction in concentrations. Well V, located downgradient of the plume control wells 111, 112, and 113, appears to have relatively steady concentrations. The latest measurement in this well is lower, but a significant declining trend cannot be inferred from a single sample.

Contaminant concentrations in the shallow aquifer extraction wells have not been reported.

Carimona Aquifer

The extraction well in the Carimona aquifer, well 108, has been operated continuously at rates varying between 20 and 30 gpm since December 1985. Figure 11 shows the water levels measured in the Carimona monitoring wells in April 1988. Figure 11 appears to indicate that the zone of capture of well 108 extends to a radius of several hundred feet in all directions, although the inward radial gradients are not very strong. The Carimona aquifer naturally has relatively flat gradients in this area. The lack of a strong regional gradient makes establishment of a capture zone easier. However, the Carimona is thought to behave as a leaky (or semi-confined) aquifer, which can severely limit the radius of influence of a recovery well. The leakage characteristics do not seem to have been quantified, even though an aquifer test was run on well 108 in 1984.

One of the objectives of the Carimona aquifer extraction well was to minimize further downward flow of contaminants to the underlying Magnolia Member of the Platteville Formation by reversing the natural vertical gradients to induce upward flow. Figure 12 shows the water levels measured in the Magnolia monitoring wells in April 1988. With the exception of the water level measured in well 108,

all of the Carimona water levels are still higher than the Magnolia water levels in the vicinity of the site.

Figure 13 shows the distribution of TCE concentrations measured in the Carimona monitoring wells in April 1988. The measurements show that the plume of concentrations above the target level of 27 ppb extended at least 250 feet from the source area in the north and probably more than 1,000 feet from the source in the east, west, and south. No map of contaminant distributions in the Carimona before the start of extraction is available for comparison (MNPCA, 1989). However, Figures 14 and 15 show time-series plots of TCE concentrations in six of the Carimona wells. Figure 14 shows the concentration variations in three wells located in the central plume area, including the extraction well (well 108). In general, the concentrations in these wells have dropped considerably. Concentrations in well BB, to the north of the source area, and in the extraction well may show a continuing downward trend. Concentrations in well WW, to the southeast of the source area, appear to have leveled off at around 300 ppb. Figure 15 shows TCE concentration variations in wells 10, 11, and 13 on the periphery of the plume to the southeast. The concentration of TCE in well 10 has been reduce from relatively high initial levels, but appears to have stabilized at around 60 ppb. This is still higher than the target concentration of 27 ppb. Concentrations in well 11 started lower than in well 10, but have likewise stabilized at levels above the cleanup target.

SUMMARY OF REMEDIATION

A multi-aquifer ground-water system below the General Mills site has been contaminated with chlorinated organic solvents that were poured into a disposal pit over a period of 19 years. The pit has been removed, but the contaminated soils surrounding and below it were left in place. These materials represent a continuing source of contaminant leaching to the underlying aquifers that may take a very long time to exhaust.

In addition, it is likely that chlorinated organics may be present in one or more of the aquifers in the form of NAPLs. However, this has apparently not been investigated. The chlorinated solvents are more dense than water and, if they are present as NAPLs, they would probably have sunk to the bottom of any aquifer that they entered. These dense NAPLs would also represent a potentially long-lasting source of continued ground-water contamination.

A multi-well extraction system was installed in the shallow glacial drift aquifer in 1985 with the objectives of minimizing further downgradient migration of contamination and eventually restoring water quality. The water quality goal for both migration control and aquifer cleanup has been set at 270 ppb in the glacial drift aquifer.

The extraction wells in the shallow aquifer have been operated continuously since 1985 at their design pumping rates. The three downgradient wells appear to have established capture zones that block the migration of TCE at concentrations greater than 270 ppb. However, the vertical gradients over the majority of the plume area have not been reversed, so that contaminants can continue to move downward into the underlying aquifers.

No schedule for aquifer restoration was projected during the design of the system. During the first 2 years of operation, the concentrations along the axis of the shallow aquifer plume were not reduced dramatically. During early 1988, the concentrations appear to have declined substantially. However, 1988 was a year of severe drought, and the declining water levels in the shallow aquifer and reduced infiltration may have had some effect on these concentrations.

A single extraction well was installed near the contaminant source area in the Carimona bedrock aquifer. Its objectives were to establish a capture zone that would prevent further migration of contaminants and to restore water quality by reducing TCE concentrations to less than 27 ppb. It is clear that the hydraulic effects of this well are limited to a fairly small radius around the source zone. Except in the immediate vicinity of the well, the vertical hydraulic gradients have not been reversed. The contaminant plume in the Carimona aquifer remains large, and throughout most of the contaminated area the potential remains for continued downward migration of contaminants to lower aquifers.

Substantial concentration reductions were achieved initially in several of the centrally located Carimona monitoring wells, but the TCE concentrations have generally stabilized at levels well above the cleanup target of 27 ppb.

It appears unlikely that the aquifer cleanup goals will be achieved in the near future in either aquifer. This is because of to the continuing contaminant source that exists in the soils around the former disposal pit, and perhaps also because of the presence of NAPLs in one or more of the aquifers.

BIBLIOGRAPHY

Minnesota Pollution Control Agency, State of Minnesota. Response Order by Consent In the Matter of General Mills, Inc., dated October 23, 1984.

Barr Engineering Company. "Groundwater Pump-out System Plan, General Mills East Hennepin Avenue Site." January 1985, Minneapolis, Minnesota.

Barr Engineering Company. "1988 Annual Report, General Mills East Hennepin Avenue Site." January 1989, Minneapolis, Minnesota.

Minnesota Pollution Control Agency (MNPCA). Personal communication with Fred Campbell, April 25, 1989.

Fetter, C.W. Applied Hydrogeology. Merrill Publishing Co., Columbus, Ohio. 1988.

WDCR432/042.50

CASE STUDY 8

GenRad Corporation
Bolton, Massachusetts

CASE STUDY FOR THE GENRAD SITE

BACKGROUND OF THE PROBLEM

The GenRad Corporation facility is located in Bolton, Worchester County, Massachusetts (see Figure 1). Operating as a manufacturer of scientific and medical equipment, the facility generates metal hydroxide sludge and industrial solvent wastewater. Prior to 1984, these by-products were discharged to onsite surface impoundments. In 1984, in compliance with RCRA standards, a closure plan was developed which included ground-water investigations. Two distinct plumes of contamination were discovered: a northern plume originating from the waste treatment area, and an eastern plume in the area of the surface impoundments, adjacent to the eastern property border. Source removal of the contaminants appears to have stabilized the northern plume, and no remediation has been planned for it. The eastern plume was migrating offsite, across town/county lines. A ground-water remediation program was proposed to capture and treat the eastern plume, with the treated water being recharged back to the site. The first phase of the program, a pilot ground-water treatment system, was initiated in remediation facility, was completed in 1987. The primary contaminant of concern in the ground-water is trichloroethylene (TCE).

SITE HISTORY

The manufacturing process at the GenRad facility includes metal electroplating, and produces industrial solvent wastewater and metal hydroxide sludge as by-products. Prior to 1984, the sludge by-product was pumped to a drying bed and allowed to accumulate. Wastewater was treated, combined with sanitary wastewater effluent, and recharged to the ground water through surface impoundments that functioned as rapid sand infiltration beds. These surface impoundments are located to the east of the plant facility adjacent to the town/county lines (see Figure 2).

To comply with RCRA standards, GenRad initiated source removal remediation measures in 1984. These measures included removal of contaminated soil and sludge, excavation of underground storage tanks, and, closure and demolition of the treatment facility. Initial site investigations revealed that the ground water beneath the sludge drying area and the surface impoundments was contaminated with a variety of volatile organic compounds (VOCs), of which trichloroethylene (TCE) was the most prevalent. No estimate was made of the total quantity of VOCs dissolved in the ground water beneath the site.

Ground-water remediation and containment options were considered after more detailed studies revealed the presence of two distinct plumes of VOCs, one of which was beginning to move offsite across the town/county boundary. A pilot study was initiated in the summer of 1986 to provide preliminary information and hydrogeologic data. Operation of a long-term ground-water extraction and treatment facility began in 1987.

GEOLOGY

The GenRad facility is located in a geologic setting composed of unconsolidated glacial deposits overlying Carboniferous Age metamorphic rocks of the Nshoba Formation. No bedrock is exposed at the site although numerous outcrops are visible to the west and, to a lesser extent, to the east and south of the facility. In low-lying areas, such as along Great Brook and its tributaries, several feet of organic sediments overlie the sands and gravels. In general, approximately 15 to 20 feet of sand and gravel overlies 11 feet of glacial till, which is underlain by bedrock. The thickness of sediments is quite variable across the site and only two borings have penetrated the entire thickness of the till.

Figures 3, 4, and 5 show geologic cross sections of the site, the locations of which are shown in Figure 2. Transect A-A' (see Figure 3) is a view across an apparent glacial-fluvial, paleo-channel. Deposits of sand and gravel thicken towards the center of the former stream channel. This channel appears to have an orientation parallel to that of Great Brook. Section B-B' (see Figure 4) shows a uniform thickness of sand and gravel, overlain by 2 to 8 feet of organic deposits. Section C-C' (see Figure 5) shows the thickness of sand and gravel underneath the sand infiltration beds.

HYDROGEOLOGY

Hydrogeologic characteristics of subsurface strata, including transmissivity, porosity, and hydraulic conductivity were evaluated to help understand the nature of the underlying aquifer system. Estimates of these hydrogeologic parameters were obtained through aquifer tests, empirical correlations, and previously tabulated values. Transmissivity was estimated to range between 350 ft^2/day and 10,000 ft^2/day, depending on the nature and thickness of permeable sediments. A value of 2,500 ft^2/day was estimated for the area near the extraction wells.

During the field studies, two boreholes were drilled to bedrock. Although no faults were mapped in the area, a

4-foot core sample taken at borehole location G-IV-4b was found to be slightly to moderately fractured. No rock permeability tests were conducted, but GenRad's engineering consultants estimated the hydraulic conductivities of the bedrock to be similar to that of glacial till, which is low relative to sand and gravel. However, the bedrock is known to yield water to private water supply wells in the area.

The depth to ground water at the GenRad facility is generally about 5 feet but varies between 0 and 20 feet. The sand and gravel aquifer appear to be unconfined within the site area, with ground-water flow typically following topographic gradients. Figure 6 shows the distribution of equipotential lines across the site. The contours shown in this figure were based on water levels measured at different times of the year. Therefore, the flow directions interpreted by the primary consulting engineers may be misleading. Based on estimates of hydrogeologic parameters, transport velocities beneath the site were estimated to be between 0.5 and 0.8 feet/day.

WASTE CHARACTERISTICS AND POTENTIAL SOURCES

Two distinct plumes of VOC contamination are present at the site: a northern plume emanating from the former waste treatment site, and an eastern plume near the surface impoundments. Figure 7 shows the plume configurations in early 1987. TCE is the most prevalent contaminant in both plumes. Secondary contaminants of concern at the site include: 1,1-dichloroethane, 1,1-dichloroethylene, methylene chloride, trans-1,2-dichloroethylene, 1,1,1-trichloroethane, tetrachloroethylene, and vinyl chloride. In 1986, the maximum concentrations of total VOCs in the northern and eastern plumes exceeded 5,000 parts per billion (ppb) and 1,000 ppb, respectively. However, only 10 percent of the ground-water samples from the site had concentrations over 500 ppb at that time. The vertical distribution of VOCs in the ground water is relatively uniform with depth except in the area of the northern plume near Great Brook, where complicated flow patterns exist. Only one of the two wells installed into bedrock has shown contamination, with concentrations between 10 and 50 ppb.

Migration of the two plumes was examined in 1986 by comparing concentration distributions over time. Concentrations of total volatile organics in the northern plume appear to have been reduced naturally since source removal was completed. Figure 8 shows the variation of TCE concentrations in one well in this plume over a 4-year period. The primary consultants at the site suggested that this plume had been stabilized by discharging into Great Brook rather than migrating offsite.

REMEDIATION

SELECTION AND DESIGN OF THE REMEDY

Objectives of Remediation

As part of the closure plan, the Massachusetts Department of Environmental Quality Engineering (DEQE) required GenRad to remediate ground water associated with the site to a level commensurate with primary drinking water standards. Since contamination in the northern plume did not appear to be a threat due to dilution factors, no immediate remediation was planned for this area. Remediation was recommended for the eastern plume, which continued to move off-site across a town/county boundary. A ground-water extraction system was proposed to capture the eastern plume, treat the ground water, and recharge it back to the site.

System Configuration

A pilot extraction well, well PW-A, was installed in the first phase of the remediation to gather information that would help in the design of the final system. Specific hydrogeologic information gathered during the Phase I pilot ground-water study was used in the calibration of a computer model (MODFLOW). This model was used to assess the impact of a two well extraction system on the ground-water flow regime. Field surveys and information provided by the model were used to design and locate two extraction wells, wells PW-B and PW-C, for Phase II remediation. Field engineers predicted that these two wells (see Figure 2), each pumping at 15 gpm or greater, would create a capture zone wide enough to contain the 10 ppb concentration front of the eastern plume. The optimum extraction rates were to be determined in the field after the wells commenced operation.

The Phase II system was designed to operate 75 percent of the year. Annual shutdown occurs during the coldest portions of the winter when temperatures drop below freezing for extended periods of time. All piping and surficial equipment are drained at the time of system shutdown.

A total of 16 monitoring locations are sampled on a quarterly basis to provide information on the size of the contaminant plumes and their relative movement. Inspection and maintenance of the system occurs on a daily, monthly, and quarterly basis depending on the type of inspection or maintenance required.

EVALUATION OF PERFORMANCE

The Phase II extraction system has been in operation since late 1987. Between late 1987 and early December 1988, 17 million gallons of water were extracted and treated from the two pumping wells. The zone of influence of the two extraction wells is thought to be large enough to capture the bulk of the eastern plume. Figure 9 shows the ground-water elevation contours shortly after the start of extraction. Figure 10 shows the ground-water elevation contours shortly after the system was shut down in November 1988.

Since extraction began, GenRad's consultants estimate there has been a 40 percent reduction of contaminants in the plume. This reduction has been attributed to both the current extraction system and in-situ biodegradation. Biodegradation is alleged to have occurred in areas where the contaminants are close to organic deposits and aquatic habitat. As of November 1988, the highest concentrations in the eastern plume were 143 ppb, compared to 990 ppb 2 years earlier. Figure 11 shows the variation of TCE concentrations in well PT-4 since the beginning of 1987. This well is located in the central portion of the eastern plume, about 200 feet upgradient of the extraction wells. Figure 12 shows the configuration of the contaminant plumes in November 1988, after approximately 1 year of extraction in the eastern plume.

Figure 13 shows the variation of the TCE concentrations in the ground water extracted during 1988. The quantity of TCE removed to date has not been reported by GenRad's engineers. However, analysis of the data shown in Figure 13 indicates that the extraction system removed a total of about 2.6 pounds of TCE from the aquifer during 1988. GenRad's consultants estimate that it will take at least 5 years to flush the two or three contaminant plume volumes they judge necessary to sufficiently lower contaminant concentrations.

SUMMARY OF REMEDIATION

The extraction and treatment system has been in operation at the GenRad facility since late 1987. The effectiveness of the remediation effort is still under review by the Massachusetts DEQE.

A remediation system is in operation only in the eastern plume, where the highest concentrations of total organics have varied between 200 and 1000 ppb. Although contaminant levels are higher in the northern plume, the natural discharge of ground water to Great Brook is thought to result in significant dilution of concentrations without

significantly degrading surface water quality. Contamination of the fractured bedrock beneath both plumes is thought to be insignificant at this time.

Two extraction wells, placed downgradient at the leading edge of the eastern plume appear to be hydraulically controlling plume migration. Depending on the duration of remediation, nearly all of the eastern contaminant plume should enter the extraction wells' capture zone. Removal efficiencies of VOCs in the system's stripping tower have been at or above 99 percent. Concentrations of total organics in the eastern plume have decreased approximately 40 percent since operations began. This was determined by quarterly monitoring of observation wells on the site. Approximately 17 million gallons of water have been treated since the operation began. The extraction system has removed a total of about 2.6 pounds of TCE from the aquifer.

It was predicted that two or three aquifer volumes need to be flushed before concentrations will be low enough to warrant termination of the treatment operation. A summary of progress toward this goal is not yet available but is expected by early spring 1989.

BIBLIOGRAPHY

Goldberg, Zoino and Associates. 1984. Preliminary Environmental/Geohydrology Study, GenRad, Bolton. File No. G-3863.3.

Goldberg, Zoino and Associates. 1986. Specifications for Installation of a Groundwater Extraction/Recharge System, GenRad, Bolton. File No. G-3863.6.

Goldberg, Zoino and Associates. 1986. Groundwater Remediation Program: Phase II System and Post Closure Plan, GenRad, Bolton. File No. G-3863.6.

Environmental Applications, Inc. 1986. Pilot Groundwater Treatment Program, GenRad, Bolton. File No. R-1022.

Goldberg, Zoino and Associates. 1988. RCRA Post Closure Plan, GenRad, Bolton. Five volumes. File No. G-3863.5.

Goldberg, Zoino and Associates. 1988. December: Quarterly Groundwater Monitoring Report, GenRad, Bolton.

WDCR05/091.50

CASE STUDY 9

Harris Corporation
Palm Bay, Florida

CASE STUDY FOR THE HARRIS CORPORATION SITE

BACKGROUND OF THE PROBLEM

This case study describes remediation efforts at the Harris Corporation site near the town of Palm Bay, in Brevard County, Florida. The site includes two separate recovery and treatment systems--one at the Harris facilities and another at General Development Utilities (GDU), a water supplier to the south of the Harris facilities. The Harris Corporation operates two semi-autonomous facilities (referred to as campuses) at this site--Harris Semiconductor (the north campus), to north of Palm Bay Road, and Harris Government Systems (the south campus), between Palm Bay Road and the GDU facility to the south (see Figures 1 and 2). The north and south campuses have been occupied by Harris since 1967. The south campus was originally occupied by the Radiation Corporation, starting in the late 1940s.

The main activity in the north campus is the production of electronic components, especially semiconductors and other microelectronic components involving silicon wafers. A variety of solvents are used in the manufacturing processes. The activities at the south campus have varied during the years of operation but have included electroplating, painting, photoprocessing, and computer hardware assembly. The solvents used at the two Harris facilities include trichloroethylene (TCE), trichloroethane (TCA), xylene, phenols, acetone, and n-butyl acetate. Chemical releases by Harris have contaminated ground water beneath the Harris facilities and within the area of the GDU water supply production wells.

The Harris Corporation ground-water extraction and treatment system has been operating since May 1985. The entire site is administered by the Florida Department of Environmental Regulation (FDER), but because the Harris Government Systems campus is on the National Priorities List (NPL) of hazardous waste sites, it is also administered by EPA under the Superfund program.

The GDU facility includes a water treatment plant, a wastewater treatment plant, and several water-supply wells installed at a depth of 70 to 80 feet below land surface. The GDU facility supplies water to and processes wastewater from much of the City of Palm Bay. The contamination of the wells of the GDU well field was caused by the southward migration of contaminated ground water from the Harris facility. The GDU ground-water extraction and treatment system has been operating since April 1984.

SITE HISTORY

A contamination problem at this site was first reported in March 1982 after samples of finished water collected from the GDU water treatment plant in 1981 were found to be contaminated with volatile organic compounds (VOCs). As a result of this discovery, the 18 GDU water-supply wells were sampled, and 5 (GDU-2B, GDU-3, GDU-5, GDU-8, and GDU-19) were found to be contaminated with VOCs (McIntyre et al., 1987). These five wells were taken out of production in April 1982. GDU hired CH2M HILL to study the problem and to develop a system that would allow GDU to put the production wells back into operation. Several GDU monitoring wells have been installed since 1982 as part of the GDU study.

The system that CH2M HILL developed to put the GDU production wells back into operation called for the contaminated ground water to be pretreated with an air stripper to remove VOCs before conventional treatment at the GDU water treatment plant. A prototype GDU air stripper began operating in November 1982 and a permanent full-scale air stripper began operating in April 1984. Only four of the five contaminated production wells that had been taken out of production in April 1982 were eventually connected to the air stripper and put back into production. These wells were GDU-2B, GDU-3, GDU-5, and GDU-8. The fifth well, GDU-19, was abandoned. The installation, operation, and maintenance costs of the GDU pretreatment system were paid for by the Harris Corporation.

In April 1982, in response to the contamination discovered at GDU the previous month, the Harris Corporation requested that its consultant, Post, Buckley, Schuh, and Jernigan, Inc. (PBS&J), expand its existing monitoring program and study the hydrogeology of the site. The hydrogeologic study was completed in December 1983 (PBS&J, 1983).

In a December 1983 agreement between the FDER and the Harris Corporation, the FDER required that Harris submit a detailed assessment and cleanup plan for the site. In September 1984, Harris submitted this plan, which called for an air stripper and a system of extraction wells and wellpoints to be installed and to begin operating at the Harris facility in three stages. In stage 1, deep aquifer barrier wells GS-123D, GS-124D, and GS-125D, each with a screened interval of 68 to 78 feet below land surface, were installed at the south border of the Harris facility. In stage 2, 10 shallow aquifer wellpoints were installed to depths of 40 feet near Building 5 and well GS-127D was added to the deep well system. In stage 3, wells GS-035S, GS-035D, GS-037S, GS-037D, GS-043S, and GS-043D were installed southeast of Building 6. The stage-3 wells were installed in pairs with the suffix S indicating shallow aquifer wells and D indicating the deep aquifer. The stage-1 and stage-2 extraction systems began operating together in early May

1985, and the stage-3 extraction system began operating in September 1985. The Harris air stripper, designed to remove VOCs from the ground water extracted by the Harris wells, began operating in May 1985. The effluent from the treatment system was discharged to the ditch east of the Perimeter Road during the first few months that the system was in operation.

In April 1986, a report assessing the effectiveness of the existing Harris remediation program was completed by GDU's consultant, CH2M HILL. This report was based on the site information that was available through November 1985. It pointed out deficiencies in the capture zone of the Harris extraction system and in several other aspects of the remediation program.

In April 1986, Harris hired another consulting firm, Geraghty & Miller (G&M), to conduct a hydrogeologic assessment of the Harris/GDU study area. In November 1986, Geraghty & Miller sampled and analyzed 18 existing wells at the north campus and 37 existing wells at the south campus. From March 1987 to late June 1987, several wellpoints and 47 new monitoring wells were installed at the two Harris facilities. Ground water from new and existing wells was sampled and analyzed in April and July 1987. Soil borings from both Harris facilities were also collected and analyzed during this period.

In October 1987, G&M issued a report evaluating the capture effectiveness of the Harris ground-water extraction system. This report concluded that the majority of the VOC plume was being captured but recommended installation of two additional shallow aquifer extraction wells in areas where plume capture appeared to be incomplete.

Since mid-1987, the shallow wellpoint system near Building 5 has been replaced with two conventional extraction wells. In June 1988, one of the additional shallow aquifer wells recommended by G&M, well GS-131S, was activated. The situation in the area of the second additional shallow aquifer well recommended by G&M is still under study.

Effluent from the Harris ground-water treatment plant is now being disposed of by deep-well injection instead of discharge to the ditch east of Perimeter Road. The injection takes place at a depth of more than 2,000 feet below the site and has no hydraulic or remedial effect on the contaminated aquifers at the site.

As extraction continues, quarterly ground-water monitoring data are reviewed to track the VOC plume and ensure that it is not migrating offsite.

GEOLOGY

Five main geologic layers underlie the Harris/GDU study area. The top layer, which extends from the surface to an average depth of 42 feet, includes beds of sand, silty sand, and red-brown sandy silt. It has shells in the deepest 5 to 10 feet. Monitoring wells have typically been installed in the upper layer at depths of 15 and 40 feet, resulting in the identification of these depths as the 15-foot and 40-foot monitoring zones. Although the lithology in these zones is different, the upper layer comprises a single hydrogeologic unit. Underlying the top layer is a 22-foot-thick aquitard composed of clay-sized particles. This clay layer is reported to be regionally discontinuous (G&M, 1989b), but it has been encountered consistently at the Harris Site. The aquitard is locally sandy and contains some shells. Underlying this aquitard is a 30-foot thick unconsolidated sand layer that extends from a depth of approximately 65 feet to 95 feet below land surface. This sand layer contains some shells locally. This layer is underlain by the 100-to-200-foot-thick Hawthorne Formation, a clay confining layer of regional importance. The fifth and deepest layer is the Floridan aquifer, a 1,000-foot-thick sequence of limestone and dolomite (PBS&J, 1983). The geology of the site has been investigated to a depth of 2,800 feet below land surface as part of a Harris Corporation deep-well injection program (G&M, 1987c). A generalized geologic column is shown in Figure 3.

HYDROGEOLOGY

The upper sand aquifer is an unconfined aquifer that is used locally as a water source. A potentiometric surface map of the water elevation in the upper sand aquifer in the southern portion of the site, as measured with all of the Harris extraction wells turned off on July 26, 1985, is shown in Figure 4 (CH2M HILL, 1986). The depth to water at individual monitoring wells ranged from approximately 5 to 22 feet below land surface on that date. Figure 4 shows that ground-water flow in the upper aquifer is to the south-southeast toward the GDU well field. The hydraulic conductivity of the 15-foot zone, the permeable zone just below the upper red-brown sandy silt layer of the upper aquifer, has been estimated at 1.5 ft/day (G&M, 1987c). Estimates of the ground-water flow velocity in the 15-foot monitoring zone range from 4 ft/year to 16 ft/year (G&M, 1987c; 1989b), being generally higher to the south of the site where the influence of the GDU well field is stronger. The hydraulic conductivity of the 40-foot zone, the lower 5 to 10 feet of the upper aquifer has been estimated at 13 ft/day (G&M, 1987c). The estimates of the ground-water flow velocity in the 40-foot zone ranged from 8 to 77 ft/yr (G&M, 1987c; 1989b). There is generally very little difference in potentiometric head between the 15-foot and 40-foot monitoring zones, indicating that they have good

hydraulic interconnection. The water table aquifer receives an estimated 36 inches of recharge per year (G&M, 1989b).

The retention, or borrow pit, pond on the north campus has a localized influence on water levels in the shallow aquifer. Water levels in the pond are regulated by an outfall structure. The pond receives water from surface runoff and as ground-water seepage from the upper aquifer. Except after rainfall events, it is not considered likely that the pond is a source of recharge to the upper aquifer (Harris, 1989).

The 22-foot thick sandy clay layer below the upper aquifer acts as a leaky aquitard that retards ground-water flow between the two aquifers. Its hydraulic conductivity has been estimated at 0.4 ft/day (PBS&J, 1983), which is high for an aquitard. The head in the upper sand aquifer is greater than the head in the deep sand aquifer, indicating a potential for downward flow. The downward flow potential is particularly strong in the vicinity of the GDU well field, probably because of GDU production well pumping in the deep aquifer. Because the aquitard is somewhat permeable, downward flow from the shallow aquifer to the deep aquifer is probable.

The potentiometric surface map of the deep sand aquifer, as measured on July 26, 1985, after all of the Harris extraction wells had been shut off, is shown in Figure 5 (CH2M HILL, 1986). This map shows that ground-water flow in the deep aquifer is to the southeast. The hydraulic conductivity of the upper section of the deep aquifer was estimated to be 28 ft/day. The ground-water flow velocity estimated on the north campus based on this conductivity was 28 to 44 ft/year (G&M, 1987c). Geraghty & Miller reported an estimated flow velocity of 273 ft/year for this layer in the south campus, where the influence of the GDU well field is stronger (G&M, 1989b).

The Hawthorne Formation is a true confining layer that acts as a hydrologic barrier between the deep sand aquifer and the Floridan. Its hydraulic conductivity has been estimated to be from 1.3×10^{-5} to 1.3×10^{-3} ft/day, four to six orders of magnitude less than the deep sand aquifer (PBS&J, 1983). The Floridan aquifer is confined by the Hawthorne Formation and is brackish in this area.

WASTE CHARACTERISTICS AND POTENTIAL SOURCES

VOCs are the main contaminants of concern at the Harris/GDU study area. Trans-1-2-dichloroethylene (T-1,2-DCE), TCE, vinyl chloride, methylene chloride, and chlorobenzene occur in the highest concentrations, but 1,1-dichloroethane, ortho-dichlorobenzene, and other volatile and non-volatile organics are also present. The remediation standards for some of the organics at the site are shown in Table 1.

Approximately 4,000 gallons of waste solvents per month were being generated by the Harris facilities in 1982. About 440 gallons of this monthly volume was TCE (McIntyre, 1982). Over 4,000 gallons per month of waste acids were also generated, about half of which was waste sulfuric acid. Unspecified volumes of other waste by-products, including electroplating wastes containing metals, were also generated. Before 1982, waste generation rates were lower than the rates given above because of lower production levels.

Before 1980, most of the waste solvent volume was discharged to the GDU wastewater treatment plant, along with the domestic wastewater from the plant. The waste acids and unknown quantities of other wastes were discharged to several industrial waste ponds in the north and south campuses. Some effort was made to neutralize the acids discharged to the waste ponds.

In late 1980, a waste segregation, collection, and disposal program was begun (McIntyre, 1982). Halogenated organic solvents were reportedly put into 55-gallon drums and hauled to a certified disposal area. Non-halogenated organics were hauled offsite by a contractor. Waste acids continued to be discharged to the industrial waste ponds under the new disposal program, with the exception of concentrated hydrofluoric acid, which had been segregated and disposed of offsite. Some of the potential sources of ground-water contamination were corroded storm sewer lines, solvent sumps, industrial pipelines, drum storage areas, drainage ditches, and several waste ponds and neutralization lagoons in both the north and south campuses. Two fires occurred in the northeast corner of Building 6, one in 1967 and another in 1974. Waste released in connection with these fires may also have been a source of ground-water contamination.

Figure 6 shows concentration contours of total VOCs in the shallow sand aquifer in 1984. The contaminant distribution illustrated in this figure is considered a worst-case estimate (PBS&J, 1984) because it is based on the highest concentrations of VOCs measured in the monitoring wells between March and August 1984. The highest total VOC concentration measured in the shallow aquifer during this period was 14,648 ppb at well GS-35S. An even higher concentration of 37,120 ppb was measured at this well in August 1985. Figure 6 appears to indicate that the north campus was relatively clean during the period represented. However, total VOC concentrations of up to 100 ppb were found in several of the shallow aquifer wells in the north campus, both before and after this period. Additional areas of VOC and xylene contamination immediately south of the north campus borrow pit pond were defined by additional monitoring wells in July 1987 (G&M, 1987c).

Figure 7 shows a contour map of maximum VOC concentrations in the deep sand aquifer, as observed at the two Harris facilities between March and August 1984. The areas of highest VOC concentrations were in the south campus. Maximum VOC concentrations exceeding 10,000 micrograms per liter were observed in wells GS-035D and GS-041D, southeast of Building 6. The contaminant plume was oriented to the southeast, which is consistent with the regional ground-water flow direction and GDU production well pumping in the deep aquifer.

Figures 6 and 7 show that the shallow and deep aquifers underlying the GDU well field were contaminated in 1984. Several volatile organic constituents were found in samples taken from production wells before the startup of full-scale ground-water treatment at GDU in April 1984. Table 2 shows the maximum total VOC concentrations and major constituents observed in the GDU production and monitoring wells before April 1984. Most of the wells with high concentrations were in the southeast, near the GDU water treatment plant. The highest contaminant concentration in the GDU wells before April 1984 was a concentration of 3,400 ppb of methylene chloride, which was observed in Well 3 on December 19, 1983. Methylene chloride was not consistently the contaminant with the highest concentration in each of the GDU wells, however. Seven different constituents were present in the highest concentration in various wells, indicating that the total VOC plume is a complex mix of different constituents with different spatial distributions.

REMEDIATION

SELECTION AND DESIGN OF THE REMEDY

Objectives of Remediation

The objectives of the Harris remediation system are to prevent additional production wells in the GDU well field from becoming contaminated and to clean up the aquifers underlying the site to below established standards. The objectives of the GDU remediation system are different from those of the Harris system. The objectives of the GDU system are to provide drinkable ground water for public consumption and to prevent the migration of contaminants further downgradient to uncontaminated wells. Four of the five contaminated GDU production wells have been put back into service. These four wells are used to establish a cone of depression between the plume and the uncontaminated wells that is meant to act as a barrier to prevent further migration to the southeast. The water from the contaminated wells is pretreated and blended with uncontaminated water from other wells before being treated using conventional treatment methods for drinking water. In effect, the

contaminated production wells have become part of a well head treatment/plume containment system.

System Configuration

Figure 8 shows the current layout of the Harris remediation system. It consists of 11 extraction wells and an air stripper. Three of the extraction wells, GS-123D, GS-124D, and GS-125D, are intended to act as a barrier to prevent offsite migration of the VOC plume in the deep aquifer. Well GS-127D, also in the southern part of the site, is intended to pinch off the portion of the deep VOC plume with concentrations above 1,000 ppb. The other two deep aquifer wells, GS-37D and GS-43D, are installed in the central part of the south campus where the total VOC concentrations are highest. The extraction system in the shallow aquifer consists of wells GS-37S and GS-43S in the central high concentration region, wells GS-18S and GS-44S replacing the original well point system near Building 5, and well GS-131S in the southern portion of the site. Well GS-131S was activated as an extraction well in June 1988 to prevent offsite migration of the shallow plume, which was apparently not being completely captured by wells GS-37S and GS-43S. The extraction wells are screened from approximately 33 to 38 feet below land surface in the shallow aquifer and from 68 to 78 feet in the deep aquifer. Wells GS-35S and GS-35D were originally part of the stage-3 recovery system, but have not been operated as extraction wells since 1985.

Table 3 shows the pumping rates of the Harris extraction wells and the GDU production wells, as measured on March 24, 1987. The production rate from the wellpoint system around Building 5 is not included in this table because it was apparently not operating when these measurements were made. The wellpoint system was in operation on July 25, 1985, and its production rate was measured as approximately 30 gpm. The wellpoint system was later replaced by wells GS-18S and GS-44S, with design pumping rates of 25 gpm each (G&M, 1987b). In June 1988, well GS-131S was added to the shallow extraction system, and it has reportedly been pumped at between 12 and 17 gpm ever since (Harris, 1989a). Well GS-43D was rehabilitated in 1989, and its pumping rate increased to 50 gpm (Harris, 1989b).

The positions of the extraction wells that existed in 1986 were chosen to be near the center of the contamination or a downgradient barrier to it. The placement and pumping rates of the wells that were added since 1986 were chosen on the basis of withdrawal permits and computer modeling of various pumping configurations (G&M, 1987b). Harris has a water-use permit that allows up to 347 gallons per minute, or 0.5 million gallons per day, to be pumped from the subsurface; therefore, any increased pumping from additional wells had to be accommodated within this limit. Some of the pumping

rates of the wells in operation in 1986 were modified in response to the modeling study.

The extracted ground water is treated by air stripping towers at both the GDU and the Harris facilities. The design rates of the two systems are 1,000 and 500 gpm, respectively. The treated effluent from the Harris system is reused for production activities at the Harris facility and then injected into permeable zones over 2,000 feet deep. The treated effluent from the GDU treatment system is discharged to the GDU water treatment plant.

Figures 6 and 7 show the network of monitoring wells existing in April 1986 in the shallow- and deep-aquifer zones, respectively. Thirty-two more north campus monitoring wells and 15 more south campus monitoring wells had been added as of late 1987 (G&M, 1987a; G&M, 1987c).

EVALUATION OF PERFORMANCE

Hydraulic Control

Figures 9 and 10 show the influence of the Harris extraction wells on the distribution of potentiometric head in the shallow and deep aquifers, respectively. These figures are based on water level measurements made on March 24, 1987, the same date for which extraction well pumping rates are given in Table 3. Also shown are the estimated limits of the capture zones of the different groups of wells. Comparison of Figure 9 with the 1984 plume map for the shallow aquifer shown in Figure 6 indicates that wells GS-37S and GS-43S were capable of capturing the areas of highest contamination in the central part of the site, including most of the areas of the central plume having concentrations above 100 ppb. However, those areas of the shallow plume south of Building 15 having concentrations up to 100 ppb were not being captured. Reference to Figure 11, which illustrates the shallow VOC plume in 1987, also shows areas of the central plume south of Building 15 with concentrations greater than 100 ppb that were outside the capture zone of the extraction well system. These observations led to the decision to add well GS-131S to the shallow extraction system in 1988. No potentiometric surface maps are available to show the effects of pumping from well GS-131S, but Harris Corporation believes that its addition to the system has cut off the southward migration of the VOC plume (Harris, 1989b).

As shown in Figure 9, the high concentration region around Building 5 was outside the capture zone of wells GS-37S and GS-43S. Control and remediation of the plume in this area was to be accomplished by the system of 10 wellpoints along the east and south sides of Building 5, but this system was apparently not in operation on the day these water level measurements were made. No piezometric surface maps are

available that show the measured hydraulic effects of the wellpoint system or of the pair of shallow wells, GS-18S and GS-44S, that later replaced it. However, the numerical model used to evaluate the ground-water remediation system indicated that both systems should effectively capture the shallow plume in the Building 5 area (G&M, 1987b).

Figure 10 shows the capture zones of the Harris extraction wells in the deep aquifer, as inferred from the water level measurements made on March 24, 1987. Comparison with the 1984 plume map shown in Figure 7 shows that the extraction system was capable of capturing nearly all of the onsite portions of the worst-case estimate of the deep plume, except for small areas of VOC concentration less than 100 ppb in the southeast and southwest corners of the site. Comparison with Figure 13 suggests that by 1987, these low concentration areas along the edges of the plume may have been swept into the GDU well system, and the Harris extraction wells were capturing all of the onsite portions of the main deep aquifer plume. Contamination that had already migrated offsite toward the GDU well field was beyond the reach of the Harris system, but it was being captured and treated at the affected GDU wells.

Contaminant Plume Reduction

Figures 11 and 12 show the 1987 and 1988 average total VOC concentration contour maps for the shallow aquifer. Comparison with Figure 6 shows evidence of a reduction in the size and concentration of the west-central plume in the areas east of Building 22 and adjacent to Troutman Boulevard. The 1,000-ppb plume seems to have increased in size from 1987 to 1988 by being drawn toward recovery well GS-43S. On the other hand, the size of the 100-ppb plume decreased during this period, probably because of the activation of well GS-131S in mid-1988. The northeast part of the west-central plume appears unchanged. The size of the east-central plume near Building 5 appears to have been reduced substantially over the year of pumping.

Figures 13 and 14 show concentration maps of average total VOC concentrations in the deep aquifer for 1987 and 1988, respectively. Comparison between these maps and the 1984 plume map shown in Figure 7 shows progressive decreases in both the size and concentration of the plume. The location of the peak concentration area, to the south and east of Building 6, has not changed, but the westward extent of the plume toward Troutman Boulevard has clearly decreased. The southward extent of the 1,000-ppb contour has also been progressively reduced.

Reductions in Concentrations of Contaminants

Figure 15 shows a time-series plot of the total VOC concentrations in the influent to the GDU treatment system

from startup in late April 1984 to February 1989. This influent consists of the ground water extracted from GDU wells 2B, 3, 5, and 8. The early data were quite variable, but concentrations stabilized at approximately 15 to 20 ppb after the fourth quarter of 1986. The decrease in concentration fluctuations apparent in mid-1985 coincides with the startup of the Harris recovery program in May 1985.

Figure 16 shows a time-series plot of the total VOC concentrations in the influent to the Harris treatment system from May 1985 to March 1989. These concentrations ranged from 400 to over 9,000 ppb, generally 10 to 100 times higher than the concentrations of the influent to the GDU treatment system. These data show a steadily declining concentration trend, suggesting that the Harris extraction system is reducing the concentration and mass of contaminants in the zone of ground-water capture. No estimates of the contaminant mass removed or the estimated time to complete remediation were reported.

SUMMARY OF REMEDIATION

The multilayered, two-aquifer system beneath the Harris Corporation and GDU facilities near Palm Bay, Florida, has been contaminated with various VOCs. Five of the GDU production wells supplying water to nearby communities were shut down after they were found to be contaminated by discharges originating at the Harris facilities.

A well head treatment system with an air stripper was installed at the GDU facility to remove VOCs from the contaminated production wells before further treatment for public consumption. Four of the five contaminated production wells have been put back into operation to restore the full production capacity of the GDU water supply system and to form a hydraulic barrier between the Harris facilities and the uncontaminated GDU wells.

A system of extraction wells, monitoring wells, and a separate air stripping treatment unit were installed at the Harris facilities. The objectives of the Harris remediation system are to form a barrier to prevent offsite migration to the south and to clean up the deep and shallow aquifers.

The initial shallow aquifer extraction system in the high concentration area near Building 6 consisted of two wells, GS-37S and GS-43S, which appeared to have limited effectiveness in capturing the plume in the southern portion of the site. Consequently, a third shallow well, GS-131S, was added in mid-1988 to address this problem. The hydraulic effect of this new well has not been demonstrated, but water quality monitoring data are said to demonstrate that it is effective (Harris, 1989).

The high concentration area in the shallow aquifer near Building 5 was initially to be remediated by a system of 10 wellpoints installed along the south and east sides of the building. The wellpoint system was later replaced with two conventional wells, GS-18S and GS-44S, because of pumping problems with the wellpoints. Although the hydraulic effect of these wells on the piezometric surface of the aquifer has not been shown, they appear to have reduced the size and concentration of the contaminant plume near Building 5.

The deep aquifer extraction system appears to be effective in preventing continued offsite migration of the main contaminant plume. Initially, there may have been low concentration areas on the east and west edges of the plume that were beyond the capture zone of the Harris deep extraction system. However, the extent of the plume has subsequently been reduced so that its onsite portions appear to be hydraulically contained. The portion of the plume that has already migrated offsite to the south is beyond the influence of the Harris extraction system, but it is being captured and treated by the GDU wells. Harris Corporation continues to pay the treatment expenses incurred by GDU because of this.

Both the GDU and the Harris treatment systems showed a decrease in the influent total VOC concentration over the 3 years of remediation. The beneficial effect of the Harris extraction system was demonstrated by a sharp decrease in the total VOC concentrations produced from the contaminated GDU wells that occurred shortly after the Harris system was started up. No projected time to complete remediation was reported.

The two objectives of the GDU pump and treat system have been achieved. A hydraulic barrier to prevent southeastern migration of the deep and shallow plumes past the GDU recovery wells has been established. The system also pretreats the extracted ground water effectively, allowing the water from the contaminated recovery wells to be used by the public.

BIBLIOGRAPHY

CH2M HILL. April 1986. Assessment of the Harris Corporation Remediation Program.

CH2M HILL. April 11, 1989. Personal communication with Mr. Greg McIntyre.

Geraghty & Miller, Inc. July 1987(a). Building 6 Ground-Water Assessment Government Systems, Harris Corporation, Palm Bay, Florida.

Geraghty & Miller, Inc. October 1987 (b). An Evaluation of the Harris Corporation Ground-Water Recovery System.

Geraghty & Miller, Inc. November 1987(c). Harris Corporation Semiconductor Complex Ground-Water Assessment.

Geraghty & Miller, Inc. February 1988. Harris Corporation 1988 Ground-Water Monitoring Program, Palm Bay, Florida.

Geraghty & Miller, Inc. February 1989(a). Harris Corporation 1989 Ground-Water Monitoring Program, Palm Bay, Florida.

Geraghty & Miller, Inc. May 1989(b). Harris Corporation National Priority List Compliance Review.

Harris Corporation, December 11, 1989(a). Personal communication with Mr. Robert Sands.

Harris Corporation, December 22, 1989(b). Letter from Mr. Robert Sands to Ms. Jennifer Haley of U.S. EPA.

McIntyre, G. T., CH2M HILL. July 8, 1982. Memorandum: Site Visit, Harris Corporation.

Mcintyre, G. T., J. K. Cable, W. D. Byers. July 1987. Cost and Performance of Air Stripping for VOC Removal. Presented at 1987 ASCE National Conference on Environmental Engineering.

Post, Buckley, Schuh & Jernigan, Inc. December 1983. Harris Corporation Task B-4 Hydrogeologic Study.

Post, Buckley, Schuh & Jernigan, Inc. September 1984. Groundwater Remediation Program Phase II Plan of Action Report.

WDCR05/083.50

CASE STUDY 10

IBM - Dayton
Dayton, New Jersey

CASE STUDY FOR THE IBM DAYTON FACILITY

BACKGROUND OF THE PROBLEM

The International Business Machines Corporation's (IBM) Dayton facility is located in South Brunswick Township, New Jersey, just west of the town of Dayton (see Figure 1). Prior to 1985, the manufacturing activities at this facility included the production of punch cards for computer input and inked ribbons for printers. Since 1985, manufacturing has been discontinued, and the site has been used for administrative activities and the repair of electronic equipment.

In December 1977, Well SB-11 of the South Brunswick Township well field was found to be contaminated with chlorinated organic solvents, the majority of which were traceable to the IBM site. The principal organic solvents of concern are the volatile organics 1,1,1-trichloroethane and tetrachloroethylene. In 1978, IBM started operating an onsite ground-water extraction system to remove the contaminants from the aquifer. By 1984 the remediation appeared to have been successful, and the New Jersey Department of Environmental Protection (NJDEP) approved the termination of onsite extraction. However, post-termination monitoring has shown a reappearance of the contaminant plume, and IBM has responded with a plan for long-term extraction to contain the contaminants near their source. The remedial measures continue to be under the jurisdiction of the NJDEP.

SITE HISTORY

The discovery of contaminants in production well SB-11 in December 1977 triggered a ground-water quality investigation conducted by the NJDEP to locate the contaminant source. Initially, over 20 businesses were suspected of causing the ground-water contamination problems, but the investigation reduced this number to three industries within a 1-mile radius of well SB-11. These three industries, including the IBM facility, were then required by the NJDEP to conduct hydrogeologic investigations of their facilities. As a result of these studies, it was determined that IBM was the major contributor to the ground-water contamination problem.

In January 1978, the contaminated production well was shut down and IBM began a site assessment as required by NJDEP. During 1978, more than 60 monitoring wells and 10 onsite recovery wells were installed. Operation of the first recovery well, well GW-4, began in March 1978, and in June 1978, production well SB-11 was put back into service. The water pumped from well SB-11 was discharged to the sanitary

sewer system. In August 1978, ground-water investigation reports on the contamination problem were submitted by two different consultants, one hired by IBM and the other by South Brunswick Township. Also, during the summer of 1978, the chemical storage tanks that were the suspected source of IBM's ground-water contamination were removed.

In 1979, three reports on the ground-water contamination were prepared by the consultants for IBM and South Brunswick Township. Four more onsite extraction wells and ten more monitoring wells were installed in 1979.

In June 1980, an administrative consent order (ACO) was issued by NJDEP requiring IBM to continue operating the ground-water extraction and treatment system until it could be shown that ground-water extraction would not produce further reductions in contaminant concentrations.

For the next 4 years, the extraction system was operated with varying numbers of wells being pumped. An additional set of seven extraction wells was installed offsite in 1981 to intercept the plume movement toward production well SB-11. At the same time, an array of nine injection wells was installed along the northeast boundary of the IBM property. The locations of the wells that make up the ground-water remediation system are shown in Figure 2.

In early 1984, both IBM and South Brunswick Township informed NJDEP that in their opinions continued operation of the extraction system would not produce further substantial reductions in ground-water contaminant concentrations. By this time the offsite concentrations of total volatile organics (VOCs) in the monitoring wells had been reduced below 100 parts per billion (ppb) and only one onsite well, in the suspected source area, had total VOC concentrations higher than this level. In June 1984, NJDEP issued an amended administrative consent order (AACO) authorizing termination of ground-water extraction except at production well SB-11, which was to continue producing with a well-head treatment system installed. In response to the AACO, the six operating onsite extraction wells and the seven offsite blocking wells were shut down on September 9, 1984.

Continued monitoring of ground-water quality after the ground-water extraction was terminated showed a gradual increase in concentrations and re-emergence of the contaminant plume. In October 1987, a report was prepared by IBM's consultant documenting these increases and predicting that the offsite action levels established by the AACO would be exceeded within a year. The report recommended that IBM obtain approval from NJDEP to resume limited operation of the ground-water extraction system. In March

1988, a ground-water remediation plan was submitted to NJDEP recommending a multiphase resumption of limited ground-water extraction to prevent off-site migration of contaminants. This plan was approved by the NJDEP in January 1989, and the first phase of renewed ground-water extraction is expected to start late in the summer of 1989.

GEOLOGY

The geologic units underlying the study area are, from youngest to oldest, the Pensauken Formation (Pleistocene), the Old Bridge Sand Member of the Magothy Formation (Cretaceous), the Woodbridge Clay Member of the Raritan Formation, the Farrington Sand Member of the Raritan Formation (Cretaceous), and the Brunswick Shale (Triassic).

At the IBM site, the Pensauken Formation and the Old Bridge Sand are both composed primarily of yellow to orange-brown to gray, silty sand with occasional clayey or gravelly horizons. Discrete gravel-rich zones in the Pensauken Formation may act as channels that affect the hydraulic characteristics of the aquifer locally.

The Woodbridge Clay is characterized by interbedded clay and sand layers. In the study area, the individual clay layers range in thickness from a fraction of a foot to several feet. In some areas of the IBM property, only one layer is present, and in at least two areas near the property, the Woodbridge Clay is absent. Figure 3 shows the elevation of the top of the Woodbridge Clay in the study area and the zones north and east of the IBM property where it is absent.

The Farrington Sand is a light-gray to light-yellow, fine-to medium-grained sand with pebbles and gravel. It is approximately 60 feet thick in the study area and rests atop the Brunswick Shale bedrock.

Figure 4 shows a geologic cross section through the northeastern corner of the IBM site illustrating the configuration of these geologic units.

HYDROGEOLOGY

Two interconnected aquifers are involved in the ground-water contamination problem at the IBM Dayton site. The shallow, unconfined aquifer is comprised of the Pensauken Formation and the Old Bridge Sand, as shown in Figure 4. The water table is generally 30-to-45 feet below ground surface, leaving a saturated thickness of approximately 20 to 30 feet. The lower semi-confined aquifer consists of the Farrington Sand, which is bounded from below by the

relatively impermeable Brunswick Shale, and from above by the thin and locally discontinuous Woodbridge Clay.

The direction of ground-water flow in both aquifers is dominated by the pumping from production well SB-11. This well is located in an area where the Woodbridge Clay is absent, so that groundwater production is derived from both aquifers. During the period of operation of the groundwater extraction system, well SB-11 was normally pumped at 550 to 600 gallons per minute (gpm). Since 1985, however, its production rate has been increased to 1,100 gpm, to intensify its cone of depression. Figures 5 and 6 show contour maps of the potentiometric surfaces in the shallow and deep aquifers, respectively. They are based on water level measurements that, while not simultaneous, represent conditions in late 1987 for both aquifers. At that time, the ground-water extraction system at the IBM site was not operating, and well SB-11 was producing at 1,100 gpm.

The equipotential lines shown in Figure 6 for the Farrington Sand on the IBM property indicate a region of concentrated drawdown in the northeast corner of the site and a region of apparent recharge in the southeast corner. No explanation is given for these features in the available site data reports. Examination of these figures shows that the potentiometric head is generally higher in the shallow aquifer than in the deep, indicating the potential for downward flow through the intervening clay layer.

Aquifer tests run in the shallow aquifer on the IBM site indicated hydraulic conductivities for the shallow aquifer from 7×10^{-3} to 1.5×10^{-1} centimeters per second (cm/s). These are depth-averaged estimates of horizontal hydraulic conductivity. This wide range of values indicates that there is significant areal non-uniformity in the shallow aquifer. Slug tests performed in nests of piezometers have indicated that the hydraulic conductivity of the shallow aquifer also varies widely with depth, but no pattern could be discerned in the variations.

Average ground-water transport rates in the shallow aquifer at the IBM site have been calculated from gradients and hydraulic properties. These rates have been shown to be approximately 4 feet per day towards well SB-11. Chemical transport rates have been estimated based on the times of contaminant appearance in the shallow aquifer monitoring wells, to be approximately 1.9 feet per day for trichloroethane (REWAI, 1987).

No aquifer test results or hydraulic conductivity estimates for the deep Farrington Sand aquifer are available.

WASTE CHARACTERISTICS AND POTENTIAL SOURCES

The principal contaminants of concern at the IBM Dayton facility are the volatile organics 1,1,1-trichloroethane (TCA), and tetrachloroethylene (PCE). The maximum concentrations of these compounds that have been found in the ground water at the site are 9,590 ppb of TCA and 6,132 ppb of PCE. Considerably lower concentrations of trichloroethylene, 1,1-dichloroethylene, and 1,1-dichloroethane have also been generally present. The densities of all these contaminants are greater than the density of water.

The suspected source of the contamination is near well GW-32, at the southwest corner of Building 001. Chemical storage tanks located in this area were removed from the site in 1978, but no records have been obtained indicating that any soil contamination measurements were made at that time. In 1985 and 1986, soil samples taken from boreholes around the main IBM building were analyzed and a maximum soil concentration of 13,255 ppb of total VOCs was found at a depth of 22.5 feet near the suspected source area. No contamination was found in this borehole above this elevation, and, in general, the shallower soil samples did not show detectable levels of soil contamination.

The reappearance of elevated concentrations of the contaminants after the onsite ground-water extraction system was shut off has led IBM's consultants to suspect the presence of a residual source of dense nonaqueous liquids (DNAPLs) in one or both of the aquifers. To date, there is no record of any physical evidence of DNAPLs being found in the aquifers. Rather, their presence is suspected because of the changes that have been observed in ground-water contamination patterns and the apparent absence of widespread soil contamination near the ground surface.

The highest levels of contamination have been found in the shallow aquifer on the IBM property. Figure 7 shows the distribution of total volatile organics in the shallow aquifer based on averages of samples taken from January to June of 1978.

Contamination of the deep aquifer generally involves the same contaminants as the shallow aquifer, but the maximum concentrations detected have been lower. Figure 8 shows the time averaged concentrations of TCA in the lower aquifer for the period of January to June 1980. The highest concentration for TCA, as shown on the figure, is 2,461 ppb at the offsite well BBd.

In the late 1970s and early 1980s, when the remedial action was in progress at the site, uniform regulatory criteria for

ground-water concentrations of these organic compounds had not been established. The decision to terminate pumping of the ground-water extraction system seems to have been based primarily on the contention that continued pumping would not significantly reduce the contaminant concentrations in the ground water. In 1984, the AACO issued by the NJDEP established a TCA concentration of 100 ppb as the action level below which reactivation of the system would not be required.

REMEDIATION

SELECTION AND DESIGN OF THE REMEDY

Objectives of Remediation

The objective of the ground-water extraction system that was installed in 1978 was to restore the ground-water quality in both aquifers to levels that would be suitable for the municipal drinking water supply. In 1983, after several years of operating experience with the system, it was predicted that the upper aquifer would be fully restored by the end of 1984, and that the lower aquifer would require at least another 5 years for complete cleanup (Althoff, 1983). At that time, it was thought that the contamination problem involved a total of approximately 400 gallons of solvent, and the projected cleanup schedule was based on the estimated time required to remove this quantity of contaminants. No precise definition of what constituted complete aquifer cleanup had then been established. When the ground-water extraction was stopped in 1984, it was thought that its goals had been achieved satisfactorily. It was expected that continued pumping of production well SB-11 alone would remove the relatively low levels of remaining contamination in the aquifers.

In response to the observed re-establishment of the contaminant plumes since the system was shut off in 1984, a plan, with somewhat modified objectives, has been formulated for renewed ground-water extraction. This plan calls for three phases of the extraction system operation designed to achieve control over the migration of the plume in the upper aquifer. The progressive phases will require decreased pumping as the extent of the plume is reduced. In the final phase it is expected that relatively low rates of pumping from wells close to the source area will effectively control the plume, but the duration of this phase is indefinite.

System Configuration

The initial ground-water extraction system installed in 1978 consisted of 13 onsite extraction wells in the shallow aquifer and one onsite extraction well (Well GW-18E) in the deep aquifer. These wells were operated in conjunction with the offsite production well SB-11. The onsite pumping effort was divided between two areas (see Figure 2): the suspected source area southwest of IBM Building 001, and the downgradient area to the north and east of Building 001. There is some disagreement among the various data sources as to the pumping rates for these wells. The initial capacity of the system that treated the ground water extracted onsite was 70 gpm. This was later increased to 416 gpm. In 1983, it was reported that the average extraction rate for the onsite extraction system since the commencement of remediation had been 300 gpm (Althoff, 1983). The offsite well, SB-11, was pumped at 500 to 600 gpm during this period and the water extracted from it was discharged to the sanitary sewers. Figure 9 is a graphic illustration of the operating history of the onsite extraction wells.

In 1982, an additional offsite pumping center was added to the system midway between the IBM site and Well SB-11. The ground water extracted from the seven wells in this system was treated and then reinjected to the shallow aquifer through a line of 9 injection wells along the northeastern site boundary. The extraction and injection well locations for this new system are shown in Figures 2 and 5. The purpose of this extraction/injection well system was apparently to separate the contaminant plume into an onsite portion and an offsite portion and to accelerate the hydraulic flushing of both portions. The injection wells were used only for a short time because their efficiencies deteriorated rapidly. When the injection wells were tested later (GWC, 1988) it was found that their injection capacities had been reduced by an order of magnitude due to well deterioration.

The water extracted from the onsite wells was treated by air stripping and then returned to the ground-water system by means of a spray irrigation field located on the western portion of the IBM site (see Figure 2).

In addition to the extraction and injection wells, the remediation system included nearly 100 monitoring wells in both aquifers. These wells were used to monitor both the hydraulic performance of the system and the changes in ground-water quality. Most of the sample analysis was done in IBM's onsite laboratory. When ground-water extraction was terminated in 1984, the AACO designated a group of offsite wells in the shallow aquifer as perimeter monitoring

wells that would be sampled on a monthly basis. These wells are shown in Figure 2. If the action level (100 ppb of TCA) was exceeded in any of these wells, IBM was required to notify NJDEP, and further remedial action might be required.

In 1988, a second ground-water remediation scheme was proposed by IBM to prevent the contaminant plume in the shallow aquifer from continuing to migrate off site. This plan consists of three phases involving migration control at the site boundary and at the suspected onsite source of contamination. In Phase I, two of the former injection wells near the northeast boundary of the site will be pumped to prevent further offsite plume migration. In Phase II, two new wells will be added in the suspected source area, which will be pumped in addition to the boundary control wells. This phase will begin as soon as the new wells can be constructed. It is expected that Phase I will last for 1 to 1-1/2 years. When the extent of the plume has been reduced to the immediate area of the source by Phase II operations, the boundary control wells will be turned off. Phase III will consist of continued pumping from one or both of the source area wells for an indefinite period. The locations of these wells and their projected pumping rates were determined with the help of numerical models of ground-water flow in the shallow aquifer.

IBM has proposed that the contamination in the lower aquifer be controlled by continued pumping of production well SB-11 with well head treatment. This is recommended as a way to keep the plume in the lower aquifer from spreading to other production wells, while permitting South Brunswick Township to use the water produced for municipal water supply. The first phase of the renewed remediation is expected to begin in late summer 1989.

EVALUATION OF PERFORMANCE

IBM's consultants concluded in 1984 that the ground-water extraction system operated between 1978 and 1984 had been very successful in diminishing the size of the contaminant plume in the shallow aquifer. The authorization by NJDEP for termination of the system in 1984 indicates that the state authorities agreed with this assessment at that time. Figure 10 shows the distribution of total volatile organics in the upper aquifer in August 1984. Comparison with the corresponding distribution for January-June 1978 (see Figure 7) shows that both the size of the plume and the concentrations had been reduced dramatically. At that time it was expected that pumping from well SB-11 would be adequate to complete the aquifer cleanup.

Continued monitoring showed contamination increases in the shallow aquifer concentrations after the system was shut down. Figure 11 shows the distribution of total volatile organics in April 1987, 2-1/2 years after the termination of onsite extraction. Comparison of this figure with the distribution for August 1984 (Figure 10) shows the re-emergence of the plume in the onsite areas downgradient of the source. However, the downgradient end of the 1984 plume has disappeared and was probably swept into well SB-11.

Figures 12 and 13 show the time history of concentration fluctuations for the two primary contaminants, TCA and PCE, in two of the onsite extraction wells. Well GW-32 is near the suspected source area, where the highest contaminant concentrations have been recorded. This well was pumped steadily during the extraction period, and Figure 12 shows a fairly steady decline in concentrations from 1978 to 1984. The concentrations plotted in these figures are not the raw data, but six-month averages of samples taken every two weeks. For this reason the trends may appear somewhat smoother than would have been indicated by the raw data. After the extraction system was shut off in 1984, a clear increasing trend in the concentrations is evident. The PCE concentrations measured in this well in 1988 are considerably higher than had ever before been detected on the site. The concentrations of TCA, however, have risen only slightly since 1984. IBM's consultants have speculated that this indicates TCA depletion in the contaminant source area. TCA might be washed out of the source zone more rapidly than PCE because TCA is more soluble in water and less strongly sorbed to the soil.

Well GW-16B is an extraction well located downgradient of the source zone, but still on the IBM site. It, also, was pumped continuously during the extraction period. The trends in contaminant concentration for this well, as shown in Figure 13, are similar to those observed in well GW-32, except that the decline in concentrations in 1979 and 1980 is more precipitous.

Figure 14 shows the time history of TCA and PCE concentrations in monitoring well GW-25, located at the south end of cross section A-A', as shown in Figure 3. This well is farther downgradient than GW-32 and GW-16B, and GW-25 is not an extraction well. The concentrations observed here were much lower than in the wells closer to the source. The increases in concentrations after 1984 are more pronounced in this well than in the previous two wells. In this case the concentrations after cessation of extraction are higher than they were at the start of the remediation for both TCA

and PCE. This may be due to the increased pumping rate of the offsite production well SB-11.

Figure 15 shows the time variation of concentrations in well SB-11. This well is located in an area where the clay layer separating the upper and lower aquifers is missing. Therefore, the contaminants produced are derived from both aquifers. The concentrations of contaminants in well SB-11 seem to have established themselves at relatively low values, probably because the well continues to pump at about 1,100 gpm and significant dilution may occur as a result.

SUMMARY OF REMEDIATION

Both the shallow and deep aquifers at the IBM Dayton facility have been contaminated with chlorinated organic solvents. The ground-water remediation program has been aimed primarily at the contamination plume in the shallow aquifer. The extraction well system was successful in reducing the extent and concentrations of contaminants in the shallow aquifer during its operating period of 1978 to 1984. However, the concentrations of TCA and PCE in the immediate source area appeared to stabilize at levels above 100 ppb. This apparent stabilization of concentrations was interpreted as an indication that the system could be shut off because continued pumping would not reduce the concentrations further. When extraction was terminated, the concentrations began to rise.

The reappearance of higher concentrations has been attributed to the presence of DNAPLs in both the upper and lower aquifers. IBM's consultants have concluded that this residual source of contaminants cannot effectively be removed by ground-water extraction. Therefore, they intend to resume extraction at lower pumping rates with the objective of plume containment. The experience gained with the earlier ground-water extraction system has given them confidence that the plume can be confined to a relatively small area around the source zone with a much lower level of effort than was applied when the goal was total aquifer restoration.

BIBLIOGRAPHY

Althoff, W.F. and C.L. Maack. An Example of a Major Groundwater Cleanup in New Jersey. February 1983. NJ Division of Water Resources.

R.E. Wright Associates, Inc. (REWAI). Report on the Investigation of Chemical Reappearance in Groundwater at the IBM Dayton Site. October 1987.

Groundwater Sciences Corporation (GWC). Groundwater Remediation Plan IBM Dayton, New Jersey Facility. March 1988.

Groundwater Sciences Corporation, et al. DNAPL Geochemistry and Remedial Feasibility, Farrington Sand Aquifer. Dayton, New Jersey. August 1988.

WDR428/040.50

Evaluation of Ground-Water Extraction Remedies

Volume 2, Part 2
Case Studies 11-19

Interim Final
October 1989

Office of Emergency and Remedial Response
U.S. Environmental Protection Agency
Washington, D.C 20460

Notice

Development of this document was funded by the United States Environmental Protection Agency in part under contract No. 68-W8-0098 to CH2M HILL SOUTHEAST. It has been subjected to the Agency's review process and approved for publication as an EPA document.

The policies and procedures set out in this document are intended solely for the guidance of response personnel. They are not intended, nor can they be relied upon, to create any rights, substantive or procedural, enforceable by any party in litigation with the United States. The Agency reserves the right to act at variance with these policies and procedures and to change them at any time without public notice.

LIST OF CASE STUDIES

1. Amphenol Corporation
2. Black & Decker, Inc.
3. Des Moines TCE
4. DuPont-Mobile Plant
5. Emerson Electric Company
6. Fairchild Semiconductor Corporation
7. General Mills, Inc.
8. GenRad Corporation
9. Harris Corporation
10. IBM-Dayton
11. IBM-San Jose
12. Nichols Engineering
13. Olin Corporation
14. Ponders Corner
15. Savannah River Plant A/M-Area
16. Site A
17. Utah Power & Light
18. Verona Well Field
19. Ville Mercier

WDCR13/036.50

CASE STUDY 11

IBM General Products Division
San Jose, California

CASE STUDY FOR THE IBM-SAN JOSE SITE

BACKGROUND OF THE PROBLEM

This case study summarizes the remediation of ground-water contamination from beneath the IBM General Products Division site, located at 5600 Cottle Road in San Jose, California (Figure 1). The IBM facility, which includes 39 buildings containing offices, laboratories, and manufacturing areas, first began operation in 1956. Magnetic disks and heads for computer hardware are manufactured at this site using a variety of process chemicals and materials. The contaminants of concern are Freon 113, 1,1,1-trichloroethane (TCA), 1,1-dichloroethylene (1,1-DCE), and trichloroethylene (TCE).

SITE HISTORY

Contamination was first detected at this site in 1978 during an internal environmental review program conducted by IBM. As part of this review program, soil and ground water from both inside and outside the IBM boundaries were sampled. Halogenated organic compounds were detected in both soil and ground water onsite and in ground water offsite. The areas studied are shown in Figure 2.

As a result of the contamination detected, further soil and ground-water investigations were conducted and interim remedial actions were implemented onsite and offsite to clean up contamination and control contaminant movement through the soil and ground water. Over 23,000 cubic yards of soil have been excavated from onsite source areas and 65 buried storage tanks have been removed or placed above ground to facilitate monitoring.

Extraction wells have been installed at three onsite source areas, at the western site boundary, and at two offsite locations--at mid-plume and Edenvale Gap. The extraction systems in the onsite source areas were installed in 1982. The extraction system at the site boundary and in the mid-plume area were installed in 1983, and the Edenvale Gap system in March 1984.

In one area onsite, an accidental release of Shell Sol 140 occurred in late November 1985. In December 1985, product recovery and hydraulic control activities were implemented at the Shell Sol 140 release area.

In May 1986, the State Water Quality Control Board ordered IBM to submit an overall long-term plan for remedial action following a similar order by the Regional Water Control

Board in December 1984. In June 1987, IBM submitted a draft of its long-term remediation plan (KJC, 1987). Proposed aspects of the plan included:

- Establishing contaminant concentration goals
- Continuing the boundary-well extraction system until downgradient monitoring-well concentrations were below goal concentrations
- Installing a system of approximately five extraction wells in the A aquifer just offsite near well 12A
- Adding four more B-aquifer extraction wells along the centerline of the offsite plume
- Conducting additional vadose zone investigations onsite
- Treating the extracted water using air stripping
- Discharging the treated effluent to existing Santa Clara Valley Water District infiltration basins to promote recharge.

The decision on whether to install the proposed additional extraction wells will not be made until August 1989 (HLA, 1989b).

GEOLOGY

The IBM facility is located in the Santa Teresa Plain in the southern part of the Santa Clara Valley. The Santa Clara Valley was created by tectonic movement and remains tectonically active. Bedrock underlies the Santa Teresa Plain and forms the surrounding mountains. Most of the bedrock consists of consolidated sandstones, shales, cherts, serpentinite, and ultrabasic rocks. There are no known significant bedrock aquifers within the basin.

The valley floor is underlain by Quaternary alluvium, consisting of unconsolidated clays, silts, sands, and gravels. The thickness of the alluvium ranges from zero feet in the surrounding highlands where bedrock is exposed, to approximately 400 feet near the center of the basin.

Lithologic logs of borings within the study area along the east side of the basin indicate that the alluvium appears to be a sequence of alternating sand and gravel zones separated by zones of silt and clay. Because the alluvium was

apparently deposited by meandering streams and rivers, the individual zones are extensive lengthwise along the valley but are locally discontinuous perpendicular to the valley axis.

HYDROGEOLOGY

The coarser sand and gravel layers in the basin form a series of aquifers that are generally separated by silt or clay layers. The monitored aquifer zones are referred to as the A, B, C, D, and E aquifers, in order of increasing depth. (Note: The layering of these aquifers is illustrated in cross sections on Figures 4 and 5 in the following Section.) There are deeper aquifers in some areas and at some locations aquifers merge because of discontinuities in the aquitards. For example, the B and C aquifers merge to form the BC aquifer in the vicinity of the Edenvale Gap, and in other locations in the study area. All of these aquifers are interconnected to some degree (KJC, 1987). Vertical flow between aquifers has been estimated but has not been reported because of high spatial heterogeneity. Aquifer properties are shown in Table 1.

Table 1
AQUIFER PROPERTIES

Aquifer	Hydraulic Conductivity (ft/min)	Transmissivity (ft^2/min)	Storage Coefficient
A	0.12 to 2.2	1.0 to 45	0.0059 to 0.22
B	0.14 to 3.8	7.5 to 66	1.7×10^{-5} to 7.0×10^{-4}
C	0.26 to 1.3	7.2 to 29	6.6×10^{-5} to 1.8×10^{-4}
BC	1.4 to 1.7	25 to 100	5.8×10^{-5} to 5.2×10^{-4}
D	0.2	3.1	3.6×10^{-5}
E	NA	NA	NA

Notes: NA = not available
Compiled from HLA, 1987

The A aquifer ranges from 5 to 30 feet thick, and is first encountered at depths of 20 to 25 feet below the ground surface. The A aquifer was locally confined in the past, but is currently a perched aquifer as a result of general water level decline and remedial pumping. In the southern portion of the IBM facility, the A aquifer has been

dewatered (HLA, 1987, Plate B1-19). Ground-water flow in the A aquifer is generally to the northwest (HLA, 1987).

The B and C aquifers are more laterally extensive and coarser grained than the A aquifer (KJC, 1987). The B aquifer ranges from 15 to 45 feet thick and is encountered at depths of 50 to 60 feet below ground surface. The onsite B aquifer generally consists of two or three sand and/or gravel units separated by silts or clays. The B aquifer has become unconfined in much of the study area except in local offsite areas.

The C aquifer is confined. It is between 90 and 100 feet below ground surface and is approximately 15 to 35 feet thick. The B and C aquifers merge in the area near Edenvale Gap to form the BC aquifer which is encountered between 50 and 60 feet below ground surface and is approximately 75 to 100 feet thick (HLA, 1987). Ground-water flow in the B and C aquifers is to the northwest at approximately 6 to 10 feet per day.

The top of the confined D aquifer is from 140 to 150 feet below ground surface and the unit is approximately 10 to 20 feet thick onsite. The E aquifer is also confined, located approximately 170 to 200 feet below ground surface, and is approximately 10 to 35 feet thick.

Ground-water discharge from the basin occurs by underflow and through pumping. Total pumping volume has increased since 1983 due to operation of ground-water restoration programs at IBM and at the nearby Fairchild Semiconductor Corporation facility. Estimates of ground-water recharge and discharge indicate that the Santa Teresa Basin is being overdrawn (see Table 2). As a result, water levels in the A, B, C, and D aquifers have declined.

WASTE CHARACTERISTICS AND POTENTIAL SOURCES

The primary contaminants of concern at this site are Freon 113, TCA, 1,1-DCE, and TCE. The release of contaminants to soil and ground water at the IBM facility may have been the result of surface spills and leaking underground piping. The contaminant source areas are near buildings where organic chemicals have been used and stored. No inventory of the mass of contaminants released to the subsurface or present in the aquifers has been reported.

The distribution of contaminants at the IBM site is complex, involving several contaminants and several geologic layers. Contamination is found in all five aquifer layers and is found both onsite and offsite. Figure 3 is a cross section

location map of the site. Figure 4 shows cross section A-A', and the profile distribution of the average 1985 TCA concentrations. Cross section A-A' is oriented along the axis of the main plume and is roughly parallel to the regional flow direction. It shows that the contamination of the A aquifer appears to be limited to the boundaries of the IBM facility. It also shows that offsite contamination exists in the B, C, and D aquifers and that the B and C aquifers appear to have the highest concentrations of contaminants. The D and E aquifers have not been well characterized in the mid-plume area so it is difficult to correlate unit D near Edenvale Gap to units D and E under the IBM facility. The D and E aquifers did not appear to be contaminated directly under the IBM facility but were contaminated down to the bedrock near Edenvale Gap. This may suggest that these contaminants migrated downward as they moved laterally from the IBM site to Edenvale Gap.

The distribution of the average 1985 TCA concentrations in profile is shown in cross sections B-B' through E-E' in Figure 5. These cross sections show that the A-aquifer TCA contamination is limited to areas within or near the IBM facility boundaries. The cross sections also show that the width of the 1 ppb plume is about 1,500 feet at mid-plume and less than 500 feet at cross section E-E' near Edenvale Gap. The narrowing of the plume width at Edenvale Gap appears to be due to a convergence of ground-water flow lines at Edenvale Gap.

The 1985 Freon 113 plume was slightly more extensive than the 1985 TCA plume offsite, but otherwise had a similar distribution of contamination. The 1,1-DCE plume was considerably less extensive offsite than either the TCA or Freon 113 plumes. The contamination of the A aquifer by the three major contaminant plumes was limited to areas within or near the boundaries of the IBM facility. Other organic contaminants present at the site are also limited to areas within or near the IBM boundary.

Although Freon 113 contamination is the most extensive, it is of least concern from a health protection standpoint because of the low toxicity of Freon 113. The long-term target remediation concentrations for contaminants present in the A aquifer are shown in Table 3. The target concentrations for contaminants present in the B through E aquifers are shown in Table 4. The standards for the deeper aquifers are more conservative because the deeper aquifers are more extensive and are used for water supply.

REMEDIATION

SELECTION AND DESIGN OF THE REMEDY

IBM installed three ground-water extraction systems: an onsite system centered around known source areas, a boundary system, and an offsite system. The objective of the three systems is to reduce the contaminant concentrations in the aquifers to the target levels listed in Tables 3 and 4. An additional objective of the boundary extraction wells and the offsite wells at Edenvale Gap is to control contaminant migration.

IBM has installed 30 extraction wells to remove contamination and control ground-water movement (KJC, 1987, p. ES-1). The onsite ground-water extraction wells centered around the A-aquifer source areas pump from source areas at Building 001 (Wells A-17 and A-22), Tank Farm 067/Building 006 (Well A-29), Building 025 TCE Area (Well A-31), and the Shell Sol 140 Release area (RA-16 to RA-21) (KJC, 1987). The A-aquifer wells are shown in Figure 6.

The boundary extraction system consists of eight A-aquifer wells, seven B-aquifer wells, and two C-aquifer wells. The onsite and offsite B-aquifer wells are shown in Figures 7 and 8, respectively. The C-aquifer wells are shown in Figure 9 and the D-aquifer and E-aquifer wells are shown in Figure 10. No extraction wells in the D and E aquifers were required by the Regional Water Control Board, and as a result, no wells were installed.

Remedial pumping began in the onsite A-aquifer wells in early 1983 and in the onsite B- and C-aquifer wells in May 1982. Offsite remedial pumping began from late 1983 (ORC-1) to late 1984 (ORBC-3). Figure 11 shows the period of operation and average flow rate through early 1987. Table 5 shows the operational history for all extraction wells and the April 1988 extraction rate for the wells operating at that time. Due to basin overdraft, four B-aquifer wells, both C-aquifer wells in the boundary system, and wells ORC-1 and ORBC-2 were shut off in April, 1988.

IBM has installed over 350 monitoring wells to evaluate the distribution and concentration of chemicals in ground water, and to study the geology at each well location. Monitoring well locations in each of the aquifers are shown in Figures 6 through 10. Most of the monitoring wells installed to evaluate the effectiveness of the remedial pumping are sampled and analyzed monthly or quarterly for

selected parameters. As of June 1987, over 25,000 ground-water samples had been collected and analyzed (KJC, 1987).

EVALUATION OF PERFORMANCE

Hydraulic Control

The effectiveness of ground-water extraction systems in controlling the movement of contaminated ground water can be assessed by examining the aquifer's hydraulic response to pumping. This hydraulic response has been measured and modeled.

Figure 12 is a map of water-level elevations in the A aquifer in June 1986. The general direction of ground-water flow in the A aquifer at that time was northwest. In June 1986, only barrier well RA-2 was being pumped because of dewatering of the A aquifer. Despite a pumping rate of only 30 gpm in RA-2, there was a significant elongated depression in the potentiometric surface of the A aquifer northwest of the IBM facility in June 1986. The sediments in this area were probably deposited parallel to the valley axis, which is parallel to this depressed area. The influence of RA-2 may be extensive to the northwest because of high hydraulic conductivity along this area. Leakage down to the B aquifer may also be contributing to this effect.

The effect of extraction on the potentiometric surface of the B aquifer in June 1986 was also significant (see Figure 13). Broad cones of depression are evident at Edenvale Gap, the mid-plume area, and near the onsite barrier well system. Judging from Figure 13, the zone of capture of the onsite barrier well system appears to include the entire IBM property. An elongated depressed area northwest of the barrier wells was also present in the B aquifer in June 1986.

The zone of capture of the mid-plume system in the B aquifer also seemed to be extensive in a direction normal to the principal flow direction in June 1986. The dashed line indicating the estimated limit of the zone of capture of the mid-plume system extends laterally over 2,000 feet, both northeast and southwest of the mid-plume extraction well. This suggests that the mid-plume system was hydraulically effective in capturing the entire contaminant plume upgradient of its influence in June 1986. These same conclusions can be made based on the water level maps of the C aquifer. The D-aquifer water level maps show flow to the northwest near the IBM facility.

Reductions in Mass and Concentration of Contaminants

The effectiveness of contaminant mass removal can be assessed by reviewing evidence of regional and point decreases in contaminant concentrations and by calculating the mass of contaminants removed by the remediation system.

To assess spatial and temporal variations in contaminant distribution, concentration contour maps and time series plots of concentration are presented. Three time periods are compared on the contour maps--the second quarters of 1984 and 1986 and the last quarter of 1988. The time series plots of concentration cover the period from January 1983 through mid-May 1987.

A Aquifer. The second quarter, 1984 and second quarter, 1986 contour maps of TCA concentrations in the A aquifer are shown in Figure 14. These can be compared to the contour map for the fourth quarter of 1988 (Figure 15) to show the progress of TCA cleanup after over 4-1/2 years of operation. Concentrations of TCA in the northeast increased from 1984 to 1986 and then decreased to concentrations below the 1984 levels by the fourth quarter of 1988. In general, however, the size of the 10-ppb and 100-ppb plumes does not appear to have changed considerably from 1984 to 1988, suggesting a continuous source of TCA or ineffective extraction of TCA.

Figures 16 and 17 show contour maps of 1,1-DCE concentration for the second quarter of 1984, the second quarter of 1986, and the fourth quarter of 1988. These results show one to two order reductions in 1,1-DCE concentrations to the south, and to the east near building 001, but little change in the northwest part of the plume. 1,1-DCE concentrations remain above target levels in a few areas onsite but are below target levels offsite. Contour maps of Freon 113 concentrations over the same period of time show some evidence of reduction in the size and concentration of the onsite Freon 113 plume to the northeast and southwest.

A partial explanation of the minimal reductions in contaminant concentrations to the northwest may be that several of the eight A-aquifer boundary extraction wells in that area were shut off because of dewatering. As of the end of 1988, only RA-2 was pumping--at a rate of about 30 gpm. Nonetheless, about 73 pounds of Freon 113 and 25 pounds of TCA were removed by the A-aquifer boundary wells from early 1983 to March 1987.

B Aquifer. The second quarter, 1984 and 1986 contour maps of TCA concentrations in the B-aquifer are shown in Figure 18. A comparison to Figure 19, the equivalent map

from the fourth quarter of 1988, shows that concentrations of TCA in the mid-plume area near ORB-1 have decreased. The TCA concentration in ORB-1 was over 100 ppb in the second quarter of 1984, but was apparently less than 50 ppb in the fourth quarter of 1988. The contour maps also suggest that the concentration of TCA in wells 13-B, 2-B, and 5-B decreased from above 50 ppb in 1984 to between 10 and 50 ppb in 1988. However, other data sources show that the concentration of TCA in these wells has not declined significantly over this period. There was almost no change in the position of the 10-ppb and 1-ppb contours of TCA over the 4-1/2 year period. Freon 113 concentrations in the B aquifer also show substantial reductions in the mid-plume area near ORB-1 and virtually no change in the 10-ppb and 1-ppb contours from the second quarter, 1984 to the fourth quarter, 1988.

The second quarter, 1984 second quarter, 1986; and fourth quarter, 1988 contour maps of 1,1-DCE concentrations in the B aquifer are shown in Figures 20 and 21, respectively. 1,1-DCE concentrations were less than 10 ppb throughout the B aquifer at the site over this entire period. Virtually no change in the position or concentration of the 1,1-DCE plume over this 4-1/2 year period was evident, however.

The lack of change in the 1-ppb contour of 1,1-DCE and the lack of change in the 10-ppb and 1-ppb contours of TCA and Freon 113 are probably due to the fact that very little contaminant mass is being extracted at these concentrations. Well ORB-1 extracted only 6.1 pounds of Freon, 9.4 pounds of TCA and 0.5 pounds of 1,1-DCE in 1988 (HLA, 1989b). Furthermore, this mass is removed from a large area. Progress is expected to be very slow at these concentrations. The extraction continues in all areas despite the fact that Freon 113 and TCA appear to be well below their action levels of 4,500 ppb and 50 ppb, respectively. 1,1-DCE appeared to be at or below its B-aquifer action level of 1.5 ppb in the fourth quarter of 1988.

Evidence of progress in the B-aquifer restoration is demonstrated by the set of three graphs in Figure 22. These graphs show the mass of contaminants removed from the extracted ground water from early 1983 to early 1987. As of December 1986, 4,800 pounds of Freon 113, 153 pounds of TCA, and 27 pounds of 1,1-DCE had been removed by the onsite B-aquifer boundary extraction system. The mid-plume recovery well ORB-1 had removed about 170 pounds of Freon 113, 205 pounds of TCA, and 6.5 pounds of 1,1-DCE from the B aquifer by this same date.

An extraction system installed in the unseparated B-C aquifer at Edenvale Gap has been active since early 1984. Combined pump rates of over 2000 gpm in wells ORBC-2 and ORBC-3 have led to the recovery of about 5 billion gallons of ground water containing about 385 pounds of TCA and 370 pounds of Freon 113 as of March 1987.

C Aquifer. The second quarter, 1984 second quarter, 1986; and fourth quarter, 1988 contour maps of TCA concentrations in the C aquifer are shown in Figures 23 and 24, respectively. Comparison of these maps shows a slight decrease in TCA concentrations in the Edenvale Gap and mid-plume areas, but virtually no change elsewhere. Freon 113 concentrations appear to have increased slightly in some areas over the same period. Time series plots of the concentrations of Freon 113 and TCA in wells 9-C and ORC-1 in the mid-plume area from early 1983 to early 1987 (Figure 25) show a stable TCA concentration of about 10 ppb and a stable or slightly increasing trend in Freon 113 concentrations.

The reduction of contaminant mass in the subsurface is one indication that remediation is progressing. Table 6 presents a summary of total ground water extracted and chemical mass removed by the three systems from 1983 through 1987 (KJC, 1988, Appendix S1). From June 1983 through 1987, approximately 7,679 pounds of Freon 113, TCA, and 1,1-DCE were removed from the extracted ground water. The initial contaminant mass inventory has not been reported.

SUMMARY OF REMEDIATION

The interim remedial measures implemented at the IBM-San Jose site can be summarized as follows:

- There are four aquifer systems beneath the IBM facility that are contaminated with organic solvents. These are referred to as the A, B, C, and D aquifers. The A-aquifer contamination is mainly within the boundaries of the IBM facility. The B, C, and D concentration plumes extend offsite to beyond Edenvale Gap to the northwest.

- Three extraction systems were installed: a system of dispersed onsite extraction wells that pump from the A aquifer; an onsite barrier-well system that pumps the A, B, and C aquifers from a line of wells on the western boundary of the facility; and an offsite extraction system that pumps from the B, BC, and C aquifers.

- Six years of operation have reduced the contaminant concentrations onsite in the A aquifer in the southeastern half of the plume but have had only a minor effect on the northwestern half, possibly because of dewatering. In the B and C aquifers offsite, the extraction systems have reduced concentrations near the centerline of the plume ellipsoid, particularly near the boundary wells and at mid-plume, but have had little effect on low-concentration areas of the plume more than 400 to 500 feet perpendicular to the centerline. This may be because the reduction in contaminant mass is very small at these concentrations and pumping rates and as a result, concentrations decrease very slowly. Steady or slightly decreasing concentrations are expected in large areas of low contamination such as this. Some contamination may also be present in the unsaturated zone or sorbed to the solid phase in the saturated zone.

- Water level results from June 1986 suggest a hydraulic zone of capture that includes these areas of low concentration. The contaminated water that is not captured by the mid-plume system may be captured by the extraction system at Edenvale Gap after several years of migration driven by natural gradients.

- The offsite plume is large and has migrated more than 2 miles offsite. The concentrations observed in offsite wells screened in the B and C aquifers are generally stable or decreasing slightly. The offsite extraction systems may have to be operated for many years because of the current slow rate of decline in contaminant concentrations.

- Over 7,600 pounds of contaminants (Freon 113, TCA, and 1,1-DCE) were removed by the extraction systems from 1983 through 1987. The initial mass of solvents contaminating the subsurface is unknown.

- The detrimental dewatering effect of IBM's remediation pumping deserves attention, especially considering that the concentrations of contaminants in most offsite areas are below action levels. A 1985 ground-water balance estimate for the Santa Teresa Basin showed that 6,900 to 29,900 acre-feet of overdraft occurred in 1985. Increased regional pumping costs and land

subsidence are two anticipated effects of overdraft. The proposed discharge of the treated water to the Santa Clara Valley Water District infiltration basins (KJC, 1987) is expected to decrease the rate of decline in water levels, but some irreversible land subsidence effect is still possible. Some actions to decrease pumping and increase recharge have been taken during the last 2 years, including reductions in remediation-related pumping at the IBM facility and the nearby Fairchild Semiconductor facility (HLA, 1989b; Phil Mitchell, personal communication, May 23, 1989).

BIBLIOGRAPHY

Harding Lawson Associates. June 1987. Appendix B: Summary of Hydrogeologic Studies, Draft Comprehensive Plan, IBM Ground Water Restoration Program, IBM General Products Division, San Jose, California.

Harding Lawson Associates. January 1989(a). Quarterly Report, September 1988 through December 1988, IBM Ground Water Restoration Program, IBM General Products Division, San Jose, California.

Harding Lawson Associates. May 15, 1989(b). Letter to Mr. Phil Mitchell.

IBM. April 1988. IBM Draft Comprehensive Plan Supplement, Ground-water Restoration Program.

Kennedy/Jenks/Chilton. June 1987. Draft Comprehensive Plan, IBM Ground Water Restoration Program, IBM General Products Division, San Jose, California.

Kennedy/Jenks/Chilton. April 1988. Draft Supplement Comprehensive Plan, IBM Ground Water Restoration Program, IBM General Products Division, San Jose, California.

Mitchell, Phil. May 23, 1989. Personal communication.

WDCR428/016.50

CASE STUDY 12

Nichols Engineering and Research Corporation
Hillsborough Township, New Jersey

CASE STUDY FOR
THE NICHOLS ENGINEERING AND RESEARCH CORPORATION SITE

BACKGROUND OF THE PROBLEM

The Nichols Engineering and Research Corporation (NERC) site is located at the southwest corner of the intersection of Willow and Holmstead Roads in Hillsborough Township, Somerset County, New Jersey. It was operated as a combustion research pilot plant in which fluidized-bed and rotary-kiln incineration of slag was tested. All of the necessary chemical analyses, including feed and product stream analysis, exhaust gas analysis, and emissions testing, were done onsite. The ground water occurs in a fractured rock aquifer and has elevated levels of volatile organic compounds (VOC). All operations at the facility were terminated in the spring of 1983. In accordance with the New Jersey Department of Environmental Protection's (NJDEP) Environmental Clean-up Responsibility Act (ECRA), remedial action was taken consisting of a ground-water recovery system, which has been in continuous operation since January 22, 1988.

SITE HISTORY

The NERC facility was operated as a combustion research facility from the early 1970s until the spring of 1983. A General Information Submission (GIS), a Site Evaluation Submission (SES), and a sampling plan were filed with the NJDEP in accordance with the ECRA on February 15, March 14, and August 6, 1985, respectively.

The GIS and SES were approved on September 2, 1985, and the sampling plan was approved on November 26, 1985. A revised sampling plan was submitted on May 14 and approved on July 29, 1986.

Ground-water sampling beneath the NERC site performed in 1986 and early 1987 revealed VOC contamination centering around a subsurface wastewater settling basin adjacent to the west side of the pilot plant (see Figure 1). The basin is suspected of being the source of the ground-water contamination beneath the site.

A ground-water contaminant recovery system was installed at the NERC facility during December 1987 and January 1988. Prior to operation of the recovery system, depth-integrated ground-water samples were collected from all 12 onsite monitoring wells and discrete ground-water samples were collected from monitoring wells MW-3, MW-11, and MW-12 using pneumatic packers to isolate the zones to be sampled.

The ground-water contaminant recovery system, consisting of one extraction well, became operational on January 22, 1988. It has been in continuous operation since that time at an average pumping rate of 61 gallons per minute (gpm). The extracted ground water is discharged to the Hillsborough Municipal Utility Authority (HMUA) sanitary sewer system. In January 1989, two more extraction wells were added to the recovery system. No data have yet been obtained on the effects of this modification.

GEOLOGY

The NERC facility lies within the Newark Basin of the Piedmont Province and is underlain by the Passaic Formation. The Passaic Formation is a consolidated sedimentary unit of Triassic-age rock including shales, siltstones, sandstones, and conglomerates. The formation is 600 to 19,000 feet thick. The bedding strikes northeast to southwest, parallel to the axis of the Newark Basin, and dips to the northwest at 10 to 25 degrees. The Passaic Formation bedrock is generally found at a depth of 2 to 6 feet below ground surface. It is overlain by soil consisting of a yellowish-red shaly silt. Storch Engineers, the environmental consultants for Nichols, conducted a fracture trace analysis of the NERC facility and identified four major sets of linear features, defined as prominent vertical to near-vertical fracture sets. Two of the fracture sets strike northeast to southwest, and the other two strike northwest to southeast.

HYDROGEOLOGY

The water-table depth ranges from 20 to 40 feet below ground surface across the NERC site. Because saturated flow occurs only in the bedrock, the major pathway of hydraulic and contaminant transport in these deposits is through faults, fractures, and bedding planes. The orientation of the pre-pumping and post-pumping water tables at the NERC facility suggests that the majority of flow occurs from southeast to northwest (Storch Engineers, 1988a).

A local ground-water divide occurs naturally at the southeast portion of the site. Figure 1 shows the divide, which is centered near monitoring well-4 (MW-4). However, this divide only exists during part of the year. Ground water to the south and east of this divide flows toward the stream channel of Royce Brook, which flows north across the eastern part of the site. The gradient of the water table between MW-4 and MW-3 is 0.034, approximately 20 times greater than that between MW-3 and MW-6. The gradient between wells MW-4 and MW-8 is toward the southeast at 0.007 feet per horizontal foot.

An aquifer pumping test was conducted at the NERC facility between September 8 and September 12, 1987. Analysis of the

pump test data reveals a complex aquifer exhibiting both water-table and semi-confined behavior. A conceptual model based upon analysis of the pump test data comprises a system of two marginally independent aquifers. The uppermost water-table aquifer, exhibiting delayed yield behavior, is separated from a lower "high transmissivity", semi-unconfined zone by a 10-to 20-foot thick stratum of poorly fractured sedimentary rocks. This intervening stratum has a somewhat lower hydraulic conductivity than either the upper or lower zones. The confining layer is penetrated by a number of widely distributed vertical to near-vertical fractures. In areas of high fracture density, the two zones behave as a single fracture network exhibiting the storage characteristics of a water-table aquifer. Where fractures are less well developed, the behavior of the lower zone is semi-unconfined.

Storch Engineers postulates that the increased transmissivity in the lower zone is caused by enhanced bedding plane fracturing. The development of the cone of depression suggests that fracturing and the associated transmissivity tensor are anisotropic. The major axis of transmissivity is oriented southeast to northwest, sub-parallel to two of the four major fracture sets. The minor axis of transmissivity is oriented southwest to northeast, parallel to the strike of the Passaic Formation. It should be noted that the major axis of the contaminant plume is approximately parallel to the major axis of transmissivity.

Table 1 shows the transmissivity and storage coefficients the upper and lower zones as well as in the major and minor axes in the upper zone.

Table 1
AQUIFER TEST RESULTS

Transmissivity (ft^2/min)	Storage Coefficient		
3×10^{-2}	6×10^{-2}	Upper Zone	- Boulton (1963)
8×10^{-1}	5×10^{-2}	Lower Zone	
4×10^{-2}	2×10^{-3}	Upper Zone Major Axis (N63°W)	- Hantush (1966)
1×10^{-2}	2×10^{-3}	Upper Zone Minor Axis (N27°E)	

Based on the hydraulic properties of the upper zone, the seepage velocities were estimated by Storch Engineers to be 0.144 ft/day along the major transmissivity axis and 0.0144 ft/day along the minor axis. These estimates are based on the assumption that the aquifer behaves as a conventional porous medium and as such, would tend to underestimate the velocity of flow along discrete fractures.

WASTE CHARACTERISTICS AND POTENTIAL SOURCES

The suspected source of ground-water contamination at the Nichols Engineering site is a wastewater settling basin that was located just upgradient of wells MW-1 and MW-2 adjacent to the west side of the pilot plant. The concrete-lined basin was excavated into the bedrock to a depth of approximately 8 feet (Storch Engineers, 1989). In 1987, the basin was removed and the shallow soils surrounding it were excavated. The area of soil excavation was approximately 30 feet square. Soils surrounding the pit were found to be contaminated with heavy metals and base-neutral extractable compounds, but these compounds were not detected in the ground water. Conversely, the VOCs that are ground-water contaminants at the site were not found in the soil.

Results of water-quality analyses conducted on samples collected during the first four rounds of sampling indicate that a contaminant plume comprising the VOCs chloroform ($CHCl_3$), carbon tetrachloride (CCl_4), and tetrachloroethylene (PCE) is centered around wells MW-1 and MW-2.

The three compounds make up three individual contaminant plumes that are collectively referred to as the "plume." The CCl_4 plume is the most extensive and has, therefore, been used as the primary monitor of recovery system performance. The areal extent of the plumes of the individual VOC constituents varies, but averages approximately 70,000 ft^2. The plume boundary is defined as the 5 parts per billion (ppb) isopleth. The required ECRA clean-up levels are 5 ppb for each individual compound and 10 ppb for total VOCs. Figure 2 shows the elliptical configuration of the contaminant plume, with the major axis of elongation oriented northwest to southeast.

The three VOCs detected at the site all have limited solubility in water. In their pure forms, they are denser and less viscous than water. Consequently, if they are present in a dense, nonaqueous phase (DNAPL), they would probably sink rapidly to the bottom of the transmissive zone of the rock. DNAPLs may be present at the site, but no direct physical evidence of them has been found. The bedrock is thought to be fractured to much greater depths than have been reached by any of the wells at the site.

Of the three ground-water contaminants, chloroform has the lowest potential for sorption to organic carbon in the aquifer materials, and is normally quite mobile. PCE and CCl_4 are both moderately mobile compounds with respect to adsorptive retardation. However, in fractured rock aquifers, solute retardation can also be caused by matrix diffusion in the rock adjacent to the fractures (Freeze and Cherry, 1979). This effect would tend to reduce the mobility of all three compounds.

REMEDIATION

SELECTION AND DESIGN OF REMEDY

Objectives of Remediation

The primary objective of the recovery system is to remove the contaminated ground water. This entails extracting contaminated ground water by means of one or more recovery wells and subsequently lowering the concentration in the ground water to a maximum level of 5 ppb for $CHCl_3$, CCl_4, and PCE and 10 ppb for total VOC.

The recovery system was implemented in accordance with a secondary objective of minimizing installation time and cost while maximizing the rate of contaminant removal. This resulted in a phased approach for the recovery system design, including the implementation of an initial, or pilot, recovery system followed by a final recovery-system design. Adjustments or modifications to the initial recovery-system design constitute the final design.

System Configuration

The initial recovery system includes a single pumping well located within the contaminant plume at well MW-3. The recovery well operates at a discharge rate of approximately 60 to 65 gpm. Well MW-3 extends to a depth of 100 feet with the pump intake set at 90 feet. The well penetrates to the lower "high transmissivity" zone. The decision to pump from the lower zone instead of the upper zone was based upon the increased lateral extent of the associated capture zone as well as the significant interconnection of the two zones. Aquifer tests conducted in September 1987 indicate the well is capable of delivering a sustained yield of 200 gpm. However, extraction has been maintained at less than 70 gpm because of disposal limitations.

The initial recovery system consisted of a single recovery well, mainly because of the associated low initial costs and time requirements. A single recovery well is less costly to install and often less expensive to operate than a multiple recovery well system. The startup time of a single recovery

well is, in most cases, much shorter than that for a multiple recovery well system because the design is simpler and construction time reduced. The existing monitoring well MW-3 was used for extraction because of its central location in the plume and because aquifer test results suggested that it would provide the necessary capture zone.

The performance of well MW-3, as a recovery well, was analyzed using the capture zone type-curve technique (Javandel and Tsang, 1986). Figure 3 presents the analysis graphically showing that the contaminant plume lies within the capture zone of the recovery well pumping at 70 gpm.

All ground water removed by the recovery well is discharged to the HMUA sewer system without pretreatment. This method of disposal was chosen because it could be implemented quickly, with limited installation and maintenance costs. However, the discharge rate was limited to 100,000 gallons per day (gpd), the maximum withdrawal allowed without a discharge permit, to avoid the time delay and additional costs associated with a ground-water diversion permit application.

In January 1989, pumping was initiated from wells MW-1 and MW-11 in addition to the continued extraction from well MW-3, although the total extraction rate was still limited to 70 gpm. This change was made because experience with well MW-3 indicated that its capture zone did not extend to well MW-11. Also, the designers of the system felt that the rate of VOC reduction per unit of ground water removed could be increased by distributing the extraction process among the three wells.

All samples collected are analyzed using U.S. EPA Method 624 (GC/MS) for the priority pollutant VOCs. The original sampling schedule proposed in the extraction system design is presented in Table 2. Monthly sampling was done only with wells MW-1, MW-2, MW-3, and MW-11. Wells MW-5, MW-7, MW-8, MW-9, and MW-12 were analyzed initially and yielded concentrations below the detection limit or had trace concentrations below the reporting limit. These wells were not analyzed again until 7 months after the initial sampling. Wells MW-4, MW-6, and MW-10 were sampled for the first 4 months, then again 3 months later.

Table 2
ORIGINAL PROPOSED SAMPLING SCHEDULE

Monthly	Quarterly	Closure
** * * * * *	* * * * * *	* *
1 2 3 4 5 6	7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24	25 26 27 28 29 30 Time (Months)

Initial Sampling:	Sample all monitoring wells and the recovery well for volatile organic compounds (EPA 624)
Biweekly:	Sample those wells showing signs of contamination, above acceptable levels, in the initial sampling round
Monthly:	Sample those wells showing signs of contamination, above acceptable levels, in either of the two prior sampling rounds
Quarterly:	Initial quarterly round (6 months)--sample all monitoring wells and recovery wells; remaining rounds--sample those wells showing signs of contamination, above acceptable levels, in either of the two prior sampling rounds
Closure:	When a quarterly round indicates compliance with ECRA cleanup standards, sample all monitoring wells and recovery well for two consecutive quarters

* - sampling event

The NJDEP has expressed concern that the VOCs may be present in the ground water downgradient of the disposal basin at depths below the existing monitoring wells. In response to this concern, Storch Engineers installed wells MW-11 and MW-12 to depths of 100 feet and extended well MW-3 to that depth during November 1987. Another deep well, MW-10D, was installed to a depth of 100 feet adjacent to well MW-10.

A discrete sampling program was performed on wells MW-3, MW-11, and MW-12 to establish the vertical configuration of the contaminant plume upgradient and perpendicular to the regional direction of ground-water flow. Discrete sampling was accomplished by using inflatable packers to isolate the interval of the well to be sampled. The results of the discrete sampling are shown in Table 3. These results suggest that most of the VOC contamination is near the water table.

Table 3
RESULTS OF CHEMICAL ANALYSES
DISCRETE GROUND-WATER SAMPLING
Sample ID and Concentration (ppb)

	MW-3			MW-11			MW-12		
	A	B	C	A	B	C	A	B	C
	Depth in Feet								
Contaminant	43-50	68-75	88-95	43-50	68-75	88-95	43-50	68-75	88-95
Methylene Chloride	ND	ND	ND	ND	ND	ND	BMDL	BMDL	ND
Chloroform	3.0	ND	ND	3.0	ND	ND	ND	BMDL	ND
Carbon tetrachloride	14	ND	ND	120	ND	ND	BMDL	4.9	ND
Trichloroethylene	BMDL	ND	ND	ND	ND	ND	ND	ND	ND
Tetrachloroethylene	ND	ND	ND	ND	ND	ND	ND	ND	ND
Toluene	17	15	3.8	5.0	23.0	1.1	7.6	2.1	2.3

ND = None detected.
BMDL = Below method detection limit.

EVALUATION OF PERFORMANCE

The recovery system has been operating continuously since January 22, 1988. Figure 4 illustrates the impact the recovery well has had on the potentiometric surface. Roughly 21,596,600 gallons of ground water had been recovered as of October 6, 1988. The average flow rate was approximately 60 gpm or 86,400 gpd.

Table 4 presents the results of the sampling analyses done throughout the operation of the recovery system. The results indicate that wells MW-4, MW-6, MW-7, MW-8, MW-9, MW-10, and MW-12 all have concentrations of CCl_4, $CHCl_3$, and PCE below the 5-ppb cleanup level. However, this was true before operation of the recovery system began. Varying concentrations of these contaminants are still being detected in wells MW-1, MW-2, MW-5, and MW-11. Figure 5 shows the relationship between the concentration of CCl_4 in wells MW-1, MW-2, MW-10, and MW-11 and the volume of ground water discharged over the period of operation. Note that the concentrations are plotted on a logarithmic scale.

Wells MW-1 and MW-2 have yielded the highest concentrations of VOCs, 980 and 610 ppb, respectively. Based on results of the October 6, 1988 sampling round, CCl_4 concentrations in wells MW-1 and MW-2 have been reduced by roughly 90 and 80 percent, respectively. However, the cleanup level calls for a reduction to 5 ppb in all wells. The concentration of CCl_4 in well MW-11 does not appear to have been affected by the recovery system.

Figure 6 shows the relationship between CCl_4 concentration, water level, and precipitation for wells MW-1 and MW-2. The concentration of CCl_4 in wells MW-1 and MW-2 can be seen to have stabilized or increased during periods of increased water levels or shortly thereafter. This suggests that a contaminant source exists within the unsaturated zone (Storch Engineers, 1988b).

The July 21-22, 1988, and October 6, 1988, sampling records indicate the presence of CCl_4 in well MW-5 at levels above the cleanup level (7.4 ppb and 7 ppb). CCl_4 had not been detected in well MW-5 above the reporting limit before the July sampling round. These results indicate that horizontal and/or vertical movement of ground water contaminated with CCl_4 may have occurred in the area of well MW-5. This movement suggests that the plume may not be completely contained by the recovery system, however, confirmation is limited by the data. Continued monitoring of this well has been recommended by Storch Engineers and conclusions will be drawn after more complete data become available.

Analysis of the sampling results indicate two important trends. First, the rate of decrease in contaminant concentration in wells MW-1, MW-2, and MW-11 decreased significantly after the first 50 to 80 days of extraction, as shown in Figure 5. Second, precipitation and the associated uses in water levels tend to increase the CCl_4 concentrations detected in ground water, suggesting the existence of CCl_4 within the unsaturated zone (see Figure 6).

The first trend may result from a number of factors including the record trend. The exchange of contaminant mass between the fractures within the geologic formation and the rock itself may affect the CCl_4 removal rate. This process, known as matrix diffusion, results in retardation and enhanced logitudinal dispersion in contaminant transport through fractured rock. Another factor is the presence of CCl_4 in the unsaturated zone. CCl_4 in this zone will not be removed unless leached out of the soil by infiltration. This is a slow process and that appears to be a function of precipitation. Adsorption/desorption processes may also contribute to the reduction in the removal rate.

It is important to note that the concentration of CCl_4 in well MW-11 does not appear to have been reduced at all.

This is thought by Storch Engineers to indicate that the lower zone of well MW-11 may be outside the capture zone of well MW-3. For this reason well MW-11 was converted to an extraction well in January 1989, together with well MW-1. No performance information for the expanded system has yet been made available, but Storch Engineers believe that it has accelerated the remediation substantially (Storch Engineers, 1989). They currently expect to complete remediation before the end of the year.

SUMMARY OF REMEDIATION

The NERC site has reported elevated levels of VOCs (mainly CCl_4) in the ground water. A ground-water recovery well has been in continuous operation since January 22, 1988, and as a result the CCl_4 concentration has been reduced by 80 to 90 percent in some wells. The rate of CCl_4 removal has decreased significantly during the course of operation.

The addition of two additional extraction wells to the system in January 1989, is thought to have accelerated the ground-water cleanup, but no firm indication of this is yet available.

The presence of CCl_4 within the unsaturated zone is of primary concern. The addition of two recovery wells is not likely to increase the rate of leaching of contaminants out of the unsaturated zone.

The unsaturated zone at NERC can logically be seen as two different zones. The first zone is the part of the unsaturated zone that occurs naturally in the absence of pumping. This natural unsaturated zone is bounded by the ground surface and water-table surface, which occurs 20 to 40 feet below the ground surface. The second or induced unsaturated zone is that part of the unsaturated zone created by the drawdown of the operating recovery well.

A technique that may improve the recovery rate of CCl_4 within the induced unsaturated zone is intermittent pumping. By shutting off the recovery wells and allowing the water table to resume its natural position, the induced unsaturated zone will become inundated and some dissolution of CCl_4 into the ground water will occur. Continuation of the pumping process can then remove the CCl_4 captured by this process. Intermittent operation of the recovery well(s) would increase the removal of CCl_4 from the induced unsaturated zone to some degree, but CCl_4 in the natural unsaturated zone would not be affected. The correlation between water level and CCl_4 concentration should be investigated further and the possibility of using intermittant pumping should be considered if the correlation is favorable.

The CCl_4 in the natural unsaturated zone will not be affected by ground-water extraction unless other actions are taken. Although the displacement of ground water by intermittent pumping will create air flow through this zone, the impact this air flow has on the removal of CCl_4 is probably minimal. Implementation of a soil vapor extraction system does, however, have the potential to significantly affect the removal of CCl_4 from this zone. Alternatively, the treated ground water could be recharged to the surface of the site to infiltrate through the unsaturated zone and leach out the CCl_4. The apparent correlation between precipitation and elevated levels of CCl_4 in the ground water suggests that this would be effective.

BIBLIOGRAPHY

Freeze, R.A. and J.A. Cherry. 1979. Groundwater. Prentice-Hall, Inc., Englewood Cliffs, NJ.

Javandel, I. and C.F. Tsang. 1986. Capture-Zone Type Curves: A Tool for Aquifer Cleanup. Ground Water Vol. 24 No. 5. pp. 616-625.

Storch Engineers. June 2, 1987(a). NERC Report on Ground Water Sampling Analysis, Assessment, and Conceptual Cleanup Plan.

Storch Engineers. September 28, 1987(b). NERC Ground Water Contaminant Recovery and Treatment System Design-Interim Progress Report.

Storch Engineers. February 8, 1988(a). NERC Ground Water Cleanup Plan.

Storch Engineers. September 28, 1988(b). NERC Ground Water Cleanup Progress Report--July 1988.

Storch Engineers. November 28, 1988(c). Letter to Mr. Steven Kehayes describing progress of ground-water recovery activities.

Storch Engineers. April 20, 1989. Personal Communication with David A. Jermakian.

WDCR28/005.wp

CASE STUDY 13

Olin Corporation
Brandenburg, Kentucky

CASE STUDY FOR THE OLIN CHEMICAL DOE RUN PLANT

BACKGROUND OF THE PROBLEM

Olin Chemical Corporation's Doe Run facility is located just south of the Ohio River near Brandenburg, Kentucky (Figure 1). Since 1952, the plant has utilized ground water obtained from three Ranney wells to meet its demands for process and cooling water. Initially, all of the plant's water needs were met using these wells, but as water demands increased it became necessary to construct Doe Run Lake to supplement the water supply. Presently, approximately one-third of the 14,000 gpm of water required is supplied by ground water and two-thirds by surface water out of the lake.

In the late 1960s and early 1970s, it became evident that the ground water in the vicinity of Ranney Wells 1 and 2 had become contaminated from past disposal practices: onsite thermal destruction in open burning pits and use of settling basins. The contaminants of concern are chloro-alkyl ethers, primarily dichloroethyl ether (DCEE) and dichloro-isopropyl ether (DCIPE). Ground-water extraction via the three Ranney wells has been used since 1974 to keep the contaminants from migrating offsite. The Kentucky Division of Waste Management has regulated remediation activities at the site since 1984.

SITE HISTORY

DCEE and DCIPE were found in high concentrations in the early 1970s in Ranney Wells 1 and 2. Both ethers were produced as waste by-products at the Doe Run plant. DCEE waste has not been produced since 1962 and DCIPE waste has not been produced since 1981.

These two waste by-products were disposed of by open burning pits and settling basins which, because of the relatively permeable nature of the surficial soils, led to the contamination of the ground water.

Hydrogeologic studies were conducted in 1974 and 1975, and in 1980 to determine the extent and sources of the contamination. These studies included the drilling and installation of 24 observation and/or chemical sampling wells.

The Ranney wells have been used to extract process water for the plant since the early 1950s, and as such have exerted

some control on contaminant migration for many years. Starting in late 1984, the three Ranney wells were specifically operated as part of a remediation program designed to contain and collect all contaminated ground water at the facility. Olin intends to continue this practice to satisfy the State of Kentucky's requirement for a corrective action program for the ground-water contamination at the facility.

GEOLOGY

The Doe Run facility is located within the Ohio River alluvial valley, which is approximately 1 mile wide at the site. The valley contains two terraces, a lower and an upper terrace. The lower terrace, or flood plain, has surface elevations that generally range between 415 and 430 feet above mean sea level, and is subject to frequent flooding by the river. The upper terrace, upon which most of the plant is located, varies in elevation between 450 and 460 feet above mean sea level. Presently, the low water level of the Ohio River is maintained at an elevation of 383 feet by the Corps of Engineers.

Typically, the upper 20 to 30 feet of material encountered near the river is fine-grained material with a dominance of silt and very fine sand with interbedded layers of clay. The thickness of these deposits thins to the south towards the higher terrace.

Underlying the finer-grained sediments is a thick sequence of sands with varying amounts of gravel. This coarser material represents valley train materials deposited during the Pleistocene era by glaciers retreating from the land to the north and east. The glacial meltwater drastically increased the load and discharge of the Ohio River. The hydrologic properties of these materials vary both vertically and horizontally, but they are generally moderately to highly permeable and capable of storing and transmitting relatively large volumes of water. Neither clay lenses nor zones high in silt and clay content, both sediment types that would restrict the vertical movement of water, were encountered within the saturated zone.

The bedrock below the unconsolidated materials is a thin to very thin, bedded, crystalline, fossiliferous limestone. The limestone reveals few joint patterns and appears to have very low permeability and porosity characteristics. Figure 2 is a bedrock-surface elevation map constructed using all available data. The bedrock valley walls are much steeper on the north side of the valley than along the southern margin of the valley in the vicinity of the plant.

HYDROGEOLOGY

The alluvial aquifer in the vicinity of the Doe Run plant consists of unconsolidated deposits of sands and gravel with varying amounts of silt and minor occurrences of clay. Ground water generally exists under unconfined conditions, especially in the vicinity of pumping centers, where significant dewatering has occurred. The configuration of the water table while under the influence of the Ranney well pumping is shown in Figure 3. The pumping rates of Ranney Wells #1 (PW1), #2 (PW2), and #3 (PW3) at the time that the potentiometric surface was evaluated were 1425 gpm, 1650 gpm, and 1740 gpm, respectively. The saturated thickness of the aquifer ranges from nearly 80 feet near the river, to less than 30 feet near the ethylene oxide and propylene oxide (EO and PO) off-gas burners (see Figure 4).

Hydrogeologic surveys have provided insight into the hydraulic properties of the aquifer. The aquifer east of Ranney Well #1 is comparatively less permeable and exhibits an average hydraulic conductivity of 134 ft/day. The aquifer west of Ranney Well #1 has an average hydraulic conductivity of about 267 ft/day. There is a hydraulic connection between the aquifer and the adjacent Ohio River. Since the aquifer is unconfined, the storage coefficient should approximate the specific yield of the formation and is estimated by Olin to be approximately 0.2 (Olin, 1986).

The Ohio River Valley is the natural discharge area for the region. However, the Ranney collector wells are so close to the river that 80 to 90 percent of the water produced from them is induced recharge from the river. Normal groundwater flow gradients range from 0.0007 to 0.002 and are directed towards the river. Operation of the Ranney wells has placed stress on the system, increasing the gradients and creating a discharge point. Recharge to the aquifer is also received from:

1. Precipitation which infiltrates through the soil and percolates downward to the water table

2. Leakage from the bedrock valley walls

3. Leakage from unlined ditches and streams which cross the flood plain

WASTE CHARACTERISTICS AND POTENTIAL SOURCES

Through ground-water monitoring, it has been determined that contaminants were released from the following sources:

1. The Old Burning Pit southeast of Ranney Well #1
2. The EO/PO Off-Gas Burner Area
3. The Lime Settling Lagoon

Figure 4 shows the locations of these sources. The Old Burning Pit was an atomizing burner used from 1952 through 1974 to incinerate chlorinated hydrocarbons. It is estimated that 18,000 tons of propylene dichloride, DCEE, and DCIPE were disposed of in this unit. From 1952 to 1960 the Lime Settling Lagoon settled out waste and other inert solids from a chlorohydrin-type ethylene oxide process wastewater stream. The EO/PO Off-Gas Burner was an atomizing burner used from 1959 through 1961 to incinerate off-gas from ethylene and propylene oxide chlorohydrin processes. It is estimated that 10 tons of off-gas was disposed of in this unit.

Seven additional solid waste management units are located at the Doe Run Facility (see Figure 4). These units include:

1. Combined Waste Landfill
2. Olin East Landfill
3. West Landfill
4. West Biological Sludge Landfill
5. East Biologial Sludge Landfill
6. Clinker Disposal Area
7. Wastewater Treatment Facility

There were no known hazardous constituents disposed of in these units. The location of each solid waste management unit is shown in Figure 4.

Because of operational characteristics of the three sources, DCEE and DCIPE were selected as indicator parameters in evaluating the conditions of the facility's ground water. These indicator parameters are chlorinated ether compounds that are slightly denser than water and only slightly soluble in water. The aqueous solubilities for DCEE and DCIPE are 10,200 ppm and 1,700 ppm respectively. DCEE can be characterized as having very high mobility with a sediment-water partition coefficient (K_{oc}) of 13.9 ml/g; DCIPE is highly mobile with a K_{oc} of 61 ml/g. The water quality criteria for human health at 10^{-6} excess cancer risk are 0.03 ppb for DCEE and 34.7 ppb for DCIPE as defined by the Clean Water Act.

Figure 5 shows the areal distribution of maximum concentrations of DCEE in May 1980; Figure 6 shows the configuration for DCIPE. The area and shape of the contaminated region is similar for DCIPE and DCEE. Olin concluded that there are three areas of high DCIPE concentrations: Ranney Well #1 (RW-1), MW-6 and BH-11, and BH-35.

REMEDIATION

SELECTION AND DESIGN OF THE REMEDY

The objective of the ground-water extraction by the Ranney wells is to prevent the migration of pollutants into areas which are free of contamination. The system consists of three Ranney wells spaced about 1,500 feet apart on the southern bank of the Ohio River. These wells were constructed in 1951 and 1952. Two vertical, gravel-packed wells were installed west of Ranney Well #3 in 1978.

The ground water beneath the Doe Run facility is presently monitored using 33 monitoring wells, three Ranney wells, and two conventional production wells (Collector Wells #4 and #5). An example of a section and plan view of a Ranney well is shown in Figure 7.

Hydraulic gradients can be determined from piezometric surface measurements that were collected in the field. This defines the ground-water flow direction and illustrates the influence of each collector well on the ground water (see Figure 3). The natural ground-water flow direction in the plant area is to the north towards the Ohio River. Operation of the collector wells bordering the Ohio River increases both the natural northward gradient and flow rates towards the Ohio River.

Using computer modeling, Olin evaluated several pumping modes, and then field-tested those that looked most promising. The results of these studies are summarized as follows:

- With Ranney Wells #1 and #3 out of service and Well # 2 operating, all contaminated ground water is contained and flows toward Ranney Well #2.

- Contaminated ground-water movement is not influenced by Ranney Well #3 as long as the pumping rate from this source does not exceed the rate of Ranney Well #2 or the combined rates of Ranney Wells #1 and #2

- During the dry months (June to November), Ranney Well #1 should be operated to intercept any plume movement towards the Ohio River.

On the basis of potentiometric data, capture zone calculations, and the actual monitoring of ether movement in the ground water, the pumping rates for each well were determined. In late 1984, the Doe Run facility decided to operate the three Ranney wells as follows:

- Operate Ranney Well #3 with a pumping rate of 1000-1500 gpm

- Maintain the combined pumping rates of Ranney Wells #1 and #2 at least 100 gpm higher than the pumping rate of Ranney Well #3

- Operate Ranney Well #1 from July to October at a minimum pumping rate of 500 gpm

Continued operation of the Ranney wells using these criteria should contain and collect all contaminated ground water at the facility.

It can be observed from the field data that under the above pumping conditions, ground-water flow from beneath all solid waste management units is intercepted by the Ranney wells and the collector wells. The field data are supported by capture zone calculations performed on each well.

EVALUATION OF PERFORMANCE

Ether concentrations have been tracked in the monitoring wells by semiannual sampling. Several monitoring wells can be used directly to monitor plume movements. For example, monitoring well MW-7 is directly downgradient from the EO/PO Off-Gas Burners, an area of known past release. The concentrations of DCEE and DCIPE in well MW-7 from June 1984 to October 1988 are shown in Figure 8. The concentrations are quite variable and show strong peaks, in September 1985 for DCEE and in October 1986 for DCIPE. The concentration of DCEE has declined from over 500 ppb in June 1984 to less than 50 ppb after October 1987. The concentration of DCIPE appears to have decreased slightly from June 1984 to October

1988. The peaks in DCEE and DCIPE concentrations suggest that the centers of maximum concentration of two plumes reached and then moved past well MW-7. The concentrations prior to 1984 were not reported.

On the east side of the plant, well BH-1 has shown an overall decrease in ether concentrations (Figure 9) as the ground water flowed from that area towards Ranney Wells #1 and #2. In monitoring well MW-2 located between Ranney Wells #2 and #3, the concentration of DCIPE was above the startup concentration from September 1985 to October 1987, and did not decrease to below the startup concentration until 1988 (see Figure 10). The DCEE concentration remained low until 1988, when it peaked above 2500 ppb in April before falling to low levels again by August 1988.

The plume movement can be altered by changing pumping conditions in the aquifer. By changing pumping schemes the ground-water divides will shift and plume movement may be re-directed. However, regardless of the pumping scheme, flow is still northward towards the line of interception, defined as the line formed by the three Ranney wells and the two conventional collector wells.

In the mid-1970s Ranney Well #1 contained the highest level of contamination, with DCIPE levels ranging from 15 to 30 parts per million. By 1980, the level of contamination had declined to 10 ppm. On the basis of this information, Olin claims that all ground-water flow from the Doe Run facility is intercepted at the north property line. The extracted water is first used as process water, is then biologically treated in an onsite activated-sludge wastewater treatment plant, and is then discharged through a Kentucky Pollutant Discharge Elimination System (KPDES) permitted outfall.

Olin is presently making improvements to the original ground-water program by installing five additional water wells that will provide additional water for plant needs, help clean up the contamination in the Ranney wells so that this water can be used as non-contact cooling water, and provide further assurance that no offsite migration of ground-water contamination occurs. These new wells will begin operating in June 1989.

SUMMARY OF REMEDIATION

The alluvial aquifer system at the Olin Chemical plant, bordering the Ohio River, has been contaminated with chlorinated organic compounds, notably the ethers dichloroethyl ether and dichloroisopropyl ether. An extraction scheme

using three Ranney wells located adjacent to the Ohio River was implemented in 1974 to control contaminant migration.

The pumping scheme practiced at the Olin Chemical plant appears to be hydraulically effective in controlling the migration of the contaminant plume, in part due to high pumping rates and favorable aquifer conditions. Although the goal of contaminant migration control is being achieved, the presence of contamination at a distance from the extraction wells may require containment activities to continue for an extended number of years. Contaminant concentrations are variable in most recovery wells but a declining trend is generally evident.

BIBLIOGRAPHY

Olin Chemical. September 1986. A Groundwater Assessment of Olin Chemicals Group Doe Run Plant, Brandenburg, Kentucky.

Olin Chemical. March 7, 1988 Assessment of Need for Corrective Action at the Olin Chemicals Doe Run Plant, Brandenburg, Kentucky.

WDCR437/047.50

CASE STUDY 14

Ponders Corner
Lakewood, Washington

CASE STUDY FOR PONDERS CORNER SITE

BACKGROUND OF THE PROBLEM

The Ponders Corner site, also known as the Lakewood site on the U.S. EPA's National Priorities list, is located in Lakewood, Washington, south of the city of Tacoma. The site consists of the Plaza Cleaners property and the regional aquifer within about a 2,000-foot radius of Plaza Cleaners. Two contaminated municipal water supply wells, wells H1 and H2 of the Lakewood Water District, are located about 800 feet south of Plaza Cleaners (see Figure 1). These wells serve about 600 of the 13,600 customers of the Lakewood Water District, and are an essential source of water for fire control. To the north, east, and west of the site are residential, commercial, and light industrial areas of the city of Lakewood. McChord Air Force Base is south of the site. The main contaminants of concern at the site are tetrachloroethylene (PCE), trichloroethylene (TCE), and 1,2-trans-dichloroethylene (1,2-trans-DCE), all of which are by-products of the dry cleaning operations. The site is administered under the Superfund program.

SITE HISTORY

Contamination was first detected at the site by the EPA in July 1981. Water taken from wells H1 and H2 was found to contain PCE, TCE, and 1,2-trans-DCE. As a result, these production wells were taken out of service in mid-August 1981. Subsequent sampling and inspection showed that the septic tanks and the surface disposal areas of Plaza Cleaners were the probable sources of ground-water contamination.

Between October 1981 and March 1983, ten shallow monitoring wells and 14 deep monitoring wells were installed near wells H1 and H2 so that the extent and degree of contamination at the site could be evaluated. Analysis of ground-water samples from these wells and the septic tanks at Plaza Cleaners showed that Plaza Cleaners was the main source of ground-water contamination. In October 1983, discharges to the septic tanks ceased, and 104 cubic yards of contaminated soil were excavated at the Plaza Cleaners property.

In March 1984, the EPA authorized a focused feasibility study of well head treatment alternatives for wells H1 and H2 that could be implemented by mid-1984. The goals of this interim remedial measure were to restrict the migration of contaminants in the aquifer and to bring wells H1 and H2 back into service before the summer peak demand period. Treatment by air stripping was selected and the treatment

system and wells H1 and H2 began operating September 26, 1984.

From October 1984 to February 1985, a remedial investigation was conducted during which nine more deep monitoring wells and three more shallow monitoring wells were installed, for a total of 36 monitoring wells. A Record of Decision (ROD) describing the chosen remediation plan was signed on September 30, 1985. Six more monitoring wells were installed in February 1987, one in an area of uncaptured contamination northwest of wells H1 and H2 and five at the perimeter of the McChord Air Force Base. In September 1987, the contents of the septic tanks were removed and backfilled. A vapor extraction well system designed to extract organic solvents from the vadose zone near Plaza Cleaners was installed in January 1988 and began operating in March 1988.

GEOLOGY

The Ponders Corner site is on an upland glacial drift plain that slopes gently to the northwest and terminates at the Puget Sound. The regional geology is characterized by unconsolidated to semi-consolidated alluvial and glacial deposits, including silt, clay, sand, gravel, glacial till, and peat. These sediments overlie the bedrock. The thickness of these sediments in the region varies from 0 to 2000-feet. The four uppermost geologic units important to this site study, in order of increasing depth, are: 1) the Steilacoom gravel, 2) the Vashon till, 3) the Advance Outwash deposits, and 4) the Colvos sand. A cross section of these units at the site is shown in Figure 2.

The Steilacoom gravel unit consist of sands and gravels and is 1 to 58 feet thick at the site. Although it is generally unsaturated, perched saturated zones occur locally. The Vashon till is composed of silts and clays with local sand and gravel lenses. It is a semi-confining layer at the site and is generally unsaturated but has discontinuous saturated zones within the sand and gravel lenses locally. The thickness of the Vashon till varies from 8 to 92 feet.

The top of the Advance Outwash unit underlies the Vashon till at depths of 25 to 84 feet below land surface. It is from 20 to over 90 feet thick and consists of highly layered fine to coarse sand and gravel. The Advance Outwash unit is saturated and is the primary aquifer in this area. Wells H1 and H2 are both completed in this aquifer at a depth of approximately 110 feet.

Underlying the Advance Outwash unit is the Colvos sand. The Colvos sand consists of poorly-graded silt, clay, and silty

fine sand. It is estimated to be more than 150 feet thick. The Colvos sand is two to three orders of magnitude less permeable than the Advance Outwash aquifer and may act as a partial barrier to downward flow from the Advance Outwash aquifer to deeper units.

HYDROGEOLOGY

The depth to the water table at the site varies from 20 to 60 feet below land surface, depending on surface topography. Ground-water levels vary in response to the ground-water recharge rate which varies, in turn, with the wide, seasonal fluctuations in rainfall. Annual recharge to the site is estimated at 10 to 17 inches per year, or 25 to 40 percent of the average annual rainfall of 40 inches.

The potentiometric surface of the confined to semi-confined Advance Outwash aquifer is from 20 to 40 feet below ground surface at the site. The direction of ground-water flow was west-northwest in the Advance Outwash aquifer, at the time water level measurements were taken from 1981 to 1983. The horizontal velocity of ground-water flow across the site in the Advance Outwash aquifer varied from 2.7 to 100.3 ft/day during this period, with an average velocity of about 18 ft/day. The downward vertical component of the gradient in the Advance Outwash aquifer has not been determined. Ground water in the Advance Outwash aquifer eventually flows into Gravelly Lake to the northwest of the site.

Before October 1983, the direction and rate of ground-water flow were affected by the discharge of 15,000 to 20,000 gallons of wastewater per day from the Plaza Cleaners septic tanks. This maximum discharge rate is about 40 times greater over the area of infiltration than the maximum estimated natural recharge rate of 17 inches per year (EPA, 1985).

Flow directions are also strongly affected by pumping in wells H1 and H2, which have a combined yield of about 2,600 gpm. A ground-water contour map based on measurements taken on July 23, 1984, when wells H1 and H2 had not been operating for 35 months and discharges to the septic tanks had been stopped for 9 months, is shown in Figure 3. Figure 3 shows that ground-water flow in July 1984 was to the west-northwest. The undisturbed gradients averaged about 0.005 feet per horizontal foot in July 1984.

During an aquifer test of the Advance Outwash aquifer in February 1983, the water levels in shallow monitoring wells in the Steilacoom gravel unit decreased, indicating that the two units are hydraulically interconnected. The horizontal hydraulic conductivity of the Advance Outwash aquifer was

estimated at 3,000 to 15,000 gpd/ft^2 with an average of 8,000 gpd/ft^2 (0.38 cm/sec), based on the February 1983 aquifer test.

WASTE CHARACTERISTICS AND POTENTIAL SOURCES

PCE, TCE, and 1,2-trans-DCE are the main contaminants of interest at the Ponders Corner site. The primary sources of ground-water contamination were the septic tanks and surface disposal areas at Plaza Cleaners. Dry cleaning wastes from Plaza Cleaners were discharged to a 4,250-gallon septic tank system, where they were flushed by 15,000 to 20,000 gallons of laundry wastewater each day. The supernatant water in the septic tanks was sampled in March 1983 and found to contain 550 ppb PCE and 29 ppb TCE. Calculations based on these concentrations and a 20,000 gpm discharge rate show that as much as 0.09 lbs/day of PCE and 0.005 lbs/day of TCE were discharged to the drain line of the septic tank system. The duration of this discharge has not been reported.

In addition to septic tank discharge, solvent-contaminated wastewater and sludge generated by the dry cleaning operations were poured onto the ground outside of the Plaza Cleaners building. Samples of the dry cleaning wastewater were found to contain 60,000 to 100,000 ppb of chlorinated organic solvents, while sludge samples contained 3,600 ppb of TCE and 9,600 ppb of 1,2-trans-DCE. The duration of surface disposal of these waste was also unreported.

The contaminants introduced by septic tank overflow and surface disposal migrated downward with the wastewater and natural recharge to contaminate the aquifer. A potential subsurface pathway for the contaminant migration is illustrated in Figure 4. The contaminants appear to have migrated downward through the Steilacoom gravel, then laterally along the Vashon till. Finding one or more permeable conduits, the contaminants appear to have then migrated farther downward to the Advance Outwash aquifer, and then laterally toward wells H1 and H2 under the influence of pumping.

The lateral extent and magnitude of contamination in the Steilacoom gravel and Vashon till have not been well characterized. However, the Steilacoom gravel appears to contain tens of pounds of PCE, while the Vashon till may contain up to 1300 pounds of PCE (EPA, 1985). The concentration data for ground-water samples taken from February to May 1985, along with the estimated inventory of contamination at that time, are shown in Table 1. These estimates include both contaminants sorbed to the solid phase and contaminants dissolved in the liquid phase. It should be noted, however,

that the mass inventory calculations for the Vashon till and the Steilacoom gravel are based on data from only one or two wells. For this reason, these estimates may be inaccurate.

A contour map of PCE concentrations in the Advance Outwash aquifer in February 1985 is shown in Figure 5. Wells H1 and H2 had been pumped for about six months at a total rate of 2,000 gpm at the time these data were collected. This followed the mid-August 1981, to September 1984 period during which wells H1 and H2 were not in service. The plume in Figure 5 shows that flow occurred to the northwest under the natural northwestward gradient during the 3-year period of no pumping.

Three potential source areas within the long-term capture zone of wells H1 and H2 have been identified within McChord Air Force Base (see Figure 6). In order to detect migration of contaminants out of these areas towards wells H1 and H2, five wells--37, 38, 39A, 39B, and 40--were installed at the perimeter of McChord Air Force Base in February and March 1987. Chlorobenzene, acetone, and TCE were detected intermittently at low concentrations in wells 38, 39A, and 39B in early 1987. Methylene chloride, potentially associated with McChord Air Force Base source areas, was detected in wells MW12 and MW14 in February and March 1983 (EPA, 1985).

REMEDIATION

SELECTION AND DESIGN OF THE REMEDY

The objectives of the well head treatment interim remedial measure (IRM) were to restrict the spread of contamination in the aquifer and restore the water supply to the Ponders Corner area by the mid-1984 summer peak period. The focused feasibility study of treatment alternatives, in March 1984, showed that air stripping was the most cost-effective treatment alternative. An air stripping well head treatment system was constructed and began operation in September 1984 at the same time that pumping of wells H1 and H2 was restored.

Wells H1 and H2 have generally been operated at a total rate of about 2,000 gpm since they were put back into service in September 1984. This pumping rate was chosen based on the needs of the Lakewood Water District rather than on criteria related to remediation or aquifer capacity. Nonetheless, this pumping rate was found to capture the entire plume except for a small part of the plume which escaped when the wells were shut down. No other extraction wells have been added to wells H1 and H2 to enhance cleanup effectiveness.

However, a vapor extraction well system designed to address unsaturated zone contamination began operating in March 1988 on the Plaza Cleaners property.

Although the emphasis of the well head treatment IRM was to restore the H1/H2 water supply, this emphasis was also consistent with the objective of restricting the migration of contaminants because wells H1 and H2 were near the centroid of the plume. It is worth noting, however, that the lack of pumping from August 1981 to September 1984 led to the migration of the contaminants beyond the zone of capture of wells H1 and H2 once they were placed back into operation.

There were 42 monitoring wells installed at the site. Five of these wells are used to monitor potential contaminant migration from McChord Air Force Base. The remaining 37 wells have been or are being used to monitor the main plume or to assess the initial extent and degree of contamination. As the lateral extent of the contaminant plume has decreased, sampling of some of these monitoring wells has been discontinued to save costs.

EVALUATION OF PERFORMANCE

The restoration of pumping in wells H1 and H2 in September 1984 changed the potentiometric surface of the Advance Outwash aquifer by establishing a cone of depression around wells H1 and H2. A water level contour map of the aquifer in March of 1987 is shown in Figure 7. The approximate limit of the hydraulic zone of capture was sufficient to capture most of the contaminant plume with the exception of a small section to the northwest that had escaped during the 3-year period when wells H1 and H2 were out of operation.

Contour maps of PCE concentrations in December 1986 and March 1987 are shown in Figures 8 and 9, respectively. These two maps show a reduction in the size and concentration of the main plume over time. They also show the section of the contaminant plume that had migrated beyond the zone of capture of wells H1 and H2 prior to the September 1984 startup. The extent of the uncaptured portion of the plume has not been well characterized to date, but concentrations of contaminants are low. The maximum concentration detected in well 32 was 6.9 ppb of PCE in May 1985. The concentration of PCE in well 32 rose to 6.9 ppb and then declined, suggesting that the centroid of the uncaptured portion of the plume may have migrated to the northwest past well 32. Results of chemical analyses of ground water from the monitoring wells at the site for PCE and TCE are listed in Tables 2 and 3, respectively.

Time series plots of the concentration of PCE and TCE entering the well H1 and H2 recovery system from the time of startup in September 1984 to April 1989 are shown in Figures 10 and 11, respectively. These plots generally show a steep initial decline in concentrations followed by a gradual decline to levels which are either low or below detection limits. The PCE concentrations in well H2 are an exception, however. The PCE concentration data for well H2 show a stable or slightly declining trend from late 1985 to early 1989. This trend suggests that a source of PCE may be present that releases PCE into the aquifer gradually. At an average rate of 1,200 gpm and an average concentration of 45 ppb, approximately 20 lbs of PCE were being extracted by well H2 each month from late 1985 to early 1989.

Geologic evidence and limited sampling data suggest that the Vashon till may be the source of PCE, given its low permeability and significant inventory of PCE (CH2M HILL, 1988). Because of the low permeability and relatively high retardation ability of the Vashon till, the PCE contamination in the Vashon till is likely to be a persistent source of PCE. Analysis of precipitation data shows that concentrations of contaminants increase following periods of high recharge and decrease following periods of low recharge, supporting the conclusion that the till may be a continuing source of contamination at the site.

With continued operation of the wellhead treatment system as part of the final corrective action for the site, it has been projected that the system will have to be operated a minimum of 10 more years before the water quality standards prescribed for the site are achieved consistently (CH2M HILL, 1988). The prescribed standard for the effluent from the air stripping system is 0.8 ppb for PCE, 2.7 ppb for TCE, and 27 ppb for 1,2-trans-DCE (EPA, 1984), through these standards may be changed. These standards compare with the current federal health-based standard of 0.88 ppb for PCE under the Clean Water Act and an MCL of 5 ppb for TCE under the Safe Drinking Water Act. Because of the possibility of a continuing contaminant source at the Ponders Corner site, the projection of complete aquifer restoration by as early as 1997 may be too optimistic. The vapor extraction system that began removing organic solvent vapors from the unsaturated zone in early 1988 should have a beneficial effect on remediation.

SUMMARY OF REMEDIATION

The contamination by organic solvents originating from a dry cleaning operation at the Ponders Corner site has affected three geologic units, including the regional aquifer that is

a source of water for about 600 of the 13,600 customers of the Lakewood Water District.

The two production wells supplying ground water to the Lakewood Water District ceased operation in August 1981, after contamination was discovered. After a focused feasibility study of treatment alternatives and the construction of an air stripping well head treatment system, the wells began operating again in September 1984.

Operation of the production wells has reduced the concentration and size of the main plume of PCE and TCE since start-up. However, the 3-year absence of production well pumping allowed a portion of the main plume to migrate beyond the zone of capture of the production wells, under the influence of the natural northwestward gradient. This portion of the plume cannot be remedied by the existing system as it is currently designed and operated.

One important conclusion that can be drawn from Table 1 is that the silts and clays of the Vashon till appear to contain almost 90 percent of the total contaminant inventory at the site. This is problematic for two reasons. The first is that the low permeability of the Vashon till inhibits flow of contaminated water out of this unit. Most of the water extracted by wells H1 and H2 will be drawn from the more permeable Advance Outwash aquifer rather than the low permeability Vashon till.

The second problem is that adsorption of contaminants on the solid phase is favored by silts and clays, and that the contaminants are likely to be retained in the Vashon till as a result. Estimates of site specific retardation factors range from 3 to 21, depending on the sediments and the specific contaminant. These estimated retardation factors suggest that the contaminants are drawn towards the well at 1/3 to 1/21 of the speed of the water contained in the same porous medium. For the silts and clays of the Vashon till, retardation is likely to be toward the high end of the estimated range. As a result, not only will the flow of ground water out of the Vashon till be limited, the velocity of contaminant migration out of the Vashon till is likely to be much slower than the velocity of ground-water flow.

Time series plots also suggest that the Vashon till is acting as a continuing source of PCE. The contamination in the Vashon till is likely to be released slowly and be quite persistent because of the low permeability and strong chemical retention ability of the silts and clays. Even though the main aquifer is quite permeable, the present system may

have to be operated for many years because of the slow release rate of the overlying Vashon till.

BIBLIOGRAPHY

CH2M HILL. April 1987. Predesign Report, Ponders Corner, Washington. EPA-62-ON22.

CH2M HILL and EPA. September 1987. Unpublished Draft Case Study for RCRA Corrective Actions at the Ponders Corner Site, Lakewood, Washington.

CH2M HILL. February 1988. Final Aquifer Cleanup Assessment Report, Ponders Corner, Washington.

EPA. June 1984. Superfund Record of Decision: Ponders Corner Site, Washington (IRM). EPA/ROD/R10-84/002.

EPA. September 30, 1985. Record of Decision, Remedial Alternative Selection, Ponders Corner Site, Lakewood, Washington.

WDCR218/017.50

CASE STUDY 15

Savannah River Plant A/M - Area
Aiken, South Carolina

CASE STUDY FOR THE SAVANNAH RIVER PLANT
A/M-AREA SITE

BACKGROUND OF THE PROBLEM

This study covers the remediation of a contaminated aquifer system underlying the A- and M-areas of the Savannah River Plant in Aiken, South Carolina. The Savannah River Plant is part of a system of weapons plants in the United States that conduct research and manufacture products necessary for the production and upkeep of nuclear weapons. The M-area manufacturing operations include aluminum forming and metal finishing. The A-area includes administrative buildings and the Savannah River Laboratory. The aquifers beneath parts of the A- and M-areas of the plant have been contaminated with volatile organic degreasing solvents as a result of these activities. 1,1,2-trichloroethylene (TCE), tetrachloroethylene (PCE), and 1,1,1-trichloroethane (TCA) have been the main degreasing solvents used at the plant. The Savannah River Plant is administered by a private company under contract to the Department of Energy. The South Carolina Department of Health and Environmental Control regulates the remediation at the site.

The A- and M-areas of the Savannah River Plant are on a hilltop about 2,000 to 3,000 feet south of the northwest boundary of the plant (see Figure 1). The site consists of administrative (A-area) buildings and manufacturing (M-area) buildings and other facilities. The M-area is in the southern part of the A/M-area complex, and the Hazardous Waste Management Facility (HWMF) is in the south corner of the M-area itself (see Figure 2). The HWMF includes an unlined settling basin, overflow areas, Lost Lake, and a process sewer line leading from the plant.

SITE HISTORY

Production activities in the M-area began in 1954. At that time, process wastewater was released directly to Tims Branch, a nearby stream. From 1954 until 1958, Tims Branch received all the wastewater from the plant. However, because the wastewater contained enriched uranium, a settling basin was constructed in 1958 to settle out and contain uranium and other heavy metals discharged from the plant. The settling basin, and other structures of the HWMF, received wastes from the M-area from 1958 until 1985. Tims Branch also continued to receive some wastes from the plant from 1958 until May 1982. The history of these discharges is shown in Table 1. Table 1 shows that over

2.1 million pounds of solvents were released to the HWMF settling basin from 1952 to 1982.

Table 1
SOLVENT USE AND RELEASE HISTORY AT THE M-AREA

	Solvents		
	TCE	PCE	TCA
Years used	1952-1979	1962-1979	1979-1982
Total used (lb)	3,700,000	8,700,000	670,000
Released to settling basin (lb)	317,000	1,800,000	19,000
Released to Tims Branch/A-014 Outfall* (lb)	383,000	1,000,000	12,000

*USDOE, 1986.

(Colven et al., 1985, p. 5-13)

Following the discovery of contamination underneath the settling basin at the HWMF in June 1981, a system of monitoring wells was installed to assess the extent of contamination. This initial monitoring-well network was later expanded to further delineate the contamination at the site. Soil and sludge samples were also collected and analyzed. In response to the contamination encountered during the site investigations, a pilot remediation system consisting of one recovery well and a pilot air stripper was installed and began operating at the HWMF in February 1983. The final implemented system was later expanded to include a large production air stripper near the M-area buildings, and 11 recovery wells and 236 monitoring wells over a broad area (USDOE, 1989). The expansion of the well system was made necessary by the discovery of several sources of contamination upgradient from the HWMF, primarily in the M-area. This full-scale extraction and treatment system began operation in September 1985. The discharges to the HWMF were stopped in July 1985.

GEOLOGY

The site is in the Upper Atlantic Coastal Plain province of South Carolina on the Aiken Plateau in an area dissected by tributaries of the Savannah and Congaree rivers. The site is underlain by a wedge of unconsolidated to semiconsolidated sediments that dip and thicken towards the southeast. The formations of interest that underlie the plant, in order of increasing depth, are the Barnwell Group, the McBean Formation, the Congaree Formation, the Ellenton Formation, and the Black Creek Formation. These formations are shown in Figure 3.

The Barnwell Group is composed of the Upland unit, the Tobacco Road Formation, and the Dry Branch Formation. The Upland unit is a poorly sorted mix of sand, cobbles, silt, and clay with a thickness of approximately 57 feet. It contains 50 percent clay and silt. The Tobacco Road Formation is a moderate to well-sorted, fine-to-medium sand containing some pebbles and 13 percent silt and clay. The Tobacco Road Formation is up to 97 feet thick. The Dry Branch Formation is a moderately to well-sorted medium sand containing 18 percent silt and clay. It is from 30 to 55 feet thick.

The McBean Formation is typically a moderately to well-sorted fine sand with some calcareous zones and approximately 25 percent silt and clay. Clay and silt layers make up 14 percent of the 16- to 34-foot thickness of the McBean Formation. There does not appear to be a distinct laterally extensive clay layer within the McBean Formation in the M-area (USDOE, 1986).

The Congaree Formation is predominantly sandy with a discontinuous clayey zone in the middle of the section. For hydrogeologic reasons, the Congaree Formation is divided into the Upper and Lower Congaree. The Upper Congaree is a well-sorted, fine-to-medium sand containing 16 percent silt and clay. Silt and clay beds make up 7 percent of the 14- to 60-foot thickness of the Upper Congaree. The discontinuous clay beds separating the Upper and Lower Congaree contain 70 percent silt and clay. The Lower Congaree is a moderately to well-sorted medium sand containing 17 percent silt and clay. Silt and clay beds compose 6 percent of the 4- to 44-foot thickness of the Lower Congaree.

The Ellenton Formation is composed of clay, clayey silt, and poorly sorted, fine-to-coarse, clayey sand. The Ellenton Formation contains 62 percent silt and clay. Its thickness is quite variable, ranging from 32 to 95 feet. The Ellenton

Formation contains two major clay layers separated by a poorly sorted sand. The bottom clay is from 10 to 56 feet thick and is the principal confining unit for the underlying Black Creek Formation.

Most of the Black Creek Formation consists of very poorly to well-sorted, medium-to-coarse sands. Silt and clay beds make up 5 percent of a 152- to 180-foot thick section of the Black Creek Formation. Most of the silt and clay beds are in the lower part of the section. The upper Black Creek is an important production zone for water-supply wells in the M-area.

HYDROGEOLOGY

The flow regime and other hydrogeological features of the aquifers underlying the site can best be described by referring to potentiometric surface maps and cross sections. Figure 4 shows the potentiometric surface of the unconfined water-table unit in the McBean Formation in the first quarter of 1985, before remediation pumping began. The water table was approximately 60 to 120 feet below the land surface of the A- and M-areas of the plant. The 244-foot contour delineates the limit of a broad plateau in the water-table surface surrounding most of the A/M-area in plan view. The flow in the water-table unit below the A/M-area is complex, but radial flow is expected outward from the 244-foot contour.

Figure 5 is a potentiometric surface map of the Upper Congaree aquifer in the first quarter of 1985. Figure 5 shows that flow in this aquifer ranged from southwest to northeast near the A/M-area. The direction of flow north of Route 19 was unclear from these data. Flow under the HWMF was south-southeast.

Flow was mainly to the east and south in the Lower Congaree Formation and to the southeast in the Ellenton Formation during 1985 and 1986.

The vertical dimension of flow at the site is shown in the potentiometric cross sections B-B' and E-E' for the third quarter of 1985 (Figures 6 and 7; A- and M-areas shown in inset map). Cross section B-B' runs northwest-southeast to the west of the M-area, through the seepage basin and recovery well RMW-4. This cross section shows that there is a downward vertical gradient beneath the M-area. The horizontal component of the gradient is to the south in the area south of the seepage basin. The flow in the northern part of the M-area is strongly downward and slightly to the north

at and near the water table as suggested by Figure 4, but Figure 6 shows that the flow paths in this area turn to the south with depth.

Figure 7 shows cross section E-E', running north-south through Lost Lake and across the northern M-area. This figure also shows a significant downward component to the gradient, especially beneath the M-area. Southward and northward flow also seems to exist in the McBean and Congaree Formations near the outer limits of this cross section. The true direction of the horizontal component of the gradient is best judged from plan view potentiometric surface maps rather than cross sections, however. Vertical flow rates have been estimated to be from tens to hundreds of feet per year (USDOE, 1989, p. 5-6).

Ground water in the water-table unit and the Upper Congaree aquifer is derived primarily from recharge in the A/M-areas. The ground water in these units flows radially from the site at a rate of approximately 50 to 100 ft/year and eventually discharges into Tims Branch, a tributary of Upper Three Runs. Ground water in the Lower Congaree and the Ellenton formations is derived from recharge in the M-area and from recharge areas upgradient to the north. This water flows southward at approximately 250 ft/year and eventually discharges into Upper Three Runs. Ground water in the Black Creek Formation is recharged primarily from areas north of the Savannah River Plant and flows to the southwest at approximately 365 ft/year. The rate of downward Darcian flux to the water table in the unsaturated zone beneath the settling basin has been estimated to be 5 to 7 feet per year (USDOE, 1986, Section D.10).

Specific capacity, step-drawdown, and constant-rate pumping tests were performed on the 11 recovery wells to determine the composite hydrogeologic characteristics of the screened intervals. Most of the screened intervals are in permeable zones of the Congaree and lower McBean Formations. The average transmissivity of the 11 recovery wells was 25,000 gpd/ft, while the median transmissivity was 16,000 gpd/ft. (An aquifer with a transmissivity of 100,000 gpd/ft is considered a good aquifer for water well exploitation). The observed specific capacity of the 11 recovery wells ranged from 0.6 to 7.78 gallons per minute (gpm) per foot. The hydraulic properties of some of the individual layers are shown in Table 2.

Table 2

ESTIMATES OF HYDRAULIC PROPERTIES

Formation	Hydraulic Conductivity (ft/day) Non-Directional	Horizontal	Vertical	Transmissivity (gpd/ft)
Upper McBean*	0.43			
Lower McBean*	0.23			
Congaree*	4.9			
Lower Ellenton Clay+		8.8×10^{-4}	5.4×10^{-4}	
Black Creek#				82,500

*From specific capacity tests, median values; Table D-17
+Mean value; Table D-27
#Average of 10 values; Table D-28.

Source: USDOE, July 1986

WASTE CHARACTERISTICS AND POTENTIAL SOURCES

Major products of the M-area of the plant include fuel rods, control rods, and metal targets. The physical and chemical characteristics of the wastes produced by this facility are similar to those of the wastes produced by other aluminum-forming and metal-finishing industries. These wastes include metals, metal compounds, and organic degreasing solvents. The specific problem at this site is contamination of the aquifer system by TCA, PCE, and TCE, all of which are volatile organic solvents.

The mass of solvents from degreasing operations that has contaminated the ground water along with the recharged wastewater is not known directly. However, as Table 1 showed, 2.1 million pounds of solvents were discharged to the HWMF from 1952 to 1982. Some fraction of these solvents volatilized to the atmosphere, but a substantial amount percolated downward to the saturated zone. The quantity of solvents in the saturated zone under A/M-areas has been estimated using concentration information from the monitoring well network at the site. The total amount of dissolved organic solvents was estimated at 260,000 to 450,000 pounds, of which over 75 percent is TCE (Colven et al., 1987). This amount does not include contaminants sorbed to solids in the saturated zone, contaminants in areas with concentrations below 10 parts per billion (ppb), or contaminants that are still in the unsaturated zone but will eventually reach the water table. Consequently, the actual amount of organics that would have to be removed to achieve aquifer cleanup is greater than these estimates.

Figure 8 shows the distribution of TCE contamination in the water-table unit in the third quarter of 1985, before remediation began. This map shows that TCE concentrations exceeded 100,000 ppb near the settling basin and the A-014 outfall southeast of the M-area in 1985. Both the settling basin and the A-014 outfall received wastewater from the plant in the past (see Table 1). These high concentration areas were part of a large central plume that extended underneath the entire M-area and the southern part of the A-area. A separate plume was also present to the north near the Savannah River Laboratory.

Figure 9 shows the distribution of TCE in the Upper Congaree in the third quarter of 1985. The TCE plume in the Upper Congaree appears to extend over a larger area, than in the water-table unit, especially in the area north of the M-area. The TCE concentration in the northern M-area exceeds 100,000 ppb near well MSB-24. The concentration highs are otherwise centered around the same source areas as in the water-table unit.

Figure 10 shows the vertical concentration distribution of TCE in cross section B-B' in the third quarter of 1985. This figure shows that most of the contamination is in the McBean and Congaree formations and that the thick Ellenton clay layers form a partial barrier to downward migration of contaminants. This figure also shows that the 10,000 ppb and 100,000 ppb TCE plumes have a strong vertical orientation beneath the settling basin. This vertical orientation is caused by the strong vertical hydraulic gradient in the saturated zone beneath the settling basin, which drives downward flow. Dense nonaqueous phase liquids (DNAPLs) have not been reported to be present.

The vertical distribution of TCE along cross section E-E' in the third quarter of 1985 is shown in Figure 11. Figure 11 shows evidence of a contaminant source at the north end of the cross section near the Savannah River Laboratory. It also shows contamination in the Black Creek Formation at well MSB37.

REMEDIATION

SELECTION AND DESIGN OF THE REMEDY

Objectives of Remediation

The objectives of the cleanup of the contamination at the A/M-areas of the plant are: (1) to minimize or eliminate

migration of contaminated ground water northward toward the plant boundary and downward into the Black Creek Formation, where eight A/M-area production wells are currently operating, and (2) to clean up the aquifer systems beneath the plant over a period of 30 years. The self-imposed standard for the 30-year remediation effort is to remove 99 percent of the solvent mass initially contaminating the aquifer system. The mass of solvents in the aquifer system is projected to decrease exponentially over 30 years to one percent of its initial inventory, as estimated in 1985. This approach depends on the accuracy of the initial inventory and the method of measuring the change in inventory. It was assumed that reducing the contaminant inventory at this rate would also restore the ground water to a level that no longer poses a threat to human health or the environment, but the remediation goal was not based on concentration standards per se.

System Configuration

The extraction system consists of 11 recovery wells distributed throughout the contaminated areas of the M-area (see Figure 12). Wells RWM-3, RWM-5, RWM-9, and RWM-11[1] were designed to be pumped at 55 gpm, while the remaining seven wells were designed to be pumped at 25 gpm, for a total of 395 gpm for the eleven wells. These pumping rates appear to be limited by the capacity of the air-stripper discharge pump. The high-capacity wells were placed near the centroid of the plume to maximize the rate of contaminant removal. Recovery wells RWM-1, RWM-8, and RWM-10 are near the M-area HWMF, recovery wells RWM-6 and RWM-7 are near the A-014 outfall, and most of the remaining recovery wells are near the main M-area buildings. The wells were designed to fully penetrate the McBean and Congaree Formations and are screened in the more permeable water-bearing intervals of these formations. There are four 10-foot screened intervals over the approximately 200-foot depth of each well.

In December 1988, the average total withdrawal from the recovery well system was 436 gpm. This rate was limited by the capacity of the air-stripper discharge pump. This could be increased to as much as 725 gpm if the pumps were modified to operate at full formation capacity (Colven et al., 1987). Air emission permits allow air emissions of up to 7.9 pounds of volatile organic compounds (VOCs) per hour.

---

[1]The M-Area recovery wells are designated with RWM prefixes, which have been omitted from the figures to reduce clutter.

This limit allows influent concentrations of up to 39,900 ppb at the design rate of 395 gpm and 21,740 ppb at the full formation capacity of 725 gpm. Influent concentrations for the second half of 1988 averaged about 21,000 ppb, indicating that pumping could be increased to full formation capacity without exceeding the air emissions limit. An increase to 600 gpm was recommended in the 1988 annual report (USDOE, 1989). As of late 1988, however, the equipment capacity and not the formation capacity or the air emissions permit was limiting the rate of aquifer restoration.

Figures 13 and 14 show the projected 30-year zones of capture of the 11 recovery wells in the water-table unit and the Upper Congaree Formation, respectively, as calculated using a particle tracking model (Larson et al., 1987). The 30-year zone of capture is defined as the three-dimensional volume of aquifer that contains all the ground-water flow paths that will end at a recovery well with travel times of 30 years or less (Colven et al., 1987, p.8.1). Third quarter 1986 TCE concentrations are superimposed on Figures 13 and 14 to indicate how effective the system is projected to be in capturing the contaminant plume. Both figures clearly show that the present recovery system is not projected to capture the contaminated ground water over a wide area southeast of the A/M-area. Separate uncaptured plumes are also evident west of Lost Lake and to the north, near the Savannah River Laboratory.

The zone of capture of the solvents will be smaller than the 30-year zones of capture of the ground water shown in Figures 13 and 14 because of retardation caused by partitioning between the solid and liquid phases. Although this effect was acknowledged by Colven et al. (1987), it was not evaluated quantitatively.

Once the ground water is extracted from the aquifer, it is pumped to and passed through an air stripper, where the organic solvents volatilize into the atmosphere at concentrations designed to be below federal air standards. The removal of the degreasing solvents from the extracted water by the air stripper was over 99.99 percent effective during the first year of operation and continues to be highly efficient. The air-stripper effluent is discharged to the A-014 outfall (USDOE, 1985, Section III.J.5).

Two hundred thirty-six monitoring wells have been installed at this site to assess the extent of contamination and to monitor the effectiveness of the remediation (USDOE, 1989, Section 3). These 236 monitoring wells are screened in a

three-dimensional pattern in the McBean, Congaree, Ellenton, and Black Creek formations in an attempt to track trends in potentiometric head and contaminant concentrations throughout the entire aquifer system. Eleven of these wells are point-of-compliance wells, while the remainder are plume definition wells. The ongoing sampling schedule for the wells at the site calls for sampling solvent concentrations and potentiometric head once every 2 weeks at the 11 recovery wells and quarterly at a select number of monitoring wells. One hundred and sixty-five monitoring wells were sampled in 1988 (USDOE, 1989).

EVALUATION OF PERFORMANCE

The objectives of the A/M-area remediation program are to minimize horizontal and vertical migration of the contaminant plume and to remove 99 percent of the contamination in the aquifer over 30 years. These objectives were developed internally at the Savannah River Plant and are not based on reduction of the contaminant concentrations to any health-based standard. The progress towards reaching these two objectives can be assessed by examining evidence of (1) the effect of pumping on regional gradients and flow directions, (2) a reduction in the size or migration of the plume, and (3) a decrease in the concentrations and absolute amounts of solvents in the ground water.

Hydraulic Influence

Figure 15 shows the water-table elevation in the water-table unit in the fourth quarter of 1988 after 3 years of full-scale extraction. The general appearance of the water-table surface in the fourth quarter of 1988 was similar to the appearance of the water table in the first quarter of 1985, although there was a general decline in water-table elevations caused by a drought.

The 234-foot contour defined the limits of a broad plateau in the potentiometric surface in 1988, just as the 244-foot contour did in 1985 (see Figure 4). The high areas to the west and east within this plateau were caused by artificial recharge from runoff basins and discharge points and were also present in 1985. The depression in the center of the plateau was more cone shaped in 1988 than in 1985. This was probably due to the effects of recovery wells RWM-9 and RWM-11, which are within this depression. There also seems to be a slight perturbation in the 232-, 234-, and 236-foot contours near the HWMF. In general, however, the recovery

system did not appear to have influenced flow patterns in the A/M-areas to a significant degree after three years of operation.

This lack of change is due in part to the low individual and combined pumping rates and the size of the area covered by the recovery-well system. The lack of change is also consistent with the zone-of-capture modeling, which showed small zones of capture in the water-table unit in the first few years of operation.

Figure 16 is a potentiometric surface map of the Upper Congaree Formation in the fourth quarter of 1988. The hydraulic influence of the recovery system is more pronounced in the Upper Congaree Formation than in the water-table unit, probably because a greater volume of water is pumped from the Upper Congaree. The influence of well RWM-6 near the A-014 outfall southeast of the M-area is particularly strong. Some influence is also visible in the 220-foot contour line near the settling basin and in the 226-foot contour line in the west-central part of the M-area. Although zone-of-capture modeling showed that the effects of the recovery system would be felt in the Upper Congaree faster than in other units, the zones of capture in the Upper Congaree were projected to be small in the first few years of operation.

In general, vertical flow patterns do not appear to have changed significantly since remediation began, based on comparison of potentiometric cross-sections B-B' and E-E' for the fourth quarter of 1988 (not shown) to the same cross sections for the third quarter of 1985 (Figures 6 and 7). There does appear to be a slight influence in the Congaree beneath the west-central M-area near recovery wells RWM-2 and RWM-4, consistent with the perturbation in the 226-foot contour line in Figure 16, however. Calculated vertical and horizontal flow rates based on head values measured in the fourth quarter of 1988 do not differ markedly from the flow rates calculated before remediation began (USDOE, 1989, Section 5). The exception to this is the estimated flow rate across the Ellenton from the Congaree to the Black Creek, which has decreased since remediation began. Flow rates across the Ellenton have decreased because pumping has reduced the hydraulic head in the Congaree and decreased the downward vertical gradient (USDOE, 1989, Table 5-10). The reduction in the gradient across the Ellenton should reduce the rate of downward migration of contaminants to the Black Creek, which is one of the main objectives of the remediation system.

Contaminant Plume Reduction

Figure 17 shows the TCE distribution in the water-table unit in the fourth quarter of 1988. There does not appear to have been significant change in the size and concentration of the TCE plume over the 3 years of remediation, based on comparison of Figures 8 and 17. There has been some reduction near the settling basin and recovery wells RWM-1 and RWM-10, and near recovery well RWM-6 and the A-014 outfall.

Figure 18 shows the TCE distribution in the Upper Congaree Formation in the fourth quarter of 1988. Reductions in the TCE concentrations in the south M-area near the settling basin, in the north M-area, and near the A-104 outfall southeast of the M-area are evident. The effects of pumping on TCE concentrations in the Upper Congaree appear to be greater than in the water-table unit, in part because of higher extraction rates. The portion of the plume that is distant from the recovery wells has not been affected by remediation. The plume to the north near the Savannah River Laboratory is unchanged because no recovery wells are installed there.

Figure 19 shows the vertical distribution of TCE along cross-section B-B' in the fourth quarter of 1988. This section clearly shows the 10,000-ppb plume being drawn into recovery well RWM-4. In addition, almost all measurement points show reduced concentrations compared to 3 years earlier (see Figure 10). The notable exceptions are the water-table interval of MSB-26, the interval of MSB-40 directly above the Ellenton clay, and certain wells near RWM-4 affected by the induced migration of the plume beneath the settling basin. The increases in MSB-26 and MSB-40 are consistent with the ground-water flow directions predicted by the potentiometric contour maps; that is, radially outward flow in the water-table unit and southeastward flow in the Congaree. No wells were installed downgradient of the HWMF to intercept contamination from the southern part of this facility.

Figure 20 shows the vertical distribution of TCE along cross-section E-E' in the fourth quarter of 1988. Several trends can be observed in cross-section E-E' since remediation began in September 1985 (see Figure 11). One trend appears to be the increased migration of the plume downward to the Black Creek Formation near MSB-34. Figure 11 shows a separate plume at the base of MSB-37, whereas Figure 20 shows the main plume extending below the Ellenton clays. This difference may be mainly interpretive, but concentrations in the Black Creek clearly increased from 1985 to

1988. This migration across the Ellenton clays may have been facilitated by the pinchout of the upper Ellenton clay layer in this area. Downward migration across the Ellenton clay layers also appears to have occurred near well MSB-9, which is near the settling basin.

The concentration of the contamination along cross-section E-E' between wells RWM-2 and RWM-11 has clearly decreased over the 3 years of remediation. Concentrations dropped approximately tenfold near the lower interval of well MSB-24, probably because of the proximity of the recovery wells. There is also evidence that the contamination plume centered between wells MSB-9 and MSB-11 is being drawn towards recovery well RWM-4 and that the concentration of TCE at the upper intervals of this plume is decreasing, possibly because of contaminant migration downward from the water table.

Reductions in Mass and Concentrations of Contaminants

An estimate of the mass of contaminants removed by the extraction system was calculated using a mass balance equation involving influent and effluent concentrations and flow rates to the air stripper. These calculations show that 148,000 pounds of solvents were removed by the air stripper from the startup of remediation in September 1985 to the end of the fourth quarter of 1988.

During the trial runs and pilot studies that took place before September 1985, an additional 34,000 pounds of solvents were removed. This means that by the end of 1988, 181,000 pounds of solvent had been removed from the saturated zone beneath the A/M-area. This result does not mean that the liquid phase in the saturated zone contains 181,000 fewer pounds of solvents than it did before the initial pilot studies, however, because solvents also enter the liquid phase of the saturated zone from the unsaturated zone and from the solid phase in the saturated zone.

The mass of solvents present in the liquid phase of the saturated zone beneath the A/M-area in the third quarter of 1985 was estimated by one method to be 266,000 pounds and by another to be 464,000 pounds. Table 3 shows this second value and the corresponding mass inventory estimate for the fourth quarter of 1988. A comparison of the inventory from the two periods shows that an in situ decrease of only 23,000 pounds occurred from September 1985 to December 1988. This is in contrast to the 148,000-pound reduction calculated from the air-stripper mass-balance calculations.

Reductions in contaminant mass inventory were originally projected to follow an exponential decay curve resulting in

Table 3
SUMMARY OF CHANGES IN CONTAMINANT MASS INVENTORY
(In Situ Estimates)

Hydrogeologic Unit	Mass of Trichloroethylene (lbs)		
	3Q85	4Q88	Difference
Water Table	87,000	90,836	(3,836)
Upper Congaree	221,000	139,006	81,994
Lower Congaree	22,600	38,523	(15,923)
Ellenton Sand	1,600	2,422	(822)
Total	332,200	270,788	61,412

Hydrogeologic Unit	Mass of Tetrachloroethylene (lbs)		
	3Q85	4Q88	Difference
Water Table	92,600	117,530	(24,930)
Upper Congaree	38,400	49,848	(11,448)
Lower Congaree	900	2,561	(1,661)
Ellenton Sand	200	588	(388)
Total	132,100	170,527	(38,427)

Hydrogeologic Unit	Mass of Total Degreaser Solvent (lbs)		
	3Q85	4Q88	Difference
Water Table	179,600	208,366	(28,766)
Upper Congaree	259,400	188,854	70,546
Lower Congaree	23,500	41,084	(17,584)
Ellenton Sand	1,800	3,010	(1,210)
Total	464,300	441,315	22,985

Source: USDOE, 1989, Table 7-3.

the removal of 99 percent of the mass after 30 years. The 1-, 2-, and 3-year, mass-inventory reduction totals were projected to be 64,000 pounds, 119,000 pounds, and 166,000 pounds, respectively, based on an initial inventory estimate of 450,000 pounds. The actual air-stripper mass-balance calculations showed that 53,400 pounds were removed after one year, 99,700 pounds were removed after two years, and 138,840 pounds were removed after three years. These actual air stripper VOC removal results are somewhat lower than, but are otherwise close to, projections. The 23,000-pound reduction calculated using the in situ estimating method was much less

than projections. This supports the conclusion that the original estimate of the in situ mass inventory was low because it failed to consider other sources of contaminant mass such as the unsaturated zone and the solid phase in the saturated zone.

Because of the inaccuracies of the in situ method of estimating mass inventory, the absolute quantitative changes shown in Table 3 may not be accurate. However, Table 3 does show that the TCE and PCE inventory increased in all layers, with the exception of the TCE inventory in the Upper Congaree. The reduction in the Upper Congaree is probably due to the fact that the highest concentrations and pumping, and therefore, the greatest rate of solvent mass extraction, occur in the Upper Congaree. The increases in the Lower Congaree and in the water-table unit may be due to downward migration from the Upper Congaree and the unsaturated zone, respectively.

Table 3 also shows that the greatest increases in PCE inventory occurred in the water-table unit and the Upper Congaree, whereas the greatest increase in TCE inventory occurred in the Lower Congaree. This distribution of the contaminant-mass increases is consistent with the Table 1 release history, which shows that PCE was used as a solvent from 1962 to 1979, whereas TCE was used from 1952 to 1979. For this reason, the PCE plume is expected to be shallower than the TCE plume. Comparison of cross sections of TCE and PCE distributions (not shown) confirm this conclusion.

The trend in concentrations in the 11 recovery wells over the 3 years of remediation was variable. The concentrations increased in five of the recovery wells and decreased in the remaining six wells. The trend in individual recovery wells is expected to depend on a complex three-dimensional relationship between plume and well locations, however. The combined trend of the 11 recovery wells is given by the time-series plot of the TCE and PCE concentrations in the air-stripper influent, shown in Figure 21. Figure 21 indicates a gradual decrease in the influent concentrations of both TCE and PCE since the startup of remediation in September 1985.

SUMMARY OF REMEDIATION

The effectiveness of the remediation effort at the A/M-areas of the Savannah River Plant can be summarized as follows:

- The subsurface is a multilayered system of sands, silts, and clays with a water table 60 to 120 feet below the land surface of the A/M-areas. The various permeable and impermeable layers are contaminated with an estimated 260,000 to 464,000 pounds of organic

degreasing solvents. Solvents contained in the unsaturated zone, solvents sorbed to solids in the saturated zone, and solvents dissolved in water in areas with concentrations below 10 ppb were not considered in these estimates of the initial solvent mass to be cleaned up. Excluding these solvent components from the initial estimate leads to an underestimate of the contamination at the site and makes the evaluation of progress problematic.

- The recovery wells are screened over the more permeable intervals, which increases the yield of the wells but limits access to silt and clay layers where retention of contaminants is strongest. This practice of screening only the permeable intervals may prolong remediation because undisturbed silt and clay layers will act as contaminant sources for the permeable zones.

- The hydraulic zones of capture in the various geologic layers are still comparatively small after 3 years of remediation and do not include most of the contaminant plume. Even after 30 years, the present system will not capture all of the contaminant plume. This is particularly true at the Savannah River Laboratory and to the southeast of the HWMF, where no recovery wells have been installed and gradients are away from the A/M-area. The downward gradient across the Ellenton clays, and consequently the driving force for downward contaminant migration to the Black Creek Formation, has been reduced by remediation pumping. The fact that pump rates are low and the area to be remedied is very large, limits the rate of remediation at this site.

- Some reductions in contaminant plume size and concentration as a result of remediation are evident, though the reductions are generally limited to the areas near recovery wells. The most progress is evident in the Congaree Formation, where concentrations and pumping rates are highest. Downward migration to the Black Creek is evident near the settling basin and north of the northern M-area. The concentration of TCE and PCE in the influent to the air stripper decreased gradually over the period of remediation.

- An estimated 148,000 pounds of solvents were removed by the air stripper from startup in September 1985 to the end of 1988. However, in situ, contaminant-mass inventory calculations show that there were only 23,000 fewer pounds of solvents present in the satu-

rated zone at the end of 1988 than at the time remediation began. This difference suggests that some of the solvent mass removed from the liquid phase in the saturated zone by the air stripper was replaced by mass influx from other sources, such as the unsaturated zone and the solid phase in the saturated zone. This decrease of only 23,000 pounds in the in situ mass of contaminants after 3 years suggests that it may take longer than the projected 30 years to achieve the established goal of removing 99 percent of the initial contaminant mass.

BIBLIOGRAPHY

Colven, W.P., L.F. Boone, and J.G. Horvath. February 1987. Draft First Year Report, Effectiveness of the M-Area Remedial Action Program, September 1985 to September 1986, E.I. du Pont de Nemours and Co., Savannah River Plant, Aiken, South Carolina.

Colven, W.P., J.B. Pickett, and C.F. Muska. November 1985. Closure Plan for the M-Area Settling Basin and Vicinity at the Savannah River Plant. DPSPU 84-11-11, E.I. du Pont de Nemours and Co.

Larson, S.P., et al., S.S. Papadopulos & Associates. February 1987. Three-Dimensional Modeling Analysis of Ground Water Pumping Schemes for Containment of Shallow Ground Water Contamination, presented at Conference on Solving Ground Water Problems with Models, National Water Well Association, Denver, Colorado.

United States Department of Energy (USDOE). July 1986. Application for a Post-Closure Permit, M-Area Hazardous Waste Management Facility, Volume III, Revision No. 1, Savannah River Plant.

United States Department of Energy (USDOE). March 1988. M-Area Hazardous Waste Management Facility Post-Closure Care Permit, Ground Water Monitoring and Corrective Action Program, Savannah River Plant, 1987 Annual Report.

United States Department of Energy (USDOE). March 1989. M-Area Hazardous Waste Management Facility Post-Closure Care Permit, Ground Water Monitoring and Corrective Action Program, Savannah River Plant, 1988 Annual Report.

CASE STUDY 16

Site A
South Florida

CASE STUDY FOR SITE A IN SOUTH FLORIDA

BACKGROUND OF THE PROBLEM

This case study describes the remediation at Site A[1] in south Florida. The potentially responsible party (PRP) at Site A has manufactured industrial cleaning compounds at this location since 1958. The compounds are used by NASA, the Defense Department, and in the airline and aircraft manufacturing industries. A map of the site is shown in Figure 1. Immediately to the west of the site is an area formerly occupied by a manufacturer of industrial coatings, and a manufacturer of processed metals. This area west of the Site A plant has been excavated and redeveloped and is no longer used for industrial purposes. However, it has been mentioned as a possible alternative source of the contamination at Site A. The site is contaminated with chlorinated organics and aromatic compounds. It is administered by the local county government.

SITE HISTORY

Efforts to study the extent of contamination at Site A began in early 1985 with three individual wells (referred to as BB wells) and three 2-well clusters (called the DERM wells) installed at the request of the local county. The concentrations of contaminants found in ground-water samples taken from the monitoring wells lead to the installation of 20 permanent monitoring wells and 20 temporary monitoring wells by an EPA/FIT team in October 1985. The locations of the permanent FIT wells, BB wells, and DERM wells are shown in Figure 2. The study of the site conditions culminated in a remedial investigation/feasibility study (RI/FS) report in August 1987 and a final remedial action plan (RAP) completed on September 10, 1987. These two documents were prepared for the local county government but have not been approved by EPA. As a result of the recommendations made in these reports, three more monitoring wells were installed in January 1988 and an extraction well and air stripper were installed in August 1988. The extraction system began full operation on August 29, 1988, and operated for 20-1/2 weeks until it was shut down on January 18, 1989, to assess the progress of the cleanup effort. The system was put back into operation following this shut-down period and water quality monitoring continued.

---

[1]Because of continuing disagreement concerning responsibility for the contaminants at the site and the listing of the site on the National Priorities List (NPL), no further identification of the parties involved will be made in this case study.

GEOLOGY AND HYDROGEOLOGY

Site A is located in the outcrop area of the Biscayne aquifer, which is the sole source of potable water in the county. The surficial soil at the site is a sandy organic topsoil approximately 1 foot thick, which is directly underlain by the Biscayne aquifer. The upper part of the aquifer is a soft, sandy, oolitic limestone approximately 15 feet thick, which has high horizontal and vertical hydraulic conductivity due to numerous small solution openings (see Figure 3).

The lower portion of the oolitic limestone has larger openings formed by the dissolution of fossil bryozoans (branching corals). Below the oolite is a 20-foot layer of quartz sand of which the upper 10 feet is fine- to medium-grained and the lower 10 feet is finer and has lower hydraulic conductivity. Below the sand is a solution-riddled limestone approximately 45 feet thick known as the Fort Thompson Formation. This is the lowest and most productive layer of the Biscayne aquifer. Because of its high horizontal hydraulic conductivity, which averages 10,000 ft/day, all of the high capacity wells in the area are placed in the Fort Thompson limestone.

At the base of the Biscayne aquifer is a greenish marl of fine sand, silt, clay, and shell called the Tamiami Formation, which forms a regional aquiclude to a depth of about 700 feet. Below the Tamiami Formation is the Floridan aquifer, which contains brackish water in this area.

The horizontal and vertical conductivities of the various layers that make up the Biscayne aquifer are shown in Figure 3. These values are based on regional aquifer tests, ranges of values reported by the USGS for the Biscayne aquifer, previous modeling results, and typical values for these types of sediments.

The water table is 2 to 3 feet below the land surface at the site, as shown in Figure 3. The water-table gradients that have been observed at the site are very shallow with vertical drops of 0.0002 to 0.0005 feet per horizontal foot. Assuming a porosity of 30 percent and a hydraulic conductivity of 100 ft/day, these gradients correspond to flow velocities of 24 and 61 ft/year, respectively. Because gradients are so shallow the direction of flow is difficult to determine. However, site data collected by an EPA field-investigation team (EPA/FIT) in 1985 suggest that the direction of flow is eastward during the dry season and southward to southwestward during the rainy season.

Fluctuations in the water table and changes in the flow direction are affected by the numerous drainage canals and borrow pits in the area. Flow in the lower portion of the Biscayne aquifer is undoubtedly influenced by the pumping of three municipal well fields within a radius of 2 miles from the site. However, these effects have not been explicitly studied at Site A.

WASTE CHARACTERISTICS AND POTENTIAL SOURCES

The shallow ground water in certain portions of the site have been found to be contaminated with organic compounds. The compounds that have been detected in concentrations exceeding the applicable health-based standards are: benzene, chlorobenzene, 1,4-dichlorobenzene, trans-1,2-dichloroethylene (trans-1,2-DCE), and vinyl chloride (VC). The actual source of these contaminants was not identified in the available reports. A list of health-based standards for the site are shown in Table 1.

The contamination is concentrated in the south central part of the site, as suggested by the shaded area shown in Figure 4. This shaded area represents the extent of the contaminant plume as it was acknowledged by the designers of the ground-water recovery system. The limits of the contaminant plume were estimated on the basis of samples taken from the three, 6.4-foot deep temporary wells, which had organic concentrations less than the health-based standards. The low concentrations found in these shallow wells were taken as proof that the extent of the plume was limited on the north, east, and west sides as indicated by the shaded area. The southern edge of the plume was unknown, because there were no uncontaminated monitoring wells south of the site that would indicate the southern limits of the plume.

It should be noted that samples with concentrations greater than the health-based standards have been reported for wells MWT-32 and MWS-09, which are 7 feet and 20 feet deep, respectively (see Figure 2). Hence, it appears that a more likely outline for the pre-remediation plume of contaminated ground water is as shown by the dashed line in Figure 2.

It was concluded by the PRP that ground-water contamination was limited to the upper portion of the Biscayne Aquifer in and above the fine-to-medium sand layer that lies from 15 to 25 feet below ground surface. Five monitoring wells have been drilled below this layer to depths ranging from 50 to 75 feet below ground. A sample taken from one of these wells, well CDM-03 (55 feet deep), showed a VC concentration of 2.1 ppb. Even though this is higher than the health-based standard for the site of 1 ppb for VC, the conclusion

that contaminants were limited to the shallow geologic layers was apparently not altered.

The source of the ground-water contamination at the site is the subject of ongoing dispute. If the source is offsite, as the PRP and its consultant maintain, then it could represent a continuing discharge of contaminants to the aquifer. However, this has not been proven, and remedial activities at the site have proceeded under the assumption that there is no continuing source of contaminants.

REMEDIATION

SELECTION AND DESIGN OF THE REMEDY

The objective of the remedial action at Site A is to clean up ground water contaminated by volatile organic compounds in the south central part of the site to concentrations below applicable health-based levels.

The remedial action is based on an extraction system consisting of one well centered in the contaminated area (shown in Figure 4). The position of the extraction well was chosen so that the areas of known contamination would be within a 100-foot radius of the well. The possibility of contamination south of the plant boundary or north of well MWS-11 was not investigated and was not considered when designing the extraction system. The extraction well was screened over the 10-foot interval of the medium quartz sand layer at a depth of 15 to 25 feet (see Figure 3) based on the conclusion that there was no contamination in deeper units. A pumping rate of 30 gpm was selected initially but was later increased to 50 gpm. The decision to increase pumping was made in part because of results from three-dimensional modeling of the aquifer system, which was conducted to determine the most cost-effective pumping rates and the estimated time of cleanup. The modeling indicated that 60 days would be necessary to extract all the contaminated water within 100 feet of the well if the pumping rate was 30 gpm, while only 25 days would be necessary if the rate was raised to 75 gpm.

Once the ground water is extracted, it is passed through an air stripper to remove VOCs and then pumped into the city sewer system.

Before the ground-water extraction was started, a performance monitoring plan was developed. The plan called for initial sampling of 16 wells, one of which was used as a background well. This was to be followed by intermittent sampling from a total of 20 wells.

EVALUATION OF PERFORMANCE

The performance report produced by the PRP states that the operation of the extraction well has produced "no measurable differences of water levels" in the monitoring wells. The actual water levels are not reported with reference to a uniform elevation datum so it is not possible to verify this claim. This statement was apparently intended to indicate that the system is not causing substantial dewatering of the shallow aquifer rather than to show that it is not capturing the plume of contaminated ground water. However, it is possible that upward leakage of ground water from the lower Biscayne Aquifer could substantially reduce the effective capture radius of the extraction well.

Tables 2 and 3 show the results of the water quality sampling for the Group A and Group B monitoring wells, respectively. (Only the Group A monitoring wells have been sampled since January 1989.) The concentrations of the five compounds of concern are listed together with their corresponding cleanup target concentrations. Analytical results for methylene chloride are also listed in Table 3 because this compound consistently appeared in the samples. However, the PRP's consultant concluded that methylene chloride was being leached from the PVC well materials and was not an aquifer contaminant.

The concentrations in the monitoring wells that had high levels of contamination before the cleanup began decreased during the period of extraction. This decrease is shown in Figures 5 and 6 for wells CDM-02 and DERM-05, respectively. Although the decrease in concentrations since the beginning of operation is significant, the concentrations of benzene, chlorobenzene, and VC were still above health-based standards in several monitoring wells in mid-March 1989. Wells CDM-02 and MWS-11 contained constituents above health-based levels in mid-March 1989 despite the initial projection of complete remediation in less than 60 days.

The concentration of contaminants in well MWS-11 is shown in Figure 7. It is of interest to note that, while the concentration of VC in well MWS-11 decreased from 74 ppb in January 1988 to 0.5 ppb in September 1988, the concentrations of the less mobile compounds, benzene and chlorobenzene, actually increased during the remediation period. As of mid-March 1989, chlorobenzene and benzene concentrations in well MWS-11 were above or near the cleanup goal. 1,4-dichlorobenzene also rose during remediation but decreased to below the goal of 5 ppb by mid-March 1989. This may

indicate that a high concentration region that was initially north of well MWS-11 was drawn southward past well MWS-11 by the extraction system.

Time series data describing total VOC concentrations in the treatment system influent and effluent also suggest that the aquifer concentrations are decreasing (see Figure 8). Because the extraction well is in the center of the known contaminated area and because the limits of the cone of depression are not thought to extend far beyond the delineated zone of initial contamination, the extraction well probably draws water primarily from the contaminated area. The decrease in the influent concentration of total VOCs from 24,000 ppb on the startup date to less than 500 ppb 234 days after startup shows that contaminant concentrations in the aquifer decreased in response to remediation. This conclusion is supported by the general decline in monitoring well concentrations. However, it is also possible that the total VOC concentrations in the extracted ground water have been reduced partially by dilution with clean ground water flowing upward through the fine sand layers from the lower Biscayne Aquifer.

SUMMARY OF REMEDIATION

One conclusion that can be drawn from the performance data for Site A is that the extraction system has not achieved aquifer remediation in the 25- to 60-day time frame predicted by its designers. The most likely reasons for the over-optimistic performance predictions are: (1) incomplete characterization of the initial contaminant distribution, (2) failure to account for retarded contaminant migration due to adsorption, and (3) inaccurate assessment of the hydraulic characteristics of the aquifer materials.

In order to generate accurate predictions of cleanup time, it is necessary to have an accurate description of the initial contaminant distribution. The predictions of a 25- to 60-day cleanup period seem to have been based on the assumption that the initial contaminant plume extended no farther than 100 feet from the extraction well in any direction. Analytical data from the monitoring wells does not seem to support this assumption. The southern extent of contamination has not been characterized, for example. The difference between the assumed contaminant plume shape and the shape that might have been deduced from the monitoring well data is illustrated by comparison of Figures 2 and 4. The plume that is based on monitoring well data is significantly larger and would take longer to remediate using the current extract system.

The cleanup predictions were based on the time required to draw ground water to the extraction well from a radius of 100 feet. This does not account for the potentially slower movement of the contaminants due to adsorptive retardation. The organic constituents in the contaminant plume range in mobility from vinyl chloride, which may travel nearly as fast as clean water, to 1,4-dichlorobenzene, which is listed as a low mobility compound (Fetter, 1988). If the organic carbon content of the Biscayne Aquifer is conservatively estimated at 0.1%, the retardation factor for 1,4-dichlorobenzene could be as high as 6. This would mean that the projected cleanup time should have been six times longer even if the extent of the plume assumed by the PRP's consultant were accurate.

The estimated time required for ground water to travel to the extraction well from a radius of 100 feet was based on a hydraulic cone of depression around the well that was predicted by a numerical model. There is no indication that this model was calibrated to the actual conditions at the site. Indeed, an accurate model calibration would have required hydraulic performance data from an aquifer test. No such test was done at the site. This may explain why the drawdowns observed in the monitoring wells as a result of extraction well operation were reported to be negligible. The hydraulic gradients generated by the extraction well would be very sensitive to the leakage properties of the fine sand layer that lies immediately below the screened interval of the extraction well. The vertical component of hydraulic conductivity used in modeling this layer was not accurately determined on the basis of site-specific hydraulic testing. Thus, the hydrodynamic effects of the extraction well could not be predicted accurately. Furthermore, the performance report for the site did not include piezometric measurements that would permit accurate assessment of the well's hydrodynamic effects.

In spite of the system's failure to achieve remediation in the predicted time, it does appear to have significantly reduced the contaminant concentrations in most of the monitoring wells. This effect is particularly noticeable with respect to vinyl chloride, which is probably the most mobile contaminant of concern. Two of the monitoring wells at the northern extent of the plume seem to show aquifer remediation to concentrations below health-based levels. It can be expected that other areas of the site, and perhaps even the entire plume will be remediated eventually if extraction is continued. However, since the existence of a continued source of contamination has not been ruled out, a complete cleanup cannot be predicted with certainty.

WDCR321/045.50

BIBLIOGRAPHY

Private Contractor A. September 1987. Provisional Remedial Action Plan, Site A.

Private Contractor A. February 1989. Provisional Status Report, Site A.

Fetter, C.W. 1988. Applied Hydrogeology, Merrill Publishing Company.

WDCR321/045.50

CASE STUDY 17

Utah Power & Light Pole Treatment Yard
Idaho Fall, Idaho

CASE STUDY FOR THE UTAH POWER & LIGHT SITE

BACKGROUND OF THE PROBLEM

The Utah Power & Light Company (UP&L) pole treatment yard is located in a commercial and industrial area in the southern part of Idaho Falls, Idaho, near the east bank of the Snake River (see Figure 1). Electrical power poles were treated by soaking them in a vat of heated creosote and then allowing the excess creosote to drip off into a receiving tank before the poles were stockpiled on the site. In July 1983, creosote was found to be leaking from underground piping connecting the treatment vat to a storage tank. In response to this finding, a corrective action under the Resource Conservation and Recovery Act (RCRA) was initiated, which involved removal of the pole treatment process equipment, excavation of contaminated soils, and installation and testing of recovery wells in the bedrock aquifer. Operation of the recovery wells is continuing under the provisions of a RCRA Part B permit issued in November 1987.

SITE HISTORY

In July 1983, when creosote leakage was detected at the site, the pole treatment facility had been in operation for approximately 60 years. Upon discovery of the underground creosote leak, the pole treatment process equipment was removed and a major effort was begun to remove all creosote-contaminated soil and rock materials. Between July and September 1983, approximately 37,000 tons of soil and rock were excavated. As a result, a pit was formed approximately 110 by 180 feet in area and 25 feet deep, bottoming out at the top the native basalt bedrock. Soil sampling indicated that all the contaminated soils in the vicinity of the leak had been removed. However, borings extended into the bedrock showed the presence of creosote as a nonaqueous phase liquid. Further excavation into the bedrock to recover nonaqueous creosote was thought to be impractical. Therefore, to reduce infiltration into the contaminated portion of the bedrock aquifer, the bottom of the pit was lined with a 12-foot layer of compacted clay in February 1984. Between June and September 1985, the rest of the excavation was backfilled with clean gravel, capped with a second compacted clay layer, and topped with an asphalt cover. Since then, the backfilled pit has been classified as a hazardous waste management facility (HWMF) under RCRA.

In December 1984, UP&L submitted an application for a RCRA Part B Permit to operate an HWMF at the pole treatment yard (Dames & Moore, 1984a). In support of this application, UP&L's engineering consultants, Dames & Moore, Inc., con-

ducted field investigations to characterize the subsurface contamination at the site. These investigations included 23 soil and rock borings around and under the excavated area, and the installation of 15 ground-water monitoring wells on the UP&L property. An aquifer test was run in one of the monitoring wells, and four rounds of ground-water samples were collected in 1984. In addition, 21 offsite water-supply wells were sampled.

In response to requests from the U. S. Environmental Protection Agency (EPA), an addendum to the Part B Permit application was submitted by UP&L in June 1985 (Dames & Moore, 1984b). (The addendum, Volume 4 of the Part B application, was backdated to December 1984 to correspond to the date of the original application.) The addendum contained supporting data and clarification of some of the information in the original application, as well as results of additional ground-water sampling conducted in early 1985.

In October 1985, UP&L submitted a ground-water quality assessment report to EPA (Dames & Moore, 1985) to supplement the information contained in the original Part B permit application. This report covered additional background information on regional and site hydrogeology, reported the results of an additional aquifer test, gave analytical results from new ground-water sampling rounds, and described simulations performed with a numerical ground-water flow model that had been developed for the site.

Between October 1985 and April 1986, a 6-month pilot study of ground-water extraction and treatment was conducted. Contaminated ground water was pumped from six bedrock monitoring wells and treated before being discharged to the Idaho Falls sanitary sewer system. The pilot study showed that more nonaqueous, or free-phase, creosote was produced from the wells than had been expected. The production of free-phase creosote slugs caused various operational problems, requiring corrective measures in the design of the treatment system. As a result of this test, a second 6-month pilot study was recommended before beginning full-scale extraction (CH2M HILL, 1986).

In April 1986, Dames & Moore submitted a report to EPA on the hydrologic investigations that had been conducted during the first phase of the pilot extraction program and the general design recommendations for the full-scale extraction system (Dames & Moore, 1986). This report documented the results of four additional aquifer tests in the onsite monitoring wells, gave the results of additional rounds of ground-water quality sampling, and described numerical simulations of alternative ground-water extraction systems. The recommended full-scale extraction system was to consist of

14 extraction wells operating at a combined capacity of approximately 200 gallons per minute (gpm).

The second pilot study for the extraction system was begun in February 1987. By this time, the treatment plant had been expanded and the treatment processes modified in response to experience gained from the first pilot study. Most of the ground water in the second phase was produced from wells designed for contaminant recovery rather than from monitoring wells, as had been the case in the first pilot phase. The plan for this phase was to expand the number of recovery wells incrementally as experience was gained concerning the behavior of the bedrock aquifers and the treatment system. Figure 2 shows the locations of the monitoring and recovery wells in place as of January 1988. An interim report was submitted in October 1987 covering the first 6 months of the second pilot study (CH2M HILL, 1987).

The ground-water extraction and treatment system has continued operating since the beginning of the second pilot study in February 1987. A RCRA Part B permit was issued for the site in November 1987.

In 1988, UP&L merged with PacifiCorp, and operating responsibility for the Idaho Falls site was transferred to Pacific Power & Light, a Division of PacifiCorp.

GEOLOGY

The UP&L site lies near the eastern edge of the Snake River Plain, which cuts a 50- to 100-mile swath through the Rocky Mountains across the State of Idaho. In contrast to the altitudes in excess of 12,000 feet in the adjacent mountains, the plain slopes gently and has an elevation of 4,600 to 4,700 feet in the vicinity of the UP&L site. The eastern part of the plain is a structural downwarp filled mostly with a series of basaltic lava flows of Quaternary age. The total thickness of the basalt flows is unknown, but it is known to exceed 1,600 feet near Idaho Falls. The individual lava flows are commonly 20 to 30 feet thick and are separated by interflow zones of clay, sand, gravel, cinders, and volcanic ash. Figure 3 shows a geologic cross section of the upper 200 to 400 feet of the interlayered basalt beneath the UP&L site. The location of this cross section is shown in Figure 2.

The surface soils at the site consist of 3 to 5 feet of wind-blown clayey silt (loess), underlain by sand and gravel deposits to depths of 20 to 30 feet. A veneer of silt and clay is commonly found between the sand and gravel deposits and the underlying basalt.

HYDROGEOLOGY

The interlayered basalt flows form the Snake River Plain Aquifer, which is a regional source of water supply. The interflow zones between the basalt flows are generally very permeable and are the major avenues for the horizontal movement of ground water. Fractures and broken zones within the basalt flows tend to be concentrated along the upper and lower surfaces of the flow.

Vertical movement of water between the interflow zones is through fractures in the basalt. Excavation of the creosote-contaminated gravel at the site in 1983 exposed the top of a basalt flow, which was found to have vertical fractures spaced 2 to 4 feet apart. The fractures were filled with sand and silt.

As shown in Figure 3, the consultants for UP&L have classified the basalt layers beneath the site into groups, labeled Basalt A through Basalt E. Each group may include several individual basalt flows. Basalt A and the upper layers of Basalt B are located above the water table. The fracture zones and interflow zones in the lower part of Basalt B, below the water table, have been designated as the uppermost aquifer, or Aquifer #1. This zone of relatively high permeability generally occurs between the water table and a depth of approximately 160 feet. Aquifer #1 is most densely fractured and permeable along the western edge of the site near Monitoring Wells MW-3 and MW-4 (see Figure 2). In the south-central part of the site, near Wells MW-7, MW-8, and MW-13, Aquifer #1 is much less permeable.

Table 1 lists the specific capacities and aquifer parameters that have been measured in the onsite wells. Transmissivity estimates based on aquifer tests are available for three of the wells screened in Aquifer #1. They show a wide range of variation from one well to the next. Even for a single well, there is a considerable variation in the transmissivity estimate, depending on which observation well is used for the analysis. This combination of spatial non-uniformity and directional dependence of hydraulic properties is a common feature of fractured rock aquifers.

Aquifer #1 is separated from the next lower aquifer by a very dense basalt flow, which generally extends from about 160 to 240 feet below the ground surface. However, this aquitard is not identifiable in all of the boring logs. In the northern part of the site, for instance, the log for Well MW-11 shows numerous interflow zones consisting of cinders, sand, fractures, and soft basalt in this depth range.

Aquifer #2 corresponds to the interflow zone and weathered basalt between the bottom of Basalt B and the top of Basalt C. As shown in Table 1, Aquifer #2 has a much more uniform distribution of hydraulic properties than Aquifer #1. This interflow zone is shown in only one well (MW-15) in the cross section of Figure 3. However, reference to the boring logs for other deep wells indicates that Aquifer #2 is continuous across the site, generally between 240 and 260 feet below the ground surface.

A series of interflow and fracture zones occurring between 360 and 400 feet deep has been designated as Aquifer #3. No aquifer tests have been run in Aquifer #3, but the specific capacities of the wells completed in it indicate that it is probably highly transmissive. Aquifer #3 is the deepest transmissive layer that has been investigated on the UP&L site. However, drillers' logs for deep wells located about 1-1/2 miles north of the site show that basalt layers with interflow zones extend to depths of 400 to 450 feet. Below this, a stratum of mainly sedimentary deposits, consisting of clay, sand, and gravel, extends to about 1,100 feet deep. Below this, basalt again predominates (Dames & Moore, 1984).

Three municipal water supply wells operated by the City of Idaho Falls are located less than 1 mile from the UP&L site. The wells, City Wells #1, #2, and #3, are shown in Figure 1. They produce from depths corresponding to the interflow zones identified as Aquifers #2 and #3. These wells are able to produce at rates of between 3,400 and 6,080 gpm. Transmissivity estimates made on the basis of specific capacity tests at these wells range from 2.5 to 4.9 million gallons per day per foot. These transmissivity estimates are typical of values reported in the regional hydrogeologic literature for the Snake River Plain Aquifer.

As shown in Figure 3, the water table is more than 100 feet below the ground surface at the UP&L site. The water table elevation fluctuates seasonally with an amplitude of approximately 25 feet, as shown in Figure 4. Despite the fluctuations, the head in Aquifer #1 is consistently 2 to 3 feet higher than the head in Aquifer #2. Similarly, the head in Aquifer #2 is generally about 2 feet higher than the head in Aquifer #3. The rate of vertical flow from Aquifer #1 to Aquifer #2 over the 1.5-acre area of the site has been estimated at 1.8 gpm (Dames & Moore, 1986a). This corresponds to an average vertical discharge velocity of approximately 2 feet per year. The mean velocity of vertical ground-water migration, with an effective porosity of 0.1, would be 20 feet per year. Similarly, a vertical flow rate of 8 gpm over the area of the site has been estimated between Aquifer #2 and Aquifer #3.

Regionally, the horizontal hydraulic gradients in the Snake River Plain Aquifer near Idaho Falls range between 0.001 and 0.004, with flow toward the southwest. Locally, the horizontal hydraulic gradients measured in the onsite monitoring wells seem to follow the regional trend, with flow toward the southwest. Figure 5 shows potentiometric head measurements in aquifer #2, as measured on February 13, 1985. It should be noted that the equipotentials shown on the figure are based on interpolation among only three measuring points. The limited number of measurements is probably responsible for the apparent uniformity of the gradient. If the reading from the southernmost well had been included in the countouring, the pattern would have been more complex and more typical of flow in fractured-rock aquifers. Figure 6 shows the potentiometric heads measured in Aquifer #1, also measured on February 13, 1985. Here, more measurements were used, and the flow pattern is correspondingly more complicated. The flow is generally toward the southwest, but the magnitude of the gradient is quite variable, reflecting the heterogeneity of the upper aquifer as observed in the aquifer tests.

WASTE CHARACTERISTICS AND POTENTIAL SOURCES

Creosote appears to be the only contaminant of concern at the UP&L site. Creosote is an oily, translucent distillate of coal tar whose properties vary depending on the source of the tar. Coal tar is produced as a by-product of the high-temperature carbonization, or coking, of bituminous coal. Creosote, derived from coal tar by fractional distillation, has a typical boiling range of 175 to 450 degrees Celcius. It is denser than water, having a specific gravity of 1.05 to 1.09 (at 15 degrees Celcius). Generally, its viscosity is in the range of 50 to 70 centipoise, or 50 to 70 times greater than the viscosity of water (Sale & Piontek, 1988).

More than 400 individual compounds have been identified in creosote, but most of them are present only in small amounts. Table 2 shows the results of a chemical analysis of a sample of creosote taken from a borehole drilled into the bedrock under the excavated leak area at the UP&L site. Many of the highest organic concentrations are in the category of compounds classified as polycyclic aromatic hydrocarbons (PAHs). For this reason, most of the groundwater contamination analyses at the site have been expressed in terms of total PAHs. Table 3 lists the compounds included in the category of PAHs. Most of them have very low solubility in water and correspondingly low mobility in aqueous solution.

Federal water quality criteria for human health have been established by the Clean Water Act for those PAH compounds designated with a star (*) in Table 3. The 10^{-6} excess cancer-risk criterion for the sum of the concentrations of the starred compounds is 0.0031 parts per billion (ppb), or 3.1 nanograms per liter.

Several phenolic compounds are also components of creosote. In general, they are more mobile than the PAHs and have higher regulatory cleanup levels. Pentachlorophenol, the only phenolic compound with an established maximum concentration limit (MCL), has not been found at the UP&L site and was apparently not used in the pole-treating operation. Phenol, which is listed in Table 2 as a component of the creosote at UP&L, has a 10^{-6} excess cancer-risk concentration of 3,500 ppb.

The creosote contamination at the UP&L site originated from a break in the underground pipeline connecting the pole-dipping vat with a creosote storage tank. As soon as the creosote leak was detected, a major effort was initiated to remove creosote-contaminated soil and rock. Approximately 37,000 tons of soil, much of it gravel, were excavated to form the pit shown in Figure 7. Uncontaminated gravel was stockpiled just north of the pit, as shown in the figure. Contaminated materials were sent to offsite disposal areas. The determination as to which materials were clean and which were contaminated was based on appearance and odor.

Soil samples were taken from 15 locations in the bottom and wall of the pit to monitor the adequacy of the contaminated soil removal (see Figure 7). Evaluation of the samples indicated no remaining creosote-contaminated soils. In addition, 15 borings were drilled into the soil surrounding the pit and the bedrock beneath it, as shown in Figure 7. A total of 21 soil and rock samples were taken and analyzed for creosote compounds. Borings 3 through 15 were drilled into the surficial gravel around the pit, and no creosote contamination was found in them. Borings 1 and 2 were drilled into the bedrock in the bottom of the pit to depths of 55 and 82 feet below the pit bottom, respectively. In both of these borings, contamination was apparent in the form of creosote odors and creosote coating of the drill rods.

Later, in May 1984, eight additional bedrock borings were drilled in the bottom of the excavation to verify the bedrock contamination. These borings ranged in depth from 55 to 140 feet. Only the deepest boring met the water table at a depth of 122 feet. Evidence of creosote was found in all eight borings. In most cases, the evidence was limited to odor and creosote coating of the drill rods. However,

creosote accumulations were found in the bottom of one of the borings. A sample of the creosote was taken from this hole for analysis, yielding the data presented in Table 2.

In 1984 and 1985, the excavation was backfilled to reduce the amount of ground-water recharge through the contaminated bedrock. The bottom of the pit was lined with a 12-foot layer of compacted clay. Uncontaminated gravel from the onsite stockpile was then used to backfill the pit nearly to the ground surface. A cap was then constructed consisting of a 30-inch compacted clay layer, overlain by a gravel drainage layer and a 4- to 14-inch asphalt cover.

Recognizing that creosote was present in the unsaturated bedrock above the water table as a dense nonaqueous phase liquid (DNAPL), it was suspected that lateral migration of the creosote might be controlled by the slope of the interflow zones between the basalt flows. The tops of the upper basalt flows, A1, A2, and A3 (see Figure 3) slope to the northwest at 175, 75, and 200 feet per mile, respectively. However, outside the immediate leak area, creosote was only found above the water table in monitoring and recovery wells located to the south and southwest of the HWMF. It was concluded that the basalt flows are so densely fractured and have enough vertical permeability that creosote would sink to the water table, rather than migrating laterally away from the immediate vicinity of the HWMF (Dames & Moore, 1985). It should be noted from Figure 2, however, that no wells have been drilled into the bedrock to the northwest of the HWMF.

It was concluded in the Part B Permit application (Dames & Moore, 1984a) that the total mass of contaminant discharged to the bedrock aquifer could not be estimated.

No contour maps of ground-water contaminant concentrations have been presented in any of the reports on the UP&L site that have been made available for review. Before the beginning of the first pilot study, 15 monitoring wells had been installed (Wells MW-1 through MW-15). Of these, only Wells MW-7, MW-8, and MW-13 in Aquifer #1 and Well MW-9 in Aquifer #2 were considered to be within the plume of contaminated ground water (CH2M HILL, 1985). Well MW-13, however, was the farthest downgradient well in Aquifer #1, so the extent of the plume in that layer was undetermined. In 1985, five offsite monitoring wells were installed in Aquifer #1 to the south and southwest of the site. The closest four offsite wells are between 300 and 500 feet from the south boundary of the site. The remaining offsite well is about 2,000 feet south-southwest of the site. Two of these offsite wells showed low levels (between 1 and 10 ppb) of PAHs when they were initially sampled before the wells

had been developed. In subsequent sampling after well development, all the offsite wells were free of phenols and PAH compounds. Table 4 presents a summary of the analytical results for initial rounds of sampling in the four contaminated onsite monitoring wells.

During July and August 1986, five new recovery wells were installed within the suspected plume area in Aquifers #1 and #2. Wells R-3, R-4, R-5, and R-6 were screened in Aquifer #1. Initial tests indicated that Wells R-5 and R-6 were in the central area of the plume in Aquifer #1. It was concluded that Well R-4 was near the edge of the plume in Aquifer #1 because it produced small concentrations of phenol but no PAHs. Well R-3 was judged to be outside the plume. Well R-7 produced small concentrations of phenol but no detectable PAHs, and therefore was concluded to be near the edge of the contaminant plume in Aquifer #2.

REMEDIATION

SELECTION AND DESIGN OF THE REMEDY

Objectives of Remediation

The overall goal of the recovery system is to contain and recover ground water that has been contaminated with creosote. Containment of the contaminated ground water is to be achieved by creating inward hydraulic gradients in the contaminated aquifers to prevent offsite migration. The system is intended to produce local reversal of the natural downward flow of ground water from Aquifer #2 to Aquifer #3 in the area of the contaminant plume (Dames & Moore, 1986). Another goal is to remove creosote in the nonaqueous phase to the extent found to be practical.

The recovery system has been implemented in stages, starting with the first phase of pilot recovery and treatment. The short-term goals of the first phase pilot study were:

1. To determine the hydraulic response of the aquifers to pumping and investigate any resulting change in ground-water quality

2. To improve ground-water quality by removing phenols and PAH compounds during the 6-month period of pilot operation

3. To develop a final plan of action for removal of creosote contaminants from the aquifers

4. To define the design criteria for treatment of the extracted ground water and determine the appropriate capacity of the full-scale treatment plant

At the end of the first pilot phase, it was determined that a second pilot phase would be required to work out some of the practical problems that had been encountered. However, aside from certain experiments with modifications to the treatment process, the second pilot phase can be interpreted as the beginning of the full-scale recovery operation.

System Configuration

An extraction system designed to attain the overall objectives listed above was developed with the aid of numerical ground-water flow models (Dames & Moore, 1986). The design called for seven wells in Aquifer #1 with a combined extraction rate of 46 gpm, and seven wells in Aquifer #2 with a combined rate of 145 gpm. The water extracted from these wells was to be treated and released to the Idaho Falls sewer system or to the Snake River. An alternative design, including reinjection of the treated ground water, was studied but was rejected because it would not produce the desired reversal of vertical head gradients.

The actual system that has been constructed has been implemented in stages. It is loosely based on the original design, but changes in the number and placement of wells have been made based on operating experience. The extraction and monitoring wells in place as of March 1989 are shown in Figure 8.

The first pilot phase of ground-water extraction began at the end of October 1985, with pumping from Wells MW-7, MW-13, and R-1 in Aquifer #1, and Wells MW-9 and R-2 in Aquifer #2. Well MW-8 was also to have been pumped, but it was found to be an unproductive well. It was initially intended that the pilot system would extract and treat a combined flow of up to 100 gpm, but practical difficulties limited the pumping to much lower rates. The average combined pumping rate for the first 6-month pilot study was only 25 gpm. After the first 3 months of pilot operations, it was necessary to suspend pumping from Wells MW-7 and R-1 because of seasonal low water levels in Aquifer #1. Other reasons for the low rates of extraction were:

- Treatment plant shutdowns to repair pipe breaks and perform other maintenance
- Plant shutdowns for holidays

- Reduced flow rates during monitoring well pump tests

- Limited operations while emergency safety systems were out of operation

- Plant shutdown for conversion from PVC to steel piping

Some of the problems listed above were caused by the unexpectedly large amount of nonaqueous creosote produced from the wells. Creosote was found to be incompatible with PVC, causing the piping to become brittle and crack. Nonaqueous creosote in the waste stream also caused clogging of some of the treatment processes, requiring more frequent maintenance than expected. In response to these problems, numerous changes to the treatment plant were made during the period between the end of the first pilot phase on April 29, 1986, and the start of the second pilot phase in February 1987.

The recovery wells used in the second pilot phase of extraction were MW-7, MW-13, R-4, R-5, and R-6 in Aquifer #1 and MW-9, R-2, and R-7 in Aquifer #2. During the early months of the second pilot phase, the extraction rates in Aquifer #1 were again limited by seasonal low-water levels. However, in June, July, and August the rates of extraction increased. The average combined extraction rate for the first 6 months of the second pilot test was 44 gpm. The lowest extraction rates occurred in May, with an average combined rate of 28 gpm. The month of maximum extraction was August, with an average combined rate of 103 gpm. The treatment plant is designed to accommodate a maximum flow of 200 gpm.

Since the interim report on the second pilot study was submitted in October 1987, extraction and treatment has continued with several new wells being added to the system in Aquifers #1 and #2 to fill out the system shown in Figure 8. The present system has more recovery wells than envisioned by the original design, but they are not all operated at once. The selection of which wells are to be used at any given time is based on constraints imposed by the productivity of the aquifers (Cowley, 1989). Aquifer #1 can produce a maximum of about 45 gpm when the water table is high in late summer and fall. This is a hydrologic limitation of the formation and cannot be increased by pumping more wells. The pumping rate of Aquifer #2 is limited to about 160 gpm because of the need to reduce downward flow of ground water in areas of high contamination. In the winter and spring, when the water table is low, the production rates are even lower. Figure 9 gives a summary of the wells

that have been in operation since the beginning of the first pilot study. It shows a gap in the historical record between August 1987 and January 1989 for which no data are available.

EVALUATION OF PERFORMANCE

The primary objective of the ground-water remediation is to hydraulically contain the contaminants and prevent them from moving offsite. Figures 10, 11, and 12 show the potentiometric surfaces in Aquifers #1, #2, and #3 in January 1989. Without a plume definition map, it is not immediately clear whether the flow patterns illustrated in these figures indicate that containment has been achieved. However, the head maps for Aquifers #1 and #2 do appear to show that at least the areas of demonstrated high contamination are within the capture zones with respect to horizontal flow. There are no extraction wells in Aquifer #3 because no contamination has been found there. The apparent convergence of flow toward the recovery area in Aquifer #3 is interpreted as resulting from upward leakage to the overlying aquifers caused by the extraction wells.

According to these figures, the vertical gradients have been reversed over only part of the contaminated region. However, the natural downward flow has at least been reduced over the area of concern. Currently, the EPA is studying the data to determine whether the containment objectives are being attained. It should be mentioned that the offsite flow patterns shown on these figures are not based on measurements and should probably be disregarded.

No timetable has been set for the goal of eventual aquifer restoration. It appears that the recovery system will have to continue in operation for the foreseeable future. The recovery system still produces creosote as a nonaqueous phase at irregular intervals. The production of creosote slugs results in attendant fluctuations in the concentrations of dissolved contaminants. No records have been kept of the total quantity of free-phase creosote removed.

During the first 6 months of the second pilot study, it was estimated that approximately 1,020 pounds of total PAH compounds were removed as dissolved contaminants. In general, the contaminant concentrations in the extracted ground water have been declining, but the pattern is very irregular. Figures 13, 14, and 15 show the records of total PAH compound concentrations in the treatment plant influent during Phase 1, Phase 2, and subsequent system operating periods, respectively. The variations of the total ground-water extraction rates are also shown.

During Phase 1, total PAH concentrations of more than 50,000 ppb were recorded on two occasions. However, the majority of measurements were less than 5,000 ppb (see Figure 13). In Phase 2, the highest PAH concentrations were less than 10,000 ppb, and most measurements were below 3,000 ppb (see Figure 14). The highest influent PAH concentration, measured from January 1988 to March 1989, was 1,760 ppb, and most measurements were less than 1,000 ppb (see Figure 15). Yet, with such large concentration fluctuations and relatively low sampling frequency, it is difficult to develop any quantitative description of the recovery performance. The task is made even more complicated by the fluctuations in recovery rates and the frequent switching of recovery between wells.

SUMMARY OF REMEDIATION

The combination of a dense nonaqueous contaminant and multiple fractured-rock aquifers makes the performance of the ground-water remediation program at the UP&L site difficult to assess. When the aquifers are regarded as conventional porous media, it appears that hydraulic control of dissolved contaminants can be accomplished by a system of extraction wells. The fracture density of the basalt flows is thought to be quite high, indicating that the porous media analogy may be fairly accurate. However, it is always possible that the flow in individual fractures may not be well represented by the potentiometric head maps developed by interpolation between monitoring points. Furthermore, the movement of creosote as a DNAPL may not be entirely controlled by the hydraulic gradients in the aquifers. In spite of these difficulties, it can be argued that the recovery system appears to be controlling, and perhaps preventing, the offsite movement of contaminants.

Because of the existence of creosote in the aquifers as a nonaqueous phase, it is unlikely that aquifer restoration to health-based levels will be attained within the foreseeable future. Contaminant concentrations appear to have declined, on the average, during the three and one half years of recovery system operation. However, the fluctuation of concentrations associated with the irregular withdrawal of creosote slugs makes the quantitative projection of trends difficult.

REFERENCES

CH2M HILL. June 1986. Groundwater Treatment Pilot Plant Report at the Utah Power & Light Company Pole Treatment Yard, Idaho Falls, Idaho.

CH2M HILL. October 1987. Groundwater Treatment Phase 2 Interim Report, UP&L Pole Treatment Yard, Idaho Falls, Idaho.

Cowley, J. May 25, 1989. Personal Communication with Mr. John Cowley, treatment plant operator.

Dames & Moore. December 1984(a). Part B Permit Application for Hazardous Waste Management Facility, Utah Power & Light Pole Treatment Facility, Idaho Falls, Idaho, Volumes 1, 2, and 3.

Dames & Moore. December 1984(b). Part B Permit Application for Hazardous Waste Management Facility, Utah Power & Light Pole Treatment Facility, Idaho Falls, Idaho, Volume 4.

Dames & Moore. October 1985. Groundwater Quality Assessment Report for Hazardous Waste Management Facility, Utah Power & Light Pole Treatment Yard, Idaho Falls, Idaho.

Dames & Moore. April 1986. Hydrologic Investigations and Design Recommendations, Well Field for Creosote Recovery, Pole Treatment Yard, Idaho Falls, Idaho, for Utah Power & Light Company.

Dames & Moore. January 1988. Installation of Aquifer #3 Monitor Wells, Pole Treatment Yard, Idaho Falls, Idaho, for Utah Power & Light Company.

Mabey, et al. December 1982. Aquatic Fate Data for Organic Priority Pollutants, SRI International, EPA Report No. 440/4-81-014.

Pacific Power. May 1, 1989. Utah Power & Light/Pacific Power & Light Idaho Falls Pole Yard, RCRA Post Closure Semi-Annual Report for October 88 thru March 89.

Sale, T., and K Piontek. 1989. In Situ Removal of Waste Wood-Treating Oils from Subsurface Materials. Presented at the U.S. EPA Forum on Remediation of Wood Preserving Sites. San Francisco.

WDCR436/070.50

CASE STUDY 18

Verona Well Field
Battle Creek, Michigan

CASE STUDY FOR THE VERONA WELL FIELD SITE

BACKGROUND OF THE PROBLEM

The Verona well field is an EPA Superfund site located in the northeast corner of the city of Battle Creek, Michigan. The Verona well field supplies potable water to approximately 50,000 residents, three major food-processing industries, and a variety of other commercial and industrial establishments. The site is contaminated with a number of volatile organic compounds (VOCs).

The Verona well field consists of three wells on the west side of the Battle Creek River and 27 wells and a major pumping and water treatment station on the east side of the river. A pipeline under the river connects the wells on the west side of the river to the pumping and water treatment station on the east side. The city's maximum daily demand for potable water is 19 million gallons per day (mgd), with a monthly, average daily demand fluctuating between 7.8 and 13.2 mgd.

SITE HISTORY

In August 1981, the Calhoun County Health Department performed a routine collection of water samples from private wells and residences. One water sample was found to contain VOCs. The source of this water was the Verona well field, the municipal water supply for the city of Battle Creek. Subsequently, the Calhoun County Health Department and Michigan Department of Public Health collected samples from municipal wells in the Verona well field in September of 1981. Several of the wells on the west side of the river were found to contain VOCs, principally chlorinated solvents.

An investigation revealed two plumes of contamination at the Verona well field. The Thomas Solvent Company's Raymond Road facility and the Thomas Solvent Company's Annex at Emmett Street were found to be the major sources of contamination for the southern plume, and the Grand Trunk Western Railroad (GTWRR) marshalling yard was the major source of the eastern plume contamination (Figure 1).

In October 1981, the city of Battle Creek discontinued the municipal water supply usage of any well that had contaminant levels approaching 100 micrograms per liter (ppb). Two of the most heavily contaminated wells were pumped continuously and discharged directly into the Battle Creek River in an attempt to prevent the spread of contaminated ground water into the rest of the municipal wells. This

practice was discontinued in September 1982, when a National Pollutant Discharge Elimination System permit application for the well discharges was withdrawn.

The strategy developed to remedy the contamination at Verona well field included one initial remedial measure (IRM) and four corrective-action operable units. The objectives of the four operable units are (1) to control the sources of contamination at the Thomas Solvent Raymond Road (TSRR) facility, the Thomas Solvent Emmett Street Annex, and the Grand Trunk Western Railroad marshalling yard; and (2) to institute final corrective action including management of plume migration and any remaining site closure action required by the National Contingency Plan. As of this writing, only the IRM and the source control at the TSRR facility have been instituted.

In May 1984, a Record of Decision (ROD) was signed initiating the IRM. The IRM was deemed necessary to provide the city of Battle Creek with potable water before the summertime increase in demand for water. A focused feasibility study was conducted. As a result of this study, three new wells designed to supply 6 mgd were constructed north of the Verona well field (July 1984) and a program in which five existing wells within the well field were used to block northward contaminant migration was begun (May 1984).

In 1985, the EPA signed another ROD that addressed the TSRR facility, the most severely contaminated of the three sources. The Thomas Solvent Company operated a solvent distribution business and handled a variety of liquid industrial wastes. The facility was used for storage, transfer, and packaging of chlorinated and nonchlorinated solvents.

The 1985 ROD described two distinct environmental problems at the TSRR site:

- The contaminated ground-water plume in the saturated zone
- Soil contamination in the unsaturated zone beneath the site

The remediation alternative selected for the plume problem was to extract and treat the ground water. It was estimated that this would remove 68 percent of the contamination after 3 years of operation. The extraction well system began operation in March 1987.

The remediation alternative selected for soil treatment was a soil vapor extraction (SVE) system. The SVE involved

leaving the soil in place and promoting movement of the interstitial air for enhanced volatilization. Cleanup time for the SVE system was estimated at 6 months to a year.

GEOLOGY

The oldest formation of interest underlying the Verona well field is the Marshall Formation. The Marshall Formation (Mississippian Age) is a very fine-to-medium, blue-gray sandstone containing layers of siltstone, sandstone, and shale (see Figure 2). The formation has a maximum thickness of 200 feet. The Marshall Formation aquifer system has an average thickness of 150 feet in the well field area.

The dark shale that underlies the Marshall Sandstone appears to form the bottom of the aquifer used by the Verona well field. The sandstone strata of the Marshall Formation are important water-bearing units in the Battle Creek area. The shale layers may divide the sandstone formation into several distinct aquifers. However, most bedrock wells are screened over more than one sandstone layer.

Rubble zones indicate extensive horizontal and vertical fracturing in the sandstone. The sandstone appears to contain many horizontal fractures to a depth of about 80 feet. Below 80 feet, the frequency of horizontal fractures appears to decrease substantially. Evidence of vertical fractures exists within the upper 60 feet of the sandstone. These sandstone bedrock fractures are an important feature because water wells that intersect fractures are known to produce more water than wells that do not intersect fractures. The upper surface of the Marshall Formation sandstone is very irregular. The USGS has mapped several buried bedrock valleys, some of which have been partially filled with clay material.

Glacial till, outwash and channel deposits overlie the Marshall Formation (see Figure 3). They range in thickness from a few feet to about 100 feet. The Verona well field and the identified contaminant sources are within an area of glacial outwash deposits derived from the Kalamazoo Moraine, which lies to the northwest. These deposits consist primarily of stratified and interlayered sands and gravel, with clay lenses or clay-rich layers occurring locally. Because of complex layering in the glacial deposits, it could not be determined if the clay layers are laterally continuous and to what degree the clay layers act as a barrier to downward flow to the underlying aquifer.

HYDROGEOLOGY

The aquifers in the area of the Verona well field consist of the shallow sand and gravel deposits and the underlying sandstone bedrock of the Marshall Formation. The well field itself is developed in the sandstones of the Marshall Formation, particularly in the lower sandstone aquifer. Hydraulic conductivity tests suggest that there is no significant low-conductivity layer between the surficial sand aquifer and the bedrock sandstone aquifers. The two zones appear to be hydraulically connected, allowing contaminants to pass freely from one zone to the other.

Wells in the Verona well field produce as much as 12,000 gallons per minute (gpm) during peak demand periods. Pumping tests and model simulations indicate the lower sandstone aquifer in the Marshall Formation has a horizontal hydraulic conductivity of 500 feet per day (ft/day) based on an aquifer thickness of 5 to 50 feet. The transmissivity of the lower sandstone is greatly increased by openings or fractures and ranges from 3,000 to 27,000 square feet per day (ft^2/day). Specific-capacity tests and model simulations indicate that the upper sandstone aquifer has a hydraulic conductivitiy of 150 ft/day based on an aquifer thickness of 0 to 100 feet. Its transmissivity ranges from 0 to 15,000 ft^2/d.

Values of horizontal hydraulic conductivities for unconsolidated materials in the surficial glacial deposits range from 14 to 110 ft/day. The specific yield of the outwash and channel deposits is estimated to be 0.15.

The flow velocities of the ground water in the lower sandstone aquifer in the vicinity of the Verona well field range from 1 to 4 ft/day. Pumping of the Verona production wells causes water to flow to the well field from several thousand feet away. Heavy pumping during the summer months causes ground water to flow directly northward from the contaminant source areas near the Emmett Street/Raymond Road intersection.

Figure 4 shows a generalized average potentiometric surface of the study area in both the water-table aquifer and the sandstone aquifer. The ground water in the upper water-table aquifer flows towards and feeds the surface water bodies in the region surrounding the study area. Within the study area itself, the pumping at the Verona well field is superimposed on these natural flow patterns causing two distinct areas of radially inward flow.

WASTE CHARACTERISTICS AND POTENTIAL WASTE SOURCES

The results of the monitoring data from the Verona well field from 1983 to 1984 showed increasing levels of contamination in a majority of the 27 wells east of the Battle Creek River. The three wells west of the river remained uncontaminated. There were seven compounds detected regularly during monitoring. These included:

- 1,1-Dichloroethane (1,1-DCA)
- 1,2-Dichloroethane (1,2-DCA)
- 1,1,1-Trichloroethane (1,1,1-TCA)
- 1,2-Dichloroethylene (1,2-DCE) (Cis and Trans)
- 1,1-Dichloroethylene (1,1-DCE)
- Trichloroethylene (TCE)
- Tetrachloroethylene (PCE)

Concentrations of these contaminants ranged from 1 to 100 micrograms per liter of VOCs during the sampling from 1983 to 1984. Ten other VOCs have been detected but do not appear regularly in individual wells or in the finished water supply.

Two contaminated plumes, a southern plume and an eastern plume, were identified at the Verona well field. Figure 5 illustrates the extent of total VOCs in these plumes in August, 1984. The contamination was steadily moving north and northwest from the more contaminanted wells toward the less contaminated wells in the well field.

The southern plume consists primarily of 1,2-DCE, PCE, 1,1-DCA, and 1,2-DCA. The mass of total chlorinated volatile organics dissolved in the southern plume was estimated at 5,700 pounds. In the vicinity of the TSRR facility, the total mass was estimated to be about 3,900 pounds (or 68 percent of the entire southern plume). This plume, limited to approximately 20 to 25 feet below the water-table surface in the vicinity of this facility, deepens progressively downgradient of the facility. Contaminants were estimated at levels exceeding 100,000 parts per billion (ppb) VOCs. This level is about 100 times more concentrated than contaminant levels in the majority of the plume, which are present only in the lower and middle levels in the aquifer within the well field.

The eastern plume consists of PCE; 1,1,1-TCA; 1,1-DCA; and 1,1-DCE. This plume appears to be concentrated at the water table in the source area (the GTWRR marshalling yard) and to deepen downgradient to about 40 feet below the water-table surface because of well field pumping. The total mass of

total chlorinated VOCs present in the aquifer in the eastern plume has not yet been estimated.

Past investigations have shown that the contaminants were introduced into the unsaturated zone and the ground water below from leaking underground storage tanks, above ground spills and other occurrences related to the solvent handling operations. There were 21 underground storage tanks at the TSRR facility. In March 1984, they were tested for leaks and 19 were found to have a measurable loss rate. A total of 21 chemicals were stored in these underground storage tanks. The use of the tanks was discontinued after the leak testing was performed.

Beneath the TSRR facility, the highest ground-water contaminant concentrations were observed in the shallow sand and gravel deposits. However, downgradient of the facility, the centerline of the plume appears to drop into the bedrock, and the concentration in the sand and gravel decreases. Figure 6 illustrates the distribution of one contaminant (1,2-DCE), beneath the TSRR facility.

Discontinuing use of municipal wells V-31 through V-35 in October 1981 required shifting extraction to wells farther north in the well field. Water quality data from the municipal wells indicated that this shift in extraction resulted in migration of contaminants to the north. Figure 7 shows the increase in total VOCs in well V-29 after wells V-31 through V-35 were shut down and extraction shifted to the north. In November 1983, well V-29 was shut down and well V-38 started to indicate an increase in VOC concentration. A similar scenario occurred in the western portion of the well field, as shown by the change in VOC concentration of well V-13 (Figure 8). The locations of 4 wells (V-29, V-32, V-38, and V-13) are circled on Figure 5.

The city was able to maintain a supply of water by shifting pumping away from the advancing plume, and blending waters from slightly contaminated wells with water from clean wells. However, the municipal water supply did contain detectable concentrations of VOCs during certain time periods.

There are non-aqueous phase liquids (NAPLs) present in the source zone of the aquifer. A toluene-based mixture of organic solvents is floating in a small area under the TSRR facility. This floating layer is up to 6 inches thick.

REMEDIATION

SELECTION AND DESIGN OF THE REMEDY

Three systems have been implemented at the Verona well field. These systems include the barrier-well system at the well field; and a ground-water extraction system and a soil-vapor extraction system at the TSRR facility.

The IRM--Barrier Well System

The performance objective of the barrier-well system is to protect the production wells from contamination. Two remedies were identified by the focused feasibility study (FFS). The first was to develop three new wells north of the Verona well field that would supply approximately 6 mgd. The new production wells began pumping in July 1984 producing between 5.3 and 5.7 mgd.

The second component of the IRM identified in the FFS was a barrier well system. It was implemented in May 1984 using selected wells within the field (wells V-20, V-22, V-25, V-27 and V-28) to block continued migration of contaminants to the north. These wells were located at the north edge of the southern plume.

A treatment system consisting of air stripping with vapor-phase carbon adsorption for the air emissions was selected to clean up the extracted water from the barrier well system. The wells were operated at the lowest practical pumping rate to minimize treatment costs.

Thomas Solvent Raymond Road--Ground-Water Extraction System

The 1985 ROD specified a corrective action that included a network of nine ground-water extraction wells screened in the water-table aquifer to remove contaminated ground water. This ground-water pump and treatment remedy was selected because the site geology precluded the use of passive physical vertical barriers. The only natural confining unit for barrier completion is a shale formation at a depth of 140 feet. This depth is considered too deep for the trench excavations and backfilling necessary for installation of a physical barrier.

The performance objective of the ground-water extraction well system is to get the VOC levels in the ground water at the source below EPA's maximum contaminant levels (MCLs). Table 1 shows a comparison between the MCLs and VOC levels in extraction well 3 on July 7, 1988.

Table 1
SUMMARY OF GROUND-WATER CONTAMINATION AT THE THOMAS SOLVENT RAYMOND ROAD FACILITY AND EPA DRINKING WATER CRITERIA

Verona Well Field, Battle Creek, Michigan
July 7, 1988

Identified Ground-Water Contaminants	Extraction Well 3 (ppb)	EPA MCLs (ppb)
Chloroform	33	-
1,2-Dichloroethane	26	5.0
Cis-1,2-Dichloroethylene	270	-
Methylene chloride	170	-
Tetrachloroethylene	310	-
1,1,1-Trichloroethane	330	200
Trichloroethylene	370	5.0
Ethyl Benzene	44	-
Toluene	730	-
o-Xylene	46	-

The ground-water extraction wells and other equipment began operation in March 1987. Figure 9 shows the TSRR facility and the extraction system. This extraction well configuration was selected to create a cone of depression in the area to prevent contaminants from escaping. As shown in Figure 6, the contaminants directly under the facility are in the water-table aquifer. The carbon pretreatment system will be removed if the total VOC concentration becomes low enough for the air stripper alone to meet National Pollutant Discharge Elimination System permit requirements for discharge to the Battle Creek River.

Computer modeling was used to determine that a pumping rate of 400 gpm would produce the radius of influence necessary to contain and collect the highly contaminated ground water.

A greater rate of pumping would cause upward flow of uncontaminated water from the lower sandstone aquifer, which would dilute the contaminated ground water and increase the volume of water to be pumped and treated. The 400-gpm pumping rate was also chosen to be within the capacity of the existing air stripper and emission control system.

Thomas Solvent Raymond Road--Soil-Vapor Extraction

The performance objective of the soil-vapor extraction system at the TSRR facility is to get the total VOCs below 1 mg/kg in the soil.

A soil-vapor extraction system was installed to remove VOCs from the vadose zone in the vicinity of the most contaminated source area. The system consists of a network of 23, 4-inch-diameter, PVC wells. The network of wells is connected to a surface collection manifold which directs the VOC contaminated air through a 2-part carbon absorption system and a filter unit. The air is then discharged to the atmosphere.

A pilot SVE system was started up in November 1987. Due to the high loading rates of some wells, the system could only be operated for 69 hours before reaching capacity in the 1,000 pound carbon canisters.

The SVE system began full-scale operation in March 1988.

EVALUATION OF PERFORMANCE

The IRM--Barrier Well System

The barrier well system was activated in May of 1984. This row of barrier wells was successful in blocking continued contaminant migration to the north, which resulted in a substantial decrease in total VOC concentration in wells north of the barrier wells. This reduction can be seen for wells V-13 and V-38 in Figure 8.

Thomas Solvent Raymond Road--Extraction Well System

The TSRR ground-water extraction-well system has shown a steady decrease in total VOC concentrations. Figures 10 through 13 show the rate of change of the total VOCs in extraction wells from March 1987 through July 1988. Concentrations in all the extraction wells decreased sharply during the first two months of operation from high initial concentrations. In several cases, the concentrations increased after this initial decline in concentrations; in wells 2 and 7, concentrations rose above initial concentrations. Operation of the soil vapor extraction system appears to have decreased concentration in several wells.

Ground-water extraction well number 8 is a product recovery well, combining ground-water extraction with intermittent removal of the NAPL product as it accumulates. The NAPL layer was greater than a foot thick in March 1988 and has

decreased to less than an inch following the start-up of the soil-vapor extraction system. The soil-vapor extraction system may have caused the compounds in the NAPL layer to volatilize.

As of March 1989, the extraction well system has removed VOC-contaminated ground water containing more than 10,000 pounds of total VOCs (CH2M HILL, 1989). Figure 14 shows the change in concentration of total VOCs for the combined flow from the extraction wells. The combined extraction-well concentration has decreased from an initial concentration of about 19,000 ug/l total VOCs to a January 1989 combined concentration of approximately 2,500 ug/l. The concentrations were generally high during the first 120 days of sampling, but showed a decreasing trend. The concentrations then levelled off and even increased slightly in the winter of 1987-88. The spring of 1988 saw a drop in the combined concentrations corresponding to the initiation of soil vapor extraction.

Thomas Solvent Raymond Road--Soil-Vapor Extraction

From March 1988 through January 1989, 26,750 pounds of total VOCs were removed by the soil-vapor extraction system. The loading rate of total VOCs has dropped from an initial high of approximately 45 pounds per hour (pph) to less than 10 pph.

SUMMARY OF REMEDIATION

Two contaminant plumes from three sources have been identified at the Verona well field. In response, a barrier well system has been installed in the southern portion of the well field. In addition, a ground-water extraction system and a soil-vapor extraction system have been installed at the TSRR contaminant source. Source remediation is planned for the two other contaminant source areas.

The barrier well system used existing wells within the well field. The system has been successful in blocking continued contaminant migration to the north. A substantial decrease in total VOC concentration was evidenced in wells north of the system shortly after the barrier wells began operation in May 1984.

The ground-water extraction well system at the TSRR facility has been in operation since March 1987. It was designed to extract water only in the upper aquifer because that is the area of highest VOC concentrations. As the contaminants move toward the well field, they drop into the bedrock layer where they are picked up by the barrier well system.

The TSRR extraction well system has removed approximately 11,000 pounds of total VOCs as of January 1989 (CH2M HILL, 1989). The contaminant concentrations in the wells that had the highest initial concentrations have been reduced substantially over the period of extraction. In wells that had lower initial concentrations, the concentrations have not declined so distinctly, and in some cases there have been increases. Consequently, the concentrations have become more similar among all of the extraction wells as a result of the remedial action. The continued existence of a residual source in the floating NAPL layer makes it unlikely that the remedial objectives will be met soon. However, the vapor extraction system has removed approximately 27,000 pounds of contaminants from the vadose zone during the 10 months of initial operation. If the residual source can be removed in this way the progress of the ground-water remediation should be accelerated.

BIBLIOGRAPHY

U.S. Environmental Protection Agency and CH2M HILL. January, 1988. RCRA Handbook on Groundwater Remediation Technologies--Case Studies. Unpublished Draft.

CH2M HILL. May 1988. Verona Well Field Final RI/FS Work Plan.

CH2M HILL. June 1988. Thomas Solvent Raymond Road Groundwater Extraction Well Treatment System Monitoring Report.

CH2M HILL. April 6, 1989. Personal communication with Joseph Danko, site manager for Verona well field remediation.

WDR428/039.50

CASE STUDY 19

Ville Mercier
Ville Mercier, Quebec, Canada

NATO / CCMS
Second International Conference

Demonstration of Remedial Action Technologies for Contaminated Land and Groundwater

---

Bilthoven, the Netherlands

7–11 November 1988

ABSTRACT

In November 1986, the NATO Committee on Challenges of Modern Society (CCMS) formally adopted a United States proposal for a new five year pilot study to demonstrate technologies for cleaning up contaminated land and groundwater. The participating NATO countries are Canada, Denmark, Federal Republic of Germany, France, the Netherlands, and the United States. Japan is also participating. Norway and the United Kingdom are observer countries. The Pilot Study Director is from the United States; the co-directors are from the Federal Republic of Germany and the Netherlands.

The Second International Conference was held in Bilthoven, the Netherlands on 7-11 November 1988. Seventeen projects (final and interim) were prepared including the following types of treatment: solidification/stabilization (2 projects), microbial degradation (3 projects), pump and treat (3 projects), soil extraction (4 projects), volatilization (1 project), thermal (3 projects), and chemical (1 project). The discussions at this meeting also included recent developments in the regulations and remedial technology research and development in the attending countries. The next meeting will be a workshop held in Copenhagen, Denmark on 8-10, May 1989.

GROUNDWATER CONTAMINATION
BY ORGANIC COMPOUNDS IN VILLE MERCIER: NEW DEVELOPEMENTS

BY

RICHARD MARTEL
MINISTERE DE L'ENVIRONNEMENT DU QUÉBEC

PRESENTED TO

NATO/CCMS PILOT STUDY OF REMEDIAL ACTION AND
TECHNOLOGIES FOR CONTAMINATED LAND AND GROUNDWATER

BILTHOVEN, THE NETHERLANDS, NOVEMBER 7-11, 1988

ABSTRACT

In the early 1980s, it was estimated that a draw-off of 5 times the water volume contained in a highly contaminated zone was necessary to restore the aquifer and recover it for use. At the first meeting of the NATO/CCMS pilot study in Washington, Simard and Lanctot stated: "The purpose of remedial action is not to remove all contaminants, but to remove enough for Nature to be able to complete the process of final cleaning". Today, we know that the method used at Ville Mercier is a control measure used to prevent contamination from spreading rather than a restoration measure since only minimal amounts of the contaminant have been extracted to date (20 tonnes).

1. SITE DESCRIPTION

1.1 Site Location

The Ville Mercier site, where groundwater has been polluted by the dumping of organic wastes, is located in the municipality of Ville Mercier situated in southern Québec on the south shore of the St. Lawrence River 20 km from the city of Montréal (Figure 1).

1.2 Site History

From 1968 to 1972, a waste-oil carrier dumped 40 000 m^3 of liquid waste into lagoons in an abandoned gravel pit near Ville Mercier (Poulin 1977).

Sections of piping were installed in 1971 and 1976 to rectify the groundwater contamination situation.

Some of the liquid waste was burned, but it was only in 1980 that the remaining liquid and sludge were removed from the lagoons, treated and buried in a clay landfill site 500 m east of the former site (Hydrogéo Canada Inc.).

It was not until 1983 that work aimed at controlling contamination and restoring the aquifer was undertaken.

1.3 Extent of Groundwater Contamination

The dumping of organic wastes in a site unsuited to that purpose resulted in the contamination of the groundwater in the gravel formation and in the fractured bedrock linked hydraulically to the sand/gravel aquifer.

In 1981, the groundwater contamination plume extended over an area of 30 km^2 (Hydrogéo Canada Inc, 1981). This enclave is defined by four zones (Figure 2). Zones 1 and 2 constitute the core of the high pollution levels while zones 3 and 4 present a very low degree of contamination.

Zone 1 is contaminated by more than 80 organic substances (SNC, 1982), with concentrations of phenols averaging 1000 ug/L.

Within Zone 2, this concentration averages 50 ug/L and the presence of organic substances is generalized.

Zone 3 extends southwest to Rivière de l'Esturgeon, where the groundwater flows naturally. The concentration of phenols ranges from 5 to 15 ug/L and less mobile organic substances are not found.

Zone 4 is a low contamination zone where the phenolic concentration of the samples taken was close to the range of detection covered by the method of analysis used (5 ug/L).

1.4 Hydrogeological Environment

The lagoons are formed in a gravel ridge consisting of a very permeable sand/gravel complex of glaciofluvial origin 30 m deep (Figure 3a). The gravel ridge stretches NNE-SSW over a distance of 11 km.

Under the sand/gravel deposit is a thin layer of glacial till, 3 m thick, resting erratically on the bedrock. The latter consists of dolomitic sandstone or sandstone dolomite of the Chateauguay formation.

Marine clay is encrusted on the gravel ridge and makes the region an alluvial clay plain.

The hydraulic conductivity of the sand/gravel formation ranges from 10^{-2} to 10^{-3} cm/s and from 10^{-4} to 10^{-6} cm/s in the basal till (Keysers 1962). The bedrock has a fracture permeability and the most fractured level is within the first 3 m. Under the lagoons, the average permeability coefficient in the rock is 10^{-5} cm/s and 10^{-8} to 10^{-10} cm/s in its matrix. From the lagoons to Rivière Châteauguay, the fractured rock permeability coefficient increases, sometimes to 10^{-1} cm/s.

The groundwater flow velocity, as assessed by Poulin (1977) is 110 m/yr in the sand/gravel complex, and 525 m/yr in the fractured rock. The sand/gravel and fractured rock formations have been contaminated by the liquid-waste-filled lagoons.

2. REMEDIAL TECHNOLOGY

The treatment system includes water extraction facilities and a treatment plant housing all treatment equipment.

2.1 Purge Wells

Water extraction works consist of three wells (Figure 3b), approximately 40 m apart, each equipped with a submersible pump. They were drilled through the sand/gravel formation and 4 m into the bedrock 35 m below the surface in the most highly contaminated area (Zone 1). They pumped for four years at an average rate of 47 l/s.

2.2 Treatment Plant

In the first treatment stage, hydrogen peroxide and chlorine are injected into the raw water before air stripping occurs. Once the water has been directed into the aerator, alum and polymers are injected into it on its way into a mixing chamber, where chlorine dioxide is added at a dosage of 2.5 mg/L.

Then, the water is channelled into a dynamic sludge bed clarifier (Pulsator). From there, the liquid flows towards two gravity filters, each equipped with a 42" sand bed.

After treatment, the water is discharged into an intermediate basin and pumped into the activated carbon filtration system, which consists of three pressure units. The first unit, called the "sacrifice" pressure filter, contains 200 cu. ft. of activated carbon.

Two units measuring 400 cu. ft. and called "buffers" operate in parallel and complete the treatment initiated in the "sacrifice" filter. The treated water is discharged into a stream approximately 500 m east of the plant.

The sludge remaining in the settling tank is periodically pumped into the sludge storage tank and a de-watering chamber. It is later loaded into a container and buried in a sanitary landfill site.

3. RAW WATER CHARACTERISTICS

3.1 Composition and toxicity

The following tables show the results of the chemical analysis of a sample of raw water taken from the Ville Mercier treatment plant in May 1988. Organic screening for volatile organic compounds (EPA625 method) and non-volatile organic compounds (EPA624 method) was carried out by MENVIQ's Laboratory Division in Québec City. The concentration of the 61 organic compounds detected totals 2500 ug/l and breaks down as: 97% volatile compounds and 3% non-volatile ones. Forty-three of these compounds are on the USEPA list of 129 priority pollutants (13 PAHs, 15 MAHs, 14 HHs and PCBs).

The 26 volatile organic compounds in tables 1a and 1b belong to two main categories: halogenated hydrocarbons (HHs), constituting 86% by weight of the site's total organic compounds, and monocyclic aromatic hydrocarbons (MAHs), representing 11% by weight. The 1,2 dichloroethane alone accounts for 42% by weight of the organic compounds present. The presence of vinyl chloride may indicate that chlorinated hydrocarbons are degraded in groundwaters (Wolf et al., 1987).

Six of these compounds exceed limits considered safe for drinking water using 11 available criteria. They are benzene and 5 of the most concentrated halogenated hydrocarbons. You will recall that vinyl chloride is more toxic than most original halogenated hydrocarbons.

In tables 2a, 2b and 2c, the 35 non-volatile organic compounds are represented mainly by phenolic compounds and polycyclic aromatic hydrocarbons (PAHs) in proportions equivalent to 1% by weight of the total organic compounds.

Of these non-volatile compounds, 7 are subject to drinking water guidelines. Dibenzofuran and benzo (a) pyrene, however, exceed allowable levels. In Québec, a standard of 2 ug/l is applicable to total phenolic compounds. This level is exceeded for phenol, 2,4 dimethylphenol and 4- nitrophenol.

Many of these pure substances (primarily halogenated hydrocarbons) can be categorized as dense-non-aqueous-phase-liquid (DNAPL) chemicals. These chemicals resemble petroleum hydrocarbons in that they are immiscible in water. However, their densities exceed that of water and their viscosities are less. Their relatively low solubility in water (typically 100 to 5000 mg/l) can often be many orders of magnitude higher than the drinking water standard. Mixtures of chemicals that are not individually recognized as DNAPLs can present similar characteristics. This is probably true for many of the PAHs and phenolic compounds in Tables 2a and 2b. The presence of two PAHs (dibenzo (a, h) anthracene and benzo (g, h, i) perylene) in concentrations greater than their aqueous solubility can be explained by their presence in a mixture of chemicals which can enhance solubilization.

Due to their low densities, other pure substances (mainly benzene, toluene, xylene, and ethyl benzene) can be categorized as NAPL chemicals.

The composition of this sample shows that after four years of pumping it remains hazardous to drink this well water. Moreover, the raw water must be treated to be discharged into surface waters without causing significant pollution. The plant's wells are currently recovering, at concentration far lower than the solubility limit, the organic compounds dissolved in the water and the by-products of the chemical or microbial decomposition of the original hydrocarbons.

3.2 Variation in composition

Figures 4 and 5 indicate that the concentration of 1,2 dichloroethane and phenolic compounds dropped considerably from the onset of in-plant operations to the point when 1.5 million m^3 of water had been pumped. This volume, which was obtained after 2 years, corresponds to the renewal of once the volume of water contained in the very contaminated zone. Concentrations later stabilized around 1000 ug/L for 1,2 dichloroethane and 35 ug/L for phenolic compounds. The area below the dichloroethane curve leads us to estimate that approximately 20 tonnes of organic contaminants have been extracted since operations began. This represents a very small percentage of the organic contaminants that might be present.

The drop in concentrations over the first two years can be explained by the greater dilution created by broadening the well's intake zone and progressively drawing off the pores containing mobile contaminants. The concentrations' stabilization may be due to a state of equilibrium between the uncontaminated water upstream from the highly contaminated zone and the organic non-aqueous-phase-liquid agglutinate between the particles and in the aquifer's fractures. Water is a very weak solvent for agglutinated compounds.

These two compounds are good indicators of the change in the quality of the aquifer's groundwater since they are the first to be affected, given their high aqueous solubility, weak adsorbability and high stability in groundwater (low biodegradability). High concentrations of these compounds were detected from the beginning of operations on.

The concentration curves of most organic compounds present should be comparable to figures 4 and 5. However, given retardation factor values, the decrease in concentrations is expected to extend over a relatively long time before stabilizing.

The 1,1,2 trichloroethylene acted differently (Figure 6). Concentrations declined as anticipated over the first two years but never stabilized. Values fluctuated cyclically between 40 and 110 ug/L.

Other parameters such as aroclor 1254 and 1260 behaved erratically due to their high molecular weight and adsorption affinities (figures 7 and 8). PCBs did not behave in the same manner as the majority of contaminants in the aquifer.

4. CONTAMINANT BEHAVIOR

4.1 In the very high pollution zone

Figure 9 is based on the DNAPL groundwater development concept shown in Feenstra and Cherry (1988) and on the visual appearance and odor of the water and soil samples collected in the field during the drilling campaign.

When liquid waste was dumped into the lagoons, the volume of release was sufficient to overcome the retention capacity of the vadose zone. The DNAPL chemicals' high densities cause them to penetrate downward through the groundwater zone of the sand/gravel formation.

Some of the DNAPLs settle out as a pool of free liquid on the low-permeability basal till. In some places, the basal till forms a barrier and prevents the movement of DNAPLs through the fractured porous rock formation. Because the basal till is sloped and rests erratically on the rock formation, the DNAPLs continue to move down the slope and penetrate into the fractures of the porous rock formation. On the till, the pattern of DNAPL movement need not be controlled by the direction of groundwater flow. In the rock formation, it is controlled primarily by fracture orientation and interconnection.

Because of the high vapor pressure and molecular weight of many DNAPLs, the soil and air in contact with these chemicals may acquire vapor concentrations high enough to result in density-induced sinking of chemical vapors downward to the saturated zone. Diffusion results in lateral migration of vapor through the vadose zone. These mechanisms may result in significant groundwater contamination.

Due to their low densities, the NAPLs (primarily MAHs) (figure 10), tend to form pools and spread laterally when they encounter the capillarity fringe and the water table. Zones contaminated by liquids that are lighter than water extend

over the entire range of water fluctuation. These liquids follow the declining water table but can be partially trapped under it when it rises again since only some of the liquid can be remobilized (Hunt et al., 1988a).

As described by Hunt et al. (1988a), during their migration, NAPLs and DNAPLs leave behind ganglia trapped in pores and fractures. The amount of organic liquid left behind is referred to as residual saturation and differs according to the medium and of the liquid's properties.

Schwille found that for sandy soil the residual content of NAPL or DNAPL chemicals could be 3 to 30 L/m^3 (1-10% of the pore space) in the unsaturated zone and 5 to 50 L/m^3 (2-15% of the pore space) in the saturated zone. Based on laboratory experiments by Schwille in 1988, less than 0.05 L/m^2 of NAPL or DNAPL is retained on the fracture surface.

In the saturated and unsaturated zones, ganglion measurements could range from pore size to many tens of meters in length and a few meters in width.

For very small trapped droplets, a few pore volumes of water are required to remove the contaminants. For the large ganglia, an effluent concentration far lower than the solubility limit is predicted (as observed at Ville Mercier) and considerable pumping is required to remove the contaminant.

The only way to reduce the residual saturation and ganglion sizes in the saturated zone is to increase the water velocity or decrease the NAPL or DNAPL/water interfacial tension.

The lifetime of a large ganglion is estimated at several decades or centuries. To decrease the lifetime by an order of magnitude, a three-order-of-magnitude increase in the flow velocity is required and the volume of water removed and requiring treatment is increase a hundredfold.

Based on the concept of ganglion and pool dissolution, it would appear that groundwater withdrawal from an aquifer is not a suitable solution. This concept leads us to believe that the "restoration" method currently being used in Ville

Mercier is actually a confinement measure preventing the propagation of contaminants rather than a restoration measure.

Groundwater contamination cannot be eliminated in the long term without removing the NAPL and DNAPL sources (possibly >99%). Because of their low solubility and existing low drinking water standards if they are not removed, NAPL and DNAPL chemicals can persist in subsurface waters and cause groundwater contamination problems for many decades and even centuries (Feenstra and Cherry, 1988).

At Ville Mercier, most NAPLs and DNAPLs can probably be removed by excavation in the unsaturated zone. However the same is not true for the saturated zone below 5 to 10 m. Recovery of these products trapped in the aquifer's pores and fractures may be possible by the in situ removal methods described by Feenstra and Cherry (1988), including:

- In situ biodegradation;
- Chemically-enhanced displacement;
- Steam displacement;
- Chemically-enhanced dissolution.

Unfortunately, there are currently no effective remedial methods available in field situations for removing NAPL and DNAPL sources from the subsurface. Research is needed to develop methods to provide long-term solutions to problems of groundwater contamination by these chemicals (Feenstra and Cherry, 1988).

A study sponsored by Environment Canada is currently identifying the presence and distribution of this organic liquid phase and will use laboratory tests and mathematical models to simulate the behavior of these liquids. It will also propose alternative methods for restoring the very high pollution zone.

4.2 Beyond the high pollution zone

In May 1988, organic screening for volatile and non-volatile compounds method was carried out on water samples from various piezometers outside the high pollution zone (Table 3). These points were selected in function of their position compared to the preferred path of contaminants in groundwater (Figure 2).

This sampling campaign shows that organic compounds are present beyond the perimeter created by the hydraulic trap. By activating this trap, pollutant discharge from the lagoon was cut off, but the contaminated groundwater located outside the trap's action perimeter continued to move southwest.

Based on the calculation of water flow velocities in the various formations, the contaminated water tail should be located at less than 3.3 km southwest of the former lagoons in the fractured rock and at less than 1 650 m from the source in the sand and gravel (Figure 11).

Piezometer P-51 located in zone 3 indicates that contamination does not persist in the sand 400 meters downstream of the trap.

Piezometer P-27 located in zone 3 shows that the water flowing from the first 2 m of fractured rock to 1.7 km upstream of the contaminated water tail dislodges a low concentration of contaminants adsorbed by the fractures.

Piezometer P-98, located in zone 4, 18 m down in the rock and 4.8 km southwest of the lagoons, contains organic contaminants in identical proportions but at concentrations much lower than in the plant's raw water. The two volatile and non-volatile organic compounds identified represent 2.4% by weight of the total organic compounds measured in the raw water of the well in May 1988. Since it is located in a layer presenting artesian conditions, piezometer P-98 is positioned in a preferred flowing zone.

Piezometers P-62 and P-162 are located in zone 3 and 4 in the first 4 m of fractured rock on either side of piezometer P-98 (Figure 12). No contamination was detected at piezometer P-62 and only very low concentrations of chloroform,

benzene, ethyl benzene, toluene and 1.2 dicloroethane were detected at piezometer P-62. These piezometers are outside the main area of contaminant circulation.

Sampling was repeated in October to identify the contaminant's status downstream of the well in the high pollution zone (Zone 2) and to accurately describe the status of the groundwater quality outside this zone.

CONCLUSION

- Many of the pure substances present in the raw water of the treatment plant's purge wells can be classified as DNAPL chemicals; other are NAPL chemicals.

- The concentration of organic chemicals present in the water of the purge wells dropped significantly after two years of operations and seems to have stabilized since this time.

- The amounts of organic contaminants extracted by the wells to date represent a small proportion of the organic contaminants that may have infiltrated this area. The "restoration" method used to date does not appear to provide an adequate solution for restoring aquifer formations.

- At present, aside from excavation operations, the only means of recovering DNAPLs and NAPLs is by increasing water velocity or decreasing interfacial tension in the water containing DNAPLs or NAPLs. There are no effective remedial methods available in field situations for removing these chemicals from the subsurface.

- The May 1988 samplings showed that significant contamination did not persist in the sand/gravel formation between the hydraulic trap and the contamination tail. Nevertheless, it may be considerable in the rock formation downstream of the contamination tail's farthest reachings.

References

CNRC 1983
Les hydrocarbures aromatiques polycycliques dans le milieu aquatique. Formation, sources, devenir et les effets sur le biote aquatique. CNRC No 18982 Ottawa Canada, 218 pages.

FORATEK INTERNATIONAL INC. 1982
Étude hydrogéologique de faisabilité du captage des eaux contaminées extraites de la nappe aquifère de Ville Mercier. For the ministère de l'Environnement du Québec, by M. Poulin, Report No. 514.

Feenstra, S. and S. A. Cherry 1988. Subsurface contamination by dense nonaqueous phase liquid (DNAPL) Chemicals. In Proceedings of the International Groundwater Symposium on Hydrogeology of Cold Climates and Hydrogeology of Mineralized Zones. International Association of Hydrogeologist. Canadian National Chapter, Halifax, Nova Scotia, May 1-5. 1988. p. 61-69

Hunt, J.R., N. Sitar and K. S. Udell 1988a. Nonaqueous phase liquid transport and cleanup 1. Analysis of mechanisms. Water Resources Research. Vol. 24, Bi. 8, August 1988 p. 1247-1258.

Hunt, J. R., N. Sitar and K. S. Udell 1988b. Nonaqueous phase liquid transport ans deanup II. Experimental studies. Water Resources Research. Vol. 24, No. 8, August 1988, p. 1259-1269.

HYDREGEO-CANADA INC. 1981.
Hydrogéologie et contamination des eaux souterraines, Ville Mercier. For the ministère de l'Environnement du Québec, by G. Nielson.

Keyser, J.H. 1965. Aperçu de la géologie historique, économique et appliquée. Géologie de Montréal. Soc. International de mécanique des Sols et des Travaux de Fondations. Sixième congrès Int.

The Merck index 1976, 9th edition published by Merck and co. inc. Rahway, N.J, USA, 1822 pages.

Poulin, M., G. Simard et M. Sylvestre 1985. Pollution des eaux souterraines par les composés organiques à Mercier, Québec. Sciences et techniques de l'eau, Vol. 18, No 2, May 1985.

Poulin, M. 1977. Groundwater Contamination near a Liquid Waste Lagoon, Ville Mercier, Québec. Master's thesis, University of Waterloo, Wateloo, Ontario. 158 pages.

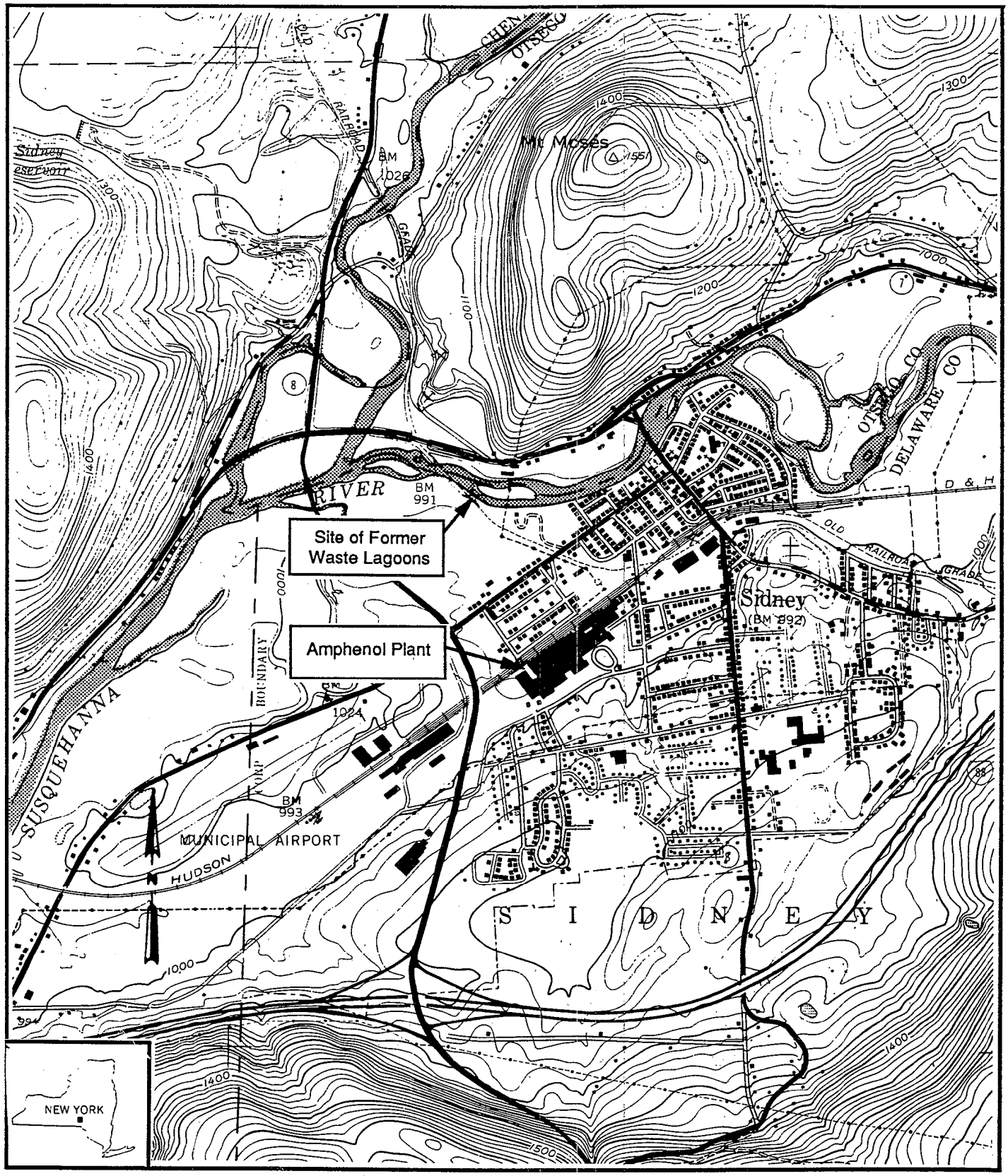
Sax, N.I. 1984. Dangerous Properties of Industrial Materials 6th edition published by Van Nostrand Reinhold Company New York, U.S.A. 3124 pages.

Schwille, F. 1984. Migration of Organic Fluids Immiscible with water in the unsaturated zone. In: Pollutants in Porous Media - The Unsaturated Zone Between Soil Surface and Groundwater. Editted by B. Yaron. G. Dagan, and J. Goldshmid, Springer-Verlag. New-York. p. 27-48.

Schwille, F. 1988. Dense Chlorinated Solvents in Porous and Fractured Media - Model Experiments Translated by J.F. Pankow, Lewis Publishers Inc., Chelsea, Michigan.

Simard, G. and J.P. Lanctôt 1987. Decontamination of Ville Mercier Aquifer for toxic organics. In proceedings of the First International Meeting of the NATO/CCMS pilot study demonstration of remedial action technologies for contaminated land and groundwater. Washington, D.C., U.S.A. novembrer 11-13 p.135-164.

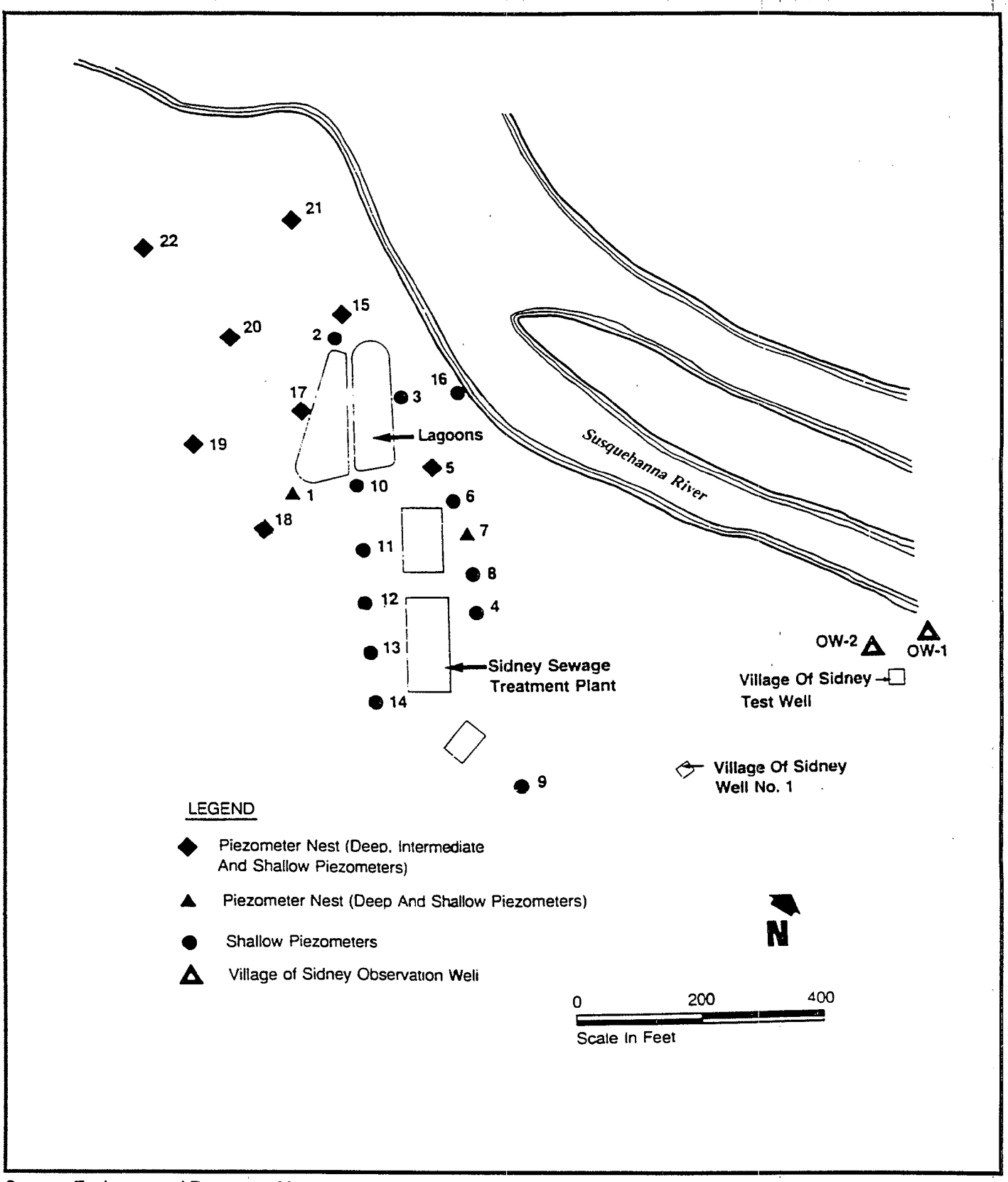
Wolf, K., R. Holland and G. Rajarothon 1987. Vinyl Chloride Contamination: the Hidden threat. Journal of Hazardous Materials 15 (1987) p. 163-184



1000 0 1000 2000 3000 4000 5000 6000 7000 FEET

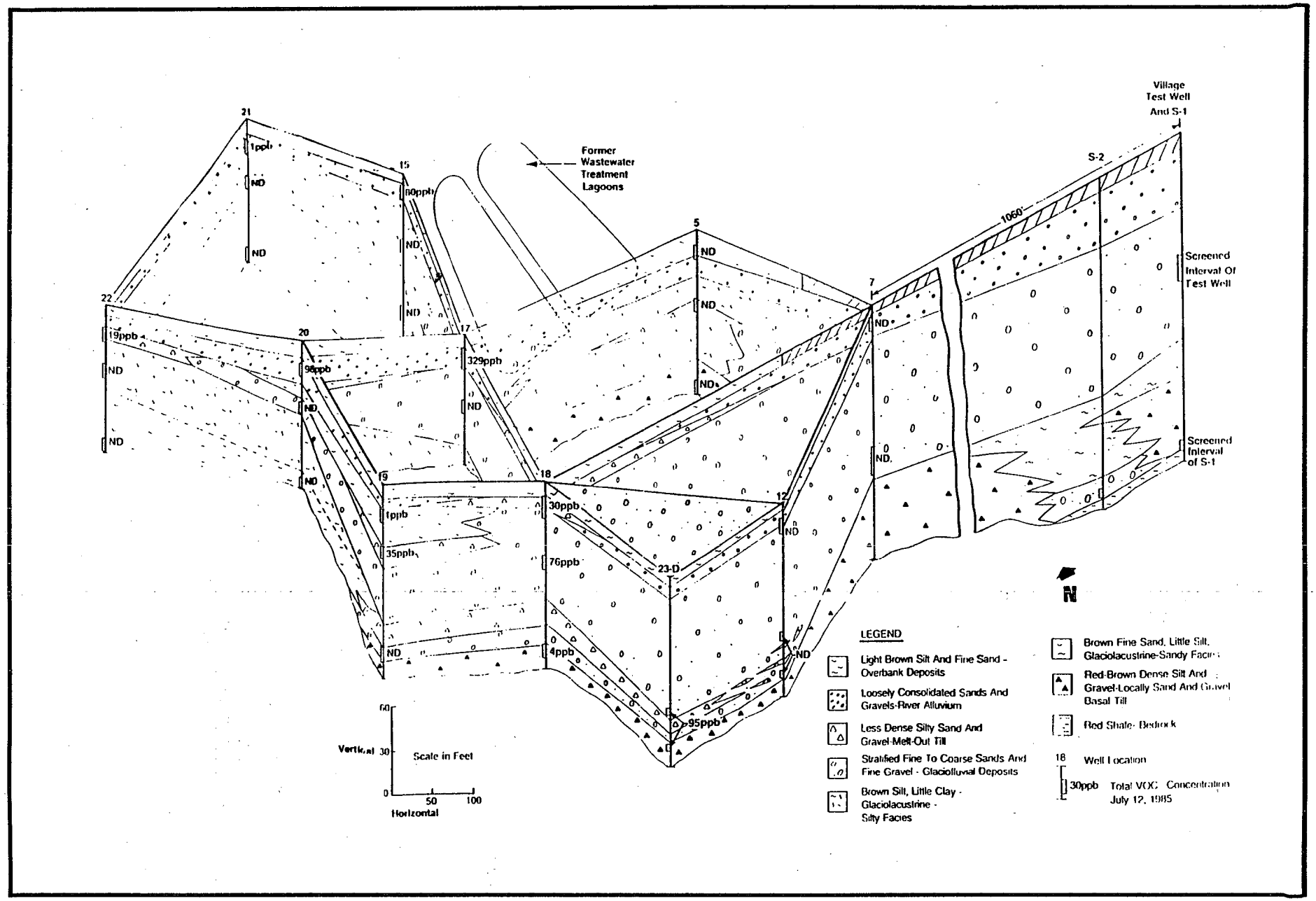
Source: USGS. 1982. Sidney Quadrangle, 7.5 Minute Topographic Series.

Figure 1
SITE LOCATION MAP
AMPHENOL SITE
SIDNEY, NEW YORK



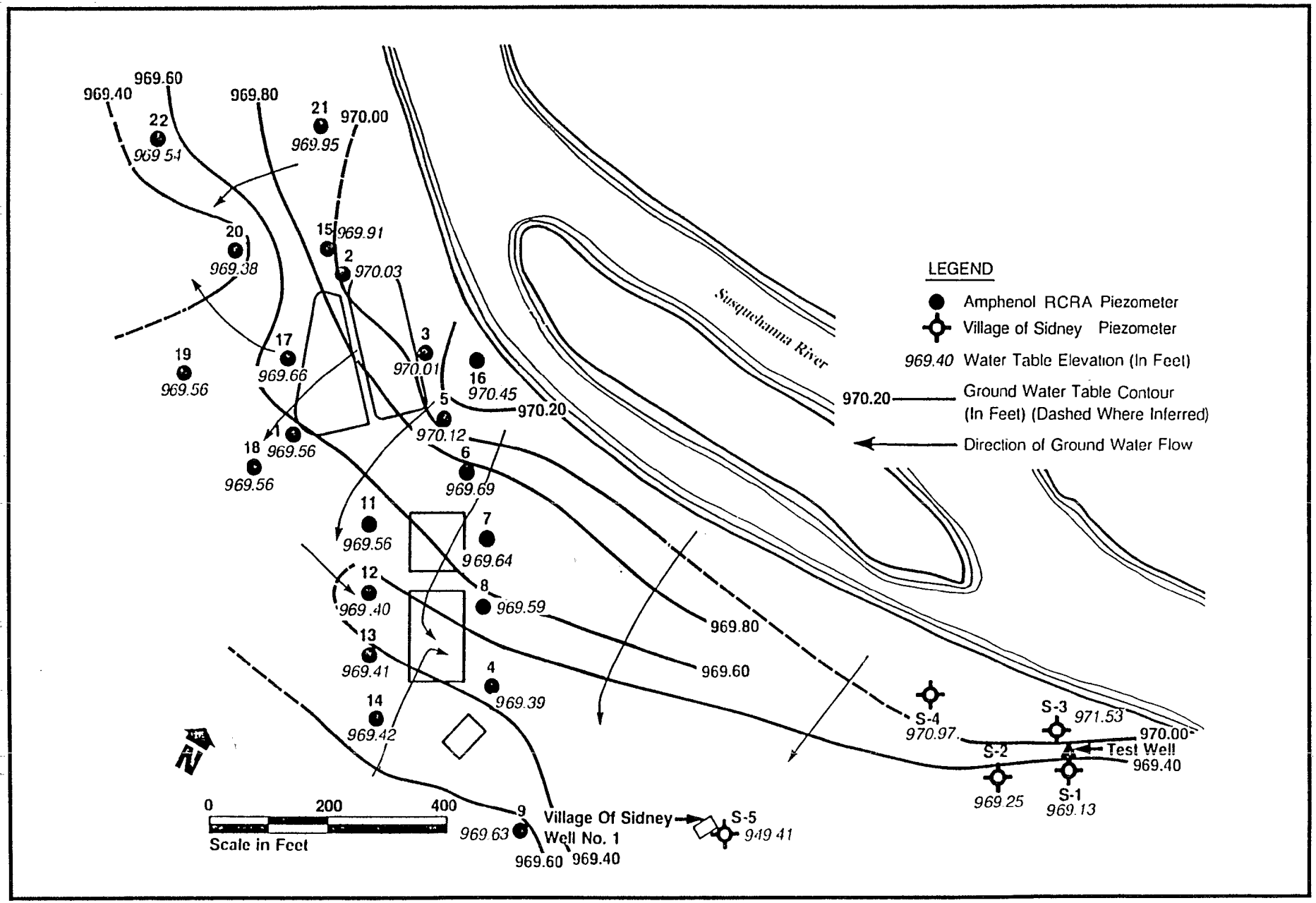
Source: Environmental Resources Management. 1985. Preliminary Report: Groundwater Assessment at Amphenol Wastewater Treatment Lagoons for Amphenol Products--Bendix Connector Operations, Sidney, New York.

Figure 2
SITE PLAN WITH MONITORING WELL NETWORK
AMPHENOL SITE



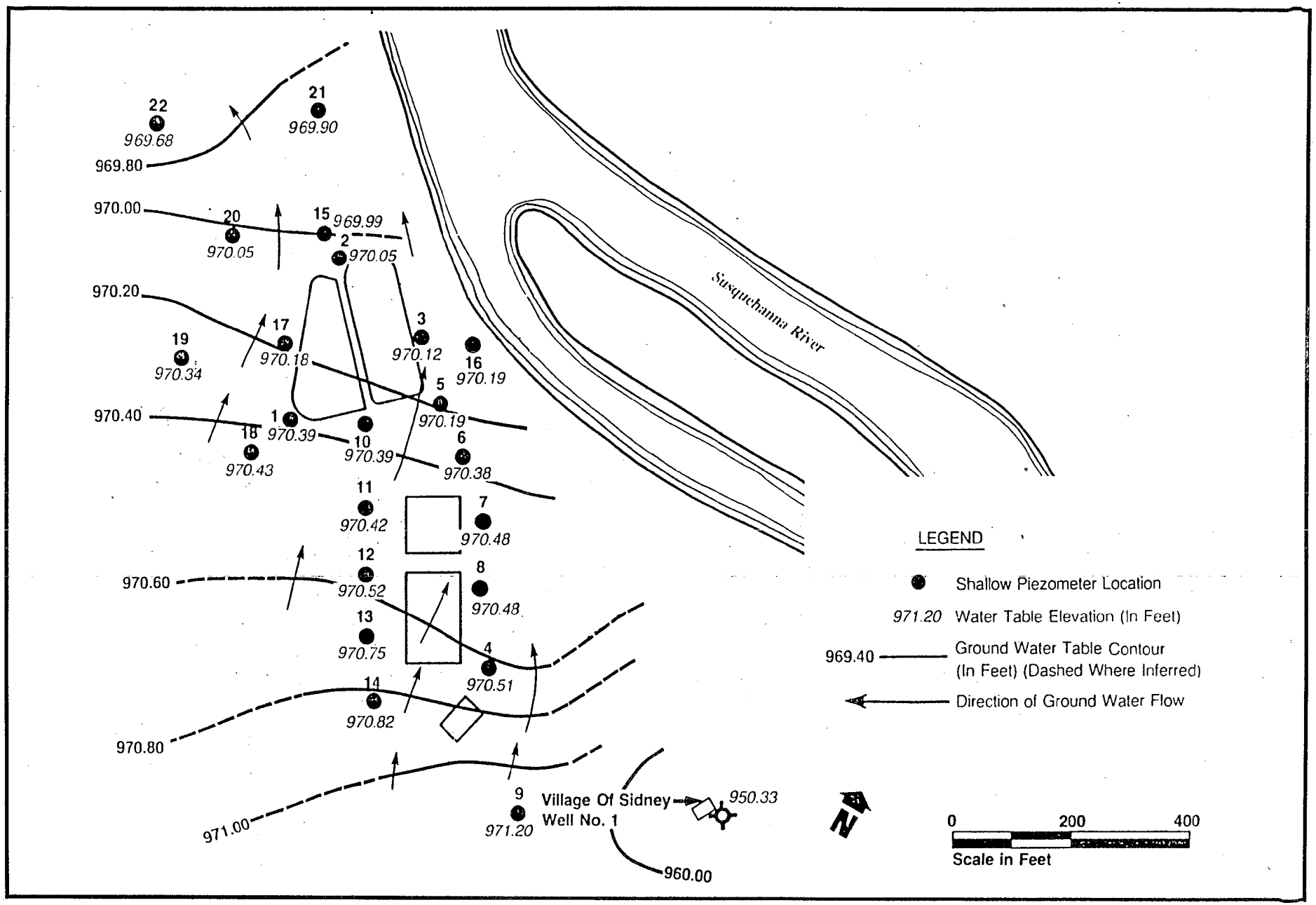
Source: Environmental Resources Management. 1986. Corrective Action Plan for the Amphenol Wastewater Treatment Lagoons for Amphenol Products--Bendix Connector Operations, Sidney, New York.

Figure 3
FENCE DIAGRAM OF SHALLOW STRATIGRAPHY
AMPHENOL SITE



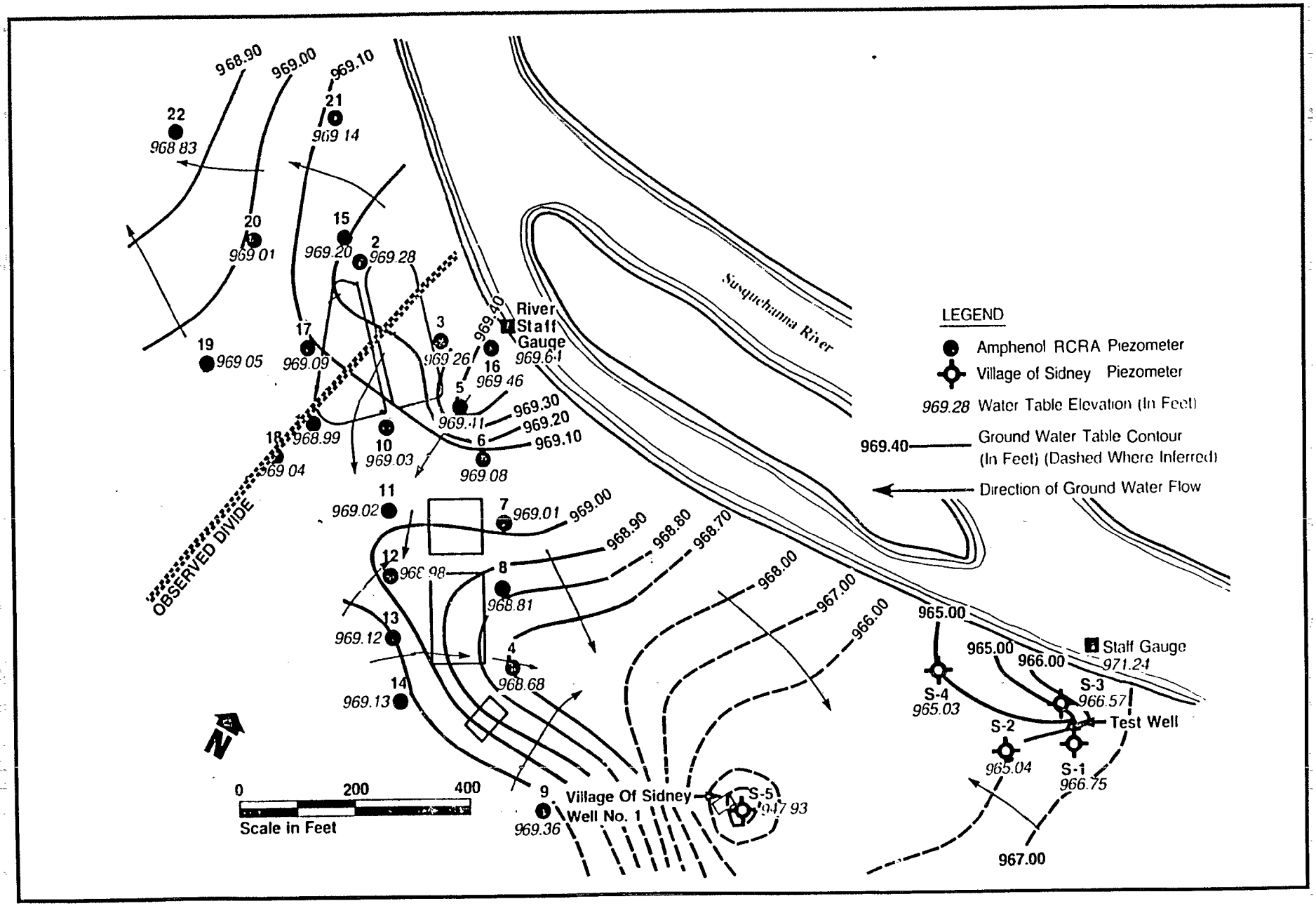
Source: Environmental Resources Management. 1986. Addendum Report: Ground-water Assessment at Amphenol Wastewater Treatment Lagoons for Amphenol Products--Bendix Connector Operations, Sidney, New York.

Figure 4
WATER LEVEL IN THE SHALLOW-AQUIFER ZONE, MAY 21, 1986
AMPHENOL SITE



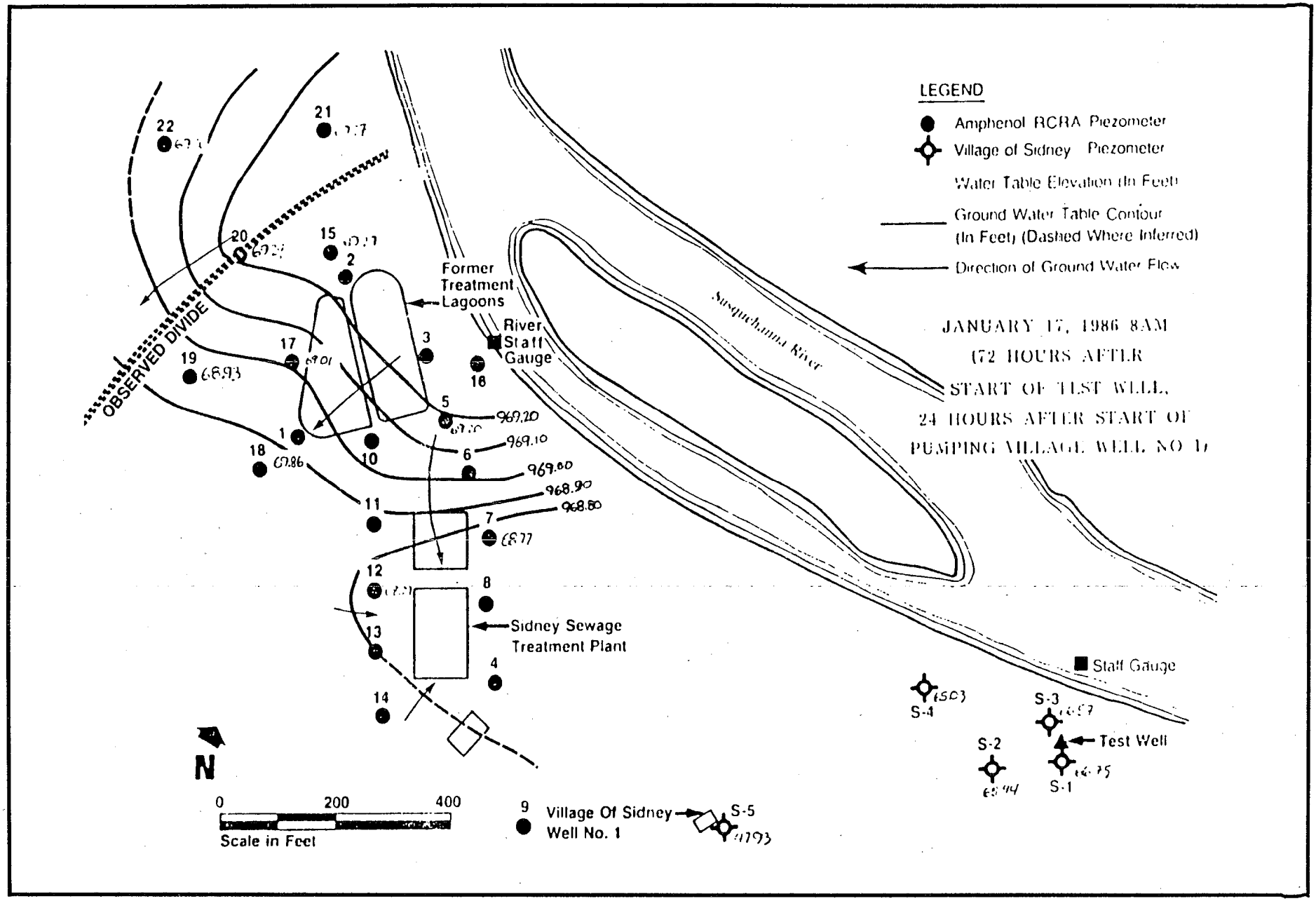
Source: Environmental Resources Management. 1986. Addendum Report: Groundwater Assessment at Amphenol Wastewater Treatment Lagoons for Amphenol Products --Bendix Connector Operations, Sidney, New York.

Figure 5
WATER LEVELS IN THE SHALLOW-AQUIFER ZONE, APRIL 21, 1986
AMPHENOL SITE



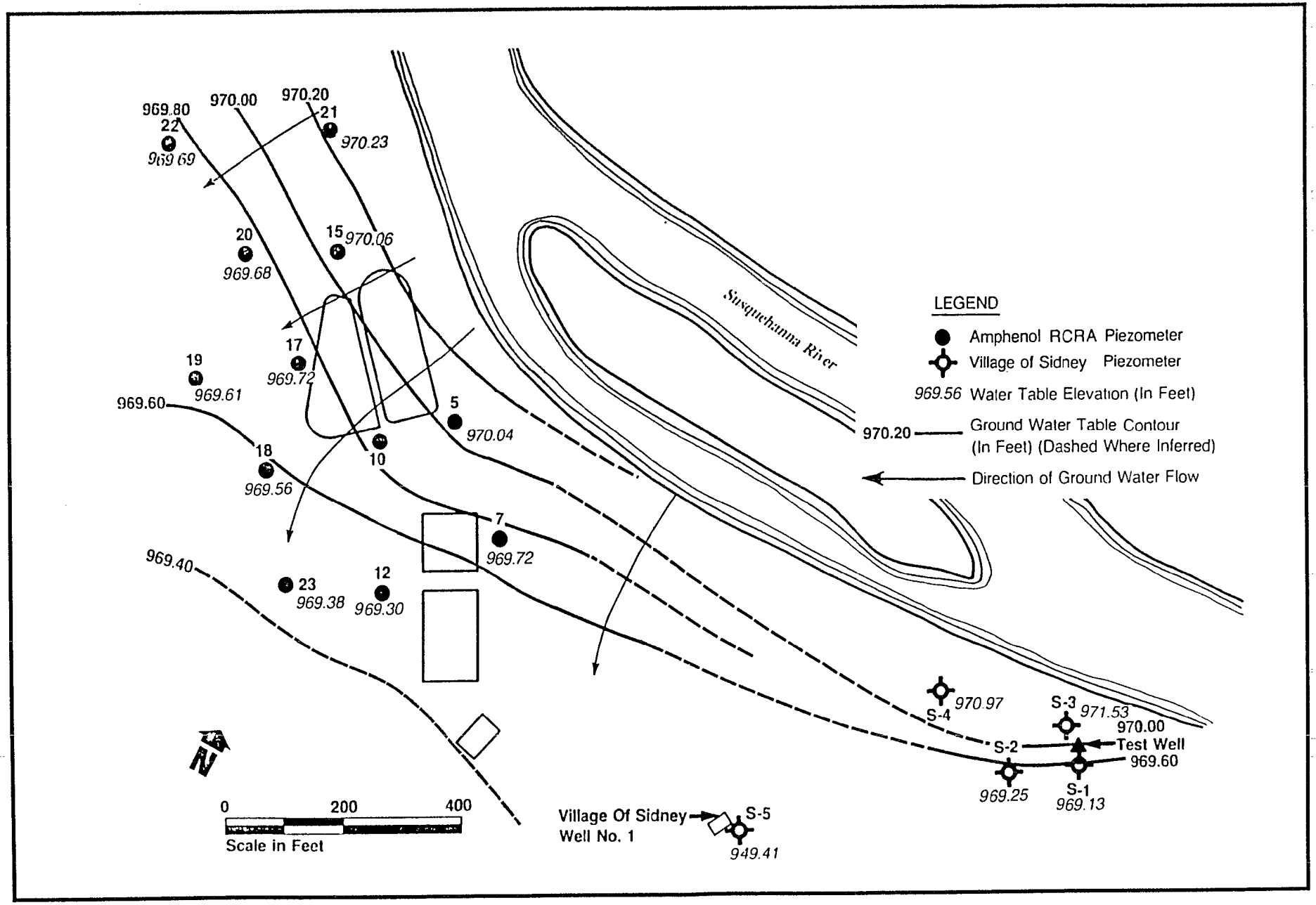
Source: Environmental Resources Management. 1986.
Corrective Action Plan for the Amphenol Wastewater Treatment Lagoons, for Amphenol Products--Bendix Connector Operations, Sidney, New York.

Figure 6
WATER LEVELS IN THE SHALLOW-AQUIFER ZONE AFTER 72 HOURS OF PUMPING, JANUARY 17, 1986
AMPHENOL SITE



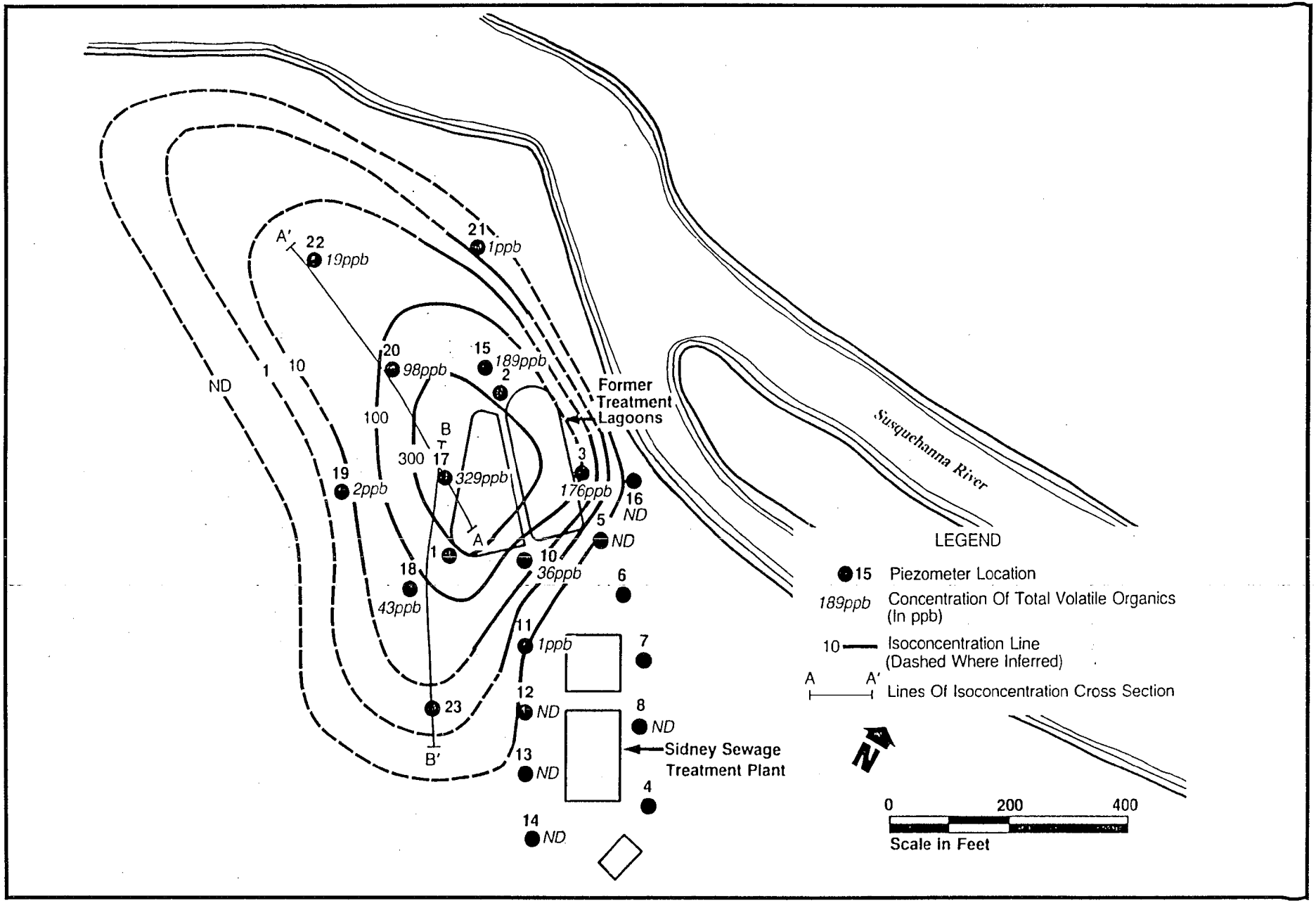
Source: Environmental Resources Management. 1986. Corrective Action Plan for the Amphenol Wastewater Treatment Lagoons for Amphenol Products--Bendix Connector Operations, Sidney, New York.

Figure 7
WATER LEVELS IN THE DEEP-AQUIFER ZONE AFTER 72 HOURS OF PUMPING, JANUARY 17, 1986
AMPHENOL SITE



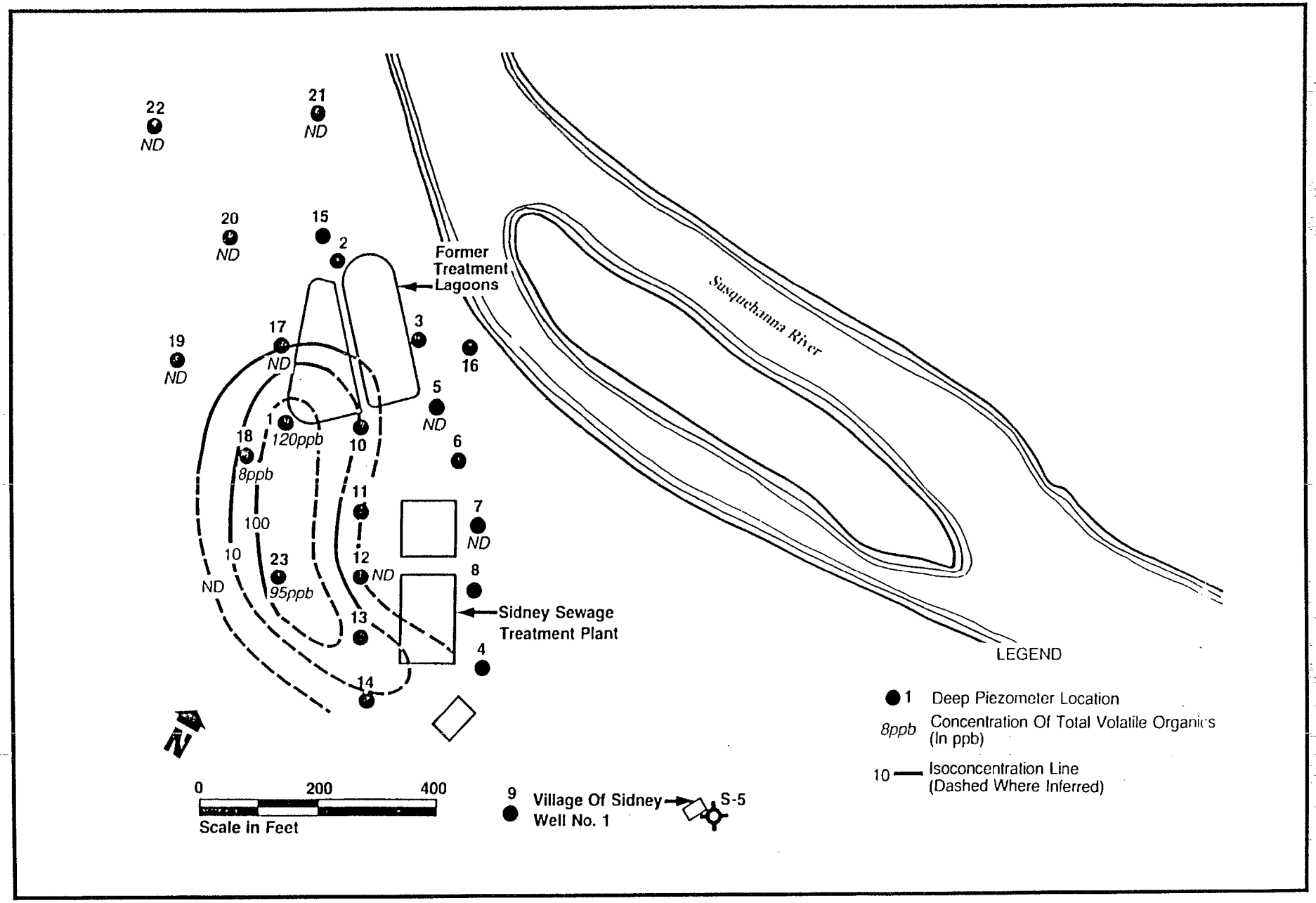
Source: Environmental Resources Management. 1986. Addendum Report: Ground-water Assessment at Amphenol Wastewater Treatment Lagoons for Amphenol Products--Bendix Connector Operations, Sidney, New York.

Figure 8
WATER LEVELS IN THE DEEP-AQUIFER ZONE, MAY 21, 1986
AMPHENOL SITE



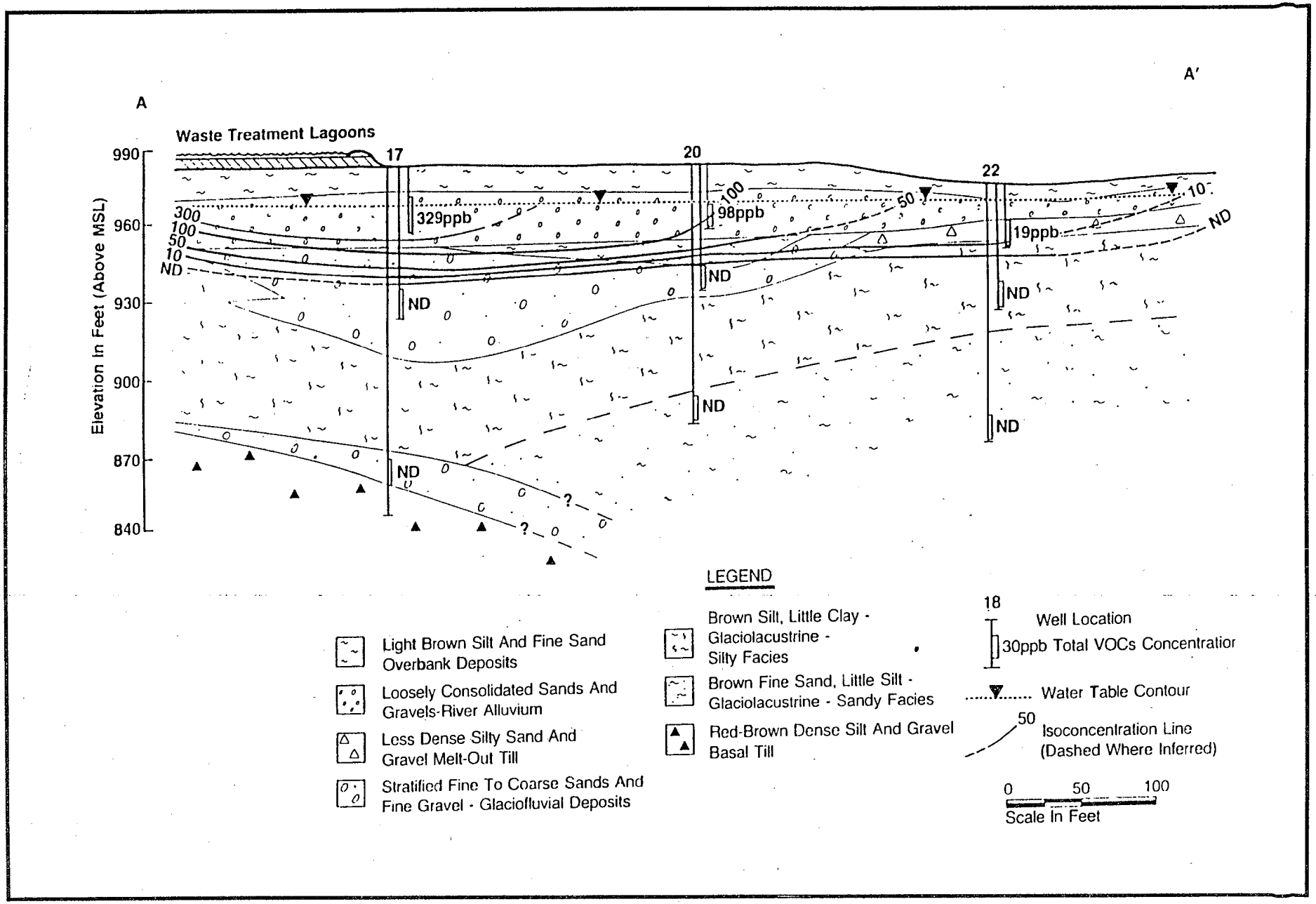
Source: Environmental Resources Management. 1986. Addendum Report: Groundwater Assessment at Amphenol Wastewater Treatment Lagoons for Amphenol Products--Bendix Connector Operations, Sidney, NewYork.

Figure 9
ISOCONCENTRATION MAP OF TOTAL VOCS IN THE SHALLOW-AQUIFER ZONE, 1985
AMPHENOL SITE



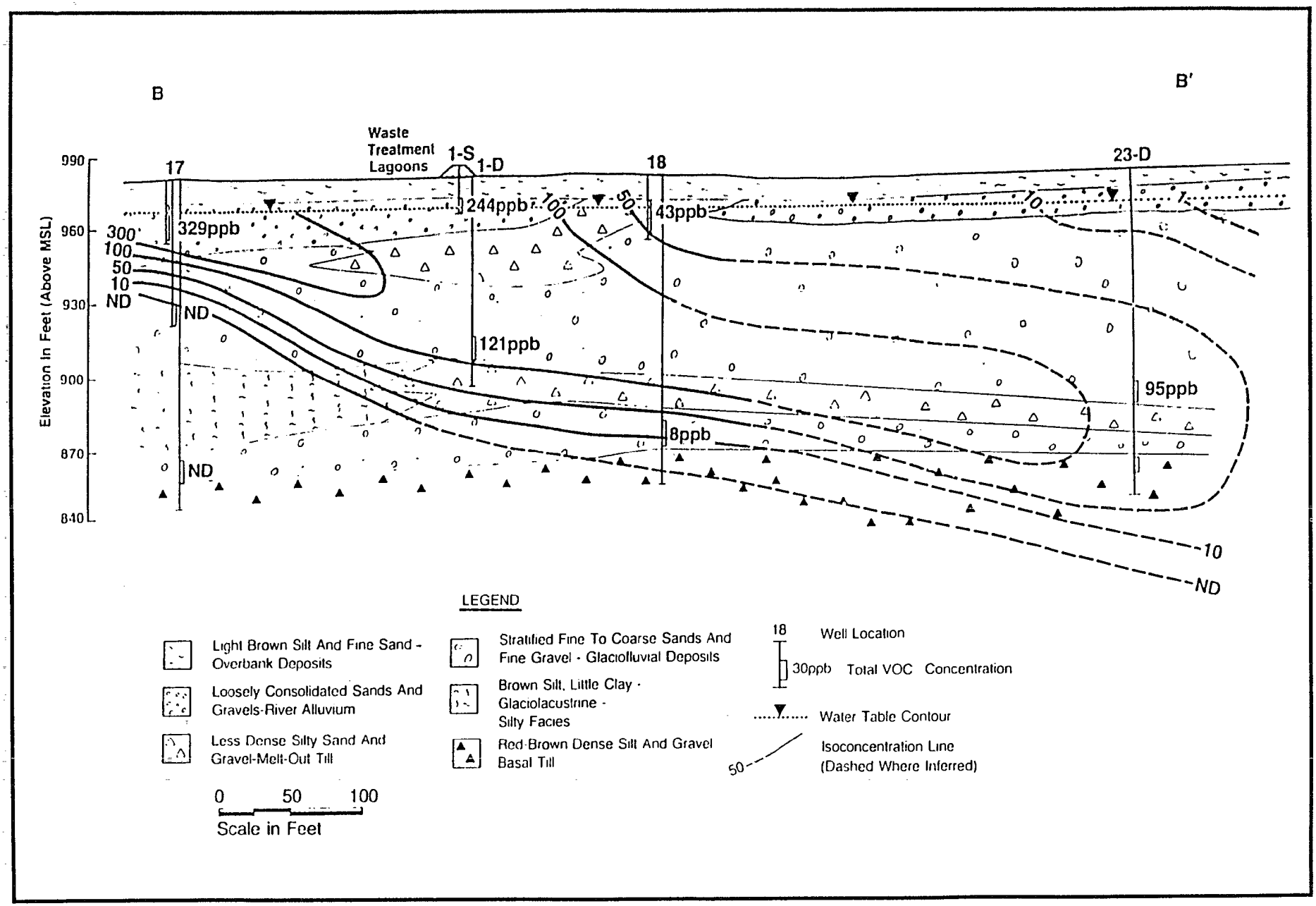
Source: Environmental Resources Management. 1986. Addendum Report: Groundwater Assessment at Amphenol Wastewater Treatment Lagoons for Amphenol Product--Bendix Connector Operations, Sidney, New York.

Figure 10
ISOCONCENTRATION MAP OF TOTAL VOCS IN THE DEEP-AQUIFER ZONE, 1985
AMPHENOL SITE



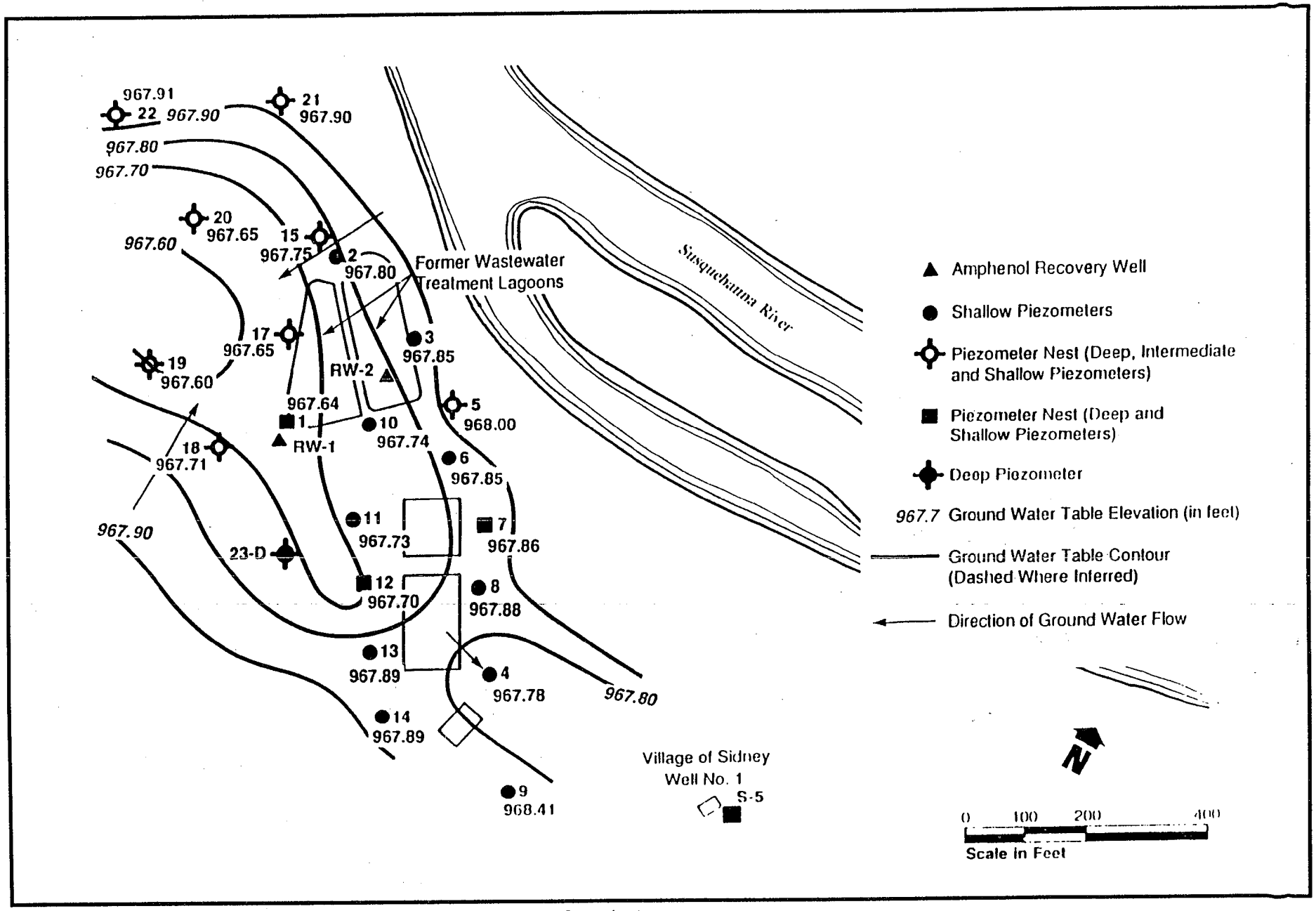
Source: Environmental Resources Management. 1986. Addendum Report: Groundwater Assessment at Amphenol Wastewater Treatment Lagoons for Amphenol Products--Bendix Connector Operations, Sidney, New York.

Figure 11
TOTAL VOC CONCENTRATION ALONG CROSS SECTION A - A' 1985
AMPHENOL SITE



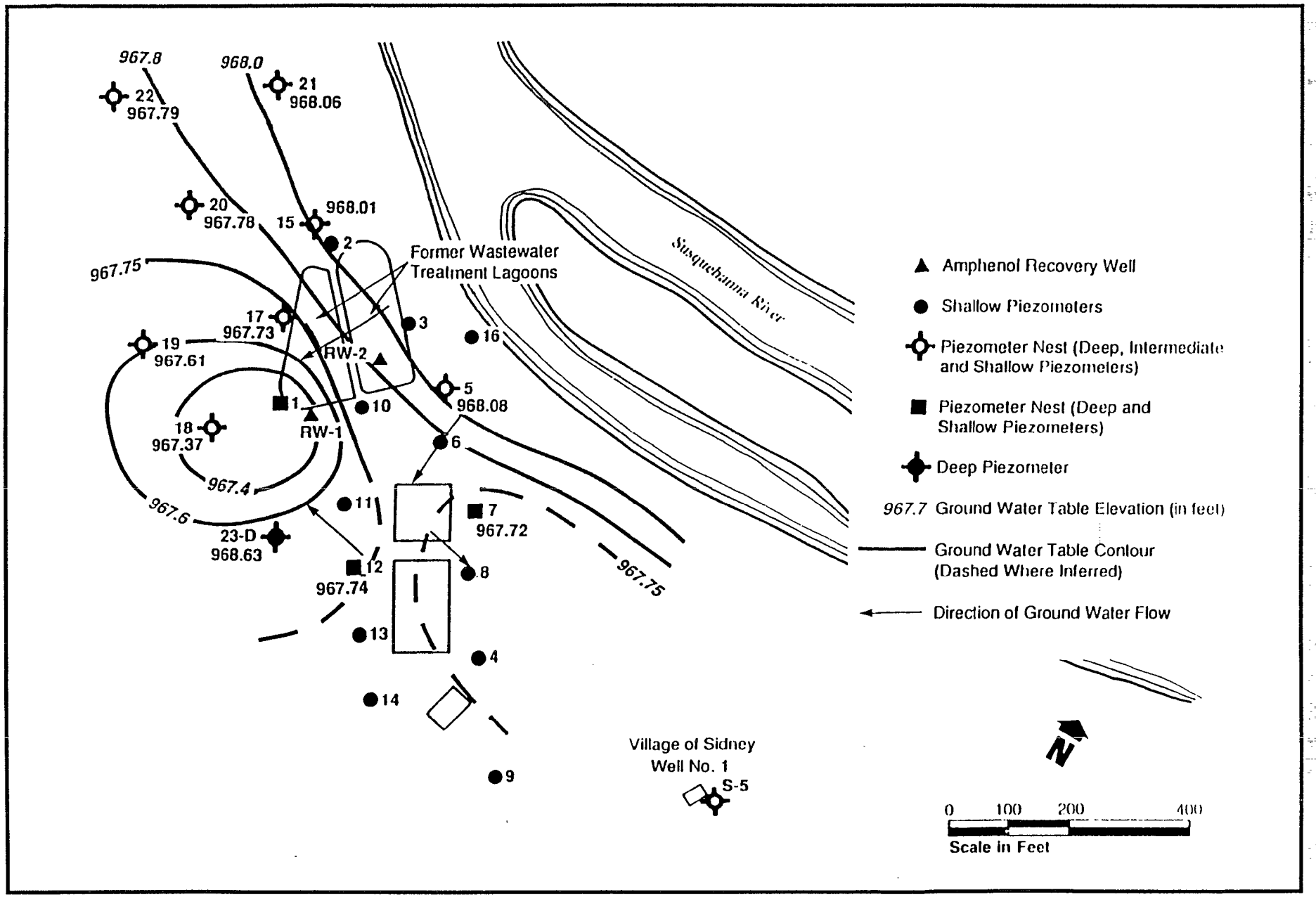
Source: Environmental Resources Management. 1986. Addendum Report: Groundwater Assessment at Amphenol Wastewater Treatment Lagoons for Amphenol Products--Bendix Connector Operations, Sidney, New York.

Figure 12
TOTAL VOC CONCENTRATION ALONG CROSS SECTION B - B', 1985
AMPHENOL SITE



Source: Environmental Resources Management. 1986. Addendum Report: Groundwater Assessment at Amphenol Wastewater Treatment Lagoons for Amphenol Products--Bendix Connector Operations, Sidney, New York.

Figure 13
WATER LEVELS IN THE SHALLOW-AQUIFER ZONE, JUNE 27, 1988
AMPHENOL SITE



Source: Environmental Resources Management. 1986. Addendum Report: Groundwater Assessment at Amphenol Wastewater Treatment Lagoons for Amphenol Products--Bendix Connector Operations, Sidney, New York.

Figure 14
WATER LEVELS IN THE DEEP-AQUIFER ZONE, JUNE 27, 1988
AMPHENOL SITE

WDC61621.AQ.02

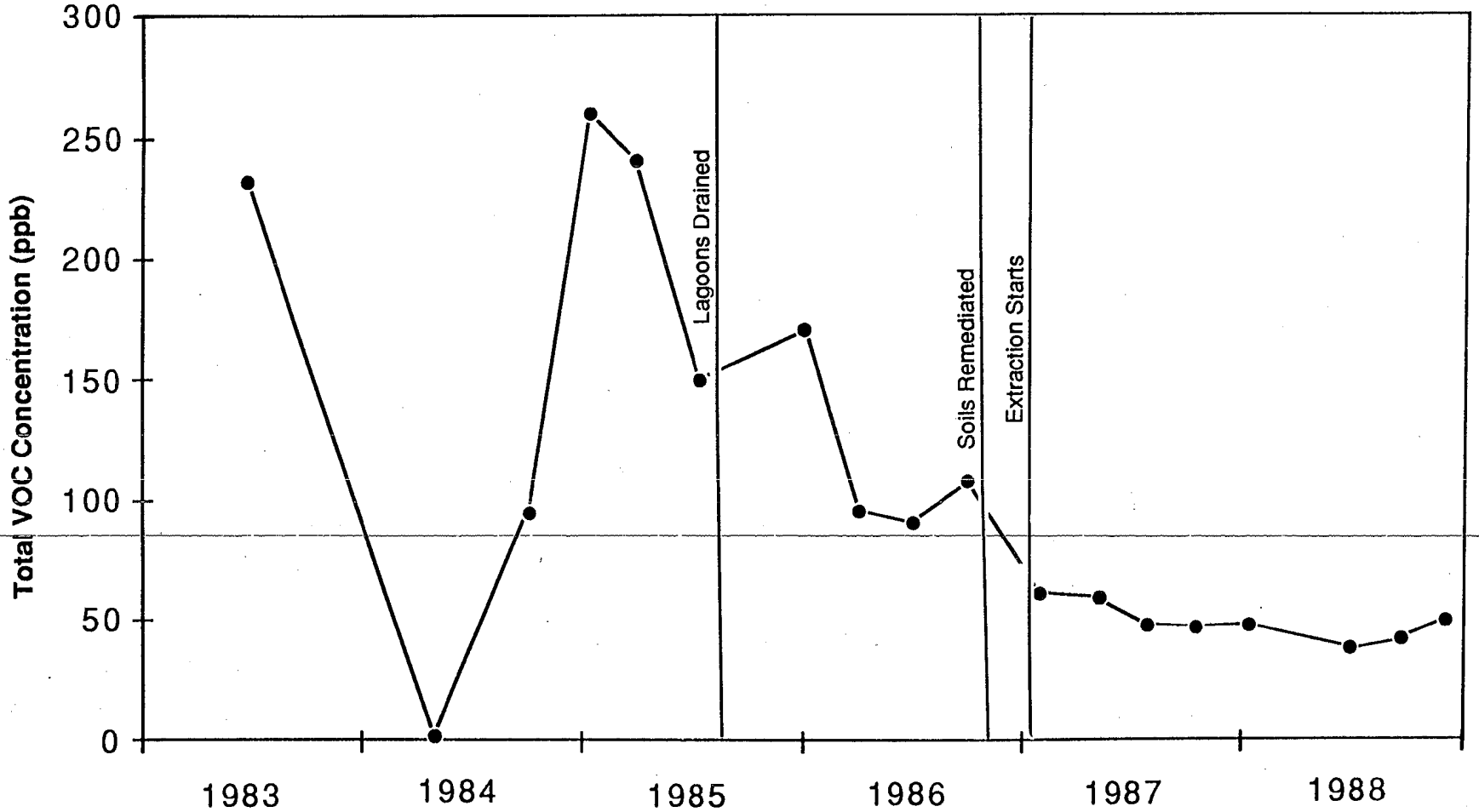


Figure 15
HISTORY OF TOTAL VOC CONCENTRATION IN MONITORING WELL 1-S, SHALLOW-AQUIFER ZONE
AMPHENOL SITE

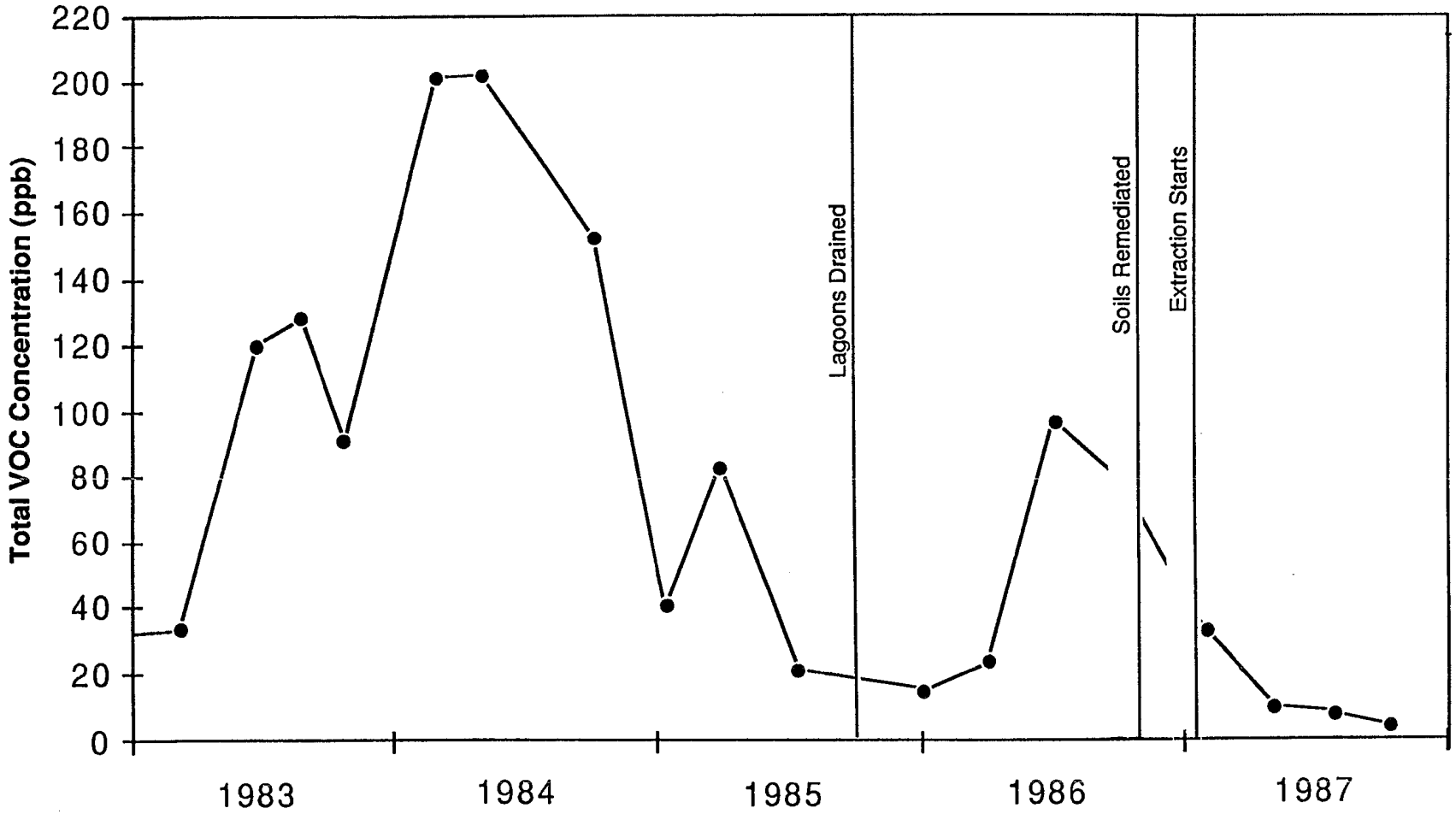


Figure 16
HISTORY OF TOTAL VOC CONCENTRATION IN MONITORING WELL 2, SHALLOW-AQUIFER ZONE
AMPHENOL SITE

WDC6162-1.A0.02

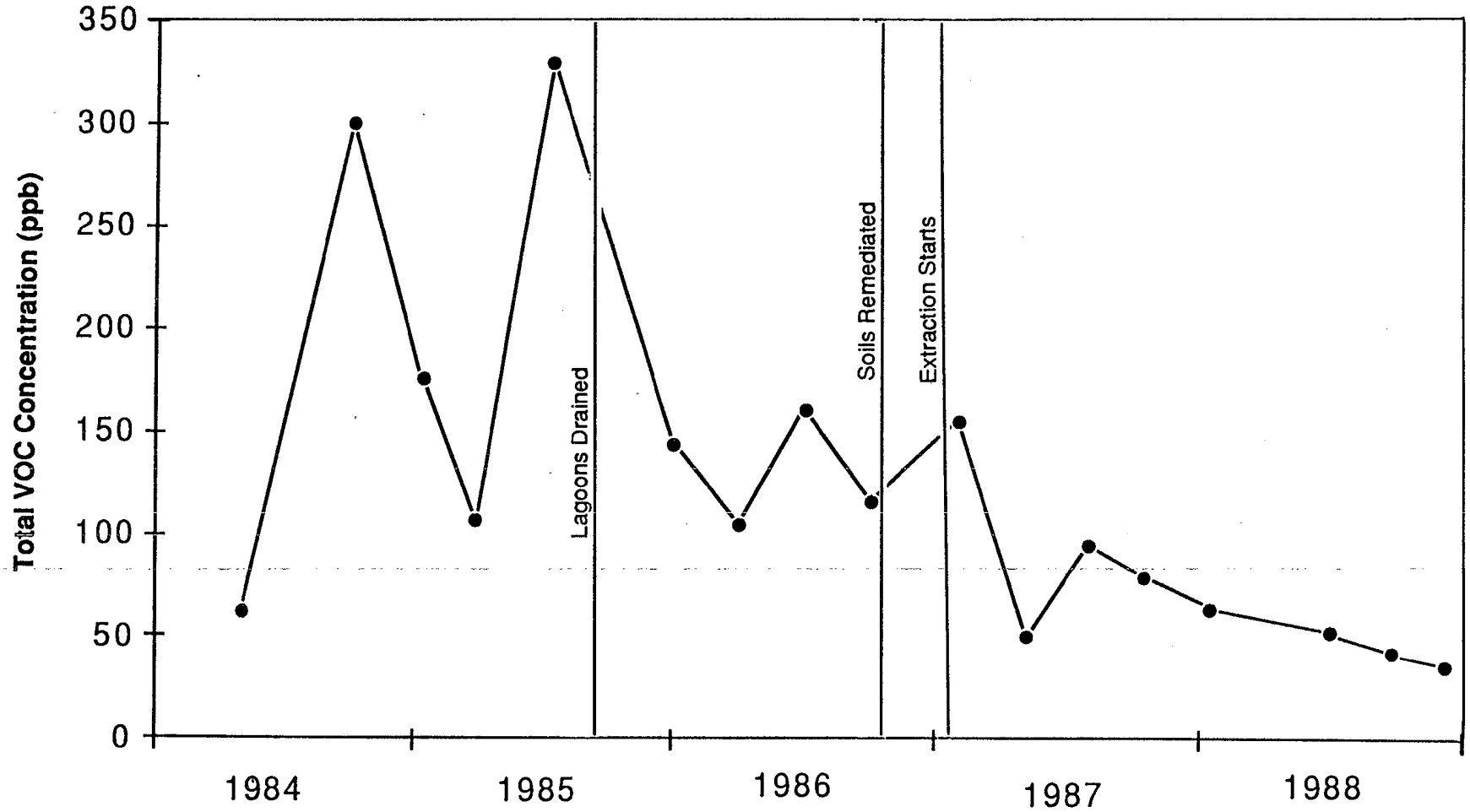


Figure 17
HISTORY OF TOTAL VOC CONCENTRATION IN MONITORING WELL 17-S, SHALLOW-AQUIFER ZONE
AMPHENOL SITE

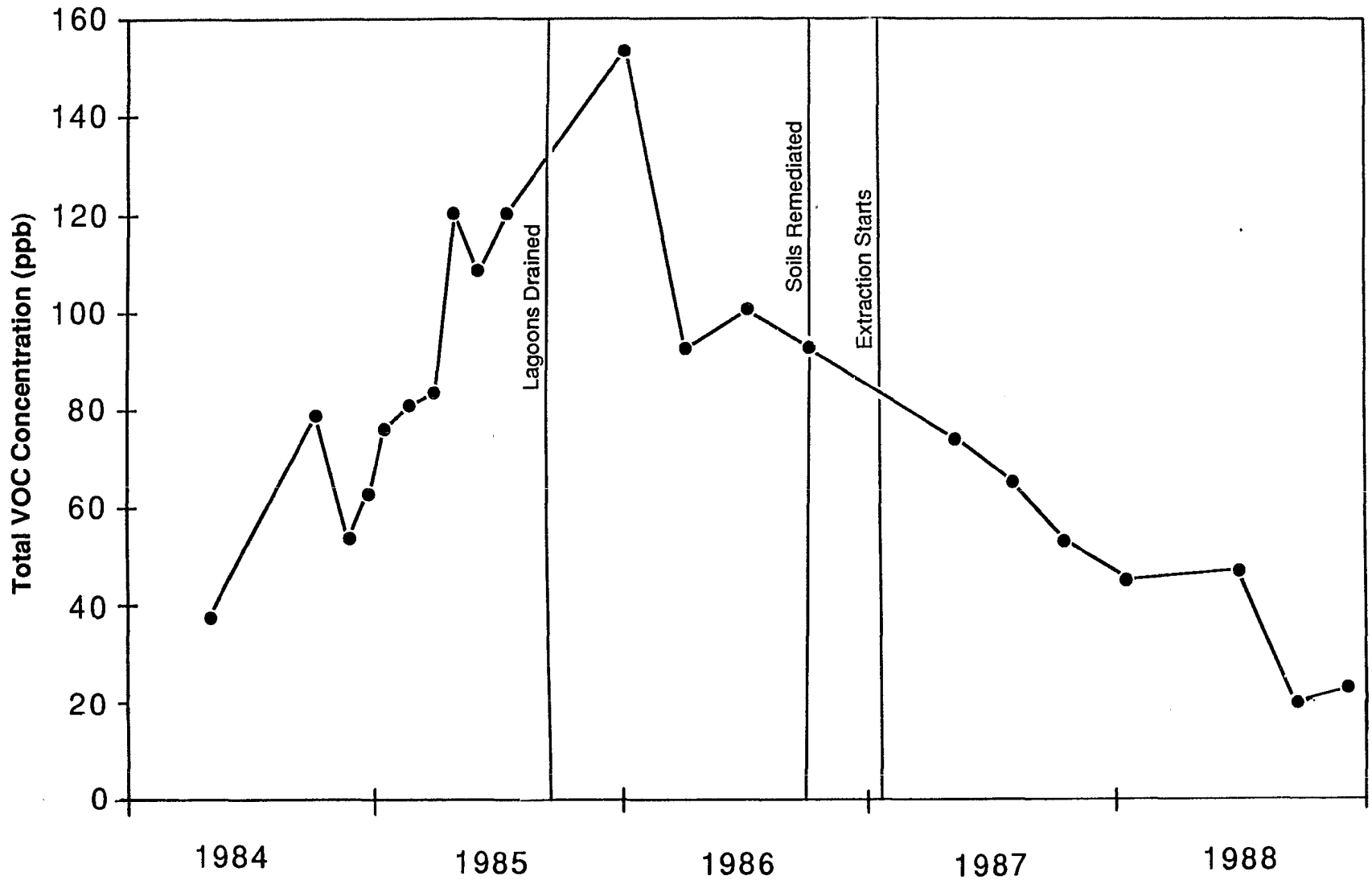
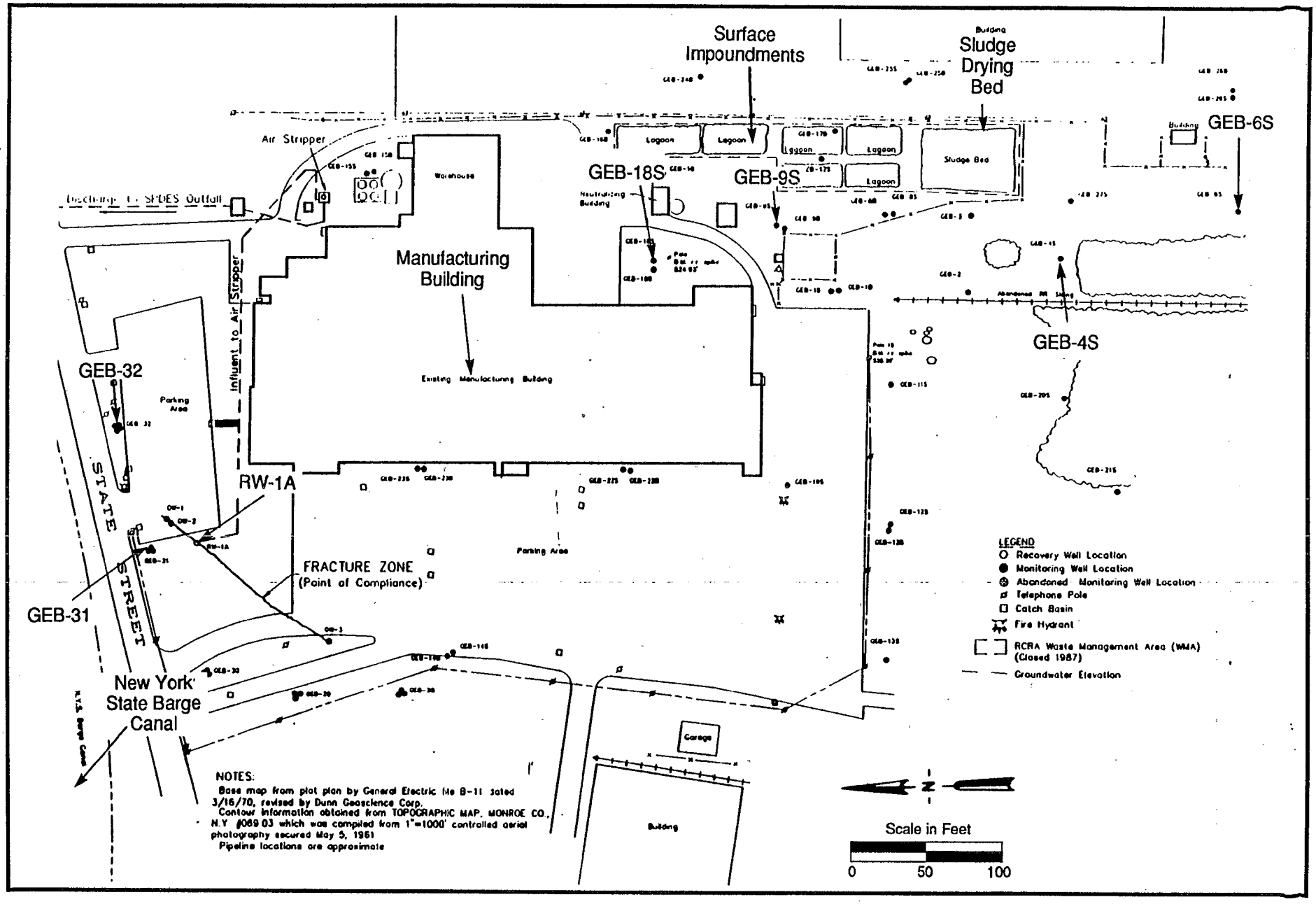


Figure 18
HISTORY OF TOTAL VOC CONCENTRATION IN MONITORING WELL 1-D, DEEP-AQUIFER ZONE
AMPHENOL SITE

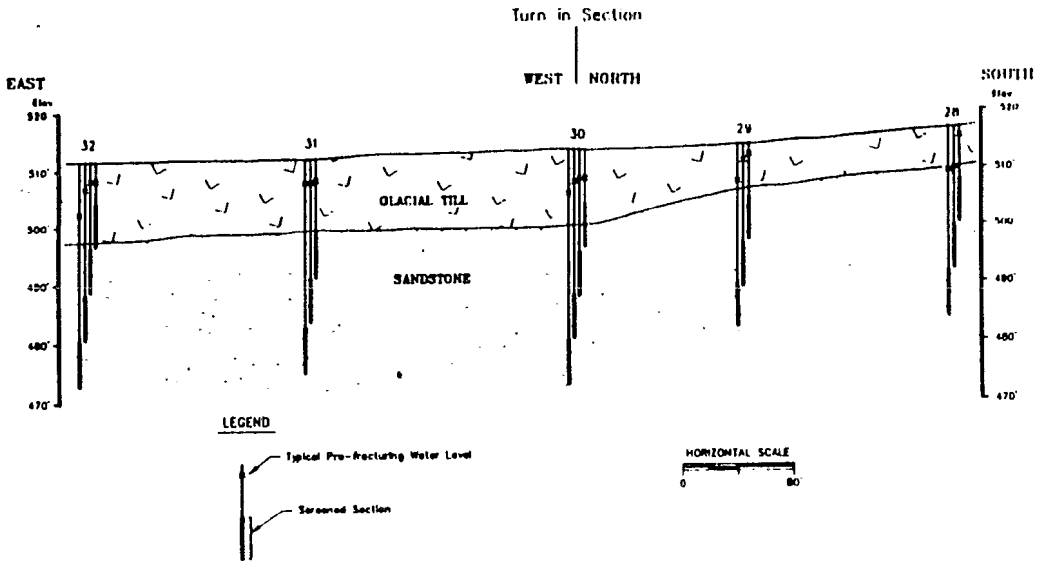
WDC 61621.AO.02



Source: Dunn GeoScience Corporation, February 1987.

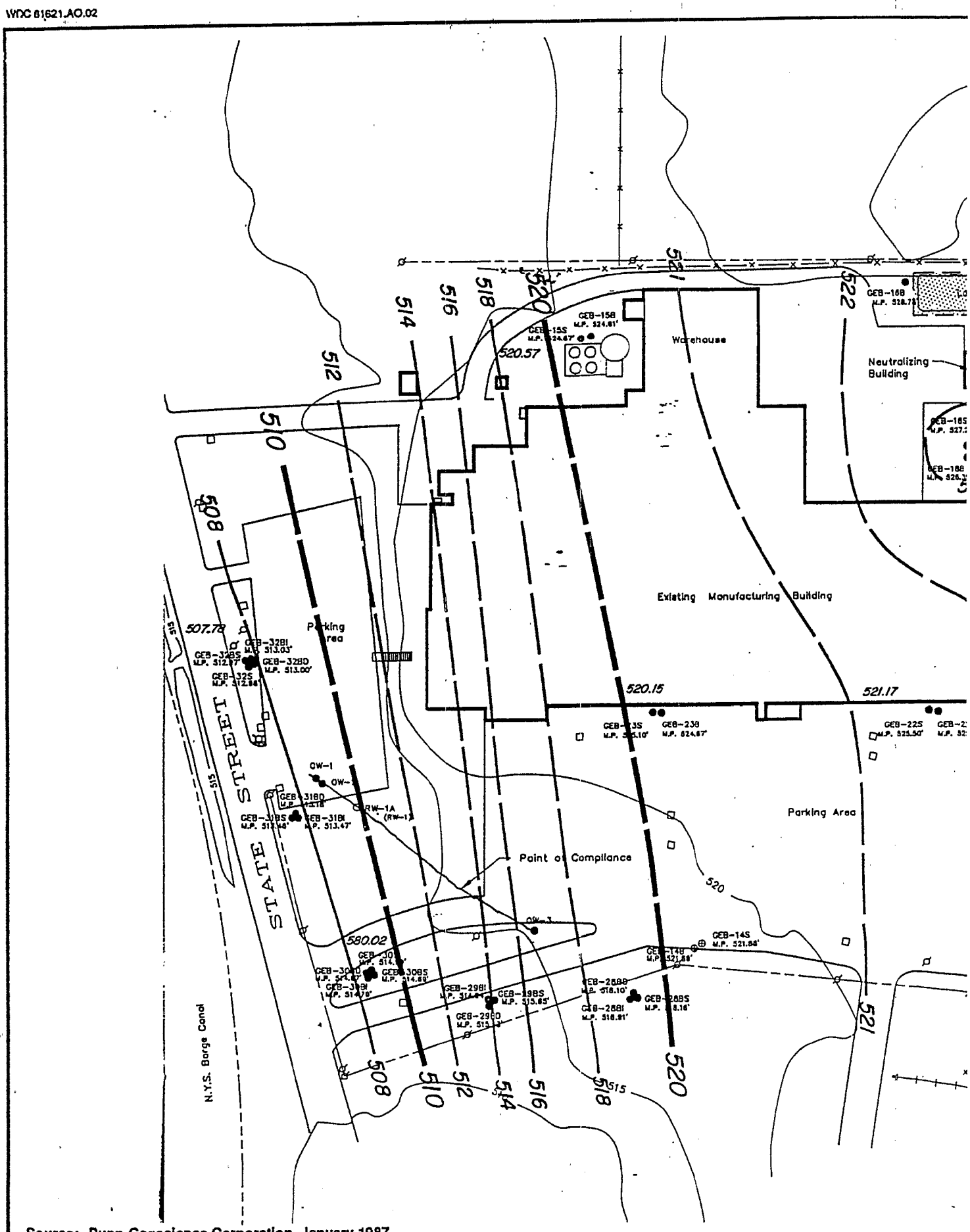
Figure 1
SITE PLAN
BLACK & DECKER SITE
BROCKPORT, NEW YORK

WDC 61621.AO.02



Source: Begor, Miller, and Sutch, January - February 1989

Figure 2
GEOLOGIC CROSS SECTION
BLACK & DECKER SITE



Source: Dunn Geoscience Corporation, January 1987.

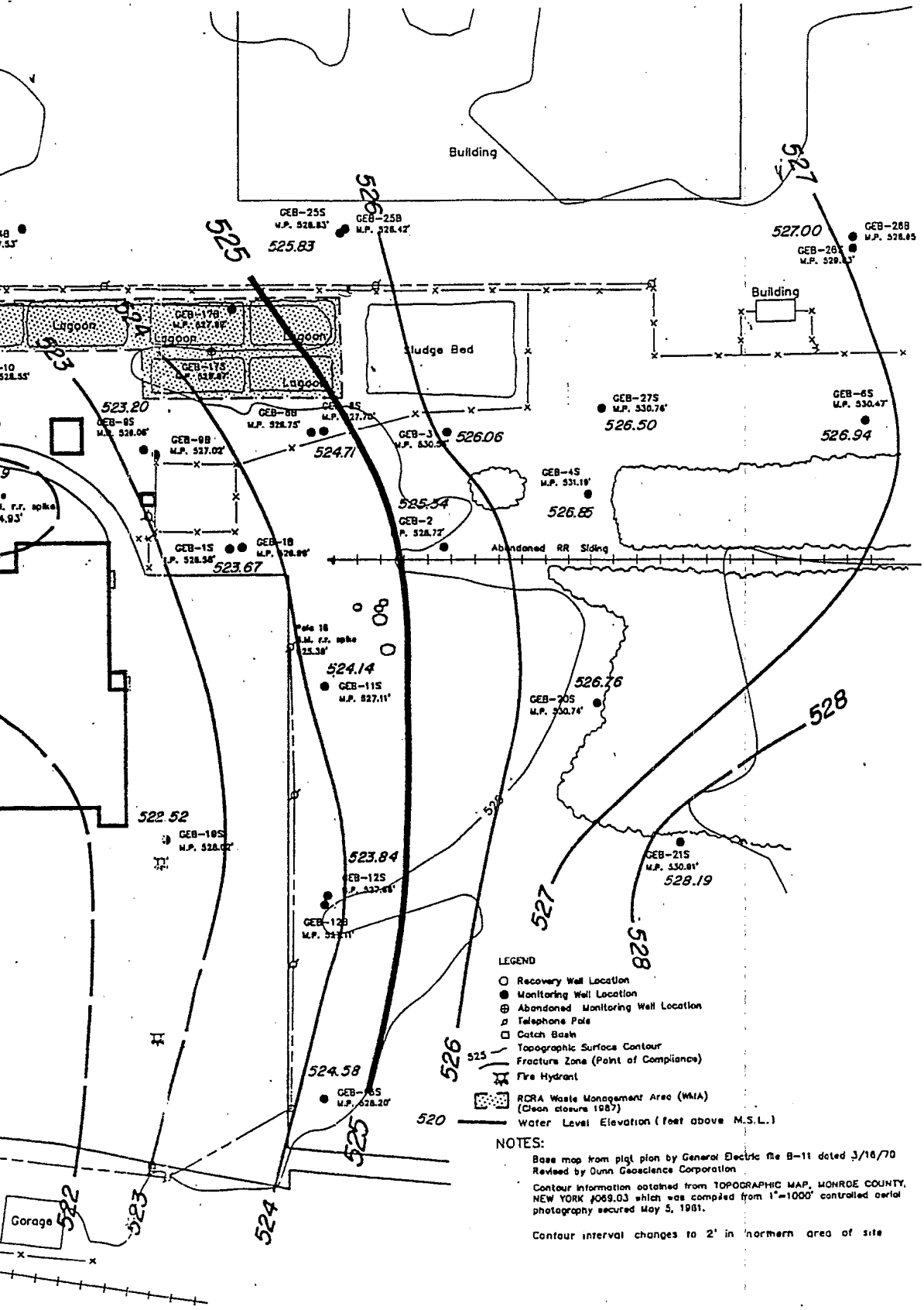
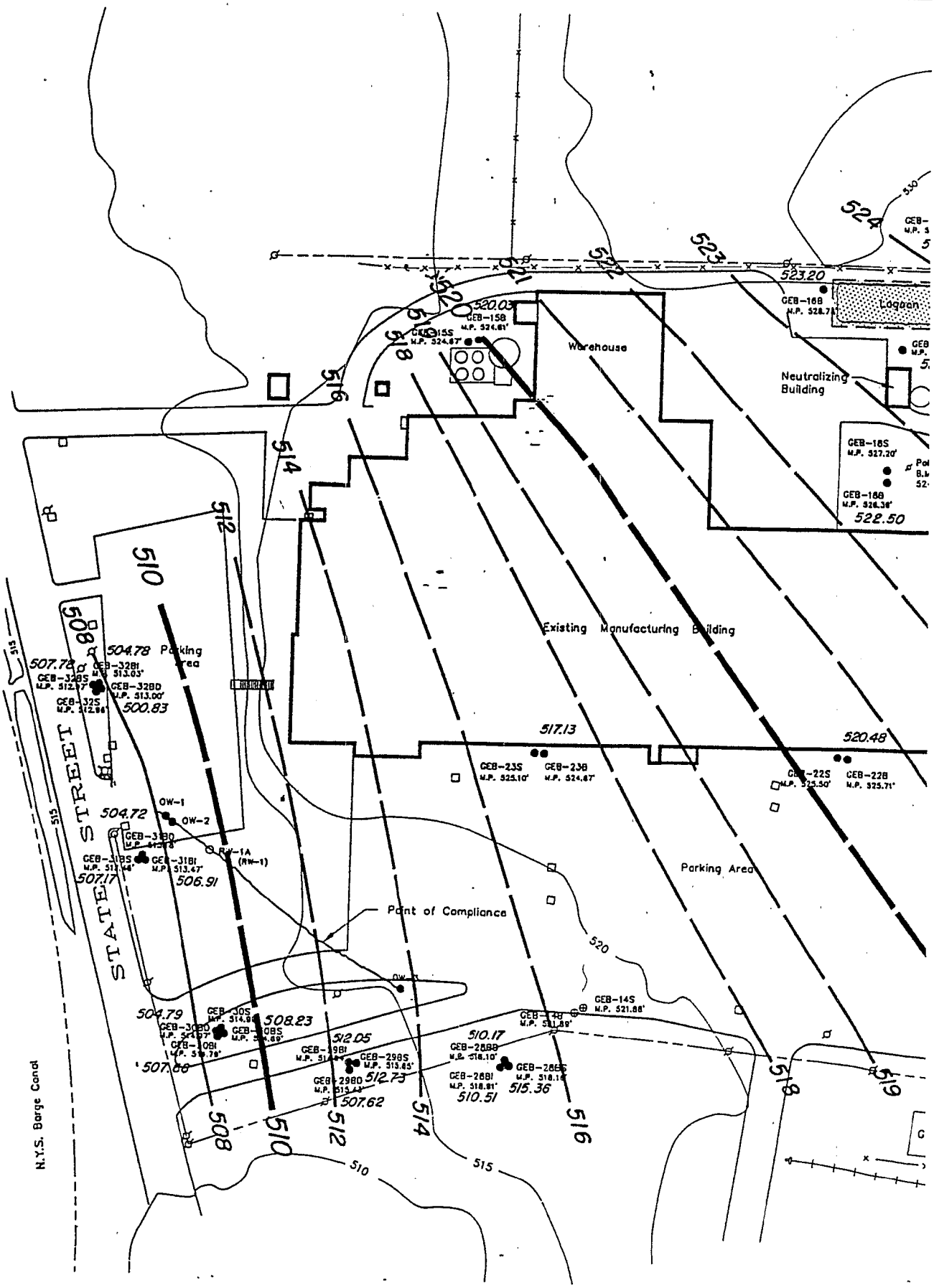


Figure 3
GROUND-WATER ELEVATION CONTOUR MAP PRIOR TO CREATION OF FRACTURE ZONE (OVERBURDEN AQUIFER), JANUARY 1987
BLACK & DECKER SITE



Source: Dunn Geoscience Corporation, January 1987

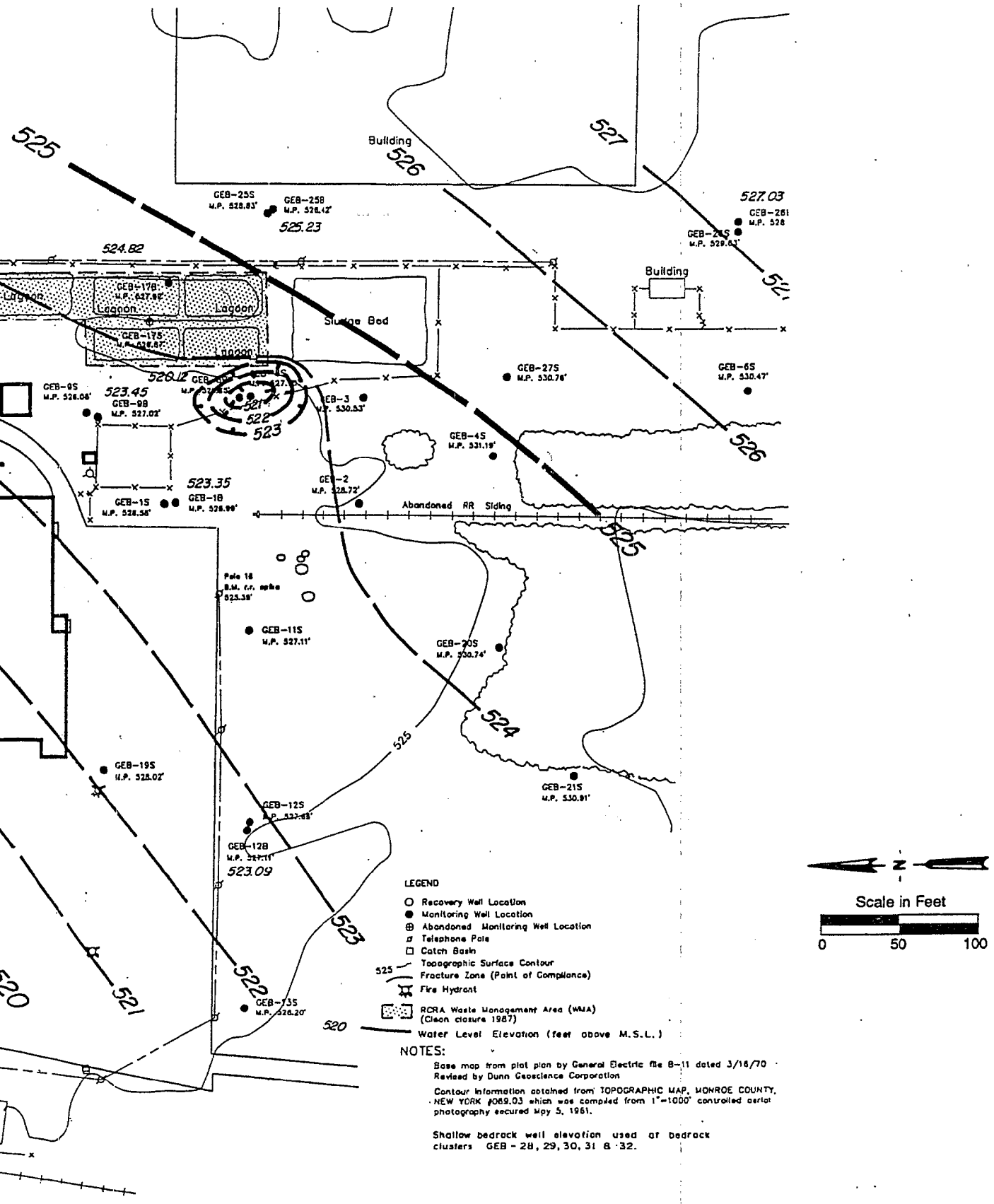
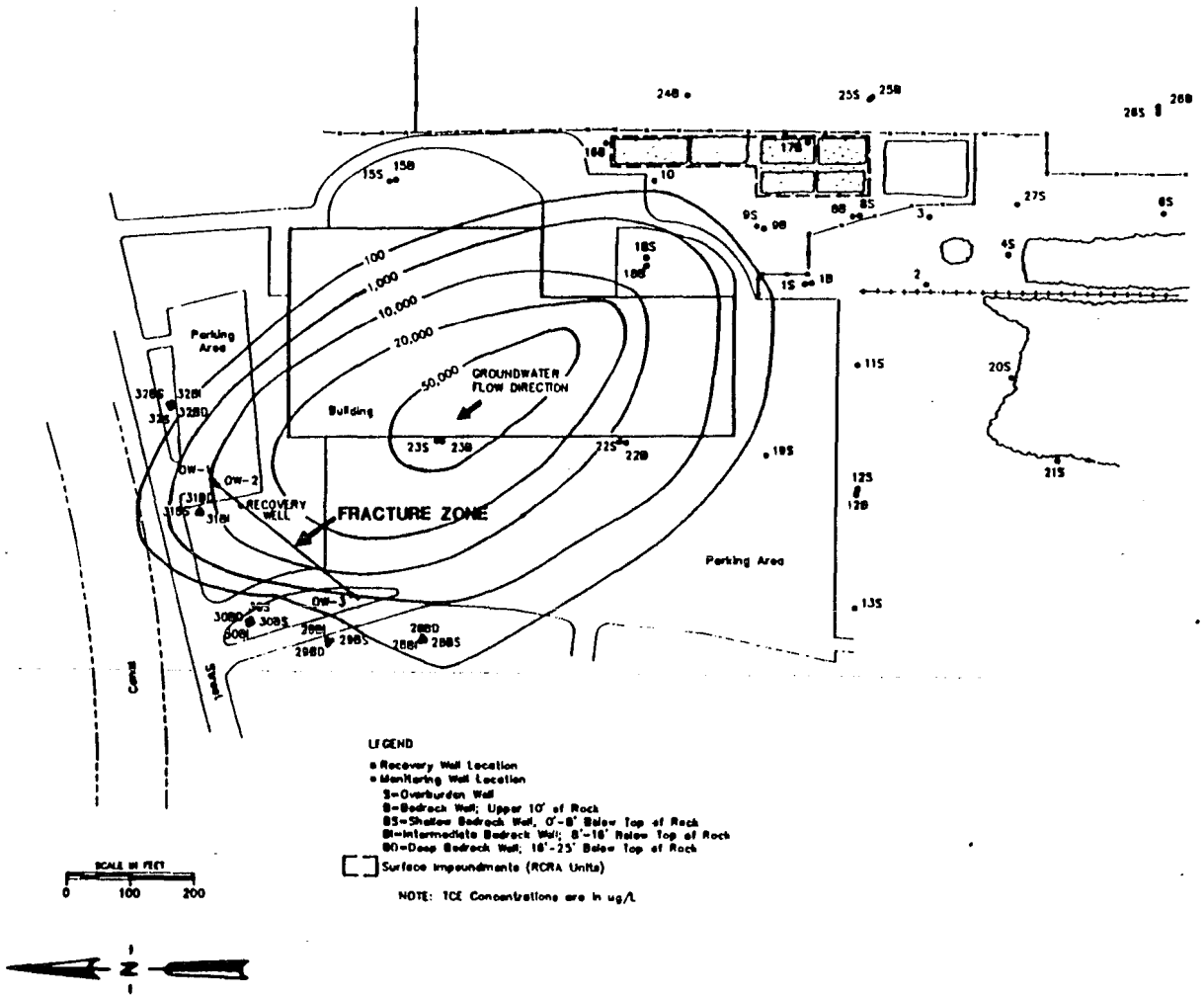


Figure 4
GROUND-WATER ELEVATION CONTOUR MAP PRIOR TO CREATION OF FRACTURE ZONE (BEDROCK AQUIFER), JANUARY 1987
BLACK & DECKER SITE

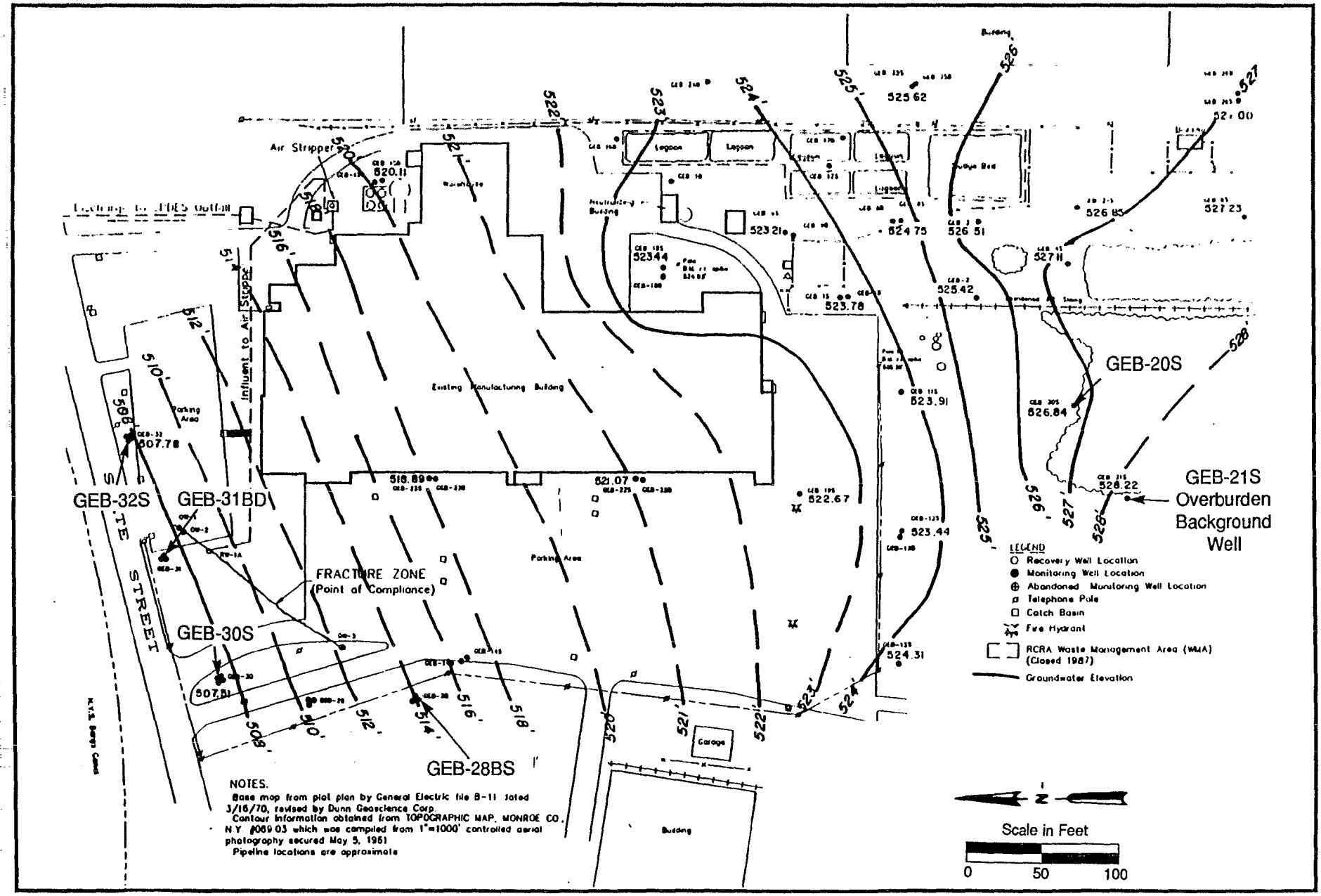
WDC 61621.AO.02



Source: Begor, Miller, and Sutch, January-February 1989

Figure 5
TRICHLOROETHYLENE CONCENTRATION (IN PPB) IN THE BEDROCK AQUIFIER PRIOR TO STARTUP
BLACK & DECKER SITE

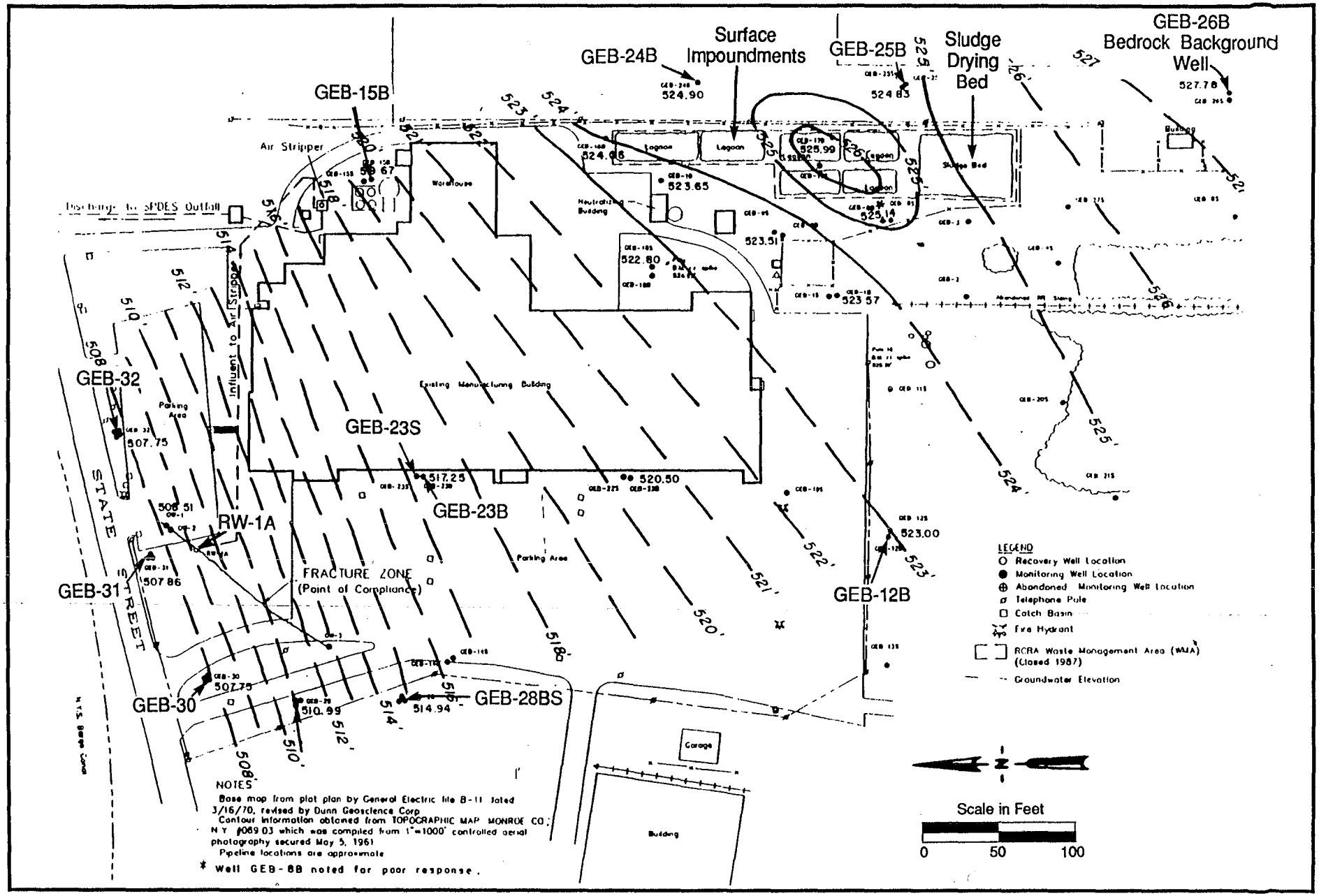
WDC 61621.AO.02



Source: Dunn Geoscience Corporation. March, 1988.

Figure 6
GROUND-WATER ELEVATION CONTOURS PRIOR TO STARTUP OF LONG-TERM EXTRACTION SYSTEM (OVERBURDEN AQUIFER), MARCH 1988
BLACK & DECKER SITE

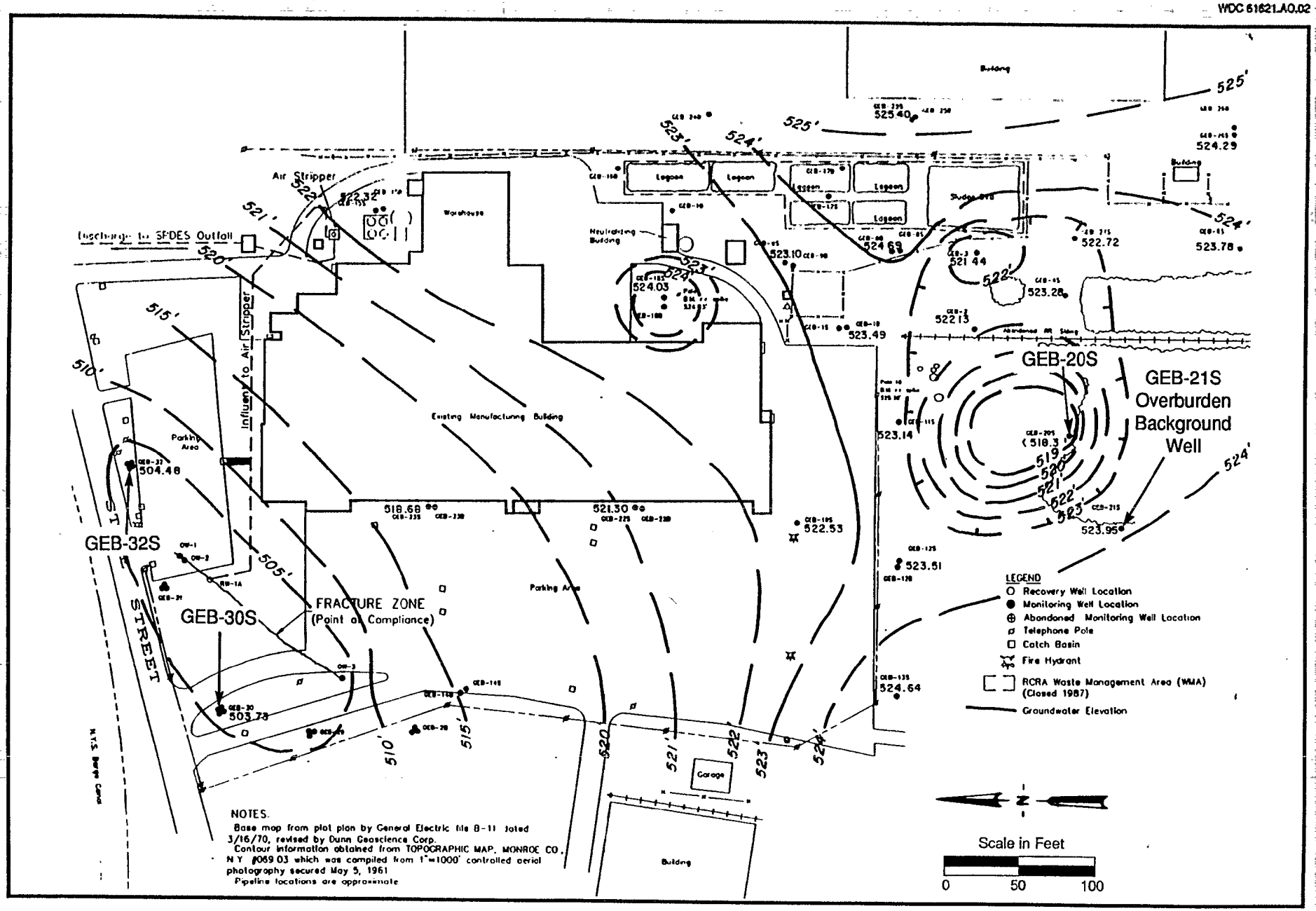
WDC 61621.AO.02



Source: Dunn Geoscience Corporation. March, 1988.

Figure 7
GROUND-WATER EVALUATION CONTOURS PRIOR TO STARTUP OF LONG-TERM EXTRACTION SYSTEM (BEDROCK AQUIFIER), MARCH 1988.
BLACK & DECKER SITE

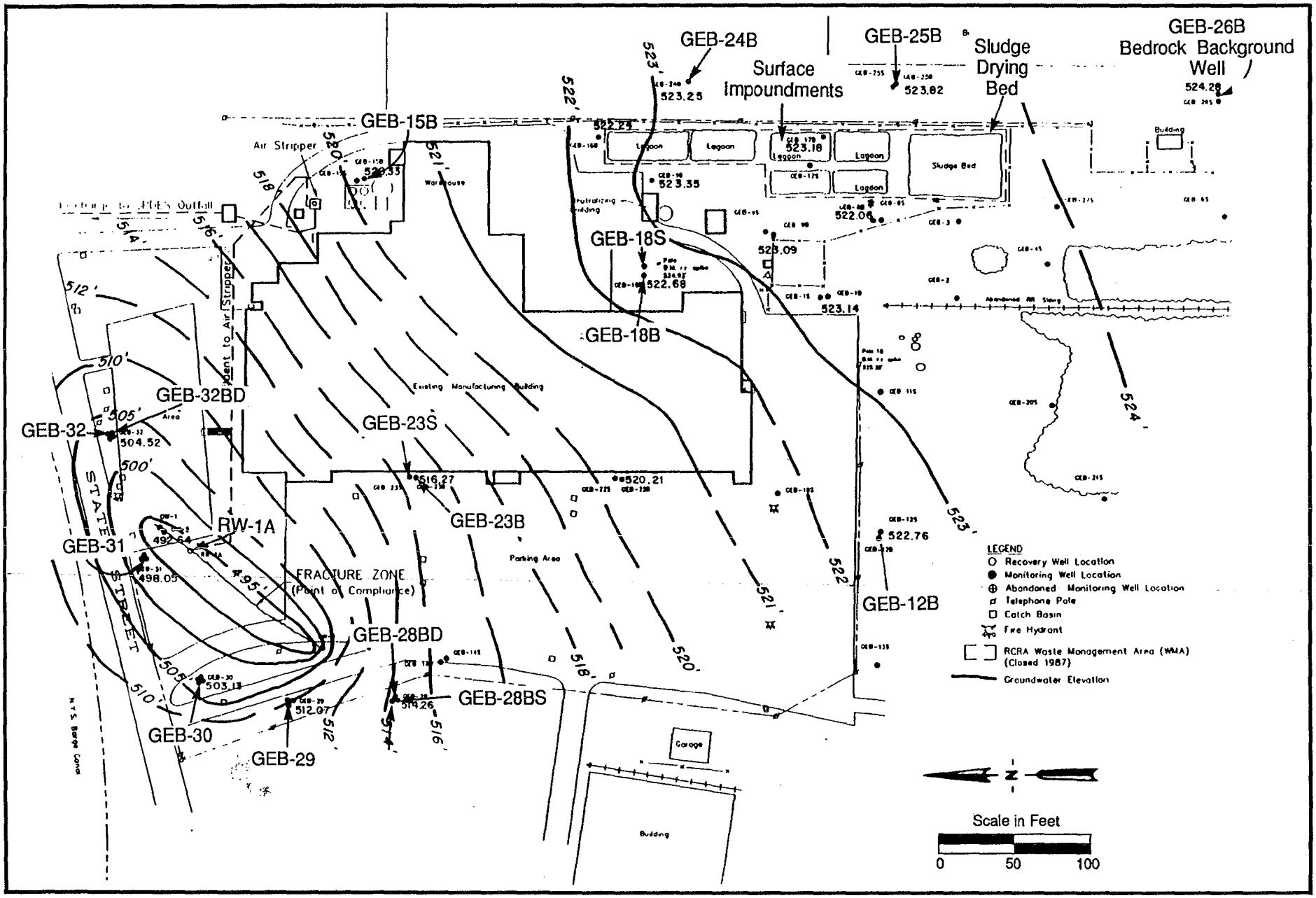
WDC 61621.AO.02



Source: Dunn Geoscience Corporation. March, 1988.

Figure 8
GROUND-WATER ELEVATION CONTOURS AFTER SIX MONTHS OF DISCONTINIOUS EXTRACTION (OVERBURDEN AQUIFER), NOVEMBER 1988
BLACK & DECKER SITE

WDC 61621.AO.02



Source: Dunn Geoscience Corporation. March, 1988.

Figure 9
GROUND-WATER ELEVATION CONTOURS AFTER SIX MONTHS OF DISCONTINUOUS EXTRACTION (BEDROCK AQUIFER), NOVEMBER 1988.
BLACK & DECKER SITE

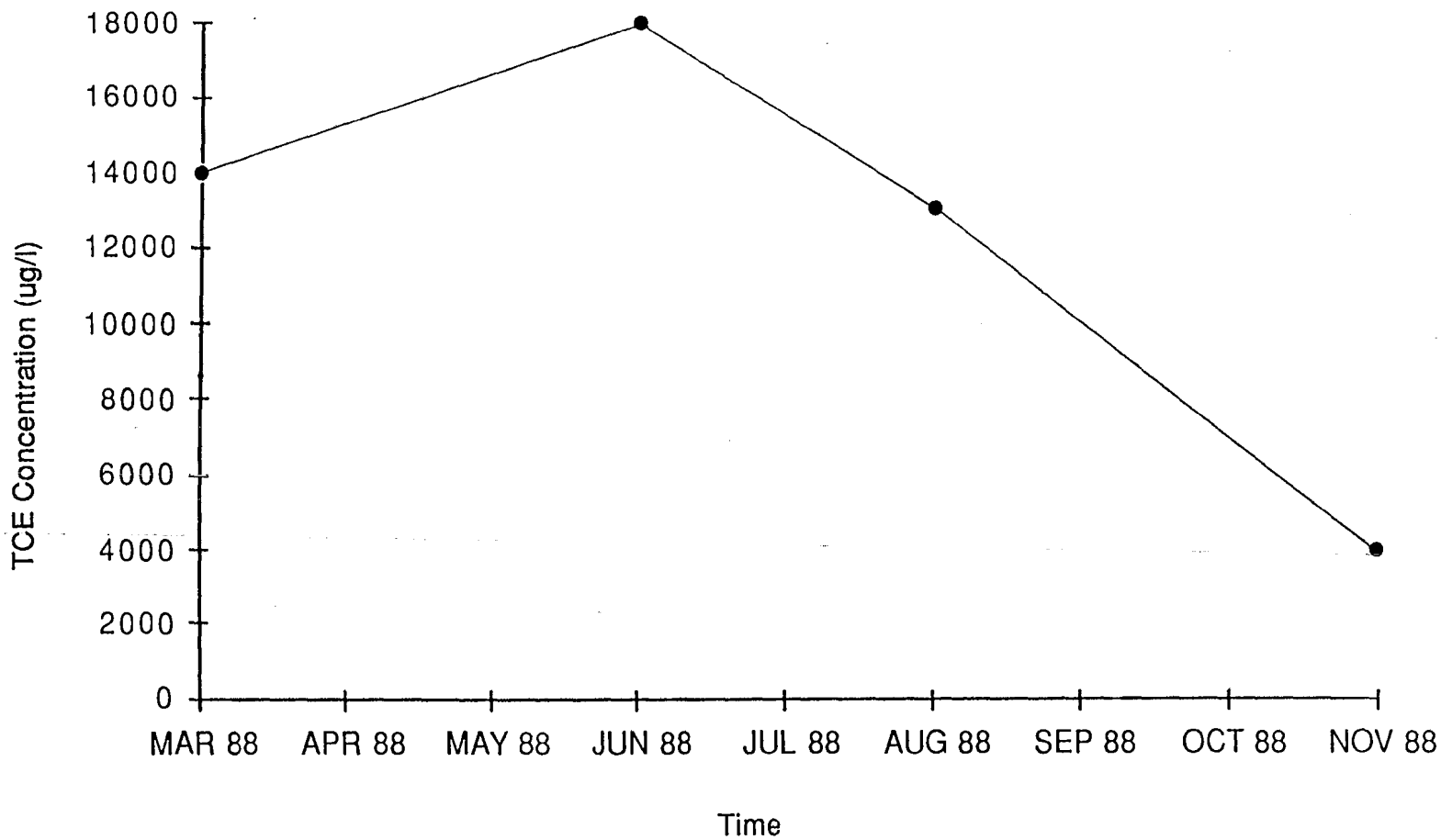
WDC 61621.AO.02

	Concentration Prior to Blasting Early 1987		Concentration After Blasting Late 1987		Concentration After Approx. One Month of Continual Pumping Late 1988	
	TCE	DCE	TCE	DCE	TCE	DCE
GEB-29BD	1	3	780	270	42	100
GEB-30BI	290	110	280	530	18	40
GEB-31BD	230	26	4700	1500	1000	430
GEB-32BI	23	15	5000	1300	110	90
GEB-32BD	4	12	1400	220	190	1200

Source: Compiled from Various Sources

Figure 10
VARIATIONS IN TCE AND DCE CONCENTRATIONS IN FIVE MONITORING WELLS
BLACK & DECKER SITE

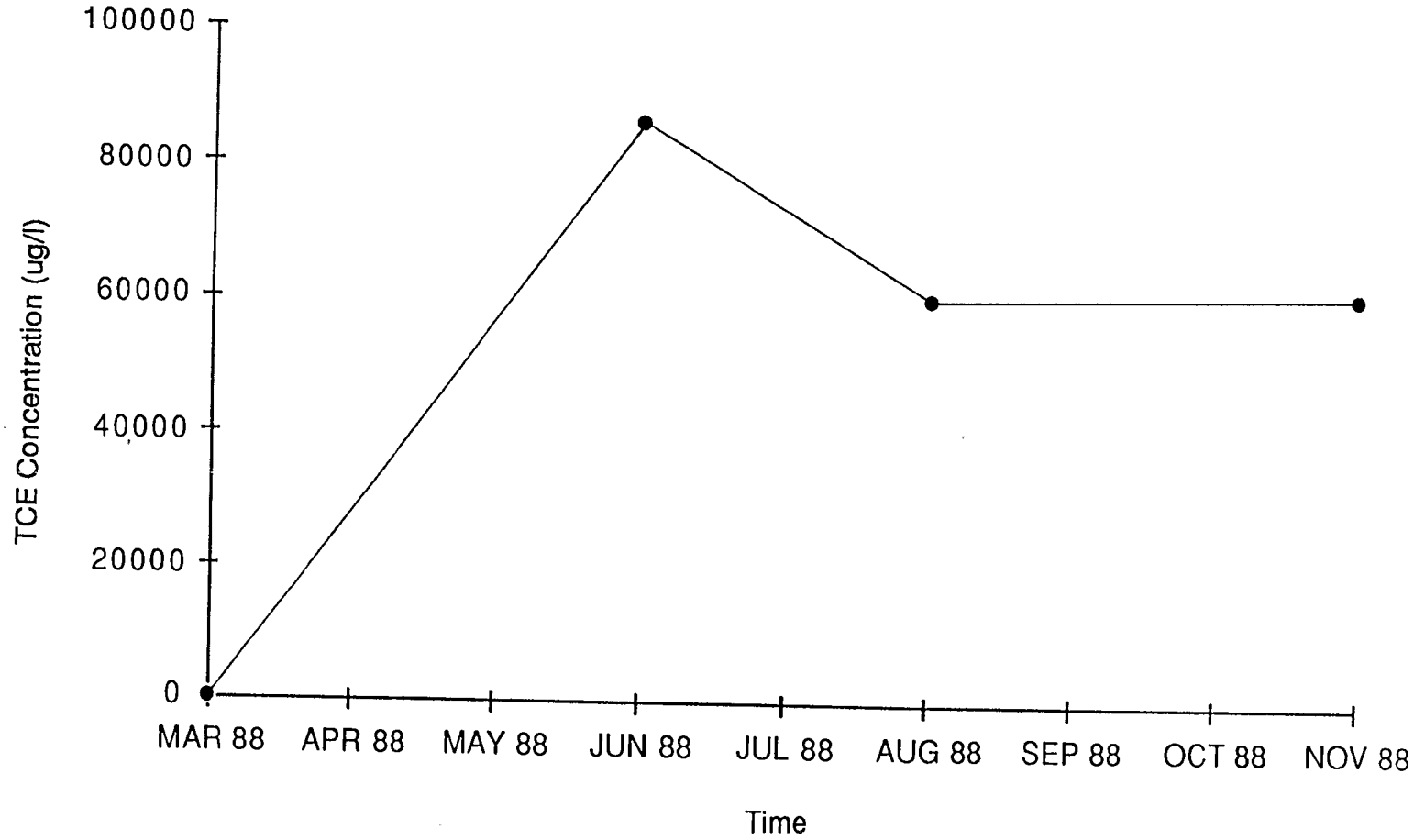
WDC 61621.AO.02



Source: Compiled from Various Sources

Figure 11
VARIATION IN TCE CONCENTRATION IN WELL 18S IN THE CENTERLINE OF THE PLUME (BEDROCK AQUIFER)
BLACK & DECKER SITE

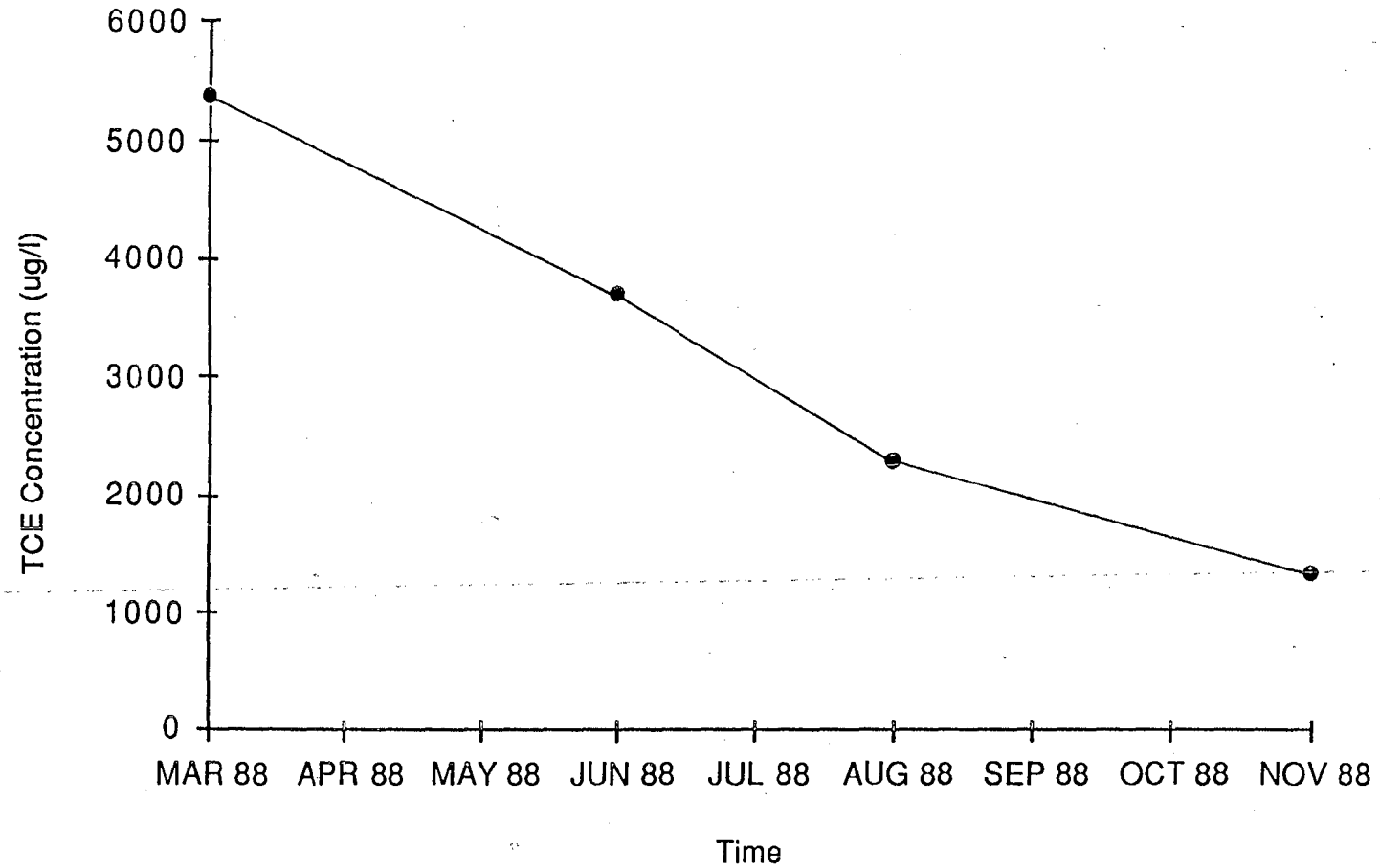
WDC61621.AO.02



Source: Compiled from Various Sources

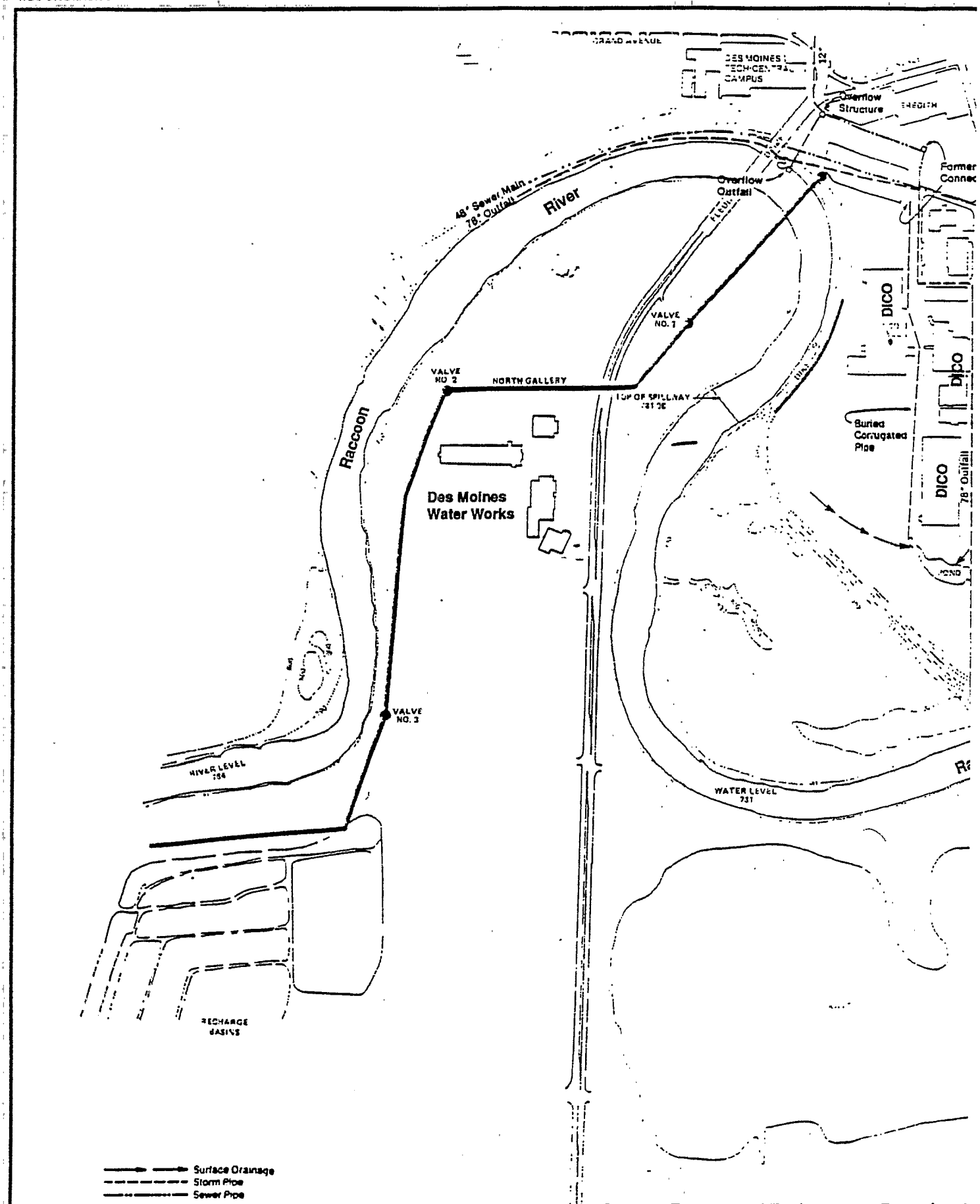
Figure 12
VARIATION IN TCE CONCENTRATION IN WELL GEB-23S IN THE CENTERLINE OF THE PLUME (BEDROCK AQUIFER)
BLACK & DECKER SITE

WDC 61621.AO.02

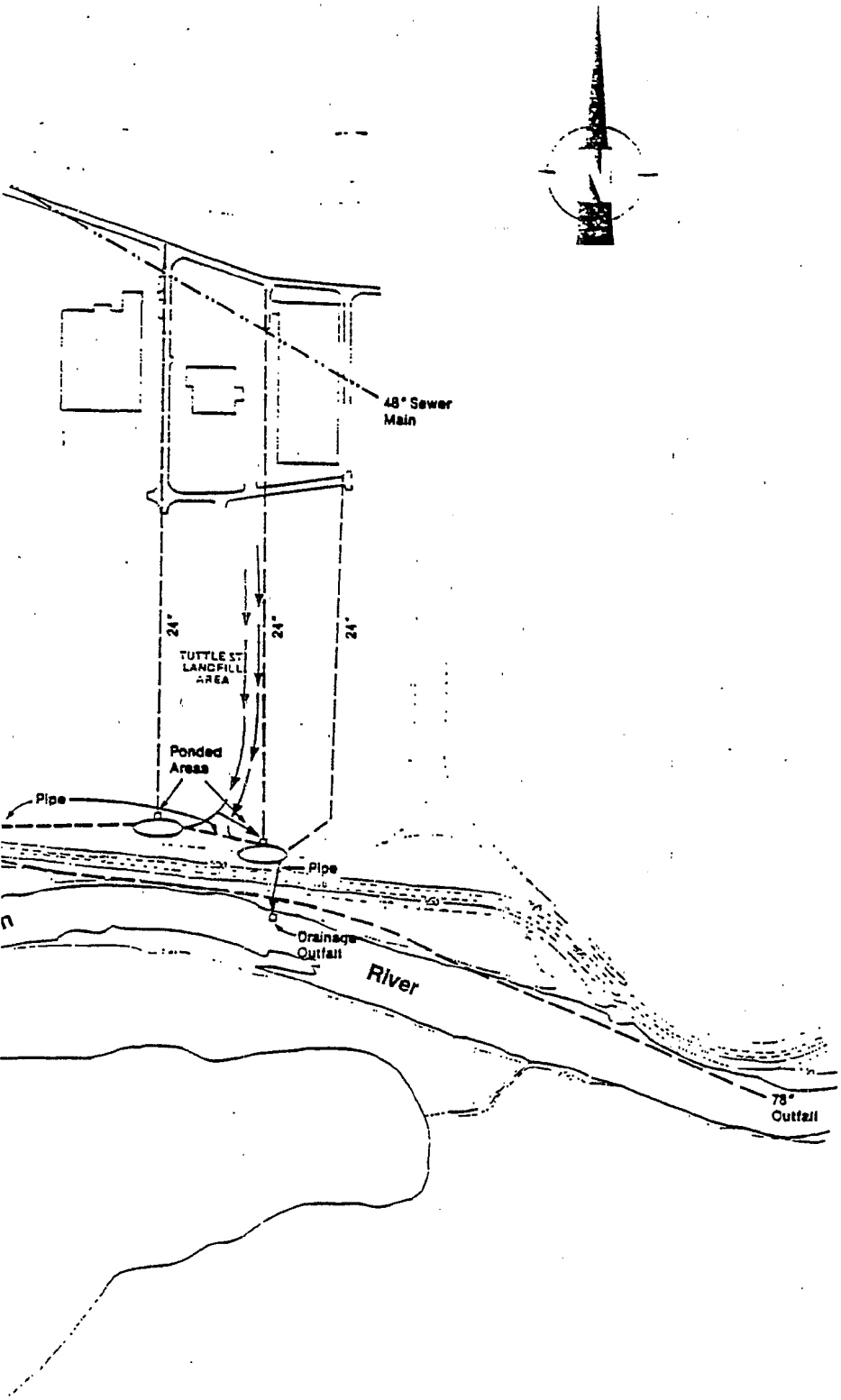


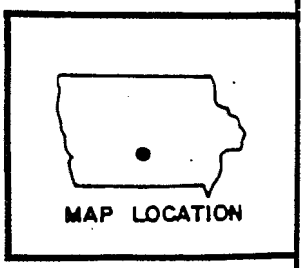
Source: Compiled from Various Sources

Figure 13
VARIATION IN TCE CONCENTRATION IN WELL GEB-30 BI DOWNGRADIENT OF FRACTURE ZONE (BEDROCK AQUIFER)
BLACK & DECKER SITE



Source: Ecology and Environment. December,1
Investigation Report, Remedial Investigation/Fea
Des Moines TCE Site, Vol. 1 of 4.

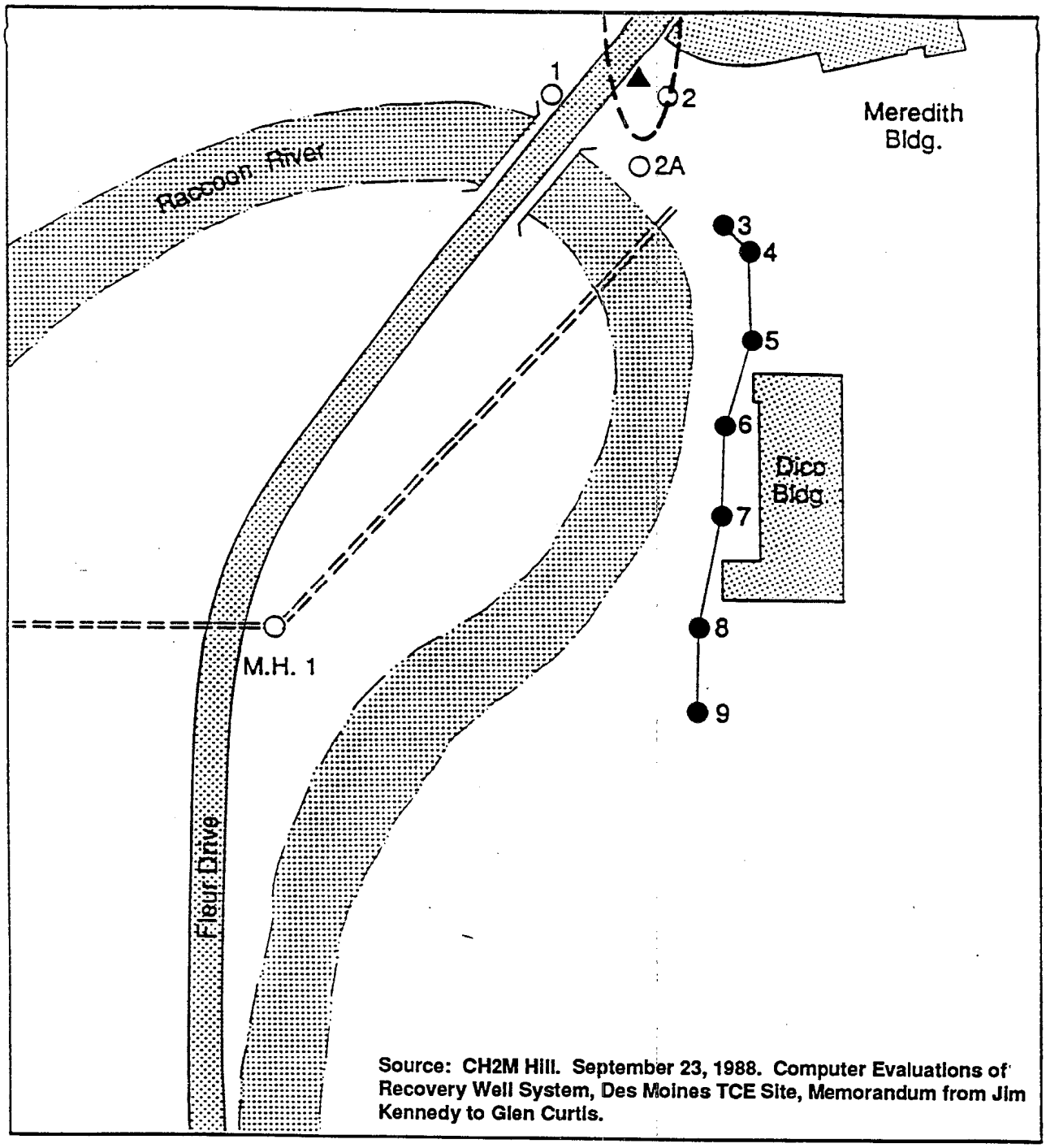




Final Remedial
y Study,

300 0 300 600
scale feet

Figure 1
MAP OF DES MOINES TCE SITE
DES MOINES, IOWA



Source: CH2M Hill. September 23, 1988. Computer Evaluations of Recovery Well System, Des Moines TCE Site, Memorandum from Jim Kennedy to Glen Curtis.

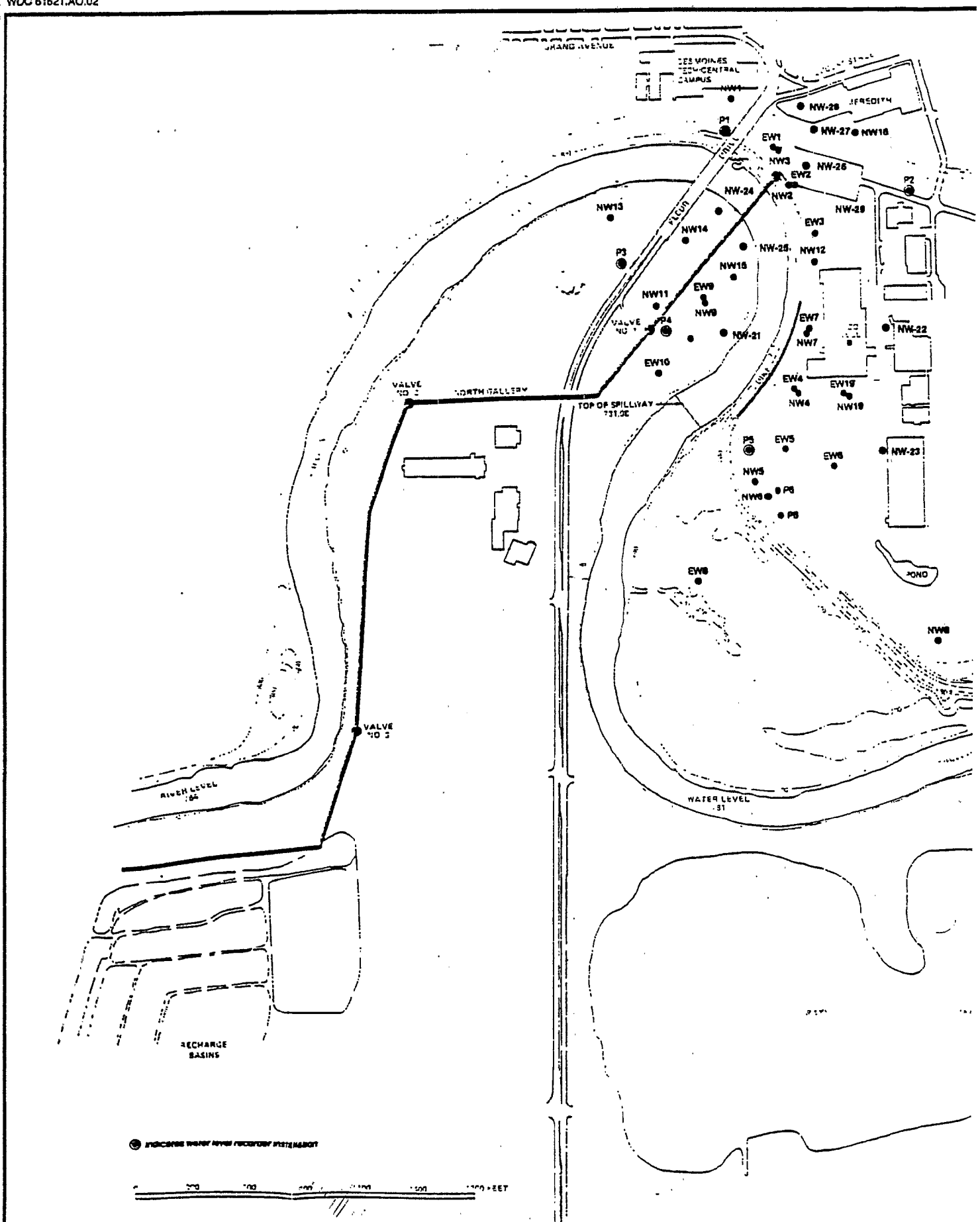
Legend

- Approximate boundary of North Plume, March 1988
- Existing recovery wells
- Simulated recovery wells
- Reference location for particle tracking
- Gallery
- Flowpath from North Plume
- Groundwater flow to gallery
- Flow along gallery and backfill

N

0 400 Feet

Figure 2
RECOVERY WELL LOCATION MAP
DES MOINES TCE SITE



Source: CH2M Hill. September 23, 1988. Computer Evaluations of Recovery Well System, Des Moines TCE Site, Memorandum from Jim Kennedy to Glen Curtis.

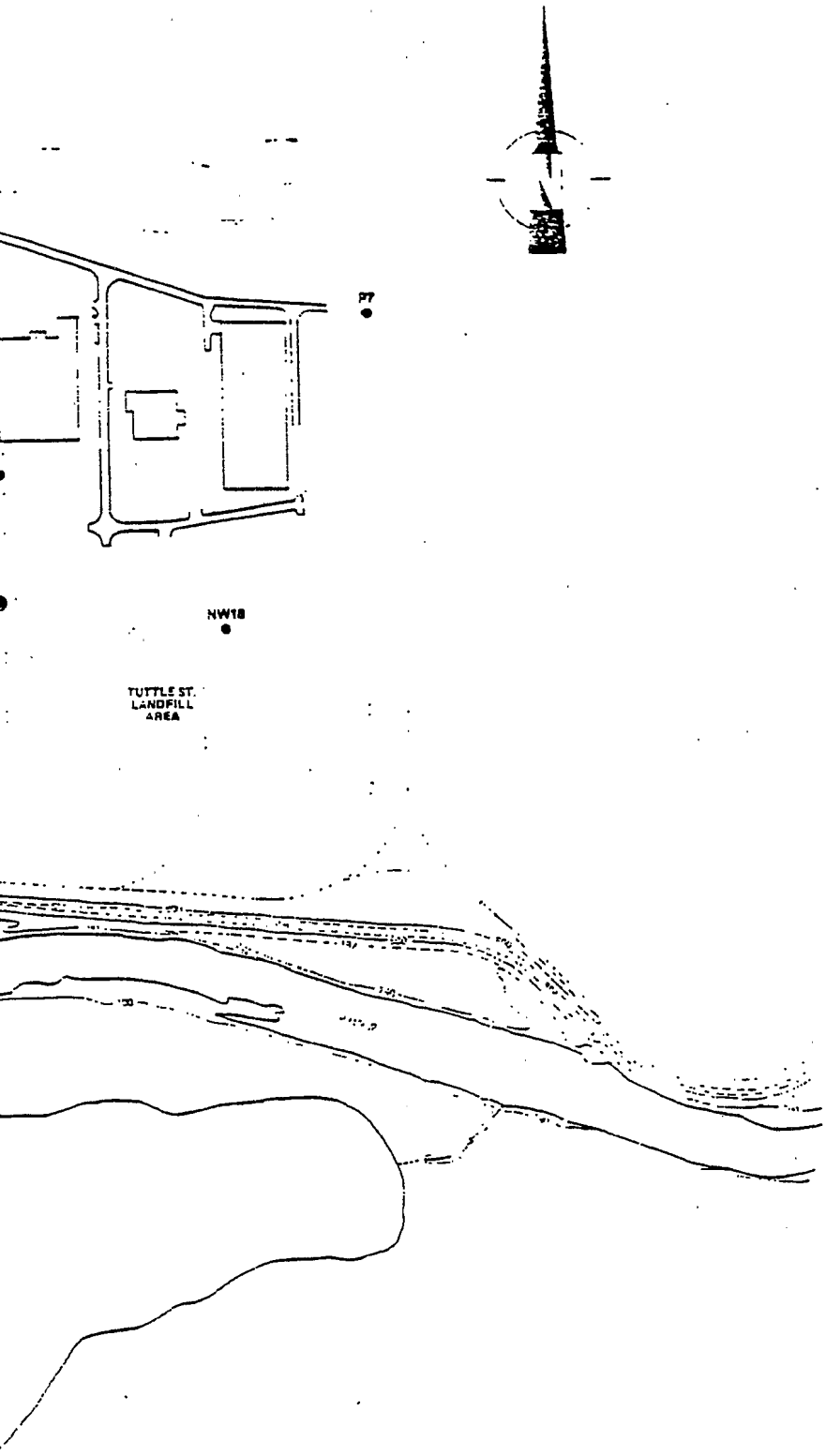
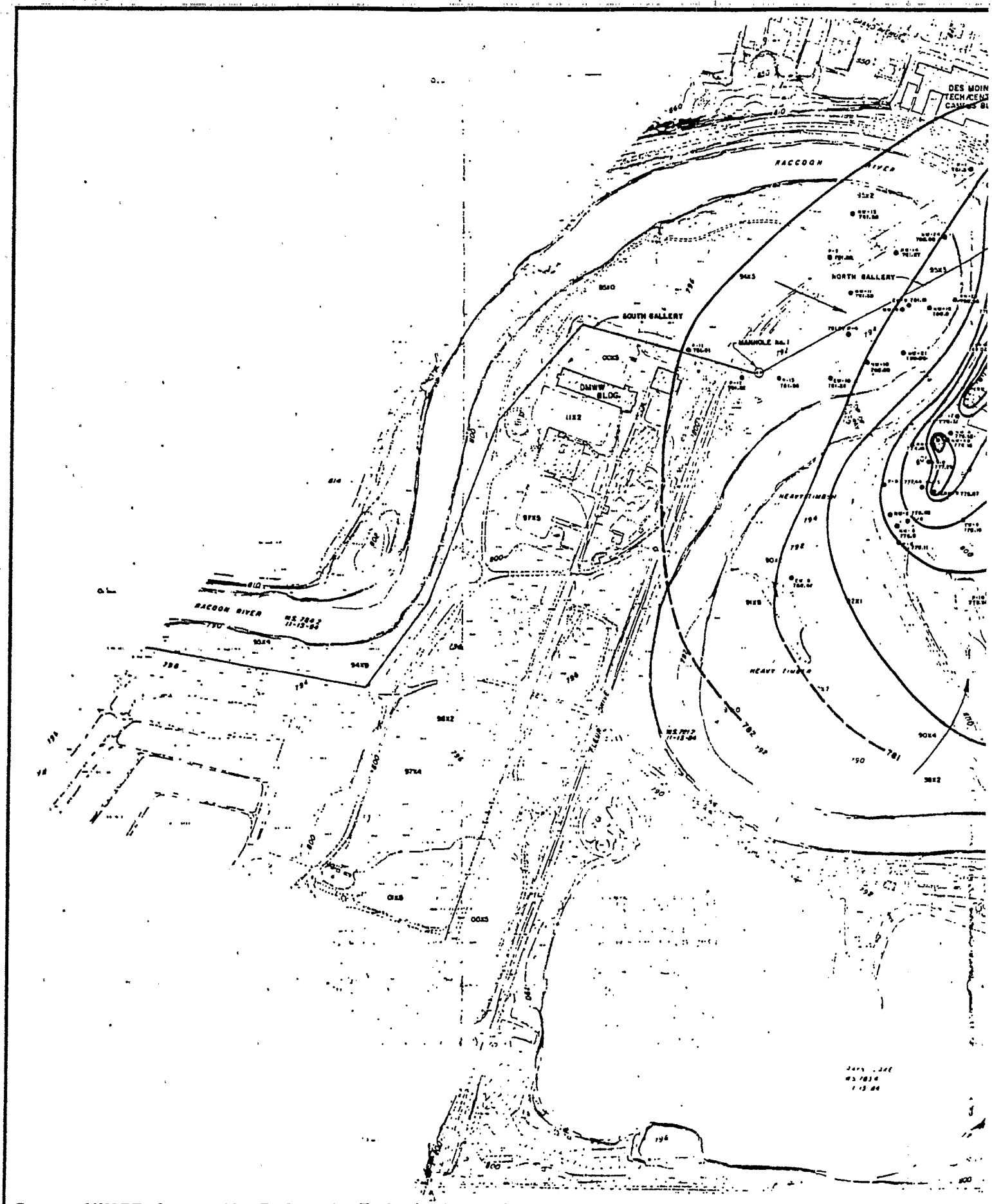


Figure 3
MONITORING WELL AND PIEZOMETER LOCATION MAP
DES MOINES TCE SITE



Source: AWARE. August,1988. Performance Evaluation Report No. 2 (March 1988 through June 1988) Groundwater Recovery and Treatment System, Des Moines TCE Site.

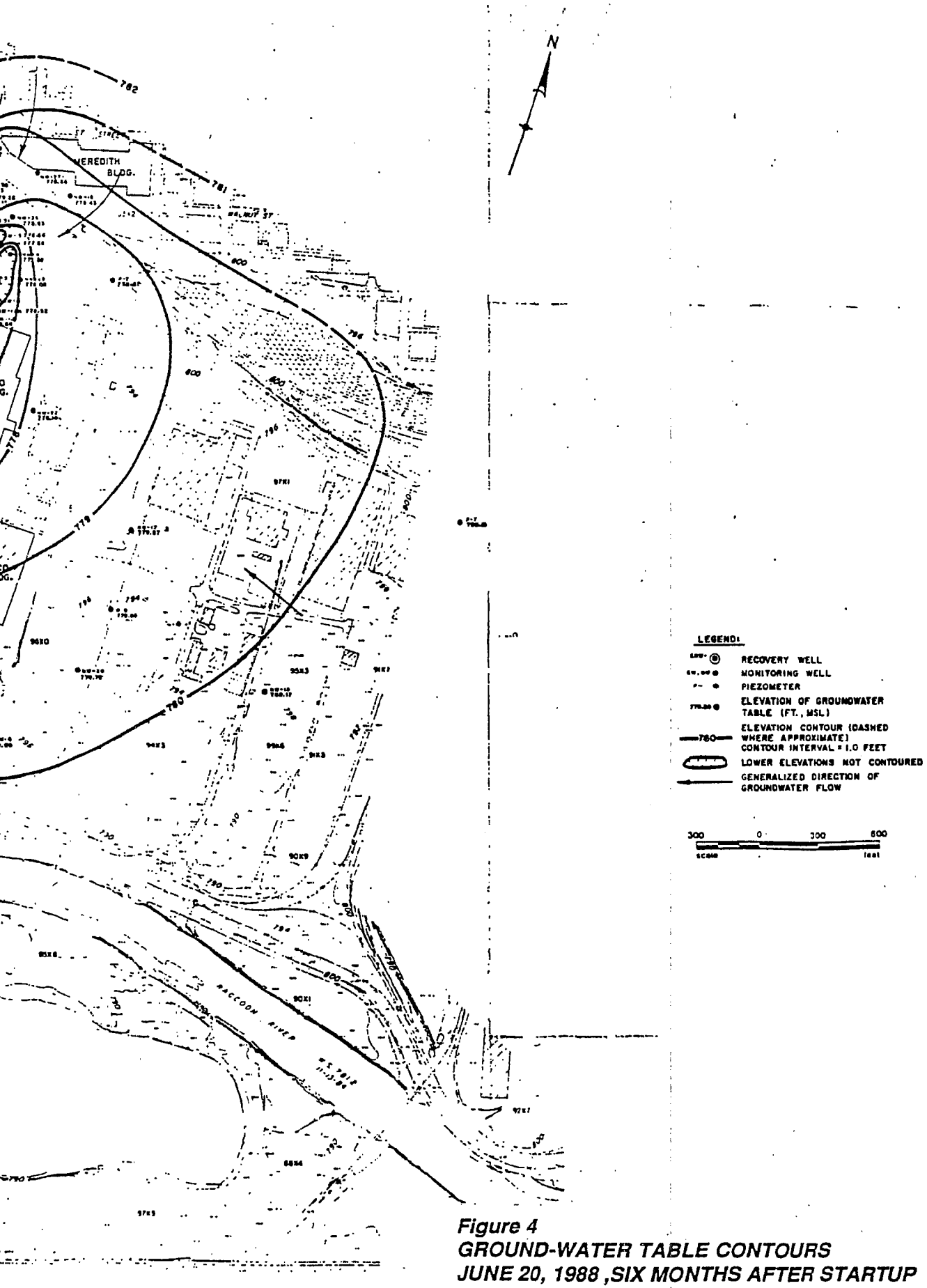
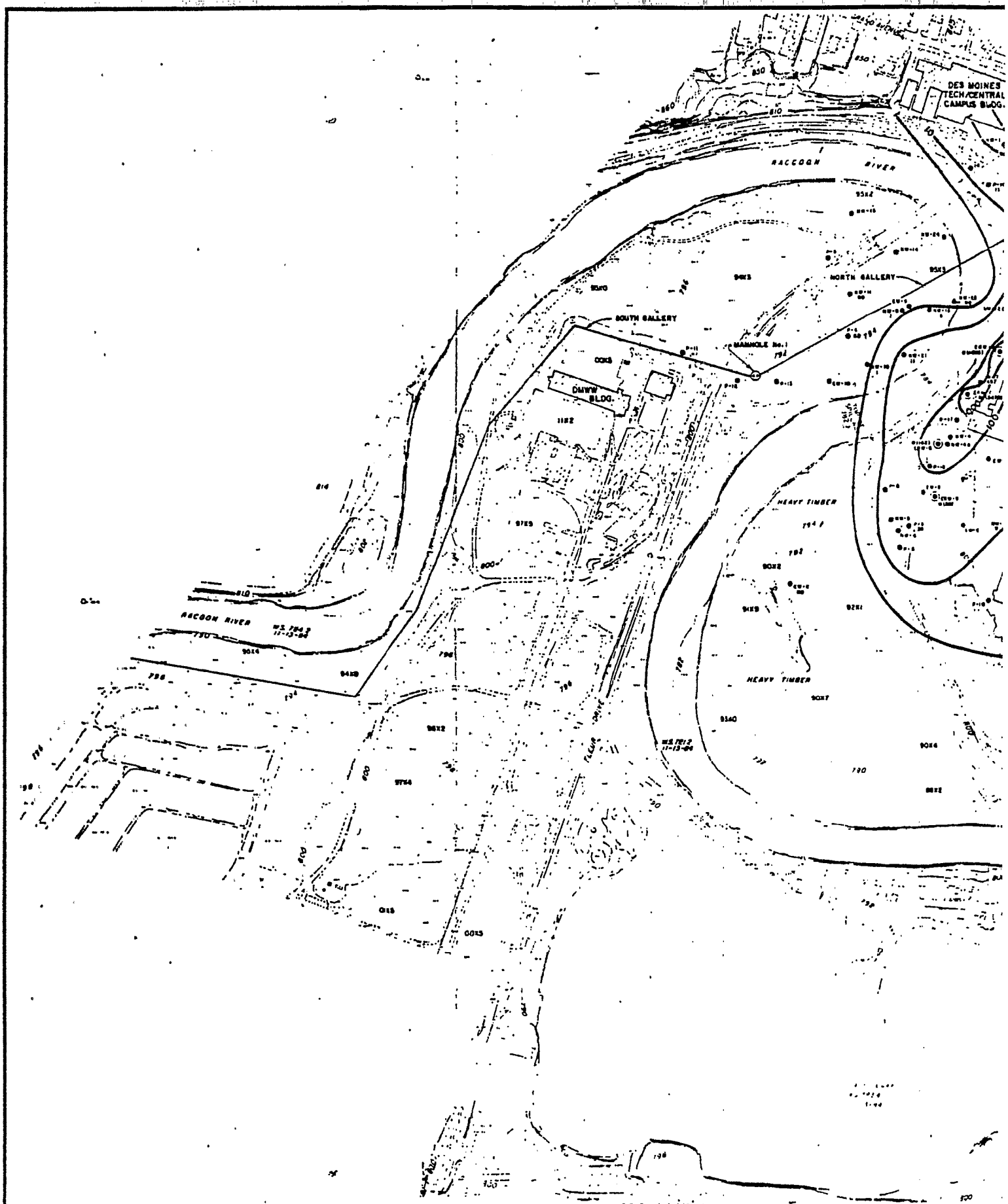


Figure 4
GROUND-WATER TABLE CONTOURS
JUNE 20, 1988 ,SIX MONTHS AFTER STARTUP
DES MOINES TCE SITE



Source: AWARE. August, 1988. Performance Evaluation Report No. 2 (March 1988 through June 1988) Groundwater Recovery and Treatment System, Des Moines TCE Site.

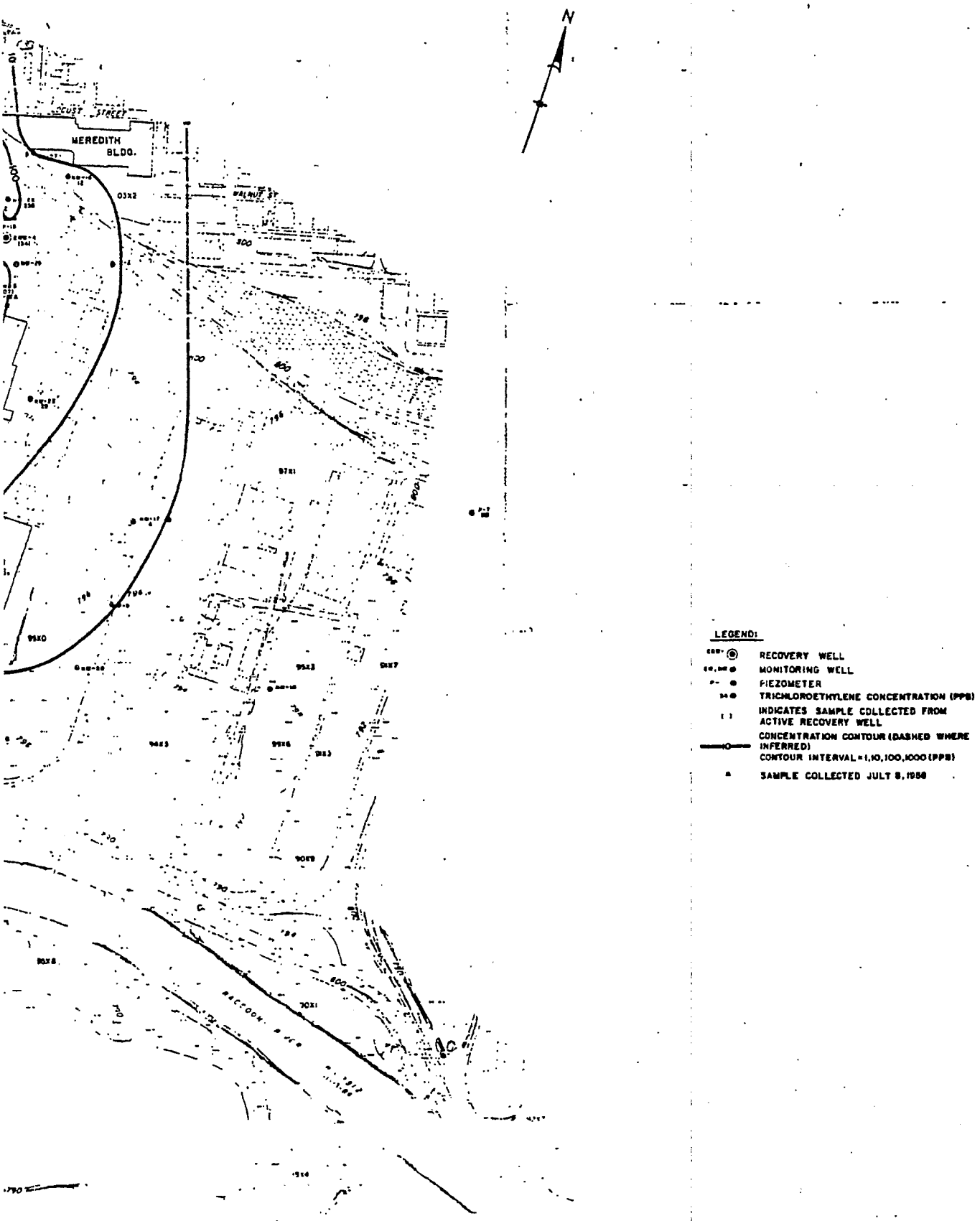
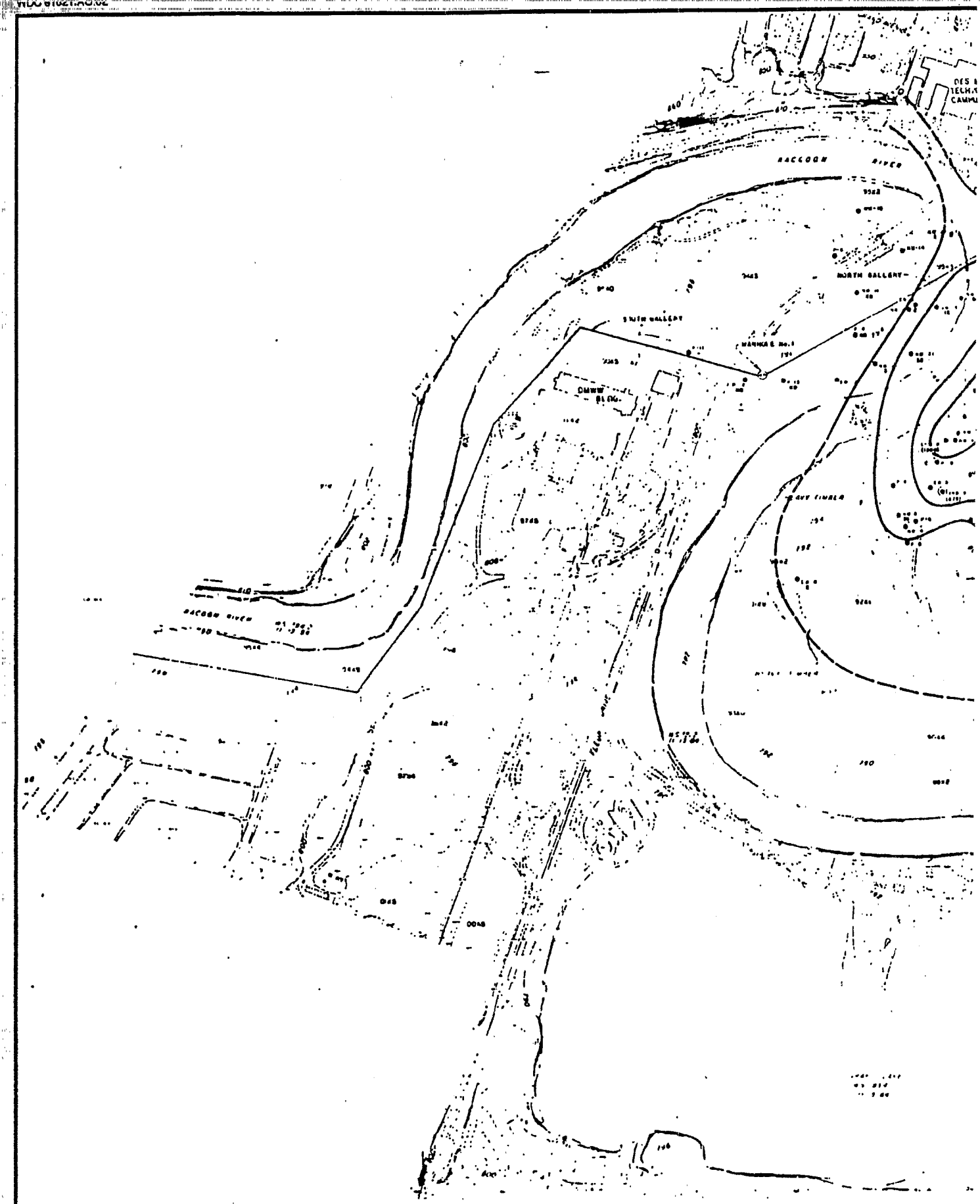


Figure 6
DISTRIBUTION OF TRICHLOROETHYLENE, JUNE 21-24, 1988, SIX MONTHS AFTER STARTUP
DES MOINES TCE SITE



Source: AWARE. April, 1988. Performance Evaluation Report No. 1 (December 1987 through March 1988) Groundwater Recovery and Treatment System, Des Moines TCE Site.

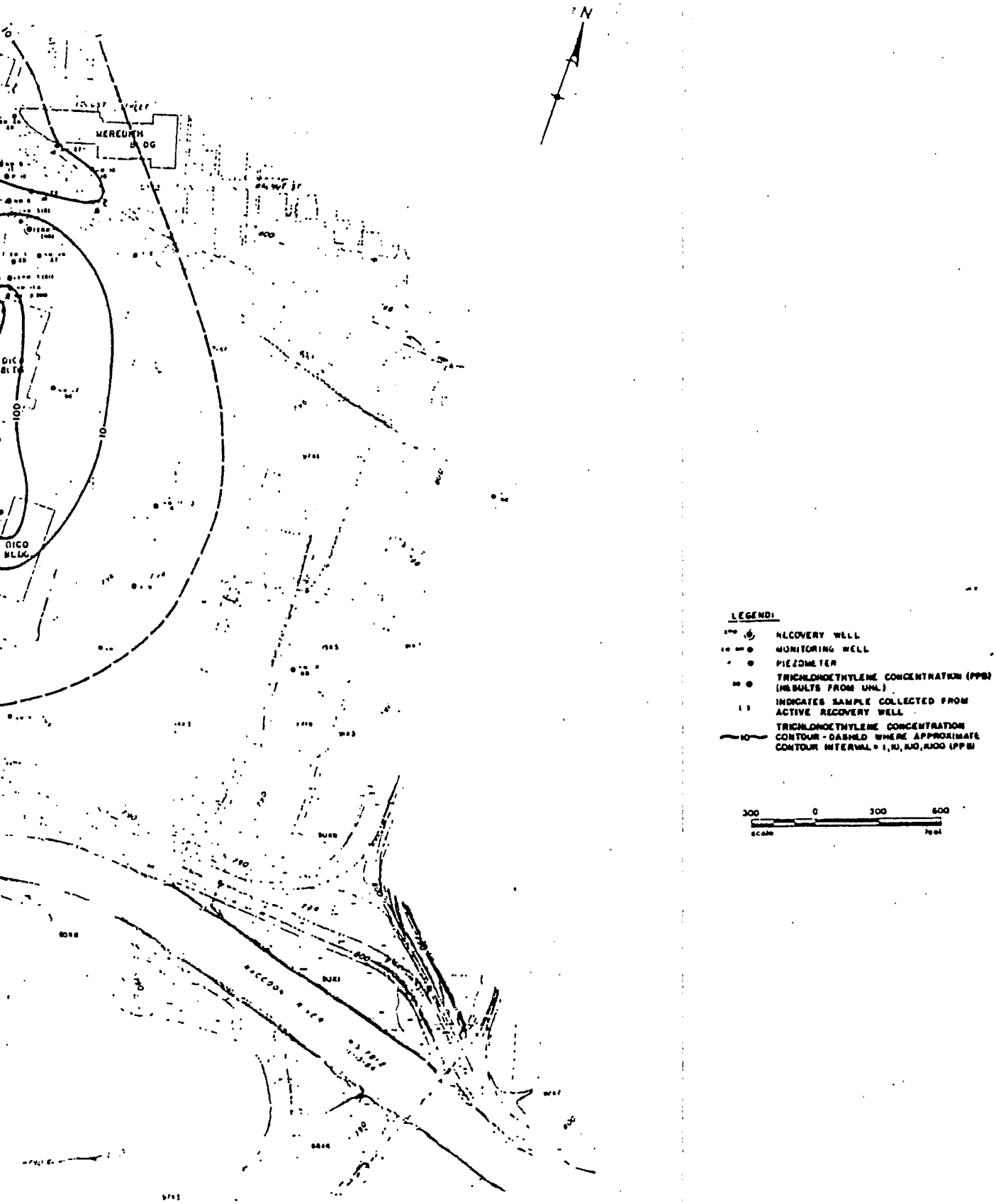


Figure 5
DISTRIBUTION OF TRICHLOROETHYLENE, DECEMBER 9 TO 16, 1987, PRIOR TO STARTUP
DES MOINES TCE SITE

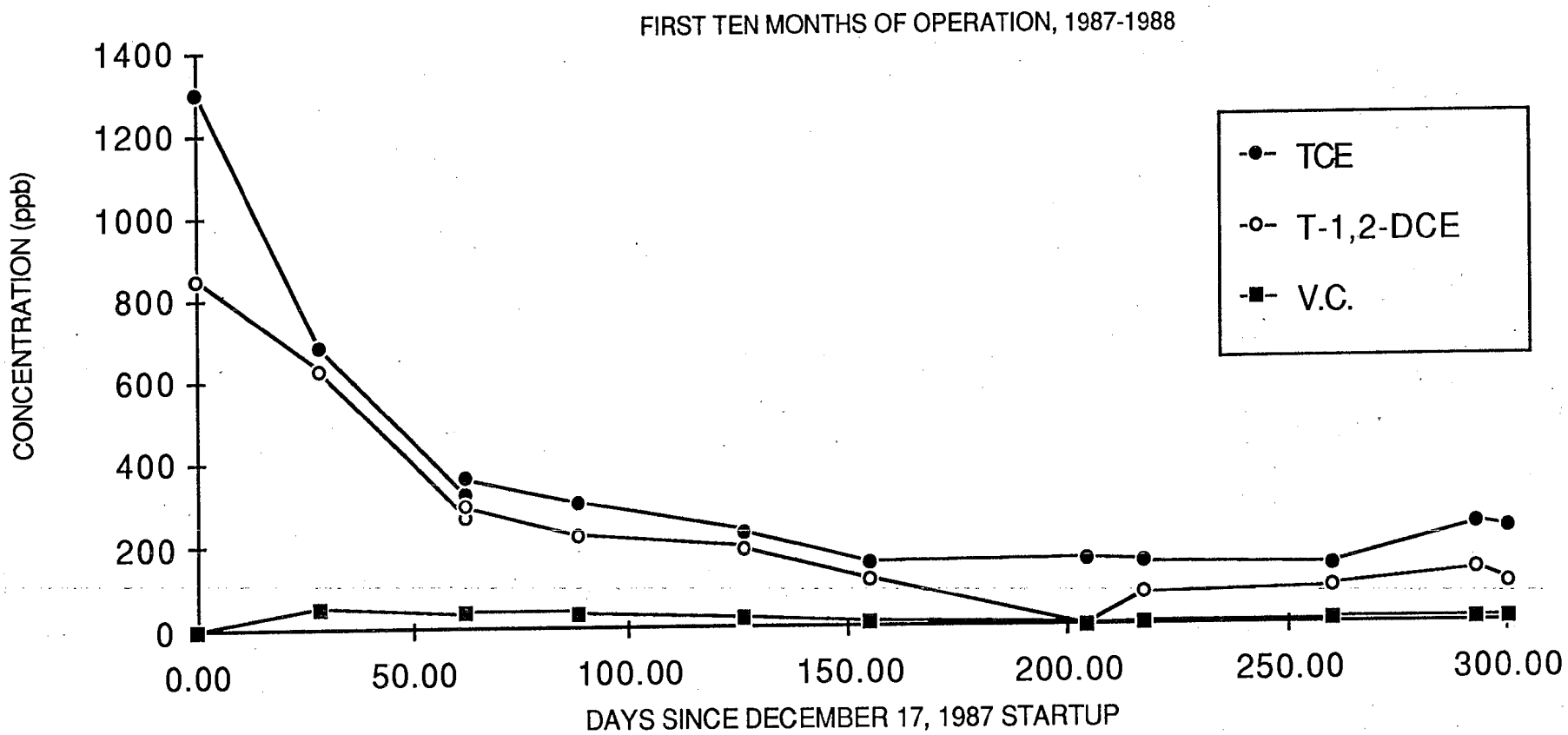


Figure 7
GROUNDWATER QUALITY
DES MOINES TCE SITE
WELL ERW-8

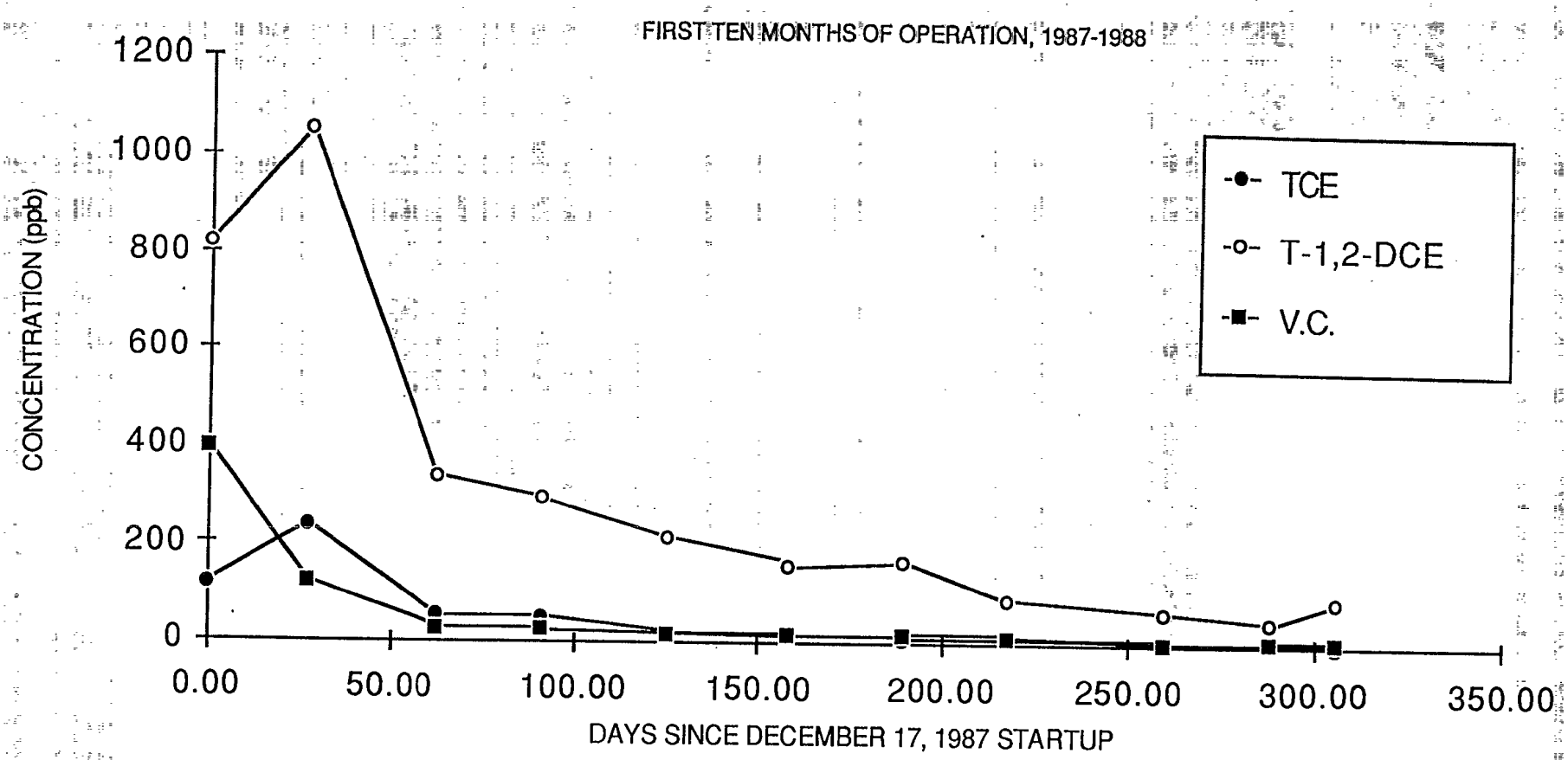


Figure 8
GROUNDWATER QUALITY
DES MOINES TCE SITE
WELL NW-23

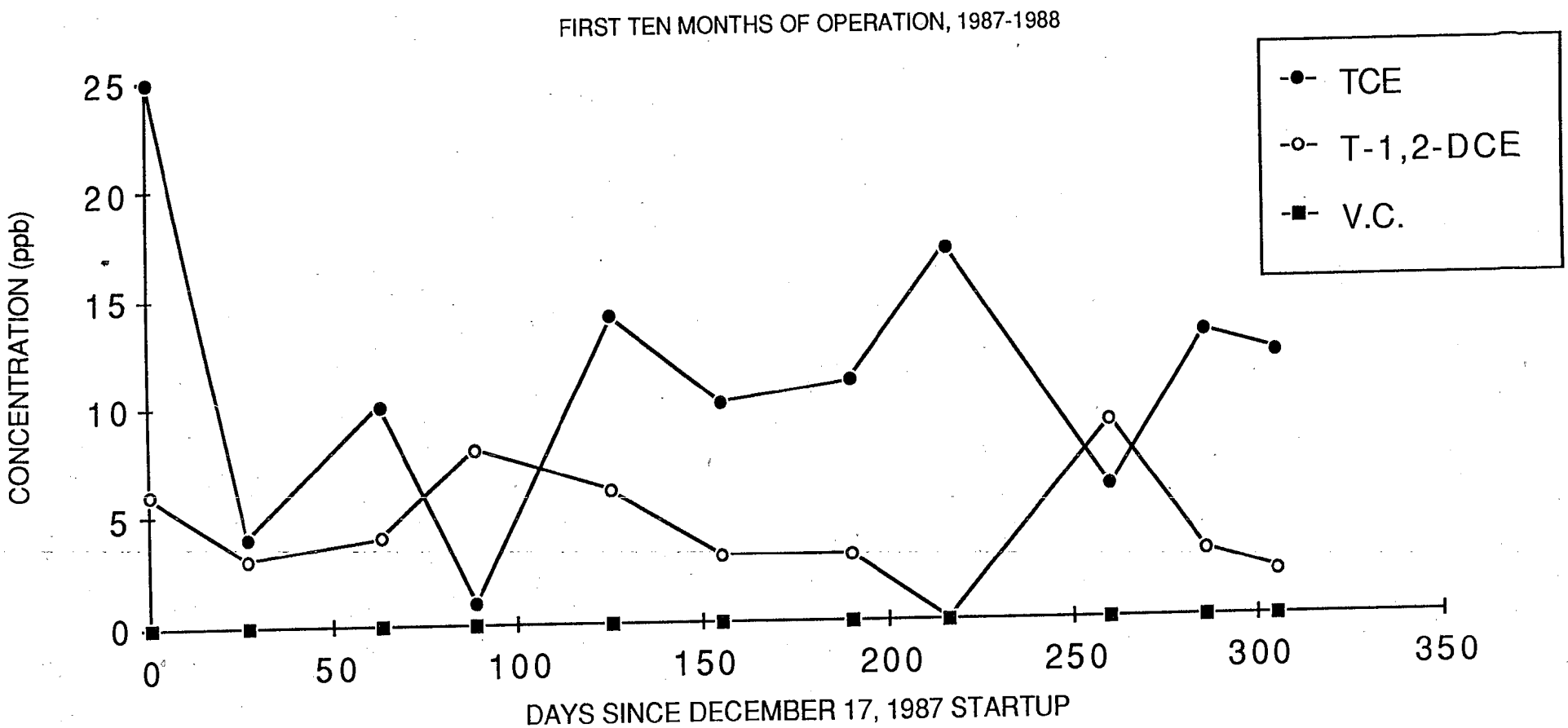


Figure 9
GROUNDWATER QUALITY
WELL NW-21

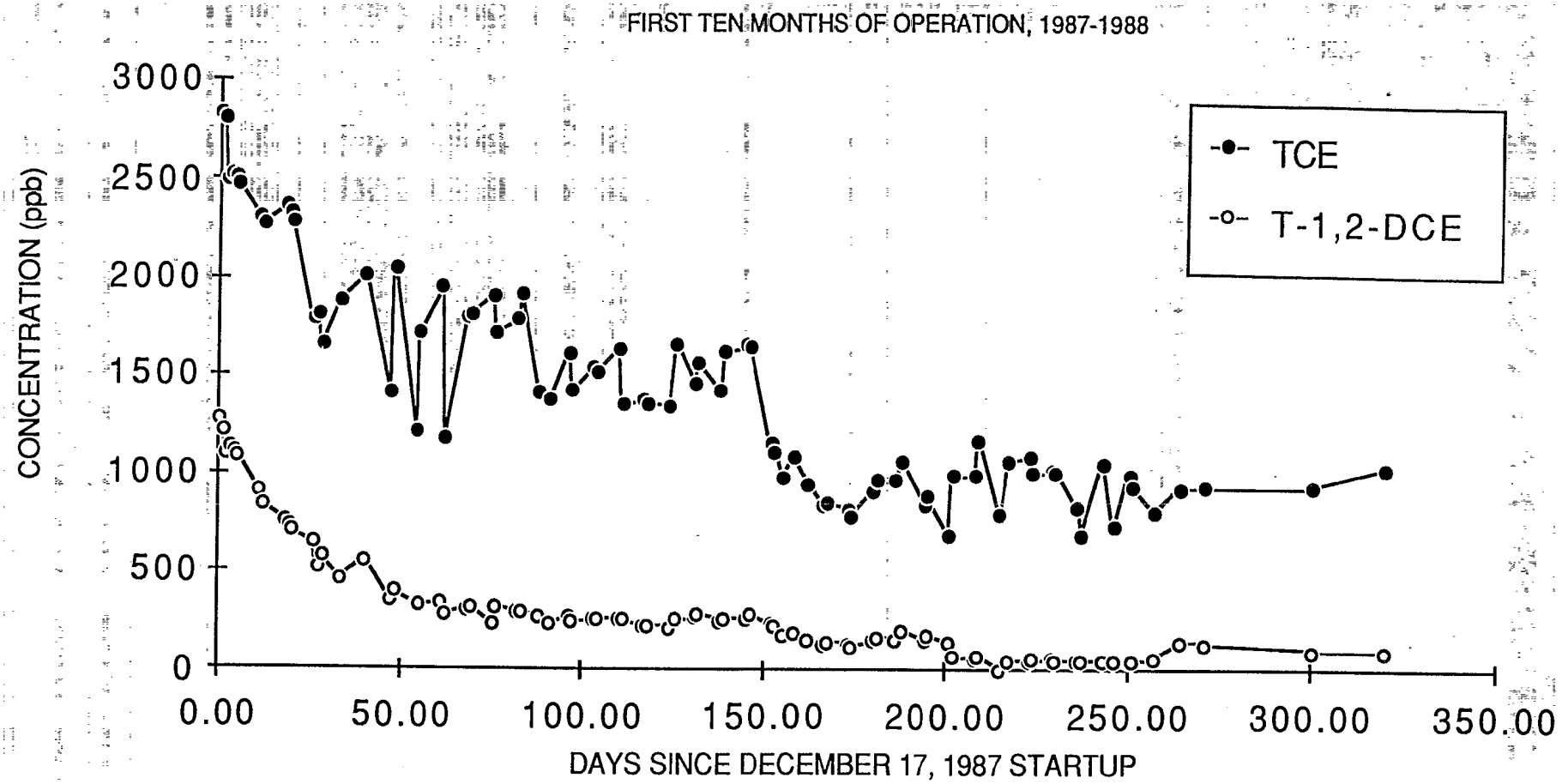
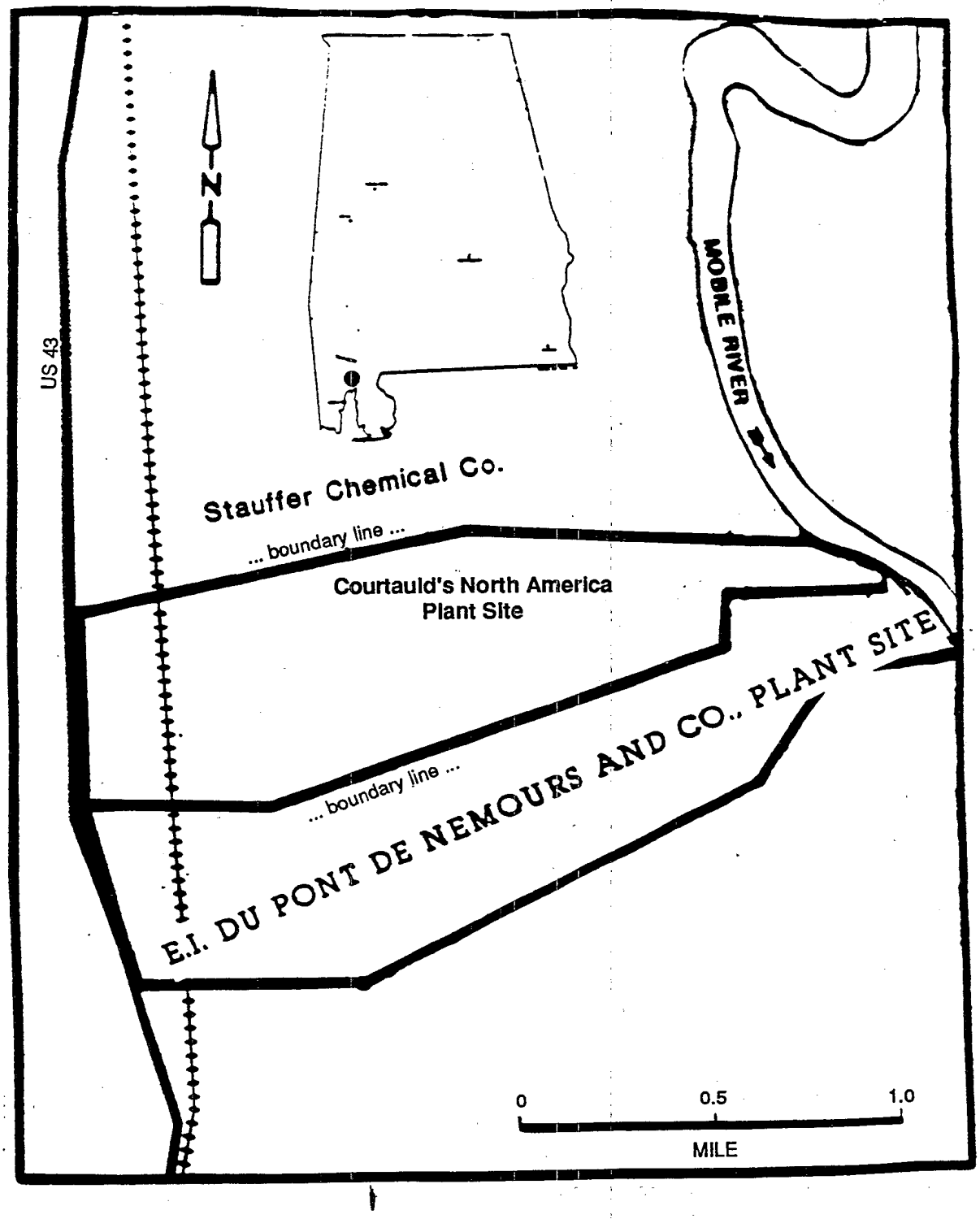
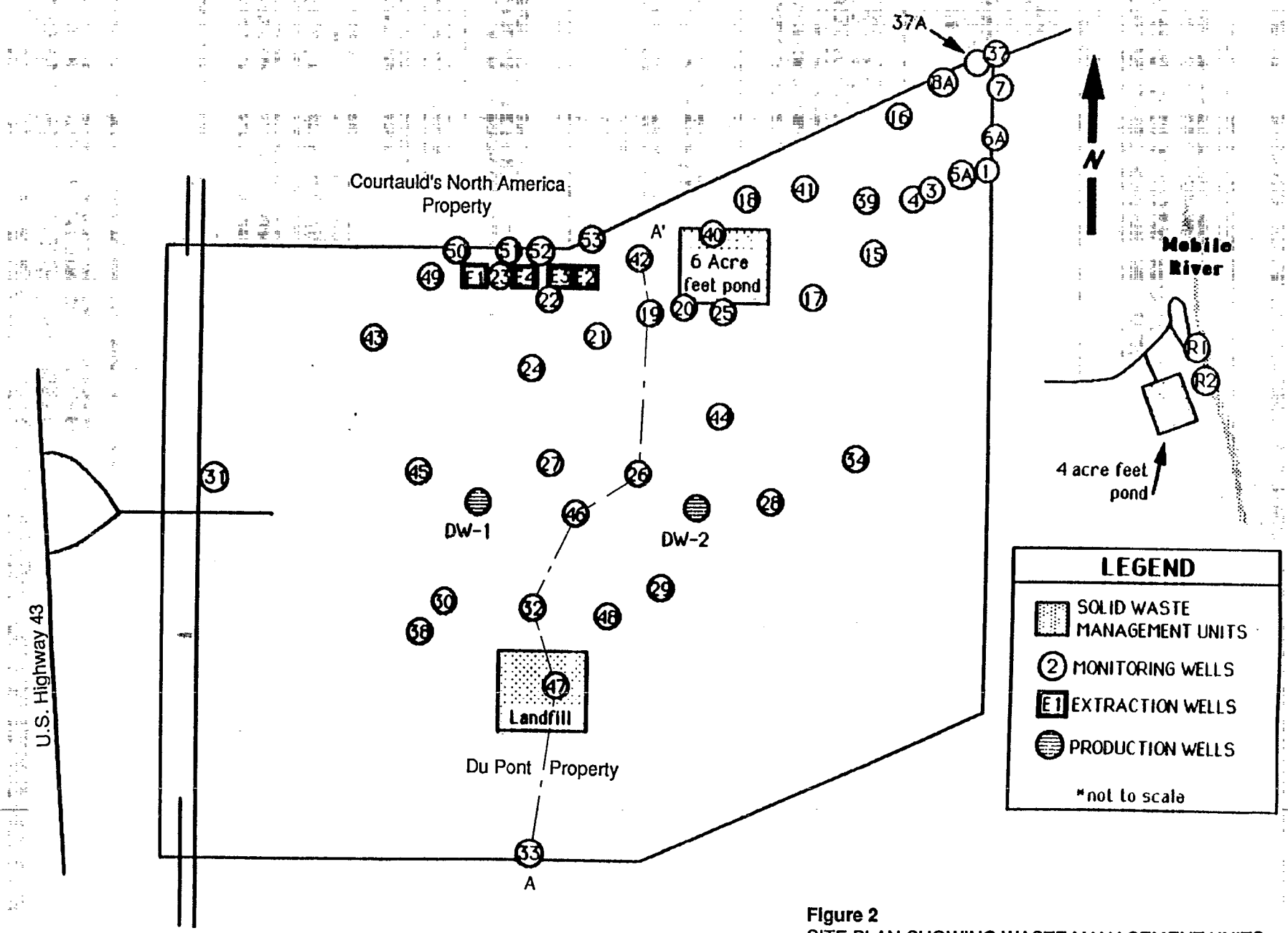


Figure 10
AIR STRIPPER INFLUENT CONCENTRATIONS



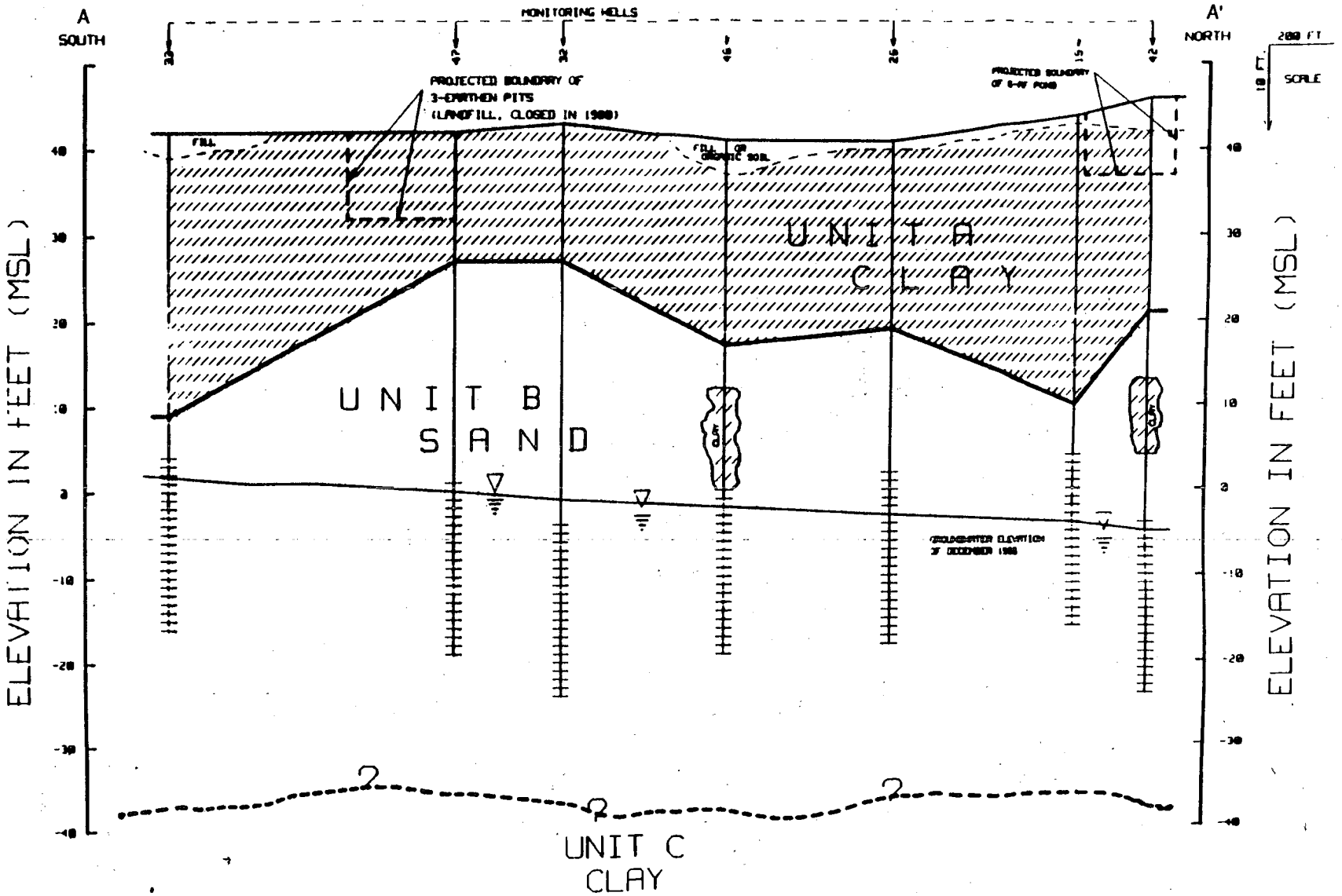
Source: DuPont. November, 1988.

Figure 1
SITE LOCATION MAP
DU PONT MOBILE PLANT
AXIS, ALABAMA



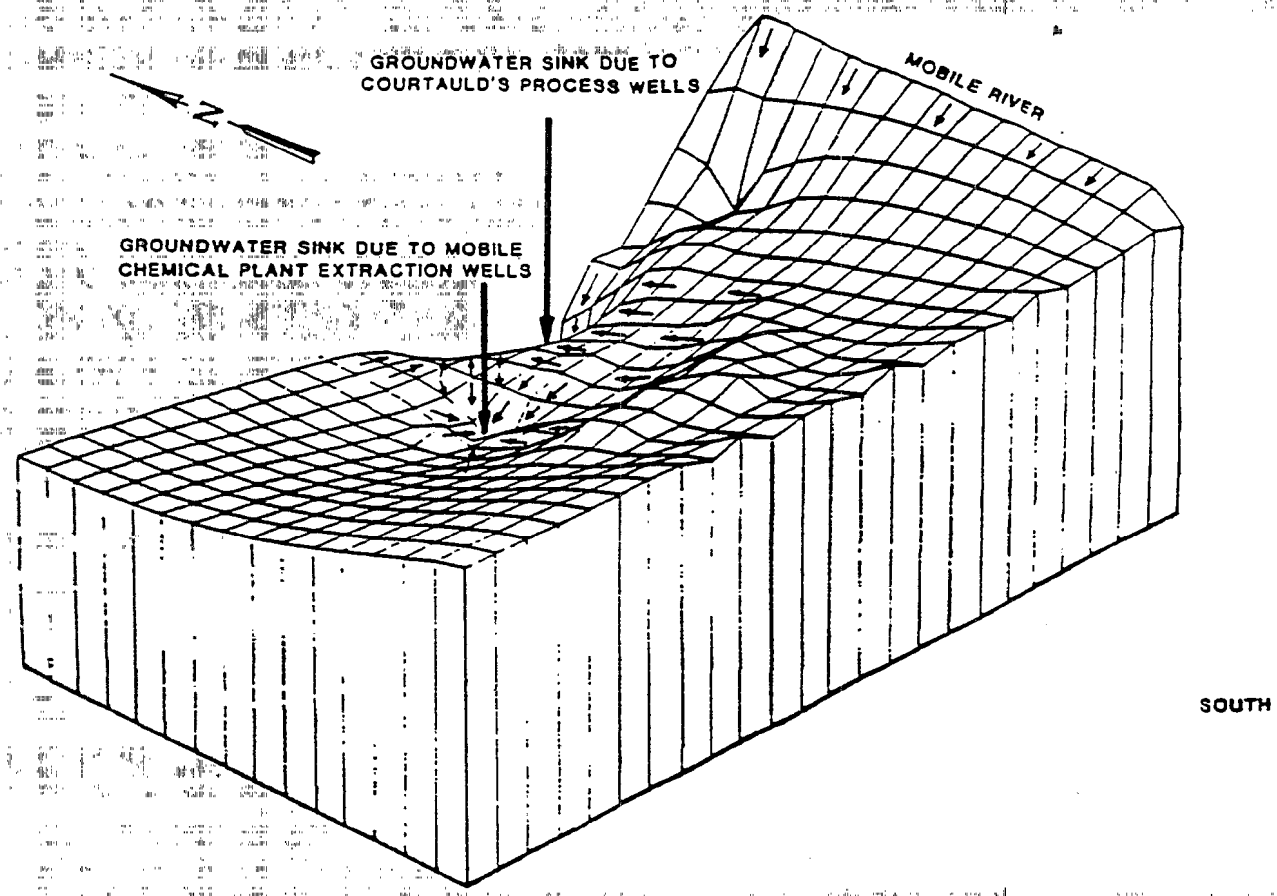
Source: DuPont. November, 1988.

Figure 2
SITE PLAN SHOWING WASTE MANAGEMENT UNITS, WELLS, AND LOCATION OF GEOLOGIC CROSS-SECTION A-A'
DU PONT MOBILE PLANT



Source: DuPont. November, 1988.

Figure 3
GEOLOGIC CROSS-SECTION A-A'
DU PONT MOBILE PLANT



Source: DuPont. November, 1988.

Figure 4
GROUND-WATER SOURCES AND SINKS AT THE DU PONT MOBILE SITE

Table 2
MAXIMUM CONCENTRATIONS OF CHEMICAL CONSTITUENTS OBSERVED IN GROUND-WATER MONITORING WELLS

Ground-Water Chemical Constituent	Regulatory Standard (ug/l)*	Soil-Water Partition Coefficient** K_{oc}	Maximum Concentration (ppb)	Monitoring Wells	Dates
Volatile Organics					
Acrolein	540	0.49	144	DW-2	9-84
Benzene	5	65	5	51	7-85
Carbon Tetrachloride (CBT)	5	232	5,815	52	6-87
Chloroform (CRF)	100	34	2,200	24	7-84
Chlorobenzene	488	318	42	22	12-87
Dibromochloropropane	--	--	3.2	27	11-84
Dichlorobromomethane	--	61	260	27	11-84
1,1-Dichloroethylene	7	65	10	23, 51, 52, 53	3-87
Ethylbenzene	2,400	1,100	11.2	51	7-85
Methylene Chloride	--	9	63	27	11-84
Tetrachloroethylene	0.88	364	48.8	32	11-84
Toluene	15,000	300	12.8	51	7-85
1,2-Trans-dichloroethylene	--	59	42	24	8-86
1,1,1-Trichloroethane	200	152	42	27	11-84
Trichloroethylene (TCE)	5	126	3,940	24	9-84
1,2-Dichloroethane	5	14	3.24	E-2	9-86
1,1,2,2-Tetrachloroethane	0.17	118	73	32	6-87
1,1-Dichloroethane	--	30	13.9	23	9-86
Base Neutrals					
Isophorone	5,200	87	19	32	11-84
1,2,4-Trichlorobenzene (TCB)	--	9,200	6,270	32	11-84
Pesticides					
Atrazine	--	--	179	25	6-87
Bladex	--	--	193	25	6-86
Rabon	--	--	2	18, R-1	7-84
Pydrin	--	--	4.4	32	12-87

*Safe Drinking Water Act MCL, if applicable. Otherwise, excess 10^{-6} cancer risk concentration.

**K_{oc} in ml/g compiled from a variety of sources.

WDR426/020.50

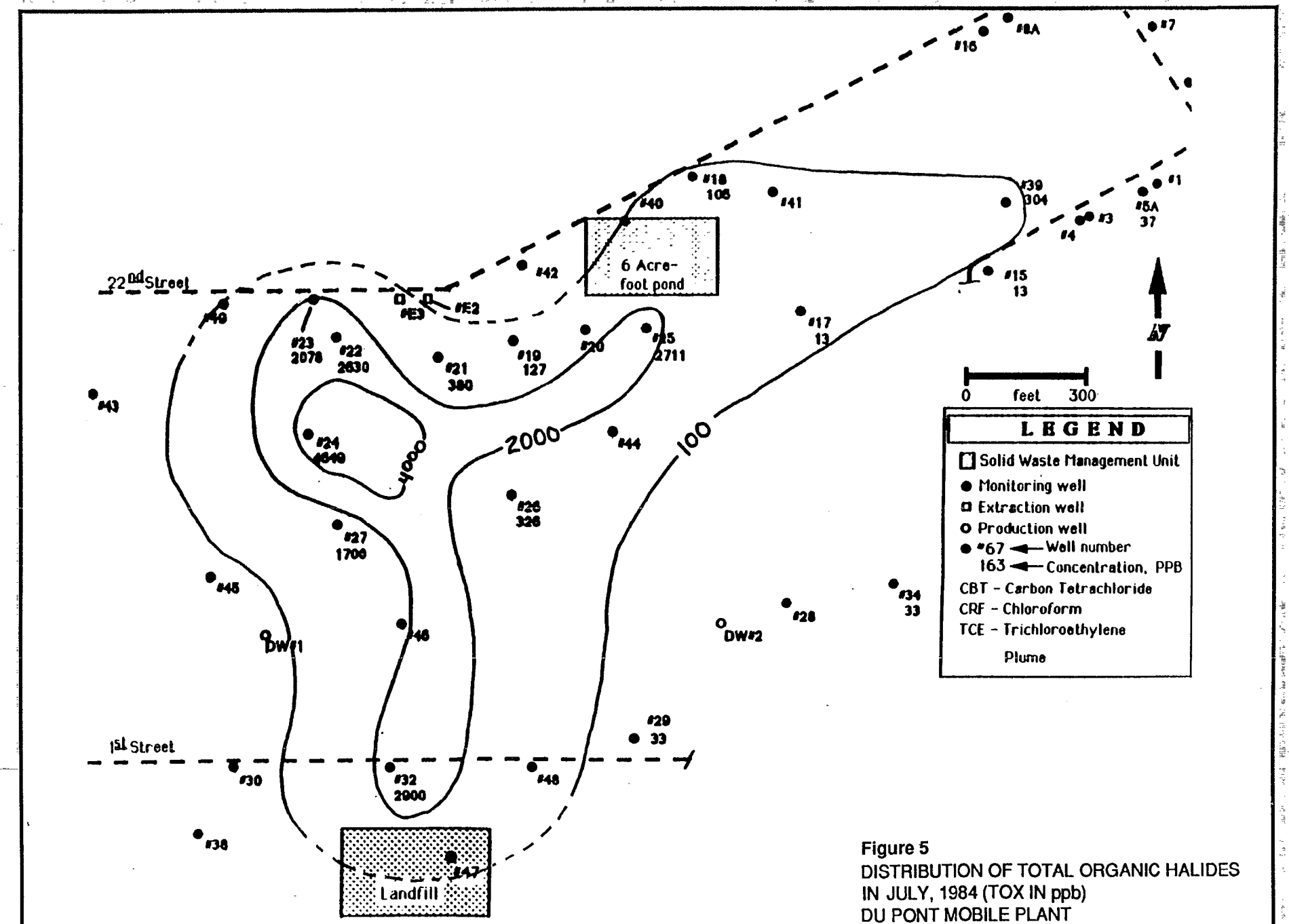


Figure 5
DISTRIBUTION OF TOTAL ORGANIC HALIDES
IN JULY, 1984 (TOX IN ppb)
DU PONT MOBILE PLANT

Source: DuPont. November, 1988.

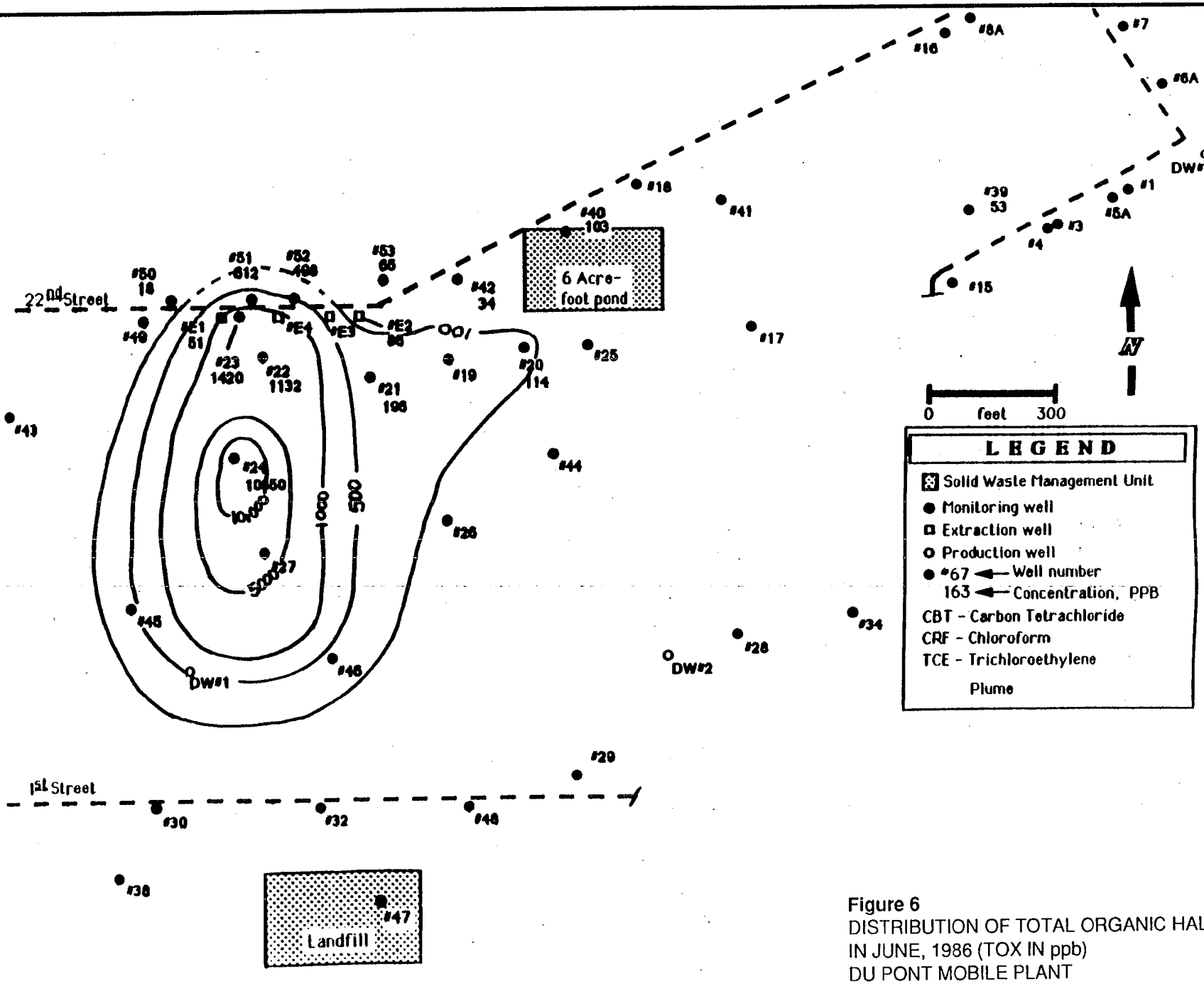


Figure 6
DISTRIBUTION OF TOTAL ORGANIC HALIDES IN JUNE, 1986 (TOX IN ppb)
DU PONT MOBILE PLANT

Source: DuPont. November, 1988.

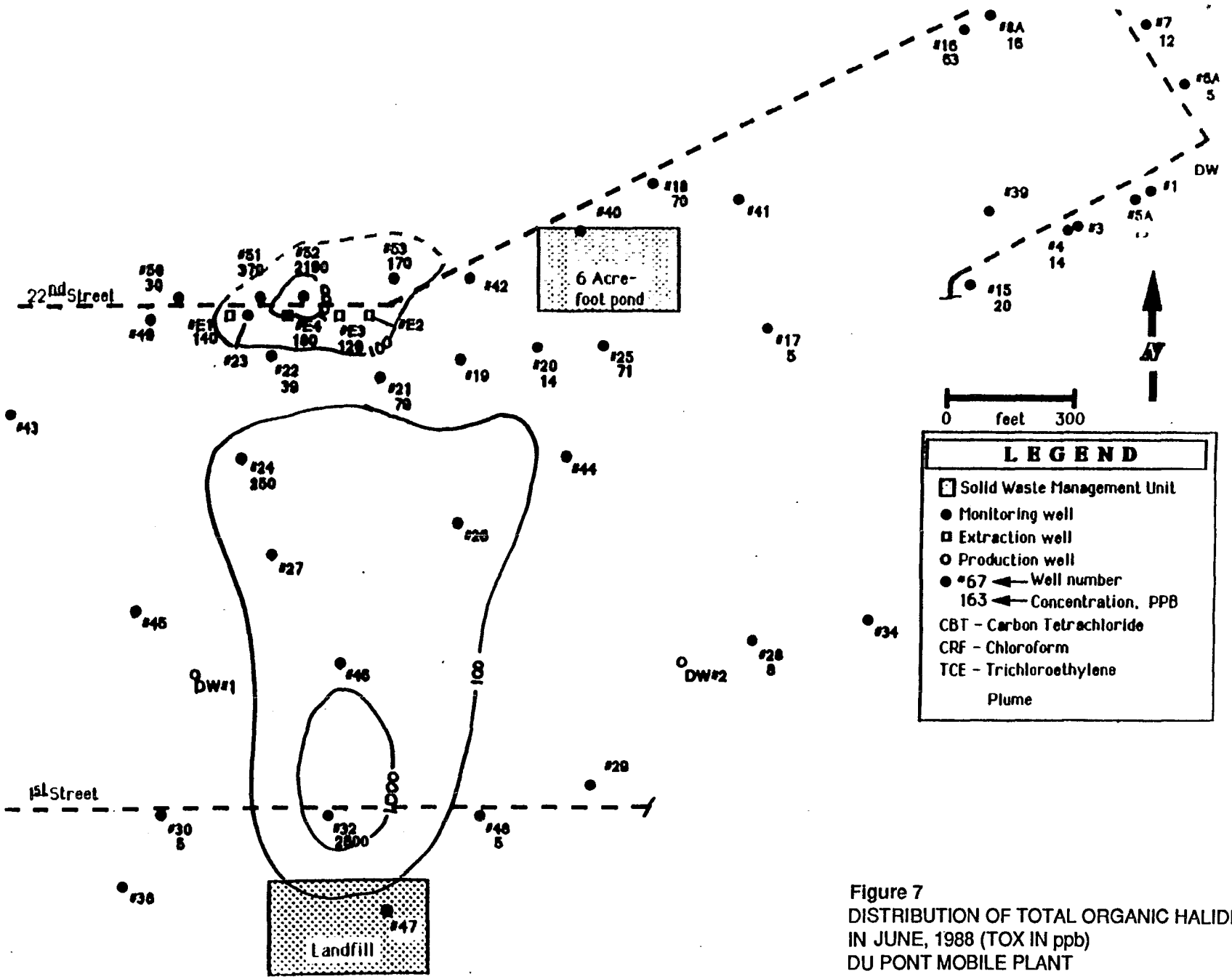


Figure 7
DISTRIBUTION OF TOTAL ORGANIC HALIDES
IN JUNE, 1988 (TOX IN ppb)
DU PONT MOBILE PLANT

Source: DuPont. November, 1988.

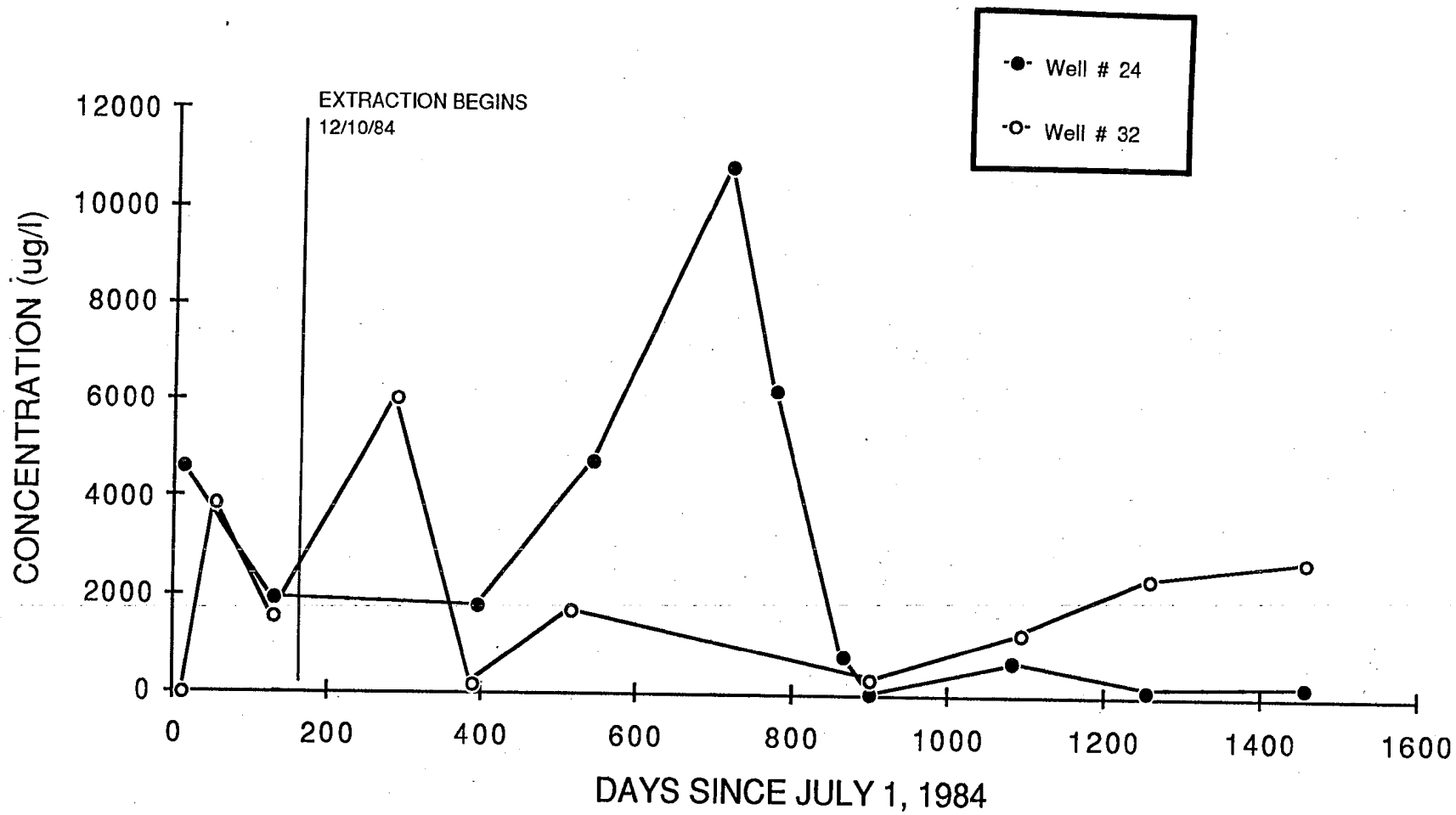


Figure 8
TOX CONCENTRATIONS IN TWO WELLS INSIDE THE PLUME
DU PONT MOBILE PLANT

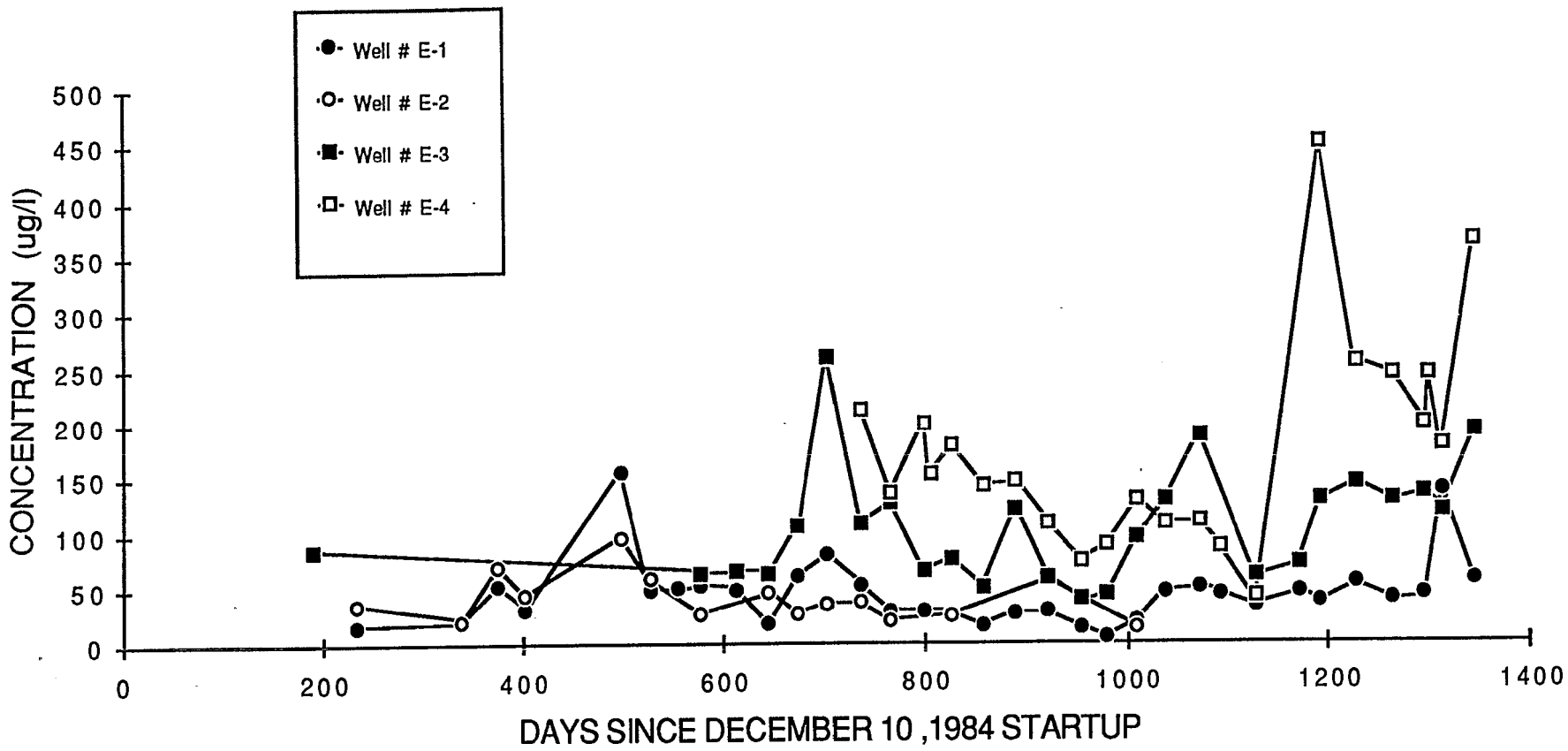
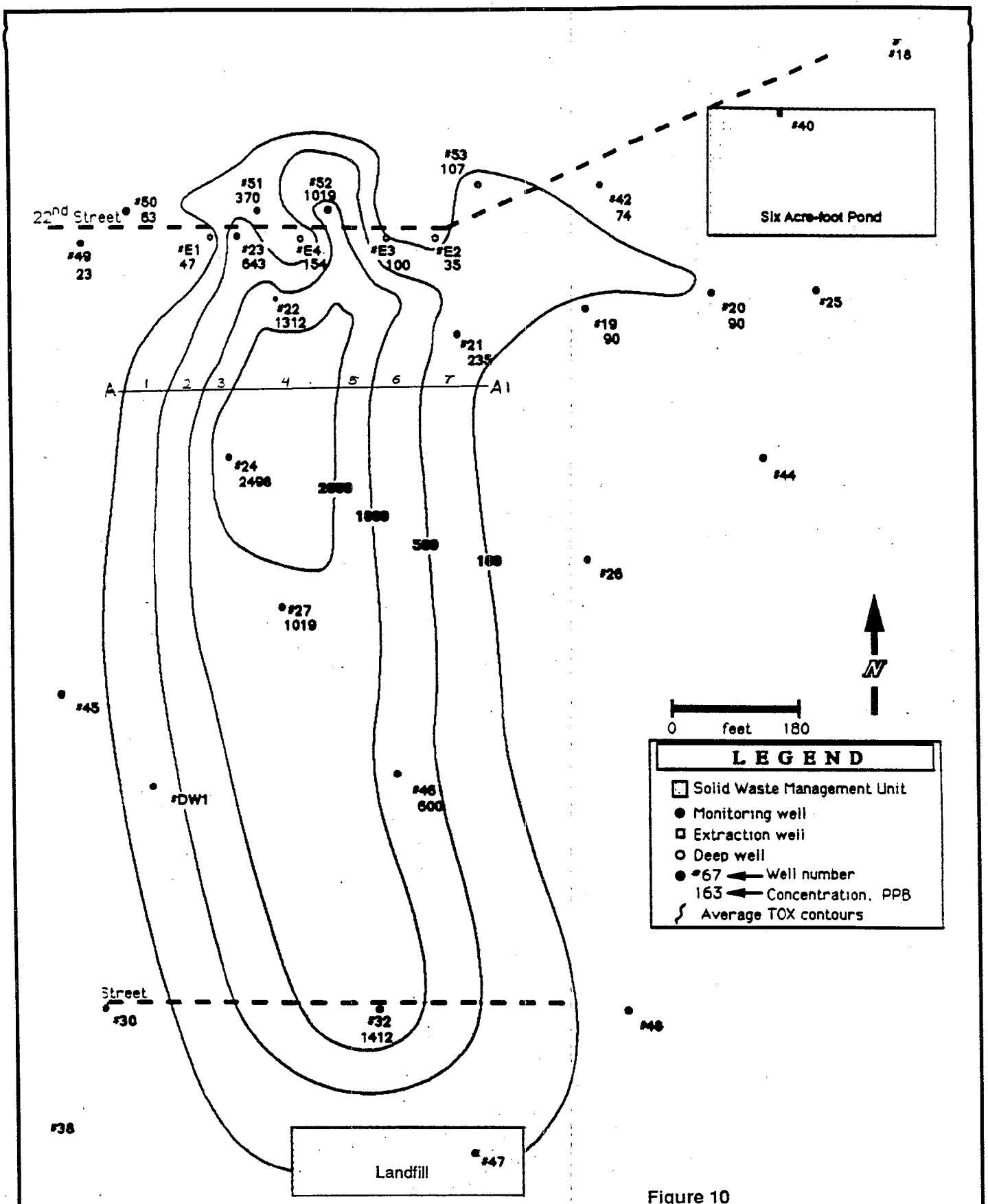
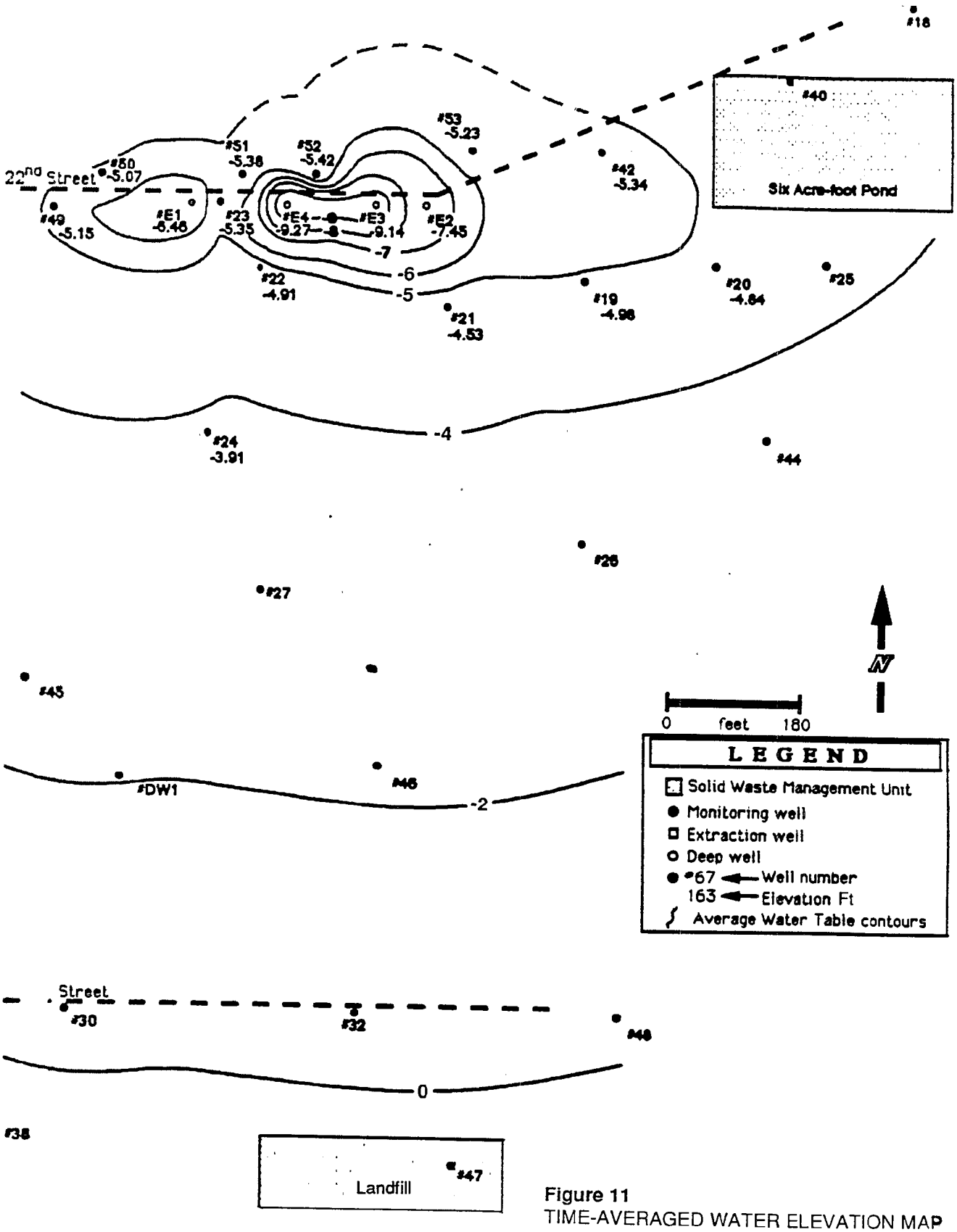


Figure 9
TOX CONCENTRATIONS IN FOUR
EXTRACTION WELLS
DU PONT MOBILE PLANT



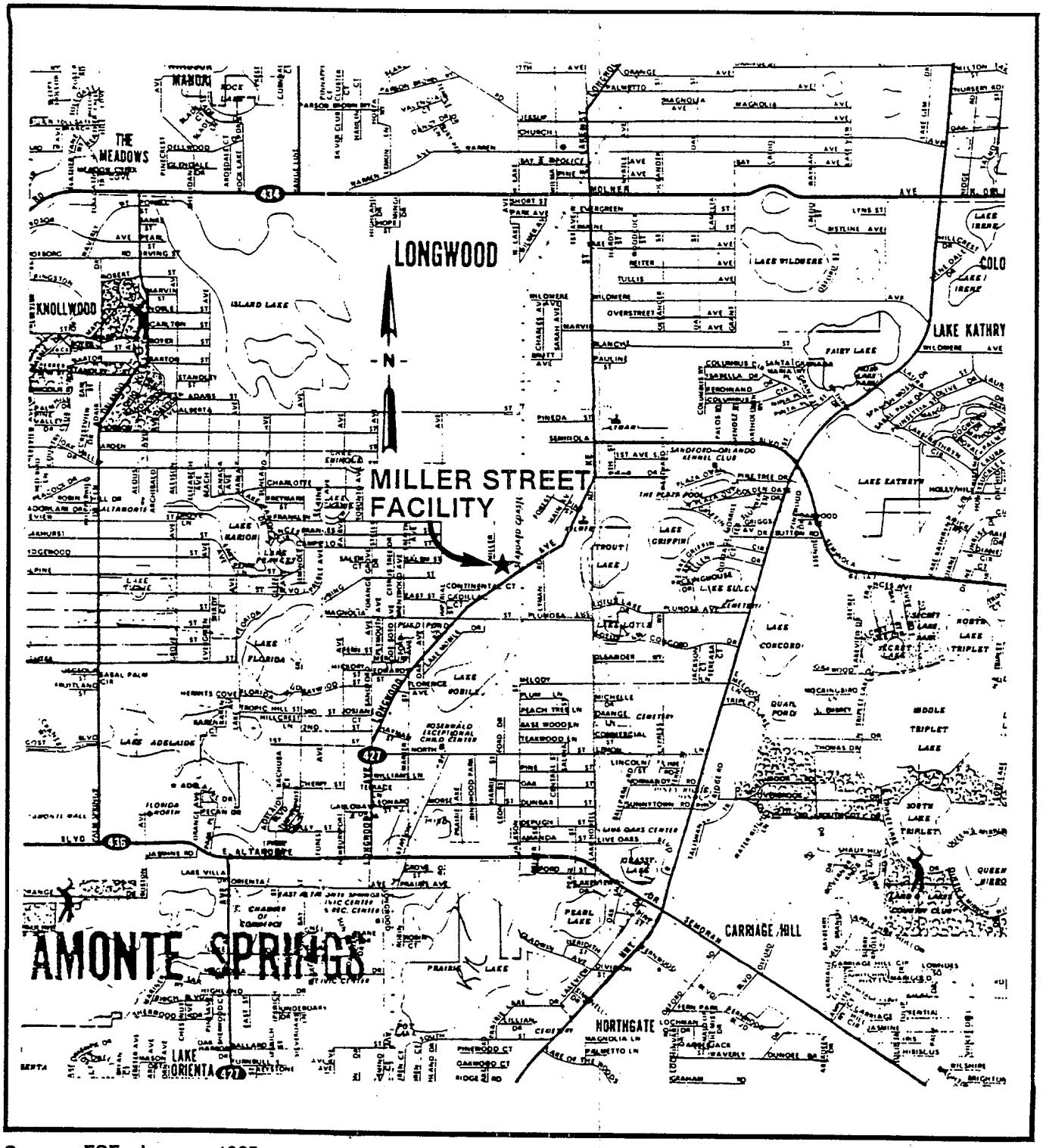
Source: DuPont. November, 1988.

Figure 10
TIME-AVERAGED TOTAL ORGANIC HALIDE PLUME
DU PONT MOBILE PLANT



Source: DuPont, November, 1988.

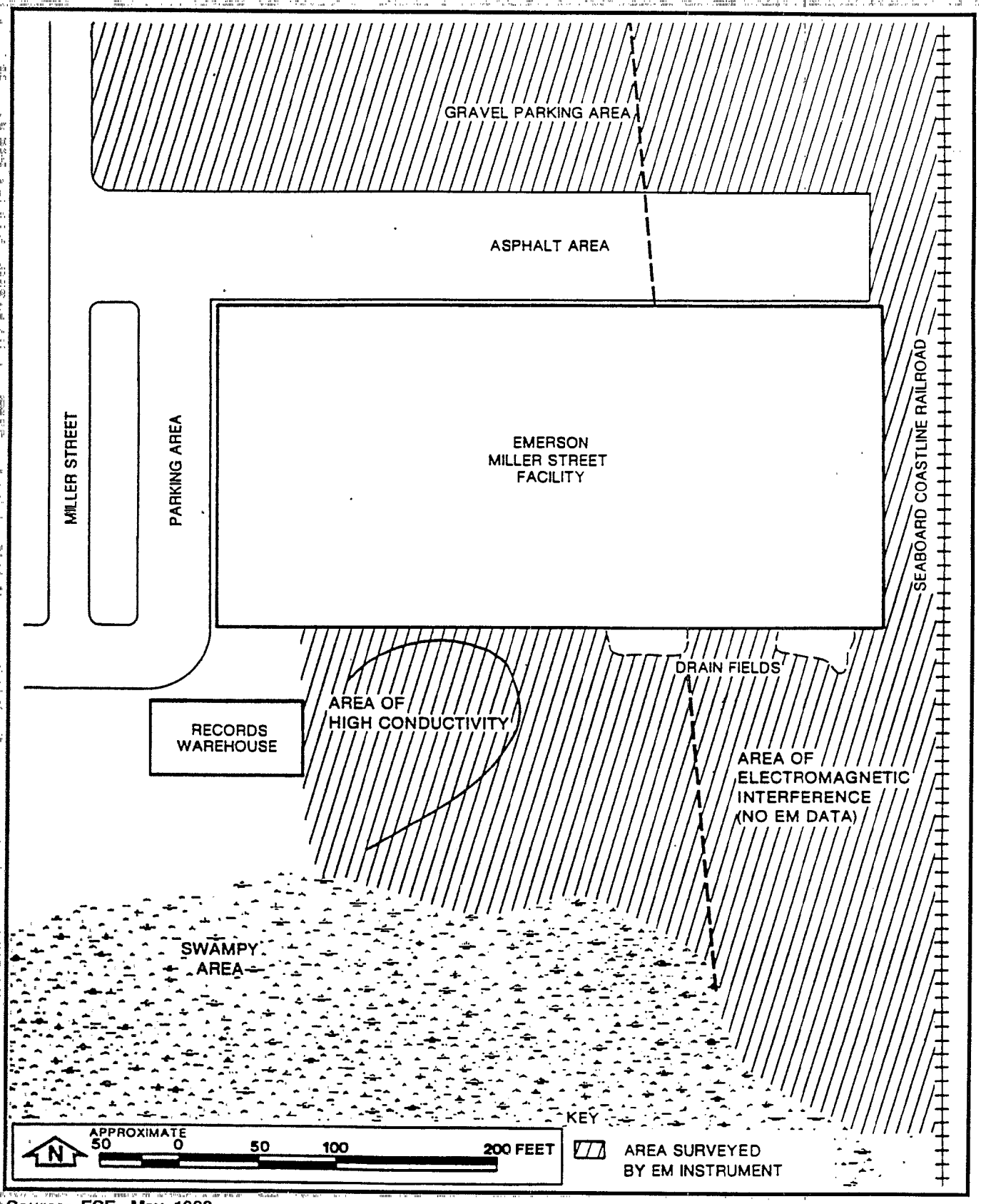
Figure 11
TIME-AVERAGED WATER ELEVATION MAP
DU PONT MOBILE PLANT



Source: ESE. January, 1985.

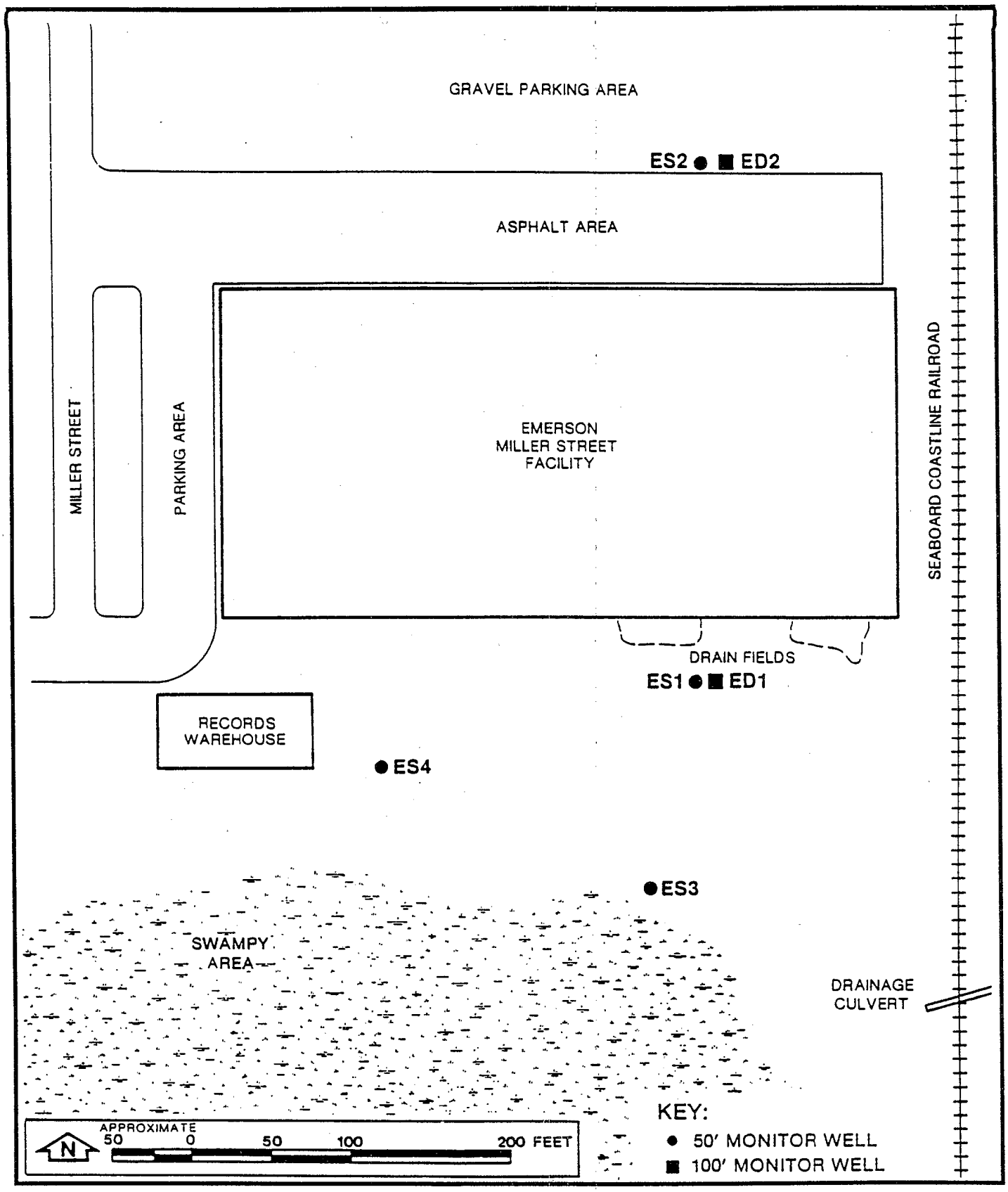
Figure 1
LOCATION MAP
ATLANTIC SPRINGS, FLORIDA
EMERSON ELECTRIC SITE

WOC 61621.AO.02



Source: ESE. May, 1982.

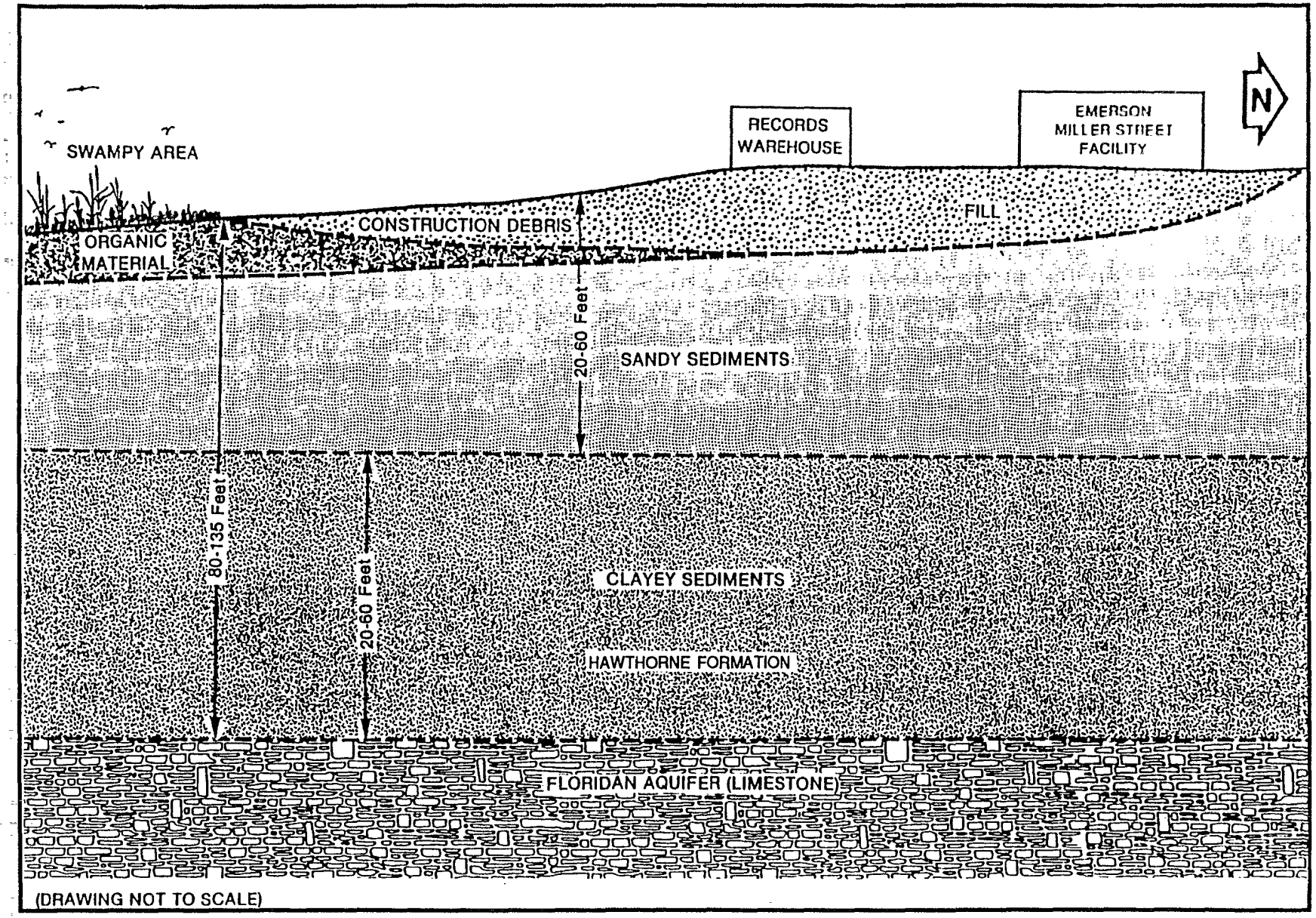
Figure 2
CONDUCTIVITY SURVEY
EMERSON ELECTRIC SITE



Source: ESE. November, 1982.

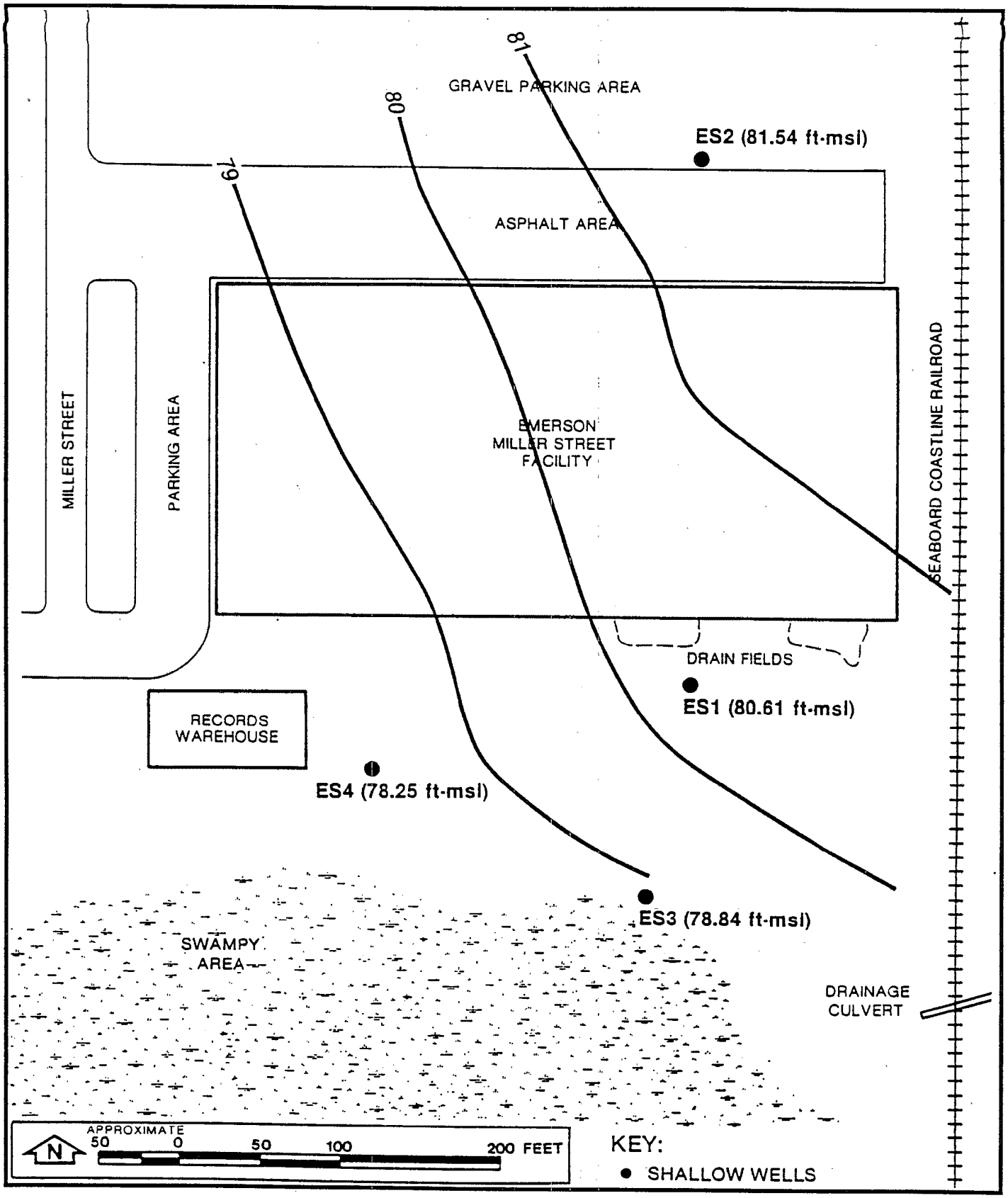
Figure 3
DETAILED SITE MAP SHOWING LOCATIONS OF WELLS INSTALLED IN AUGUST 1982
EMERSON ELECTRIC SITE

WDC 61621.A0.02



Source: ESE. May, 1982.

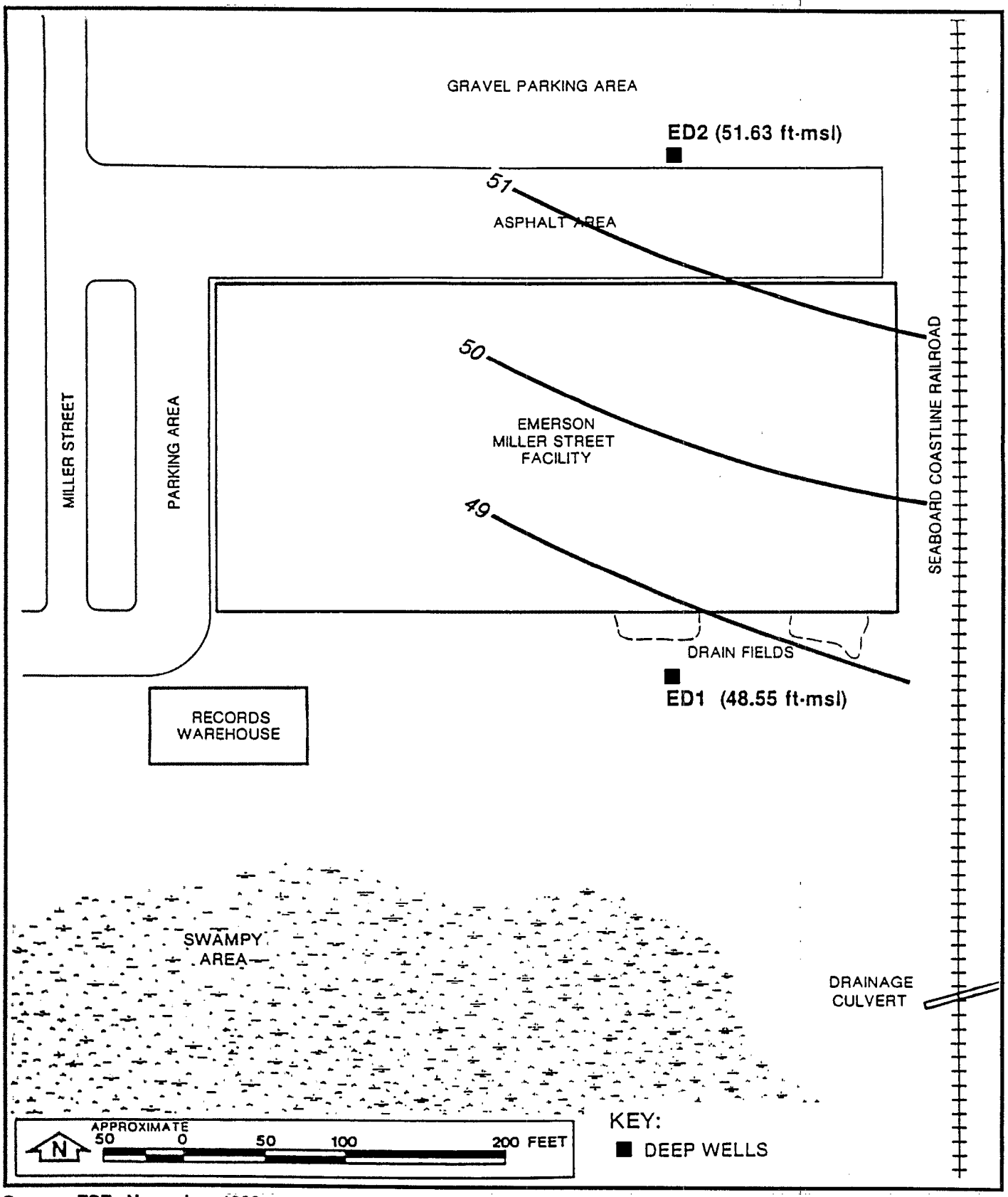
Figure 4
GENERALIZED GEOLOGIC CROSS SECTION
EMERSON ELECTRIC SITE



Source: ESE. November, 1982.

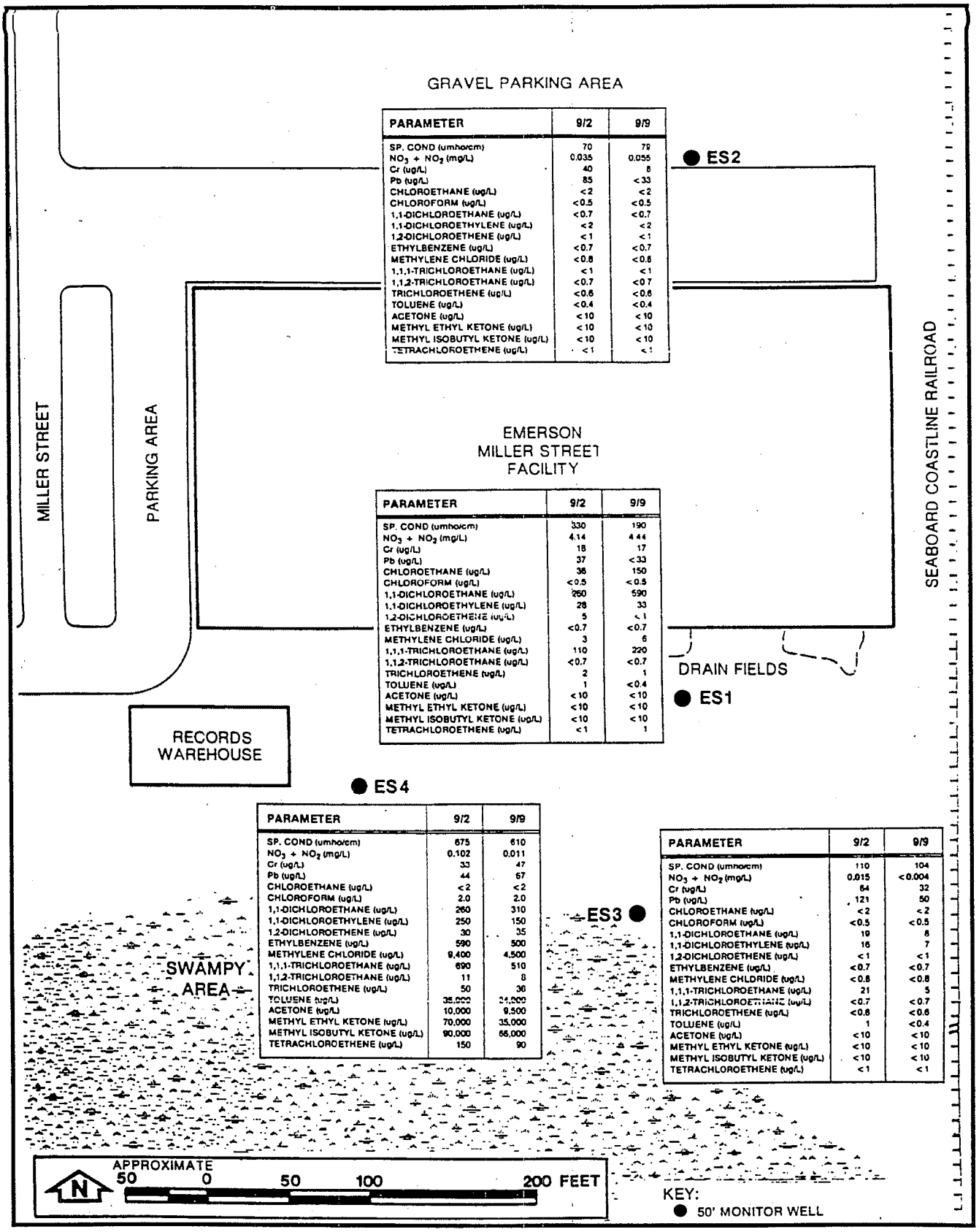
Figure 5
POTENTIOMETRIC SURFACE MAP OF SHALLOW AQUIFER SEPTEMBER 2, 1982
EMERSON ELECTRIC SITE

WDC 61621.AO.02



Source: ESE. November, 1982.

Figure 6
POTENTIOMETRIC SURFACE MAP OF FLORIDAN AQUIFER SEPTEMBER 2, 1982
EMERSON ELECTRIC SITE



PARAMETER	9/2	9/9
SP. COND (umho/cm)	70	79
$NO_3 + NO_2$ (mg/L)	0.035	0.055
Cr (ug/L)	40	8
Pb (ug/L)	85	<33
CHLOROETHANE (ug/L)	<2	<2
CHLOROFORM (ug/L)	<0.5	<0.5
1,1-DICHLOROETHANE (ug/L)	<0.7	<0.7
1,1-DICHLOROETHYLENE (ug/L)	<2	<2
1,2-DICHLOROETHENE (ug/L)	<1	<1
ETHYLBENZENE (ug/L)	<0.7	<0.7
METHYLENE CHLORIDE (ug/L)	<0.8	<0.8
1,1,1-TRICHLOROETHANE (ug/L)	<1	<1
1,1,2-TRICHLOROETHANE (ug/L)	<0.7	<0.7
TRICHLOROETHENE (ug/L)	<0.8	<0.8
TOLUENE (ug/L)	<0.4	<0.4
ACETONE (ug/L)	<10	<10
METHYL ETHYL KETONE (ug/L)	<10	<10
METHYL ISOBUTYL KETONE (ug/L)	<10	<10
TETRACHLOROETHENE (ug/L)	<1	<1

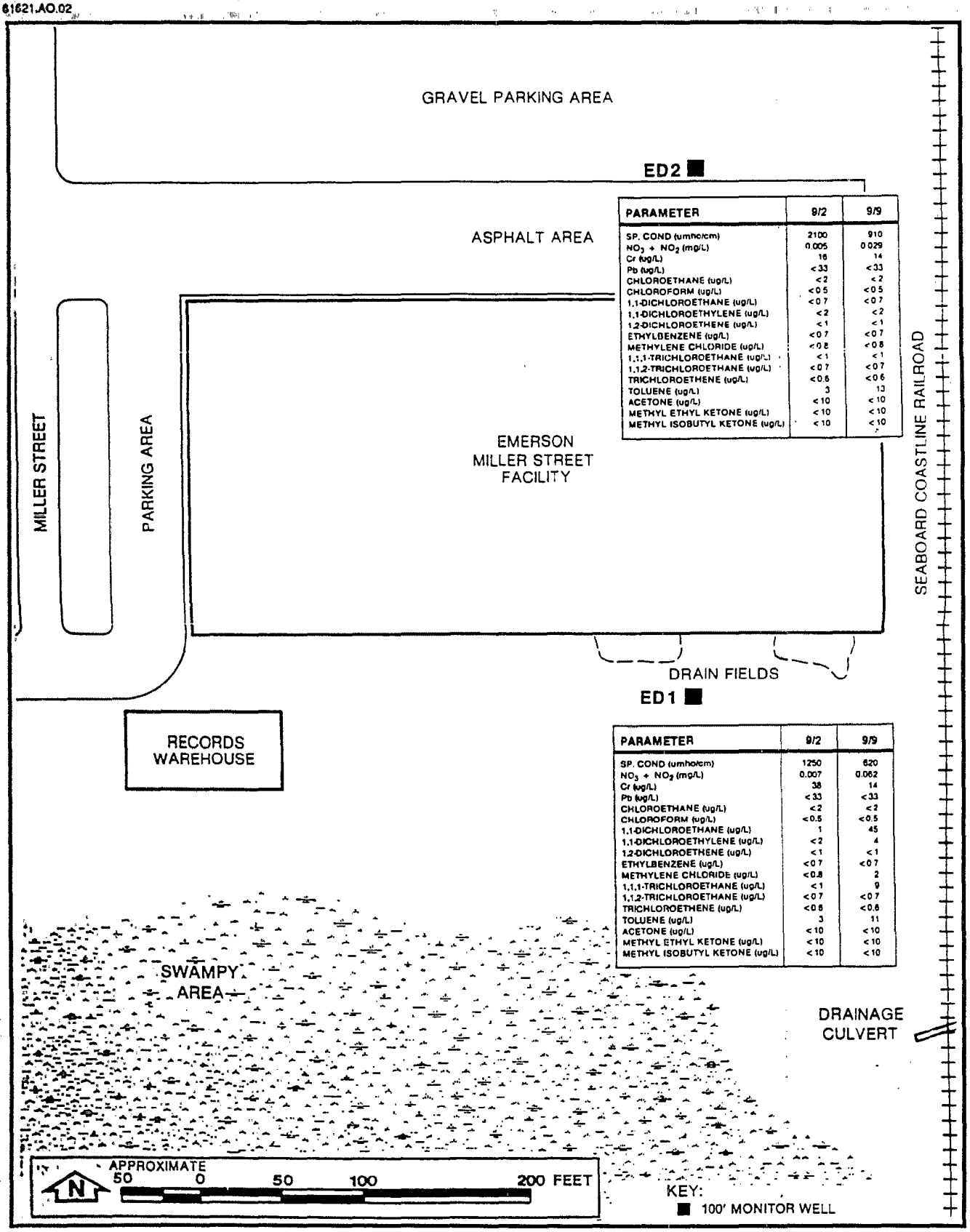
PARAMETER	9/2	9/9
SP. COND (umho/cm)	330	190
$NO_3 + NO_2$ (mg/L)	4.14	4.44
Cr (ug/L)	18	17
Pb (ug/L)	37	<33
CHLOROETHANE (ug/L)	36	150
CHLOROFORM (ug/L)	<0.5	<0.5
1,1-DICHLOROETHANE (ug/L)	260	590
1,1-DICHLOROETHYLENE (ug/L)	28	33
1,2-DICHLOROETHENE (ug/L)	5	<1
ETHYLBENZENE (ug/L)	<0.7	<0.7
METHYLENE CHLORIDE (ug/L)	3	6
1,1,1-TRICHLOROETHANE (ug/L)	110	220
1,1,2-TRICHLOROETHANE (ug/L)	<0.7	<0.7
TRICHLOROETHENE (ug/L)	2	1
TOLUENE (ug/L)	1	<0.4
ACETONE (ug/L)	<10	<10
METHYL ETHYL KETONE (ug/L)	<10	<10
METHYL ISOBUTYL KETONE (ug/L)	<10	<10
TETRACHLOROETHENE (ug/L)	<1	1

PARAMETER	9/2	9/9
SP. COND (umho/cm)	675	610
$NO_3 + NO_2$ (mg/L)	0.102	0.011
Cr (ug/L)	33	47
Pb (ug/L)	44	67
CHLOROETHANE (ug/L)	<2	<2
CHLOROFORM (ug/L)	2.0	2.0
1,1-DICHLOROETHANE (ug/L)	260	310
1,1-DICHLOROETHYLENE (ug/L)	250	150
1,2-DICHLOROETHENE (ug/L)	30	35
ETHYLBENZENE (ug/L)	590	500
METHYLENE CHLORIDE (ug/L)	9,400	4,500
1,1,1-TRICHLOROETHANE (ug/L)	690	510
1,1,2-TRICHLOROETHANE (ug/L)	11	8
TRICHLOROETHENE (ug/L)	50	36
TOLUENE (ug/L)	35,000	24,000
ACETONE (ug/L)	10,000	9,500
METHYL ETHYL KETONE (ug/L)	70,000	35,000
METHYL ISOBUTYL KETONE (ug/L)	90,000	66,000
TETRACHLOROETHENE (ug/L)	150	90

PARAMETER	9/2	9/9
SP. COND (umho/cm)	110	104
$NO_3 + NO_2$ (mg/L)	0.015	<0.004
Cr (ug/L)	64	32
Pb (ug/L)	121	50
CHLOROETHANE (ug/L)	<2	<2
CHLOROFORM (ug/L)	<0.5	<0.5
1,1-DICHLOROETHANE (ug/L)	19	8
1,1-DICHLOROETHYLENE (ug/L)	16	7
1,2-DICHLOROETHENE (ug/L)	<1	<1
ETHYLBENZENE (ug/L)	<0.7	<0.7
METHYLENE CHLORIDE (ug/L)	<0.8	<0.8
1,1,1-TRICHLOROETHANE (ug/L)	21	5
1,1,2-TRICHLOROETHANE (ug/L)	<0.7	<0.7
TRICHLOROETHENE (ug/L)	<0.8	<0.8
TOLUENE (ug/L)	1	<0.4
ACETONE (ug/L)	<10	<10
METHYL ETHYL KETONE (ug/L)	<10	<10
METHYL ISOBUTYL KETONE (ug/L)	<10	<10
TETRACHLOROETHENE (ug/L)	<1	<1

Source: ESE. November, 1982.

Figure 7
CONTAMINANT CONCENTRATIONS OBSERVED IN SURFICIAL AQUIFER, SEPTEMBER 1982
EMERSON ELECTRIC SITE



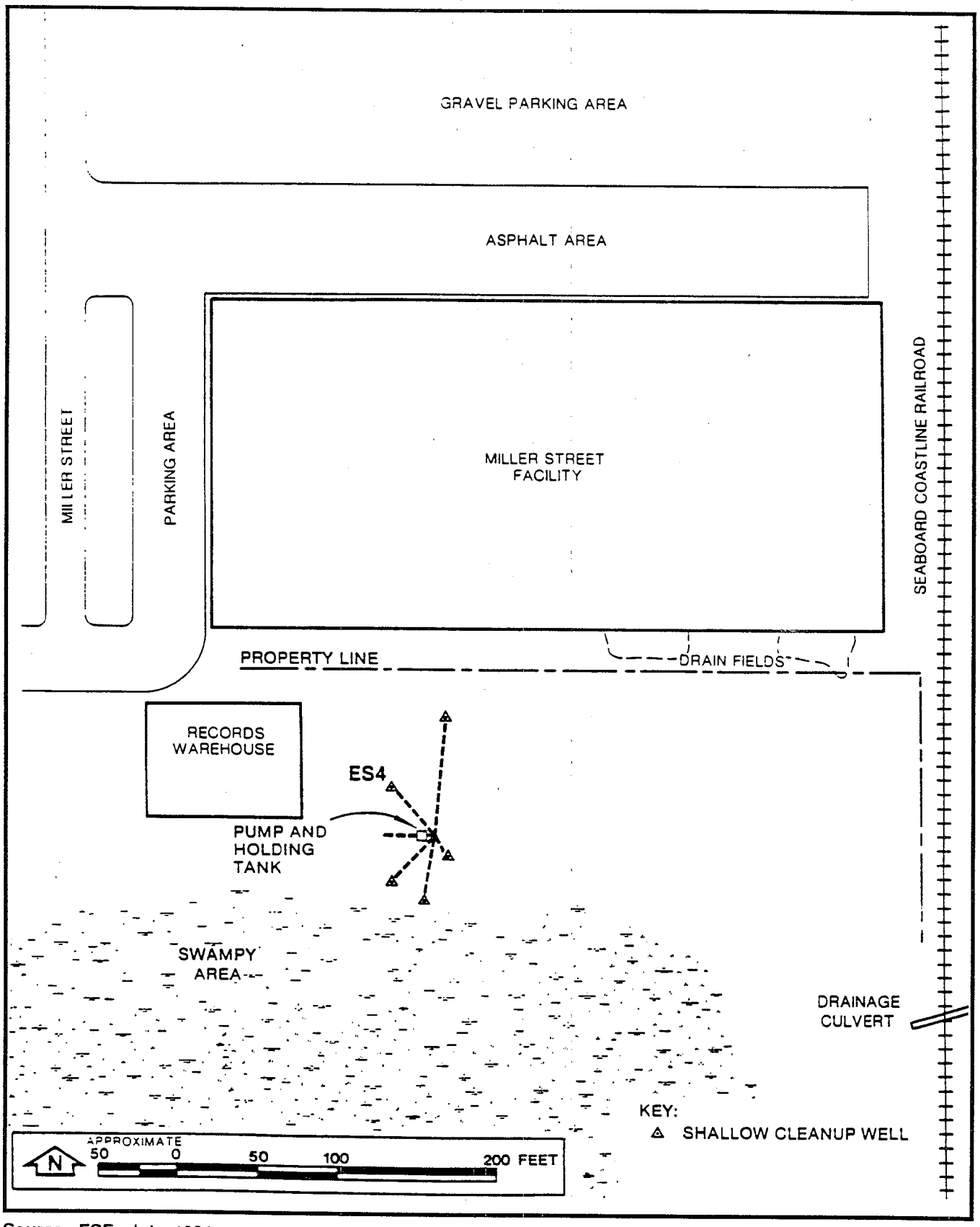
PARAMETER	9/2	9/9
SP. COND (umho/cm)	2100	910
NO_3 + NO_2 (mg/L)	0.005	0.029
Cr (ug/L)	16	14
Pb (ug/L)	< 33	< 33
CHLOROETHANE (ug/L)	< 2	< 2
CHLOROFORM (ug/L)	< 0.5	< 0.5
1,1-DICHLOROETHANE (ug/L)	< 0.7	< 0.7
1,1-DICHLOROETHYLENE (ug/L)	< 2	< 2
1,2-DICHLOROETHENE (ug/L)	< 1	< 1
ETHYLBENZENE (ug/L)	< 0.7	< 0.7
METHYLENE CHLORIDE (ug/L)	< 0.8	< 0.8
1,1,1-TRICHLOROETHANE (ug/L)	< 1	< 1
1,1,2-TRICHLOROETHANE (ug/L)	< 0.7	< 0.7
TRICHLOROETHENE (ug/L)	< 0.6	< 0.6
TOLUENE (ug/L)	3	13
ACETONE (ug/L)	< 10	< 10
METHYL ETHYL KETONE (ug/L)	< 10	< 10
METHYL ISOBUTYL KETONE (ug/L)	< 10	< 10

PARAMETER	9/2	9/9
SP. COND (umho/cm)	1250	620
NO_3 + NO_2 (mg/L)	0.007	0.062
Cr (ug/L)	38	14
Pb (ug/L)	< 33	< 33
CHLOROETHANE (ug/L)	< 2	< 2
CHLOROFORM (ug/L)	< 0.5	< 0.5
1,1-DICHLOROETHANE (ug/L)	1	45
1,1-DICHLOROETHYLENE (ug/L)	< 2	4
1,2-DICHLOROETHENE (ug/L)	< 1	< 1
ETHYLBENZENE (ug/L)	< 0.7	< 0.7
METHYLENE CHLORIDE (ug/L)	< 0.8	2
1,1,1-TRICHLOROETHANE (ug/L)	< 1	9
1,1,2-TRICHLOROETHANE (ug/L)	< 0.7	< 0.7
TRICHLOROETHENE (ug/L)	< 0.6	< 0.6
TOLUENE (ug/L)	3	11
ACETONE (ug/L)	< 10	< 10
METHYL ETHYL KETONE (ug/L)	< 10	< 10
METHYL ISOBUTYL KETONE (ug/L)	< 10	< 10

Source: ESE. November, 1982.

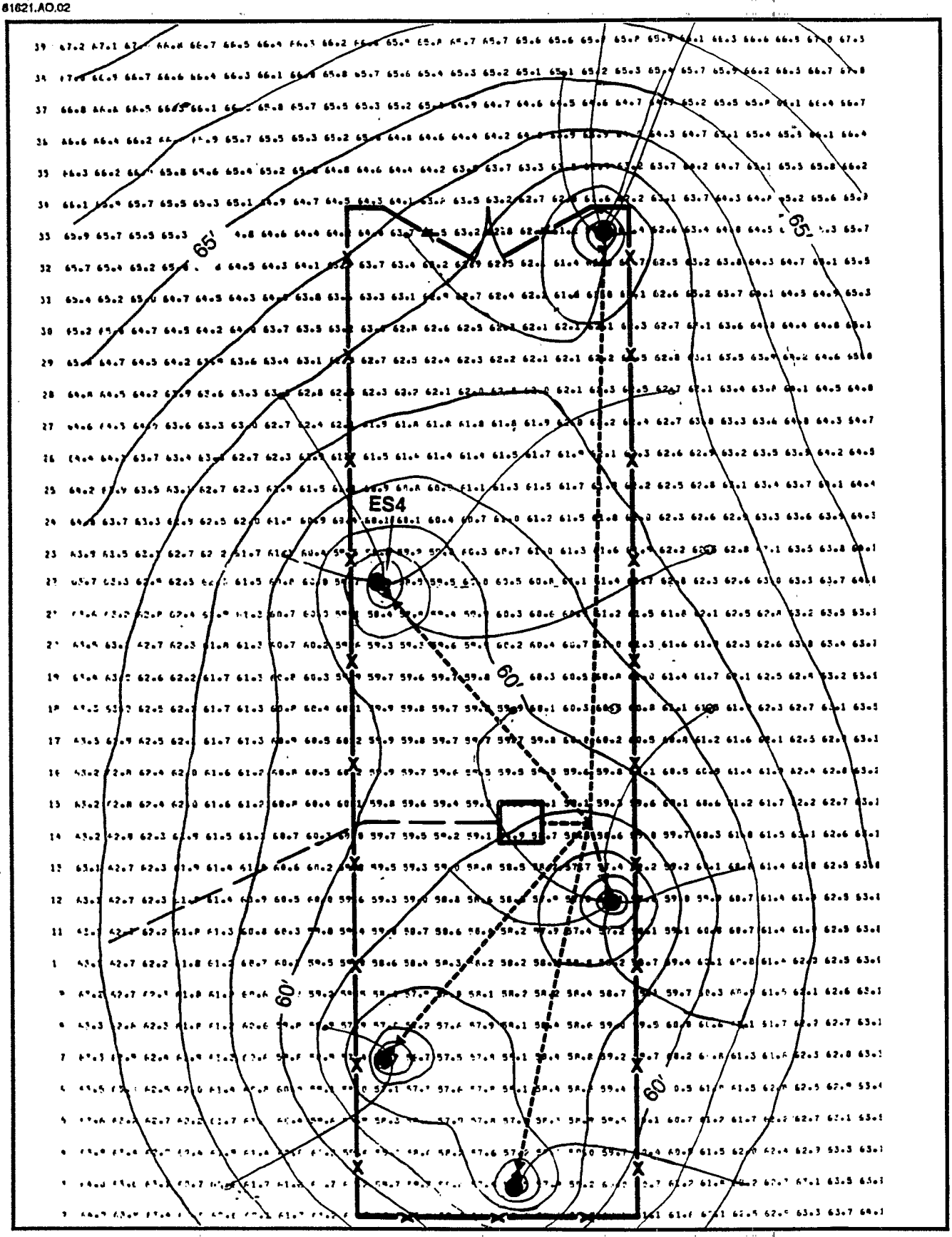
Figure 8
CONTAMINANT CONCENTRATIONS OBSERVED IN FLORIDAN AQUIFER, SEPTEMBER 1982
EMERSON ELECTRIC SITE

WDC61621.AO.02



Source: ESE. July, 1984.

Figure 9
EXTRACTION WELL SYSTEM
EMERSON ELECTRIC SITE



Source: ESE. July, 1984.

Figure 10
WATER LEVELS AND STREAMLINES PRODUCED BY COMPUTER MODELING OF EXISTING EXTRACTION SYSTEM
EMERSON ELECTRIC SITE

Table 1
COMPOSITE CONCENTRATION DATA FOR
EMERSON ELECTRIC TREATMENT SYSTEM

Compounds (ug/l)	Standards	1/85	2/85	3/85	4/85	5/85	6/85	9/85	11/85	12/85	1/86	2/86	3/86	4/86	5/86	6/86
Xylenes	440@	70	308	560	52	49	38	91	44	30	40	40	40	40	28	28.7
Methyl Ethyl Ketone	172+	240	115	454	360	430	280	1010	310	170	250	94	140	150	93	47
Methyl Isobutyl Ketone	NL	140	320	200	160	110	120	710	380	200	300	160	460	230	180	140
Acetone		130	137	135	64	140	78	257	43	70	BDL	40	40	70	15	9.1
Benzene	1	0.5	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
1,1-Dichloroethane	810+	47	51	56	46	36	38	39	28	25.1	26.7	23	20	21	18	17
1,1-Dichloroethylene	7	110	92	85	58	47	43	31	21	16.9	16.2	14	16	12	12	11
T-1,2-Dichloroethylene	70	1.5	BDL	BDL	BDL	BDL	BDL	1.9	BDL	BDL	BDL	BDL	BDL	BDL	1.5	1.4
Ethylbenzene	680	10	18	27	22	13	13	18	11	9.30	9.85	8.8	9.5	9.2	7.2	6.3
Methylene Chloride	5	5	6	17	BDL	BDL	BDL	11	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Tetrachloroethylene	3	2.3	1.7	2.5	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
1,1,1-Trichloroethane	200	97	84	91	60	50	50	48	28	19.2	19.6	17	15	13	11	9.5
Trichloroethylene	3	4.7	4.3	5.3	4.6	3	4	2.7	BDL	BDL	1.57	BDL	BDL	BDL	BDL	1.6
Trichlorofluoromethane	2400+	4	9	BDL	BDL	BDL	BDL	2	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Toluene	2000	350	260	270	180	100	120	89	45.4	30.2	31.7	26	18	18	20	17
Chloroform	100	BDL	BDL	8.9	BDL	BDL	BDL	BDL	BDL	BDL	1.9	BDL	BDL	BDL	BDL	BDL
1,1,2-Trichloroethane	6*	BDL	BDL	4	BDL	BDL	BDL	2.2	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL

Source: Internal FDER table
July, August, and October 1985--No data, recovery system down
All samples are composite samples except for May 1988 sample
NL - No established level
\+ - UIC Guidance concentration (10/86)
* - 10^{-5} cancer risk
@ - Proposed MCL, Safe Drinking Water Act, as amended as of 9/87
BDL - Below Detection Limit; Personal communication with Mr. James Breck Dalton/FDER, May 1, 1989

Table 1
(Continued)

Compounds (ug/l)	Standards	8/86	9/86	10/86	11/86	12/86	2/87	3/87	4/87	5/87	6/87	9/87	5/88#
Xylenes	440@	27.1	19.6	17	16	13	13	<12	12	<12	12	BDL	BDL
Methyl Ethyl Ketone	172+	24	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	<10
Methyl Isobutyl Ketone	NL	58	26	<12	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	<10
Acetone		<22	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Benzene	1	<1.0	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	1.5	<5 (Peak Absent)
1,1-Dichloroethane	810+	15	10	15	13	11	10	9.2	5.9	8.0	6.0	<4.7	<5
1,1-Dichloroethylene	7	10	6.2	9.1	11	7.5	8.0	5.2	5.3	6.0	4.0	<2.8	<5
T-1,2-Dichloroethylene	70	BDL	BDL	BDL	2.3	<1.6	BDL	BDL	BDL	BDL	BDL	BDL	<5
Ethylbenzene	680	6.4	4.4	<7.2	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	<5
Methylene Chloride	5	<2.8	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Tetrachloroethylene	3	<3.0	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	<5
1,1,1-Trichloroethane	200	7.9	5.5	6.5	8.1	5.9	8.8	<3.8	6.4	4.0	<3.0	<3.8	<5
Trichloroethylene	3	<3.0	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	<5
Trichlorofluoromethane	2400+	<3.2	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	<5
Toluene	2000	5.8	6.3	<6.0	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	<5
Chloroform	100	BDL	BDL	BDL	7.1	<1.6	BDL	BDL	BDL	BDL	BDL	BDL	<5
1,1,2-Trichloroethane	6*	<5.0	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	<5

Source: Internal FDER table
July, August, and October 1985--No data, recovery system down
All samples are composite samples except for May 1988 sample
NL - No established level
+ - UIC Guidance concentration (10/86)
* - 10^{-5} cancer risk
@ - Proposed MCL, Safe Drinking Water Act, as amended as of 9/87
# - Three of five individual wells sampled
BDL - Below Detection Limit; Personal communication with Mr. James Breck Dalton/FDER, May 1, 1989

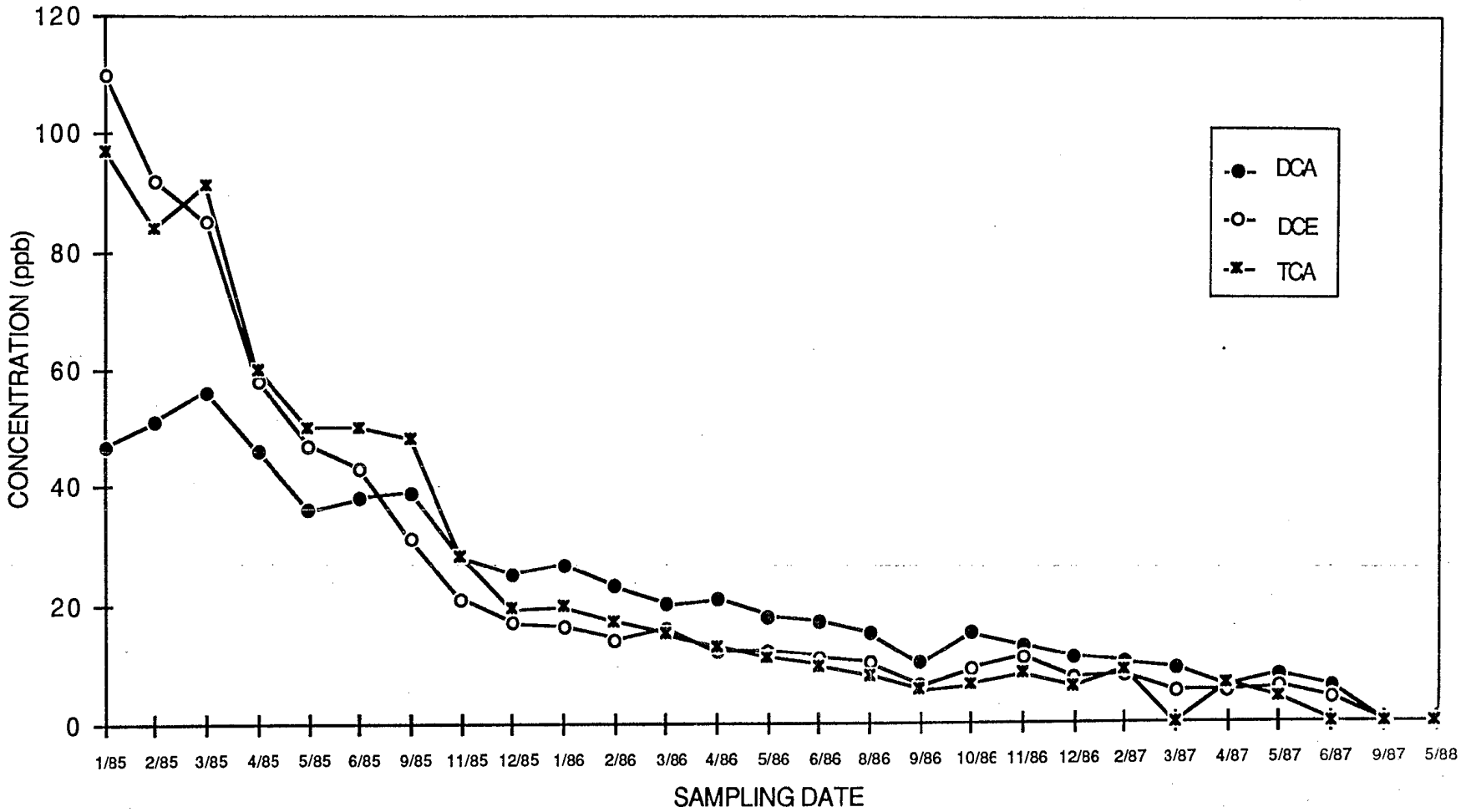


Figure 11
TIME SERIES PLOT OF THE CONCENTRATION OF TCA, DCE AND DCA
EMERSON ELECTRIC SITE

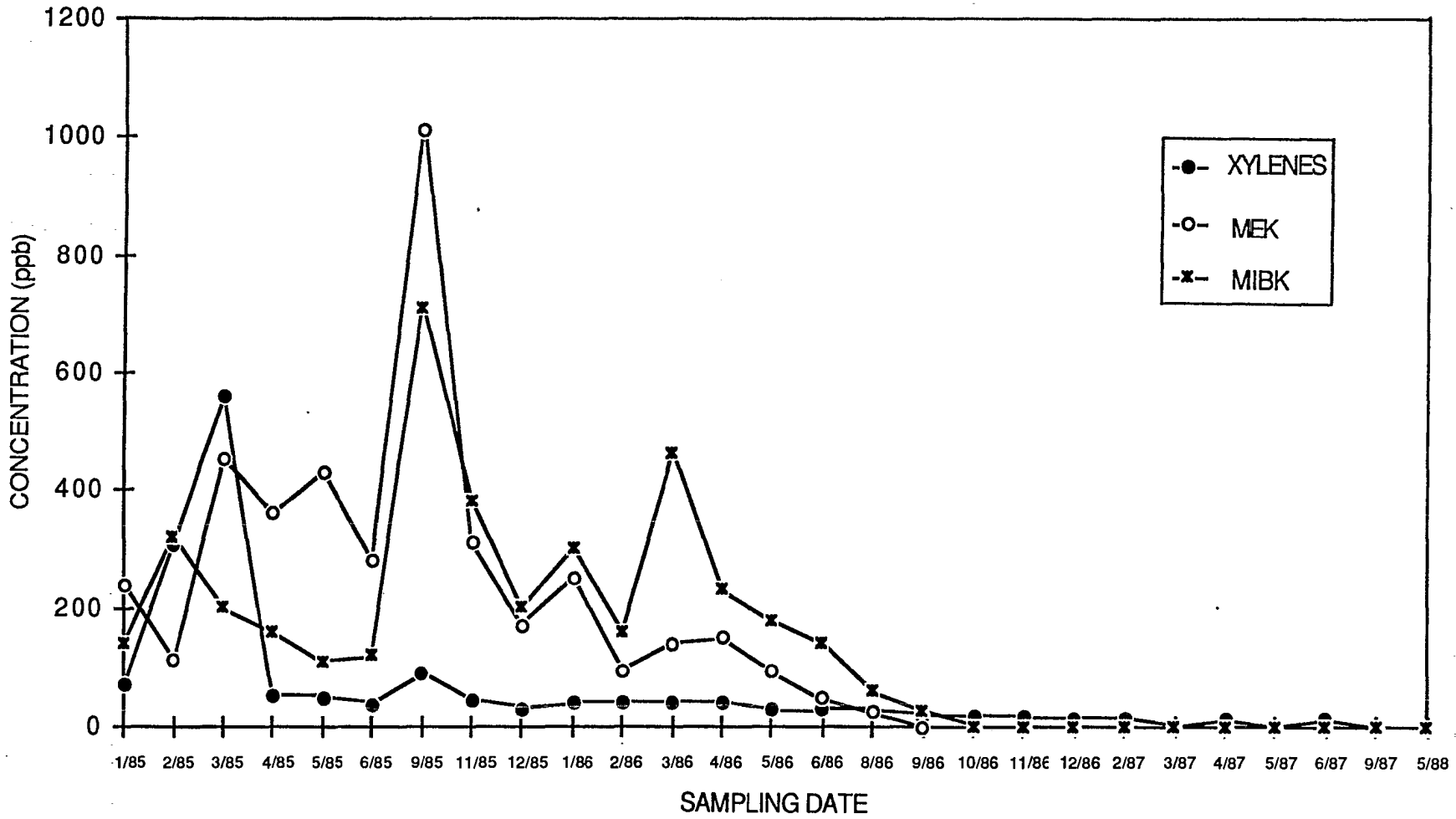


Figure 12
TIME SERIES PLOT OF THE CONCENTRATION OF XYLENES, MEK AND MIBK
EMERSON ELECTRIC SITE

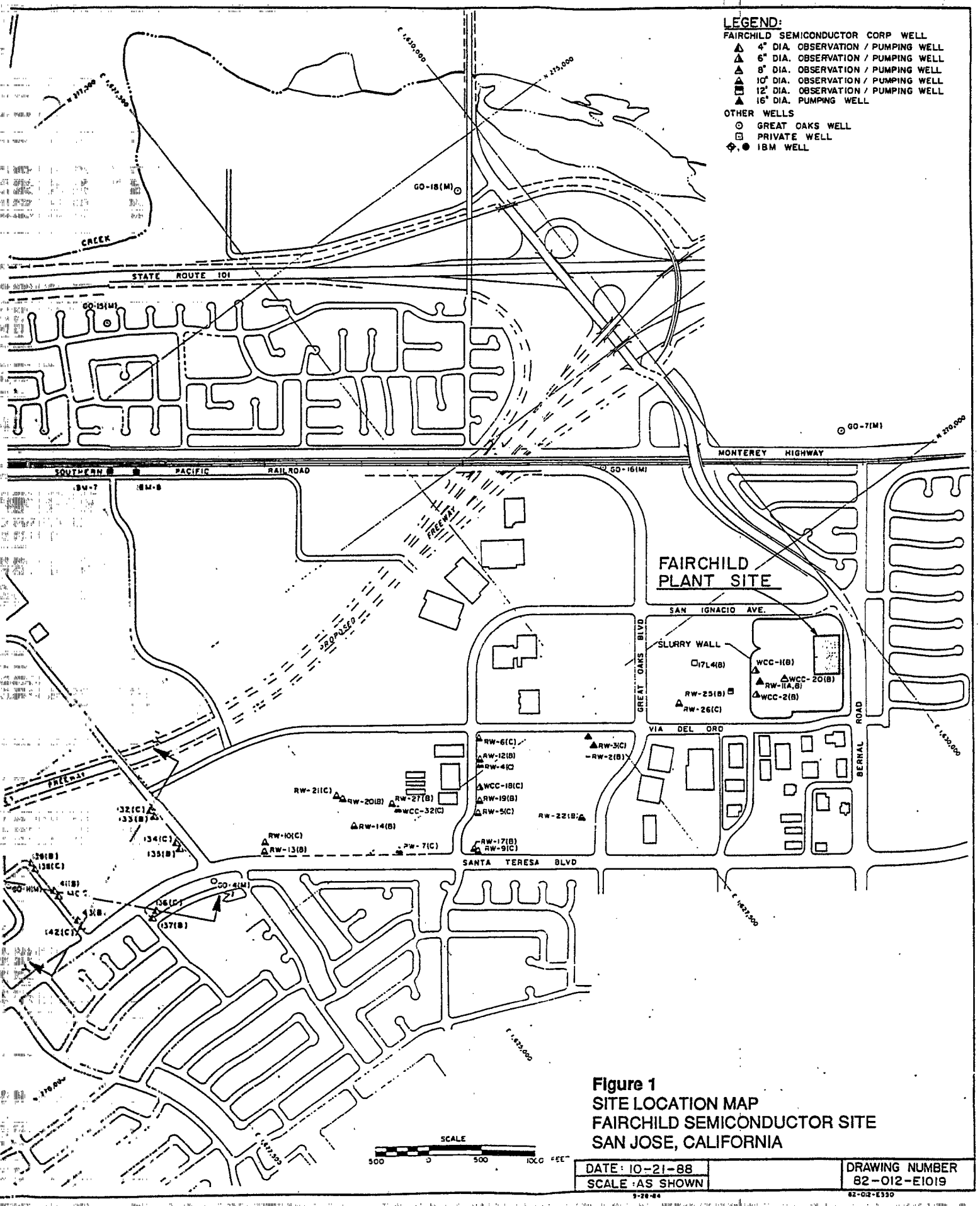
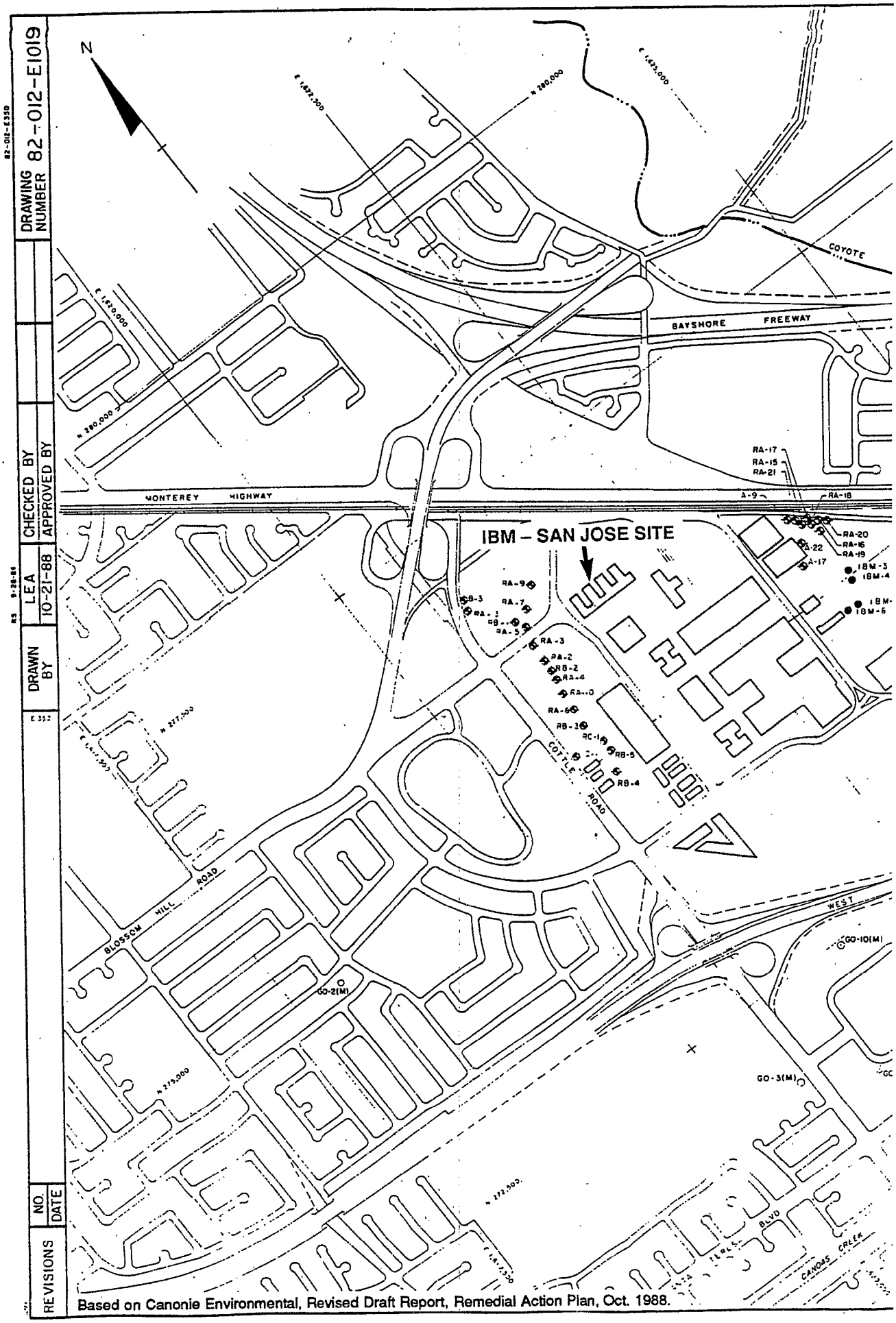


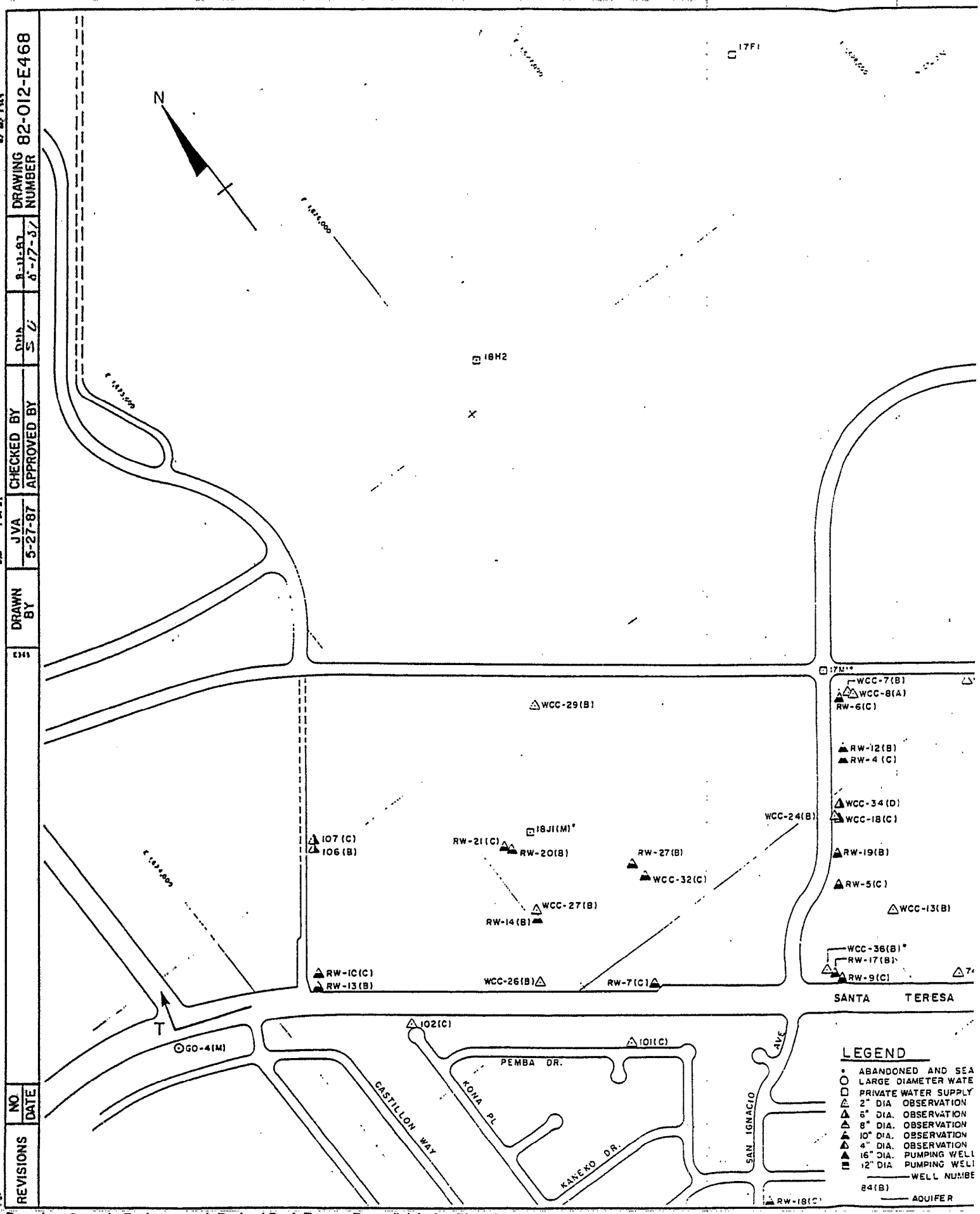
Figure 1
SITE LOCATION MAP
FAIRCHILD SEMICONDUCTOR SITE
SAN JOSE, CALIFORNIA

DATE: 10-21-88	DRAWING NUMBER
SCALE: AS SHOWN	82-012-E1019



Based on Canonie Environmental, Revised Draft Report, Remedial Action Plan, Oct. 1988.

DRAWING NUMBER	CHECKED BY	APPROVED BY	DRAWN BY	LEA	10-21-88	REVISIONS	NO.	DATE
82-012-E1019								



Based on Canonie Environmental, Revised Draft Report, Remedial Action Plan, Oct. 1988.

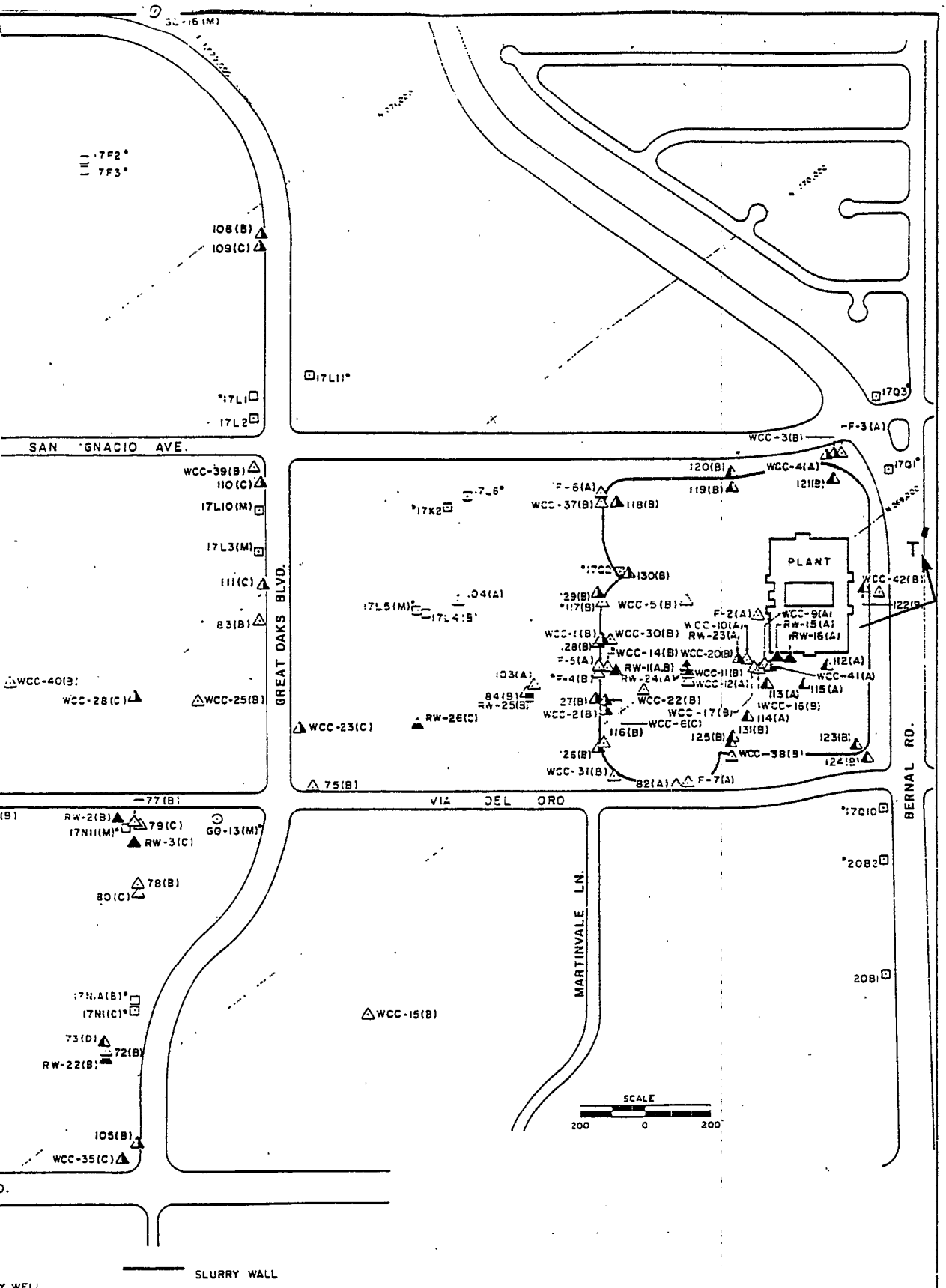
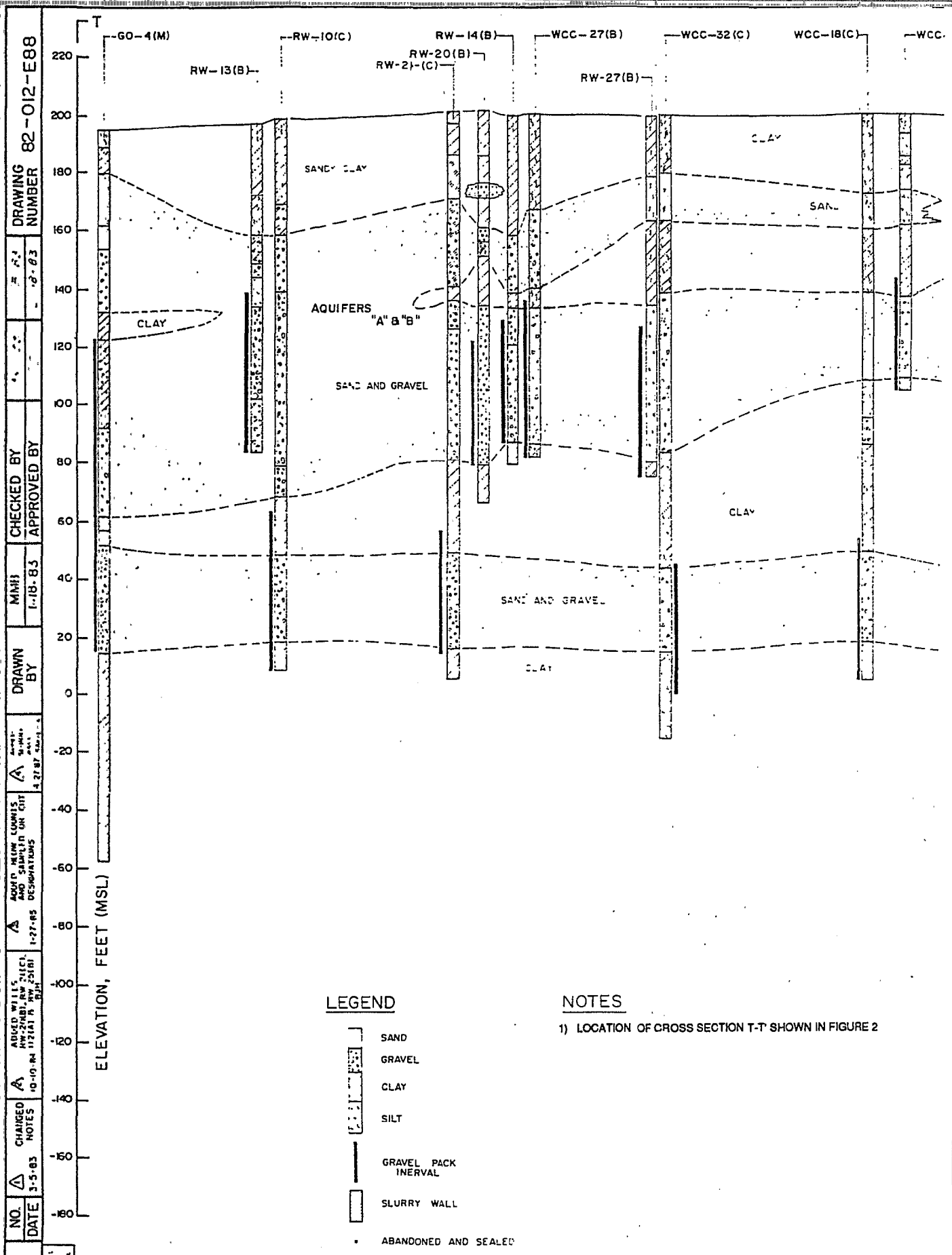
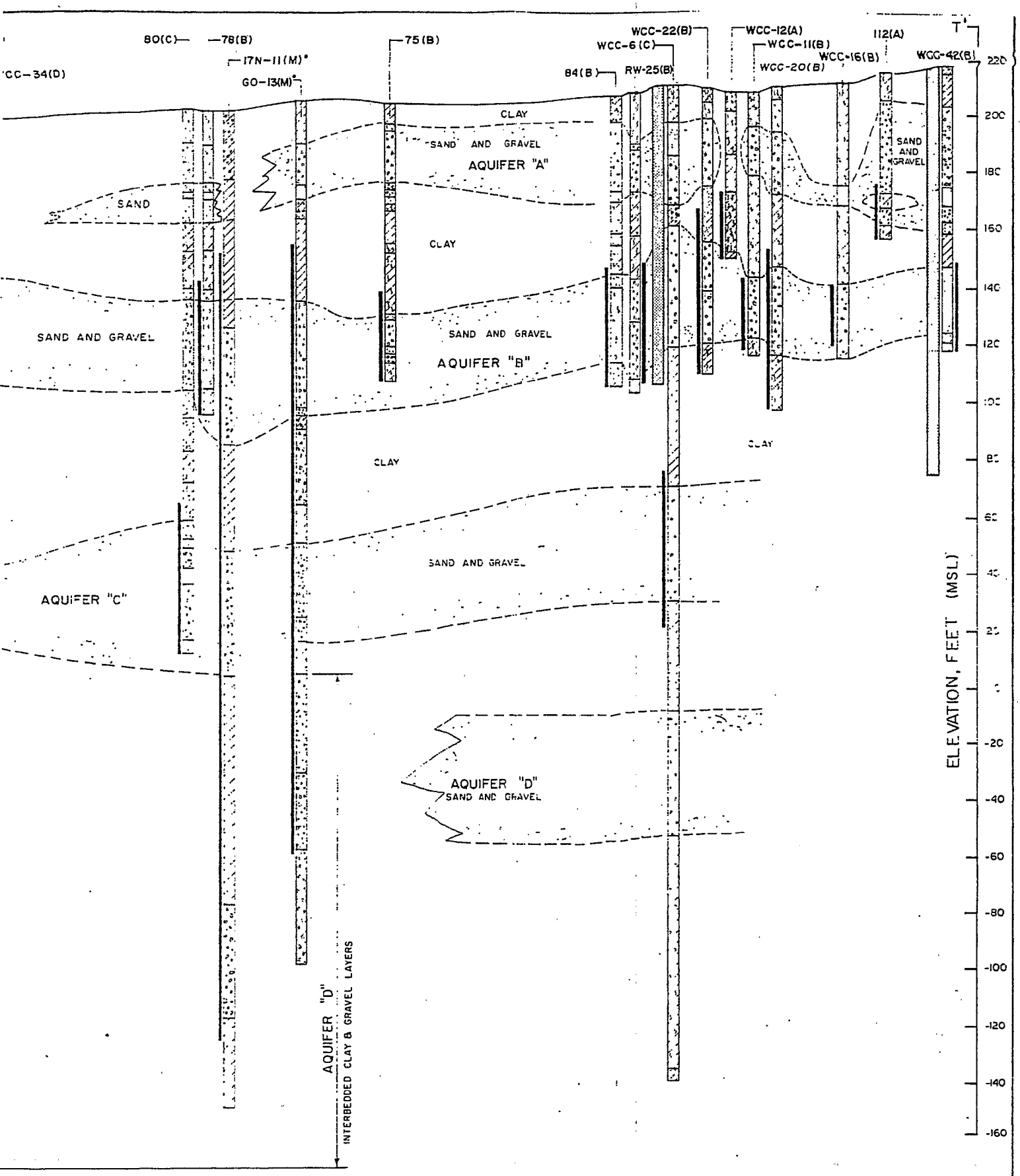


Figure 2
SITE MAP WITH SLURRY WALL AND WELL LOCATIONS
FAIRCHILD SEMICONDUCTOR SITE

DATE: 5-27-87		DRAWING NUMBER
SCALE: AS SHOWN		82-012-E468



Based on Canonie Environmental, Revised Draft Report, Remedial Action Plan, Oct. 1988.

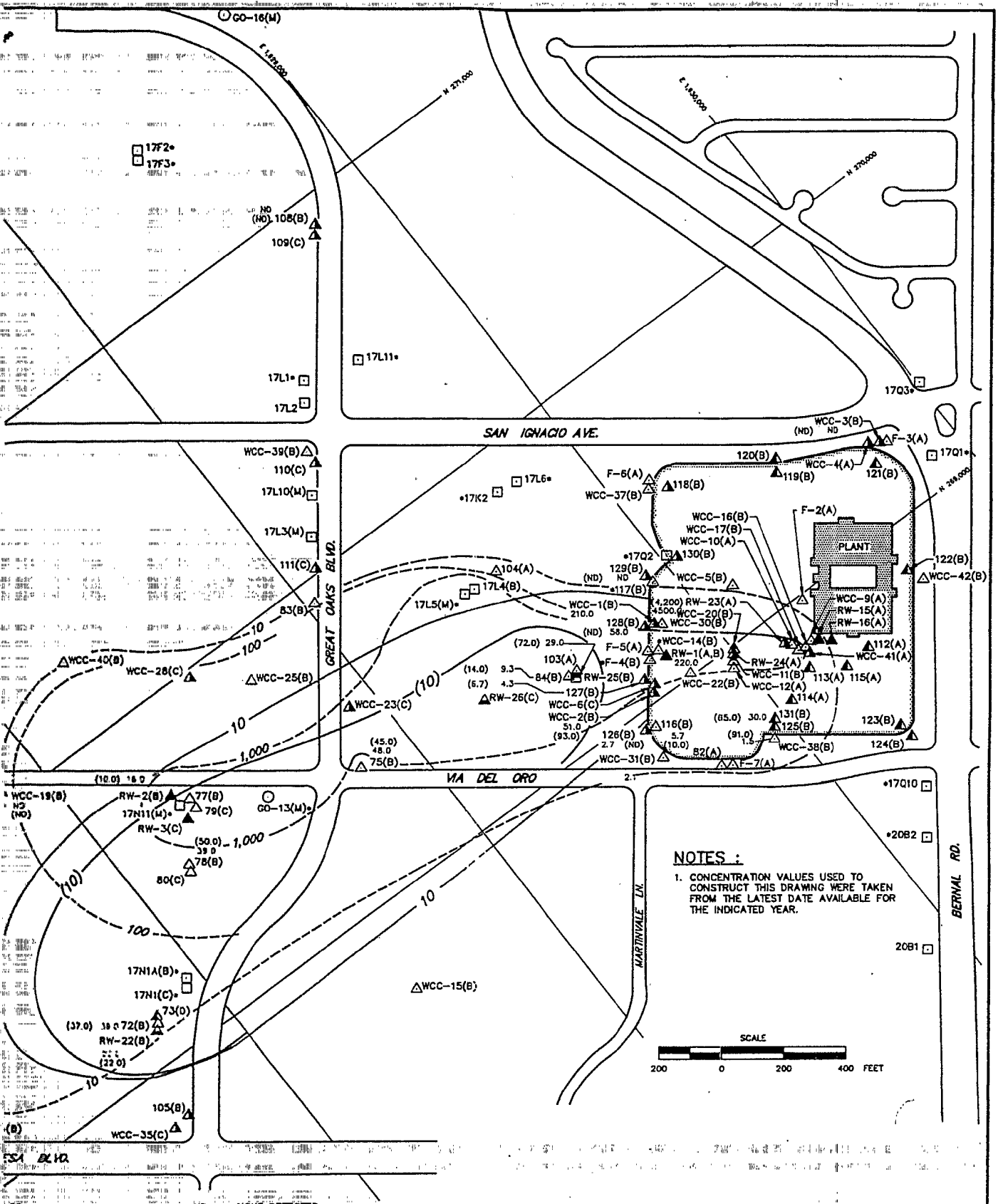


HORIZONTAL SCALE:
200 ft 0 200

VERTICAL SCALE:
20 ft 0 20 ft

Figure 3
GEOLOGIC CROSS SECTION T-T' ACROSS FAIRCHILD SEMICONDUCTOR SITE

DATE 1-18-83		DRAWING NUMBER
SCALE: AS SHOWN		82-012-E88



ND NONE DETECTED (DETECTION LIMIT 0.5 PPB)

(2.7) 1,1,1 TRICHLOROETHANE CONCENTRATION AT OBSERVATION WELL (PPB) WEEK ENDING 12-31-1987

(10) 1,1,1 TRICHLOROETHANE CONCENTRATION CONTOUR (PPB) WEEK ENDING 12-31-1987

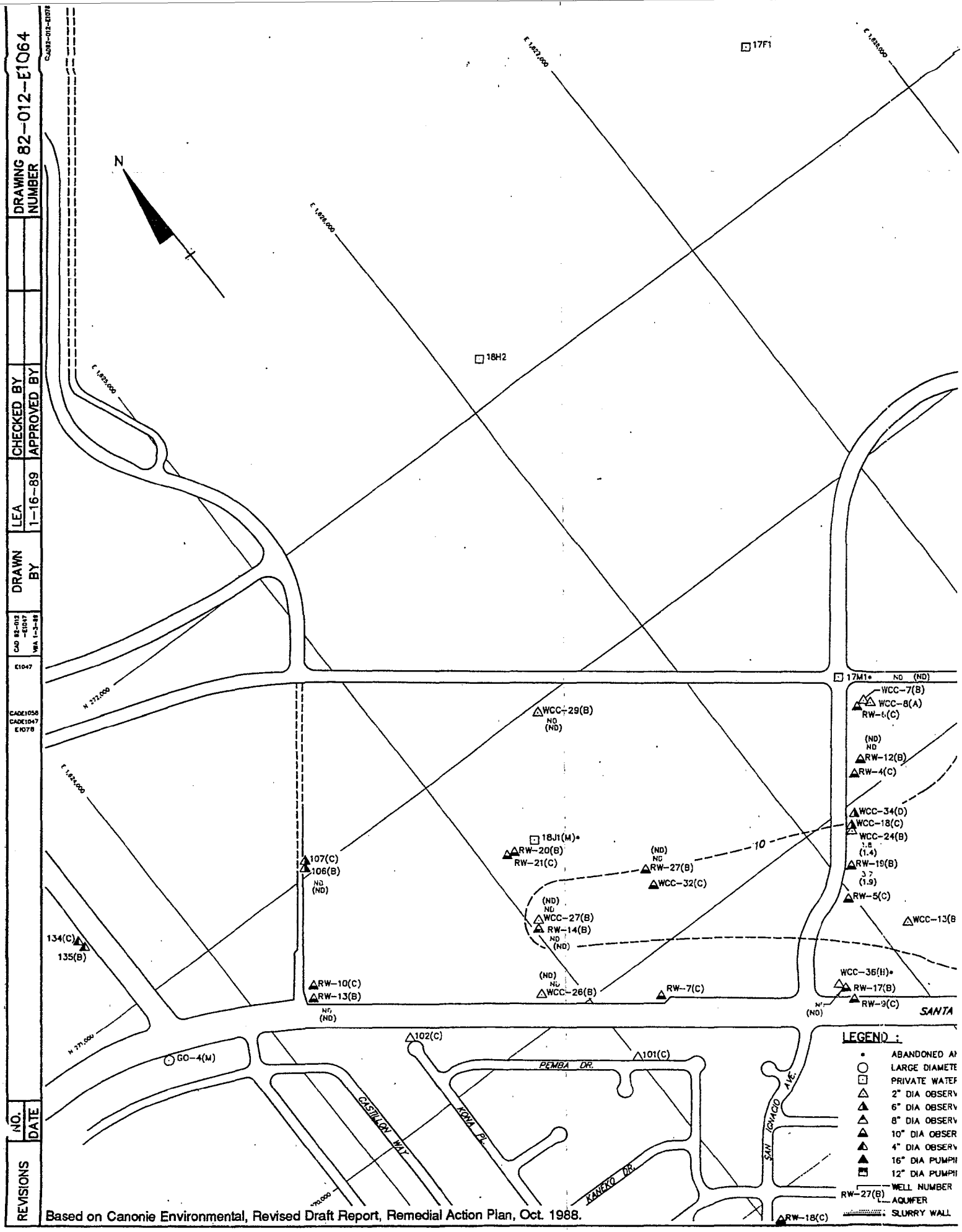
3.7 1,1,1 TRICHLOROETHANE CONCENTRATION AT OBSERVATION WELL (PPB) WEEK ENDING 12-31-1988

10 1,1,1 TRICHLOROETHANE CONCENTRATION CONTOUR (PPB) WEEK ENDING 12-31-1988

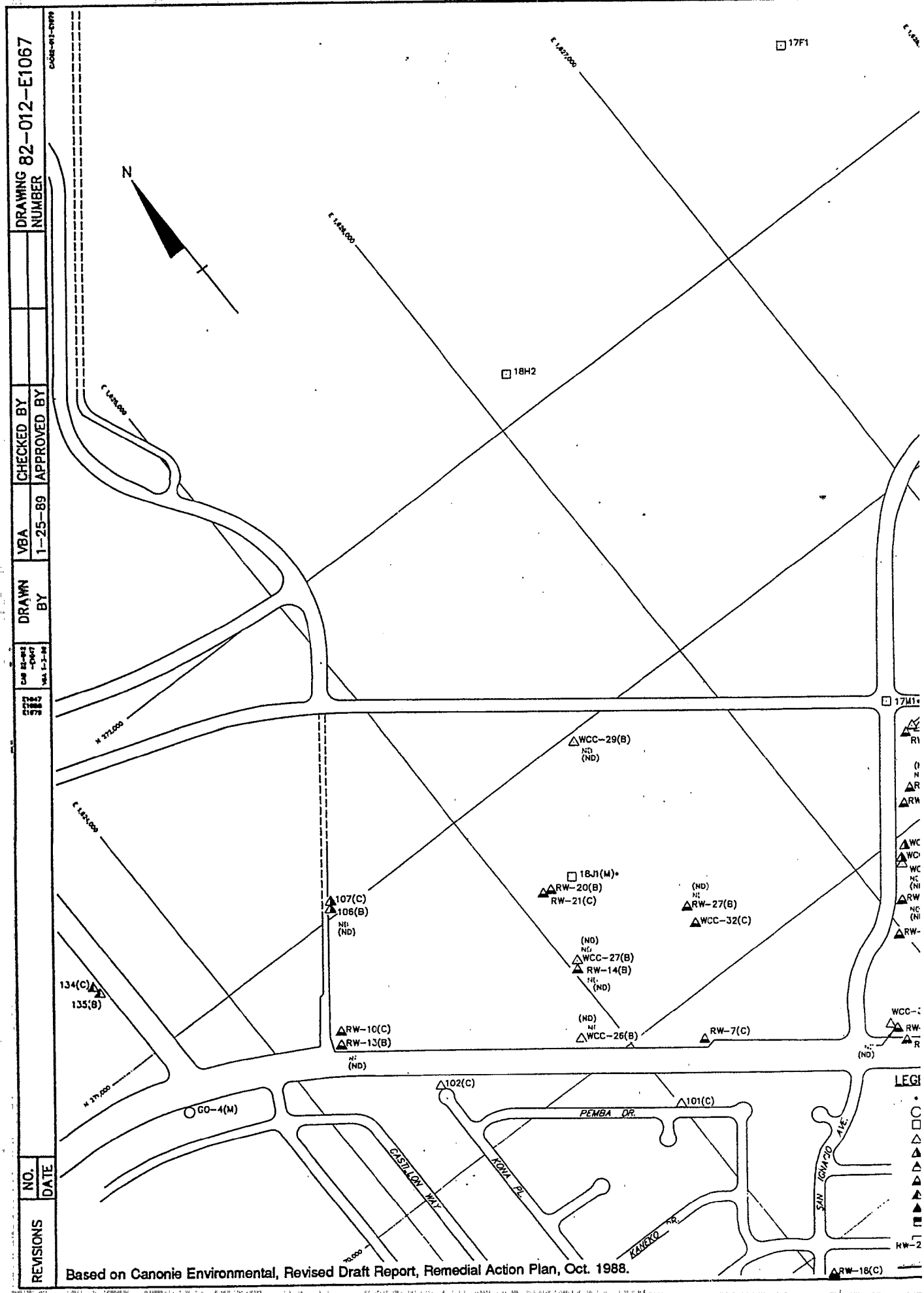
10 1,1,1 TRICHLOROETHANE CONCENTRATION CONTOUR (PPB) OCTOBER 31, 1982

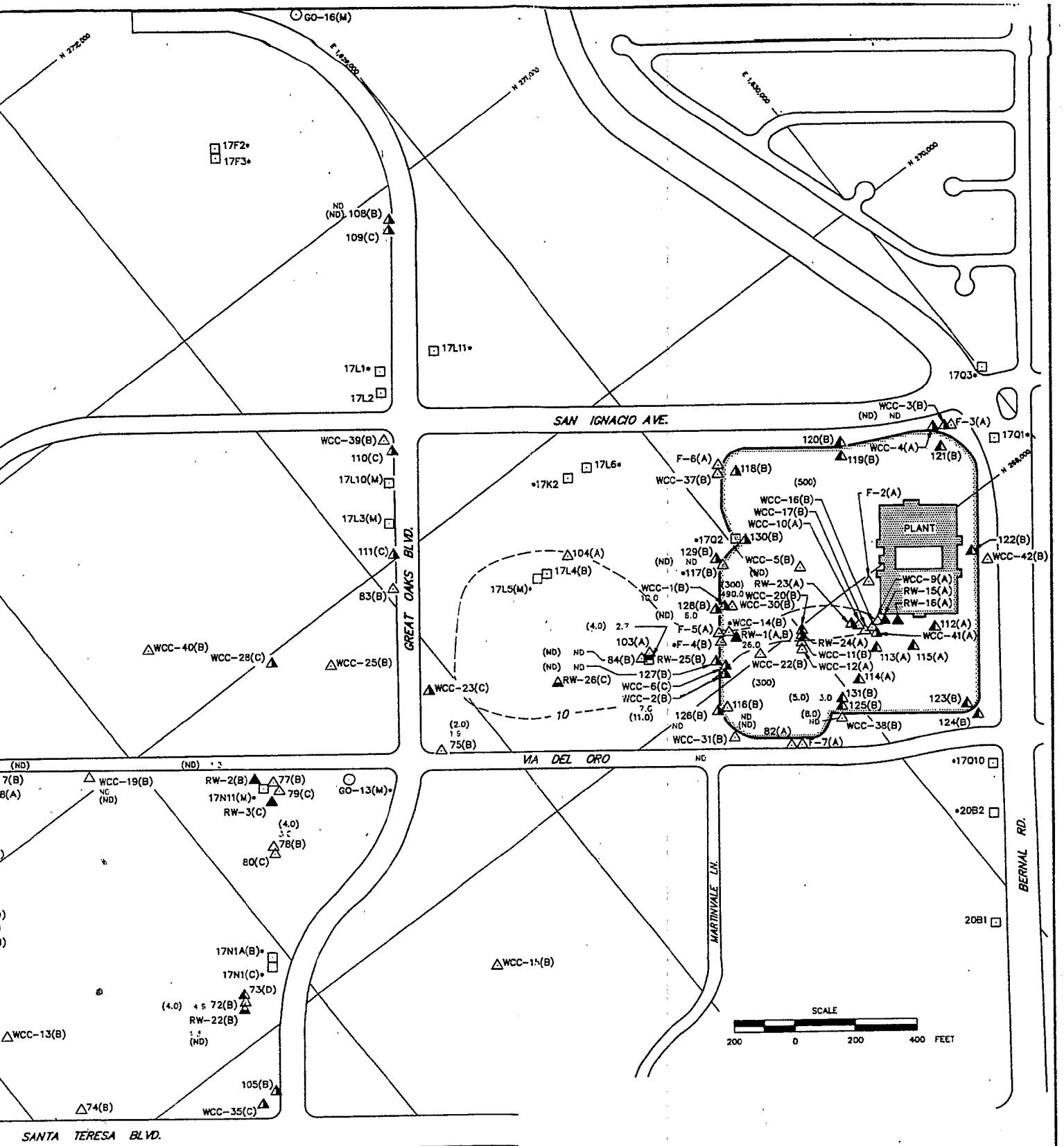
Figure 4
B AQUIFER TCA CONCENTRATIONS THROUGH DECEMBER 31, 1988
FAIRCHILD SEMICONDUCTOR SITE

DATE: 1-16-89		DRAWING NUMBER
SCALE: AS SHOWN		82-012-E1064



Based on Canonie Environmental, Revised Draft Report, Remedial Action Plan, Oct. 1988.


DRAWING NUMBER 82-012-E1067
CHECKED BY
APPROVED BY
VBA 1-25-89
DRAWN BY
NO.
DATE
REVISIONS
N
17F1
18H2
17M1
WCC-29(B)
ND
(ND)
18J1(M)
RW-20(B)
RW-21(C)
107(C)
106(B)
(ND)
RW-27(B)
WCC-32(C)
WCC-27(B)
RW-14(B)
134(C)
135(B)
RW-10(C)
RW-13(B)
WCC-26(B)
RW-7(C)
102(C)
101(C)
GO-4(M)
PEMBA DR.
CASTILLON WAY
KONA PL.
KANEKO DR.
SAN IGNACIO AVE.
RW-18(C)
Based on Canonie Environmental, Revised Draft Report, Remedial Action Plan, Oct. 1988.

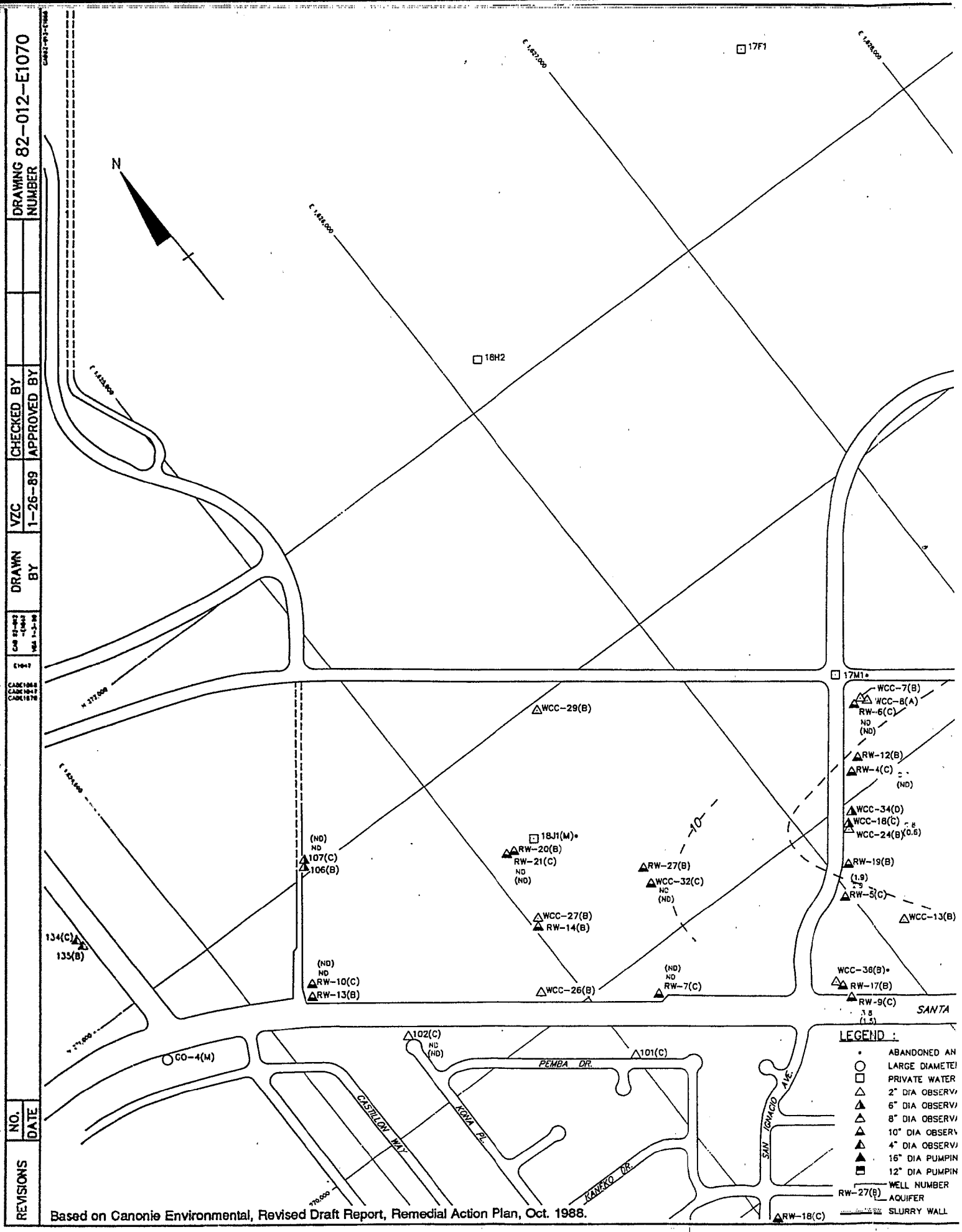


ANDONED AND SEALED
ARGE DIAMETER WATER SUPPLY WELL
RIVATE WATER SUPPLY WELL
DIA OBSERVATION WELL
DIA OBSERVATION WELL/PUMPING WELL
DIA OBSERVATION WELL/PUMPING WELL
" DIA OBSERVATION WELL/PUMPING WELL
DIA OBSERVATION WELL
" DIA PUMPING WELL
" DIA PUMPING WELL
ELL NUMBER
QUIFER
CARRY HALL

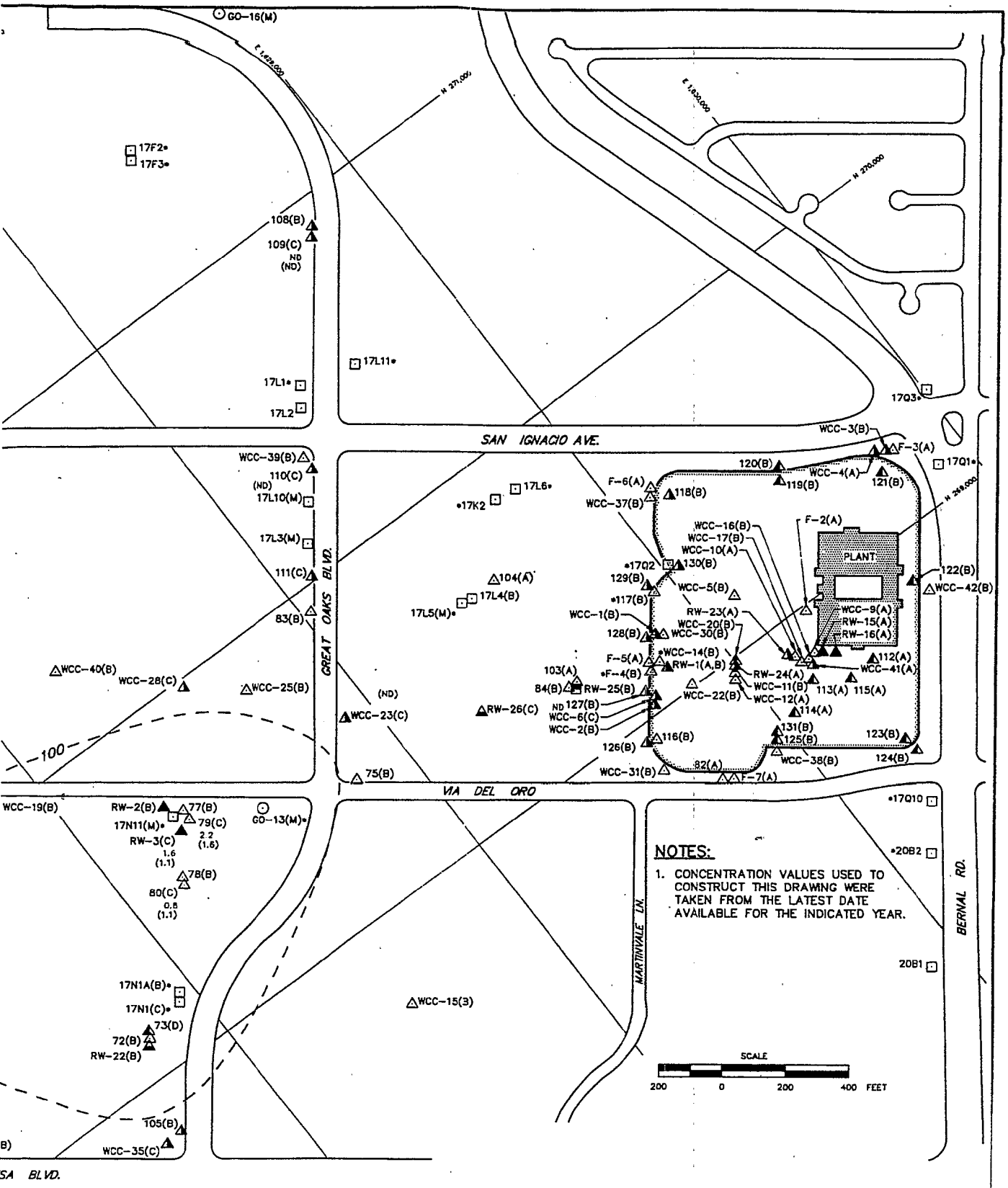
ND	NONE DETECTED (DETECTION LIMIT 1.0 PPB)
(5.0)	1,1-DICHLOROETHENE CONCENTRATION AT OBSERVATION WELL (PPB) WEEK ENDING 12-31-1987
10	1,1-DICHLOROETHENE CONCENTRATION CONTOUR (PPB) WEEK ENDING 10-31-1988
4.9	1,1-DICHLOROETHENE CONCENTRATION AT OBSERVATION WELL (PPB) WEEK ENDING 12-31-1988

Figure 5
B AQUIFER DCE CONCENTRATIONS
THROUGH DECEMBER 31, 1988
FAIRCHILD SEMICONDUCTOR SITE

DATE: 1-25-89		DRAWING NUMBER
SCALE: AS SHOWN		82-012-E1067



Based on Canonie Environmental, Revised Draft Report, Remedial Action Plan, Oct. 1988.

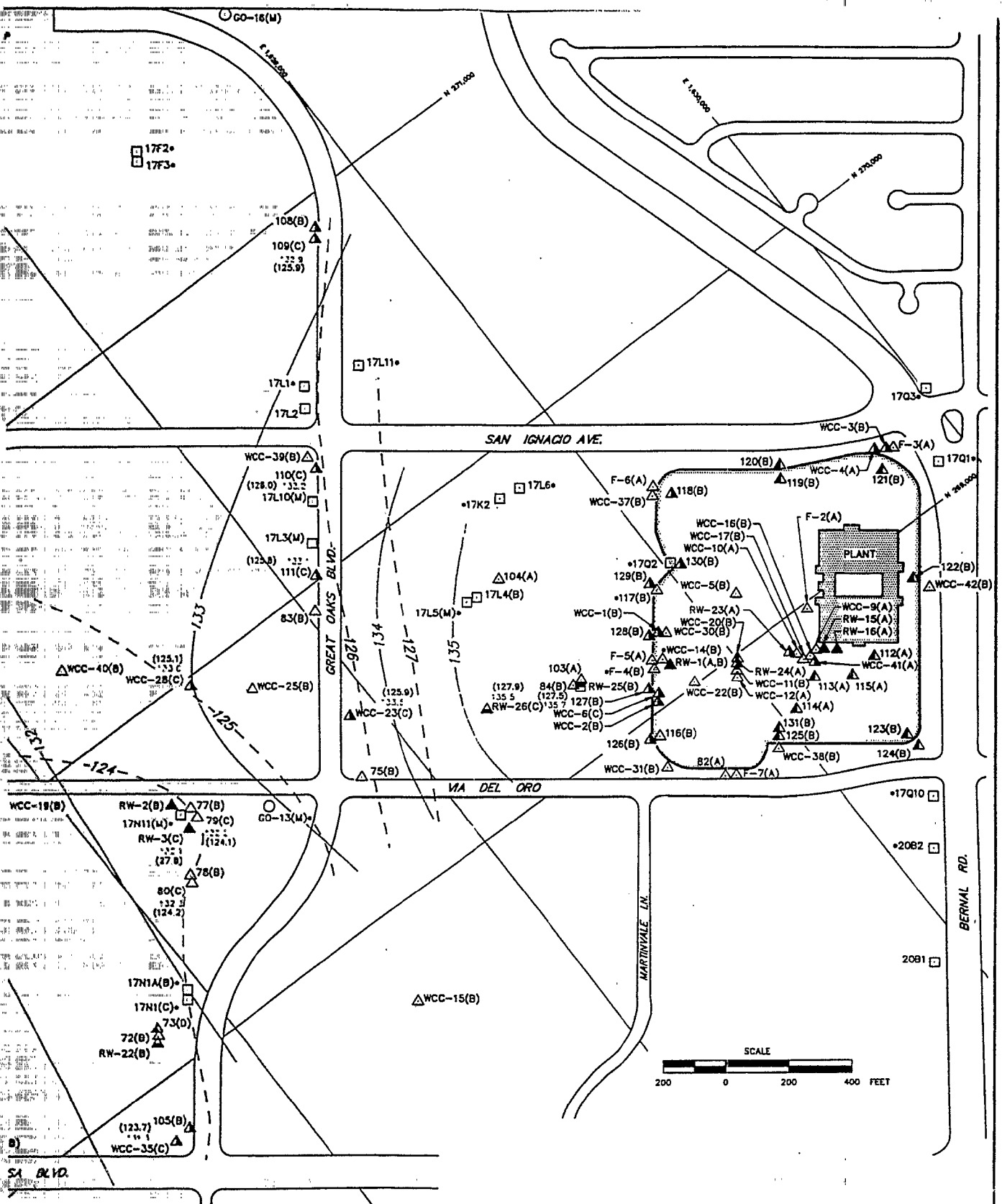


ED	ND	NONE DETECTED (DETECTION LIMIT 0.5 PPB)
R SUPPLY WELL		
Y WELL	3.8	1,1,1 TRICHLOROETHANE CONCENTRATION AT OBSERVATION WELL (PPB) WEEK ENDING DECEMBER 31, 1987
VELL		
VELL/PUMPING WELL		
VELL/PUMPING WELL	100	1,1,1 TRICHLOROETHANE CONCENTRATION CONTOUR (PPB) WEEK ENDING OCTOBER 31, 1982
WELL/PUMPING WELL		
VELL	1.6	1,1,1 TRICHLOROETHANE CONCENTRATION AT OBSERVATION WELL (PPB) WEEK ENDING DECEMBER 31, 1988

Figure 6
C AQUIFER TCA CONCENTRATIONS THROUGH DECEMBER 31, 1988
FAIRCHILD SEMICONDUCTOR SITE

VBA 1-3-89
CAD 82-012-E1086 CAD 82-012-E1047

DATE: 1-26-89		DRAWING NUMBER
SCALE: AS SHOWN		82-012-E1070



CO
R SUPPLY WELL
Y WELL
ELL
ELL/PUMPING WELL
ELL/PUMPING WELL
WELL/PUMPING WELL
ELL

123.8 AQUIFER 'C' GROUND WATER ELEVATION AT OBSERVATION WELL (FEET, MSL) WEEK ENDING DECEMBER 15, 1987

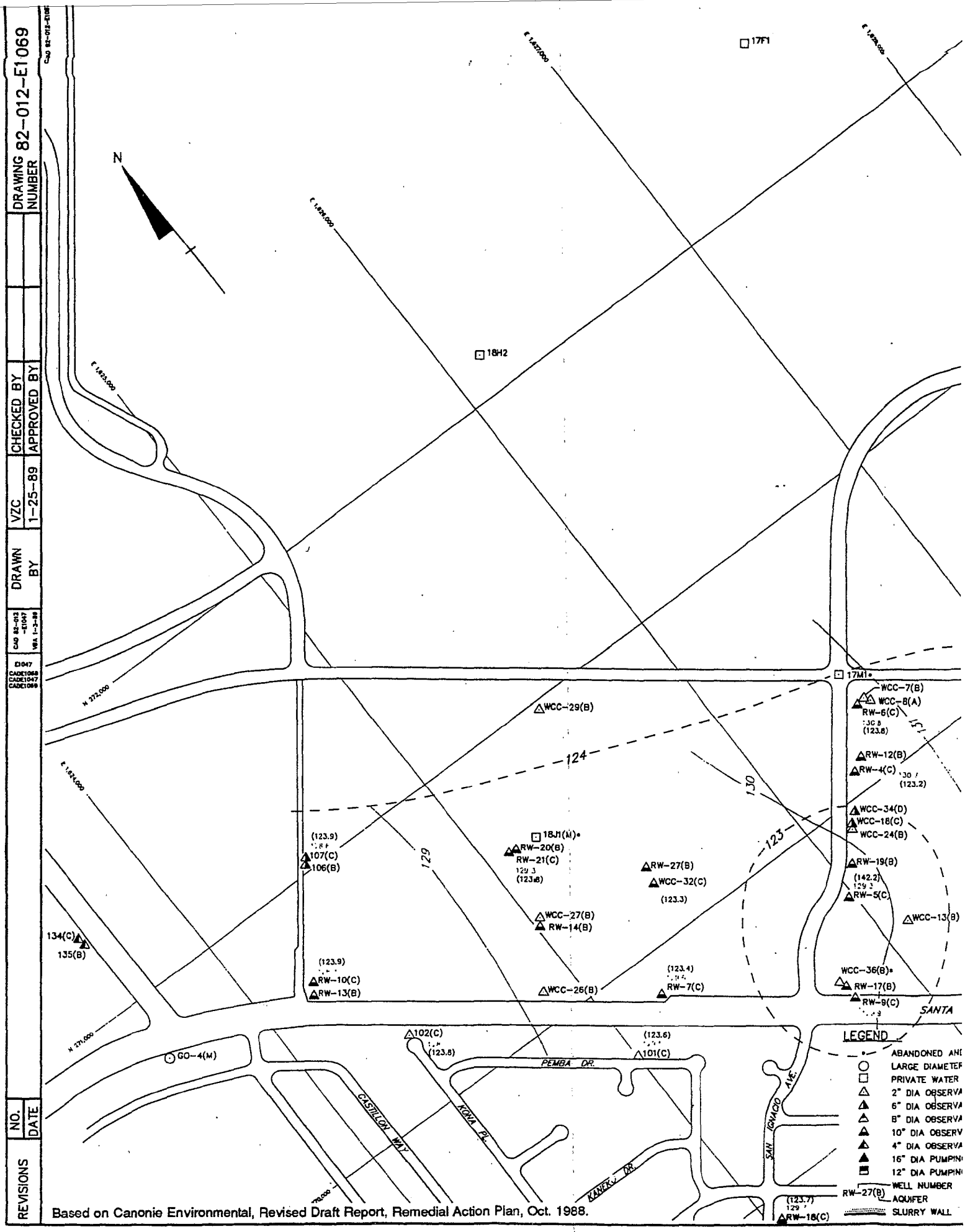
-123- AQUIFER 'C' GROUND WATER ELEVATION CONTOUR (FEET, MSL) WEEK ENDING DECEMBER 15, 1987

130.8 AQUIFER 'C' GROUND WATER ELEVATION AT OBSERVATION WELL (FEET, MSL) WEEK ENDING DECEMBER 15,1988

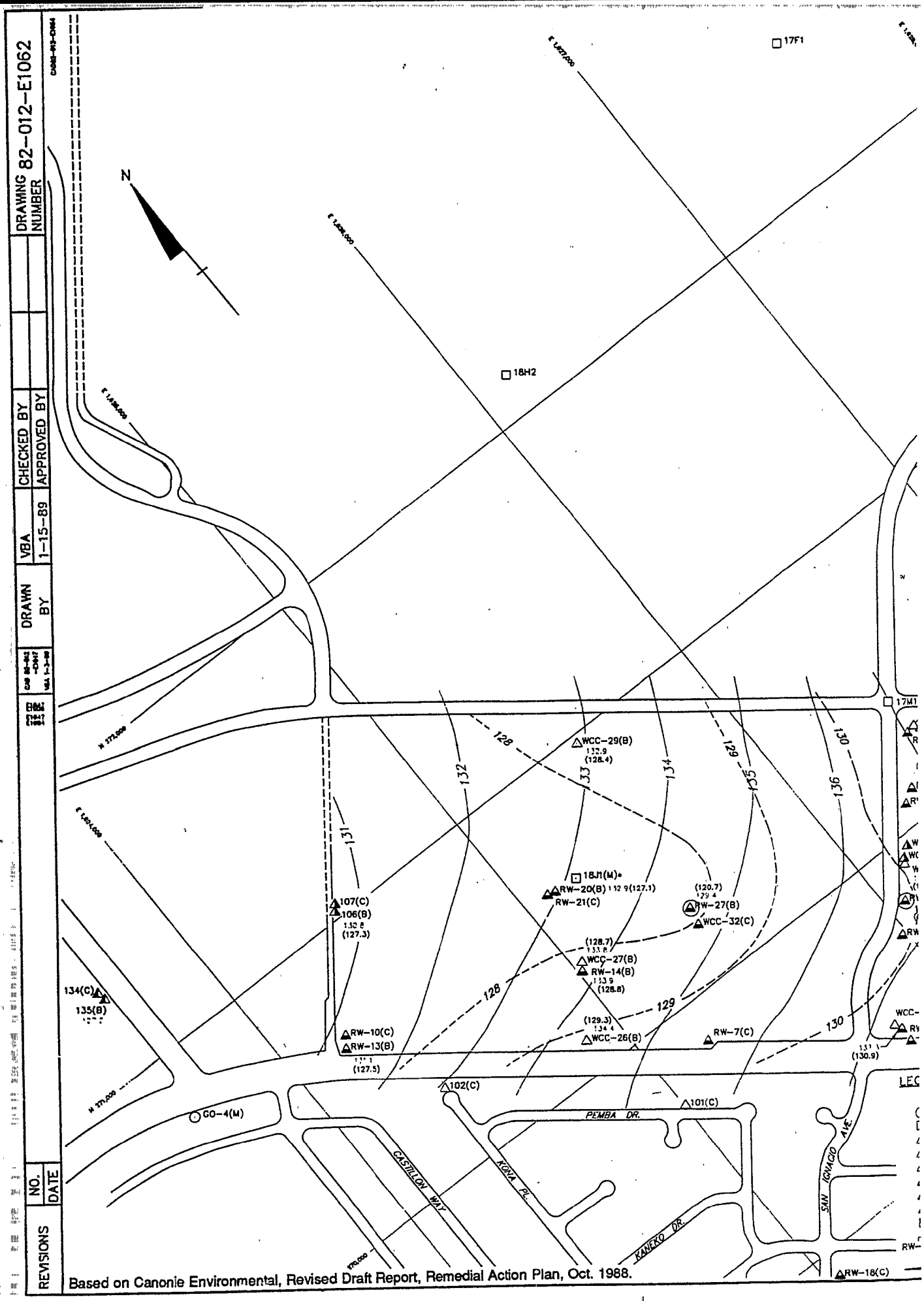
-130- AQUIFER 'C' GROUND WATER ELEVATION CONTOUR (FEET, MSL) WEEK ENDING DECEMBER 15, 1988

Figure 8
C AQUIFER GROUND-WATER CONTOURS, DECEMBER 1987 AND DECEMBER 1988
FAIRCHILD SEMICONDUCTOR SITE

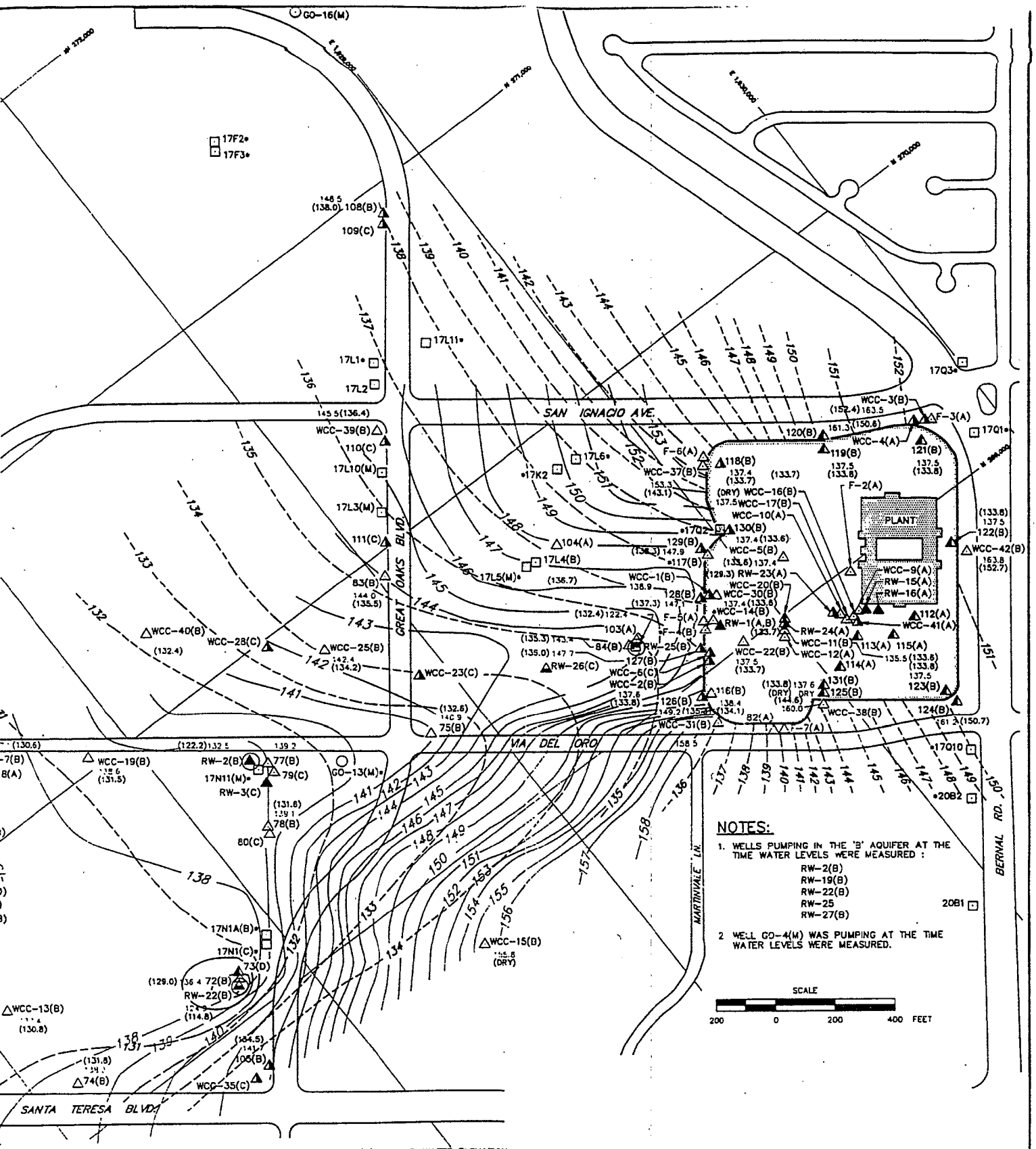
DATE: 1-25-89		DRAWING NUMBER
SCALE: AS SHOWN		82-012-E1069



Based on Canonie Environmental, Revised Draft Report, Remedial Action Plan, Oct. 1988.



Based on Canonie Environmental, Revised Draft Report, Remedial Action Plan, Oct. 1988.



ANDONED AND SEALED
RGE DIAMETER WATER SUPPLY WELL
IVATE WATER SUPPLY WELL
DIA OBSERVATION WELL
DIA OBSERVATION WELL/PUMPING WELL
DIA OBSERVATION WELL/PUMPING WELL
" DIA OBSERVATION WELL/PUMPING WELL
DIA OBSERVATION WELL
" DIA PUMPING WELL
" DIA PUMPING WELL
LL NUMBER
UIFER
URRY WALL

(137.0) AQUIFER 'B' GROUND WATER ELEVATION AT OBSERVATION WELL (FEET, MSL) WEEK ENDING 12-15-1987

—135— AQUIFER 'B' GROUND WATER ELEVATION CONTOUR (FEET, MSL) WEEK ENDING 12-15-1987

137.5 AQUIFER 'B' GROUND WATER ELEVATION AT OBSERVATION WELL (FEET, MSL) WEEK ENDING 12-15-1988

—150— AQUIFER 'B' GROUND WATER ELEVATION CONTOUR (FEET, MSL) WEEK ENDING 12-15-1988

Figure 7
B AQUIFER GROUND-WATER CONTOURS, DECEMBER 1987 AND DECEMBER 1988
FAIRCHILD SEMICONDUCTOR SITE

DATE: 1-15-89		DRAWING NUMBER 82-012-E1062
SCALE: AS SHOWN		

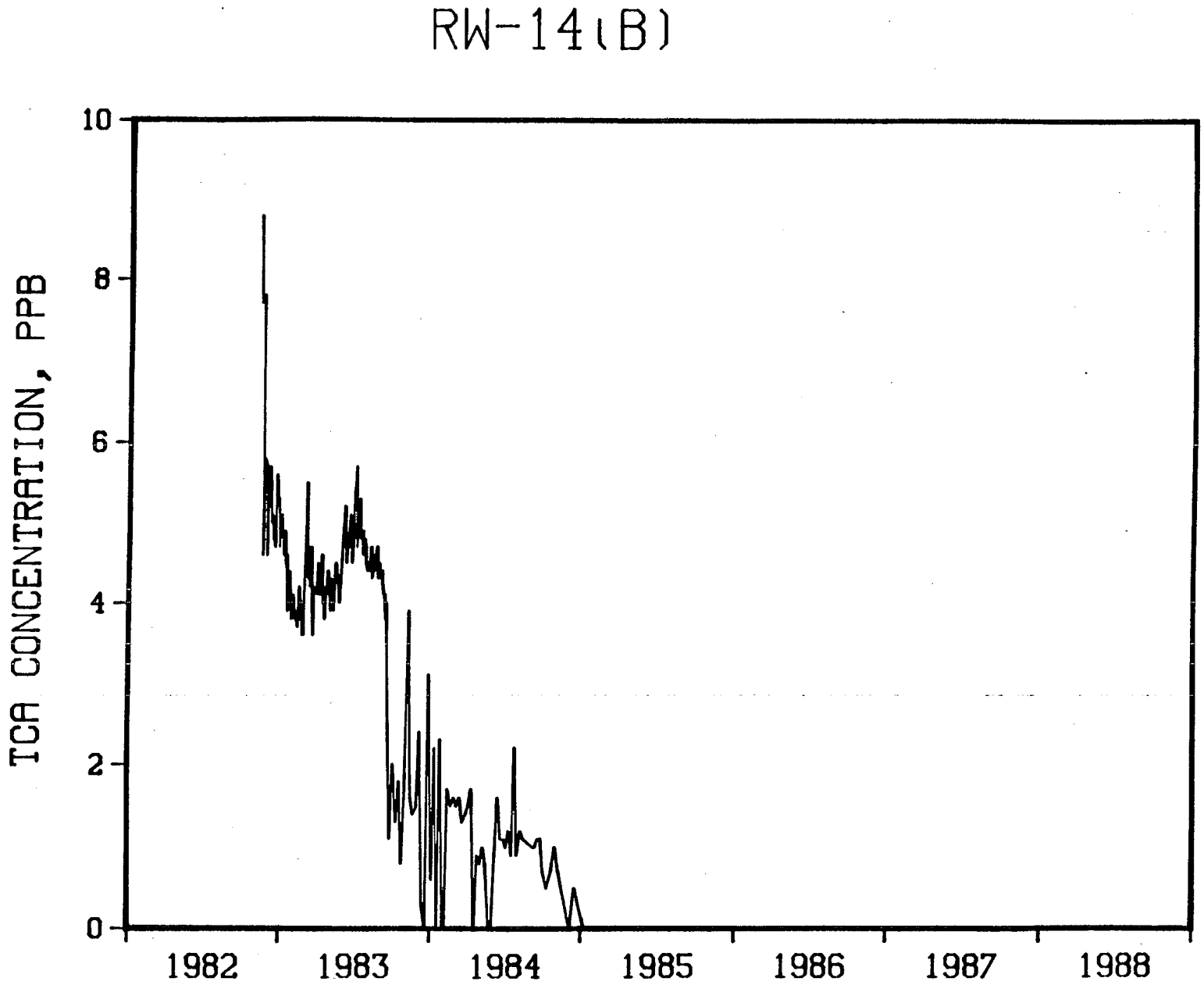


Figure 9
AQUIFER B CONCENTRATION OF TCA IN PUMPING WELL RW-14 FROM 1982 THROUGH 1988
FAIRCHILD SEMICONDUCTOR SITE

Based on Canonie Environmental, Revised Draft Report, Remedial Action Plan, Oct. 1988.

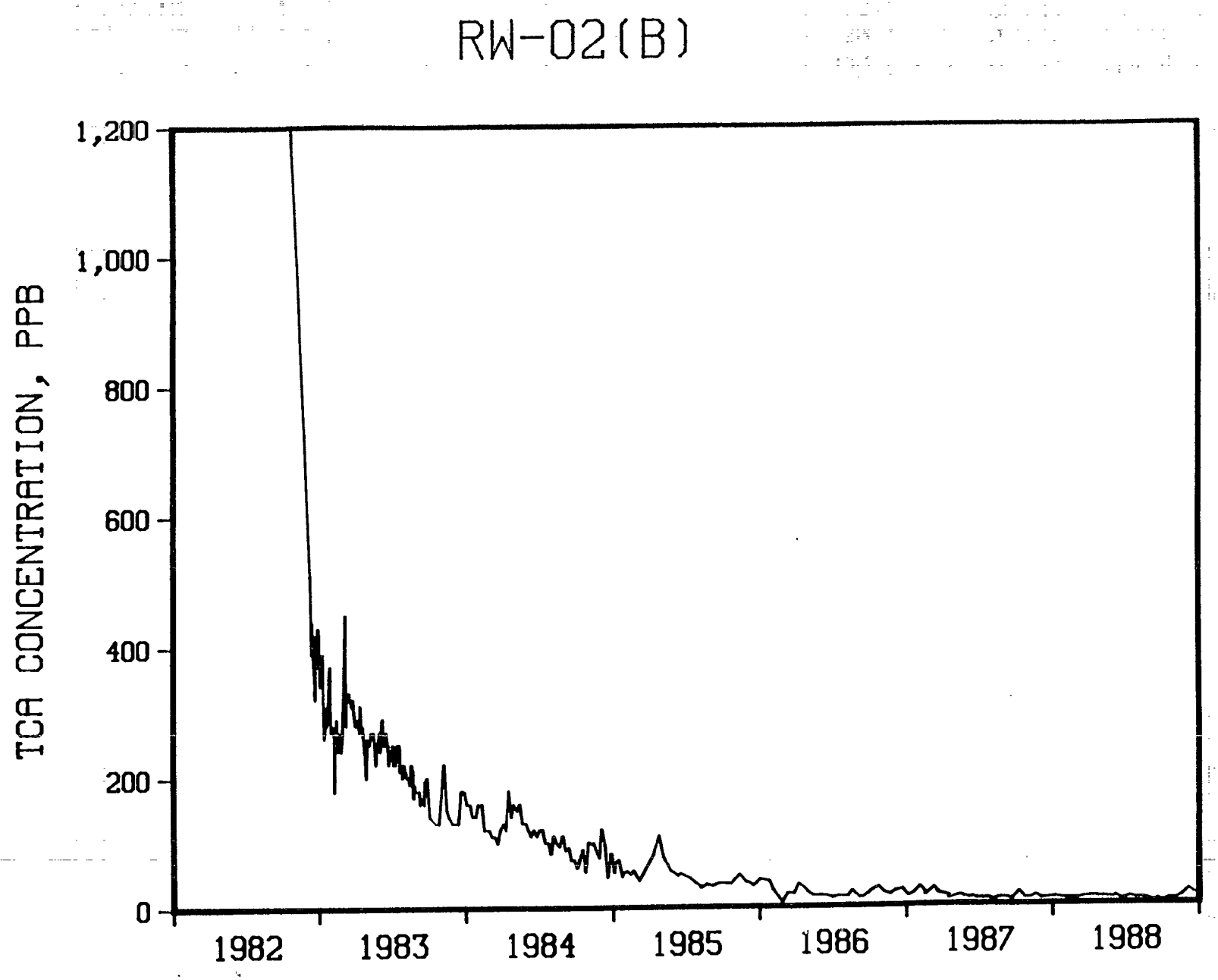
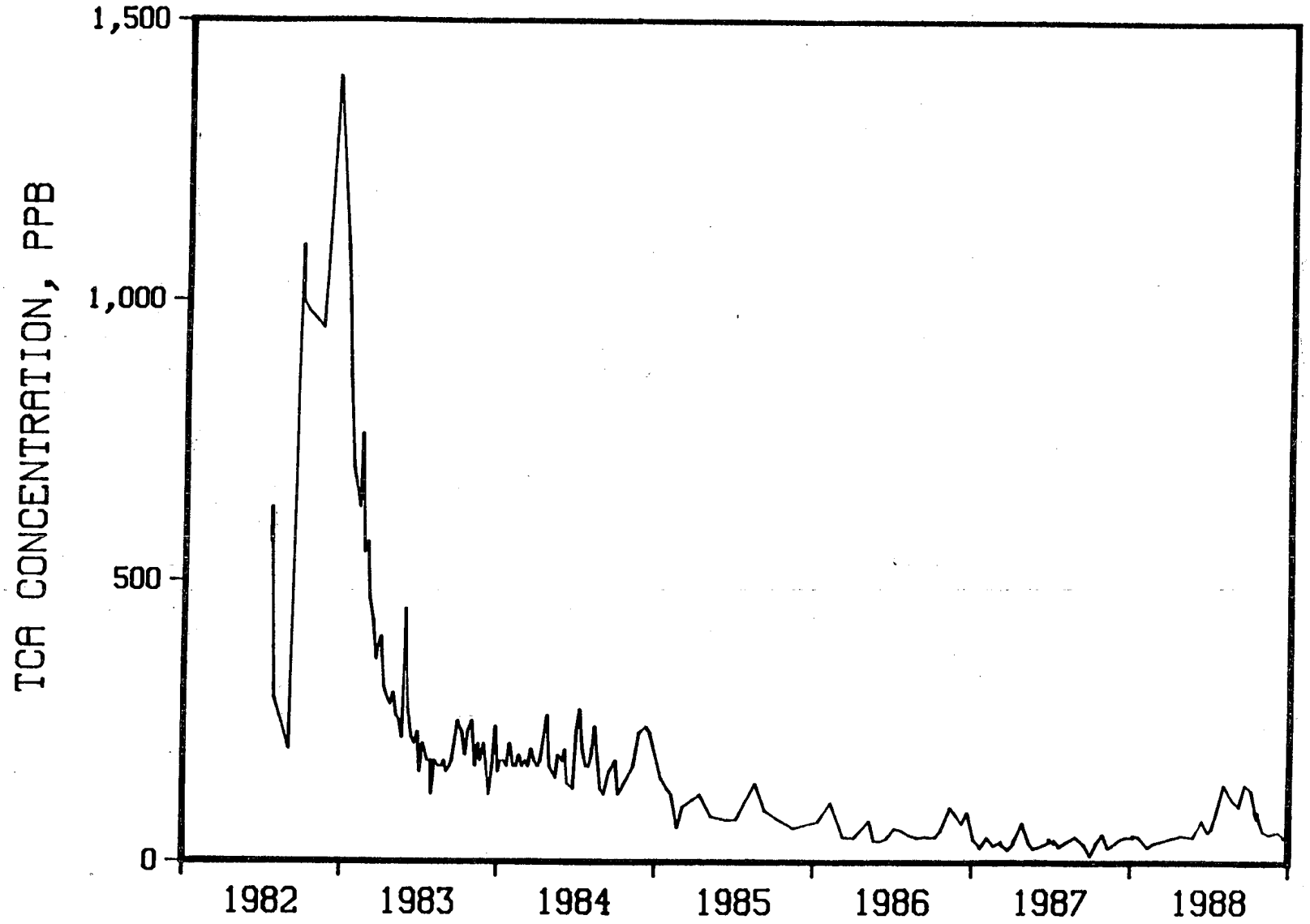


Figure 10
AQUIFER B CONCENTRATION OF TCA IN PUMPING WELL RW-02 FROM 1982 THROUGH 1988
FAIRCHILD SEMICONDUCTOR SITE

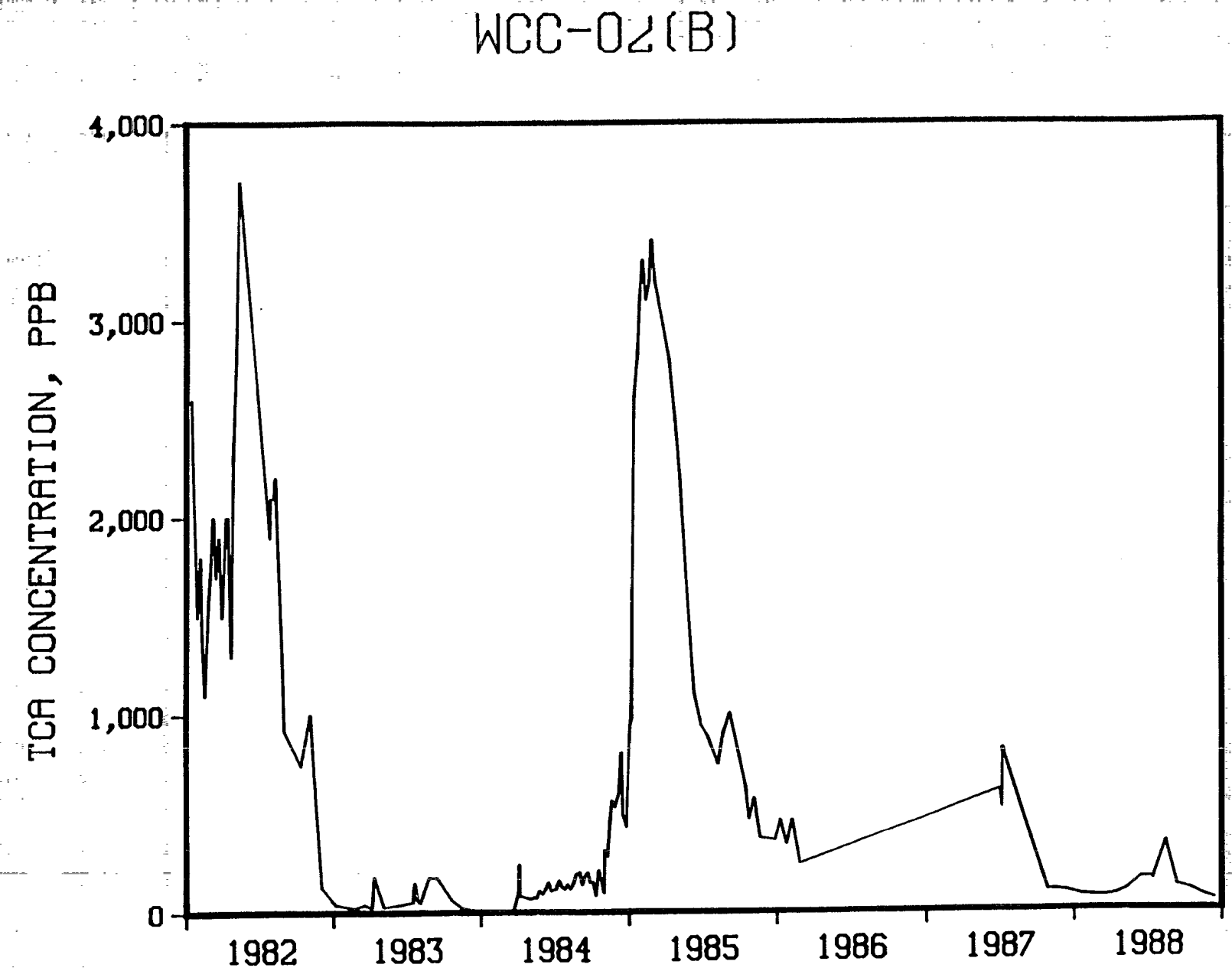
Based on Canonie Environmental, Revised Draft Report, Remedial Action Plan, Oct. 1988.

75(B)



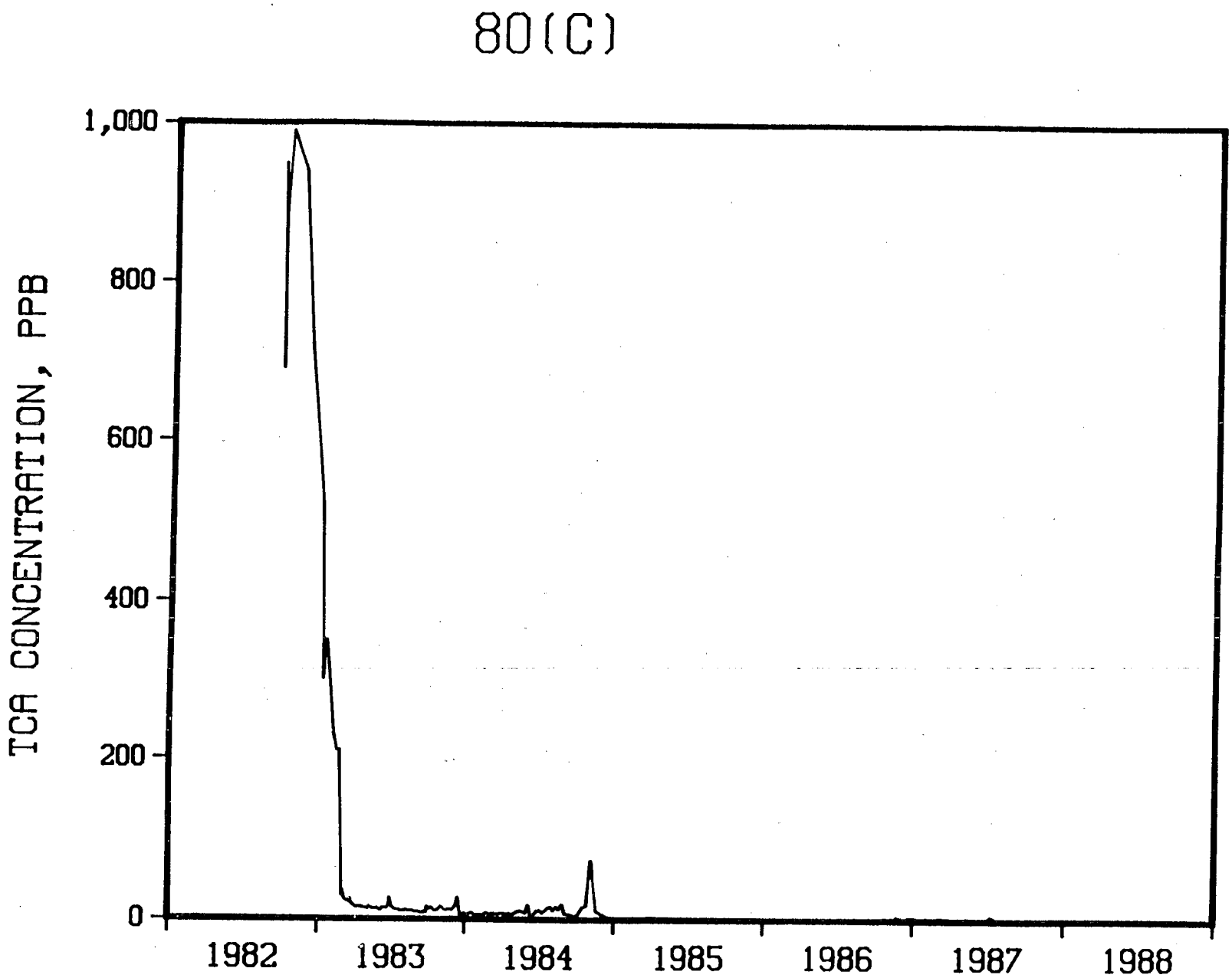
Based on Canonie Environmental, Revised Draft Report, Remedial Action Plan, Oct. 1988.

Figure 11
AQUIFER B CONCENTRATION OF TCA IN PUMPING WELL 75 FROM 1982 THROUGH 1988
FAIRCHILD SEMICONDUCTOR SITE



Based on Canonie Environmental, Revised Draft Report, Remedial Action Plan, Oct. 1988.

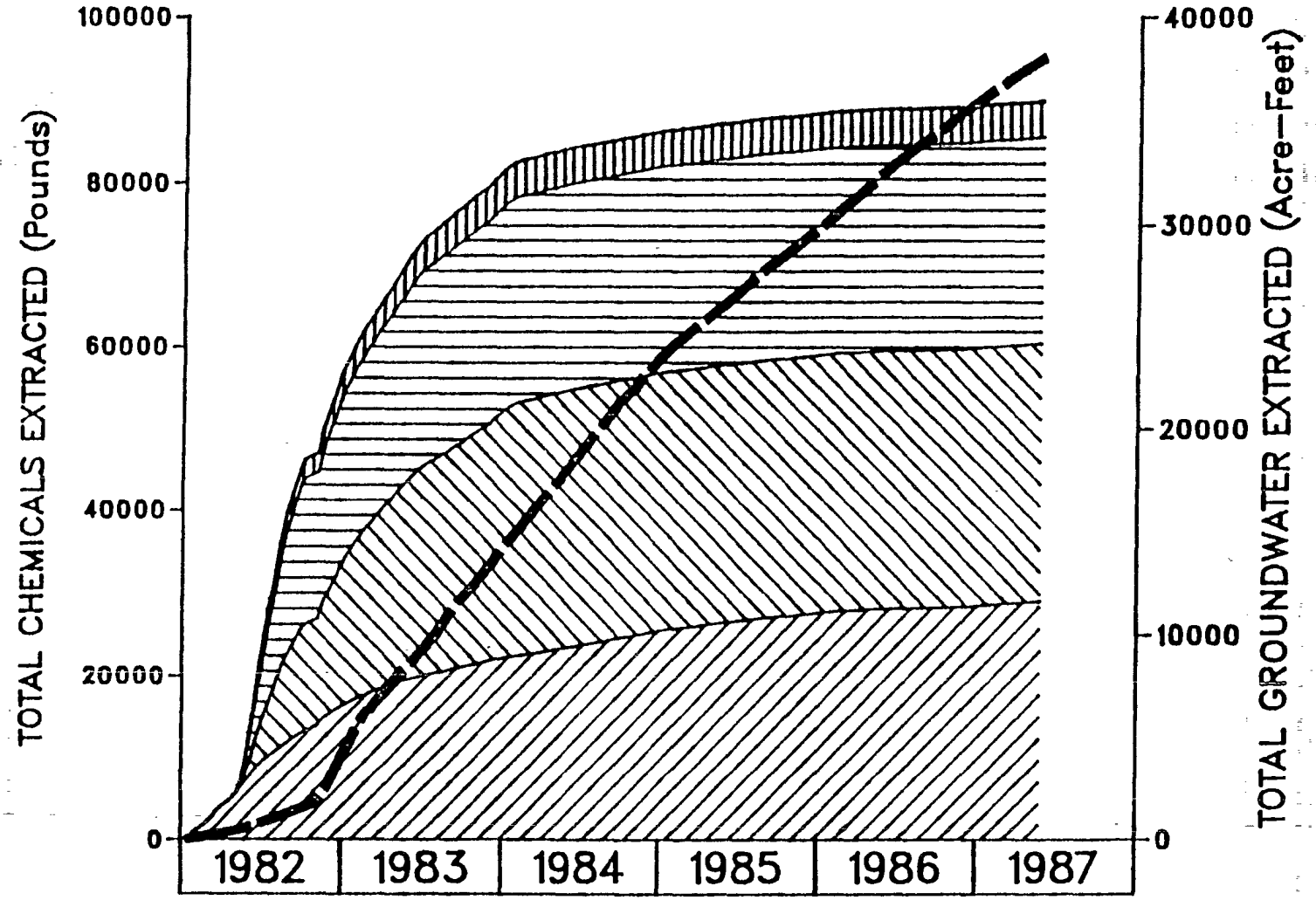
Figure 12
AQUIFER B CONCENTRATION OF TCA IN PUMPING WELL WCC-02 FROM 1982 THROUGH 1988
FAIRCHILD SEMICONDUCTOR SITE



Based on Canonie Environmental, Revised Draft Report, Remedial Action Plan, Oct. 1988.

Figure 13
AQUIFER C CONCENTRATIONS OF TCA IN OBSERVATION WELL 80 FROM 1982 THROUGH 1988.
FAIRCHILD SEMICONDUCTOR SITE

GROUNDWATER And CHEMICALS EXTRACTED CUMULATIVE For ALL WELLS



Legend

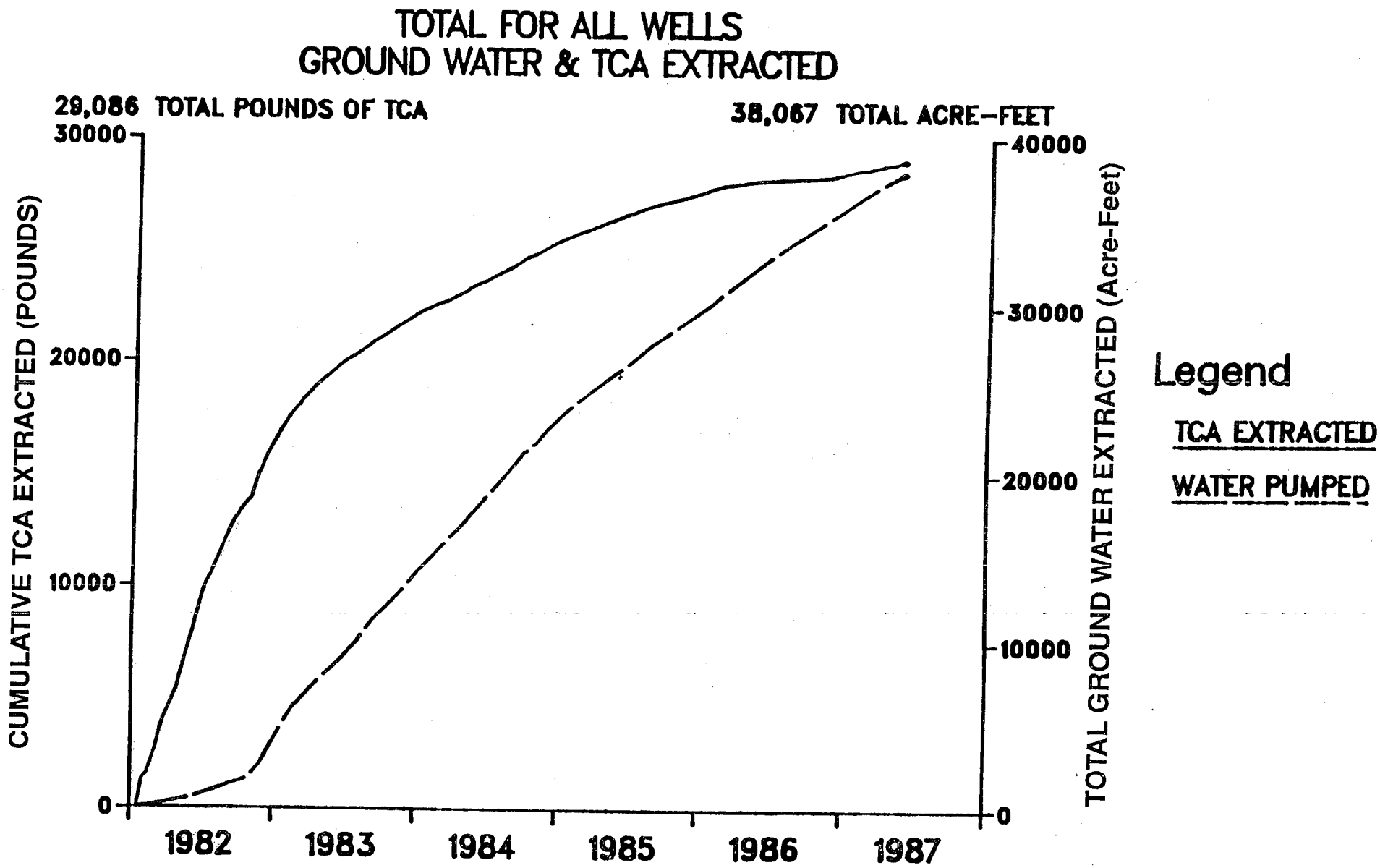
- TCA
- ACETONE
- IPA
- XYLENE

WATER PUMPED

Chemical	Weight Removed
TCA	29,090 lbs.
IPA	25,340
Acetone	31,350
Xylene	4,180
TOTAL	89,960 lbs.

Based on Canonie Environmental, Revised Draft Report, Remedial Action Plan, Oct. 1988.

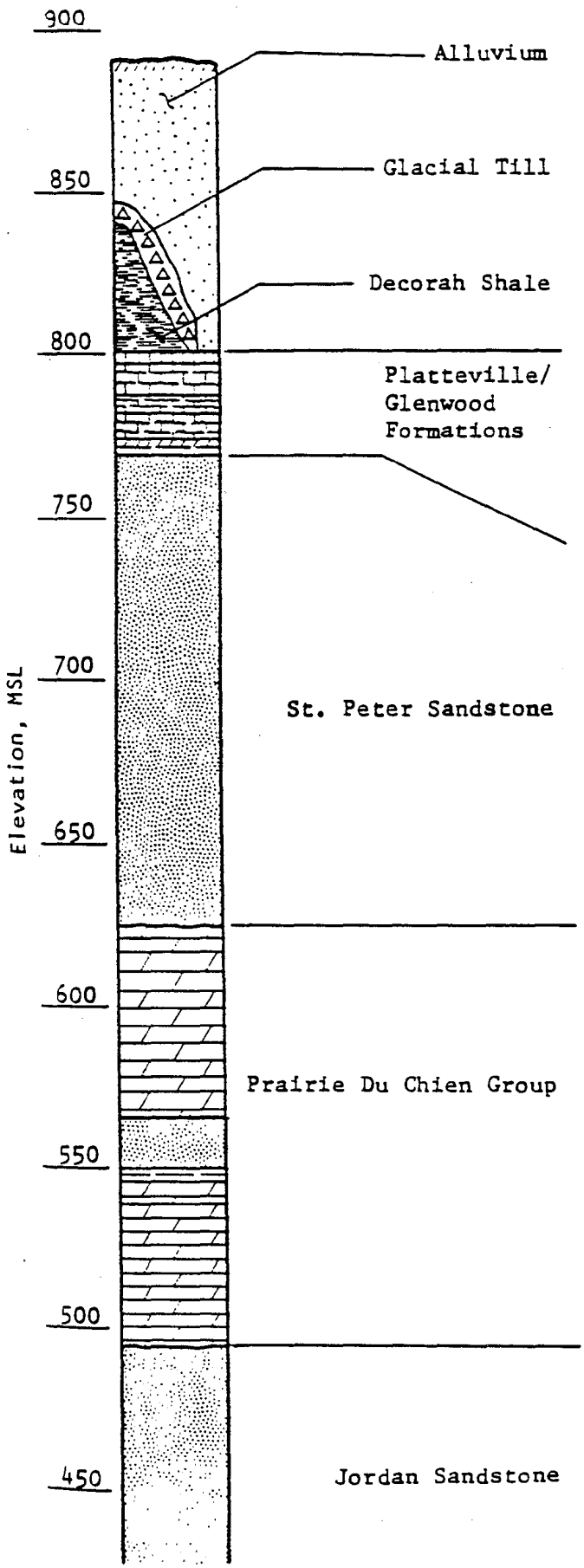
Figure 14
CUMULATIVE TOTALS OF CHEMICAL MASS AND GROUNDWATER VOLUME EXTRACTED, 1982 TO MID-1987.
FAIRCHILD SEMICONDUCTOR SITE



Based on Canonie Environmental, Revised Draft Report, Remedial Action Plan, Oct. 1988.

Figure 15
CUMULATIVE POUNDS OF TRICHLOROETHANE AND VOLUME OF GROUND WATER EXTRACTED 1982 TO MID-1987.
FAIRCHILD SEMICONDUCTOR SITE

Figure 1
SITE LOCATION MAP
GENERAL MILLS SITE, MINNEAPOLIS, MN



Sand, gravelly sand and silty sand, sometimes overlain by bogs and marshes which have been drained and filled. Overlying soil is variable in composition often clayey or silty. Deposits are terrace deposits from Glacial River Warren. Thickness ranges from 23 to 57 feet.

Gray and red tills associated with Des Moines and Superior lobes. Unsorted material with variable texture containing clay sizes and boulders. Sometimes underlain by thin layer of alluvium. Contains sand lenses. Absent in many places, up to 20' thick.

Greenish-gray to olive-gray claystone, fissile, fossiliferous, contains several limestone layers. Patchy in this area. Thicknesses range up to 50'.

Carimona member - micrite, fossiliferous, often [illegible]ured and weathered, 3.5-4.5' thick.
Magnolia member - fossiliferous micrite, calcitic shale, with rippled bedding, corroded zones, some fractures. 8.5-9' thick.
Hidden Falls - micrite, shaly, fossiliferous, 6-7' thick.
Mifflin member, thin beds of limestone, interbedded shale 12-13' thick.
Pecatonica member - dolomite, hard, 1-1.5' thick.
Glenwood shale - green shale, sandy at the base, 3-5' thick.

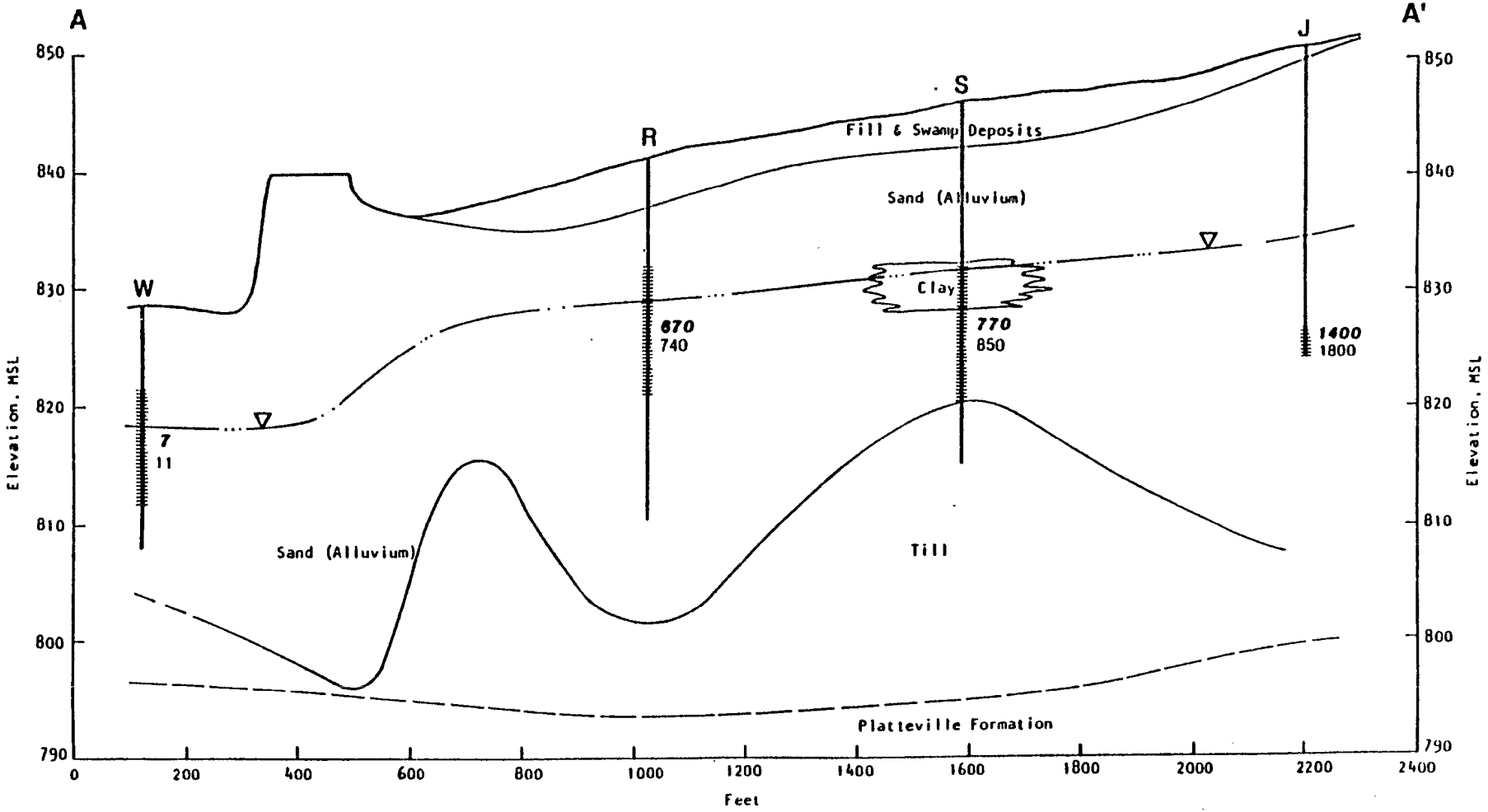
Light yellow or white, medium grained, massive appearing sandstone composed of rounded and subrounded grains. Thin beds of green shale are present. Ranges in thickness from 150-170'.

Thickness of entire formation is 120'-150'.
Willow River Dolomite - thin to thick bedded dolomite, sandy dolomite with some interbedded quartzose sandstone.
New Richmond Sandstone - fine- to medium-grained quartzose sandstone and quartzitic dolomite, minor amounts of shale and pure dolomite.
Oneota Dolomite - thin to thick bedded, light brownish gray or buff, fine- to medium-grained dolomite, silt sized dolomite matrix.

Argillaceous and dolomitic quartz sandstone with pebble-size clasts of dolomitic sandstone and thin beds of dolomite, white or yellow, coarse to medium-grained orthoquartzites to yellow, silty, fine grained quartzose sandstone. 85-100' thick. Underlain by the St. Lawrence Formation which is 120'-200' thick and contains a variety of silty or sandy dolomitic rocks.

Source: Barr, 1988

Figure 2
GENERALIZED GEOLOGIC COLUMN
GENERAL MILLS SITE, MINNEAPOLIS, MN



670 Trichloroethylene, µg/L Dec-Feb 1984

740 Sum of Volatile Organic Concentrations, µg/L Dec-Feb 1984

Soil Boring

Well Screen

Source: Barr, 1985

Figure 3
GEOLOGIC CROSS SECTION A-A'
GENERAL MILLS SITE, MINNEAPOLIS, MN

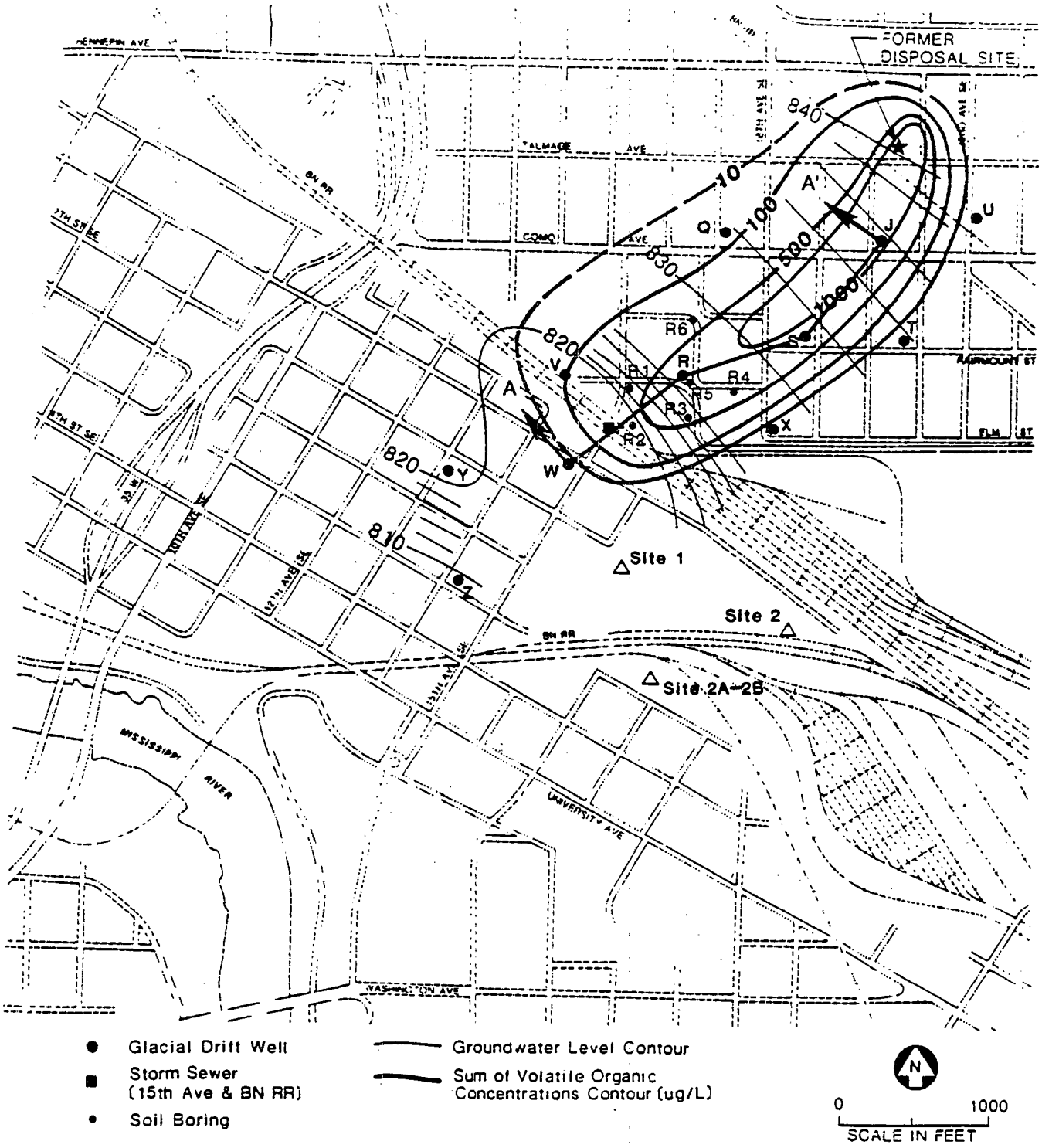
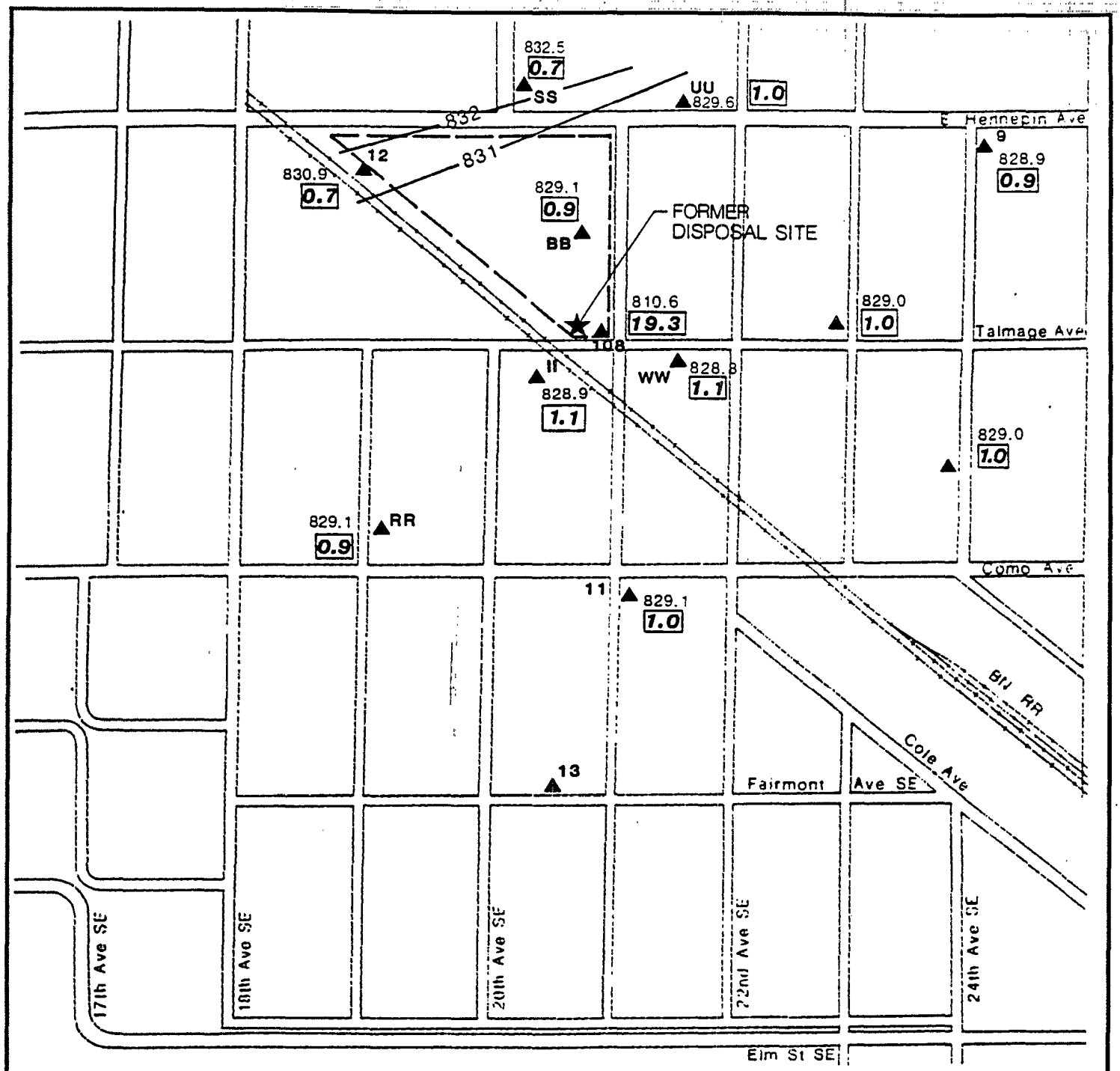


Figure 4
WELL LOCATIONS, WATER LEVELS, AND TOTAL VOC DISTRIBUTION IN THE SHALLOW AQUIFER, MARCH 1984
GENERAL MILLS SITE, MINNEAPOLIS, MN

Source: Barr, 1985



▲ Platteville Piezometer (Carimona)

829.0 Carimona Potentiometric Elevation (MSL) January 25, 1984

—— Carimona Potentiometric Contour

1.0 Pump Test Drawdown (Feet)

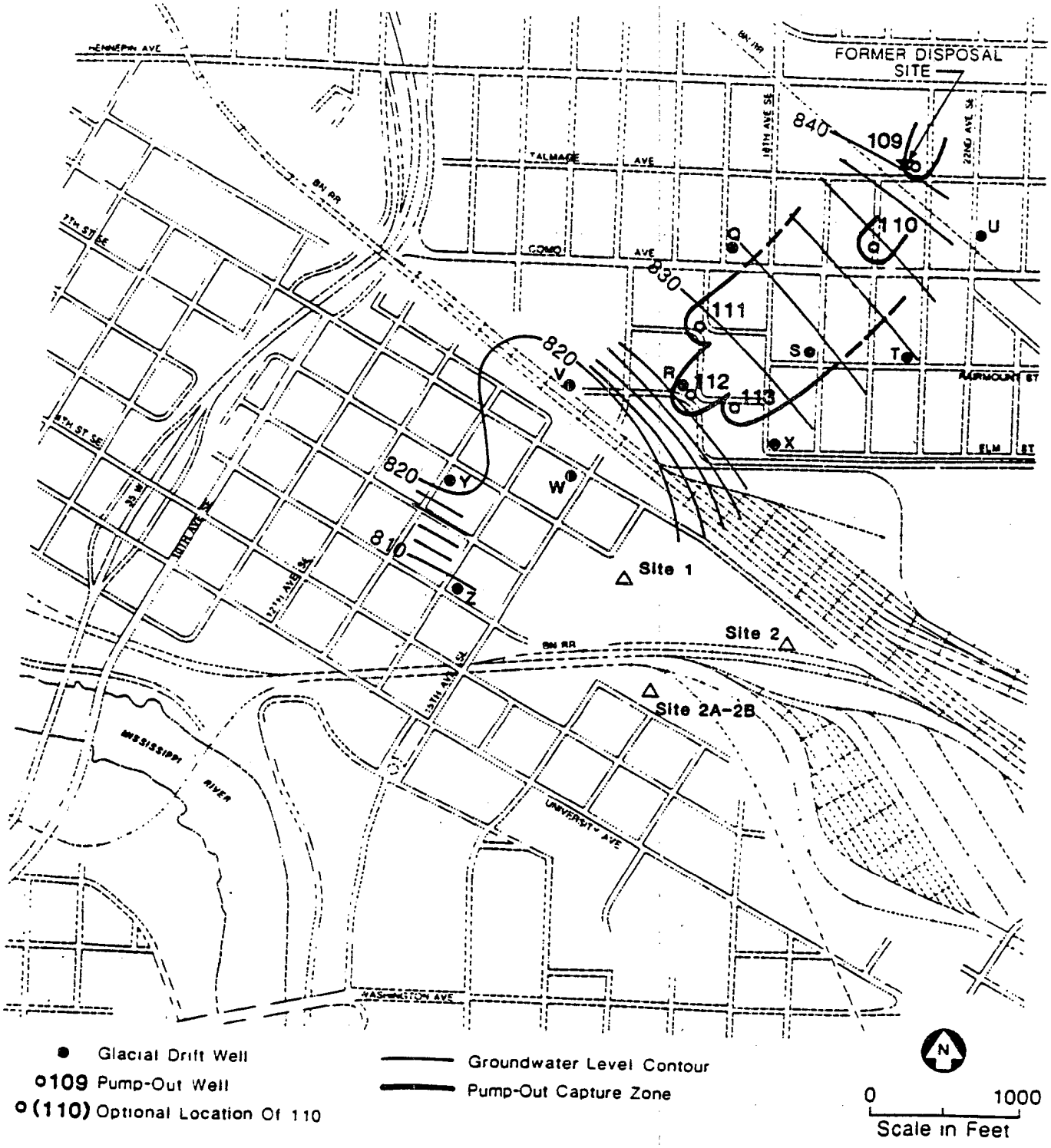
N

0 200 400

Scale in Feet

Figure 5
WELL LOCATIONS AND WATER LEVELS IN THE CARIMONA MEMBER, JANUARY, 1984
GENERAL MILLS SITE, MINNEAPOLIS, MN

Source: Barr, 1985



● Glacial Drift Well

○109 Pump-Out Well

○(110) Optional Location Of 110

Groundwater Level Contour

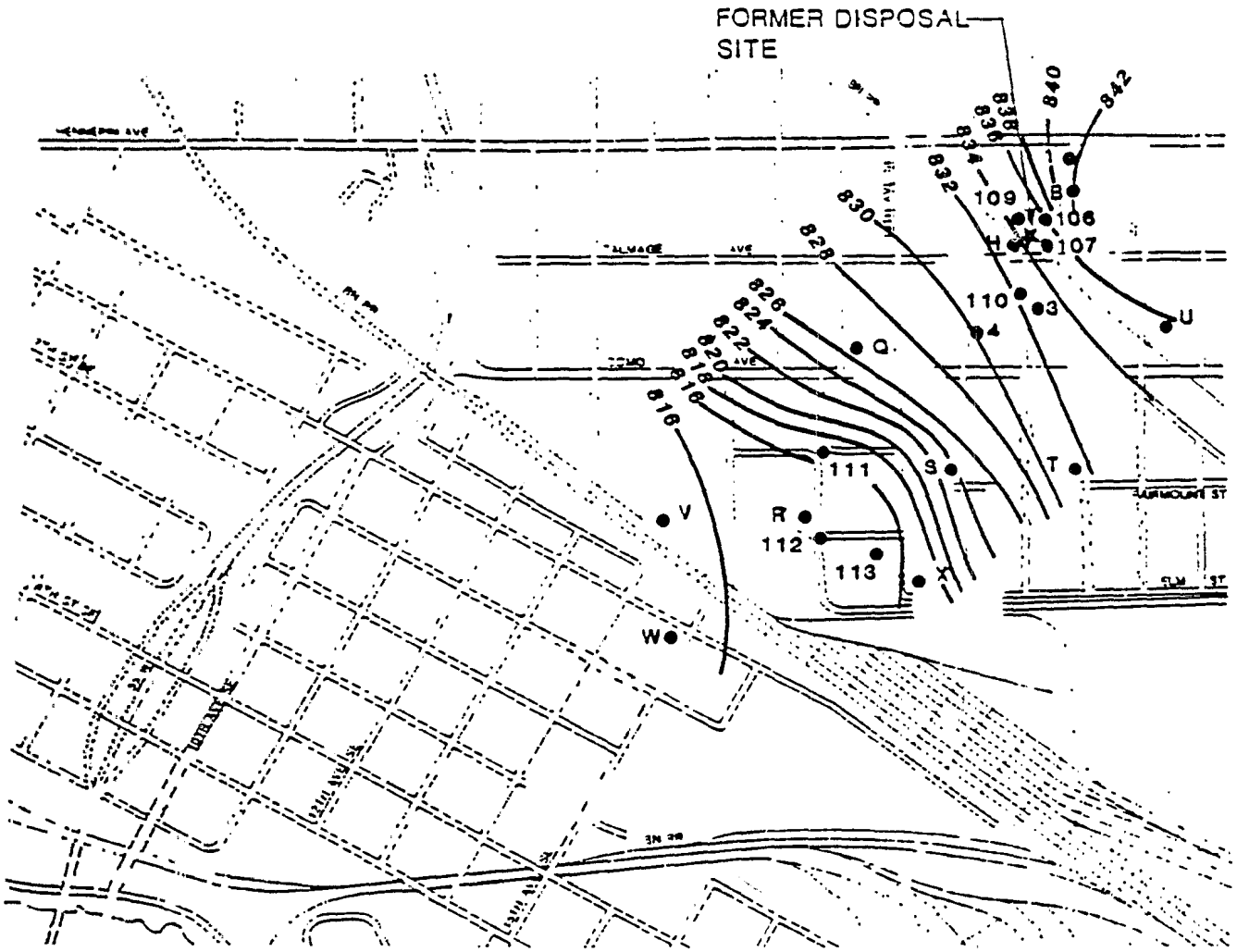
Pump-Out Capture Zone

0 1000

Scale in Feet

Figure 6
DESIGN CAPTURE ZONES OF THE SHALLOW AQUIFER EXTRACTION WELLS
GENERAL MILLS SITE, MINNEAPOLIS, MN

Source: Barr, 1985



● GLACIAL DRIFT MONITORING WELL OR SITE AND DOWNGRADIENT PUMP-OUT WELL

WATER TABLE CONTOUR (MSL)

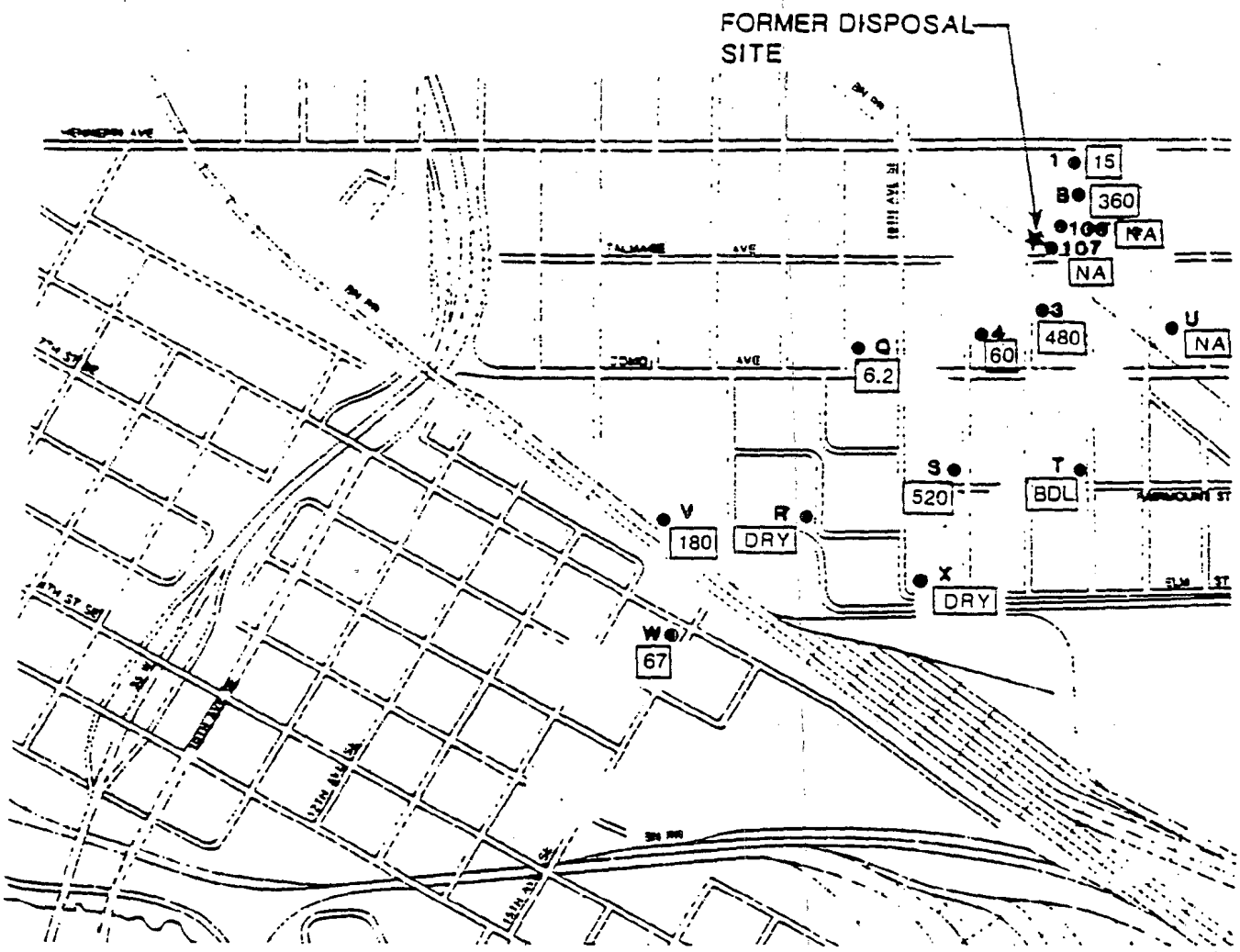
N

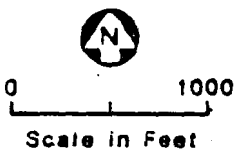
0 1000

Scale in Feet

Figure 7
WATER LEVELS IN THE SHALLOW AQUIFER, APRIL 1988
GENERAL MILLS SITE, MINNEAPOLIS, MN

Source: Barr, 1989





● GLACIAL DRIFT MONITORING WELL

[520] SUM OF VOLATILE ORGANIC CONCENTRATIONS (ug/L) (VOC)

[BDL] BELOW DETECTION LIMIT

[NA] NOT ANALYZED

Figure 8
TOTAL VOC CONCENTRATIONS IN THE SHALLOW AQUIFER, APRIL 1988
GENERAL MILLS SITE, MINNEAPOLIS, MN

Source: Barr, 1989

Table 2

1988 WATER QUALITY DATA
GLACIAL DRIFT WELLS

(concentrations in ug/L)

	B	Q	R			S		
	04/08/88	04/06/88	04/06/88	07/13/88	10/27/88	04/08/88	07/13/88	10/27/88
1,1-Dichloroethane	3.7	0.68	--	--	--	0.41	--	--
1,2-Dichloroethane	<0.10	<0.10	--	--	--	<0.10	--	--
1,2-Dichloroethylene, cis	3.0	<0.10	--	--	--	54	--	--
1,2-Dichloroethylene, trans	<0.10	<0.10	--	--	--	<0.10	--	--
1,1,2,2-Tetrachloroethane	<0.20	1.6	--	--	--	<0.20	--	--
Tetrachloroethylene	12	<0.20	--	--	--	7.1	--	--
1,1,1-Trichloroethane	10	3.1	--	--	--	1.5	--	--
Trichloroethylene	330	0.86	DRY	DRY	DRY	460	160	110

	T	V			W			X
	04/05/88	04/06/88	07/13/88	10/27/88	04/06/88	07/13/88	10/27/88	04/06/88
1,1-Dichloroethane	<0.10	<0.10	--	--	<0.10	--	--	--
1,2-Dichloroethane	<0.10	<0.10	--	--	<0.10	--	--	--
1,2-Dichloroethylene, cis	<0.10	10	--	--	24	--	--	--
1,2-Dichloroethylene, trans	<0.10	<0.10	--	--	<0.10	--	--	--
1,1,2,2-Tetrachloroethane	<0.20	1.9 s	--	--	0.20	--	--	--
Tetrachloroethylene	<0.20	<0.20	--	--	<0.20	--	--	--
1,1,1-Trichloroethane	<0.50	4.6 s	--	--	<0.50	--	--	--
Trichloroethylene	<0.50	160	33	37	43	8.1	26	DRY

	1			3			4
	04/06/88	07/13/88	10/27/88	04/08/88	07/13/88	10/27/88	04/08/88
1,1-Dichloroethane	<0.10	--	--	9.5	--	--	0.50
1,2-Dichloroethane	<0.10	--	--	<0.10	--	--	<0.10
1,2-Dichloroethylene, cis	<0.10	--	--	13	--	--	1.1
1,2-Dichloroethylene, trans	<0.10	--	--	<0.10	--	--	<0.10
1,1,2,2-Tetrachloroethane	15 s	--	--	<0.20	--	--	<0.20
Tetrachloroethylene	<0.20	--	--	11	--	--	1.6
1,1,1-Trichloroethane	<0.50	--	--	6.6	--	--	1.2
Trichloroethylene	<0.50	0.5	<0.5	440	140	98	55

---

s Potential false positive value based on statistical analysis of blank sample data.
-- Not analyzed.

.001

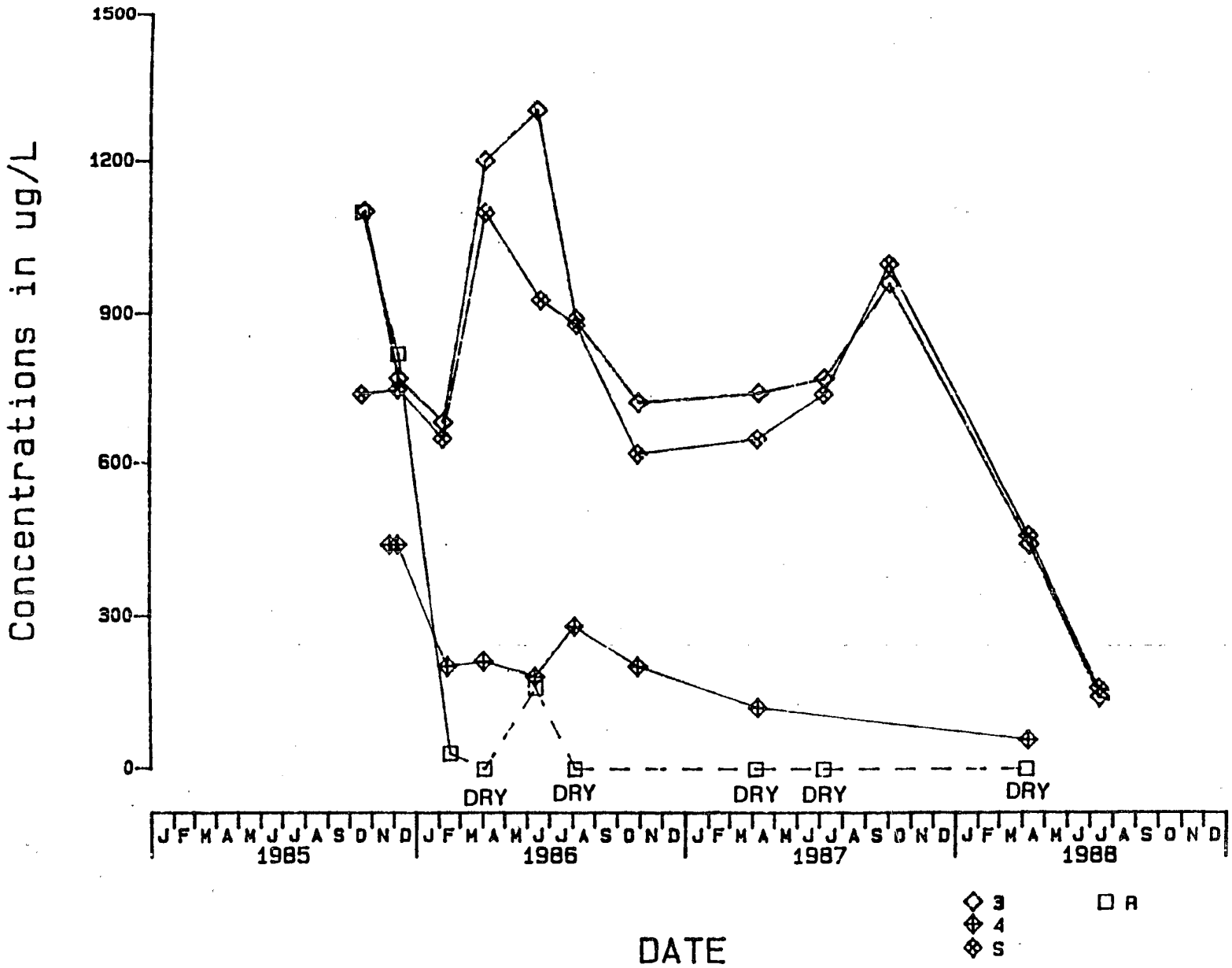


Figure 9
HISTORY OF TCE CONCENTRATION VARIATIONS IN SHALLOW AQUIFER WELLS 3, 4, S AND R
GENERAL MILLS SITE, MINNEAPOLIS, MN

Source: Barr, 1989

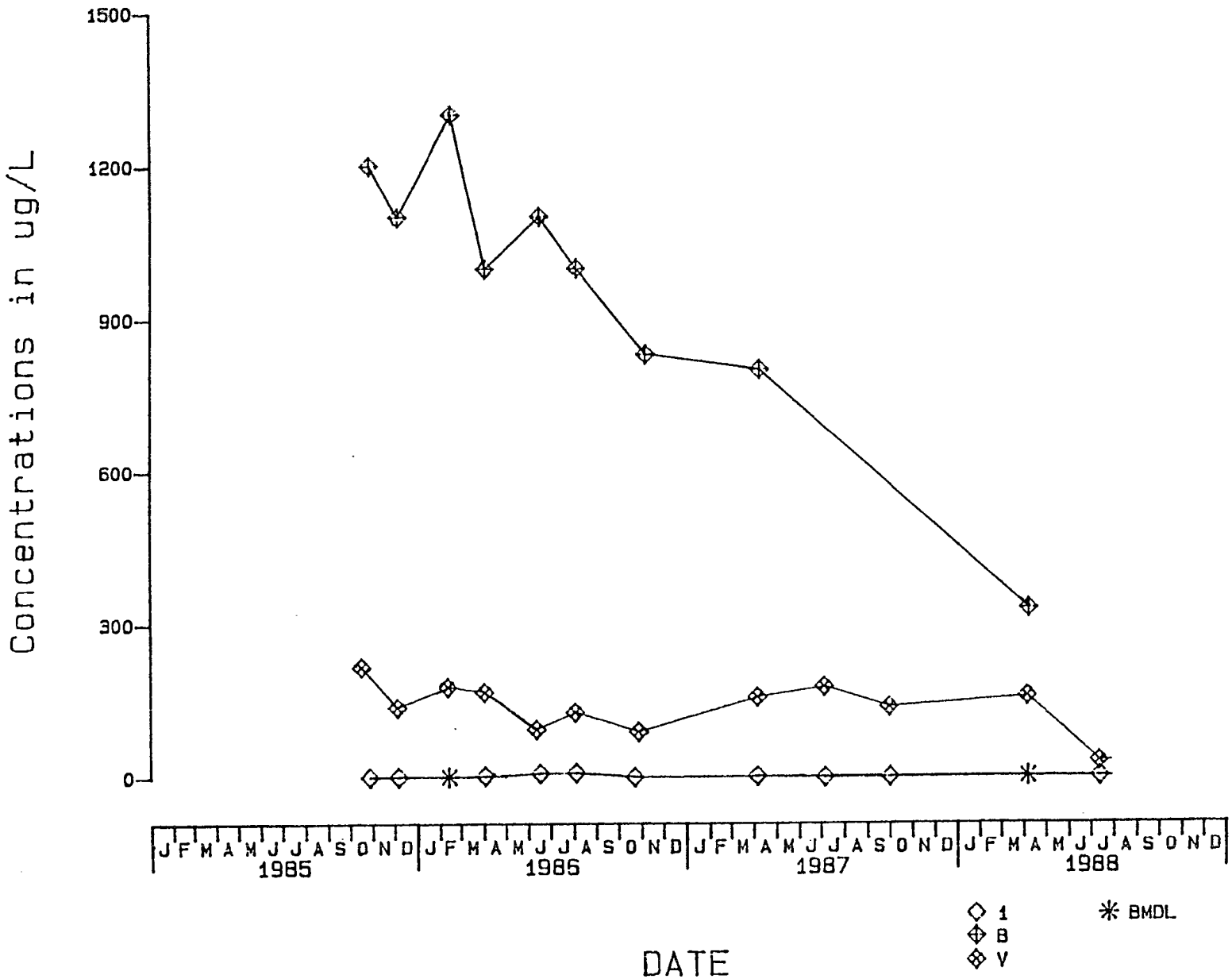
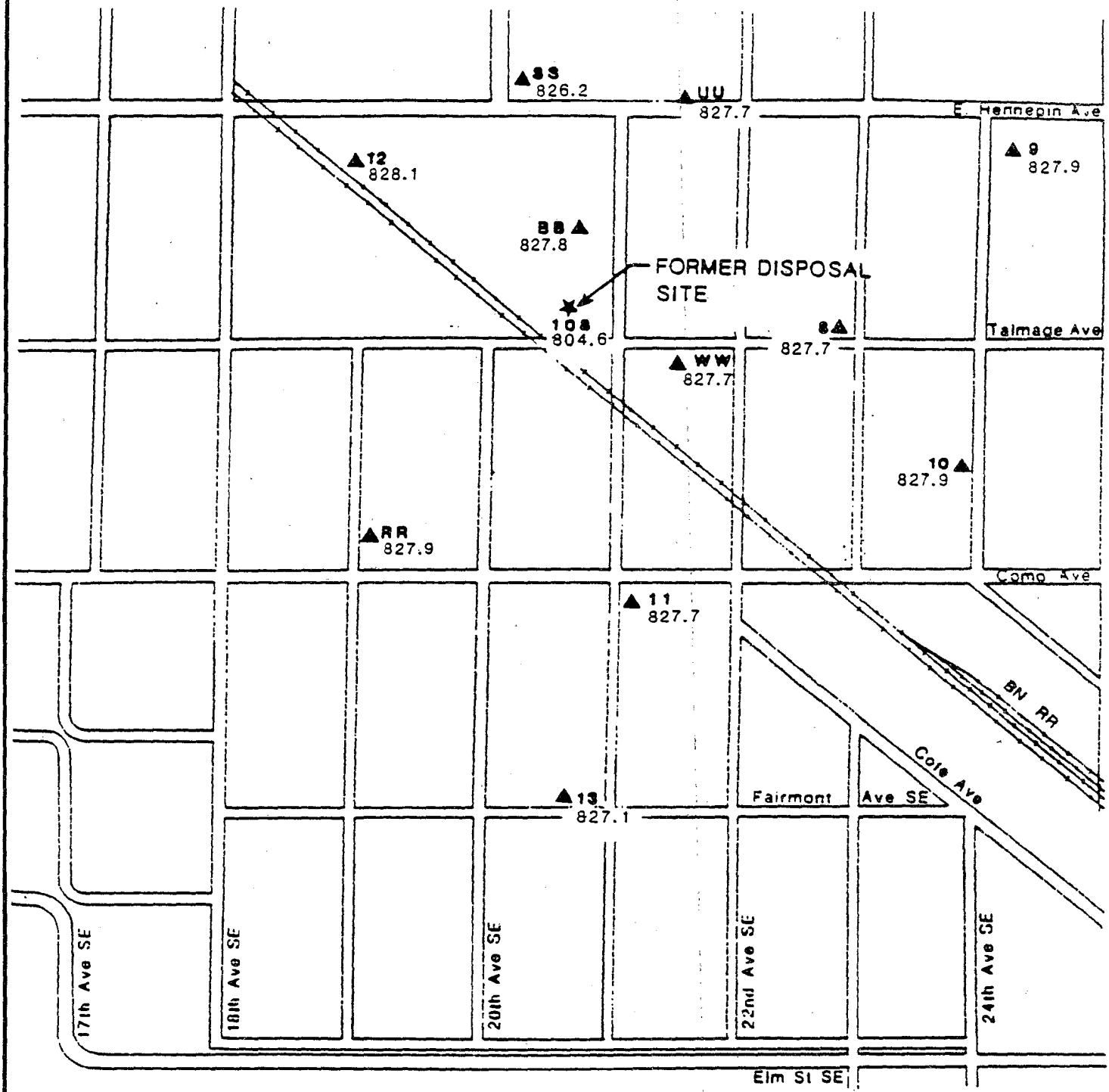


Figure 10
HISTORY OF TCE CONCENTRATION VARIATIONS IN SHALLOW AQUIFER WELLS 1, B, AND V
GENERAL MILLS SITE, MINNEAPOLIS, MN

Source: Barr, 1989



▲ CARIMONA MEMBER WELL

826.2 CARIMONA POTENTIOMETRIC SURFACE ELEVATION (MSL)

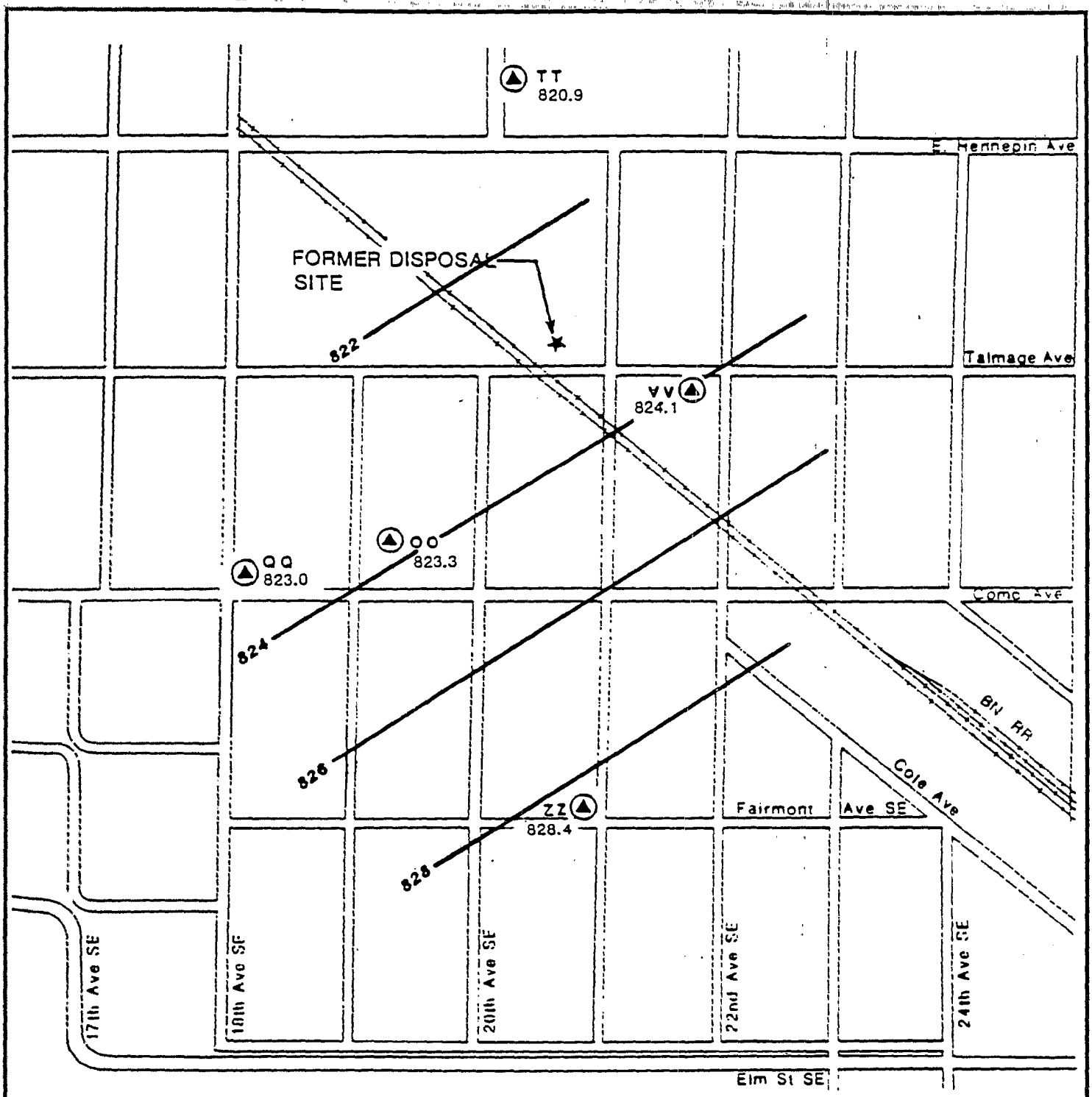
N

0 200 400

Scale in Feet

Figure 11
WATER LEVELS IN THE CARIMONA AQUIFER, APRIL 1988
GENERAL MILLS SITE, MINNEAPOLIS, MN

Source: Barr, 1989



MAGNOLIA MEMBER WELL

820.9 MAGNOLIA POTENTIOMETRIC SURFACE ELEVATION (MSL)

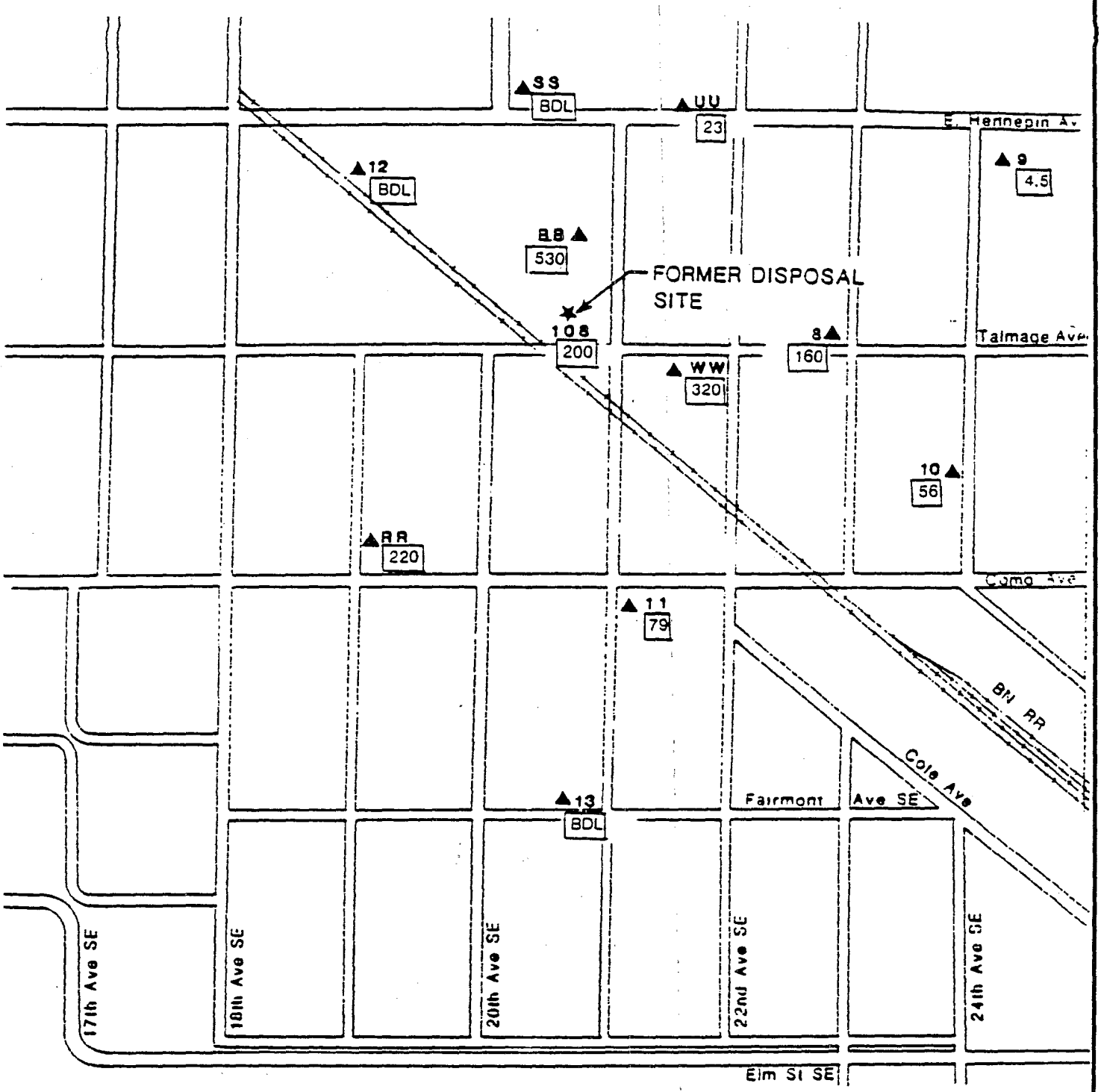
MAGNOLIA POTENTIOMETRIC SURFACE CONTOUR (MSL)

N

0 200 400
Scale in Feet

Figure 12
WATER LEVELS IN THE MAGNOLIA AQUIFER, APRIL 1988
GENERAL MILLS SITE, MINNEAPOLIS, MN

Source: Barr, 1989



▲ CARIMONA MEMBER WELL

79 TRICHLOROETHYLENE CONCENTRATION (ug/L)(TCE)

BDL BELOW DETECTION LIMIT

N

0 200 400

Scale in Feet

Figure 13
CONCENTRATIONS IN CARIMONA WELLS, APRIL 1988
GENERAL MILLS SITE, MINNEAPOLIS, MN

Source: Barr, 1985

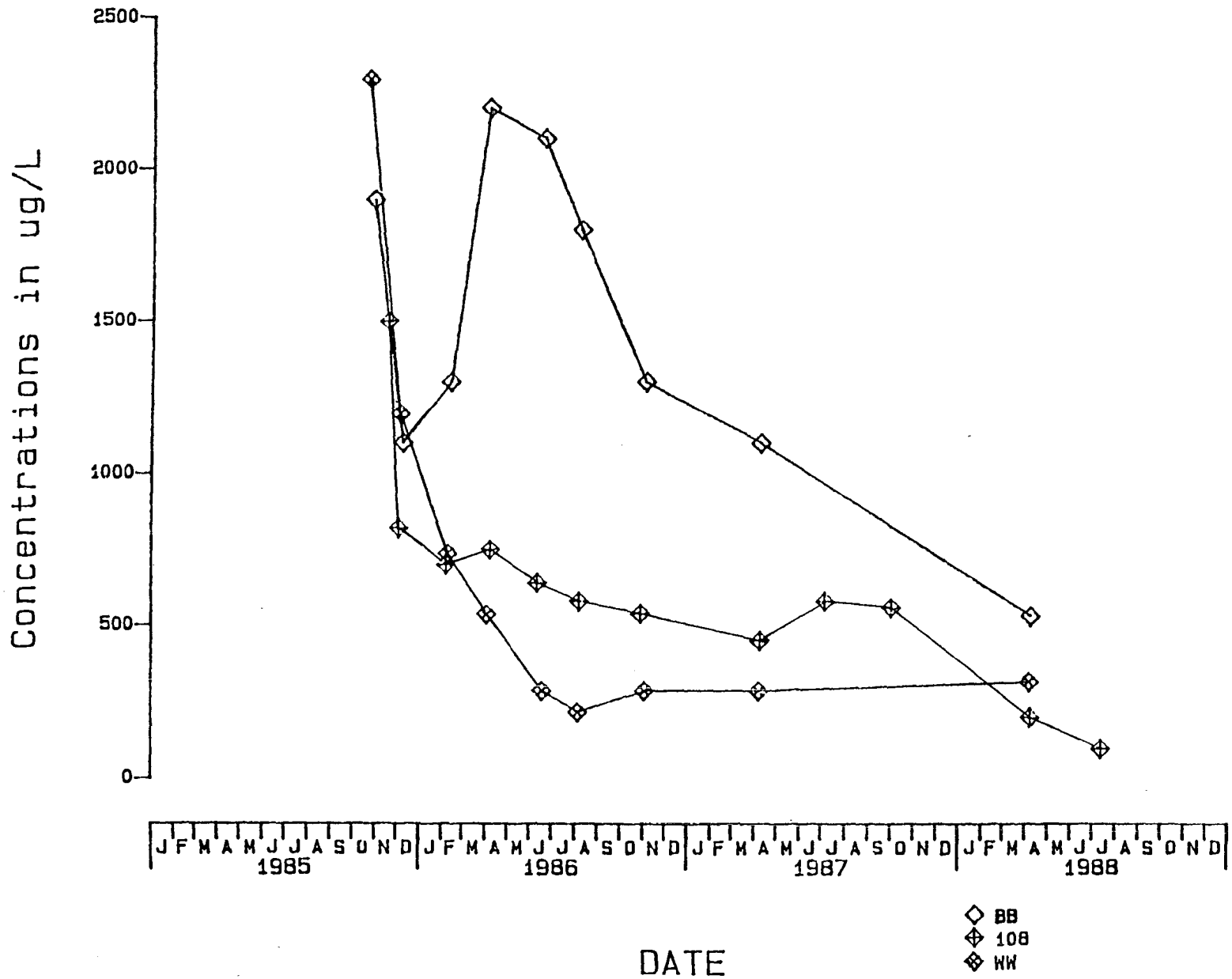


Figure 14
HISTORY OF TCE CONCENTRATION VARIATIONS IN CARIMONA WELLS BB, 108, AND WW
GENERAL MILLS SITE, MINNEAPOLIS, MN

Source: Barr, 1989

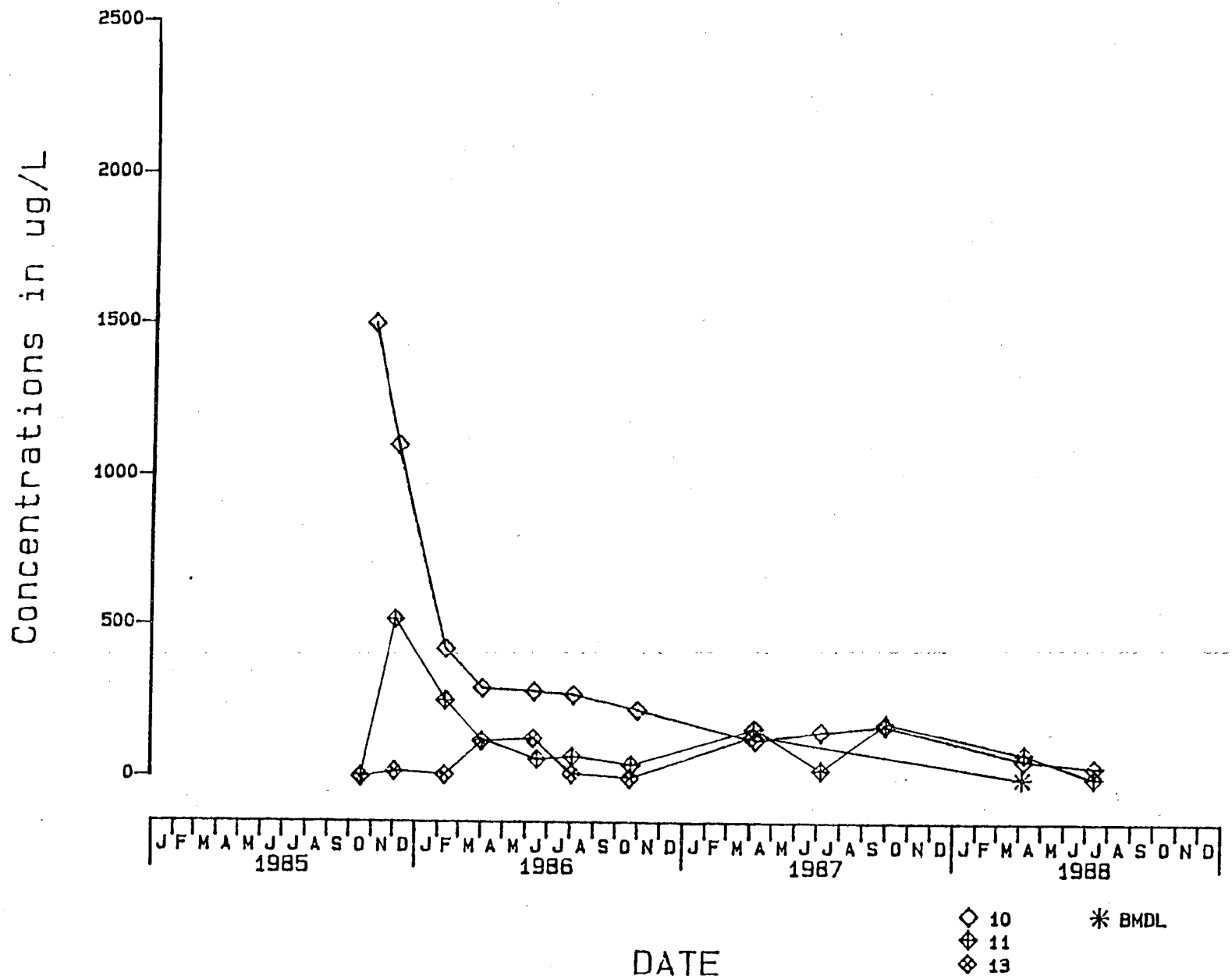
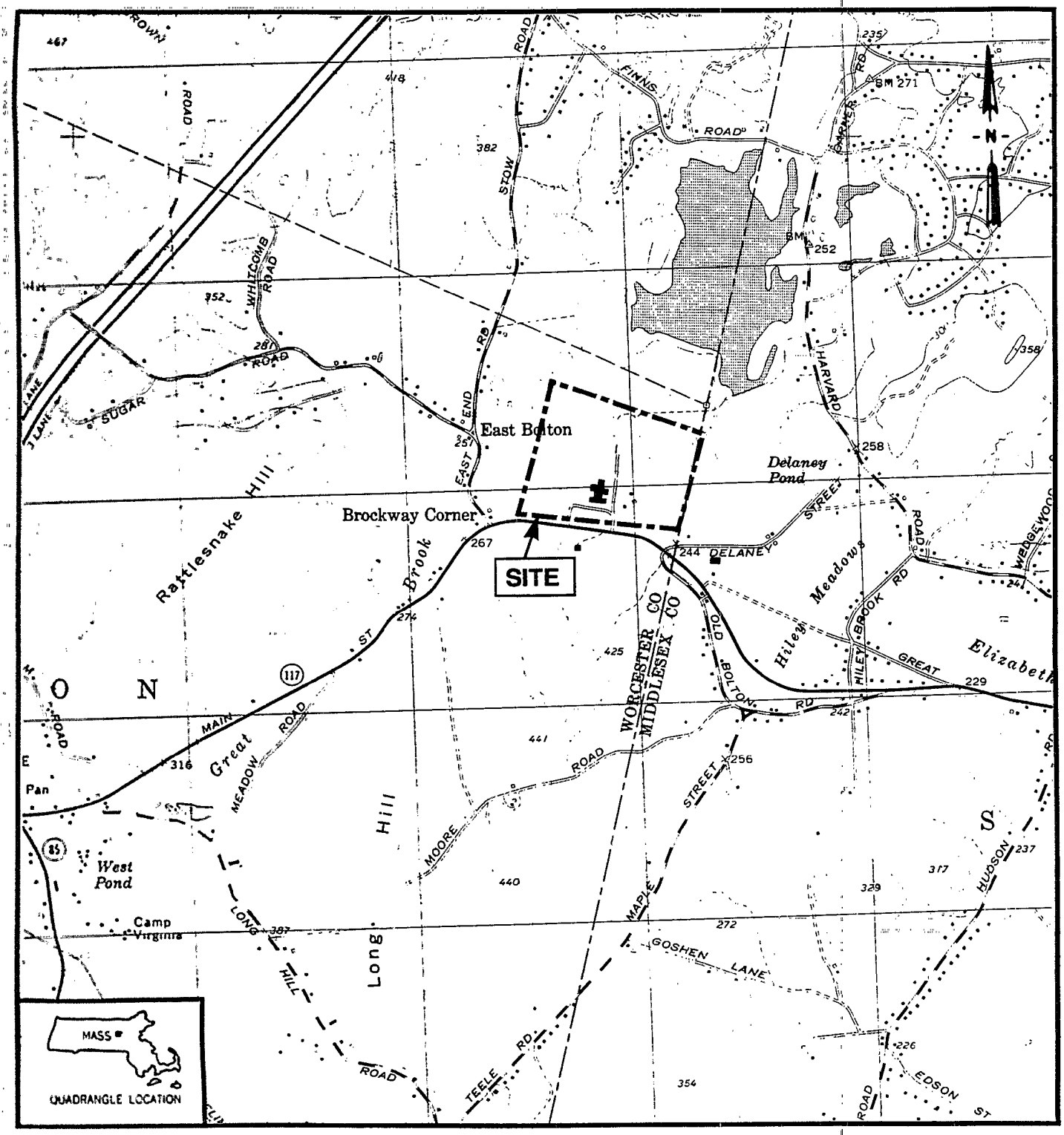


Figure 15
HISTORY OF TCE CONCENTRATION VARIATIONS IN CARIMONA WELLS 10, 11, AND 13
GENERAL MILLS SITE, MINNEAPOLIS, MN

Source: Barr, 1989

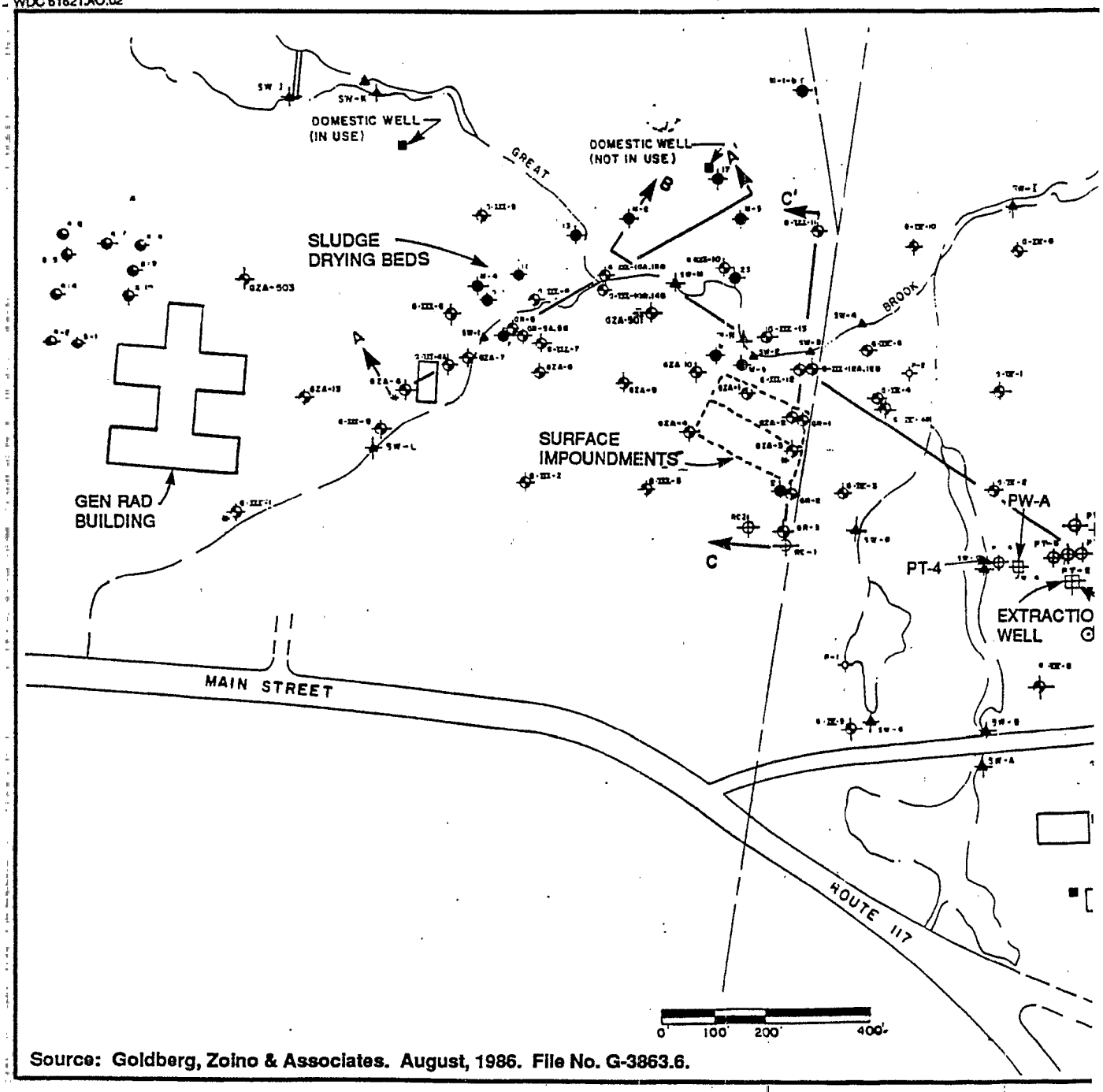


Source: USGS. 1966. Hudson, Massachusetts Quadrangle Map.

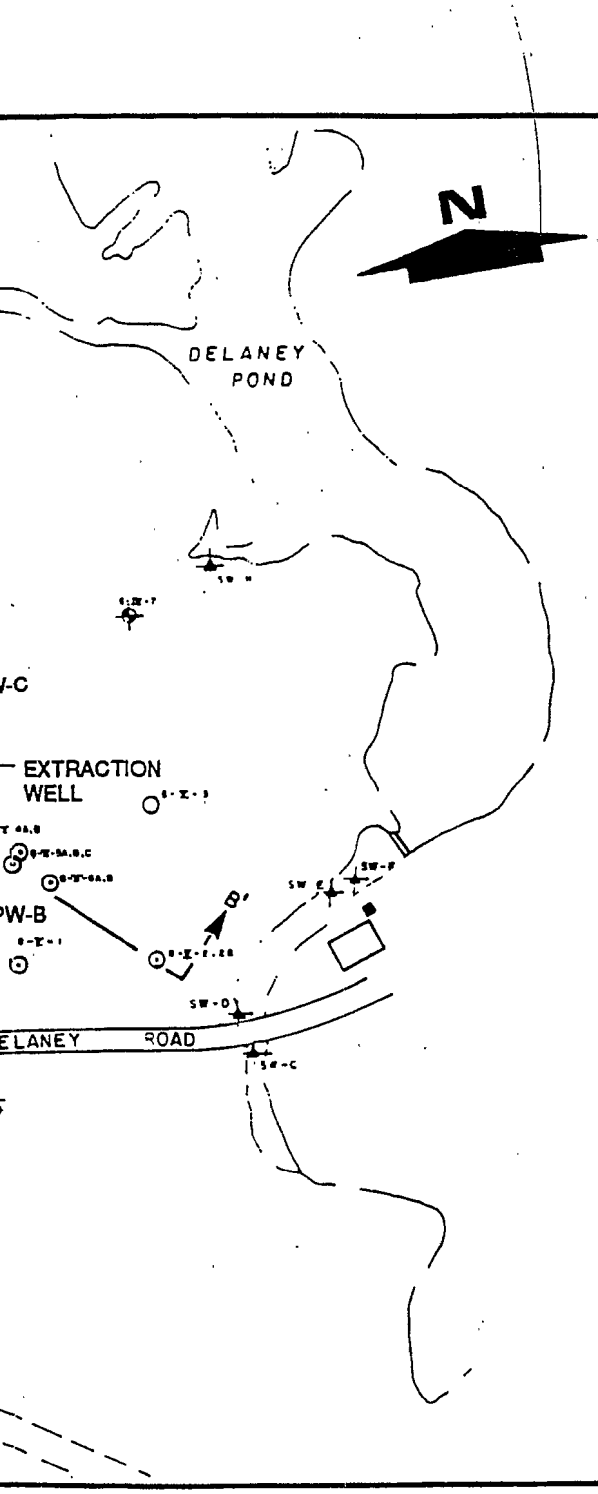
1000 0 1000 2000 3000 4000 5000 6000 7000 FEET

Figure 1
SITE LOCATION MAP
GEN RAD SITE
BOLTON, MASSACHUSETTS

WDC 61621.AO.02



Source: Goldberg, Zoino & Associates. August, 1986. File No. G-3863.6.



NOTES:

1) BASE MAP DEVELOPED FROM PLAN PROVIDED BY JOHN E. O'DONNELL AND ASSOC. ENTITLED "PROPERTY MAP, STOWE, MASSACHUSETTS", DATED 1971, AND FROM A PLAN PROVIDED BY AVIS AIR MAP, INC. ENTITLED "TOWN OF BOLTON, MASSACHUSETTS ASSESSOR'S MAP", DATED 1968.

2) THE LOCATIONS AND ELEVATIONS OF THE BORINGS AND SAMPLING LOCATIONS WERE DETERMINED BY OPTICAL SURVEY. THIS DATA SHOULD BE CONSIDERED ACCURATE ONLY TO THE DEGREE IMPLIED BY THE METHOD USED.

3) THE LOCATION OF BORINGS PERFORMED IN JULY 1986 WERE APPROXIMATELY DETERMINED BY FIELD MEASUREMENTS

LEGEND:

A A' — LOCATION OF PROFILE LINE

GR-1 — INITIAL PHASE BORINGS (GR SERIES), PERFORMED BY GZA DRILLING, INC. (MARCH, 1984)

GZA-1 — SECOND PHASE BORINGS (GZA SERIES), PERFORMED BY GZA, DRILLING, INC. (APRIL, 1984)

G-III-1 — THIRD PHASE BORINGS (G III SERIES), PERFORMED BY GZA, DRILLING, INC. (MAY—JULY, 1984)

G-IV-1 — FOURTH PHASE BORINGS (G-IV SERIES), PERFORMED BY GZA DRILLING, INC. (AUG.—SEPT., 1984)

P-1 — AUGER PROBE PERFORMED BY GZA DRILLING, INC. (MAY—JUNE, 1984)

SW-1 — SURFACE WATER SAMPLING POINT BY GZA PERSONNEL

TP-1 — ANDERSON—NICHOLS (ANCO) TEST PIT

B-7 — BORINGS PERFORMED BY GZA DRILLING, INC. FOR ANCO (OCT, 1983)

B-5, TP-11 — BORINGS AND TEST PITS PERFORMED FOR PREVIOUS GEOHYDROLOGIC STUDIES REFER TO GZA REPORTS DATED APRIL, 1980 AND NOVEMBER, 1983

M-1 — EXISTING MONITORING WELLS

PRIVATE WATER SUPPLY

BORINGS PERFORMED BY GZA DRILLING, INC. (MAY 1985) (BORINGS GZA-501, 502, 503)

SW-C — SURFACE WATER ELEVATION MEASUREMENT LOCATIONS LOCATED BY GZA PERSONNEL

BORINGS PERFORMED BY GZA DRILLING, INC. (JAN.—FEB., 1986)

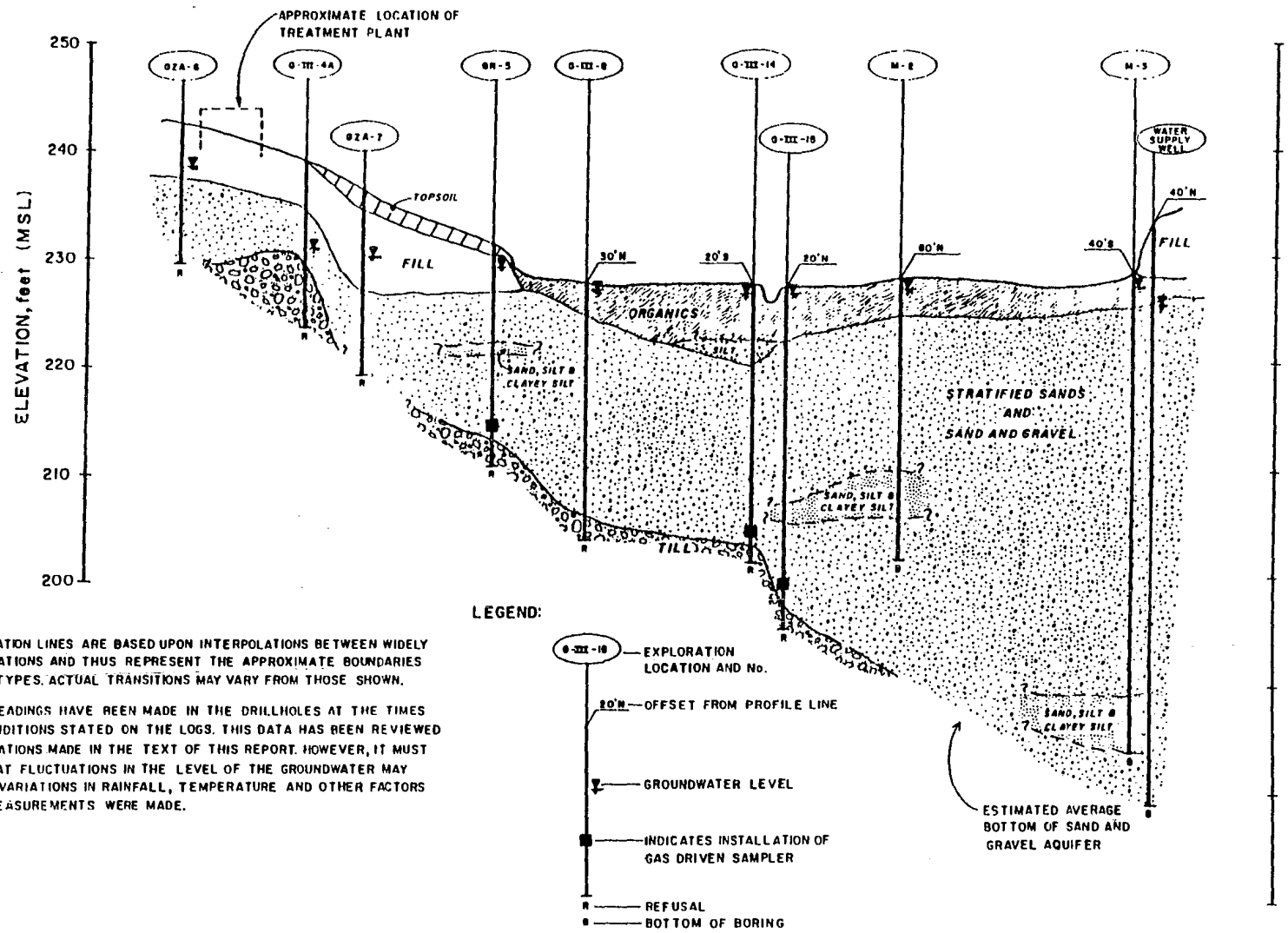
EXTRACTION WELL INSTALLED BY GZA DRILLING, INC. (APR., 1986, AUG., 1987)

BORINGS PERFORMED BY GZA DRILLING, INC. (JULY 1986, JUNE, 1987)

INDICATES WELL HAS BEEN ABANDONED AND/OR DESTROYED

HAND-DRIVEN PIEZOMETERS INSTALLED BY GZA PERSONNEL (JULY, 1987)

Figure 2
EXPLORATION LOCATION PLAN
GEN RAD SITE



NOTES:

1) THE STRATIFICATION LINES ARE BASED UPON INTERPOLATIONS BETWEEN WIDELY SPACED EXPLORATIONS AND THUS REPRESENT THE APPROXIMATE BOUNDARIES BETWEEN SOIL TYPES. ACTUAL TRANSITIONS MAY VARY FROM THOSE SHOWN.

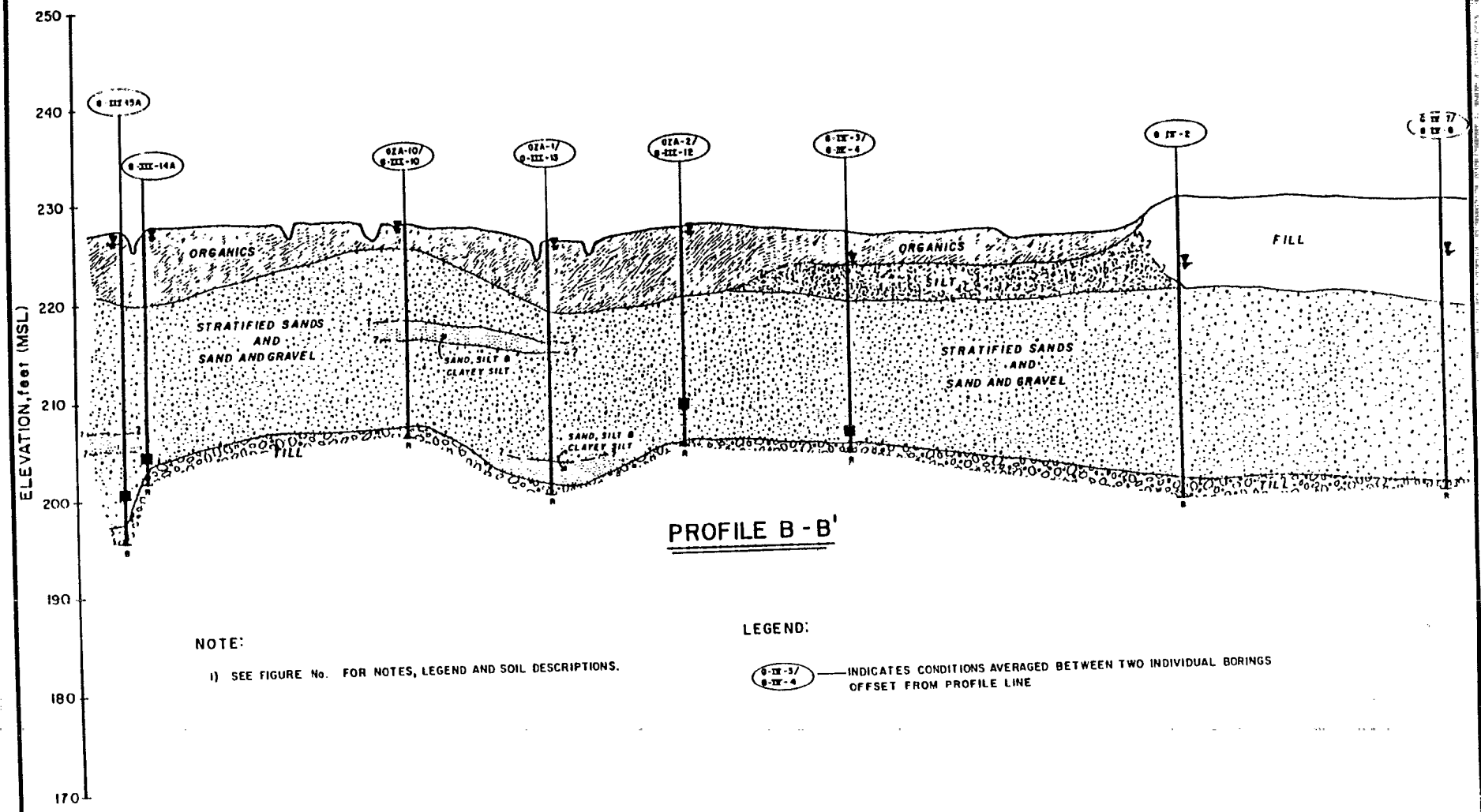
2) WATER LEVEL READINGS HAVE BEEN MADE IN THE DRILLHOLES AT THE TIMES AND UNDER CONDITIONS STATED ON THE LOGS. THIS DATA HAS BEEN REVIEWED AND INTERPRETATIONS MADE IN THE TEXT OF THIS REPORT. HOWEVER, IT MUST BE STATED THAT FLUCTUATIONS IN THE LEVEL OF THE GROUNDWATER MAY OCCUR DUE TO VARIATIONS IN RAINFALL, TEMPERATURE AND OTHER FACTORS AT THE TIME MEASUREMENTS WERE MADE.

LEGEND:

- EXPLORATION LOCATION AND No.
- 20'N — OFFSET FROM PROFILE LINE
- GROUNDWATER LEVEL
- INDICATES INSTALLATION OF GAS DRIVEN SAMPLER
- R — REFUSAL
- B — BOTTOM OF BORING

Figure 3
GEOLOGIC CROSS SECTION - TRANSECT A-A'
GEN RAD SITE

Source: Goldberg, Zoino & Associates. File No. G-3863.4.



NOTE:

1) SEE FIGURE No. FOR NOTES, LEGEND AND SOIL DESCRIPTIONS.

LEGEND:

(B-IX-3/ B-IX-4) —— INDICATES CONDITIONS AVERAGED BETWEEN TWO INDIVIDUAL BORINGS OFFSET FROM PROFILE LINE

Figure 4
GEOLOGIC CROSS SECTION - TRANSECT B-B'
GEN RAD SITE

Source: Goldberg, Zoino & Associates. File No. G-3863.4.

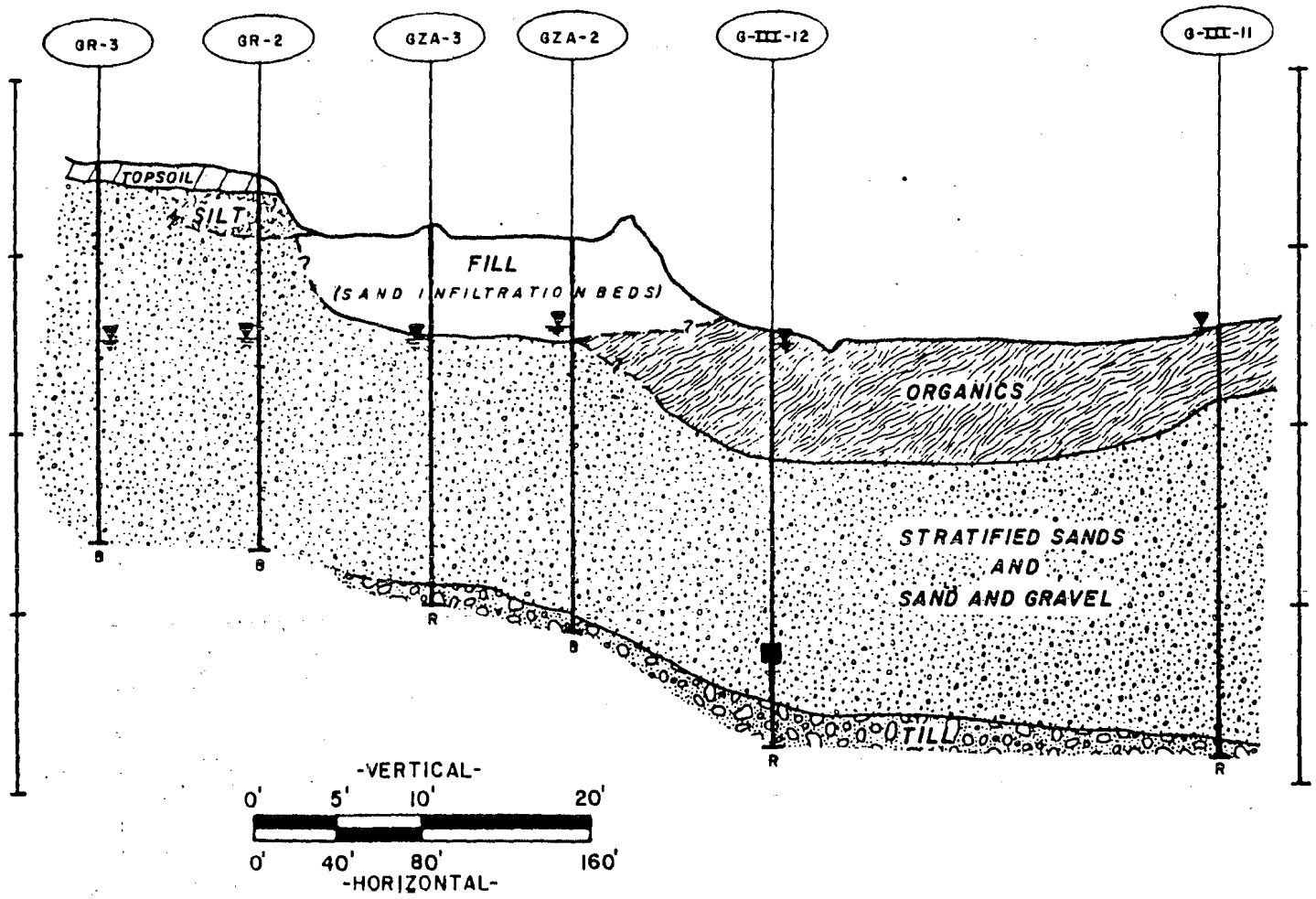
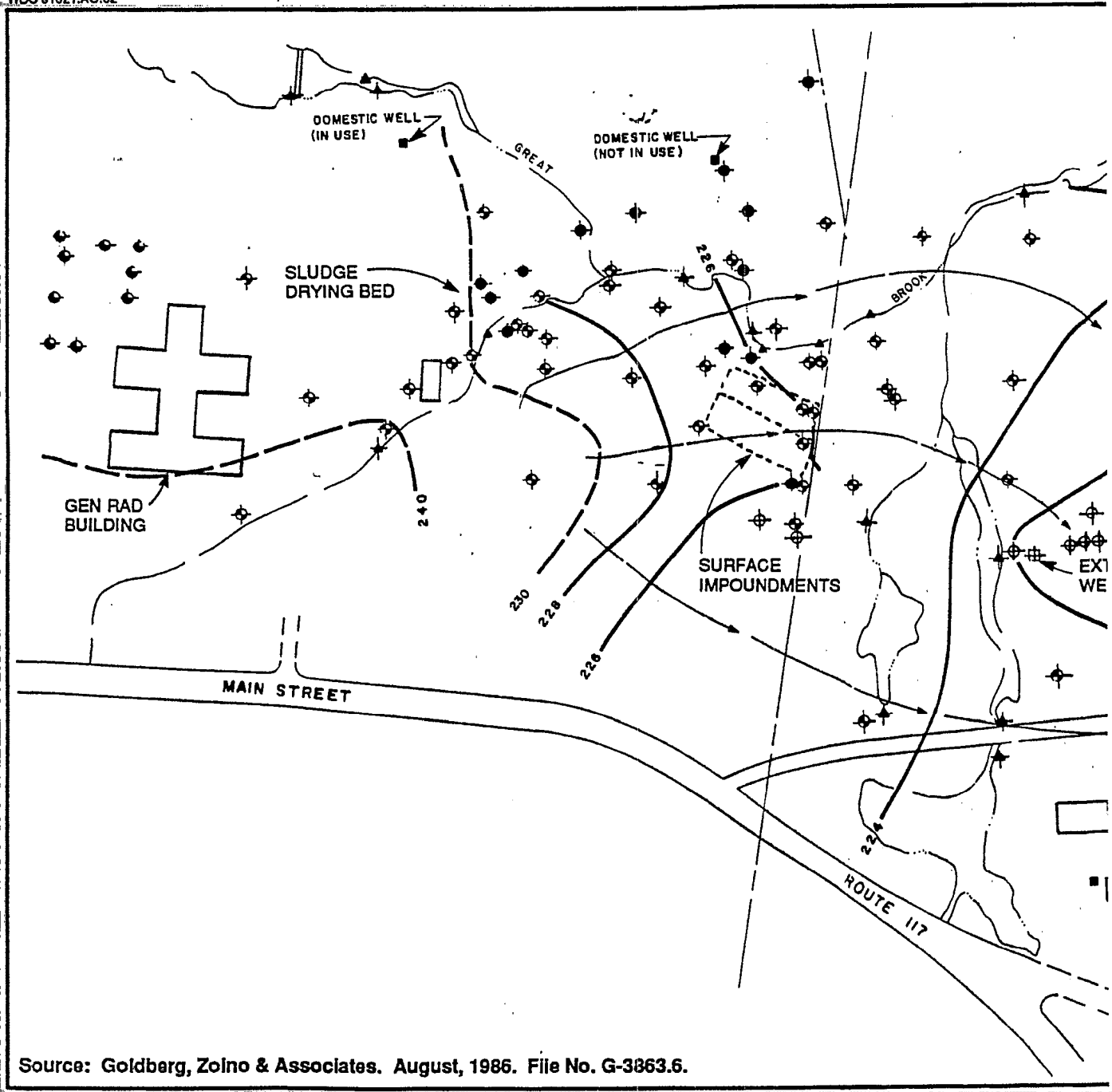


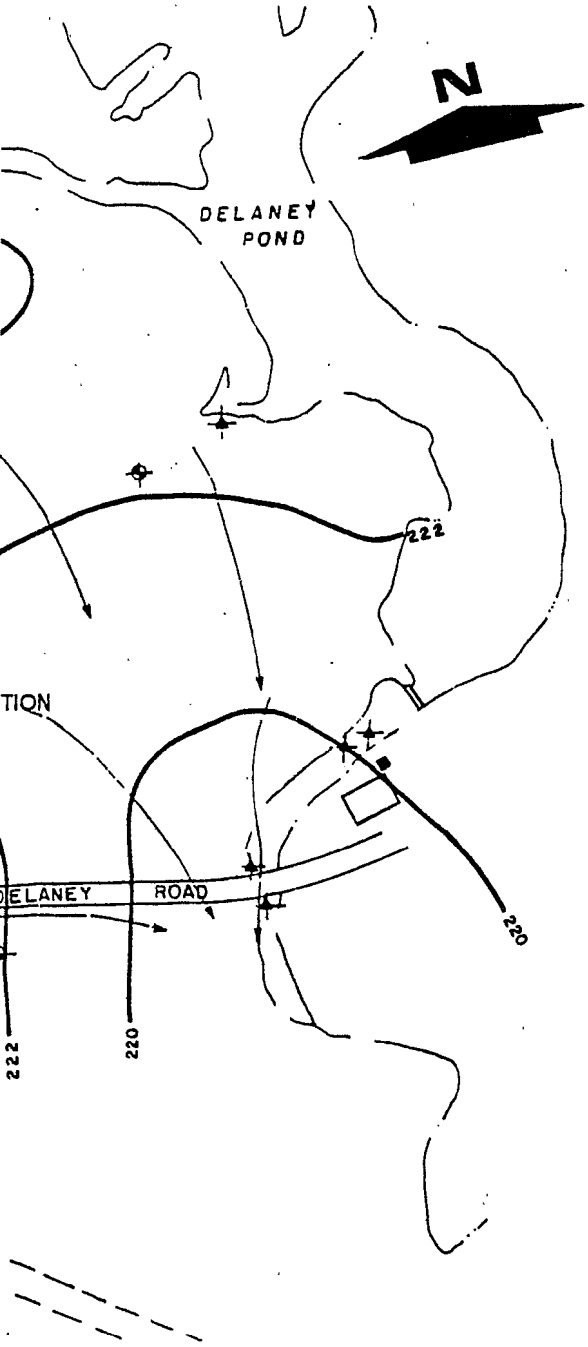
Figure 5
GEOLOGIC CROSS SECTION - TRANSECT C-C'
GEN RAD SITE

Source: Goldberg, Zoino & Associates. File No. 4-3.

WDC 61621.AO.02



Source: Goldberg, Zoino & Associates. August, 1986. File No. G-3863.6.



NOTES:

1) GROUNWATER CONTOURS ARE BASED ON DATA FROM WIDELY SPACED EXPLORATIONS AND MAY NOT REFLECT ACTUAL SUBSURFACE CONDITIONS.

2) REFER TO FIGURE NO.2 FOR ADDITIONAL NOTES AND LEGEND.

3) REFER TO FIGURE No.2 FOR MARKINGS INDICATING ABANDONED AND/OR DESTROYED WELLS.

LEGEND:

224 — CONTOURS OF GROUNDWATER ELEVATIONS ARE BASED ON DATA COLLECTED ON 5/14/86 AND 9/25/86 (BASE DATUM = MSL).

■—PRIVATE WATER SUPPLIES

CONTOURS OF GROUNDWATER ELEVATIONS ARE BASED ON DATA COLLECTED ON 7/10/84. (BASE DATUM = MSL).

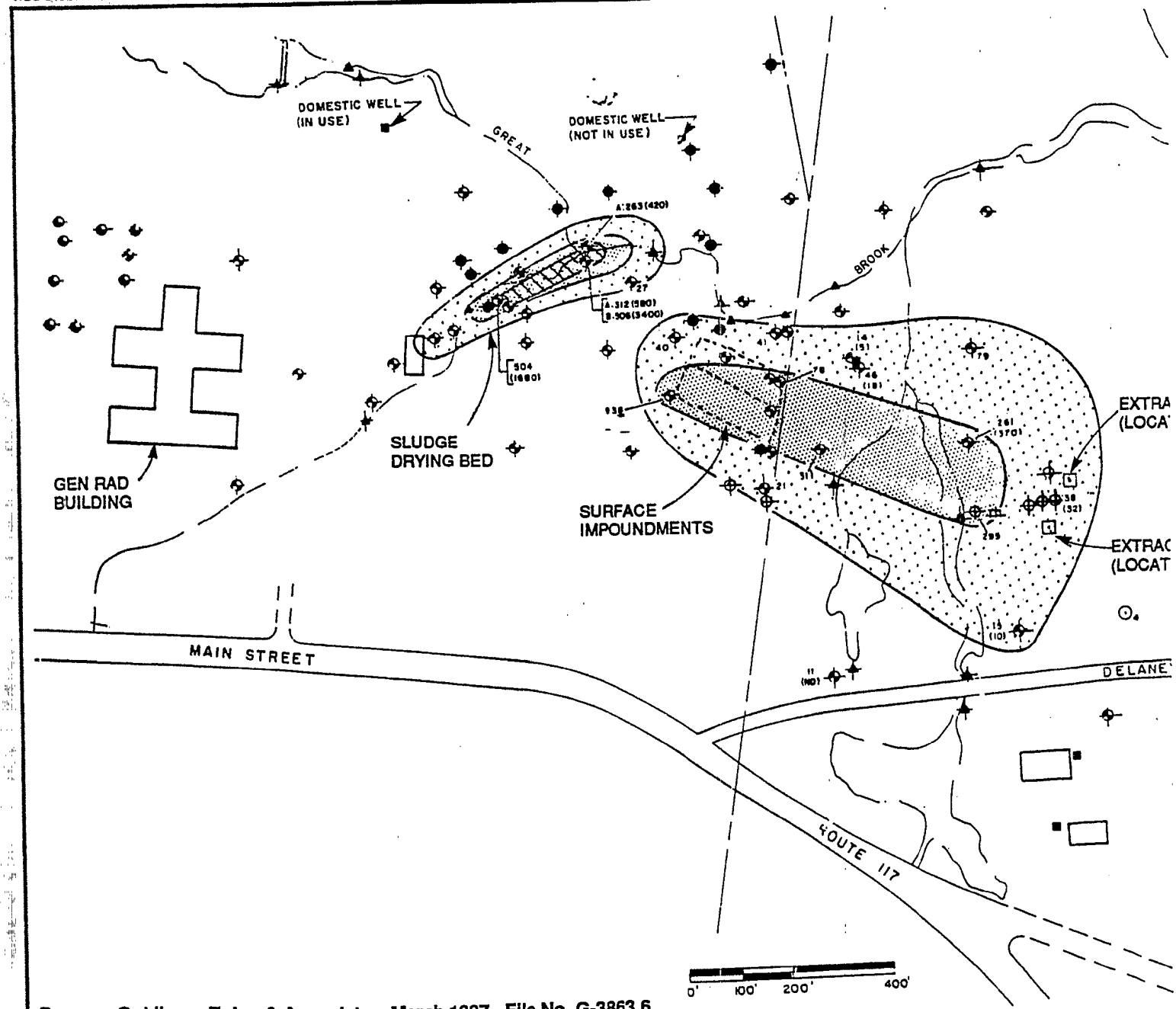
GROUNDWATER FLOWLINES

'SCALE'

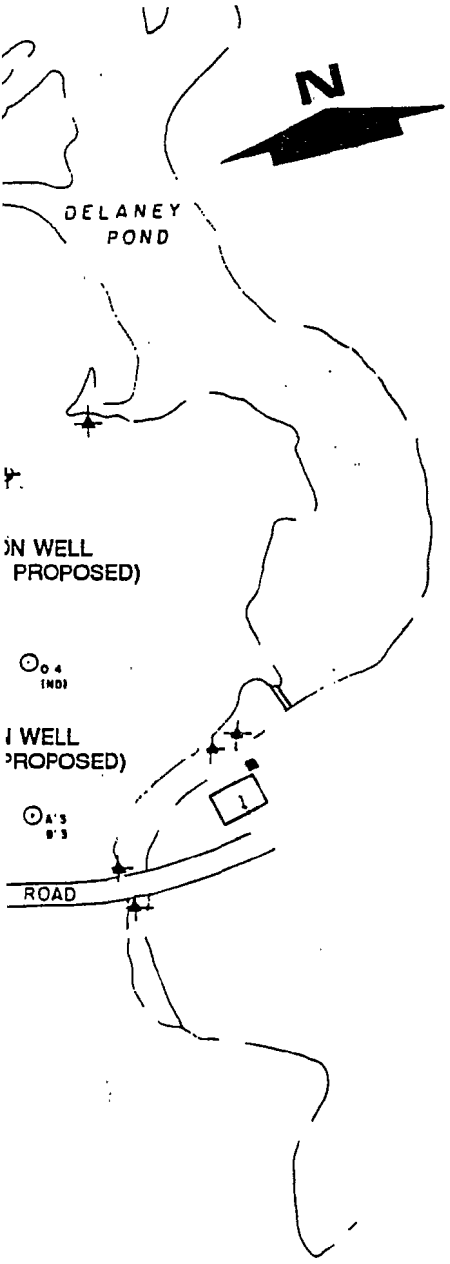
0' 100' 200' 400'

Figure 6
CONTOURS OF GROUND-WATER ELEVATIONS, VARIOUS DATES PRIOR TO EXTRACTION
GEN RAD SITE

WOC 61621.AO.02



Source: Goldberg, Zoino & Associates. March 1987. File No. G-3863.6.



NOTES:

1) REFER TO FIGURE No. 2 FOR ADDITIONAL NOTES AND LEGEND.

2) LIMITS AND LOCATIONS OF SHADED AREAS DEPICT APPROXIMATE EXTENT OF TOTAL VOLATILE ORGANIC CHEMICAL CONCENTRATIONS OBSERVED IN GROUNDWATER SAMPLES FROM SELECTED LOCATIONS USING EPA METHOD 624 AND/OR 601. THIS PLAN IS DEVELOPED FROM LIMITED DATA. ACTUAL CONDITIONS MAY BE MORE COMPLEX AND ARE SUBJECT TO CHANGE WITH TIME.

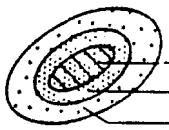
3) PLUME CONTOURS ARE BASED ON DATA COLLECTED DURING FEBRUARY AND MARCH, 1987.

4) 601 ANALYSES PERFORMED BY GZA WERE CONDUCTED WITHIN AN OPTIMUM DETECTION RANGE OF 1 TO 100 ppb. REPORTED CONCENTRATIONS GREATER THAN 100 ppb SHOULD BE CONSIDERED IN RELATIVE TERMS.

5) CHEMICAL CONCENTRATIONS VARY WITH DEPTH.

6) REFER TO FIGURE No. 2 FOR MARKINGS INDICATING ABANDONED AND/OR DESTROYED WELLS.

LEGEND:



TOTAL VOLATILE ORGANIC CONCENTRATIONS ≥500 PPB

TOTAL VOLATILE ORGANIC CONCENTRATIONS ≥100 PPB < 500 PPB

TOTAL VOLATILE ORGANIC CONCENTRATIONS ≥10 PPB < 100 PPB

PROPOSED EXTRACTION WELL LOCATION (PHASE II)

312 (580) — PARENTHESES INDICATE TOTAL VOC LEVELS FROM SAMPLES COLLECTED ON 2/3/87 (ANALYZED BY CAA USING 601 ANALYSIS)

TOTAL VOC LEVELS FROM SAMPLES COLLECTED 2/3 THROUGH 3/6/87 (ANALYZED BY GZA USING 601 ANALYSIS)

Figure 7
PLUME CONTOURS OF TOTAL VOLATILE ORGANICS, FEBRUARY-MARCH 1987
GEN RAD SITE

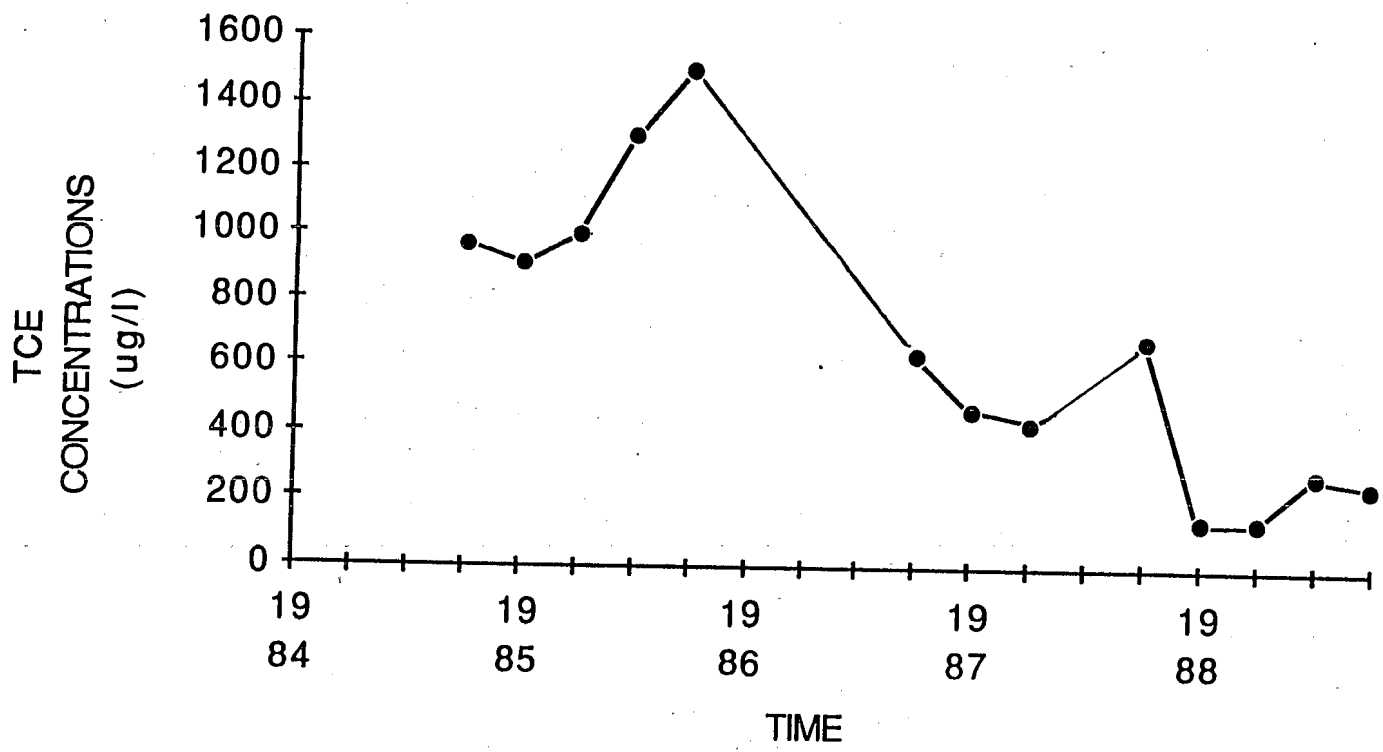
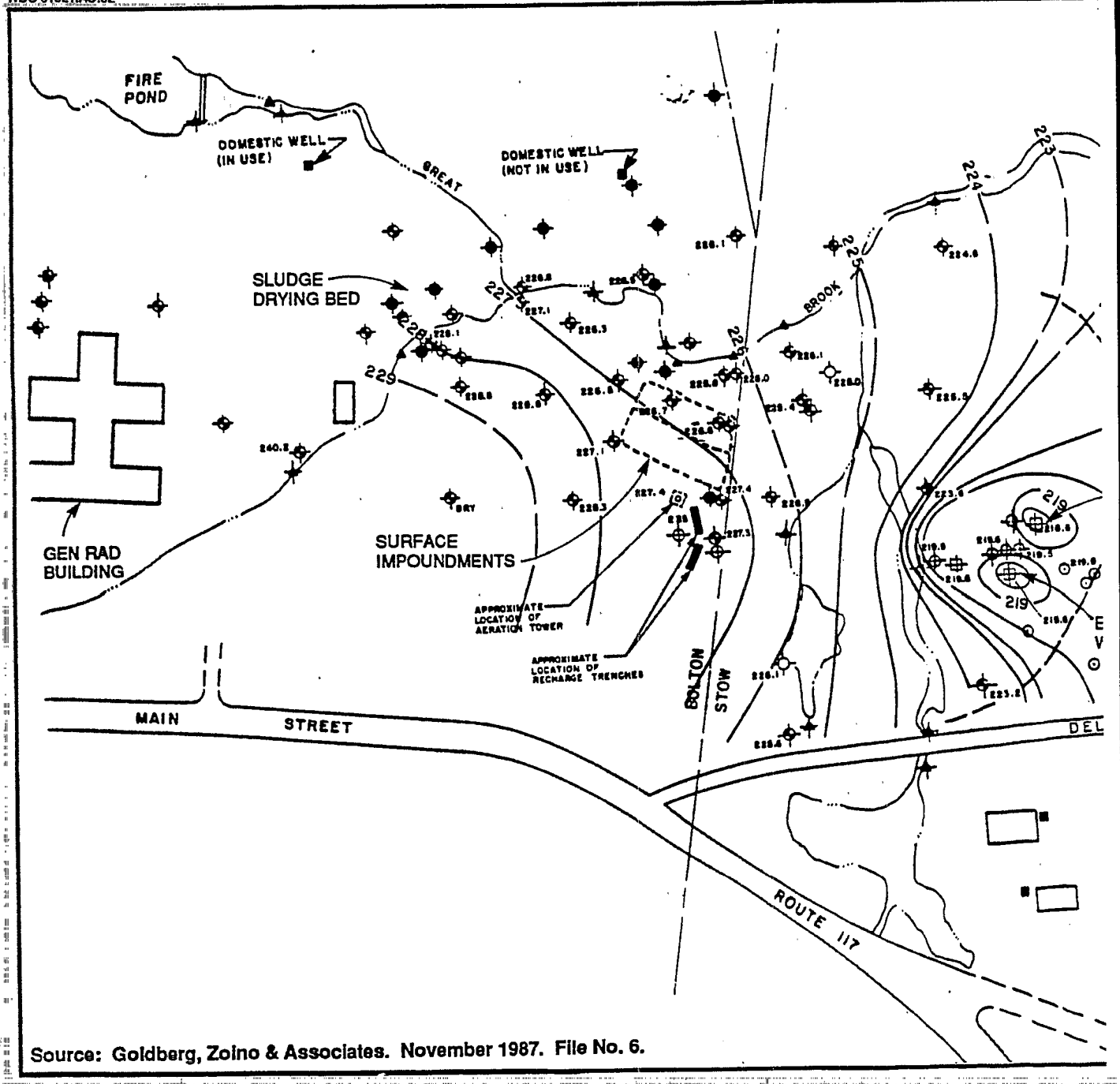
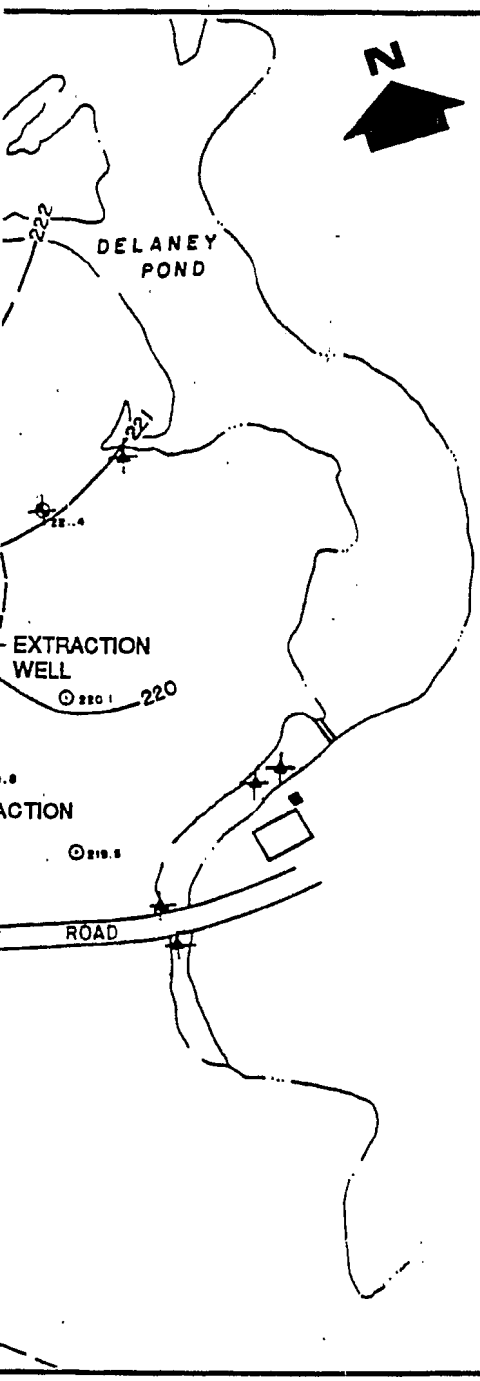


Figure 8
VARIATIONS IN THE TCE CONCENTRATIONS IN WELL G-III-14A (NORTHERN PLUME)
GEN RAD SITE

WDC 61621.A0.02



Source: Goldberg, Zoino & Associates. November 1987. File No. 6.



NOTES:

1) GROUNDWATER CONTOURS ARE BASED ON DATA FROM WIDELY SPACED EXPLORATIONS AND MAY NOT REFLECT ACTUAL SUBSURFACE CONDITIONS.

2) WATER LEVEL READINGS HAVE BEEN MADE VIA AN ELECTRIC WATER INDICATOR ON THE DATE OR DATES SPECIFIED BELOW. THIS DATA HAS BEEN REVIEWED AND INTERPRETATIONS MADE IN THE TEXT OF THIS REPORT. HOWEVER, IT MUST BE STATED THAT FLUCTUATIONS IN THE LEVEL OF THE GROUNDWATER MAY OCCUR DUE TO VARIATIONS IN RAINFALL, TEMPERATURE AND OTHER FACTORS PRESENT AT THE TIME MEASUREMENTS WERE MADE.

3) REFER TO FIGURE No. 2 FOR ADDITIONAL NOTES AND LEGEND

LEGEND:

221.6 — GROUNDWATER LEVEL MEASURED IN BOREHOLE

221 — CONTOURS OF GROUNDWATER ELEVATIONS ARE BASED ON DATA COLLECTED 10/28 AND 10/29/87. (BASE DATUM = MSL)

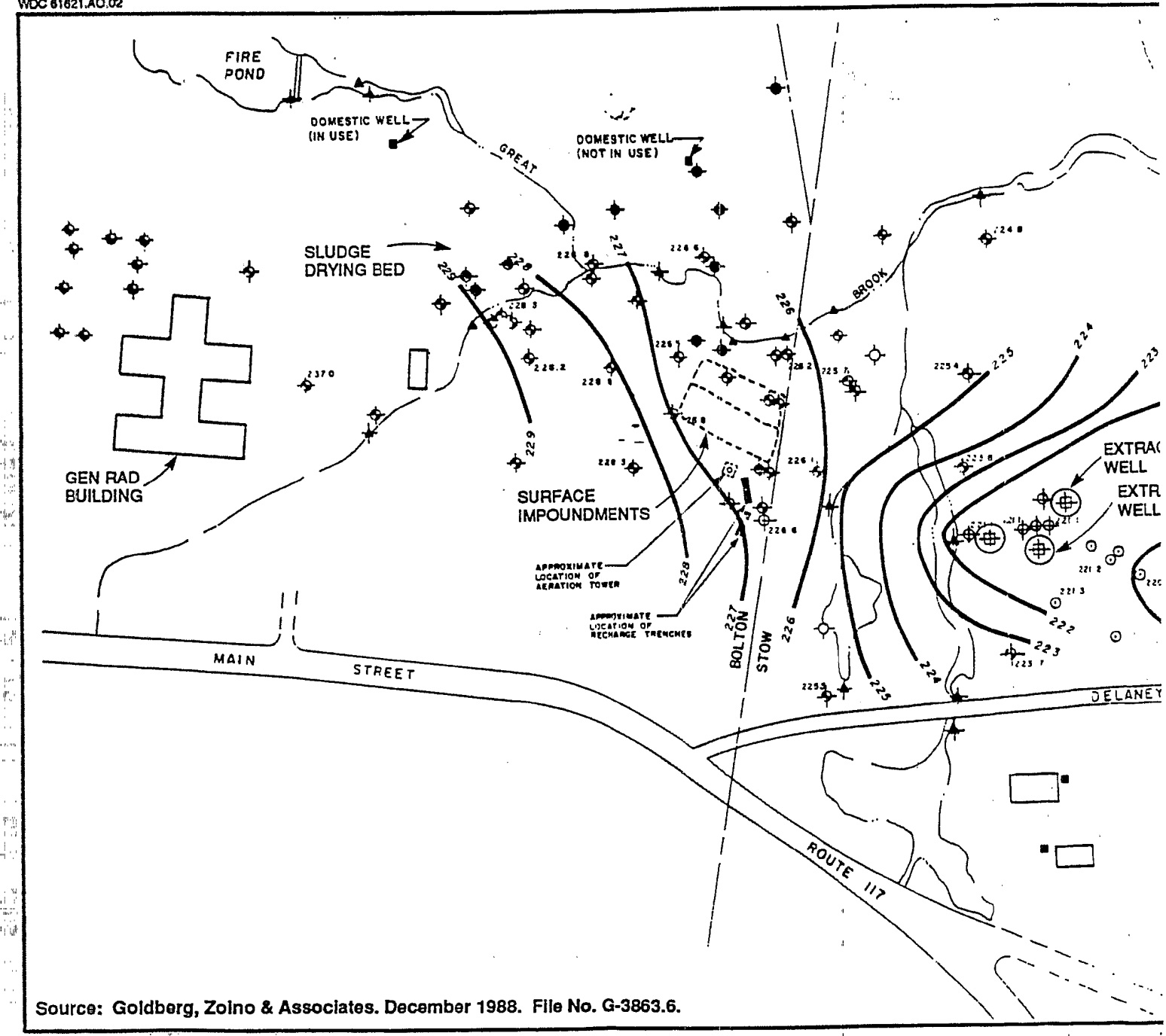
■ PRIVATE WATER SUPPLIES

APPROXIMATE LOCATION OF CAPTURE BOUNDARY

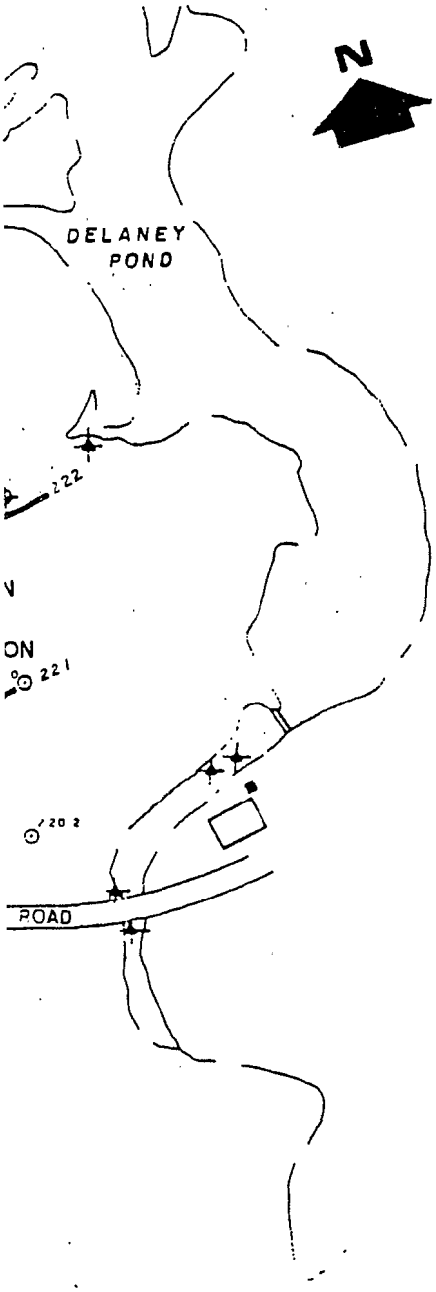
0' 100' 200' 400'

Figure 9
CONTOURS OF GROUND-WATER ELEVATIONS, OCTOBER 1987
GEN RAD SITE

WDC 61621.AO.02



Source: Goldberg, Zoino & Associates. December 1988. File No. G-3863.6.



NOTES:

1) **SEE FIGURE No. 2 FOR ADDITIONAL NOTES AND LEGEND.**

2) GROUNDWATER CONTOURS ARE BASED ON DATA FROM WIDELY SPACED EXPLORATIONS AND MAY NOT REFLECT ACTUAL SUBSURFACE CONDITIONS

3) WATER LEVEL READINGS HAVE BEEN MADE VIA AN ELECTRIC WATER INDICATOR ON THE DAY OR DATES SPECIFIED BELOW THIS DATA HAS BEEN REVIEWED AND INTERPRETATIONS MADE IN THE TEXT OF THIS REPORT HOWEVER, IT MUST BE STATED THAT FLUCTUATIONS IN THE LEVEL OF THE GROUNDWATER MAY OCCUR DUE TO VARIATIONS IN RAINFALL TEMPERATURE AND OTHER FACTORS AT THE TIME MEASUREMENTS WERE MADE

221.6 GROUNDWATER MEASURED IN BOREHOLE

221 CONTOURS OF GROUNDWATER ELEVATIONS ARE BASED ON DATA COLLECTED ON 11/8 & 11/9/88 (BASE DATUM = MSL)

PRIVATE WATER SUPPLIES

0' 100' 200' 400'

Figure 10
CONTOURS OF GROUND-WATER ELEVATIONS, NOVEMBER 1988
GEN RAD SITE

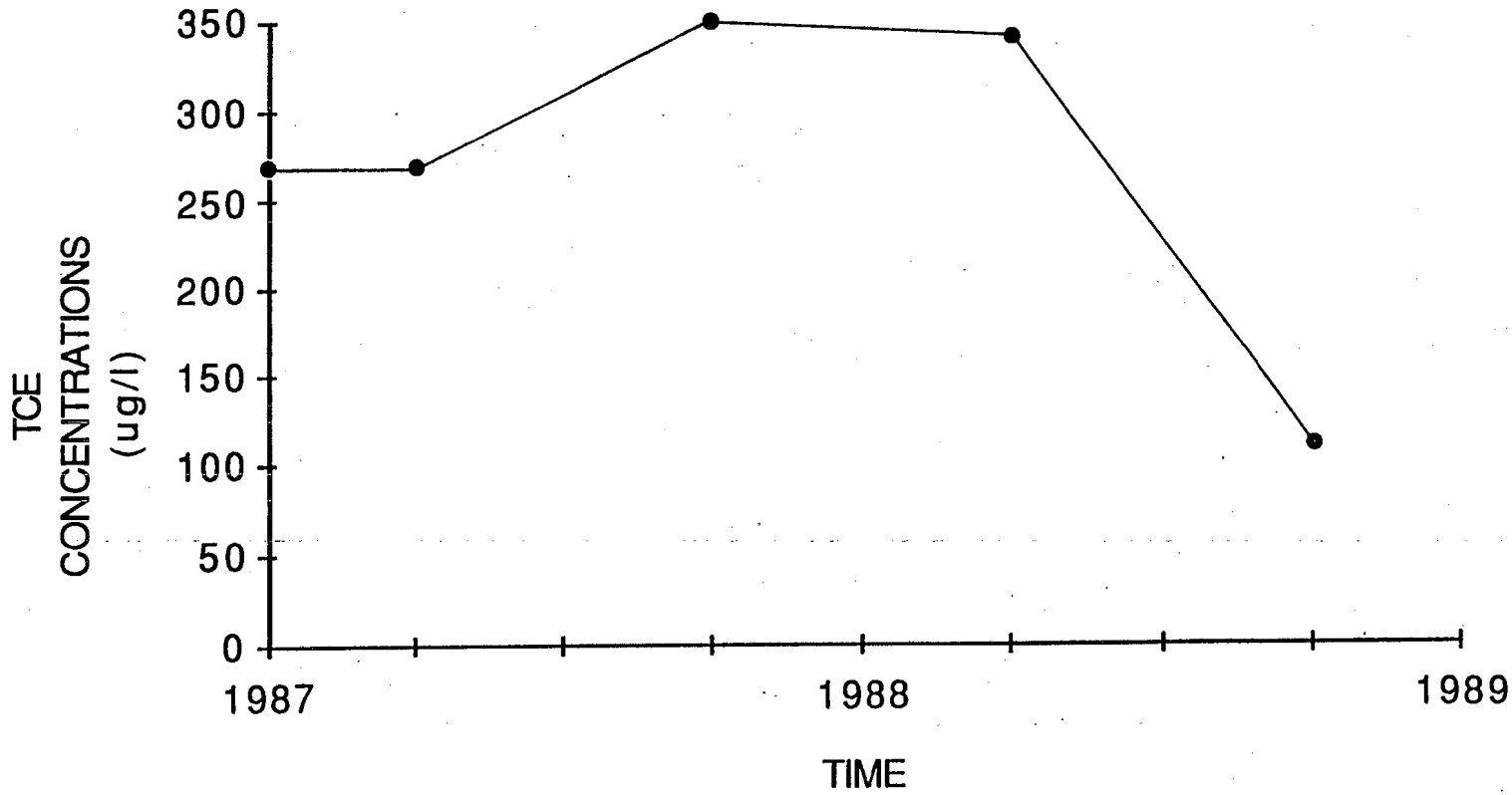
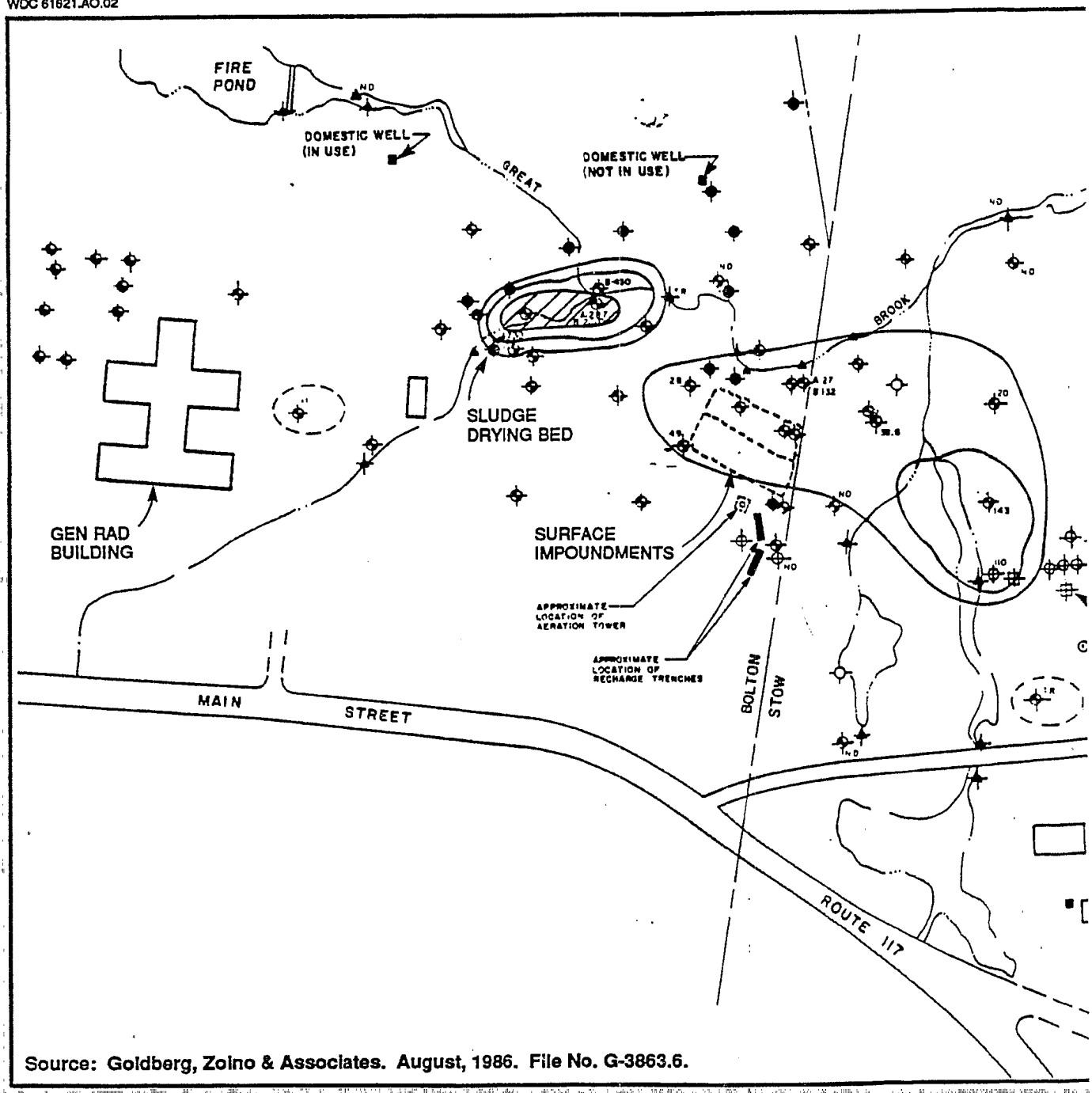
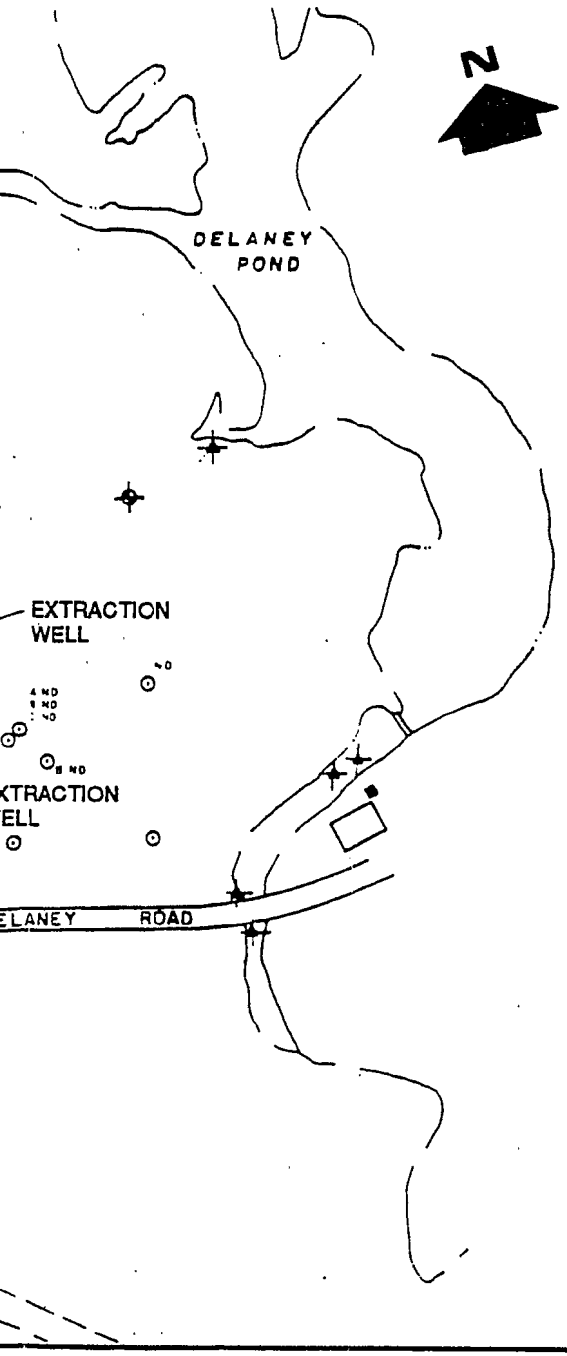


Figure 11
VARIATION OF TCE CONCENTRATIONS IN WELL PT-4 (EASTERN PLUME)
GEN RAD SITE

WDC 61621.AO.02



Source: Goldberg, Zoino & Associates. August, 1986. File No. G-3863.6.



NOTES

1) LIMITS AND LOCATIONS OF SHADED AREAS DEPICT APPROXIMATE EXTENT OF TOTAL VOLA ORGANIC CHEMICAL CONCENTRATIONS OBSERVED IN GROUNDWATER SAMPLES FROM SELECTE LOCATIONS USING EPA METHOD 624 AND/OR 601. THIS PLAN IS DEVELOPED FROM LIMITED DAT. ACTUAL CONDITIONS MAY BE MORE COMPLEX AND ARE SUBJECT TO CHANGE WITH TIME.

2) EASTERN PLUME CONTOURS ARE BASED ON DATA COLLECTED ON 11/8 AND 11/9/88.

3) NORTHERN PLUME CONTOURS ARE BASED ON DATA COLLECTED ON 11/8 AND 11/9/88.

4) CHEMICAL CONCENTRATIONS VARY WITH DEPTH

5) REFER TO FIGURE No 2 FOR ADDITIONAL NOTES AND LEGEND.

LEGEND

TOTAL VOLATILE ORGANIC CONCENTRATION LEVEL DETECTED AT THIS LOCATION VIA EPA METHOD 601

TOTAL VOLATILE ORGANIC CONCENTRATIONS ≥500 PPB

TOTAL VOLATILE ORGANIC CONCENTRATIONS ≥00 PPB <500 PPB

TOTAL VOLATILE ORGANIC CONCENTRATIONS ≥10 PPB <100 PPB

AREA WHERE LOW VOLATILE ORGANIC CONCENTRATIONS (<10 PPB) HAVE BEEN DETECTED. THE GENERAL LOCATION APPEARS TO BE OUTSIDE THE MAIN BODY OF THE PLUME VOCs AT G-IV-8 MAY BE A RESULT OF FORMER GROUNDWATER PATTERNS THAT EXISTED PRIOR TO RIB SHUTDOWN VOCs AT GZA-13 HAVE ONLY RECENTLY BEEN DETECTED FUTURE RESULTS WILL BE MONITORED CLOSELY

0' 100' 200' 400'

Figure 12
PLUME CONTOURS OF TOTAL VOLATILE ORGANICS, NOVEMBER 1988
GEN RAD SITE

WDC 61621.AO.02

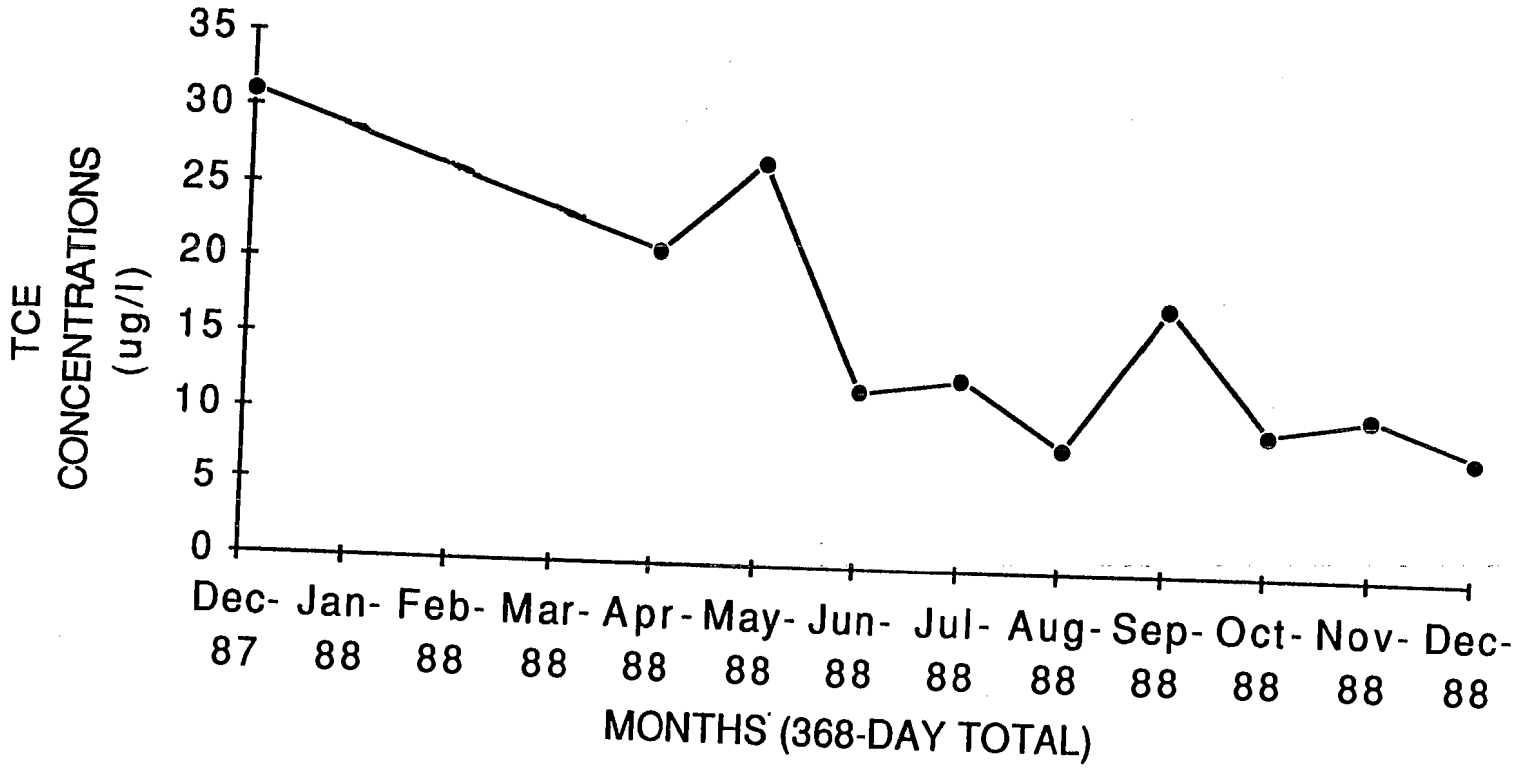
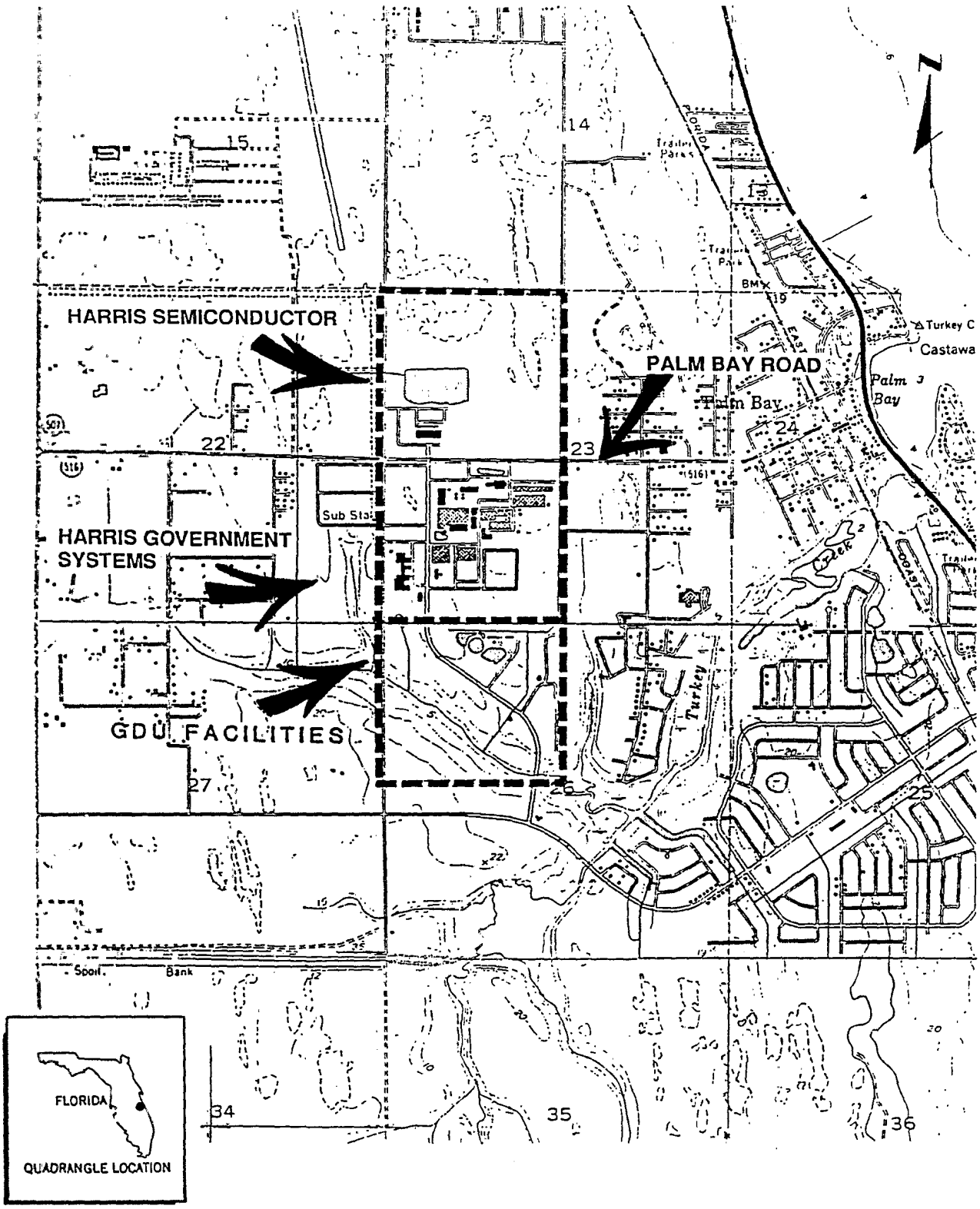
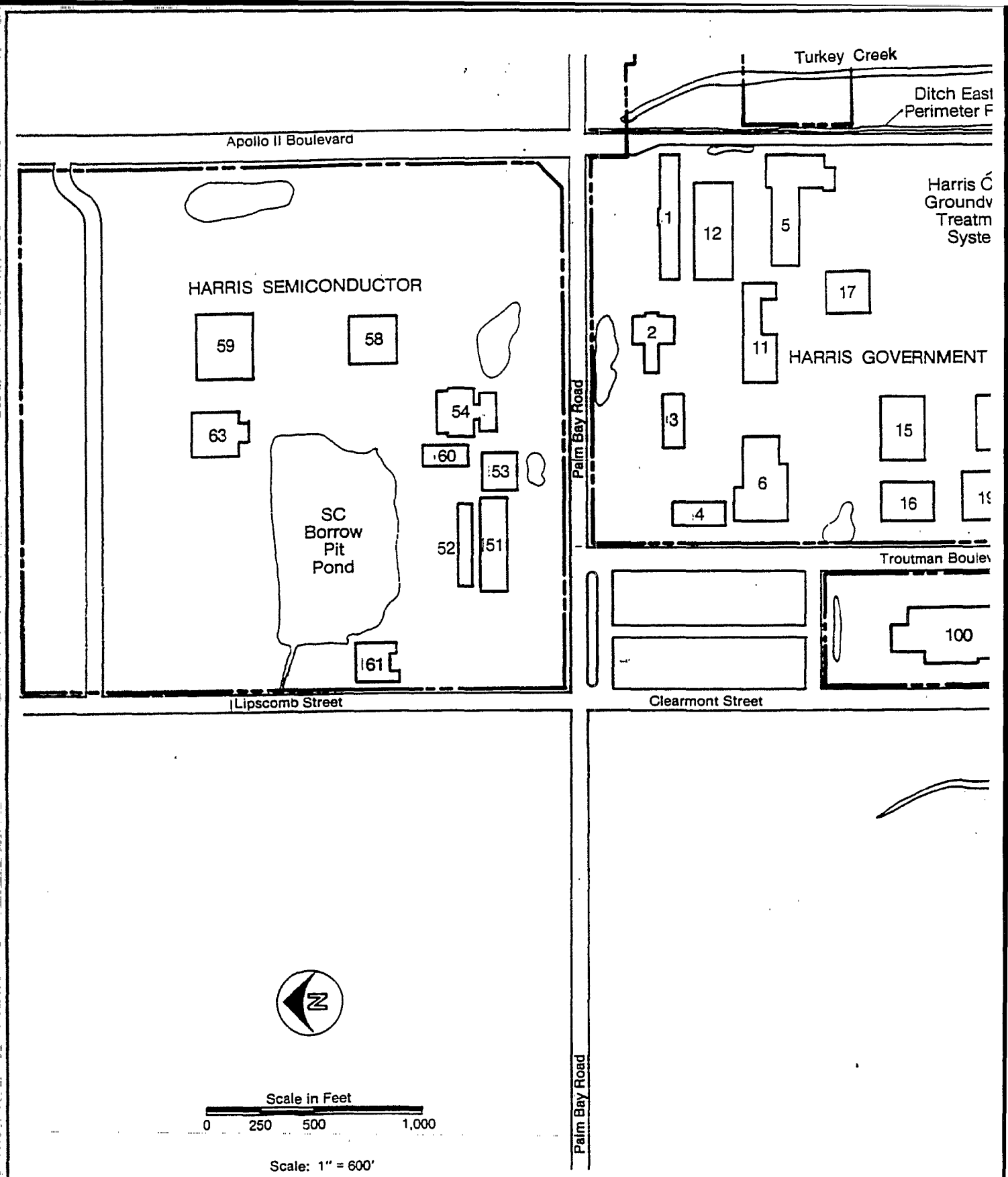


Figure 13
RECORD OF TCE CONCENTRATION IN THE TREATMENT PLANT INFLUENT
GEN RAD SITE



Source: Post, Buckley, Schuh & Jernigan, Inc. December 1983.
Harris Corporation Task B-4 Hydrogeologic Study.

Figure 1
GENERAL SITE LOCATION MAP
HARRIS CORPORATION SITE
PALM BAY, FLORIDA



Source: CH2M HILL, April 1986. Assessment of the Harris Corporation Remediation Program.

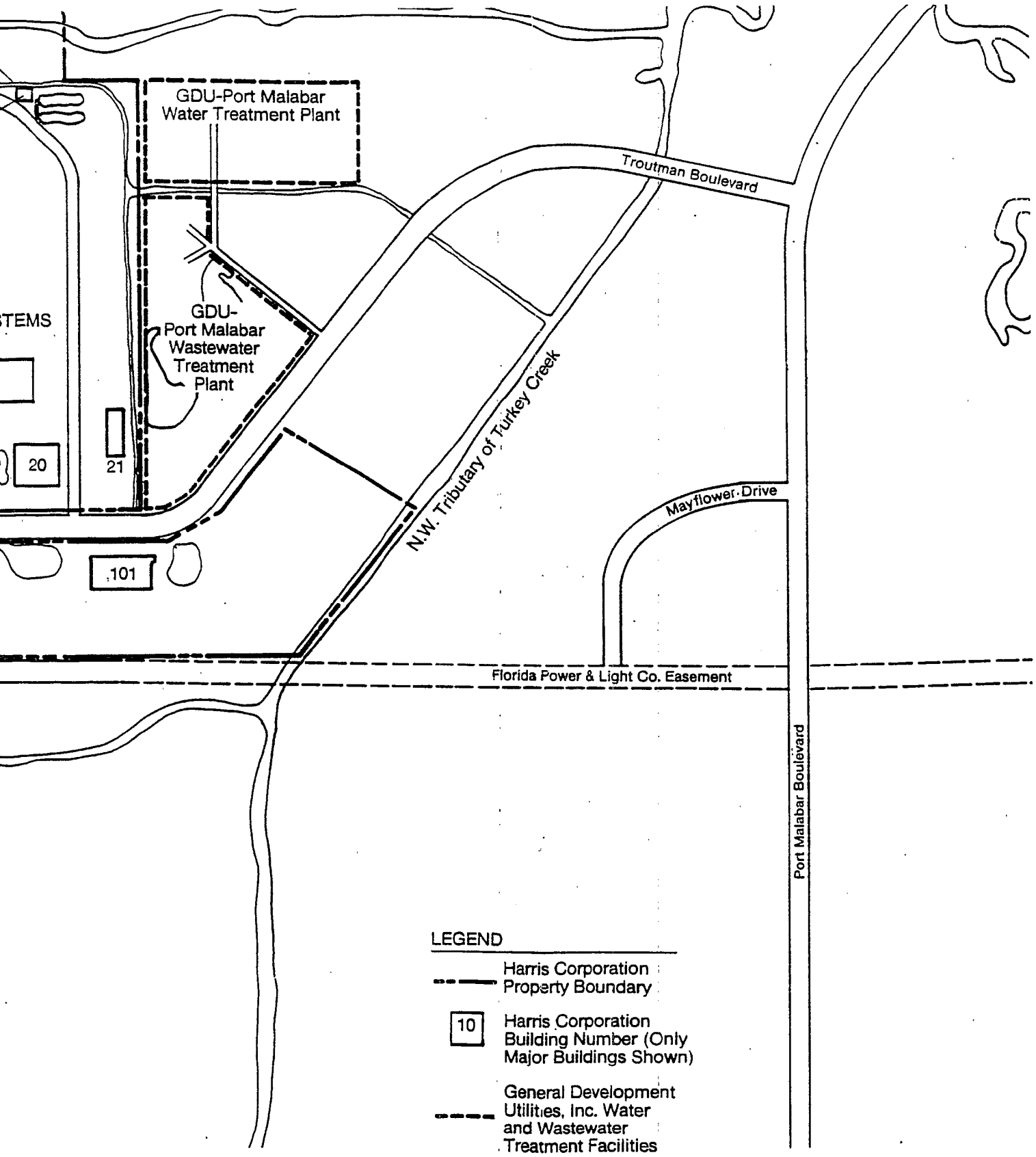
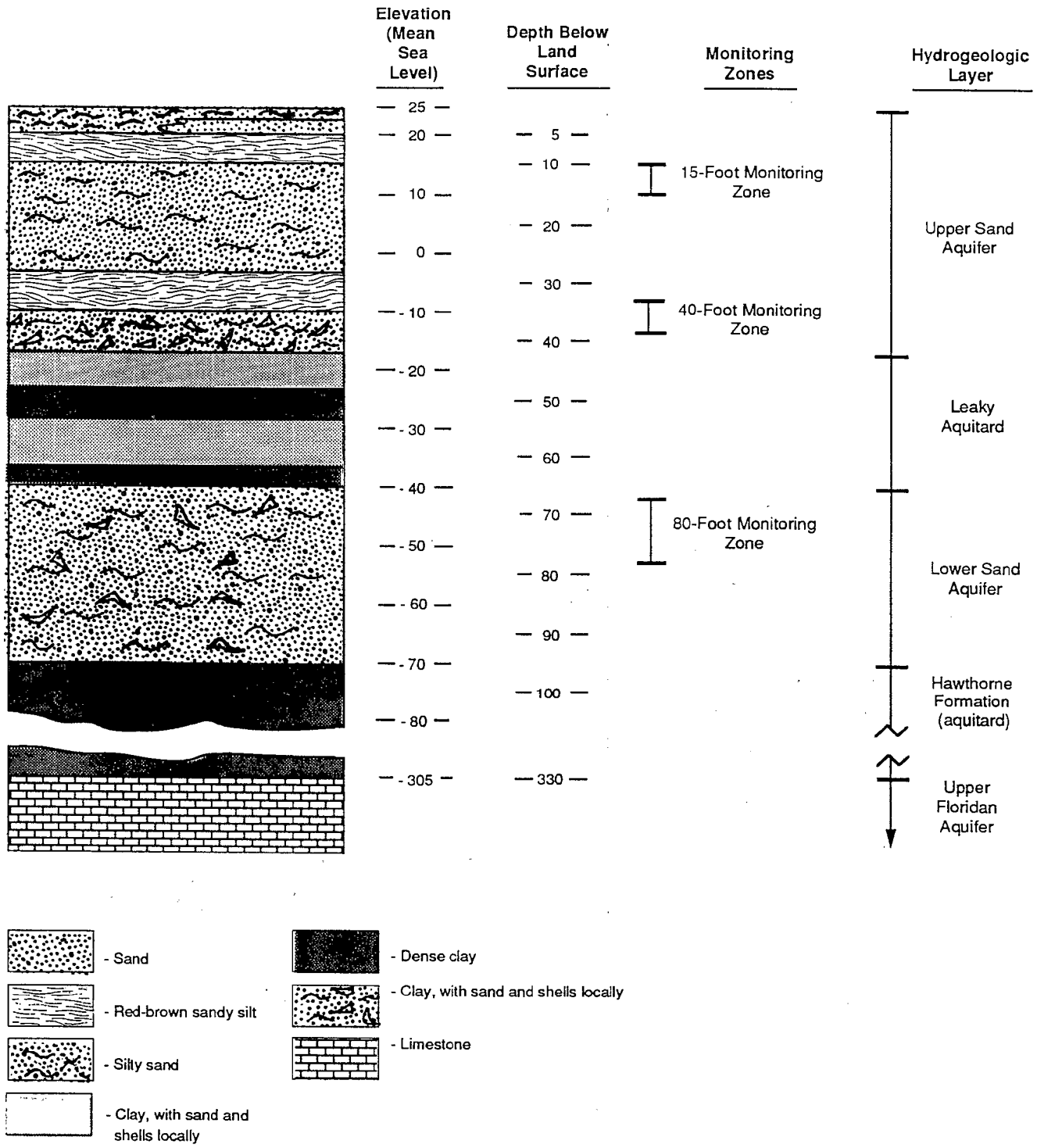
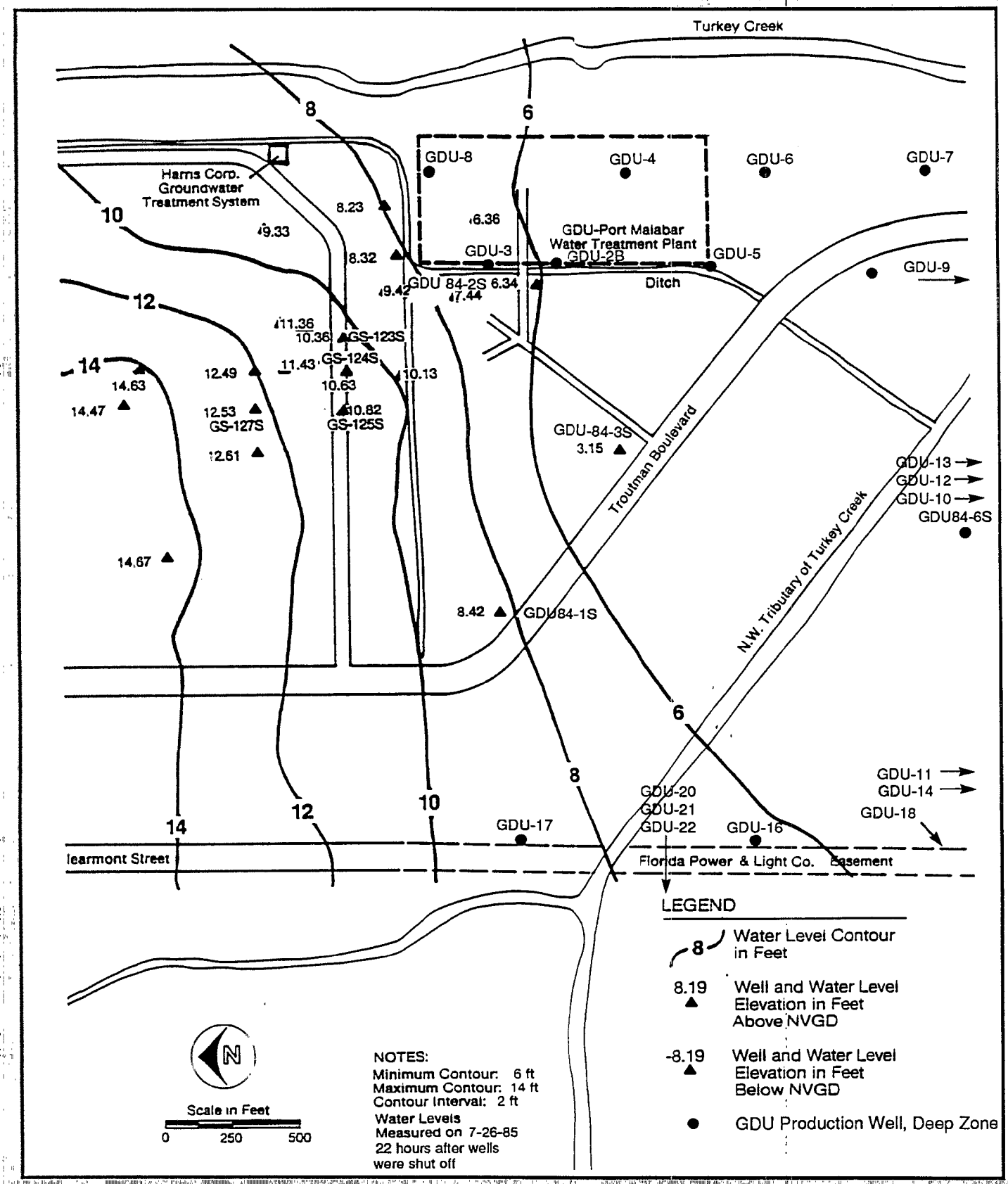


Figure 2
DETAILED SITE MAP
HARRIS CORPORATION SITE



Source: Compiled from Post, Buckley, Schuh and Jernigan Inc., December 1983. Geraghty & Miller, Inc., November 1987; and Geraghty & Miller, Inc., July 1987.

Figure 3
GENERALIZED GEOLOGIC COLUMN
HARRIS CORPORATION SITE



Source: CH2M HILL, April 1986. Assessment of the Harris Corporation Remediation Program.

Figure 4
POTENTIOMETRIC SURFACE MAP OF SHALLOW-AQUIFER ZONE WITH ALL HARRIS EXTRACTION WELLS SHUT OFF
HARRIS CORPORATION SITE

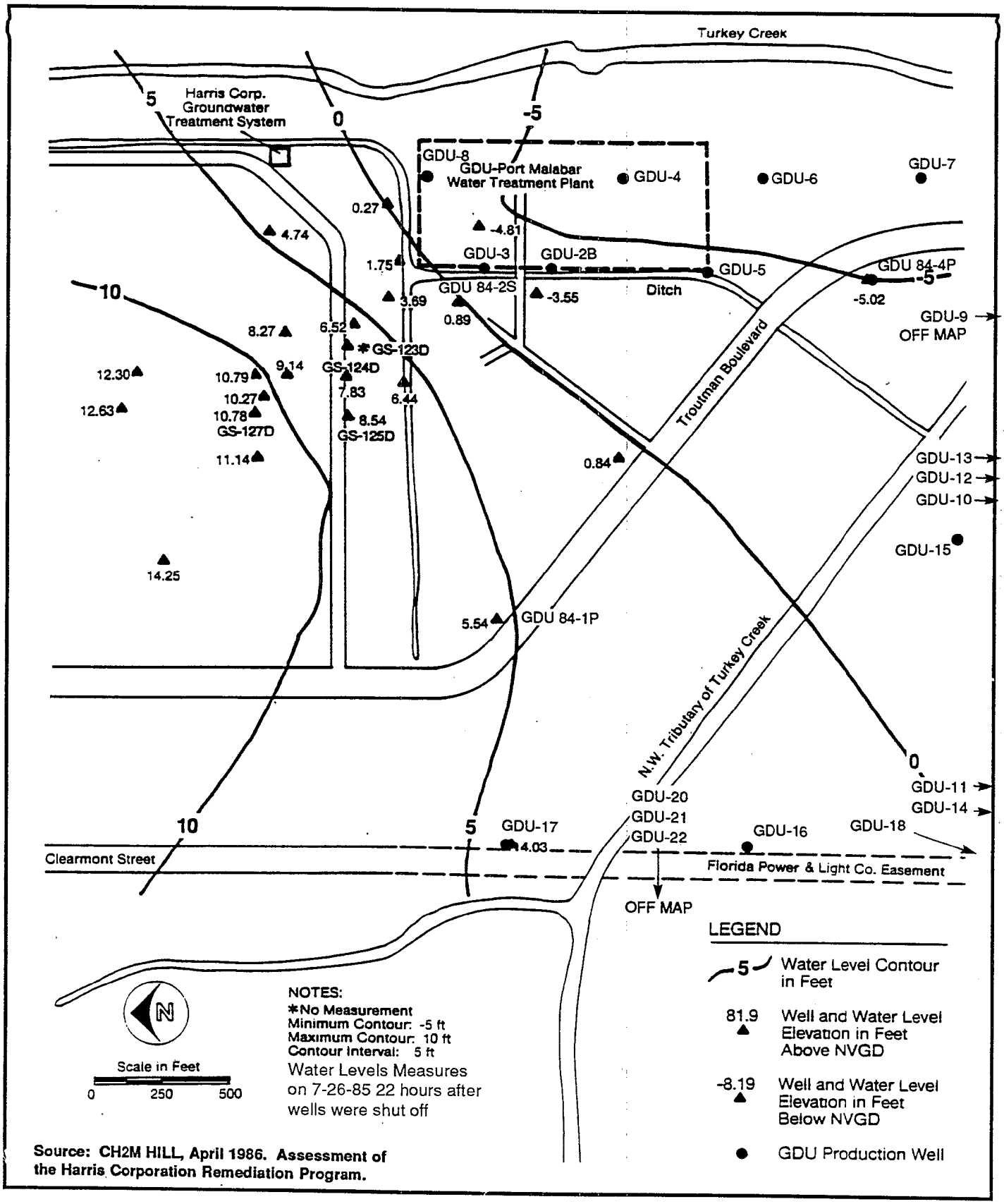


Figure 5
POTENTIOMETRIC SURFACE MAP OF DEEP-AQUIFER ZONE WITH ALL HARRIS EXTRACTION WELLS SHUT OFF
HARRIS CORPORATION SITE

Table 1

APPLICABLE STATE AND FEDERAL GROUND-WATER QUALITY STANDARDS

Constituent	Harris Seimconductor/GDU Standard (ug/l)*	Harris Government Systems Ground-Water Standard (ug/l) #	Harris Government Systems Surface Water Discharge Standard (ug/l) #
Fluoride	1,400 - 2,400[a] 4,000[c]		
Lead	0.05[a]		
Benzene	1.0[a]		
Chlorobenzene	60[c]	<25	<50
1,2-Dichlorobenzene (ortho-)	620[c]	<25	<50
1,3-Dichlorobenzene (meta-)	620[c]	-	-
1,1-Dichloroethane	810[c]	<5	<25
1,1-Dichloroethylene	7.0[b]	<5	<25
trans-1,2-Dichloroethylene	70[c]	<5	<25
cis-1,2-Dichloroethylene	-	<5	<25
Ethyl Benzene	680[c]	<25	<50
Tetrachloroethylene	3.0[a]	-	-
Toluene	2,000[c]	<25	<50
1,1,1-Trichloroethane	200[a]	<5	<25
Trichloroethylene	3.0[a]	<5	<25
Vinyl Chloride	1.0[a]	<5	<25
Xylenes (total)	440[c]		
bis(2-ethylhexyl)phthalate	4,200[d]		

NOTES:

[a] State of Florida Drinking Standard

[b] EPA Proposed MCL (Maximum Contaminant Level)

[c] EPA Proposed RMCL (Recommended Maximum Contaminant Level)

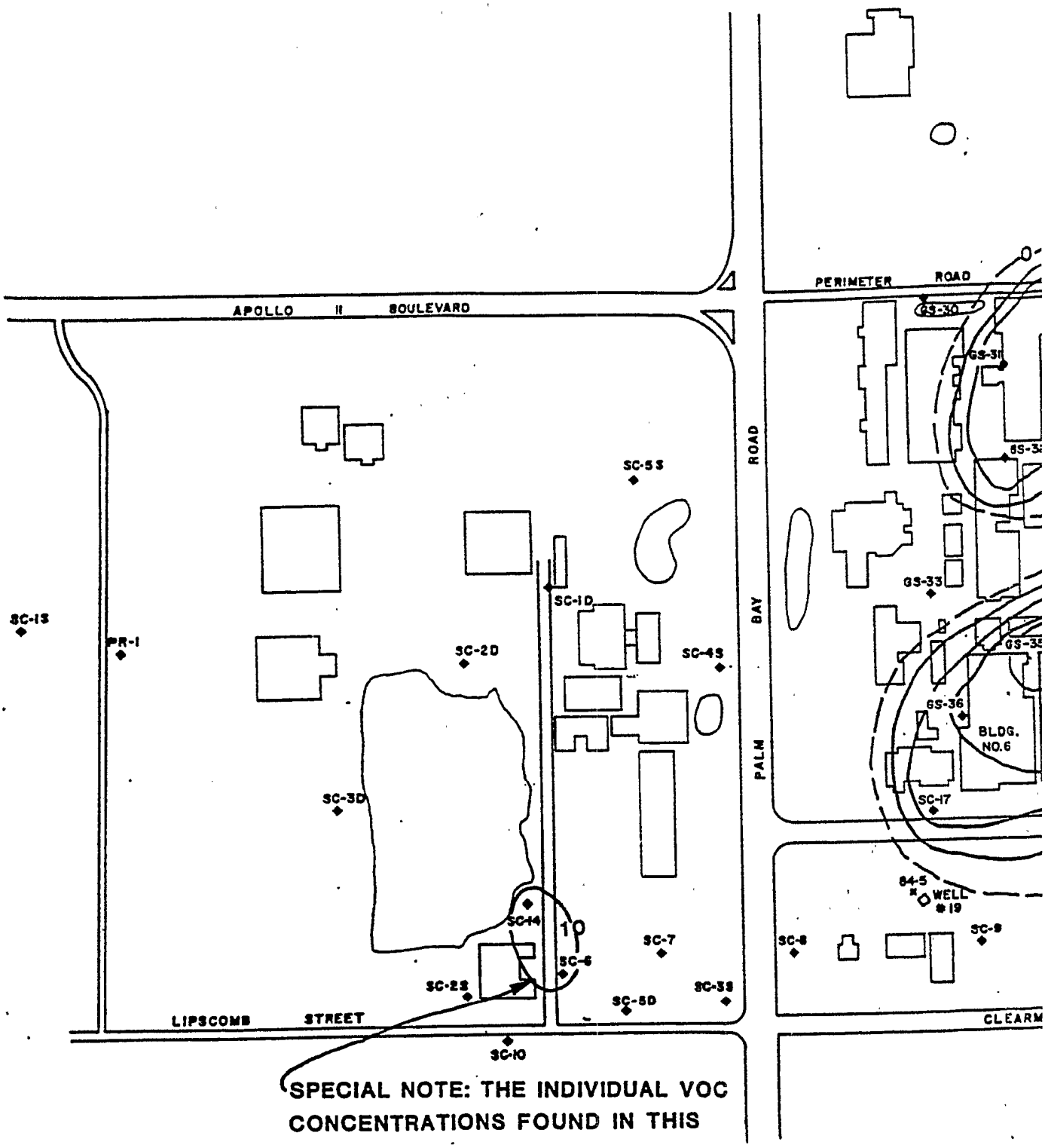
[d] EPA PPCL (Preliminary Protective Concentration Limit)

Sources:

* Geraghty & Miller. November 1987. Harris Corporation Semiconductor Complex Ground-Water Assessment.

Geraghty & Miller. May 1989. Harris Corporation National Priority List Compliance Review.

WDR218/025



SPECIAL NOTE: THE INDIVIDUAL VOC CONCENTRATIONS FOUND IN THIS AREA DO NOT EXCEED HARRIS/DER AGREEMENT LIMITS

Source: Post, Buckley, Schuh & Jernigan, Inc., September 1984
Groundwater Remediation Program Phase II Plan of Action Report

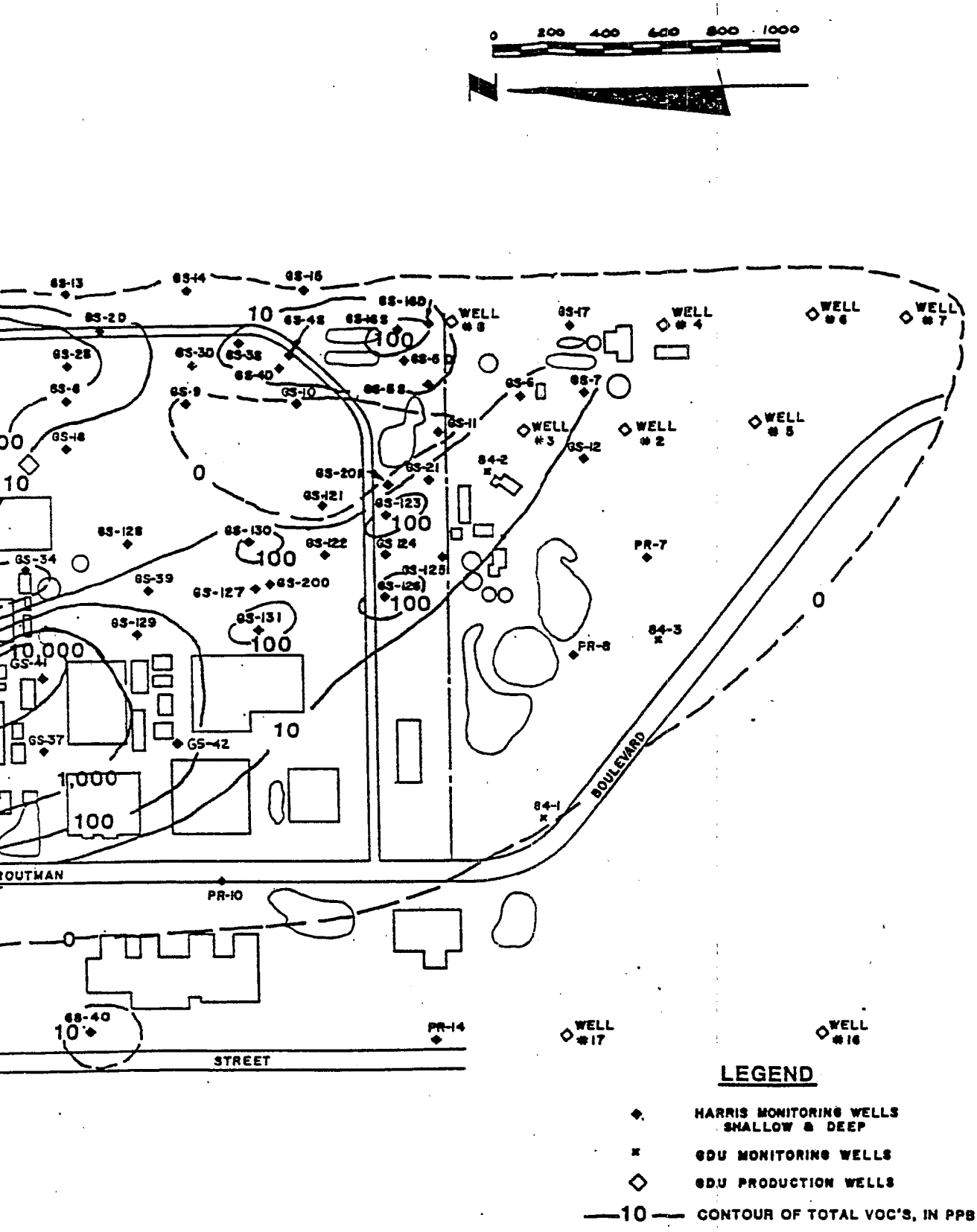
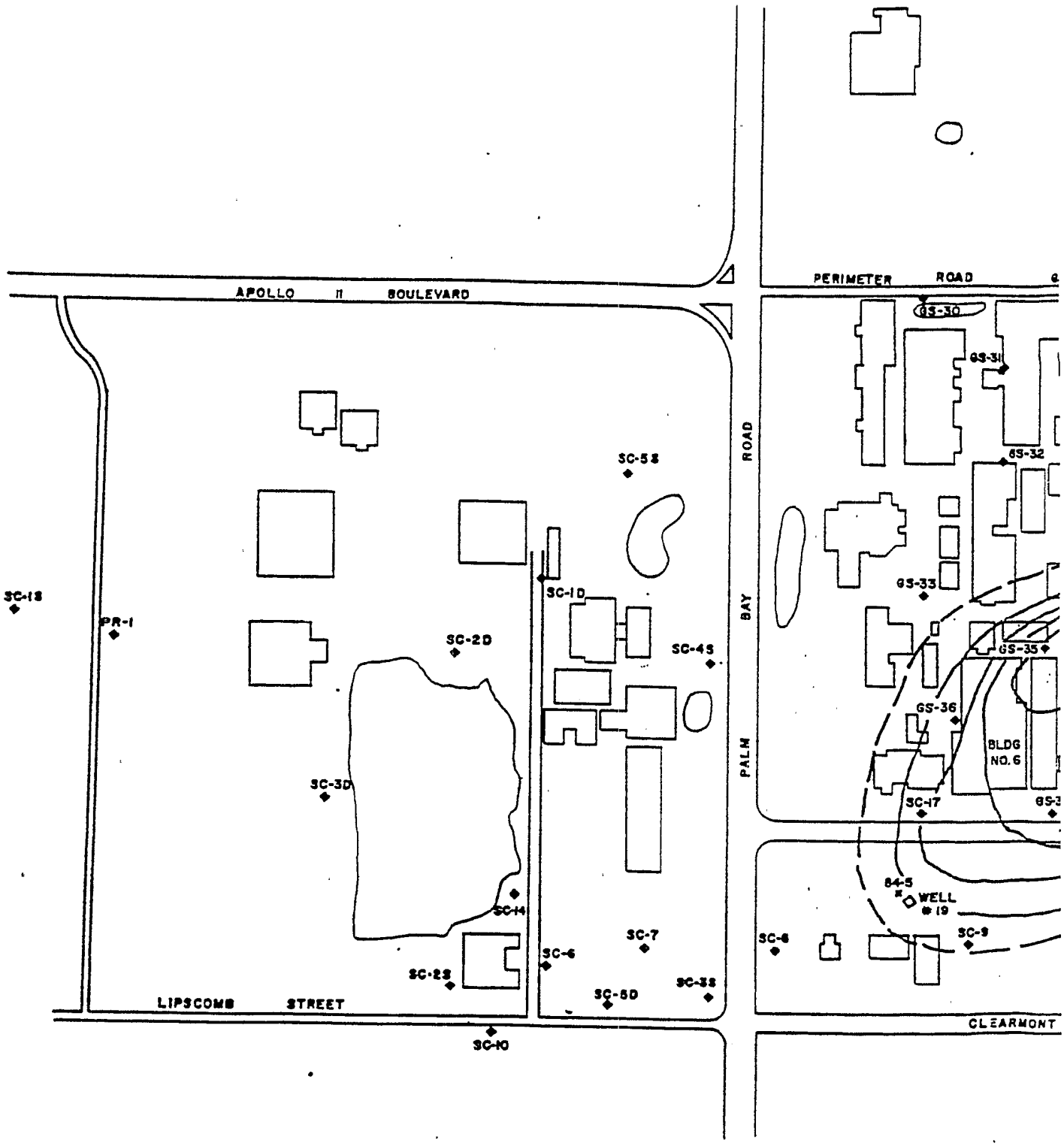


Figure 6
CONTOUR MAP OF WORST-CASE TOTAL VOC CONCENTRATIONS IN THE SHALLOW-AQUIFER ZONE FOR THE PERIOD MARCH-AUGUST, 1984
HARRIS CORPORATION SITE

WDC61621.AO.02



Source: Post, Buckley, Schuh & Jernigan, Inc., September 1984
Groundwater Remediation Program Phase II Plan of Action Report

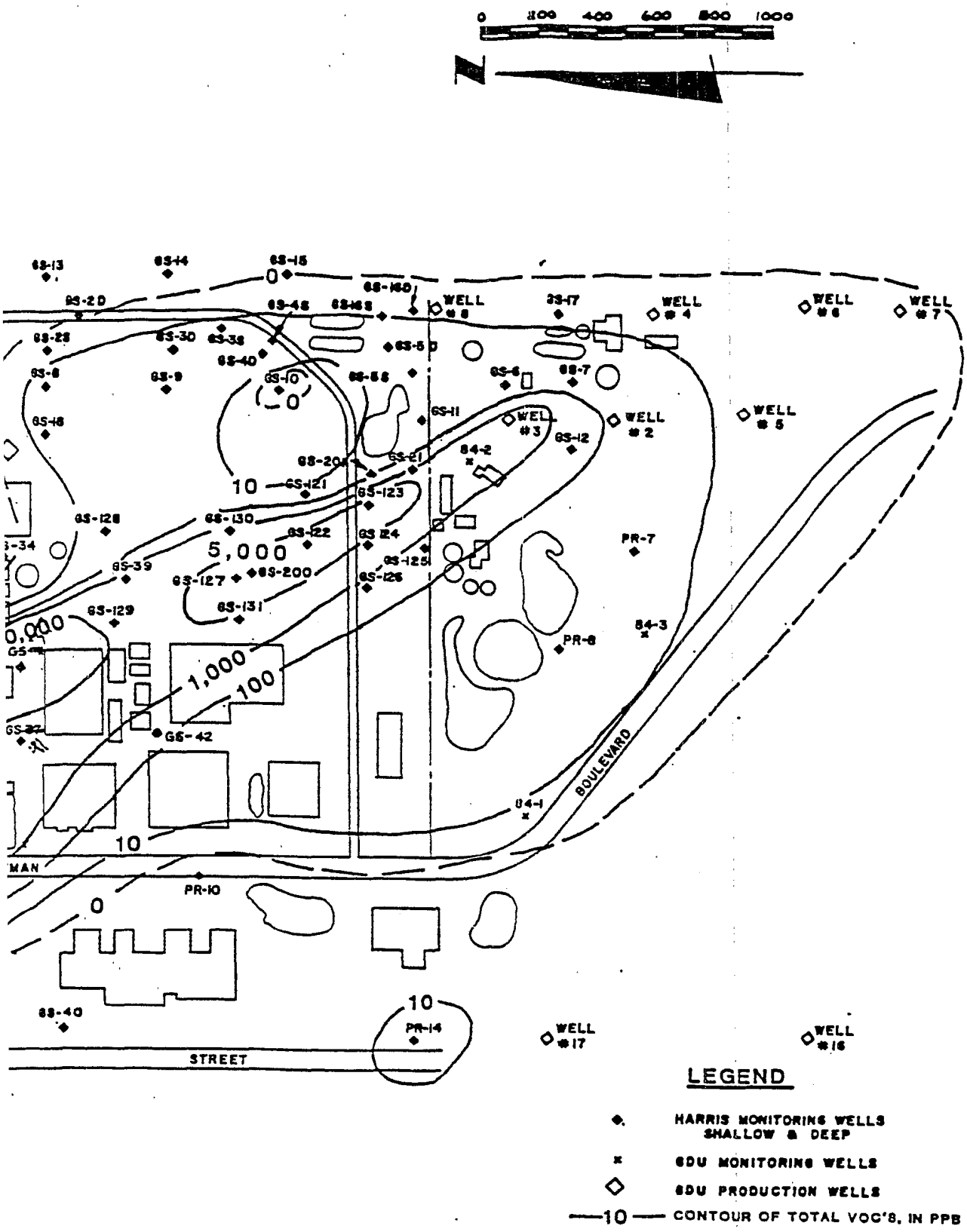


Figure 7
CONTOUR MAP OF WORST-CASE TOTAL VOC CONCENTRATIONS IN THE DEEP-AQUIFER ZONE FOR THE PERIOD MARCH-AUGUST, 1984
HARRIS CORPORATION SITE

Table 2
MAXIMUM TOTAL VOC'S IN GDU WELLS BEFORE
FULL TREATMENT SYSTEM STARTUP IN APRIL 1984

GDU Production Wells	Depth/ Interval	Date	Maximum Total VOC (ppb)	Major Components (ppb)
2B*	Deep Aquifer	5-14-82	77.0	TCE (27.0), T-1,2-DCE (24.0), DCE (14.0), DCA (12.0)
3*	Deep Aquifer	12-19-83	3786.0	MC (3400), VC (220), T-1,2-DCE (80), DCE (40)
4	Deep Aquifer	5-14-82	14.6	o-DCB (12.9), C-1,2-DCE (1.1), TCE (0.6)
5*	Deep Aquifer	5-14-82	106.1	MC (90.3), DCA (11.6), C-1,2-DCE (3.2), TCE (1.0)
6	Deep Aquifer	7-06-83	5.0	T-1,2-DCE (3.0), DCA (2.0)
7	Deep Aquifer	5-14-82	1.3	o-DCB (1.3)
8*	Deep Aquifer	11-07-83	130.0	CB (11[illegible].0), VC (9.[illegible]), T-1,2-DCE (6.0), DCA (2.[illegible])
9	Deep Aquifer	5-14-82	0.0	
10	Deep Aquifer	5-14-82	0.0	
11	Deep Aquifer	5-14-82	0.0	
12	Deep Aquifer	5-14-82	0.0	
13	Deep Aquifer	5-14-82	0.0	
14	Deep Aquifer	5-14-82	0.0	
15	Deep Aquifer	5-14-82	0.7	C-1,2DCE (0.7)
16	Deep Aquifer	5-14-82	0.0	
17	Deep Aquifer	5-14-82	0.9	o-DCB (0.9)
18	Deep Aquifer	5-14-82	0.0	
19	Deep Aquifer	5-05-82	109.0	VC (38.0), TCE (37.0), T-1,2-DCE (30.0)

Table 2 (Continued)
MAXIMUM TOTAL VOC'S IN GDU WELLS BEFORE
FULL TREATMENT SYSTEM STARTUP IN APRIL 1984

GDU Production Wells	Depth/ Interval	Date	Maximum Total VOC (ppb)	Major Components (ppb)
20	Deep Aquifer	11-07-83	0.0	
21	Deep Aquifer	11-07-83	0.0	
22	Deep Aquifer	11-07-83	0.0	
GDU Monitoring Wells				
8S	Shallow Aquifer	7-05-83	32.0	T-1,2-DCE (11.0), VC (8.0), CB (5.0), Toluene (5.0), DCA (3.0)
19S	Shallow Aquifer	7-05-83	0.0	
84-1D	83 ft	1-05-84	8.4	Toluene (5.0), TCE (3.0)
84-1P	70 ft	1-05-84	7.0	Toluene (7.0)
84-1S	52 ft	2-16-84	0.0	
84-2D	81 ft	2-17-84	2708.0	VC (1100.0), T-1,2-DCE (770.0), TCE (620.0), TCA (180.0), DCE (38.0)
84-2P	65 ft	2-17-84	2425.0	VC (820.0), T-1,2-DCE (780.0), TCE (700.0), TCA (96.0), DCE (29.0)
84-2S	40 ft	2-17-84	0.0	
84-3D	120 ft	2-17-84	0.0	
84-3P	67 ft	1-05-84	59.0	CB (29.0), Toluene (18.0), T-1,2-DCE (7.0), TCE (5.0)
84-3S	47 ft	1-05-84	7.0	CB (7.0)
84-4	83 ft	2-17-84	0.0	
84-5	40 ft	2-17-84	11.0	MC (8.0), Toluene (3.0)

Table 2 (Continued)
MAXIMUM TOTAL VOC'S IN GDU WELLS BEFORE
FULL TREATMENT SYSTEM STARTUP IN APRIL 1984

GDU Production Wells	Depth/ Interval	Date	Maximum Total VOC (ppb)	Major Components (ppb)
84-6D	Deep Aquifer	1-06-84	0.0	
84-6S	51 ft	1-05-84	0.0	

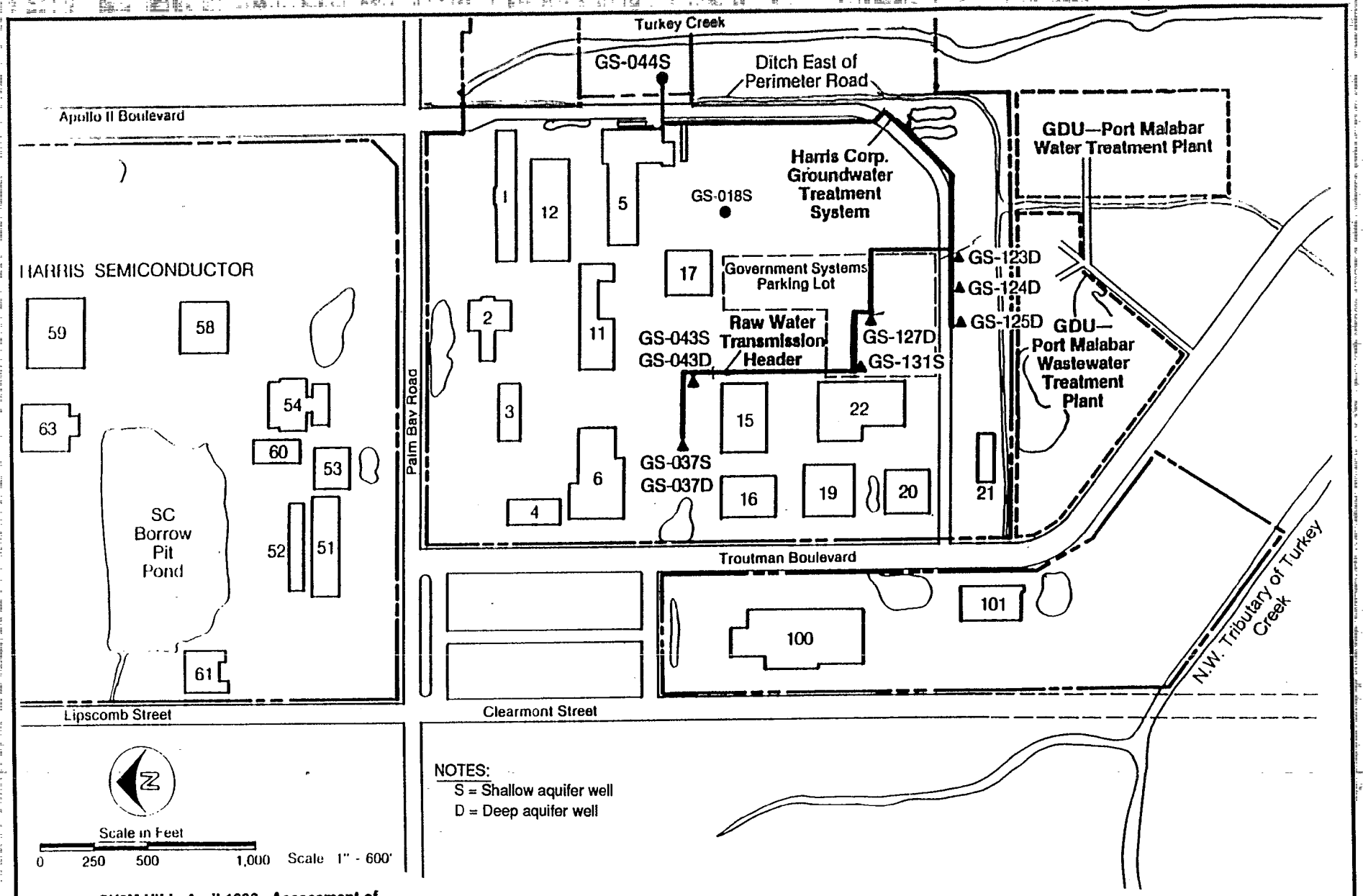
Chemical Acronyms

TCE = trichloroethylene
DCE = 1,1-dichloroethylene
C-1,2-DCE = Cis-1,2-dichloroethylene
T-1,2-DCE = Trans-1,2-dichloroethylene
VC = vinyl chloride
TCA = 1,1,1-trichloroethane
DCA = 1,1-dichloroethane
MC = methylene chloride
o-DCB = ortho-dichlorobenzene
CB = chlorobenzene
EB = ethyl benzene

*Contaminated GDU wells connected to air stripper pre-treatment system

Source: CH2M HILL. April 1986. Assessment of the Harris Corporation Remediation Program --Appendix C.

WDCR05/089.50



Source: CH2M HILL, April 1986. Assessment of the Harris Corporation Remediation Program.

Figure 8
HARRIS CORPORATION
REMEDIATION SYSTEM, EARLY 1989
HARRIS CORPORATION SITE

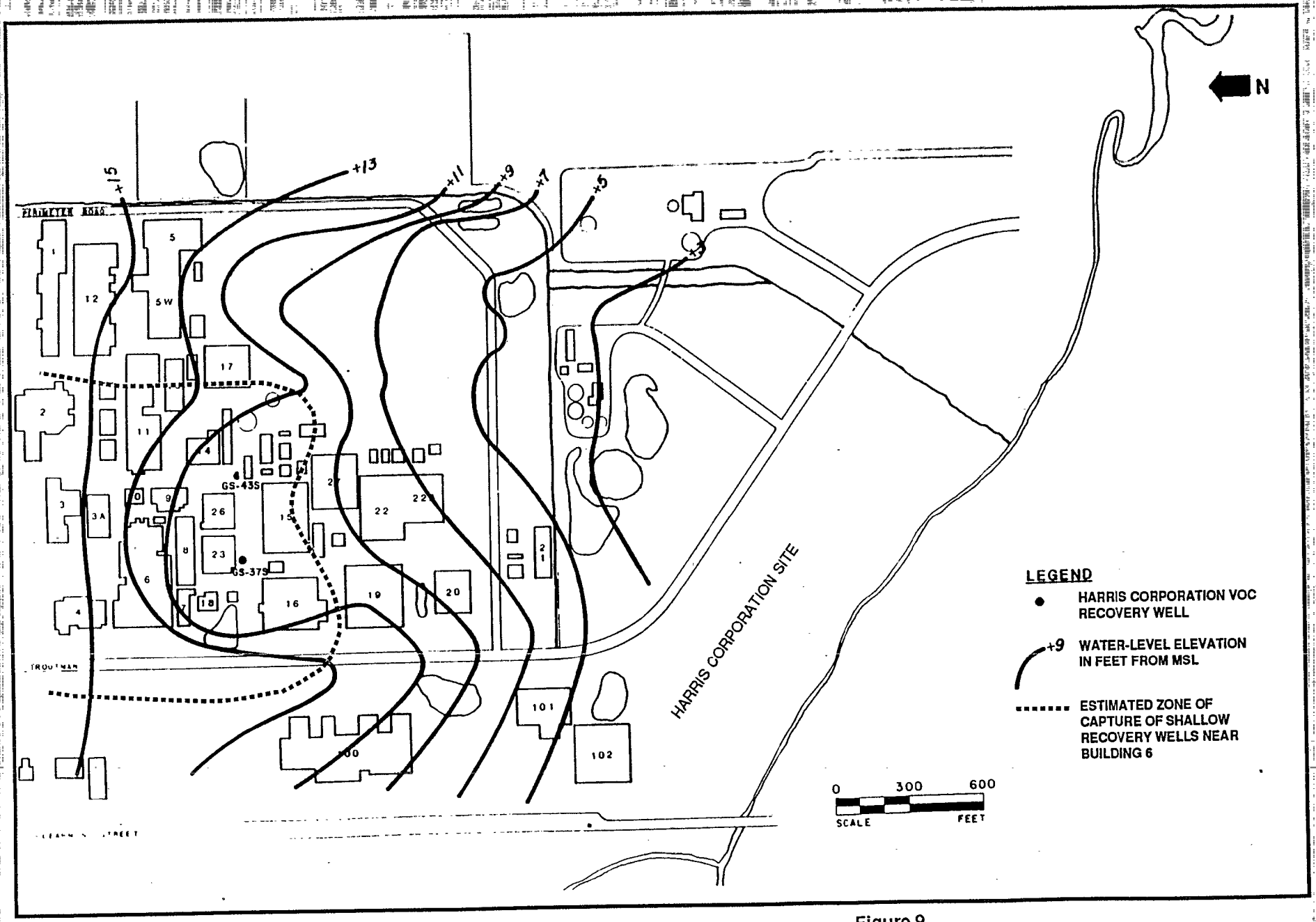
Table 3
WELL PUMPING RATES MEASURED ON MARCH 24, 1987

Harris Corporation Well	Well Pumping Rate on March 24, 1987 (Gallons Per Minute)	GDU Well	Well Pumping Rate on March 24, 1987 (Gallons Per Minute)
GS-37S	9	GDU-2B*	20
GS-43S	14	GDU-3*	45
GS-37D	45	GDU-4	95
GS-43D	25	GDU-5*	75
GS-123D	33	GDU-6	125
GS-124D	51	GDU-7	130
GS-125D	49	GDU-8*	150
GS-127D	50	GDU-9	150
		GDU-11	105
		GDU-12	190
		GDU-13	230
		GDU-14	110
		GDU-15	210
		GDU-16	170
		GDU-17	315
		GDU-18	100
		GDU-20	210
		GDU-21	100
		GDU-22	150

* = Contaminated GDU wells connected to air stripper pre-treatment system.

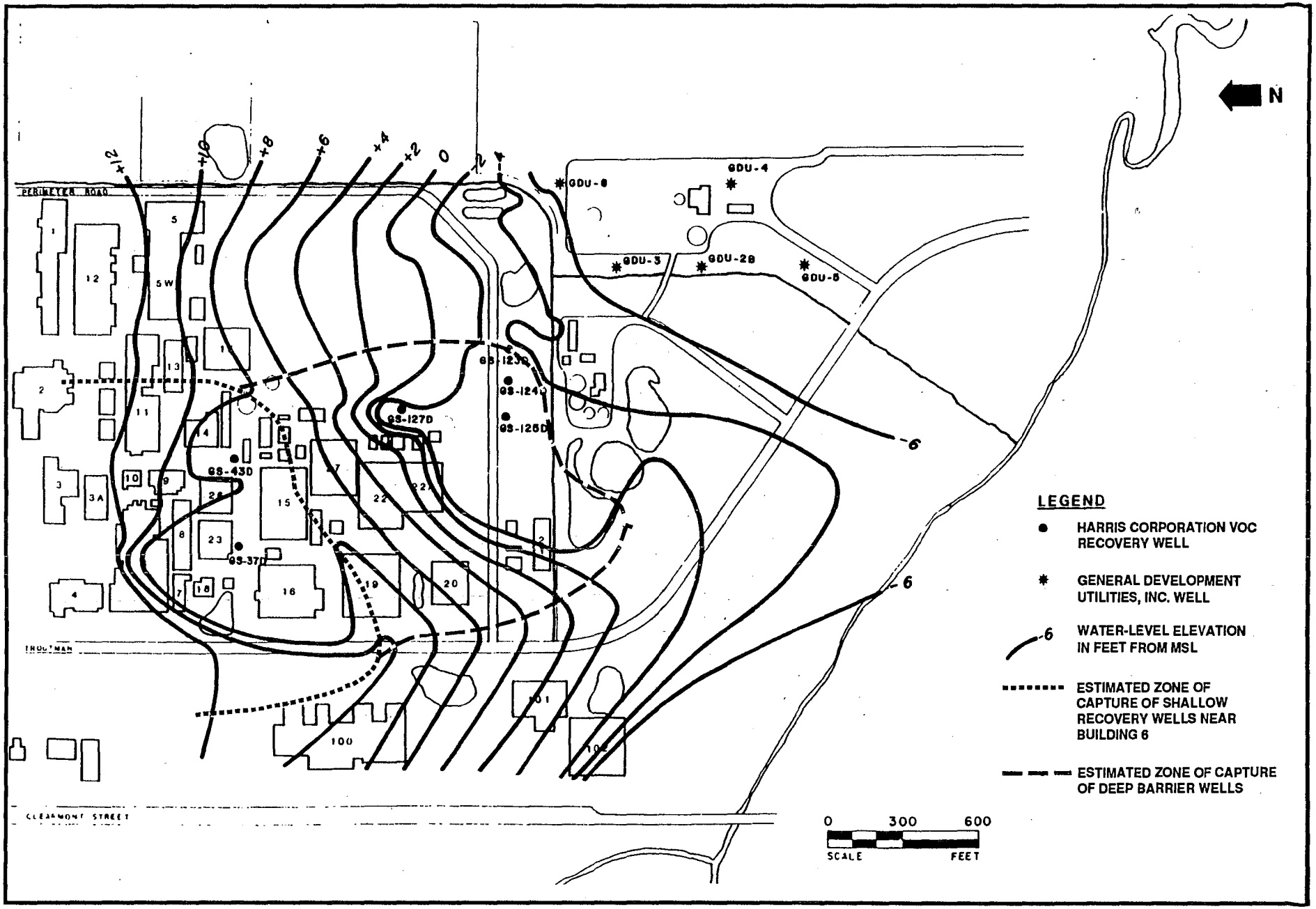
Source: Geraghty & Miller. October 1987. An Evaluation of the Harris Corporation Ground-Water Recovery System.

WDR218/026



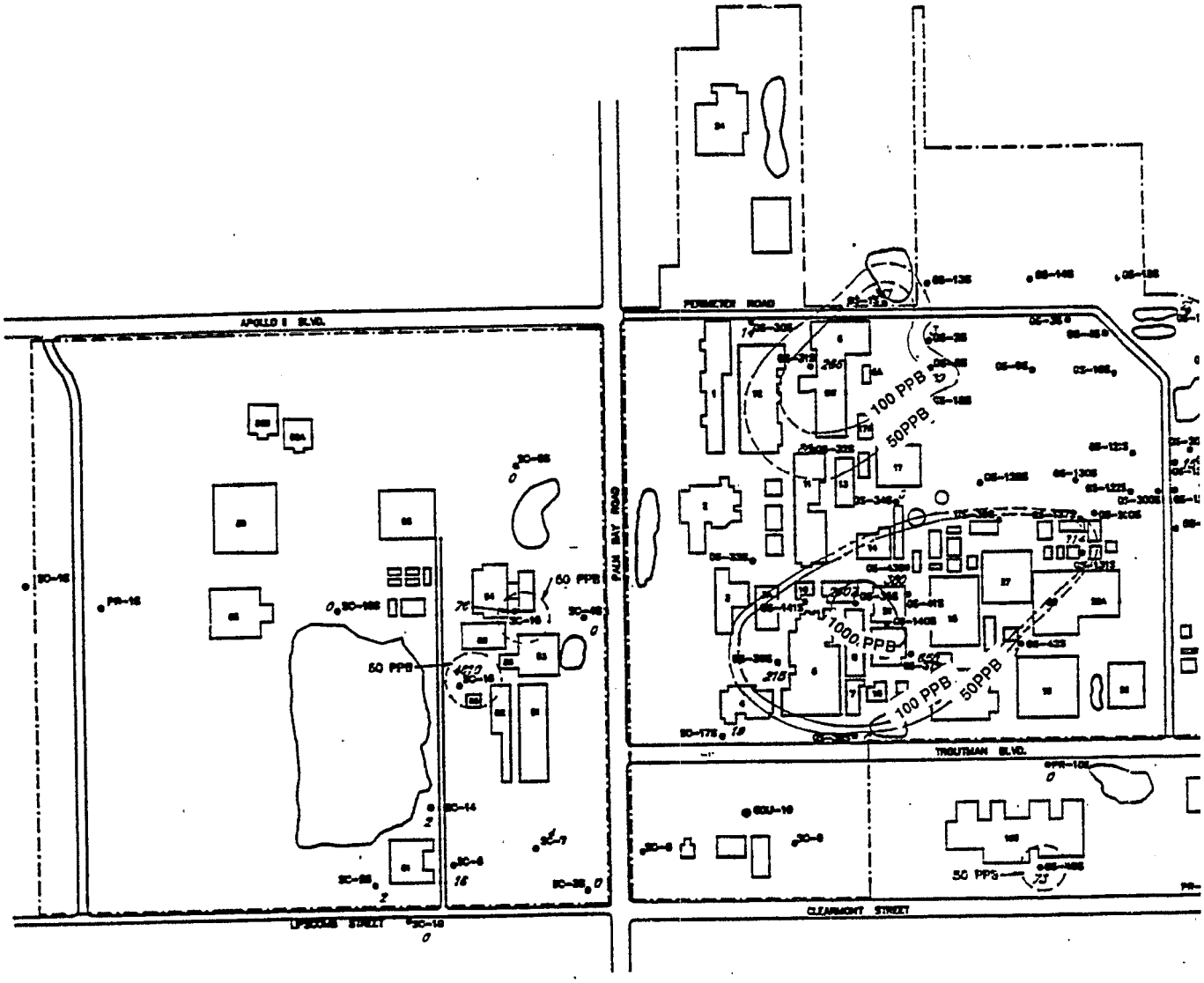
Source: Geraghty & Miller, Inc., October 1987. An Evaluation of the Harris Corporation Ground-water Recovery System.

Figure 9
POTENTIOMETRIC SURFACE OF SHALLOW-AQUIFER ZONE, MARCH 24,1987
HARRIS CORPORATION SITE



Source: Geraghty & Miller, Inc., October 1987. An Evaluation of the Harris Corporation Ground-water Recovery System.

Figure 10
POTENTIOMETRIC SURFACE OF DEEP-AQUIFER ZONE MARCH 24, 1987
HARRIS CORPORATION SITE



LEGEND

- ● EXISTING HARRIS MONITORING WELLS
- ✱ EXISTING GDU PRODUCTION WELLS
- ⌖ EXISTING GDU MONITORING WELLS
- 100 PPB — ISOPLETH OF TOTAL VOCS (PARTS PER BILLION)
- 73 — TOTAL VOCS (PARTS PER BILLION)

Source: Geraghty & Miller, Inc., February 1988. Harris Corporation
1988 Ground-Water Monitoring Program, Palm Bay, Florida

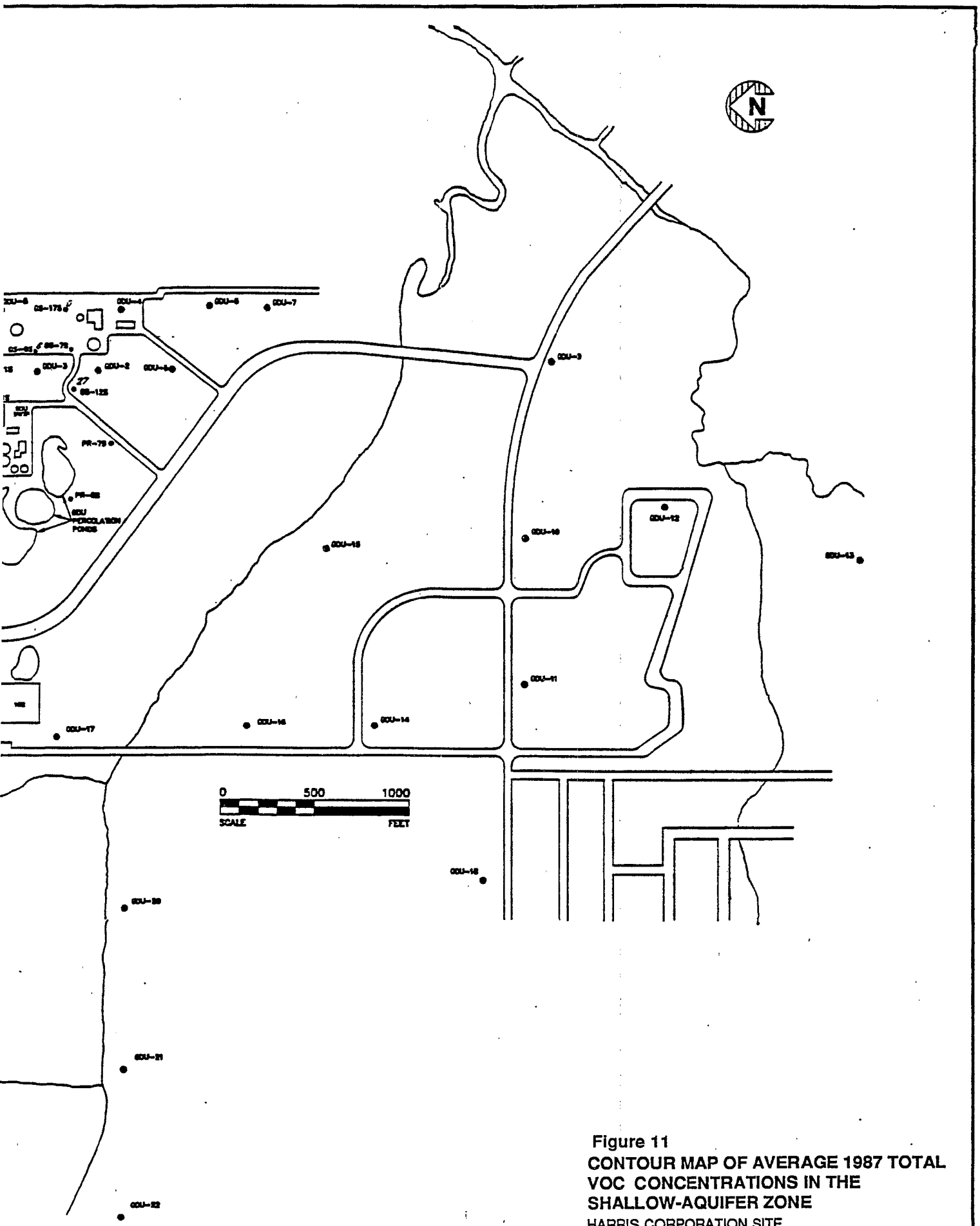
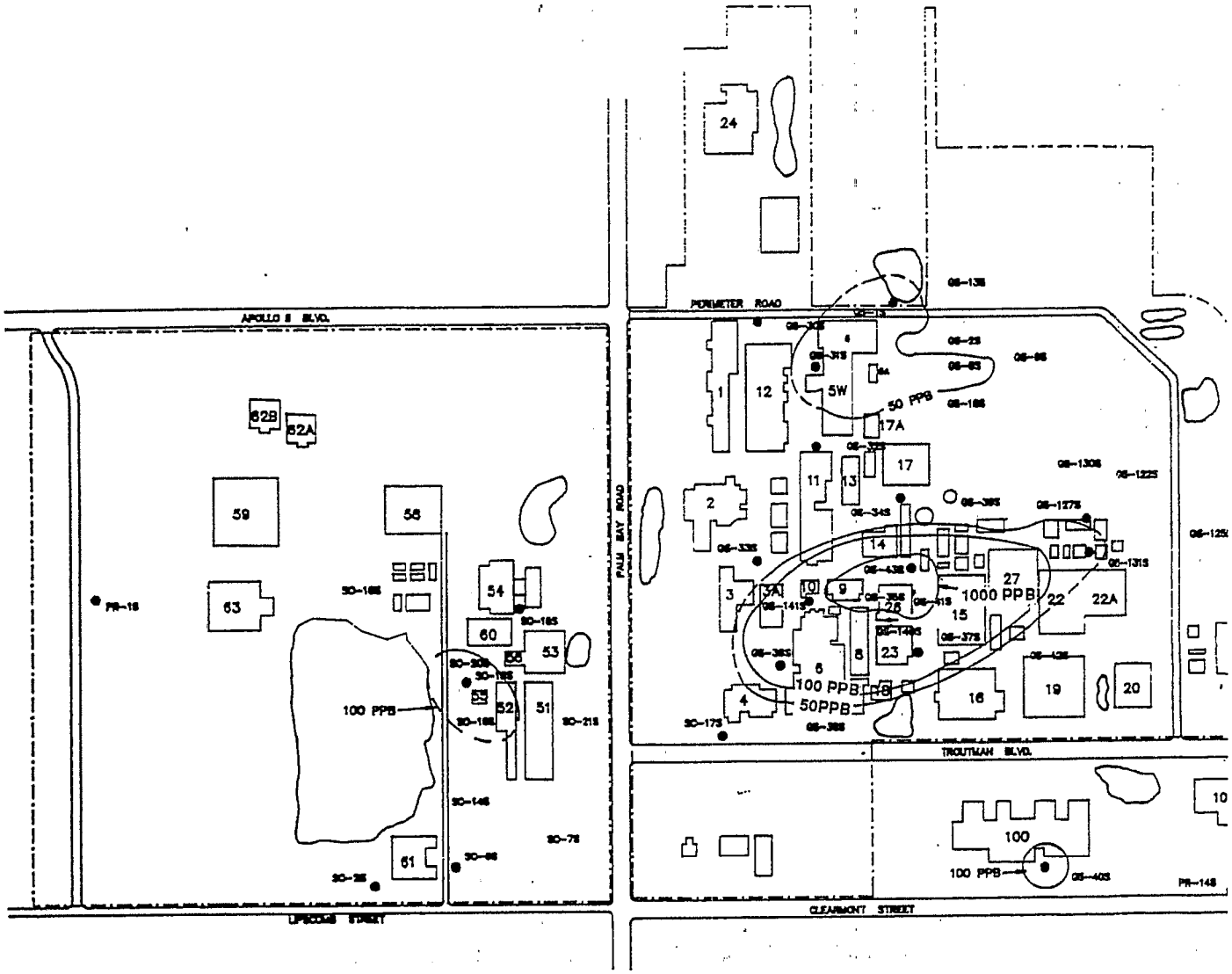


Figure 11
CONTOUR MAP OF AVERAGE 1987 TOTAL VOC CONCENTRATIONS IN THE SHALLOW-AQUIFER ZONE
HARRIS CORPORATION SITE



LEGEND

- ANNUALLY
- BI-ANNUALLY
- QUARTERLY
- 100 PPB — ISOPLETH OF AVERAGE 1988 TOTAL VOC'S (PARTS PER BILLION)

Source: Geraghty & Miller, Inc., February 1989. Harris Corporation
1989 Ground-Water Monitoring Program, Palm Bay, Florida

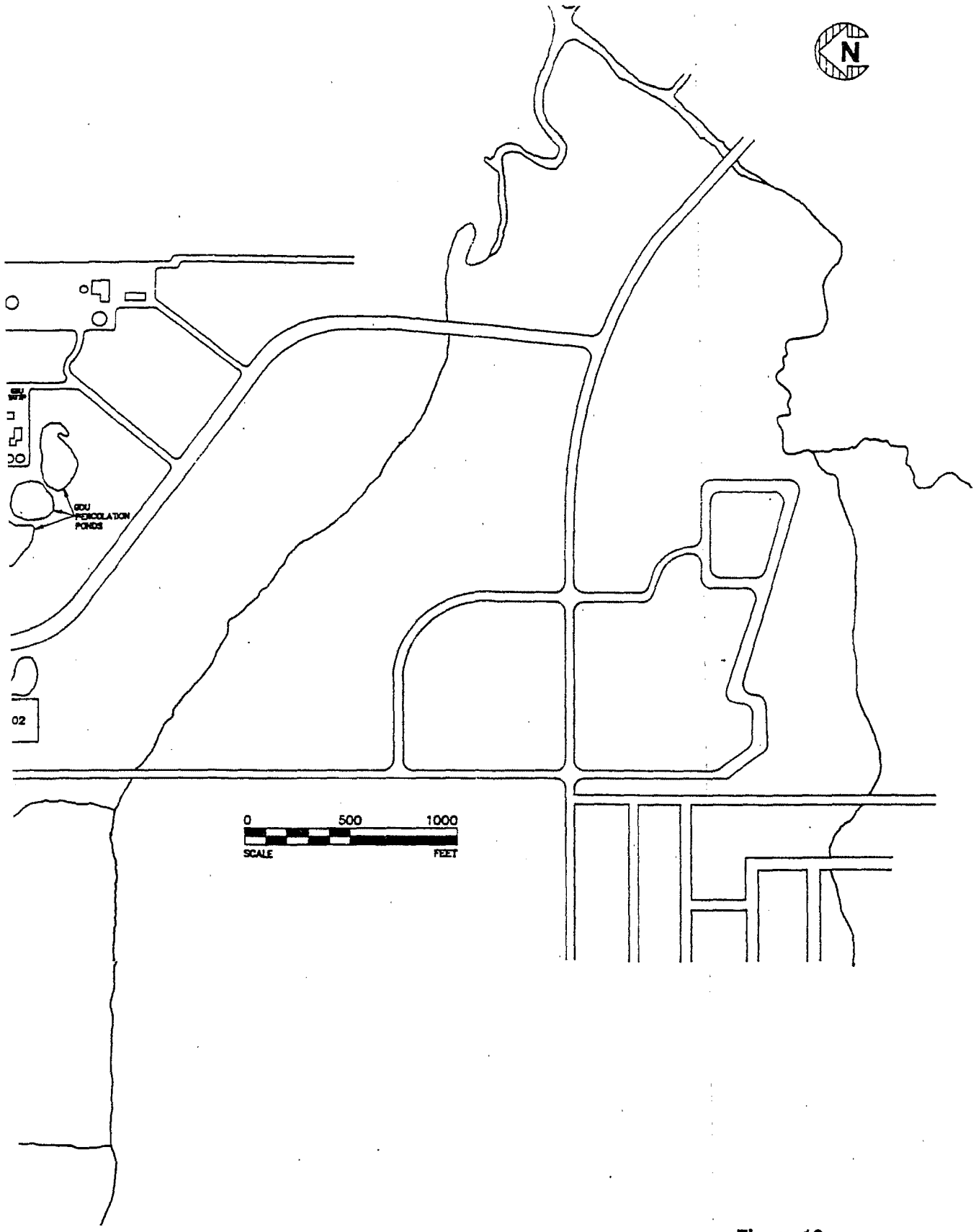
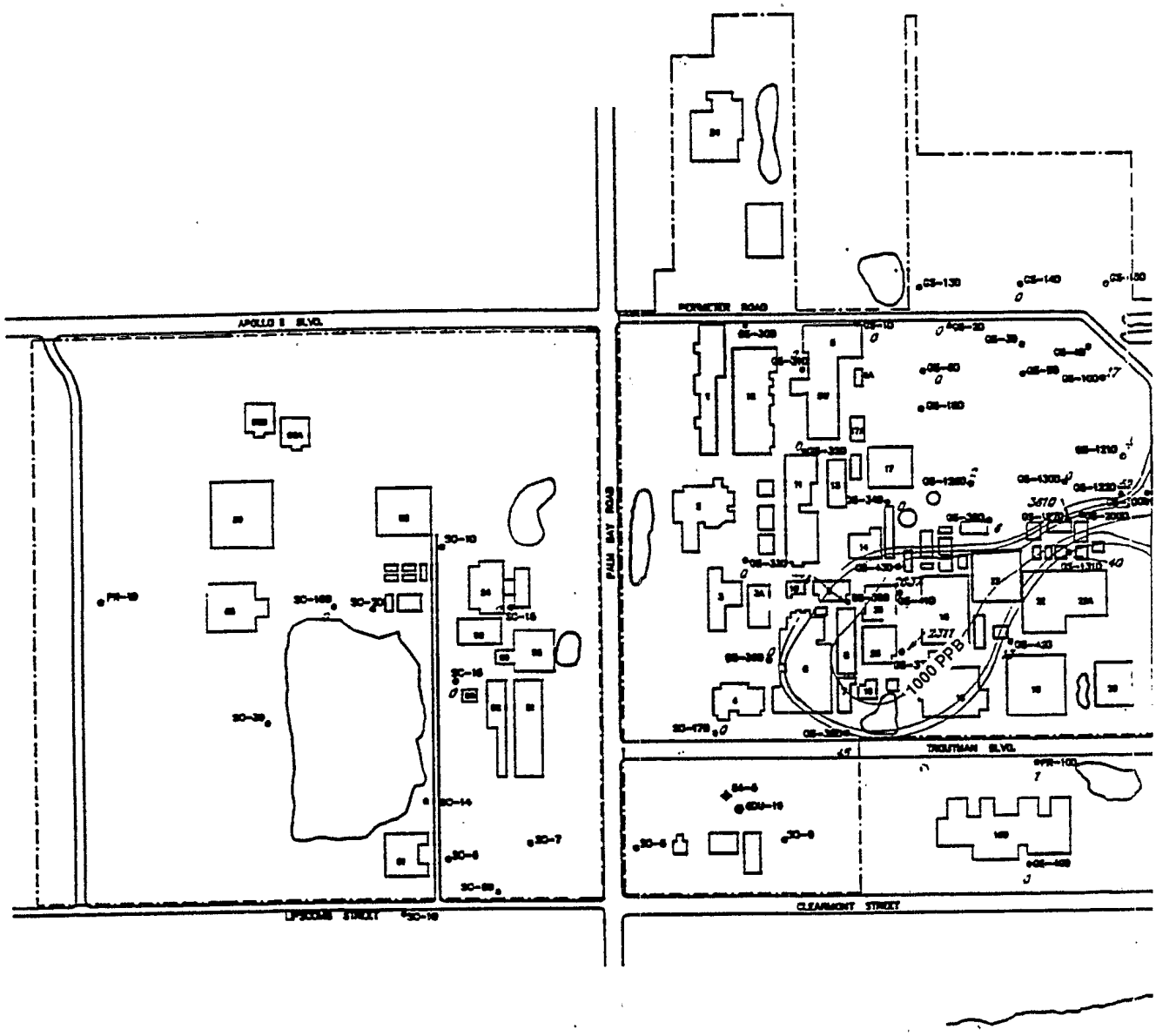


Figure 12
CONTOUR MAP OF AVERAGE 1988 TOTAL VOC CONCENTRATIONS IN THE SHALLOW-AQUIFER ZONE
HARRIS CORPORATION SITE



LEGEND

- ● EXISTING HARRIS MONITORING WELLS
- ● EXISTING GDU PRODUCTION WELLS
- ⊕ EXISTING GDU MONITORING WELLS
- 100 PPB — ISOPLETH OF TOTAL VOCS (PARTS PER BILLION)
- 27 — TOTAL VOCS (PARTS PER BILLION)

Source: Geraghty & Miller, Inc., February 1988. Harris Corporation 1989 Groundwater Monitoring Program, Palm Bay, Florida.

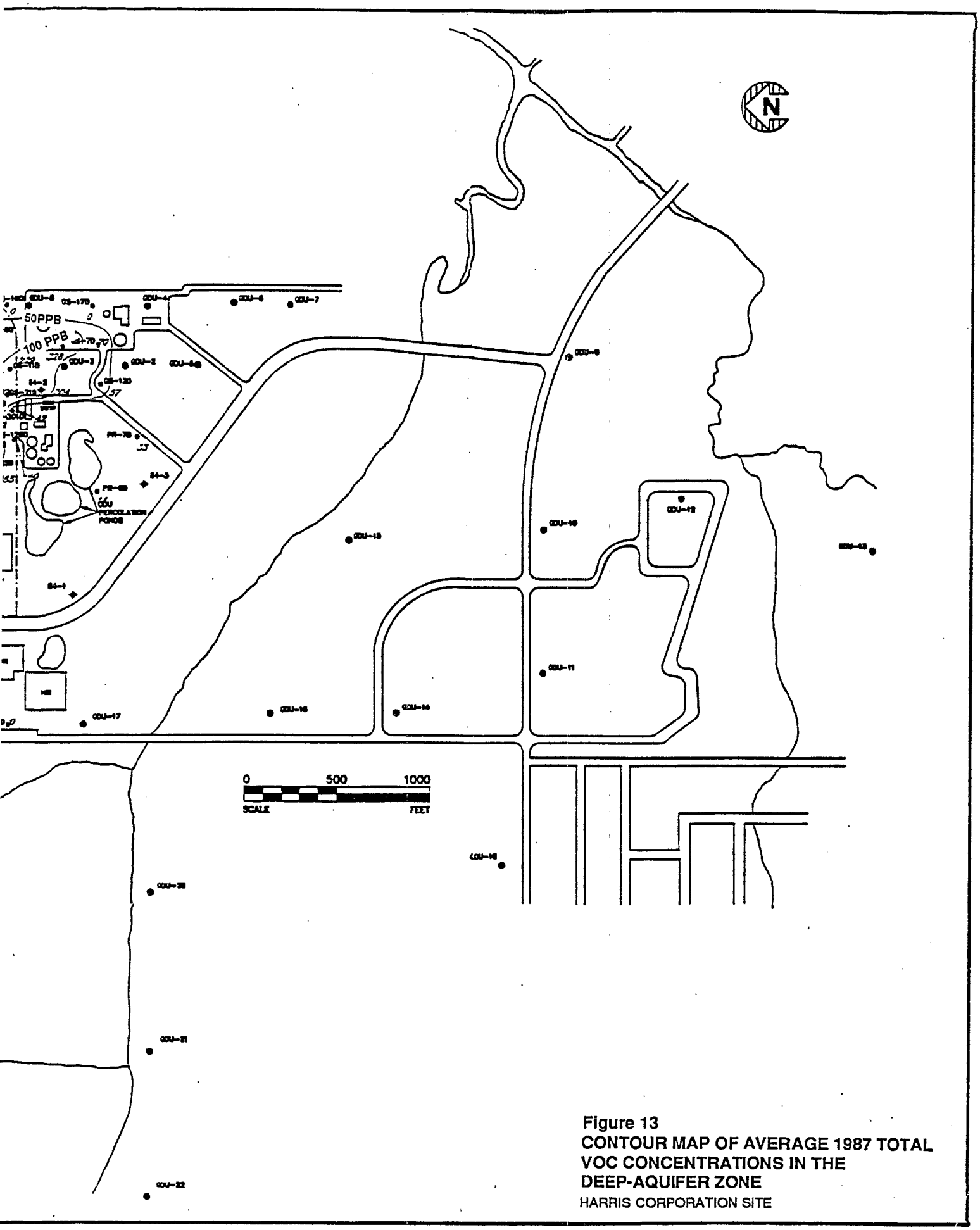
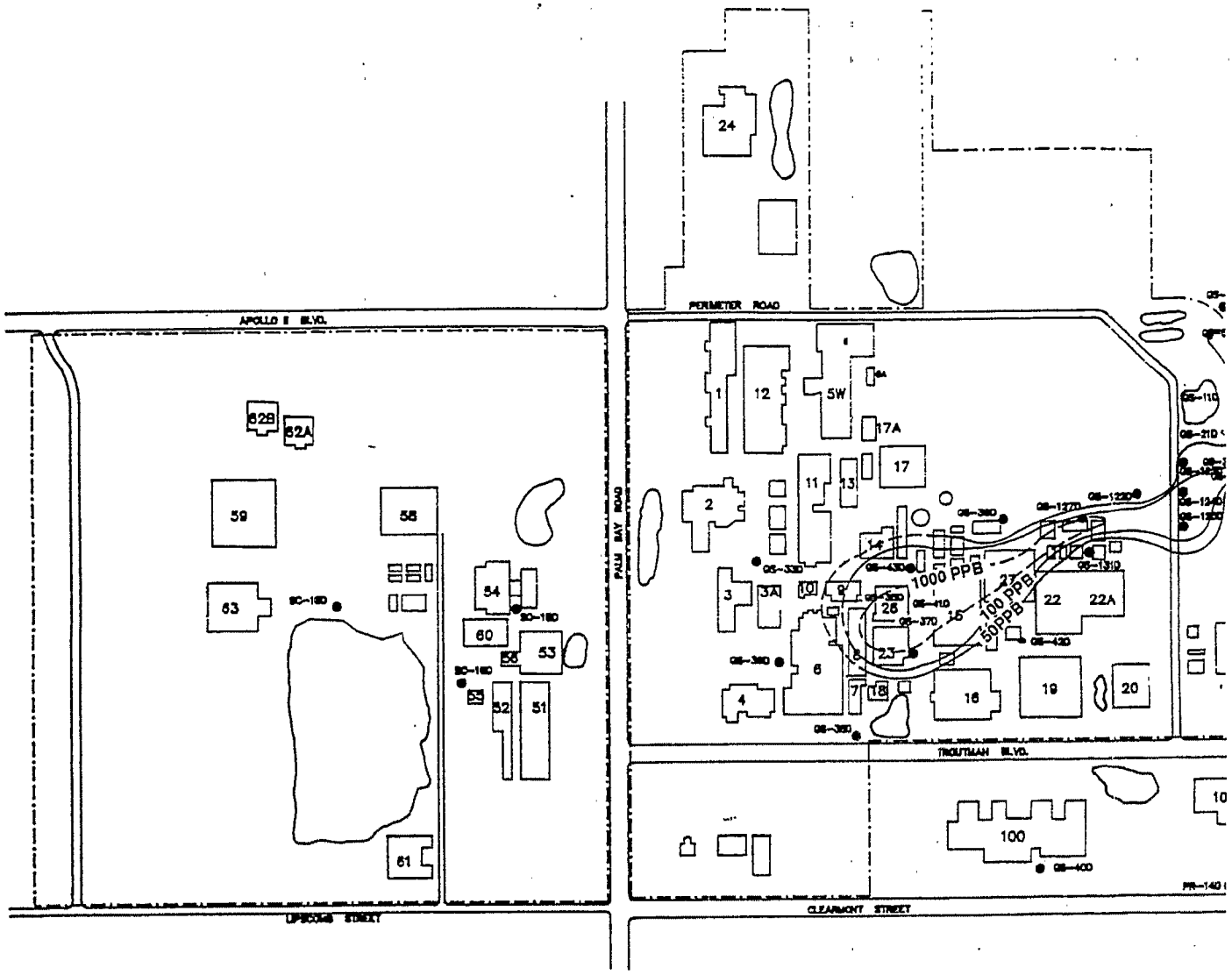


Figure 13
CONTOUR MAP OF AVERAGE 1987 TOTAL VOC CONCENTRATIONS IN THE DEEP-AQUIFER ZONE
HARRIS CORPORATION SITE



LEGEND

- ANNUALLY
- BI–ANNUALLY
- QUARTERLY
- 100 PPB — ISOPLETH OF AVERAGE 1988 TOTAL VOC'S (PARTS PER BILLION)

Source: Geraghty & Miller, Inc., February 1989. Harris Corporation 1989 Ground-Water Monitoring Program, Palm Bay, Florida

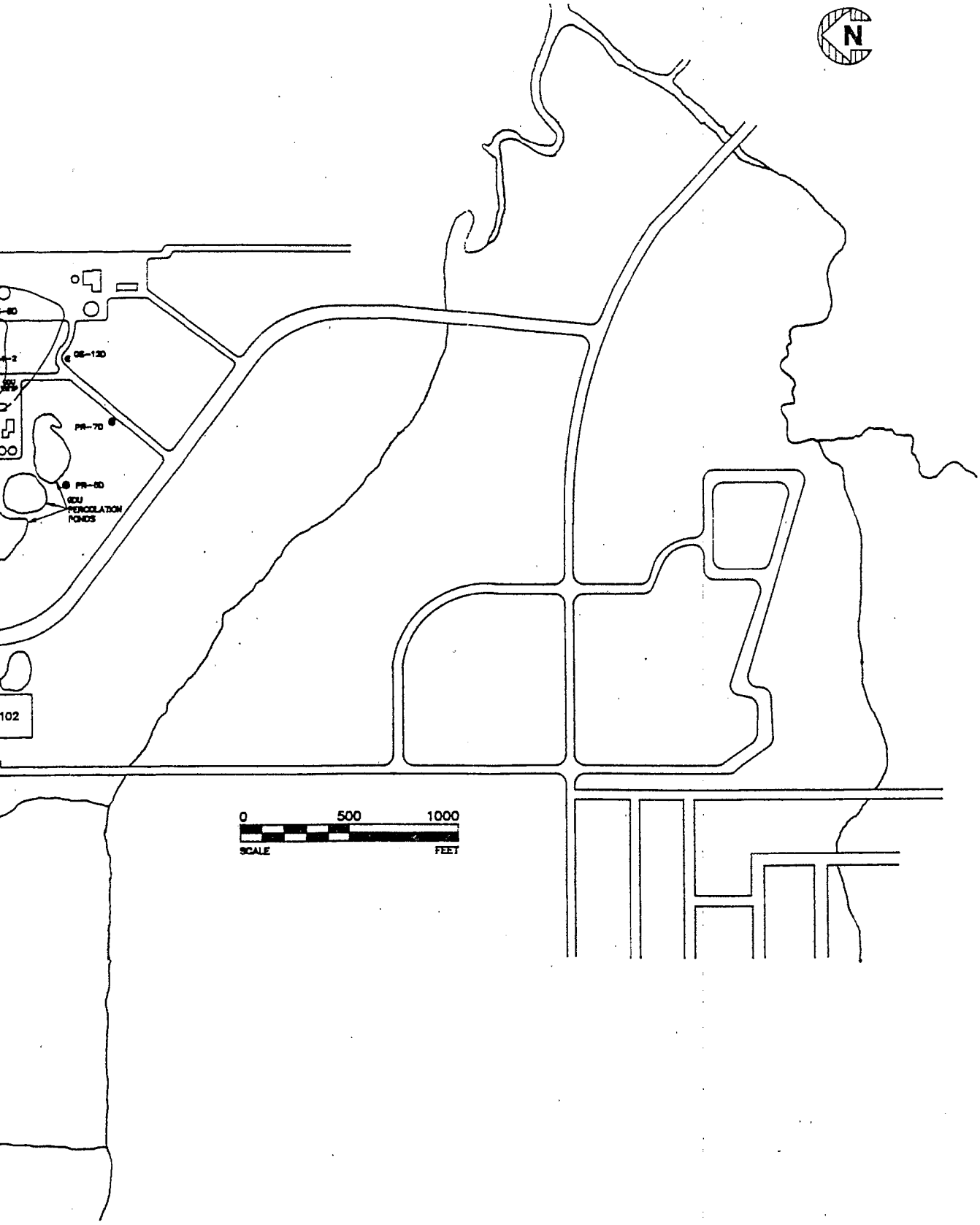
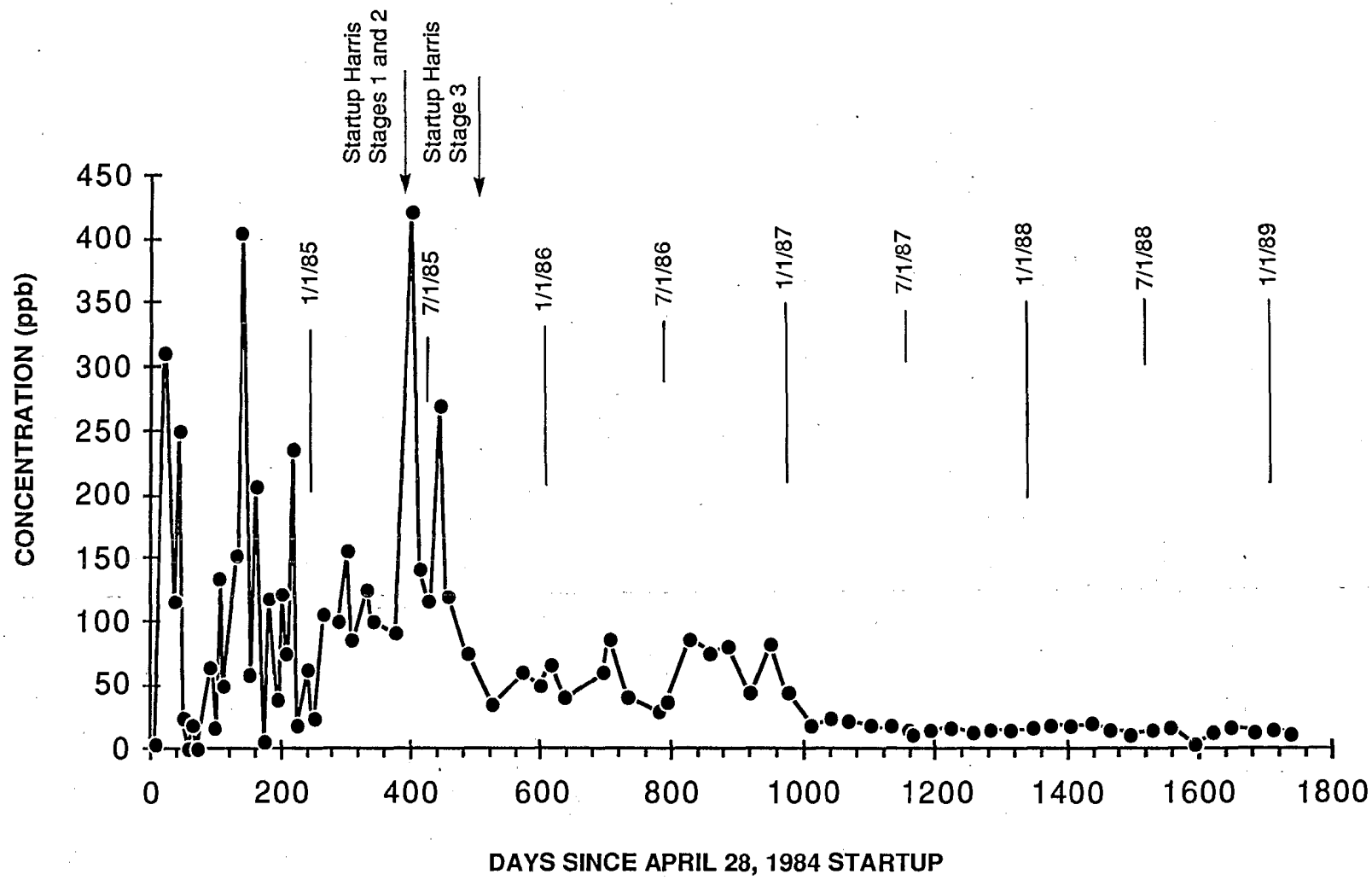


Figure 14
CONTOUR MAP OF AVERAGE 1988 TOTAL VOC CONCENTRATIONS IN THE DEEP-AQUIFER ZONE
HARRIS CORPORATION SITE



Compiled from various sources.

Figure 15
INFLUENT TOTAL VOC CONCENTRATIONS
GDU TREATMENT SYSTEM
HARRIS CORPORATION SITE

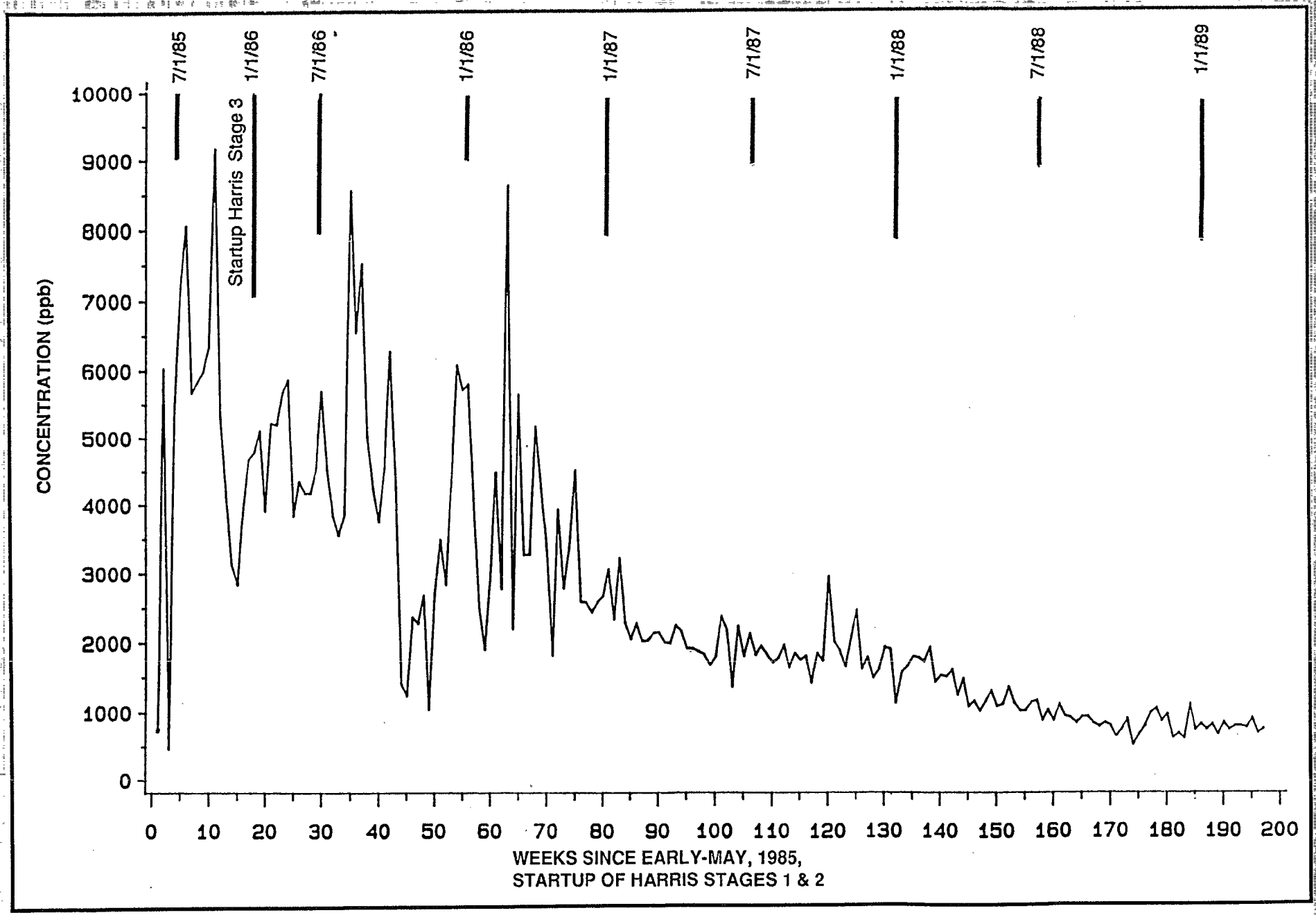
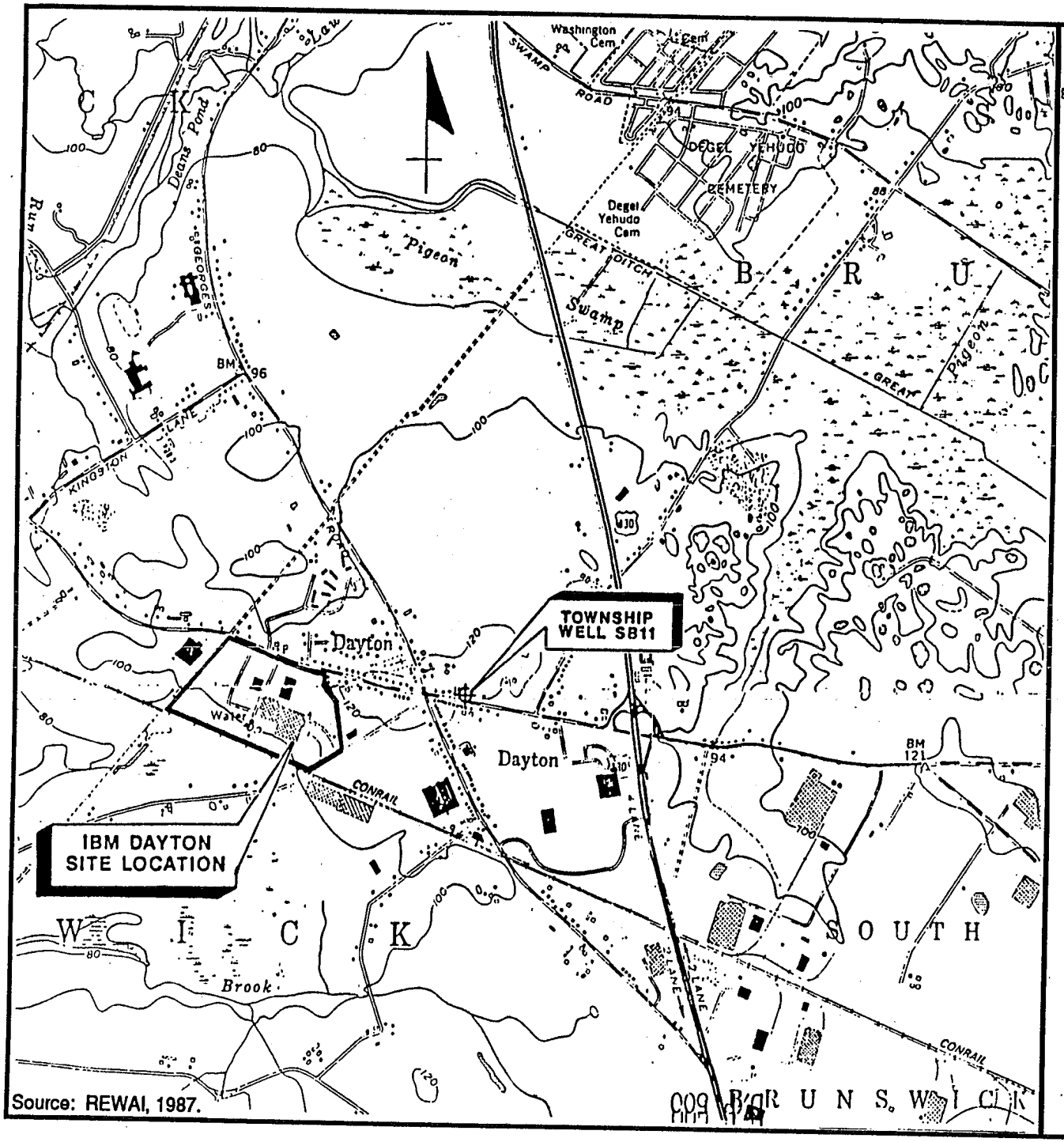


Figure 16
INFLUENT TOTAL VOC CONCENTRATIONS, HARRIS TREATMENT SYSTEM
HARRIS CORPORATION SITE



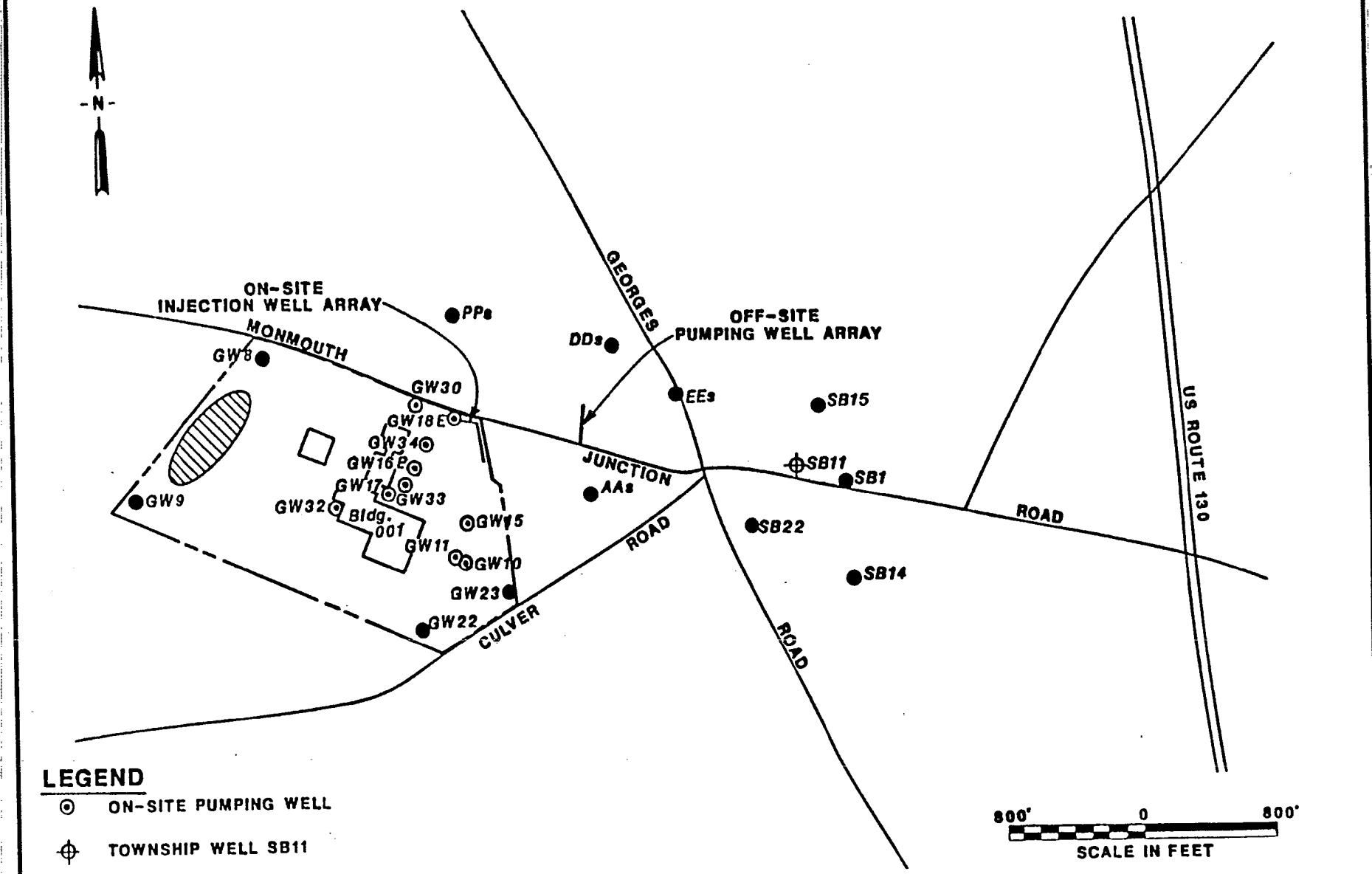
Source: REWAI, 1987.

BASE MAP FROM: Monmouth Junction, NJ, New Brunswick, NJ, Hightstown, NJ and Jamesburg, NJ USGS 7 1/2 Min. Topographic Quadrangles

2000' 0 2000'

SCALE IN FEET

Figure 1
SITE LOCATION MAP
IBM-DAYTON SITE
DAYTON, NEW JERSEY

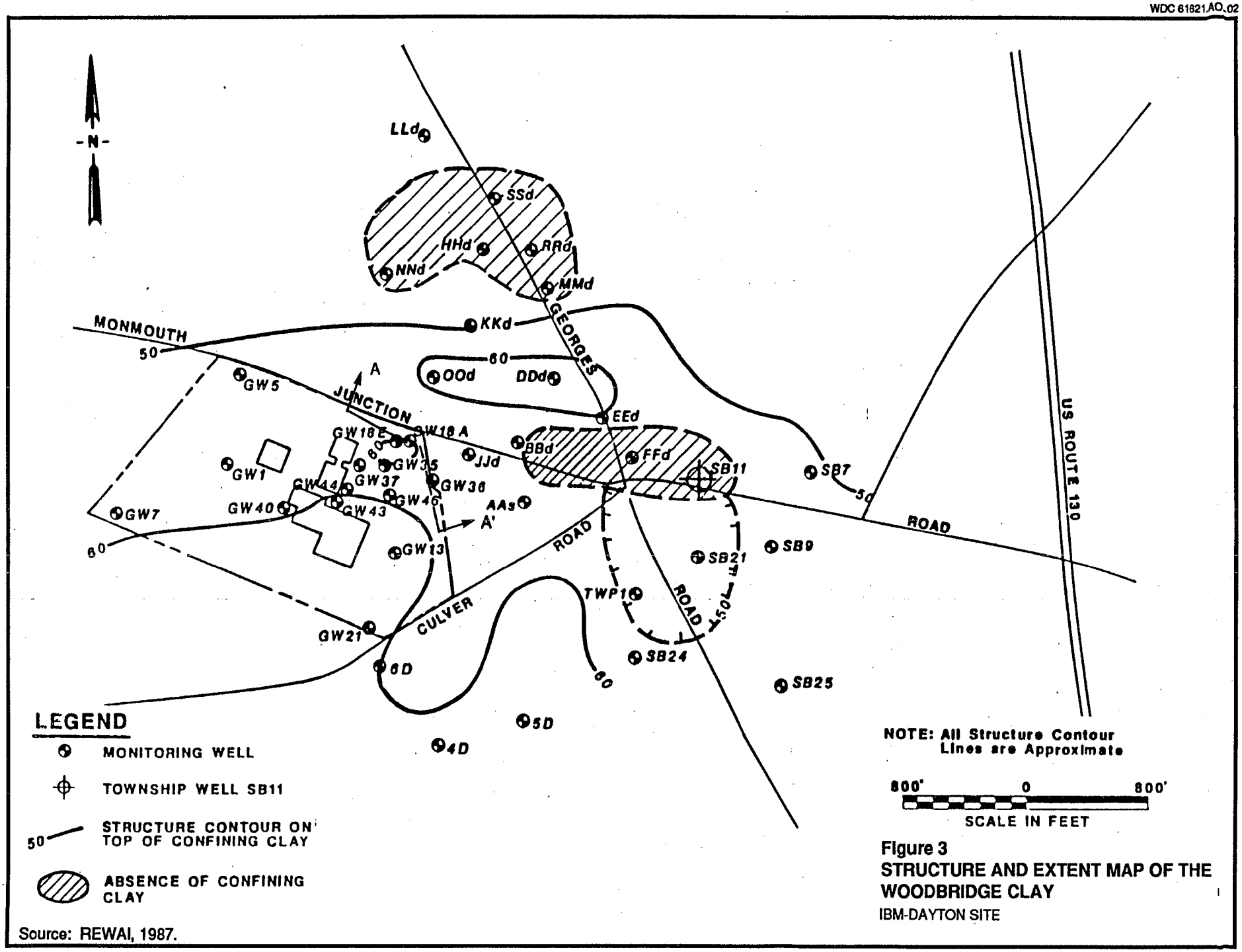


LEGEND

- ON-SITE PUMPING WELL
- TOWNSHIP WELL SB11
- ACO PERIMETER WELL
- SPRAY IRRIGATION FIELD

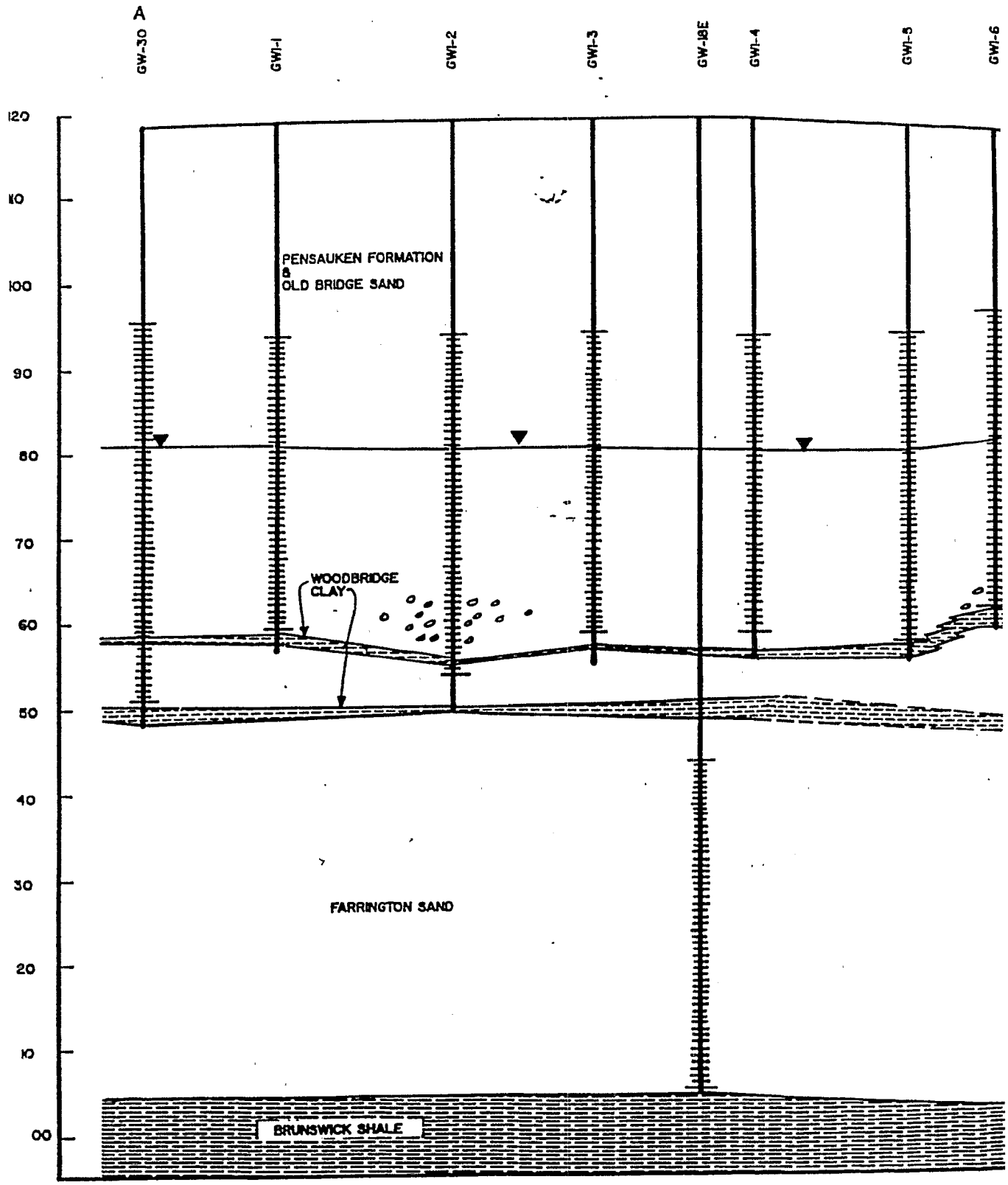
Source: REWAI, 1987.

Figure 2
SITE PLAN AND EXTRACTION WELL LOCATIONS
IBM-DAYTON SITE



Source: REWAI, 1987.

Figure 3
STRUCTURE AND EXTENT MAP OF THE WOODBRIDGE CLAY
IBM-DAYTON SITE



Source: Groundwater Sciences Corp., et al., 1988

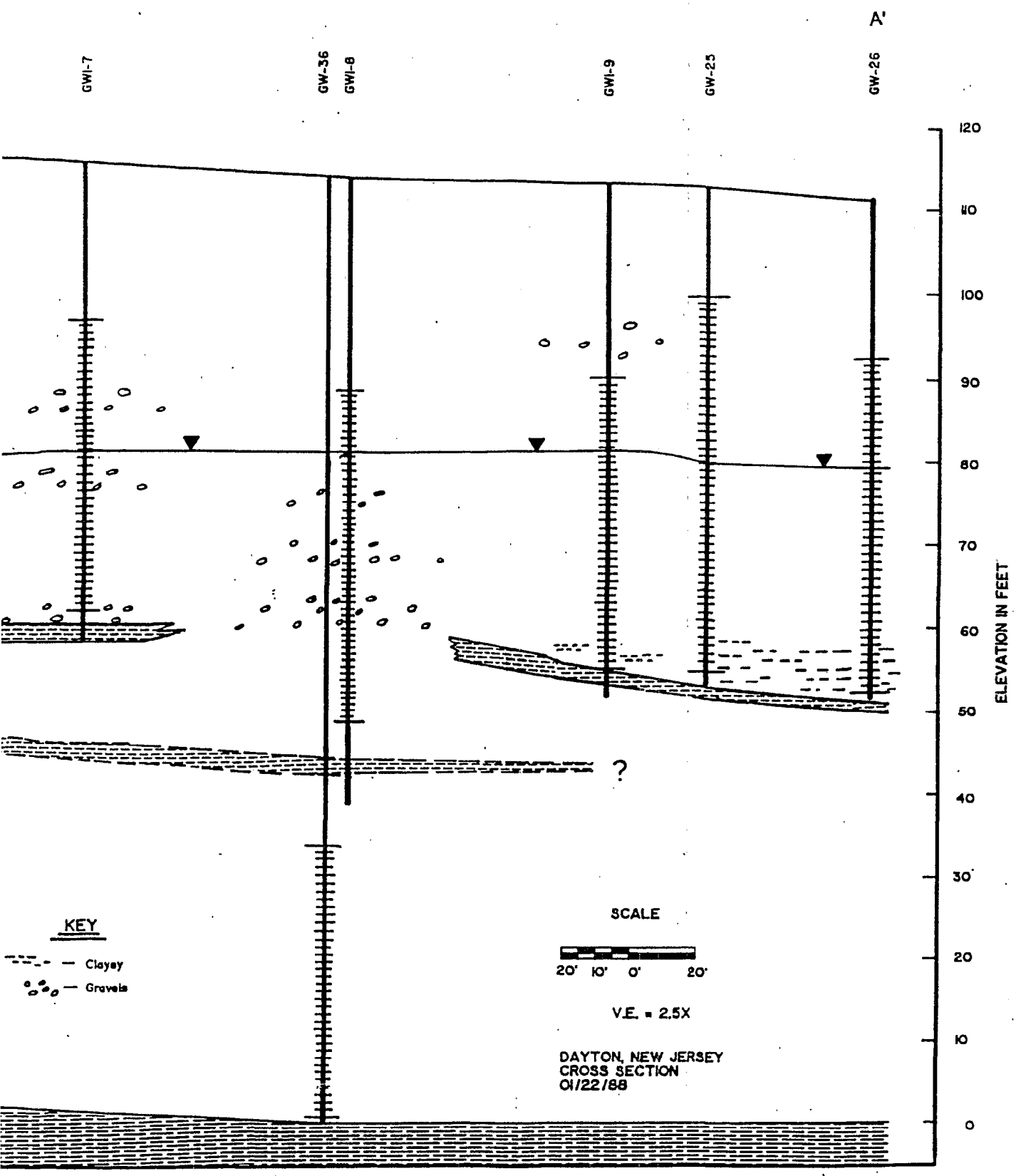
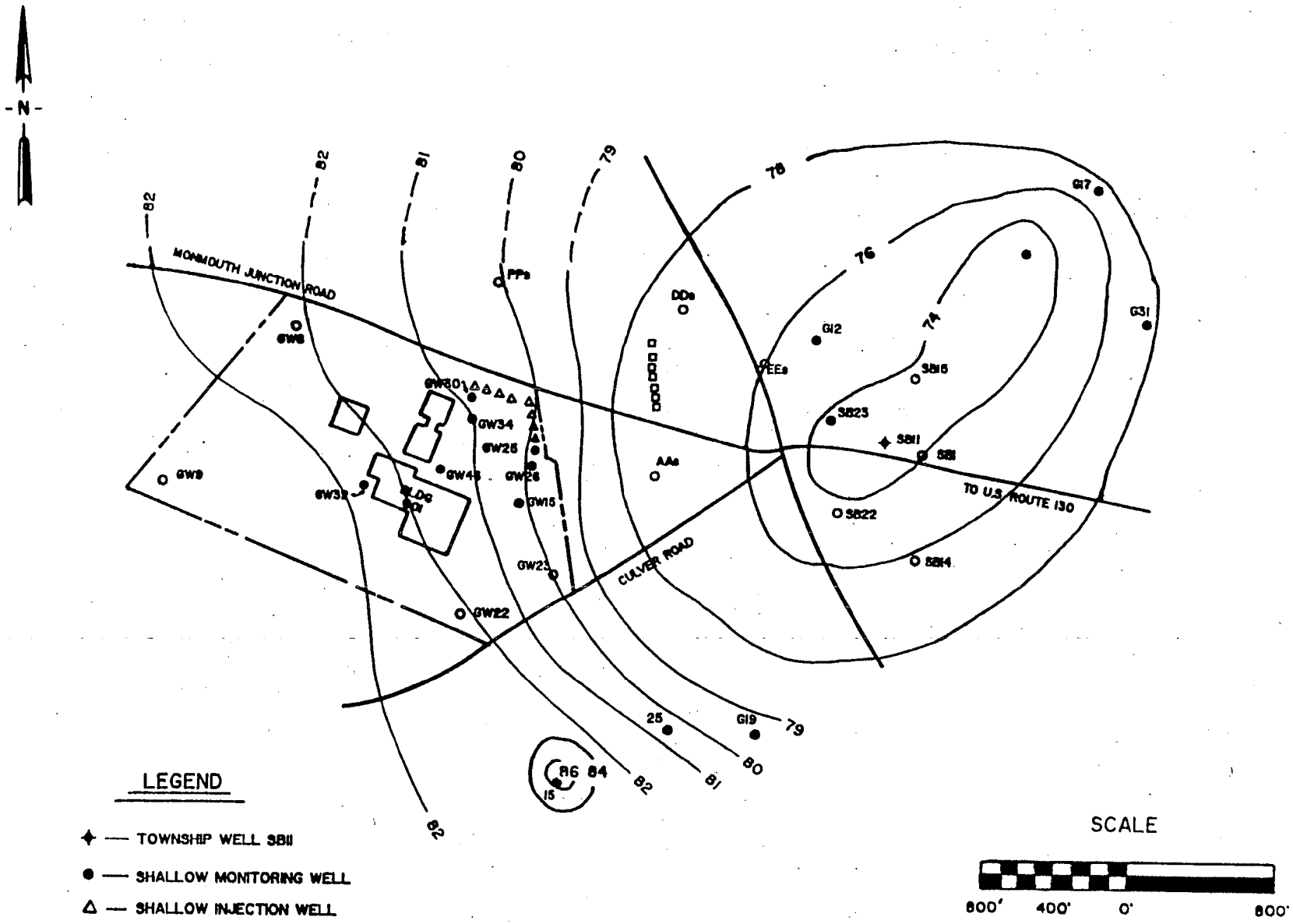


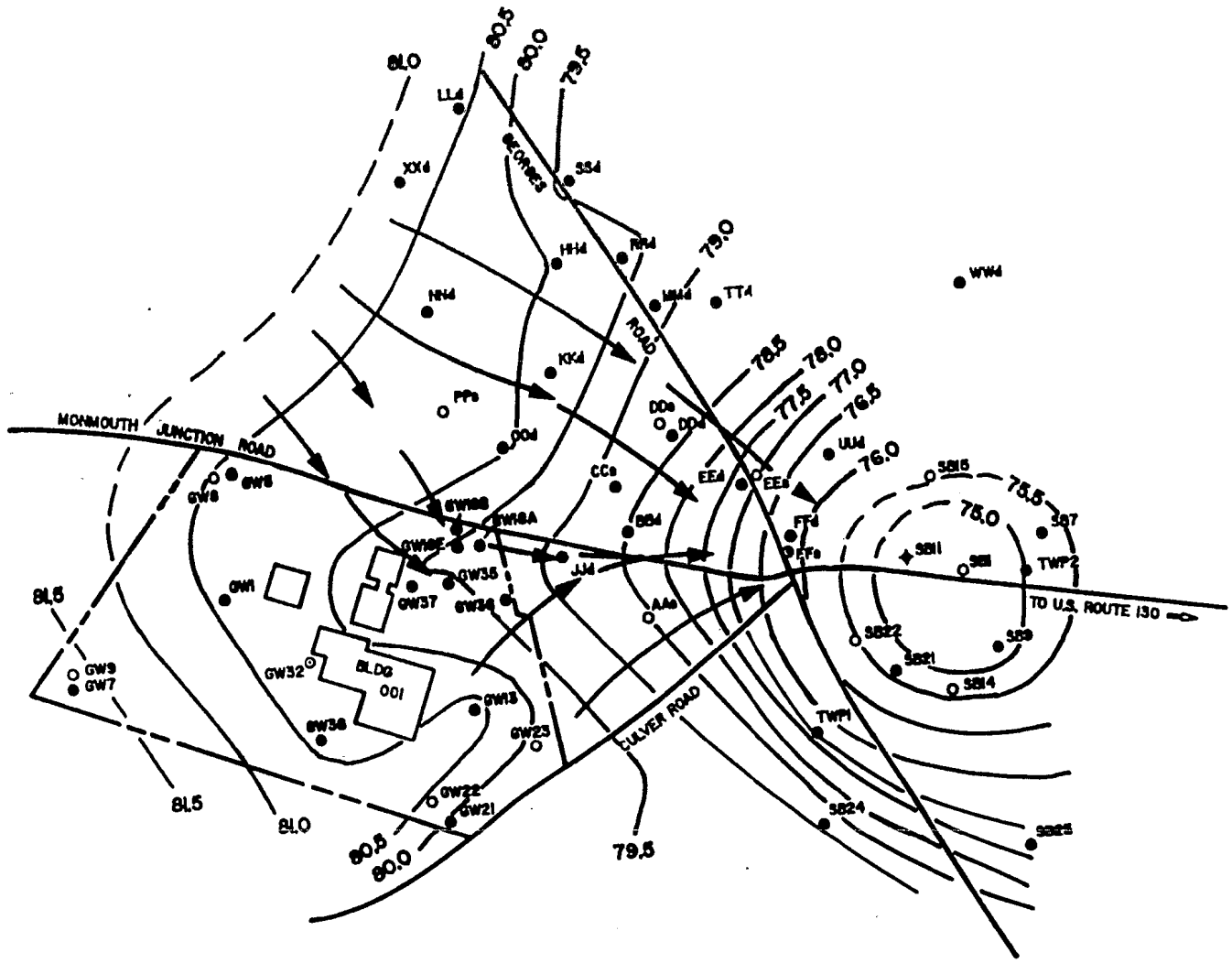
Figure 4
GEOLOGIC CROSS SECTION A-A'
(WATER LEVELS FOR JANUARY 22, 1988)

IBM-DAYTON SITE



Source: REWAI, 1987.

Figure 5
POTENTIOMETRIC SURFACE OF THE SHALLOW WATER TABLE AQUIFER, DECEMBER 1, 1987
IBM-DAYTON SITE



LEGEND

- ✦ --- TOWNSHIP WELL SB11
- ● --- DEEP MONITORING WELL
- ○ --- AACO PERIMETER WELL
- ⊙ --- AACO SHALLOW MONITORING WELL

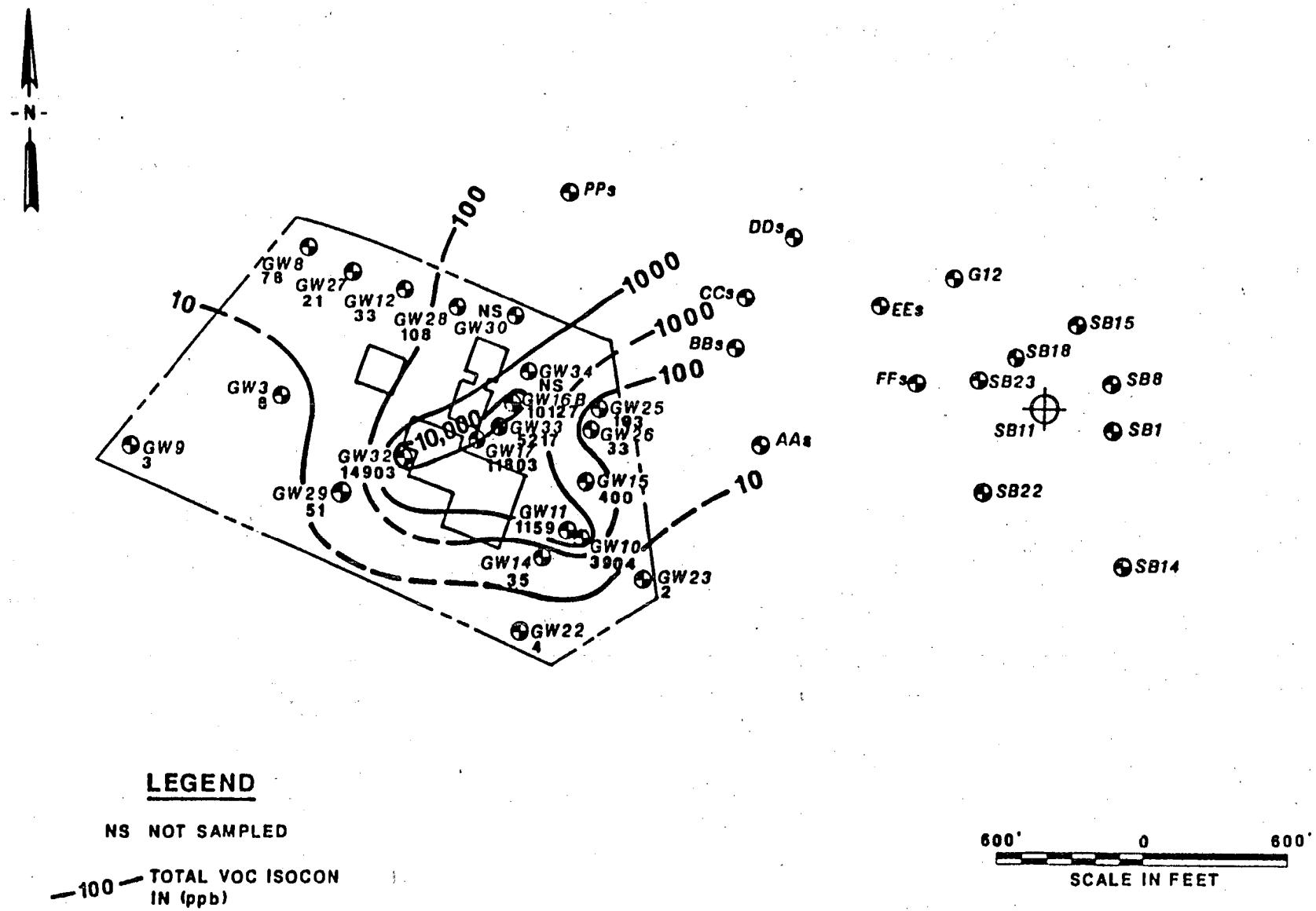
Source: GSC et. al. August, 1988.

CONTOURS IN FEET

SCALE

800' 400' 0' 800'

Figure 6
POTENTIOMETRIC SURFACE IN THE DEEP FARRINGTON SAND AQUIFER, SEPTEMBER, 1987
IBM-DAYTON SITE



LEGEND

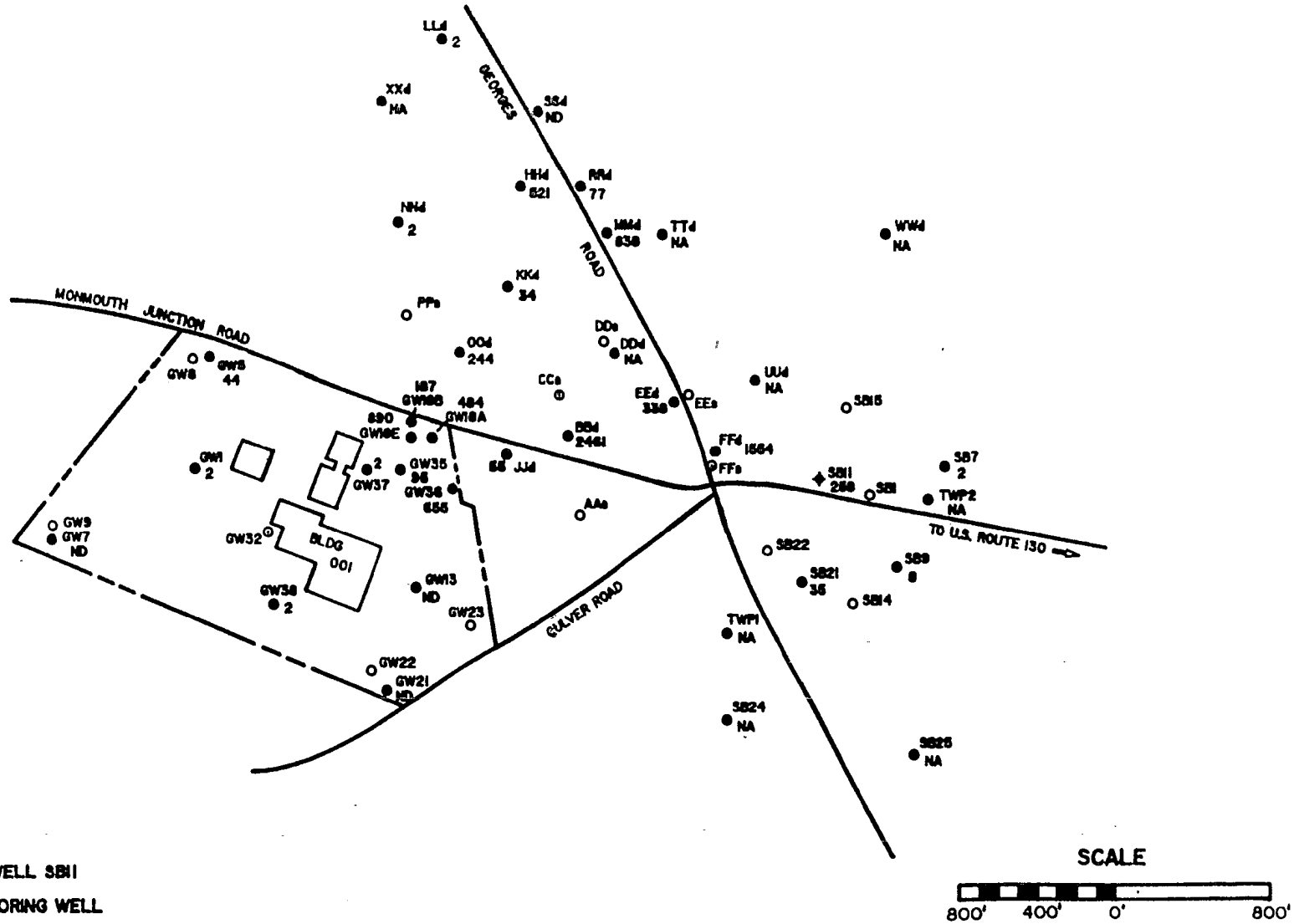
NS NOT SAMPLED

—100— TOTAL VOC ISOCON IN (ppb)

NOTE: ONLY GW SERIES WELLS WERE CONSTRUCTED BY JUNE, 1978

Source: REWAI, 1987.

Figure 7
MEAN TOTAL VOLATILE ORGANIC CONCENTRATIONS IN THE SHALLOW AQUIFER, JANUARY-JUNE, 1978
IBM-DAYTON SITE



LEGEND

✦ --- TOWNSHIP WELL SB11

● --- DEEP MONITORING WELL

○ --- AACO PERIMETER WELL

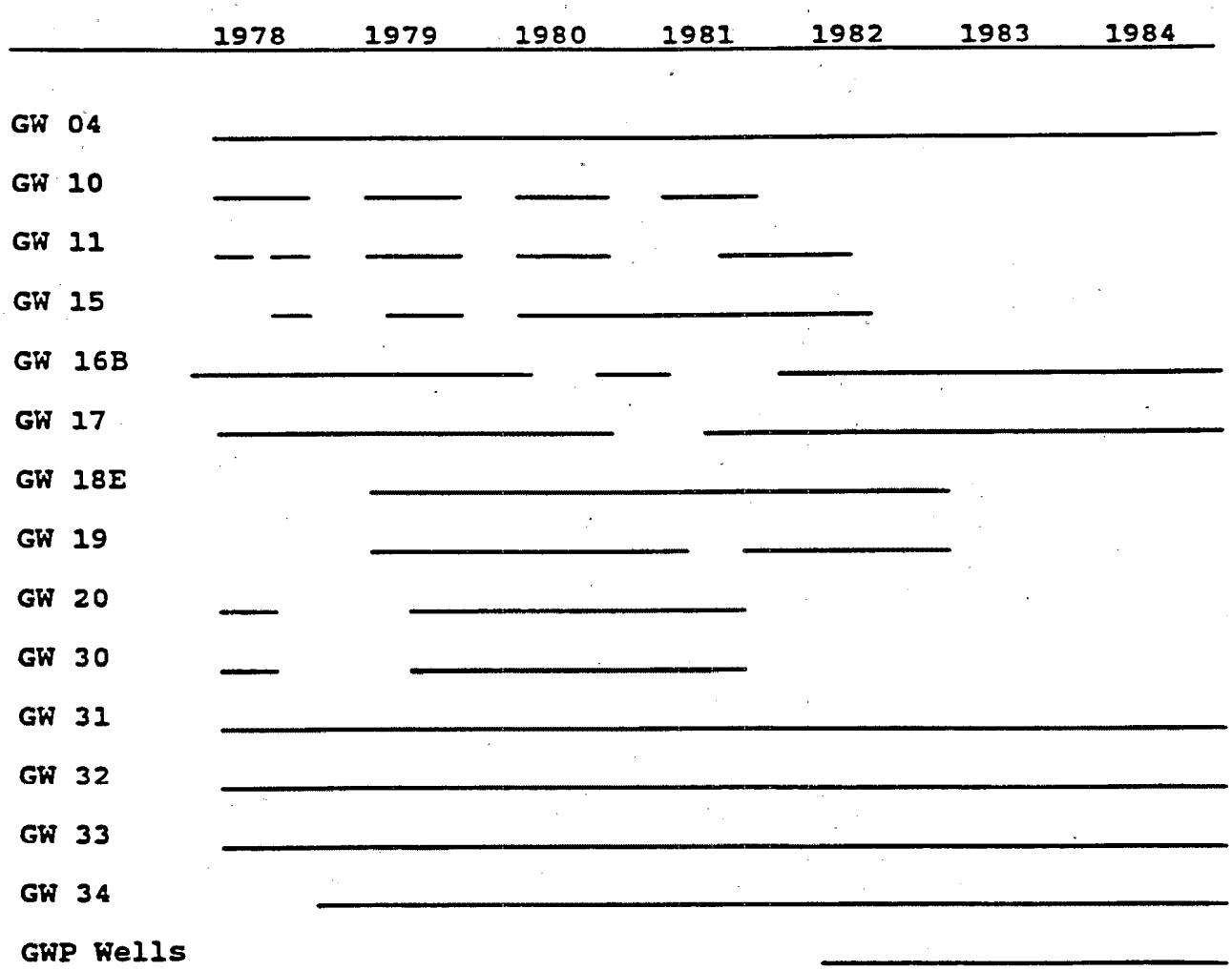
⊙ --- AACO SHALLOW MONITORING WELL

ND --- NOT DETECTED

NA --- NOT ANALYZED

Source: Groundwater Sciences Corp., et al., 1988

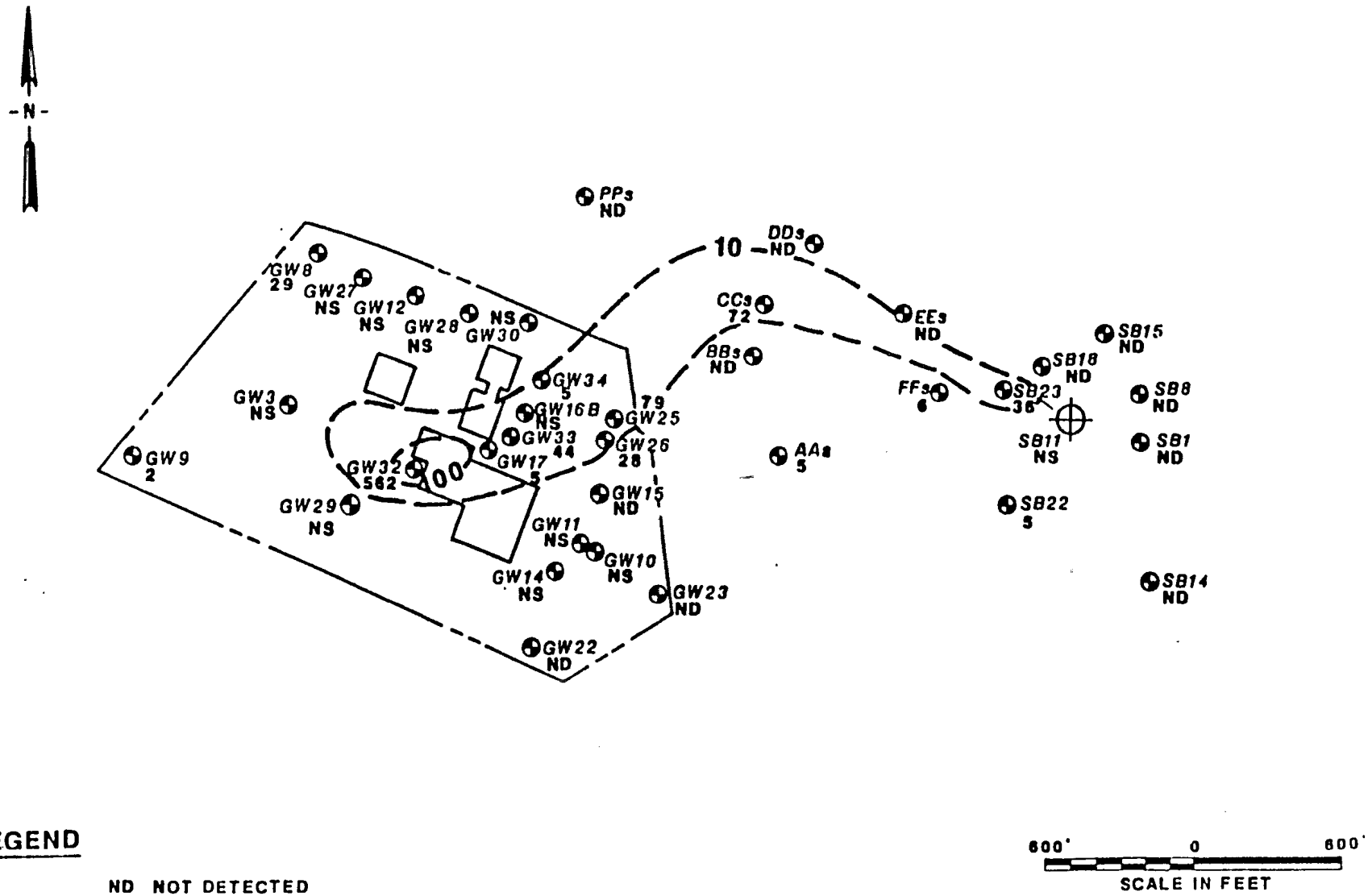
Figure 8
MEAN CONCENTRATIONS OF TCA IN THE DEEP AQUIFER, JANUARY-JUNE, 1980
IBM-DAYTON SITE



Note: GWP wells are off-site groundwater production wells.

Source: REWAI, 1987.

Figure 9
PUMPING HISTORY OF THE ONSITE EXTRACTION WELLS
IBM-DAYTON SITE



LEGEND

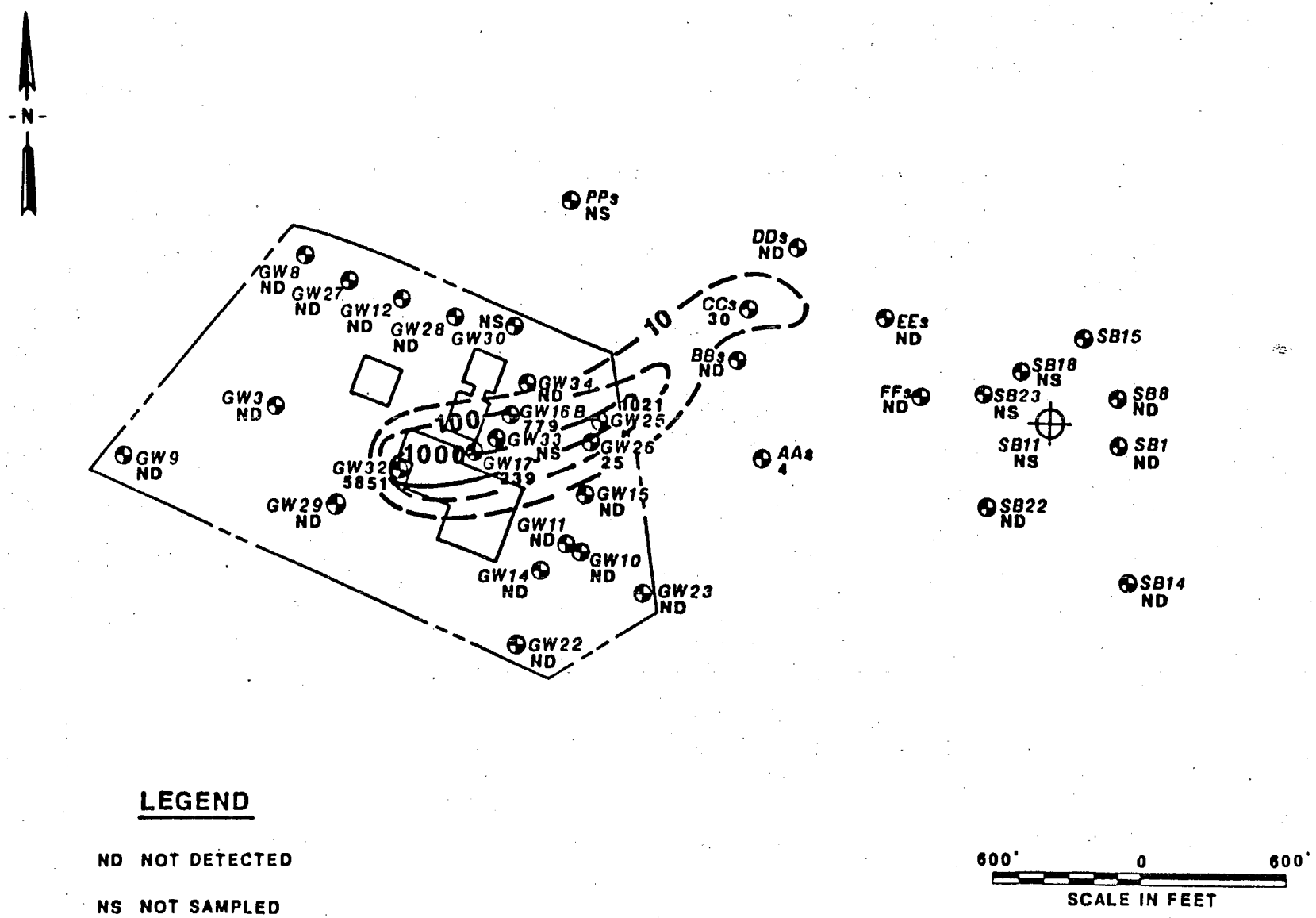
ND NOT DETECTED

NS NOT SAMPLED

—100— TOTAL VOC ISOCON IN (ppb)

Source: REWAI, 1987.

Figure 10
TOTAL VOLATILE ORGANIC CONCENTRATIONS IN THE SHALLOW AQUIFER, AUGUST 1984
IBM-DAYTON SITE



LEGEND

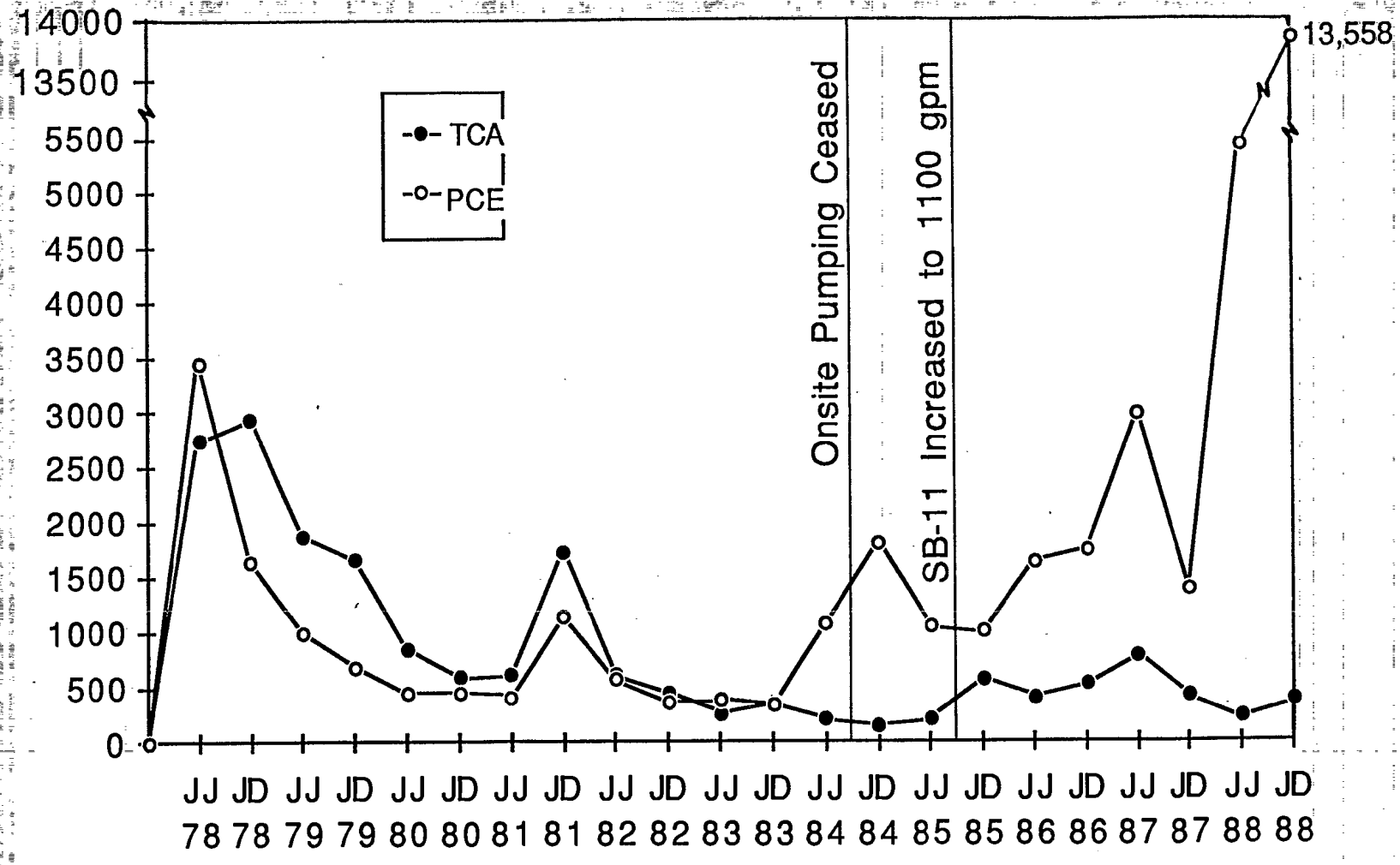
ND NOT DETECTED

NS NOT SAMPLED

—100— TOTAL VOC ISOCON IN (ppb)

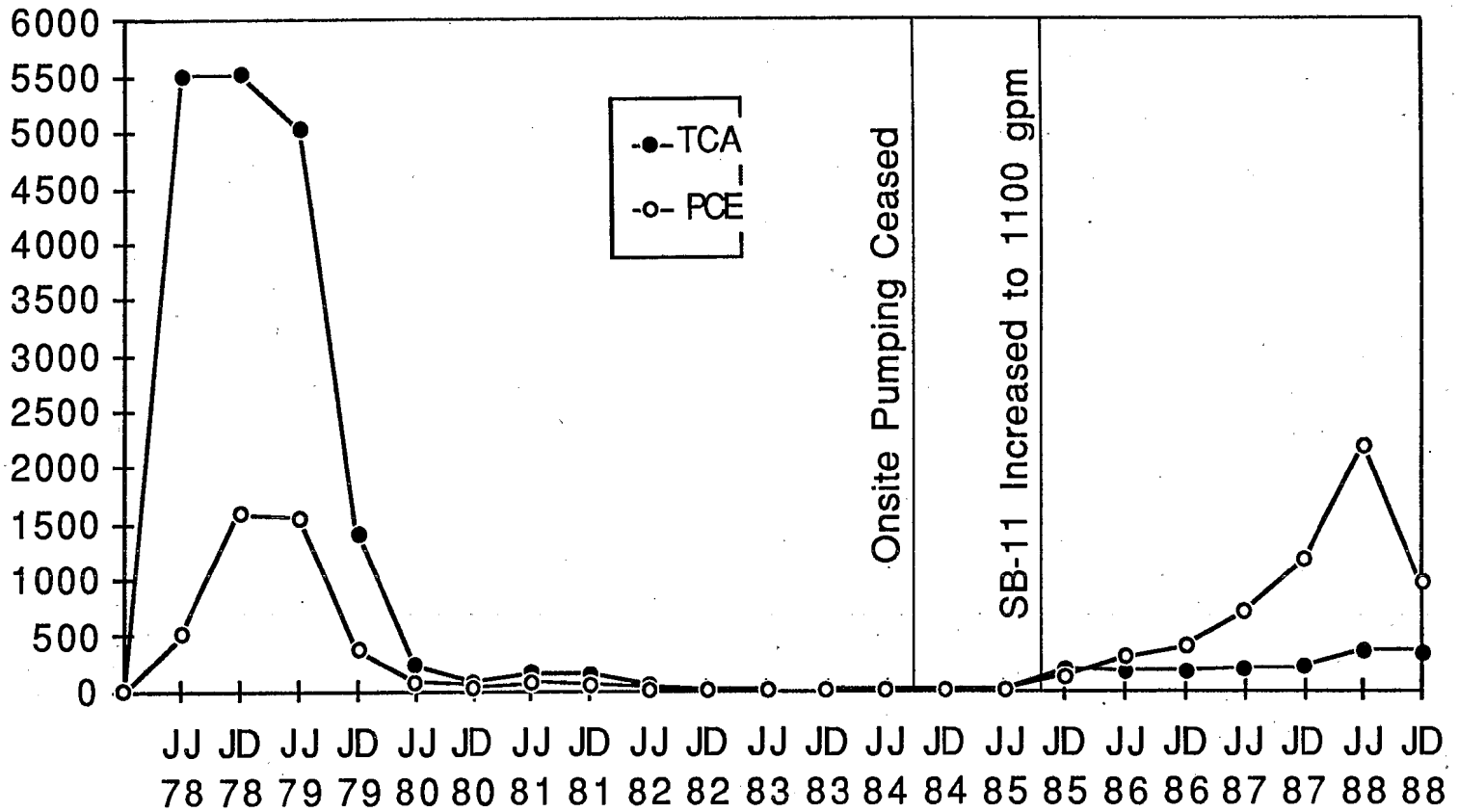
Source: REWAI, 1987.

Figure 11
TOTAL VOLATILE ORGANIC CONCENTRATIONS IN THE SHALLOW AQUIFER, APRIL 1987
IBM-DAYTON SITE



Compiled from various sources.

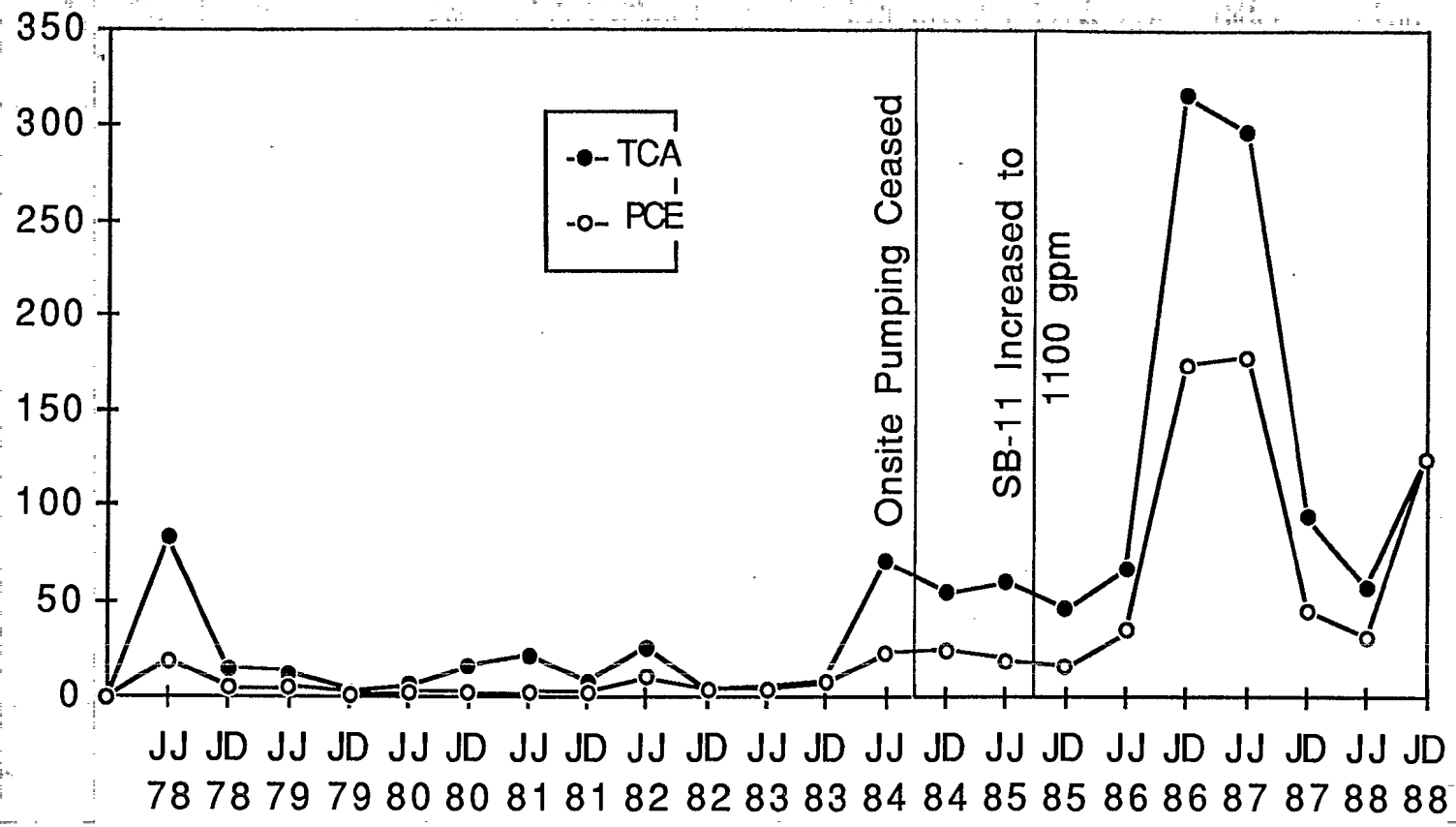
Figure 12
HISTORY OF TCA AND PCE VARIATIONS IN EXTRACTION WELL GW32
6-MONTH AVERAGE CONCENTRATIONS IN PPB
IBM-DAYTON SITE



Compiled from various sources.

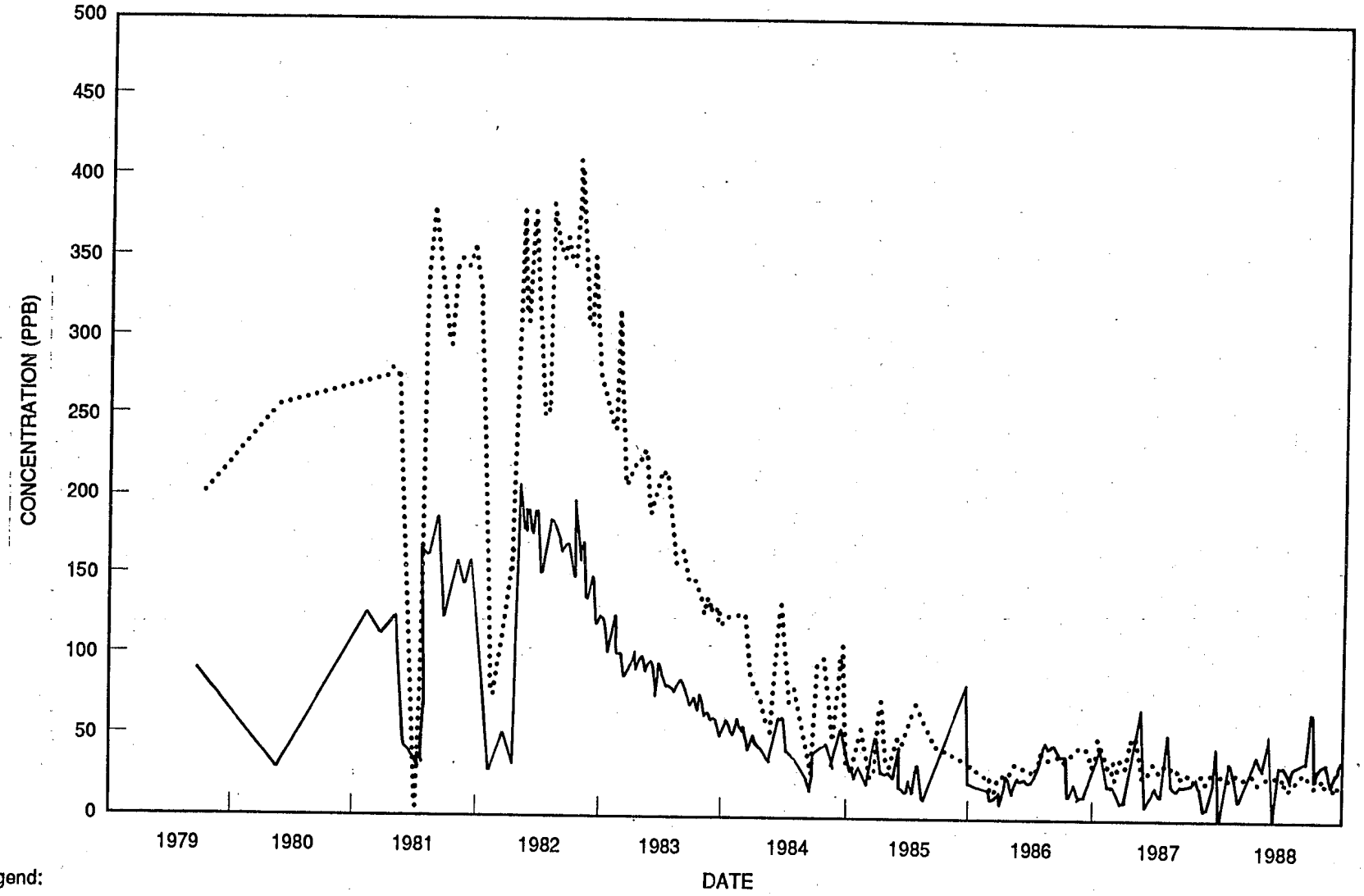
Figure 13
HISTORY OF TCA AND PCE VARIATIONS IN EXTRACTION WELL GW-16B
6-MONTH AVERAGE CONCENTRATIONS IN PPB
IBM-DAYTON SITE

WDC 61621.AO.02



Compiled from various sources.

Figure 14
HISTORY OF TCA AND PCE VARIATIONS IN EXTRACTION WELL GW-25
6-MONTH AVERAGE CONCENTRATIONS IN PPB
IBM-DAYTON SITE



Legend:

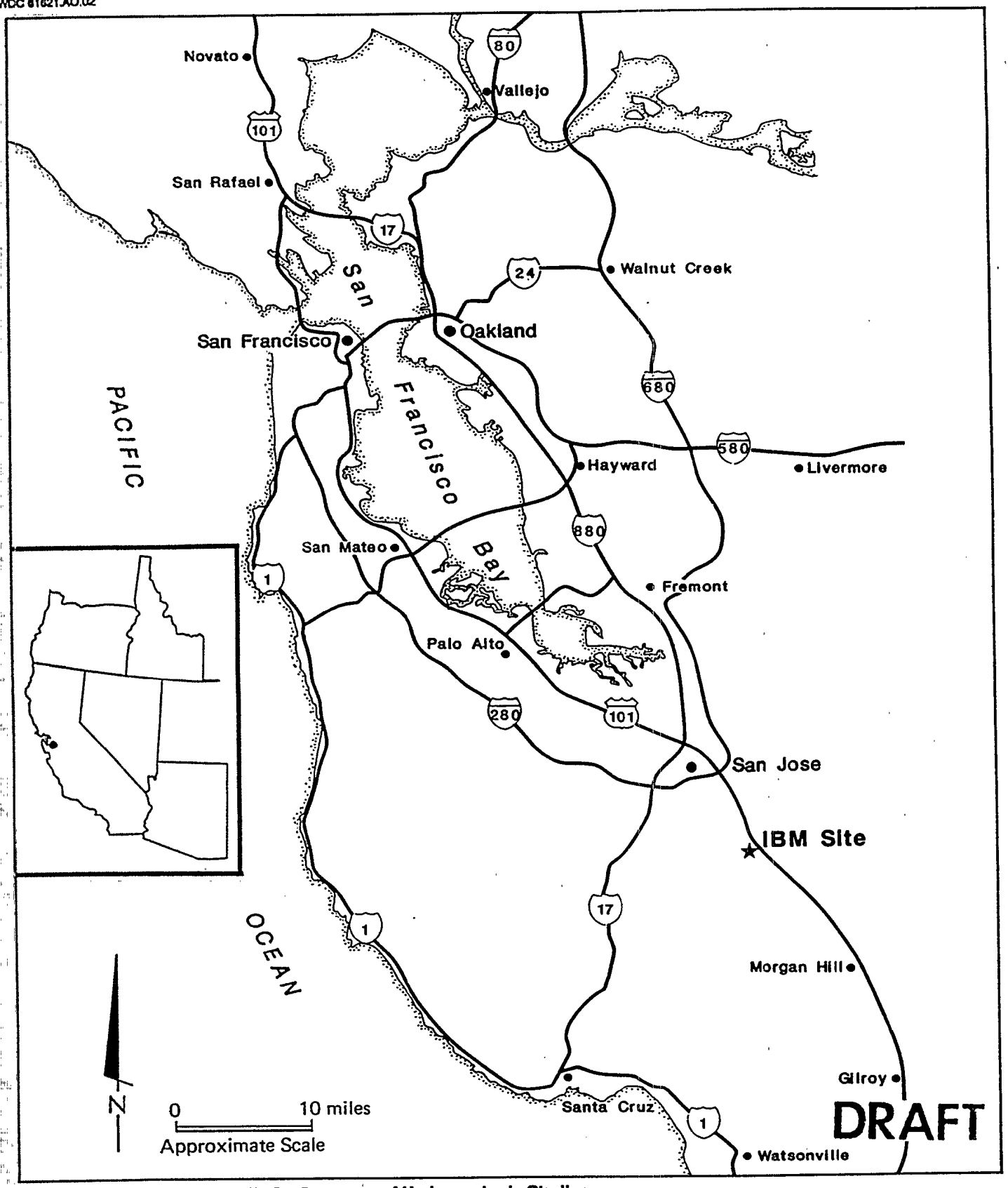
TCA ·····

PCE ———

Compiled from various sources.

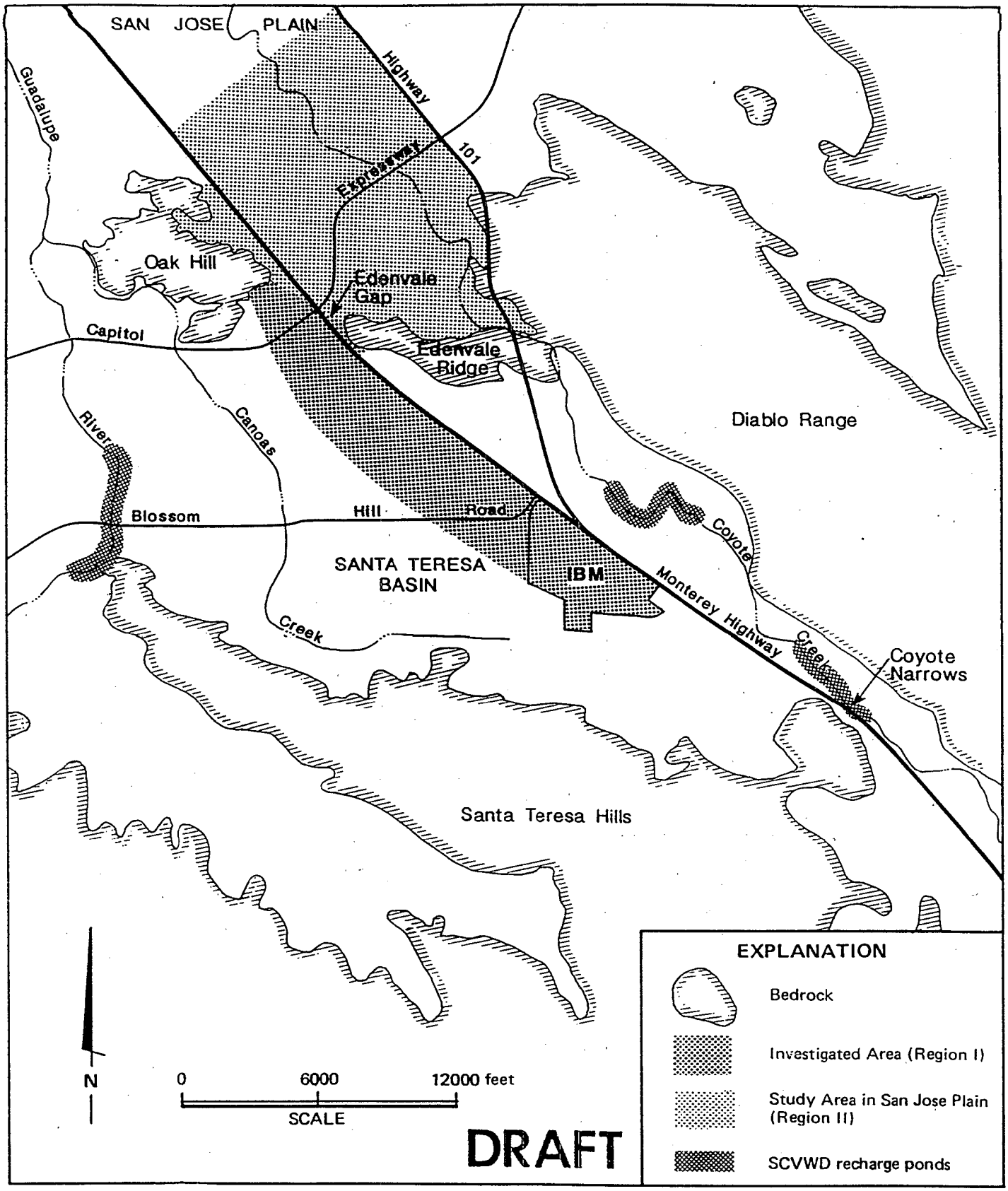
Figure 15
HISTORY OF TCA AND PCE VARIATIONS AT PRODUCTION WELL SB-11
IBM-DAYTON SITE

WDC 61621.AO.02



Source: June, 1987. Appendix B: Summary of Hydrogeologic Studies, Draft Comprehensive Plan, IBM Groundwater Restoration Program.

Figure 1
REGIONAL MAP
IBM-SAN JOSE SITE
SAN JOSE, CALIFORNIA



Source: HLA. June, 1987. Appendix B: Summary of Hydrogeologic Studies, Draft Comprehensive Plan, IBM Groundwater Restoration Program.

Figure 2
SITE LOCATION MAP
IBM-SAN JOSE SITE

Table 2

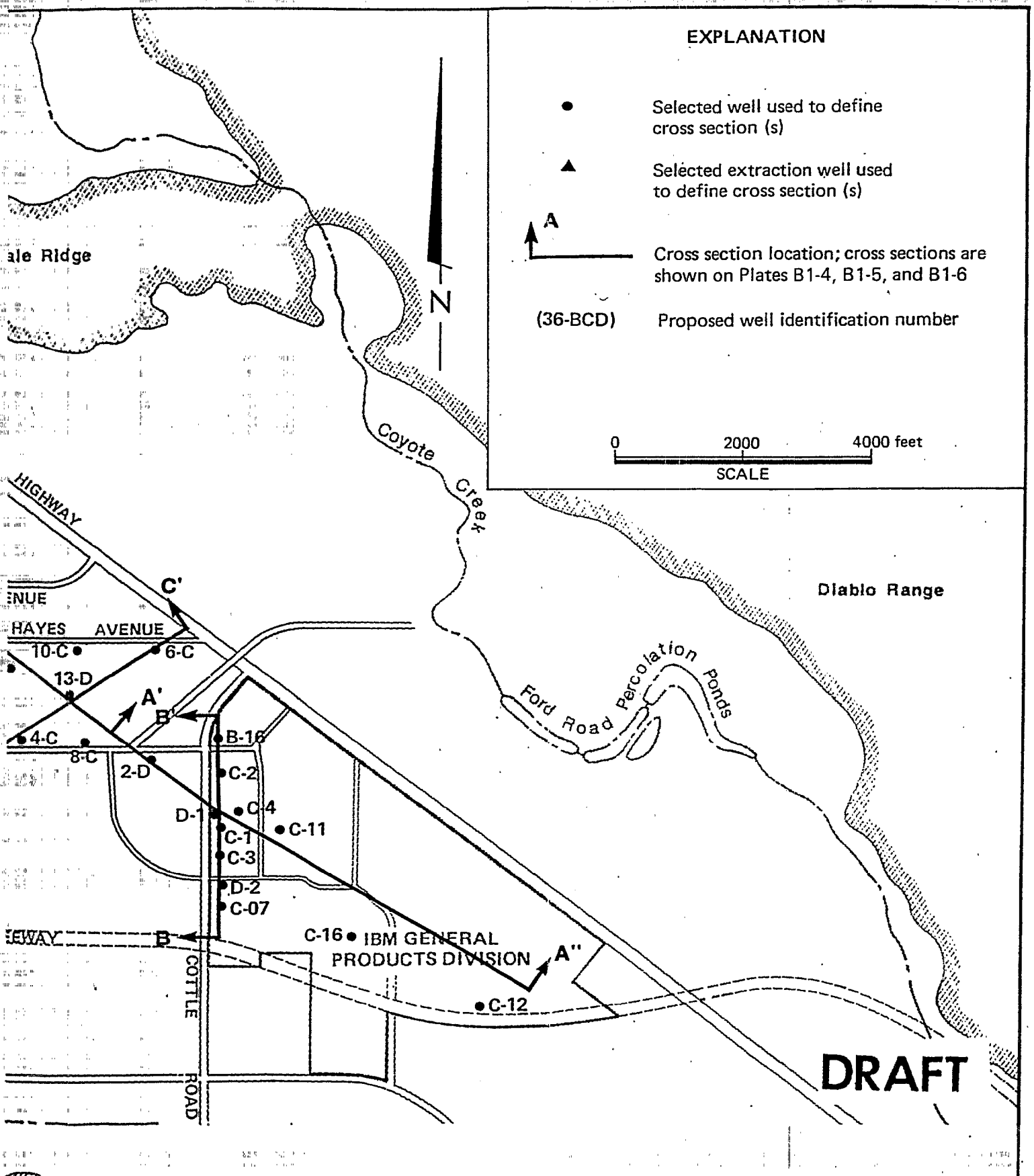
SANTA TERESA BASIN GROUND-WATER BALANCE (1985)

	Average Annual Amount*	
	Acre-feet	mgd**
INFLOWS (RECHARGE)		
Ground-Water Underflow, Coyote Narrows	7,900	7.1
Surface-Water Recharge		
Gaged recharge from Coyote Creek and ponds	16,000-20,000	14.3-17.9
Ungaged (estimated) Coyote Creek recharge	3,700	3.3
Guadalupe Creek and ponds	9,100	8.1
Mountain runoff	1,000	0.9
Precipitation and applied water	6,000	5.4
OUTFLOWS (DISCHARGE)		
Ground-Water Pumpage		
IBM	10,400	9.3
Fairchild	6,600	5.9
Great Oaks Water Company	11,800	10.5
San Jose Water Company	3,100	2.8
Others	1,700	1.5
Ground-Water Underflow, Edenvale Gap	21,000-40,000	18.7-35.7
TOTAL INFLOWS (RECHARGE)	43,700-47,000	39.0-42.6
TOTAL OUTFLOWS (DISCHARGE)	54,600-73,600	48.7-65.7
NET CHANGE IN STORAGE	(6,900)-(29,900)	(6.2)-(26.7)

*All values except surface-water inflows based on 1985 data. Surface-water inflows based on historical data. Amounts estimated using methods described in HLA Reference 1.

**mgd=Million gallons per day.

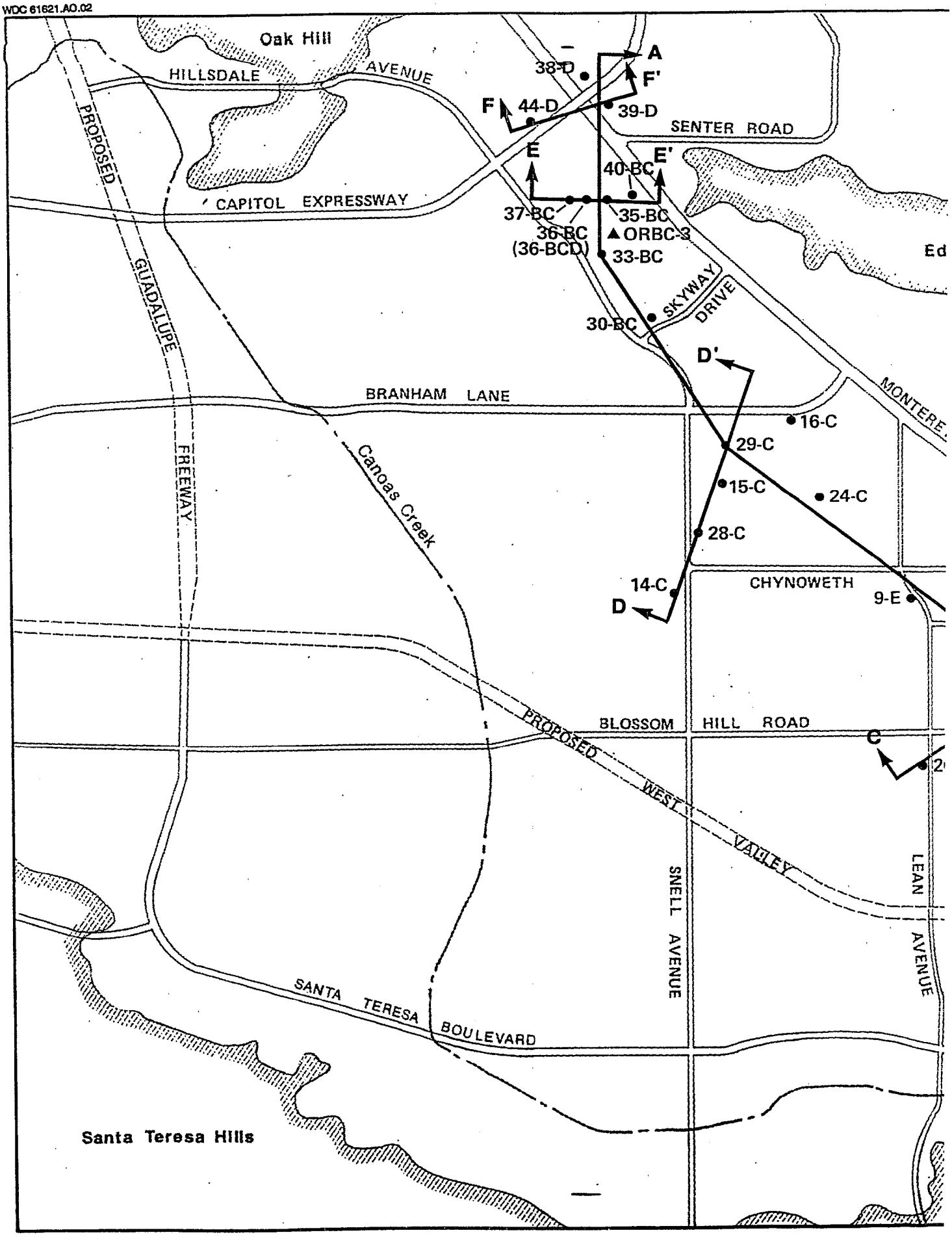
WDCR428/064.50

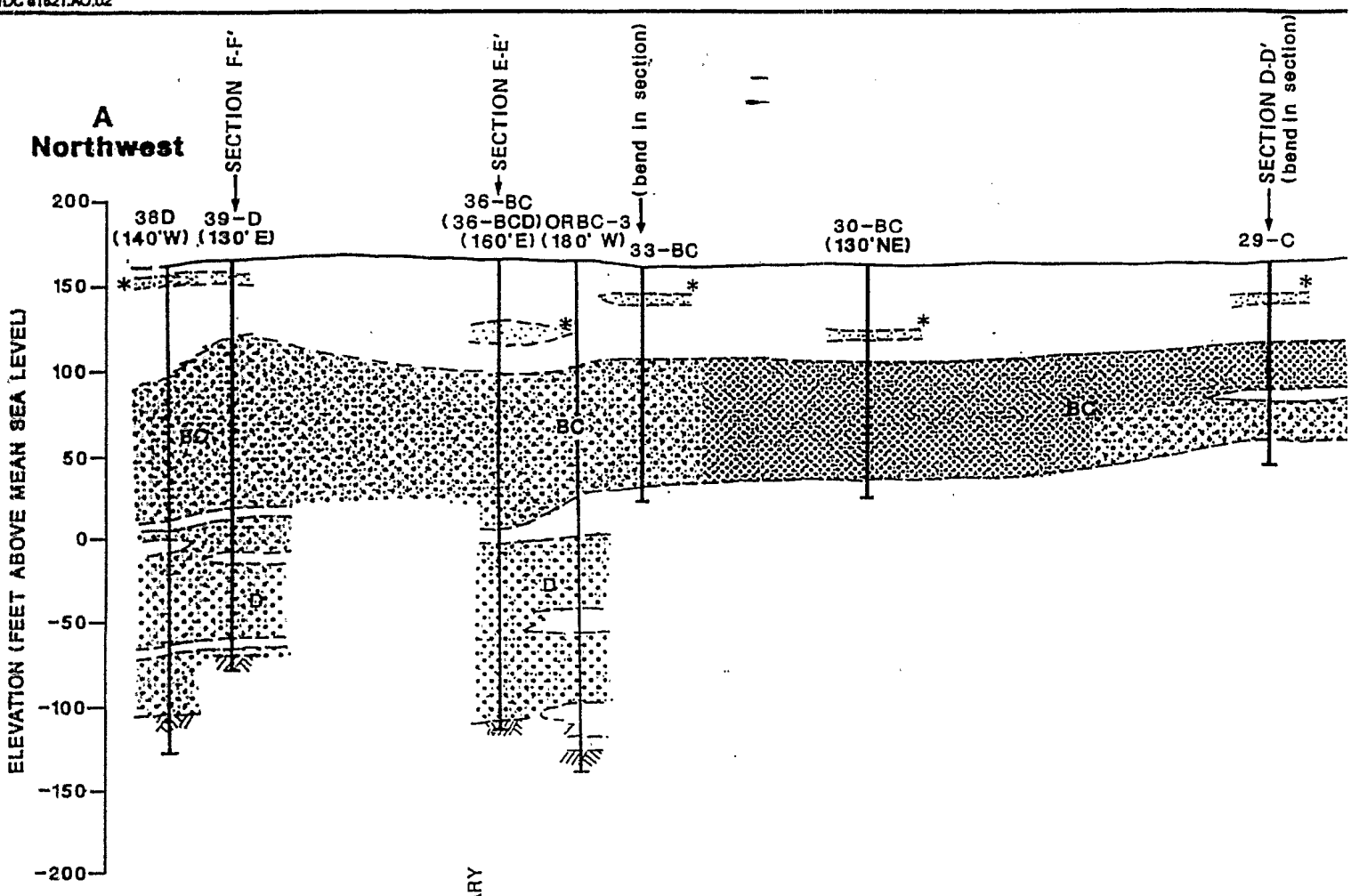


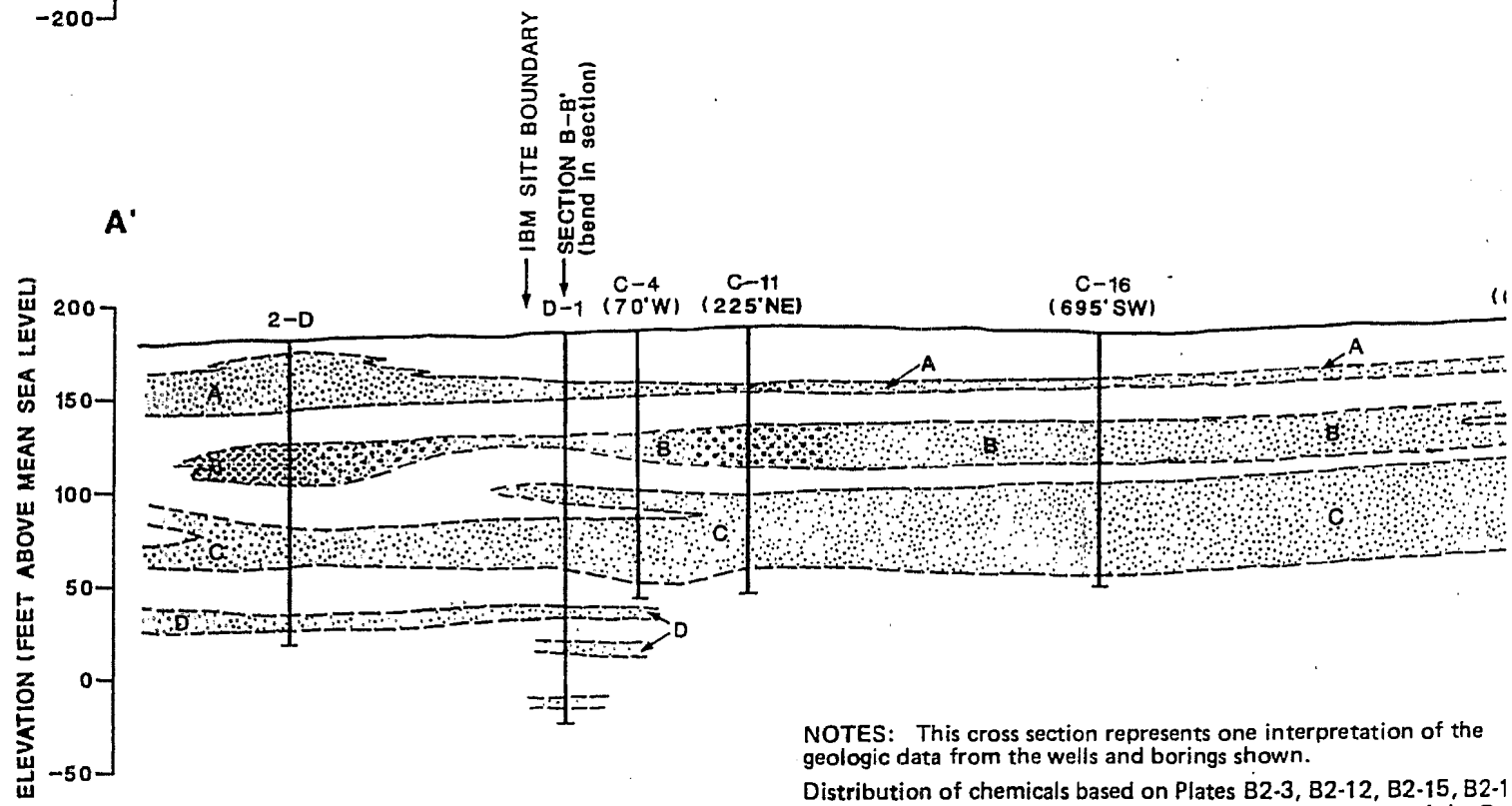
Source: HLA. June, 1987. Appendix B: Summary of Hydrogeologic Studies, Draft Comprehensive Plan, IBM Groundwater Restoration Program.

Figure 3
CROSS SECTION LOCATION MAP
IBM-SAN JOSE SITE

WDC 61621.A0.02





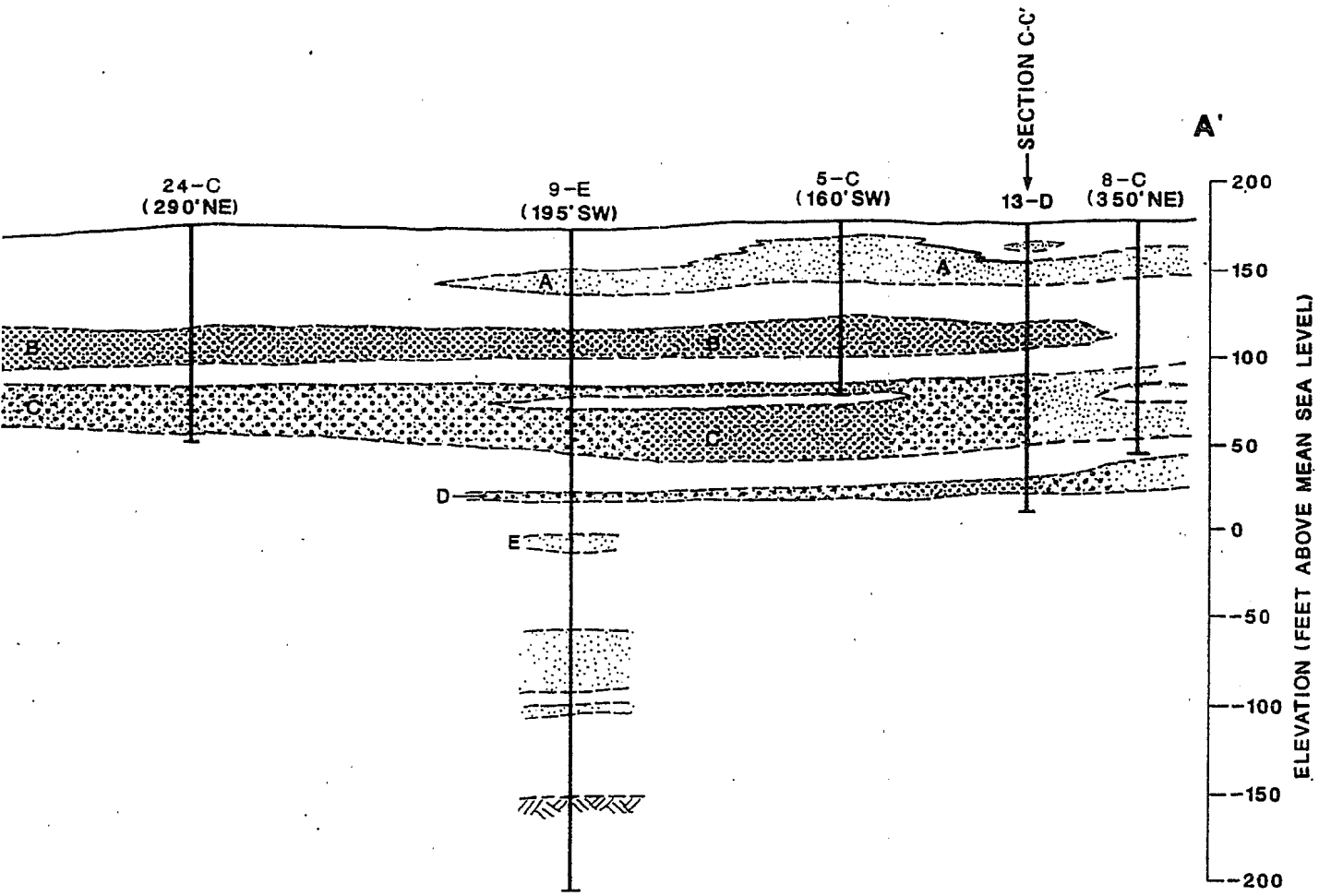


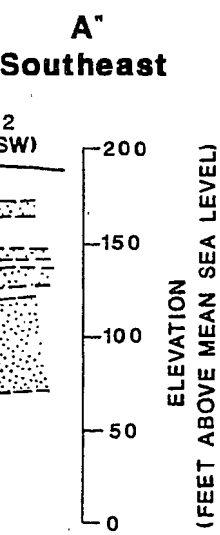
NOTES: This cross section represents one interpretation of the geologic data from the wells and borings shown.

Distribution of chemicals based on Plates B2-3, B2-12, B2-15, B2-1 and B2-20 and more recent chemical data for some areas of the D- and E-aquifer zones.

Cross-section location shown on Plate B1-3.

Source: HLA. June, 1987. Appendix B: Summary of Hydrogeologic Studies, Draft Comprehensive Plan, IBM Groundwater Restoration Program.





EXPLANATION

36-BC ← Well number
(36-BCD) ← Proposed well number
(120'NE) ← Distance and direction from section line to well

← Predominantly silts and clays

B ← Predominantly sands and gravels; letter indicates aquifer zone

← Bedrock (see HLA Ref. 8 for Edenvale Gap details)

← Bottom of boring

MEAN 1985 1,1,1-TRICHLOROETHANE CONCENTRATIONS IN AQUIFER ZONES:

* No chemical data for this zone

1985 chemical data not available for zones below the D-aquifer zone

<1.0 ppb

1.0-10 ppb

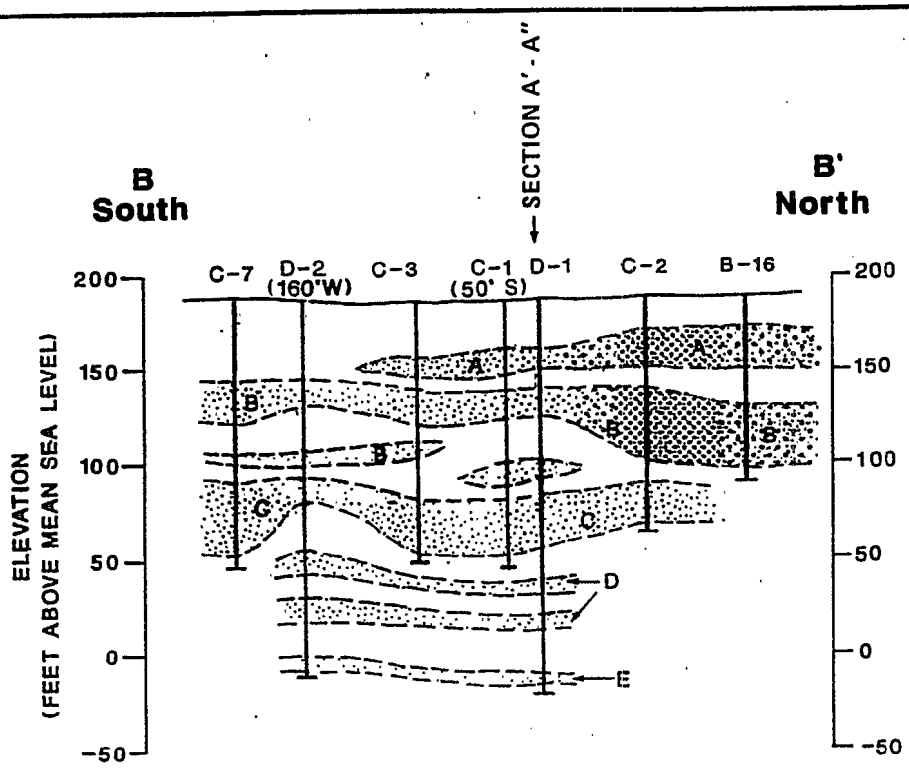
10-100 ppb

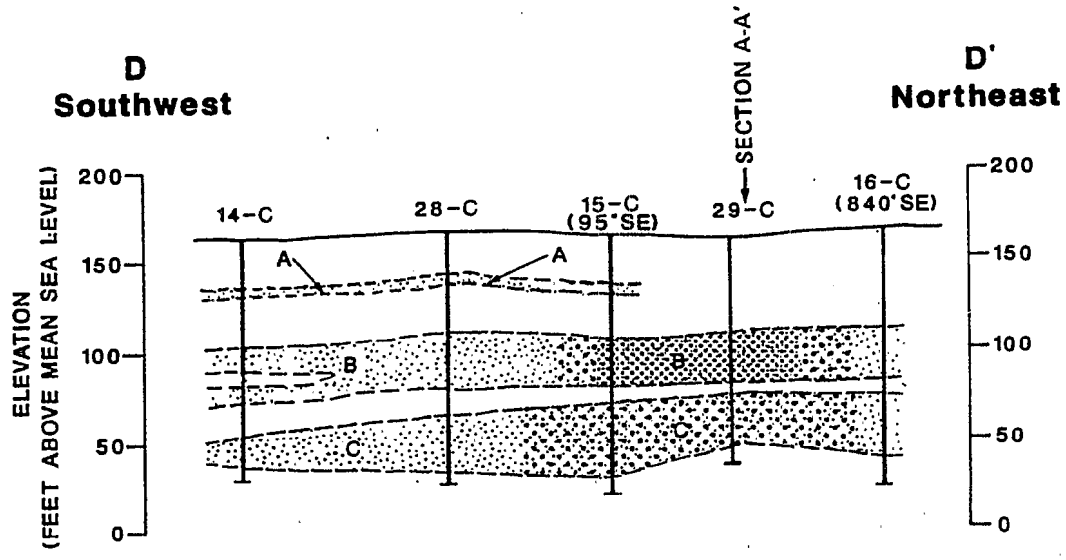
0 1000 2000 feet

SCALE

Vertical exaggeration = 10x

Figure 4
GENERALIZED DISTRIBUTION OF MEAN 1985 TCA CONCENTRATIONS IN CROSS SECTION A-A"
IBM-SAN JOSE SITE





EXPLANATION

(36-BC) ← Well number
(36-BCD) ← Proposed well number
(120'NE) ← Distance and direction from section line to well

← Predominantly silts and clays

← Predominantly sands and gravels; letter indicates aquifer zone

← Bedrock (see HLA Ref. 8 for Edenvale Gap details)
← Bottom of boring

MEAN 1985 1,1,1-TRICHLOROETHANE CONCENTRATIONS IN AQUIFER ZONES:

* No chemical data for this zone

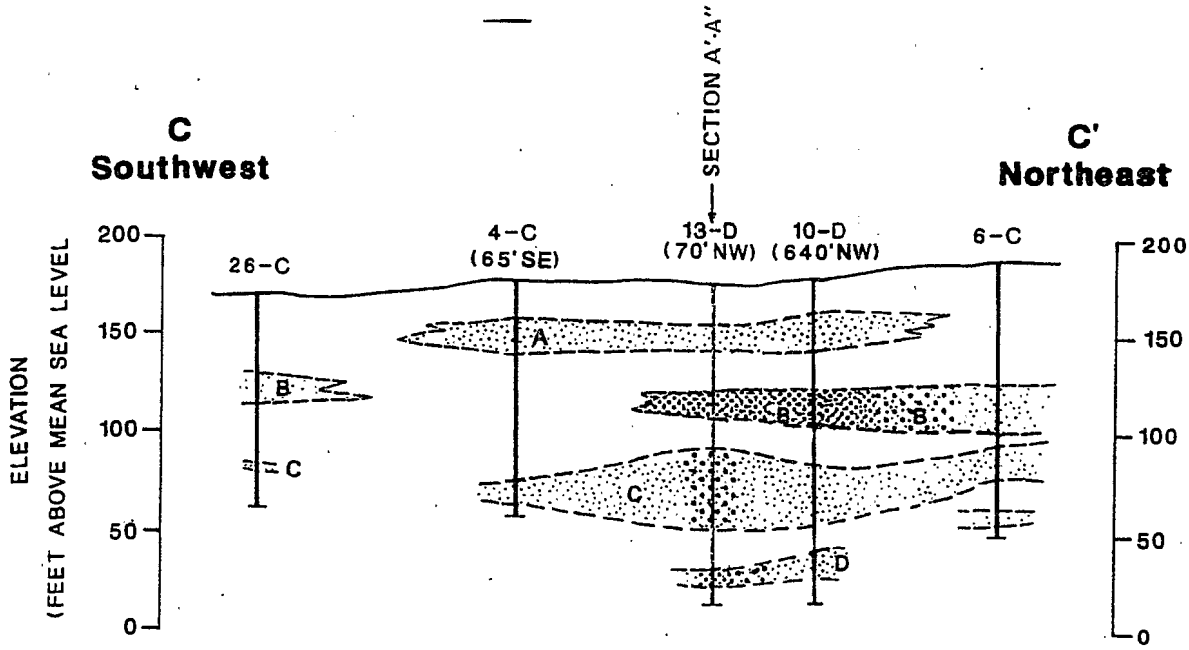
1985 chemical data not available for zones below the D-aquifer zone

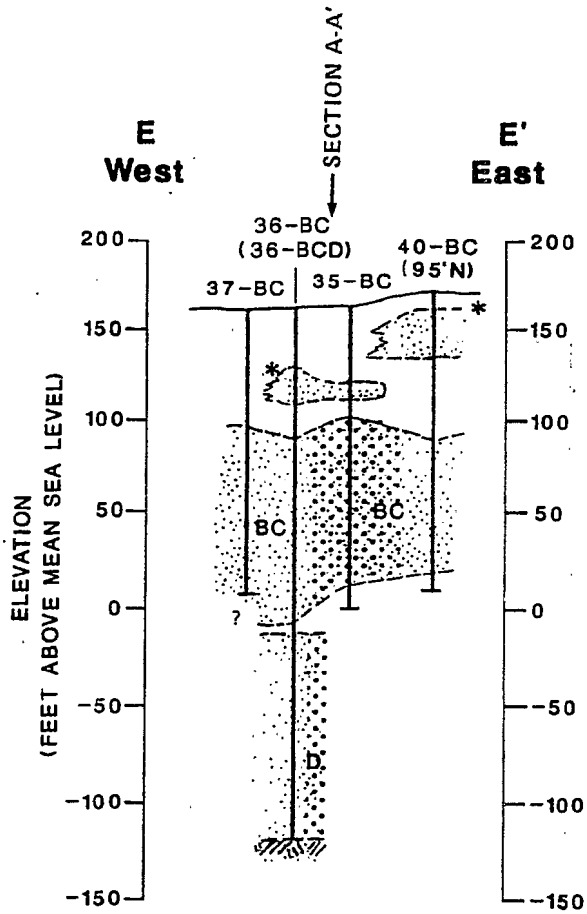
<1.0 ppb

1.0-10 ppb

10-100 ppb

Sc
Dr





NOTES: This cross section represents one interpretation of the geologic data from the wells and borings shown.

Distribution of chemicals based on Plates B2-3, B2-12, B2-15, and B2-18 and more recent chemical data for some areas of the D-aquifer zone.

Cross-section location shown on Plate B1-3.

0 1000 2000 feet

SCALE

Vertical exaggeration = 10x

DRAFT

Figure 5
GENERALIZED DISTRIBUTION OF MEAN TCA CONCENTRATIONS IN CROSS SECTIONS B-B', C-C', D-D', AND E-E'
IBM-SAN JOSE SITE

HLA. June, 1987. Appendix B: Summary of Hydrogeologic Studies, mprehensive Plan, IBM Groundwater Restoration Program.

Table 3
TARGET REMEDIATION GOALS FOR THE A-AQUIFER ZONE

Chemical	Concentration (ppb)	Source of Goal
Methylene Chloride	40	DHS Action Level[1]
Chloroform	6.0	
1,1-Dichloroethane	20	DHS Action Level
1,1,-Trichloroethane	200	DHS Action Level
1,1-Dichloroethylene	6	DHS Action Level
1,2-Dichloroethylene	16	DHS Action Level
Trichloroethylene	5	DHS Action Level
Perchloroethylene	4	DHS Action Level
Freon 11	3,400	DHS Action Level
Freon 12	750	20% of EPA RfD[3]
Freon 113	18,000	DHS Action Level
N-Methyl Pyrrolidone	700	DHS Site Criteria[4]
Isopropanol	450	DHS Site Criteria
Acetone	700	20% of EPA Rfd
Ethyl Amyl Ketone	123	DHS Site Criteria
Shell Sol 140	1,000	DHS Site Criteria
Xylene	440	EPA Lifetime Health Advisory[5]
Toluene	100	DHS Action Level
Benzene	0.07	DHS Action Level

[1]Department of Health Services 1987a.
[2]Department of Health Services 1986c.
[3]Environmental Protection Agency 1987. RfD denotes Reference Dose.
[4]Department of Health Services 1987b.
[5]Environmental Protection Agency 1985b.

Source: KJC, Comprehensive Plan, IBM Groundwater Restoration Program, June 1987.

WDCR428/058.50

Table 4
TARGET REMEDIATION GOALS FOR THE B-, C-, D-, AND E-AQUIFER ZONES

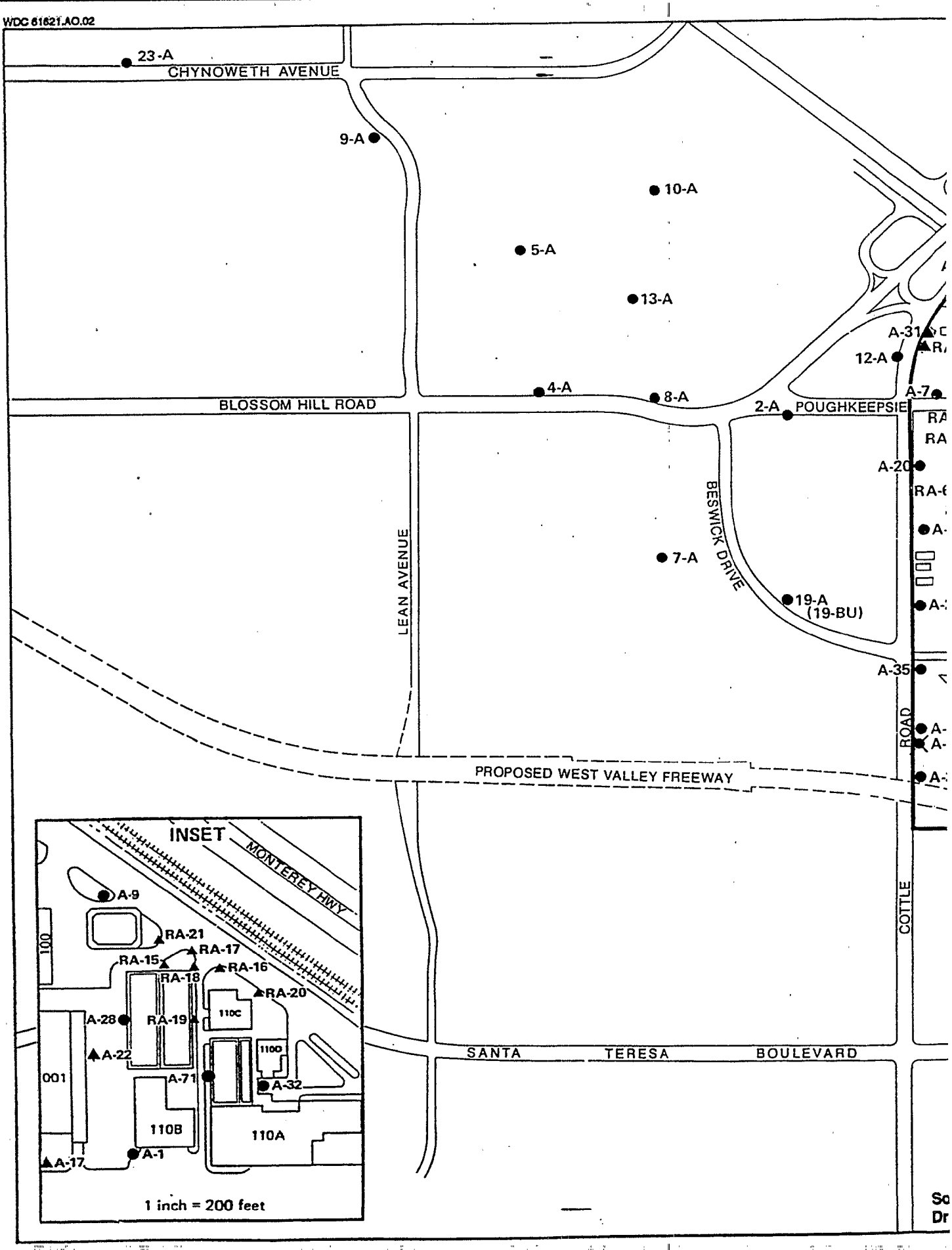
Chemical	Concentration (ppb)	Source
Freon 113	4500[3]	0.25 DHS Action Level[1]
1,1,1-Trichloroethane	50	0.25 DHS Action Level
1,1-Dichloroethylene	1.5	0.25 DHS Action Level
1,1-Dichloroethane	5	0.25 DHS Action Level
Freon 11	850[3]	0.25 DHS Action Level
Trichloroethylene	3.1	10^{-6} Risk Level[2]
Chloroform	6.0	
Methylene Chlororide	4.8	10^{-6} Risk Level

[1]Department of Health Services 1987a.
[2]Environmental Protection Agency 1987.
[3]Current concentrations found in the B- and deeper-aquifer zones are substantially below the target goals shown here.

Source: KJC, Comprehensive Plan, IBM Groundwater Restoration Program, June 1987.

WDCR428/057.50

WDC 61621.AO.02



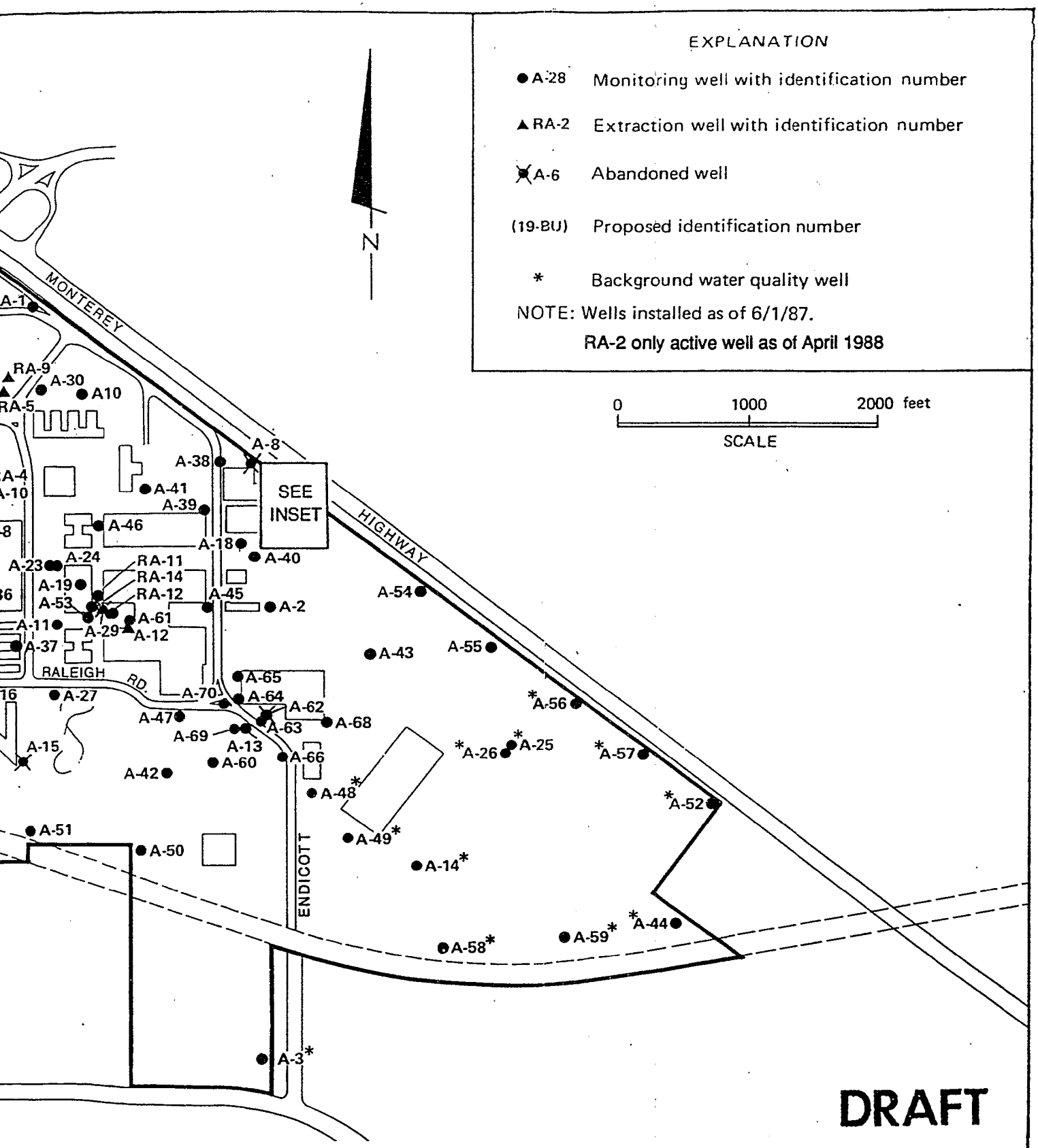
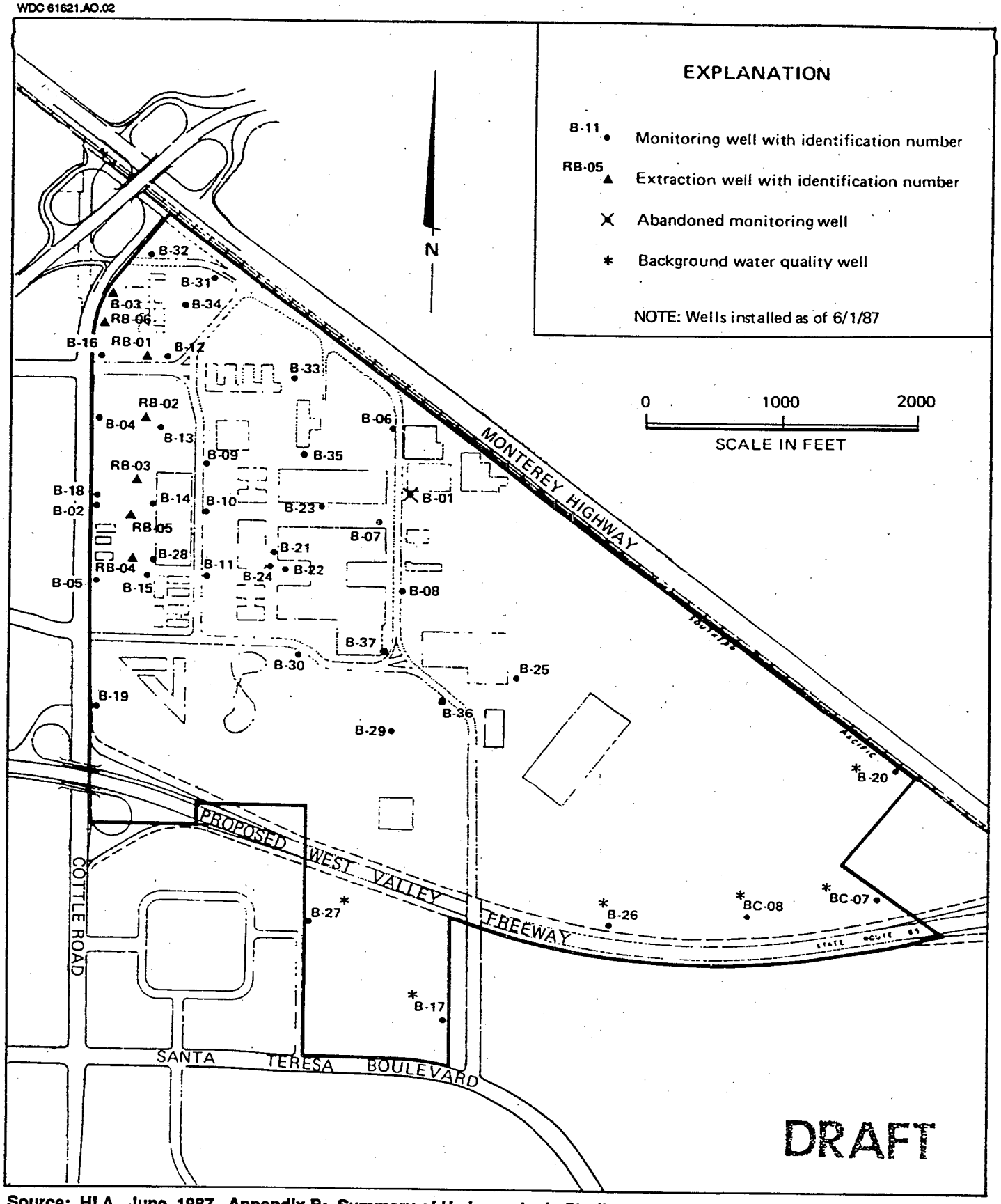


Figure 6
WELL LOCATION MAP
MONITORING AND EXTRACTION WELLS
IN THE A-AQUIFER ZONE.
IBM-SAN JOSE SITE

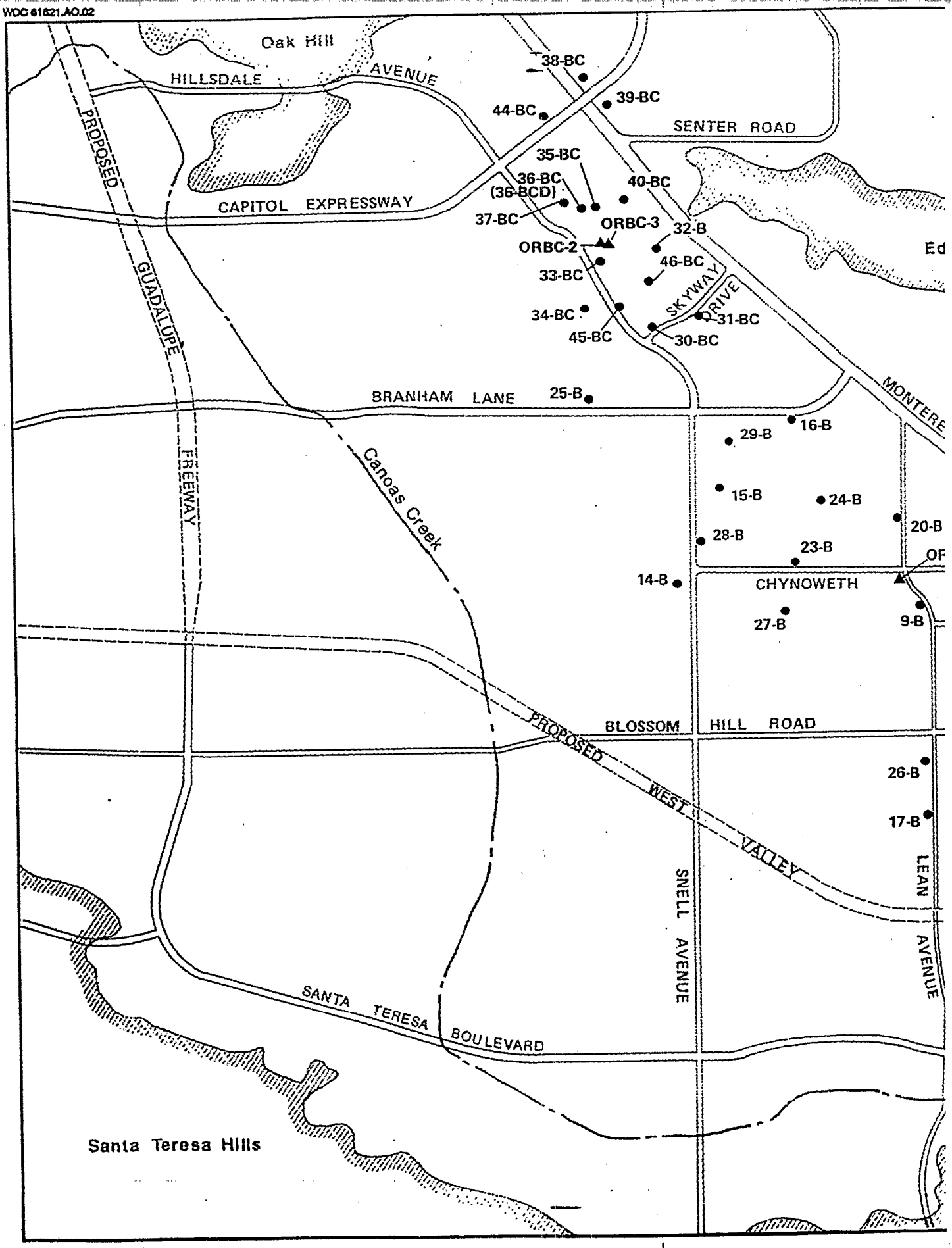
HLA. June, 1987. Appendix B: Summary of Hydrogeologic Studies, omprehensive Plan, IBM Groundwater Restoration Program.

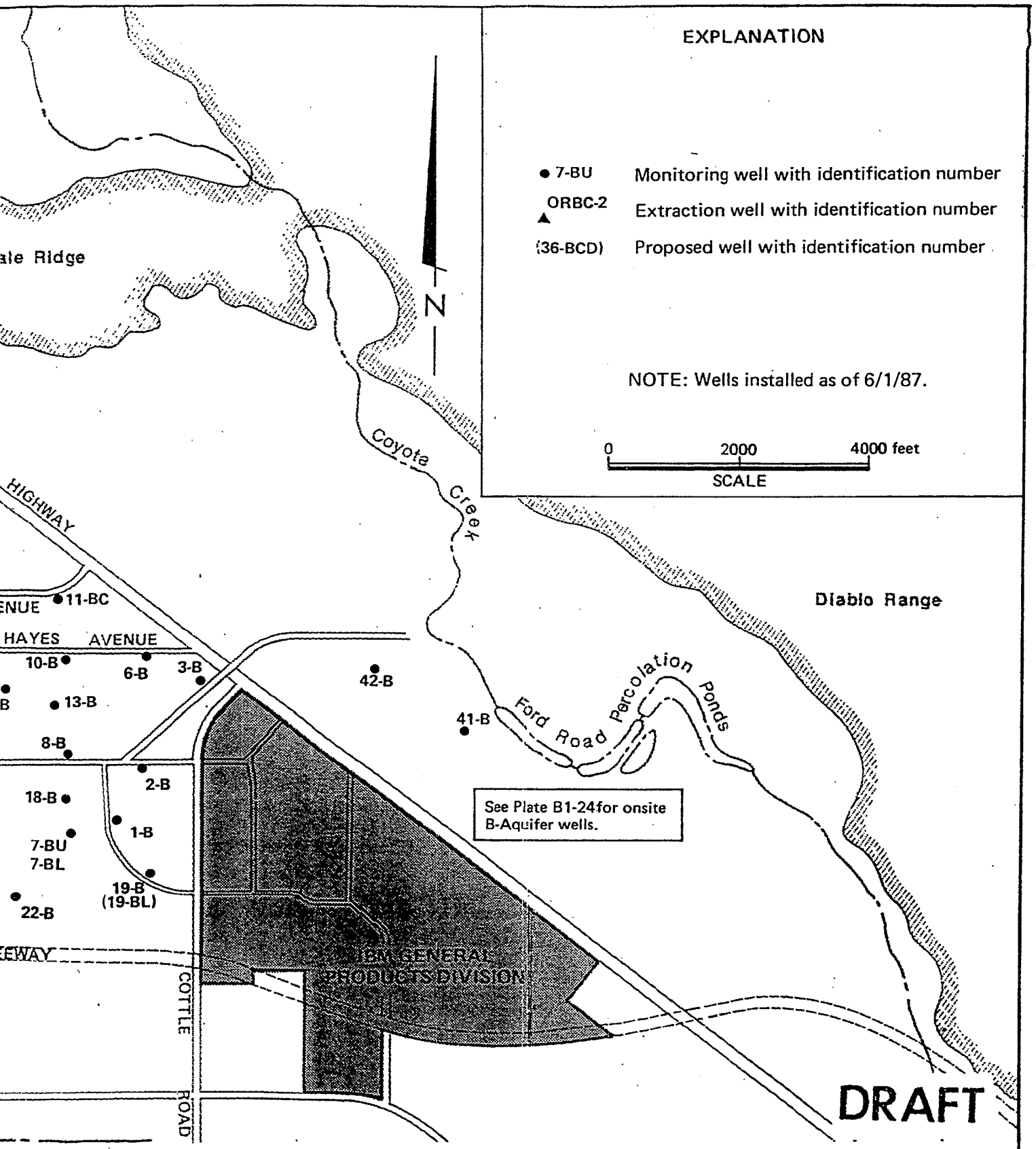


Source: HLA. June, 1987. Appendix B: Summary of Hydrogeologic Studies, Draft Comprehensive Plan, IBM Groundwater Restoration Program.

Figure 7
WELL LOCATION MAP
MONITORING AND EXTRACTION WELLS IN THE ON-SITE B-AQUIFER ZONE.
IBM-SAN JOSE SITE

WDC 61821.A0.02

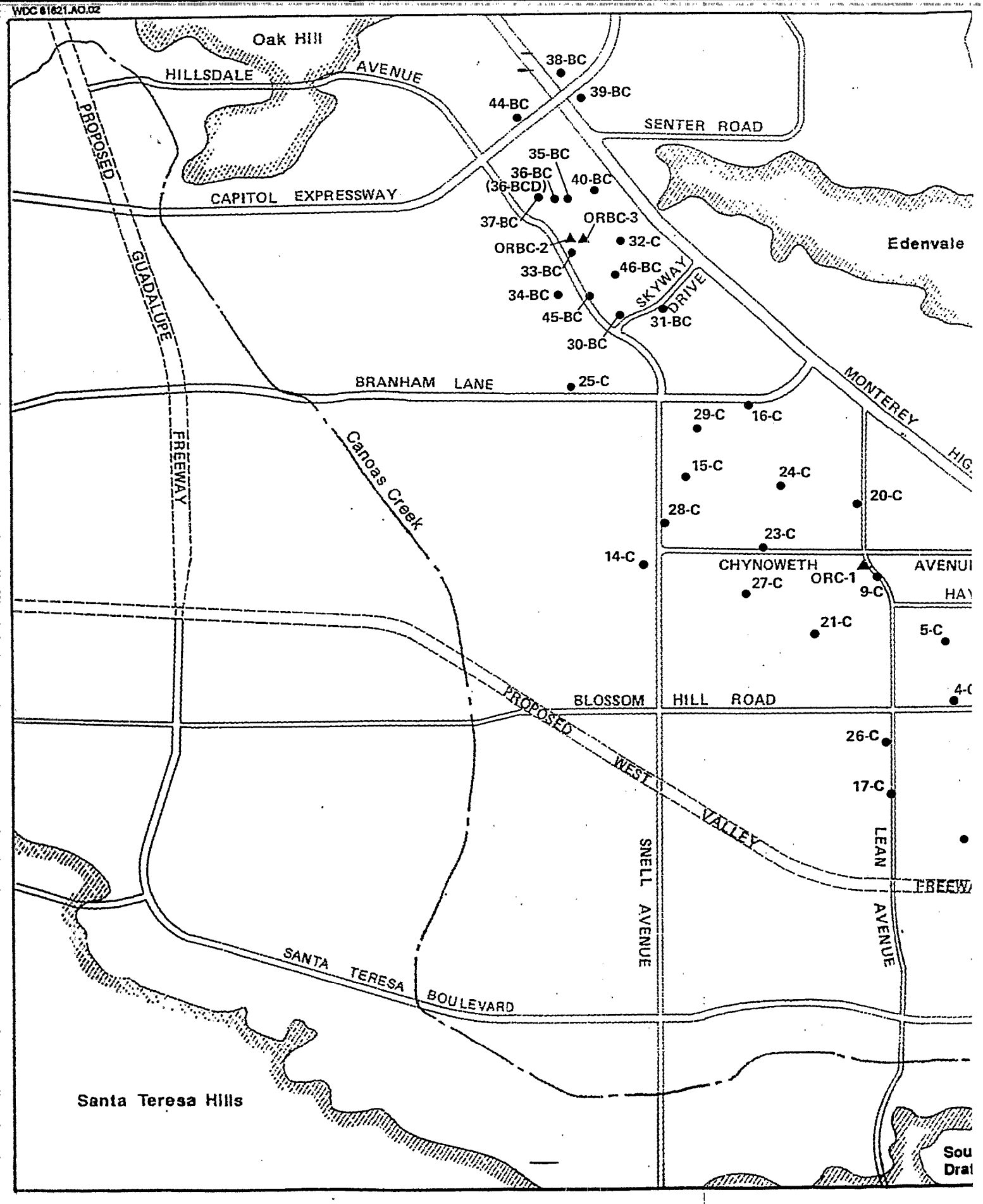


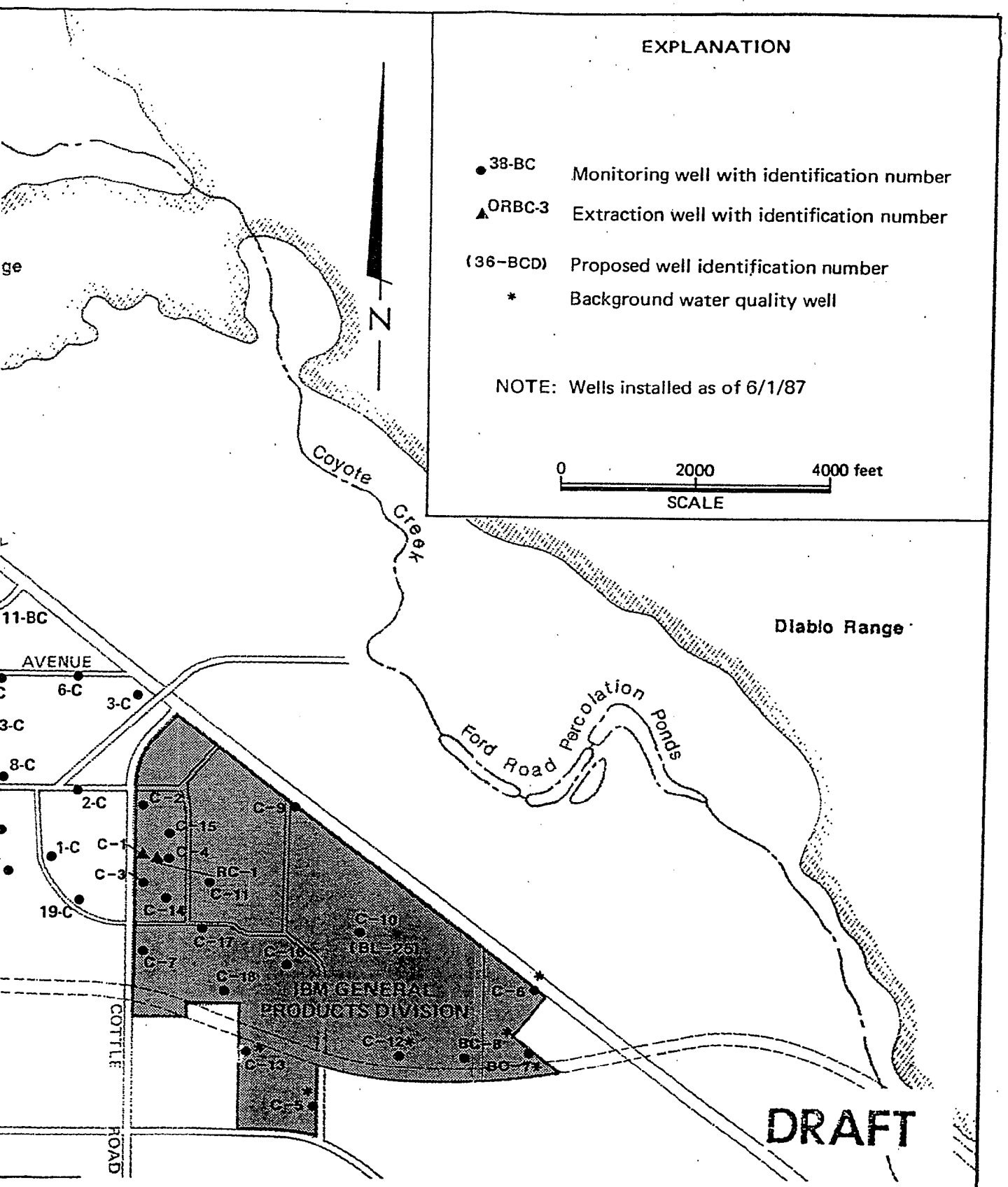


Source: HLA. June, 1987. Appendix B: Summary of Hydrogeologic Studies, Draft Comprehensive Plan, IBM Groundwater Restoration Program.

Figure 8
WELL LOCATION MAP
MONITORING AND EXTRACTION WELLS IN THE OFF-SITE B-AQUIFER ZONE
IBM-SAN JOSE SITE

WDC 61621.AO.02

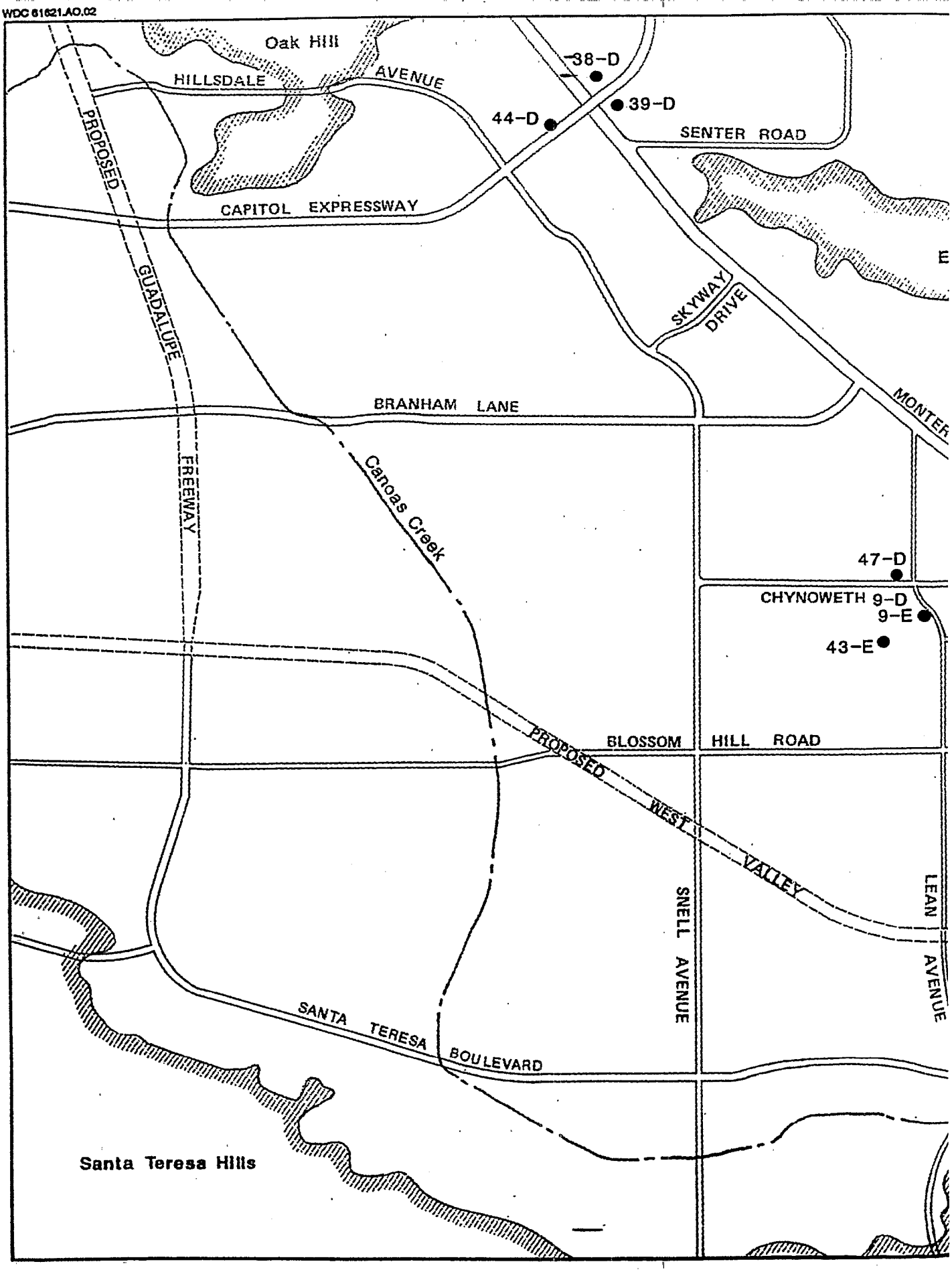


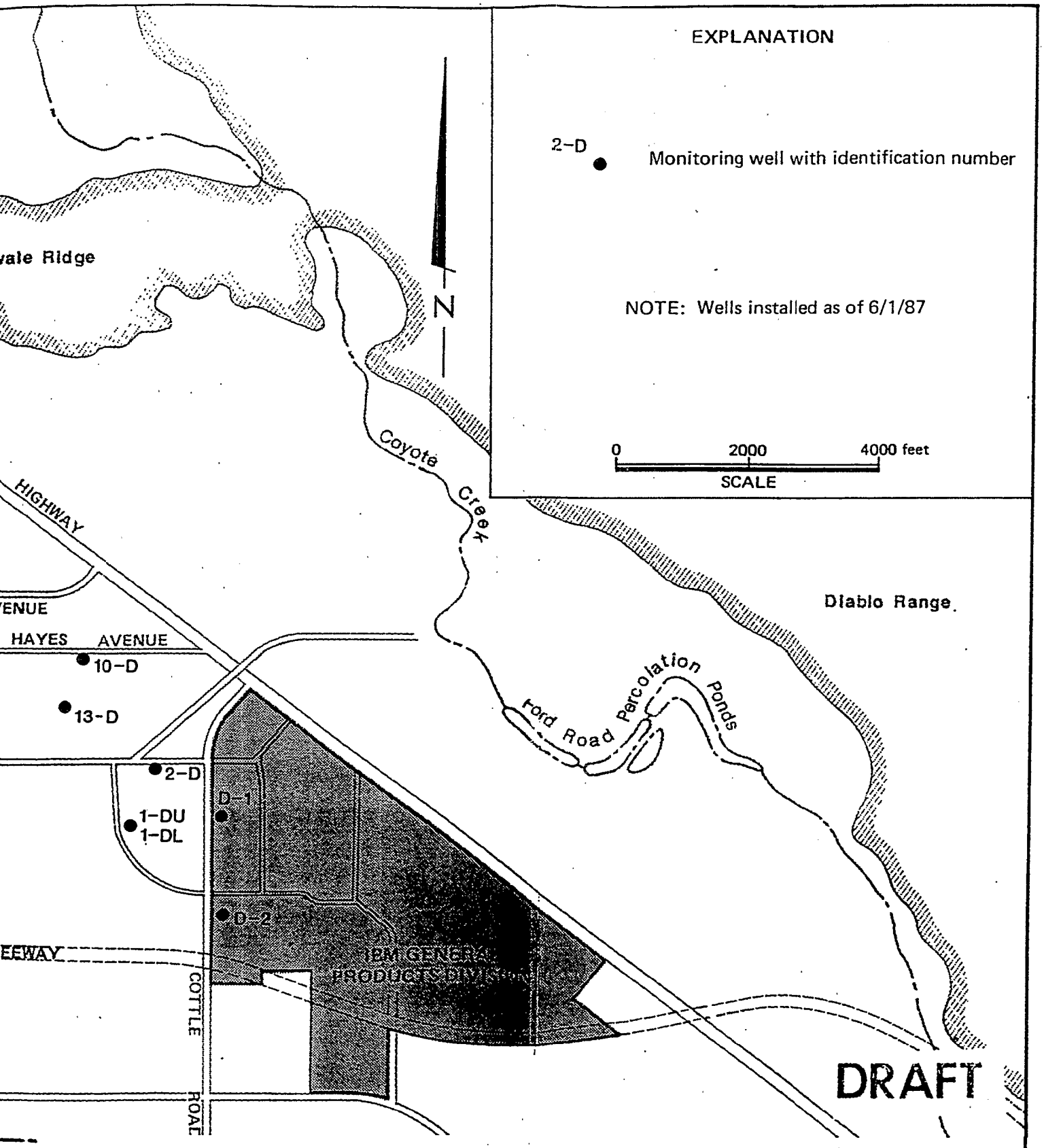


HLA. June, 1987. Appendix B: Summary of Hydrogeologic Studies, nprehensive Plan, IBM Groundwater Restoration Program.

Figure 9
WELL LOCATION MAP
MONITORING AND EXTRACTION WELLS IN THE C-AQUIFER ZONE.
IBM-SAN JOSE SITE

WDC 61621.AO.02

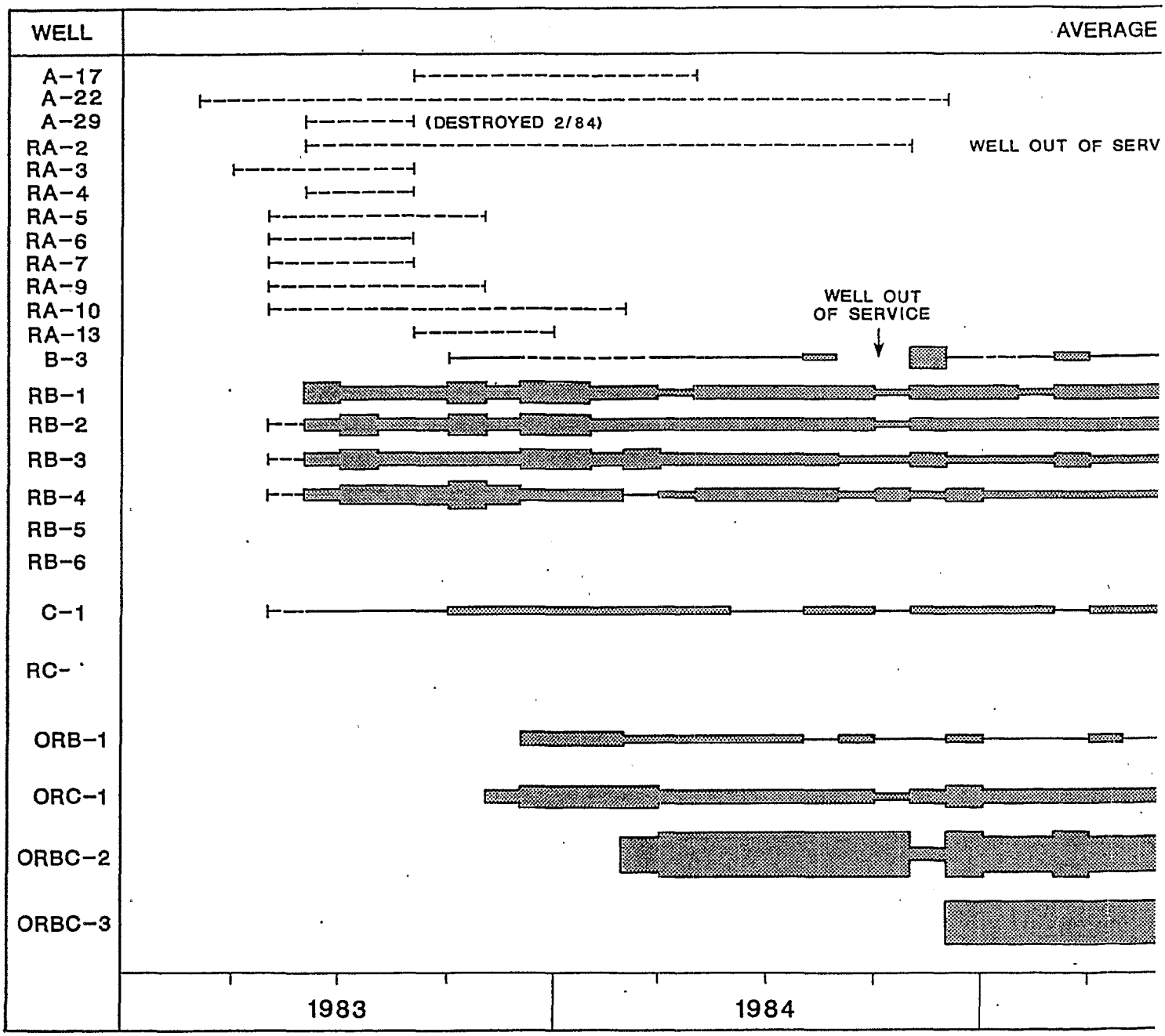




Source: HLA. June, 1987. Appendix B: Summary of Hydrogeologic Studies, Draft Comprehensive Plan, IBM Groundwater Restoration Program.

Figure 10
WELL LOCATION MAP
MONITORING AND EXTRACTION WELLS IN THE D- AND E-AQUIFER ZONES
IBM-SAN JOSE SITE

WCC 81621.A0.02

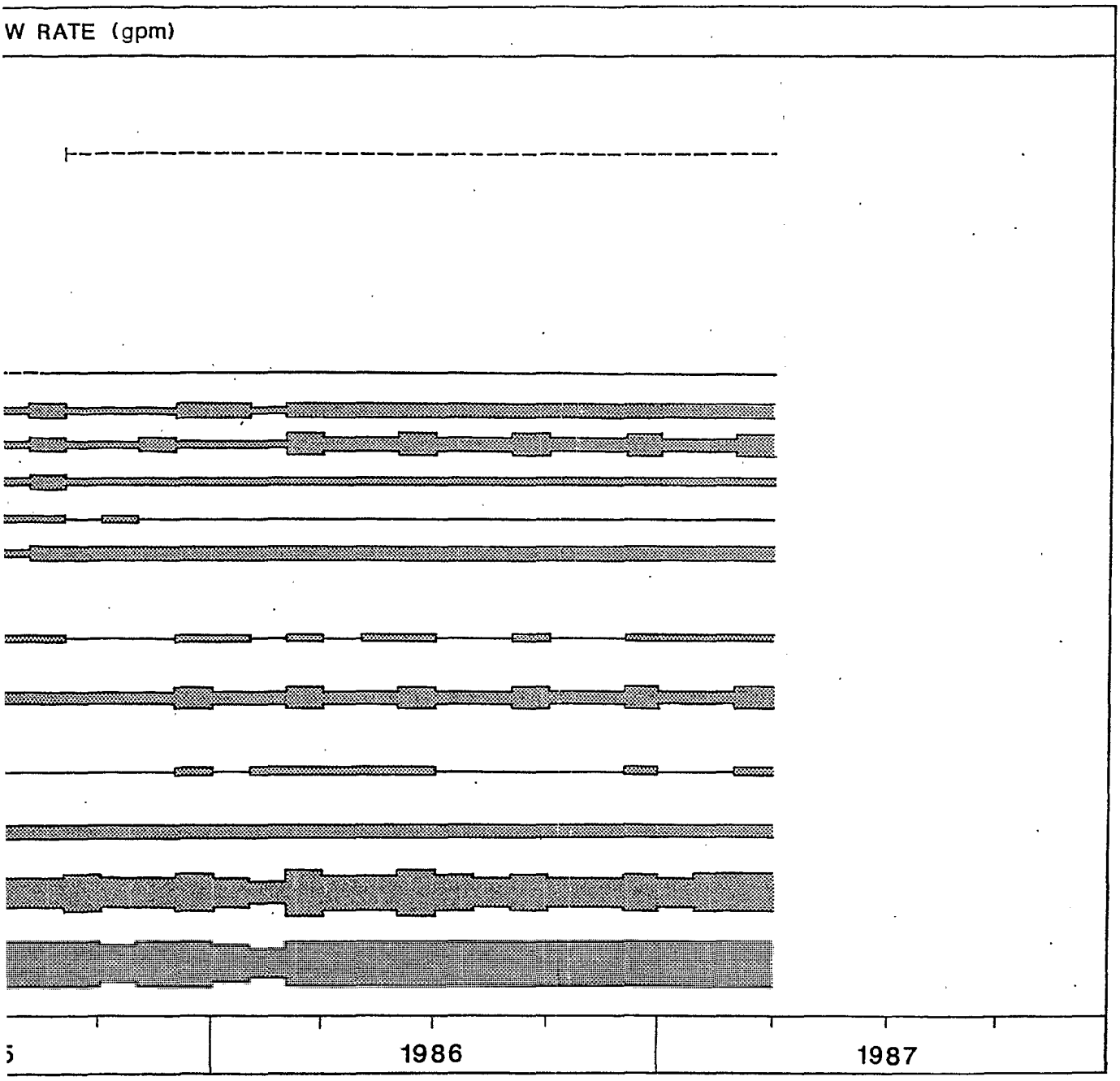


EXPLANATION

Average monthly flow rate in gallons per minute (gpm) based on weekly meter readings:

<50 | 150-299 | 600-899 | 1200-

50-149 | 300-599 | 900-1199 | >1500



DRAFT

: HLA. June, 1987. Appendix B: Summary of Hydrogeologic Studies, omprehensive Plan, IBM Groundwater Restoration Program.

Figure 11
AVERAGE MONTHLY GROUND-WATER EXTRACTION RATES
IBM-SAN JOSE SITE

Table 5
INSTALLATION AND APRIL 1988 OPERATIONAL CHARACTERISTICS
OF GROUND-WATER EXTRACTION WELLS

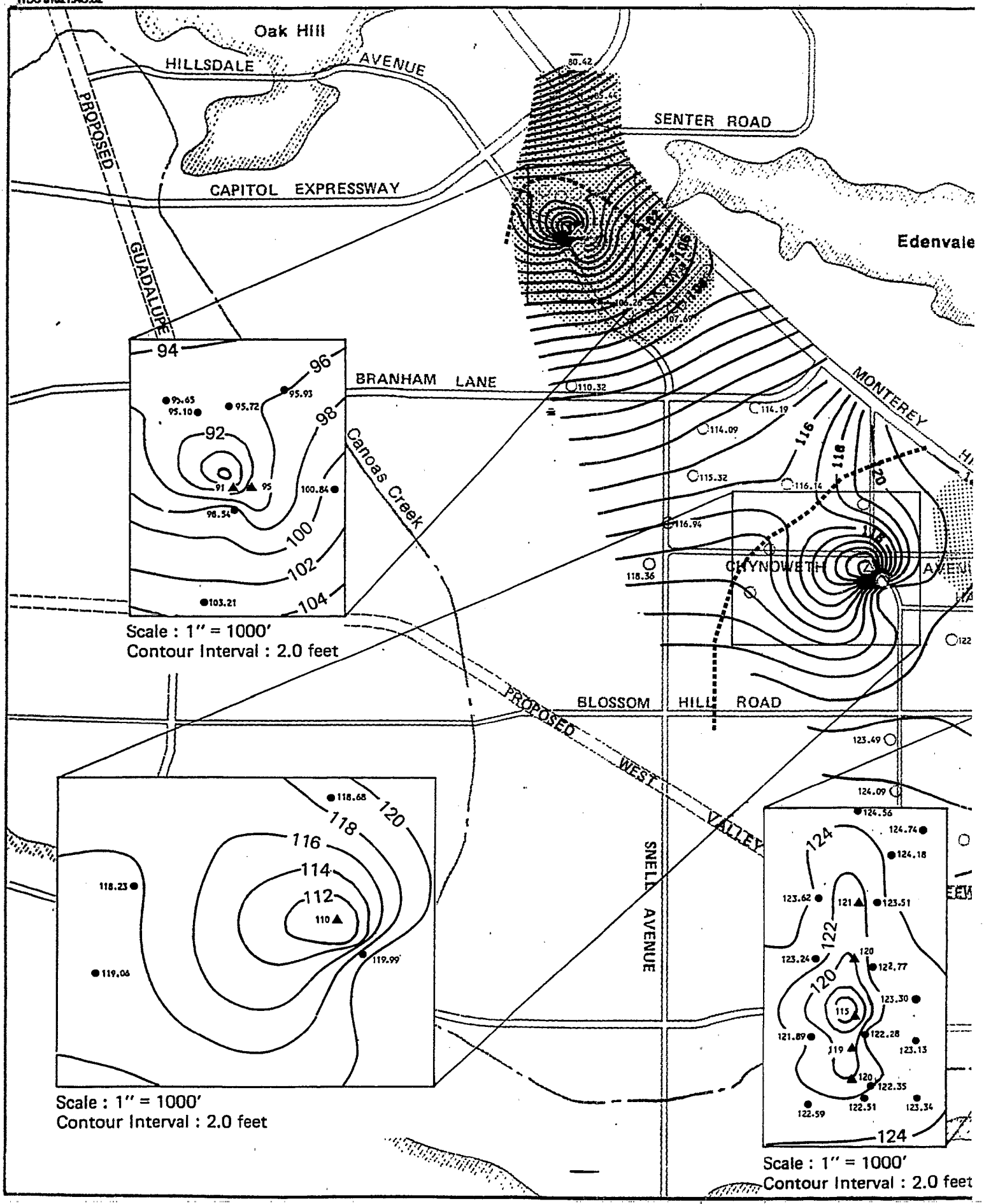
Well Number	Aquifer Zone	Dates of Installation/Operation	April 1988 Extraction Rate (gpm)
Onsite Areas			
Building 001			
A-22	A	May 1982 to November 1984	0
A-17	A	August 1983 to August 1984	0
Tank Farm 067/Building 006			
A-29[1]	A	December 1982 to August 1983	0
Boundary Wells			
A-31	A	June 1983 to August 1983	0
RA-2	A	June 1983 to present	30
RA-3	A	June 1983 to August 1983	0
RA-4	A	June 1983 to August 1983	0
RA-5	A	June 1983 to October 1983	0
RA-6	A	June 1983 to August 1983	0
RA-7	A	June 1983 to September 1983	0
RA-9	A	June 1983 to October 1983	0
RA-10	A	June 1983 to February 1984	0
RA-13	A	August 1983 to December 1983	0
RB-1	B	June 1983 to April 1988	0
RB-2	B	June 1983 to present	400
RB-3	B	June 1983 to present	250
RB-4	B	June 1983 to April 1988	0
RB-5	B	June 1985 to April 1988	0
RB-6	B	May 1987 to April 1988	0
B-3	B	October 1983 to May 1987	0
C-1	C	June 1983 to April 1988	0
RC-1	C	June 1985 to April 1988	
Offsite			
ORB-1	B	November 1983 to present	100
ORC-1	C	November 1983 to April 1988	0
ORBC-2	B	March 1984 to April 1988	0
ORBC-3	B	December 1984 to present	800

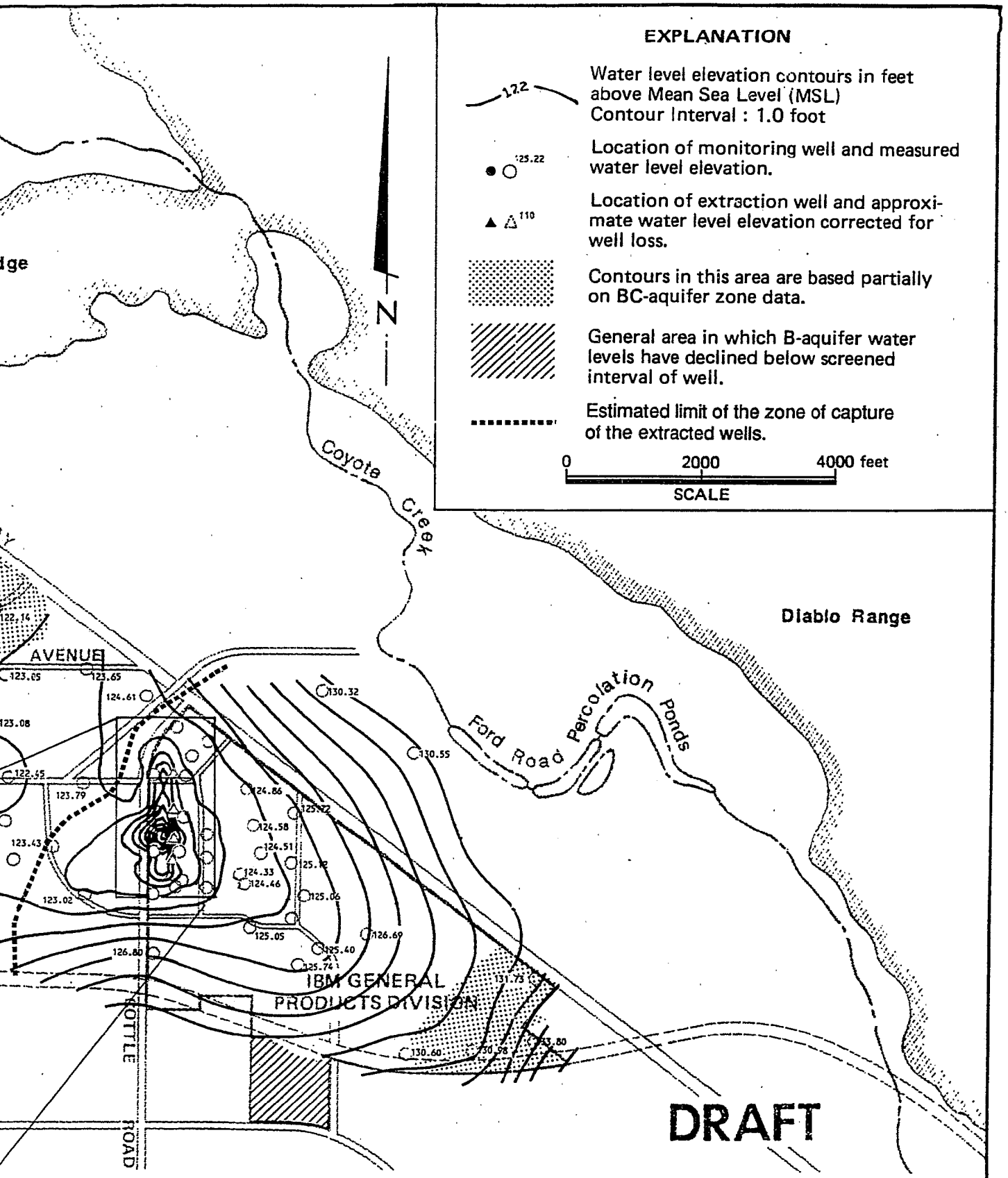
[1]Well A-29 plugged and closed in 1984 because of building construction activities.

Source: KJC, Draft Supplement, Comprehensive Plan, 1988.

WDCR428/059.50

WDC 81621.AO.02

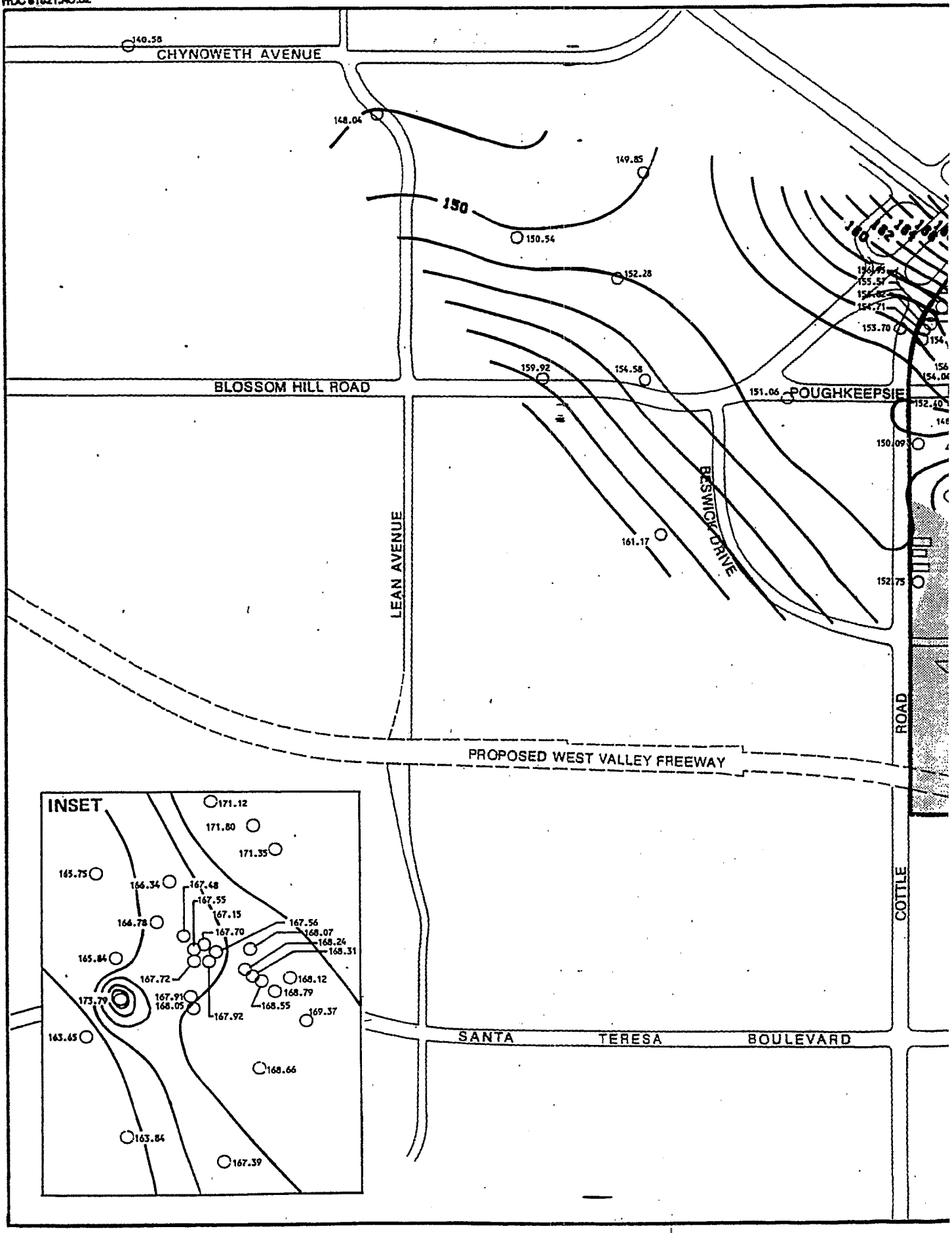




Source: HLA. June, 1987. Appendix B: Summary of Hydrogeologic Studies, Draft Comprehensive Plan, IBM Groundwater Restoration Program.

Figure 13
WATER LEVEL ELEVATIONS IN THE B-AQUIFER ZONE, JUNE 1986
IBM-SAN JOSE SITE

WDC 61621.AO.02



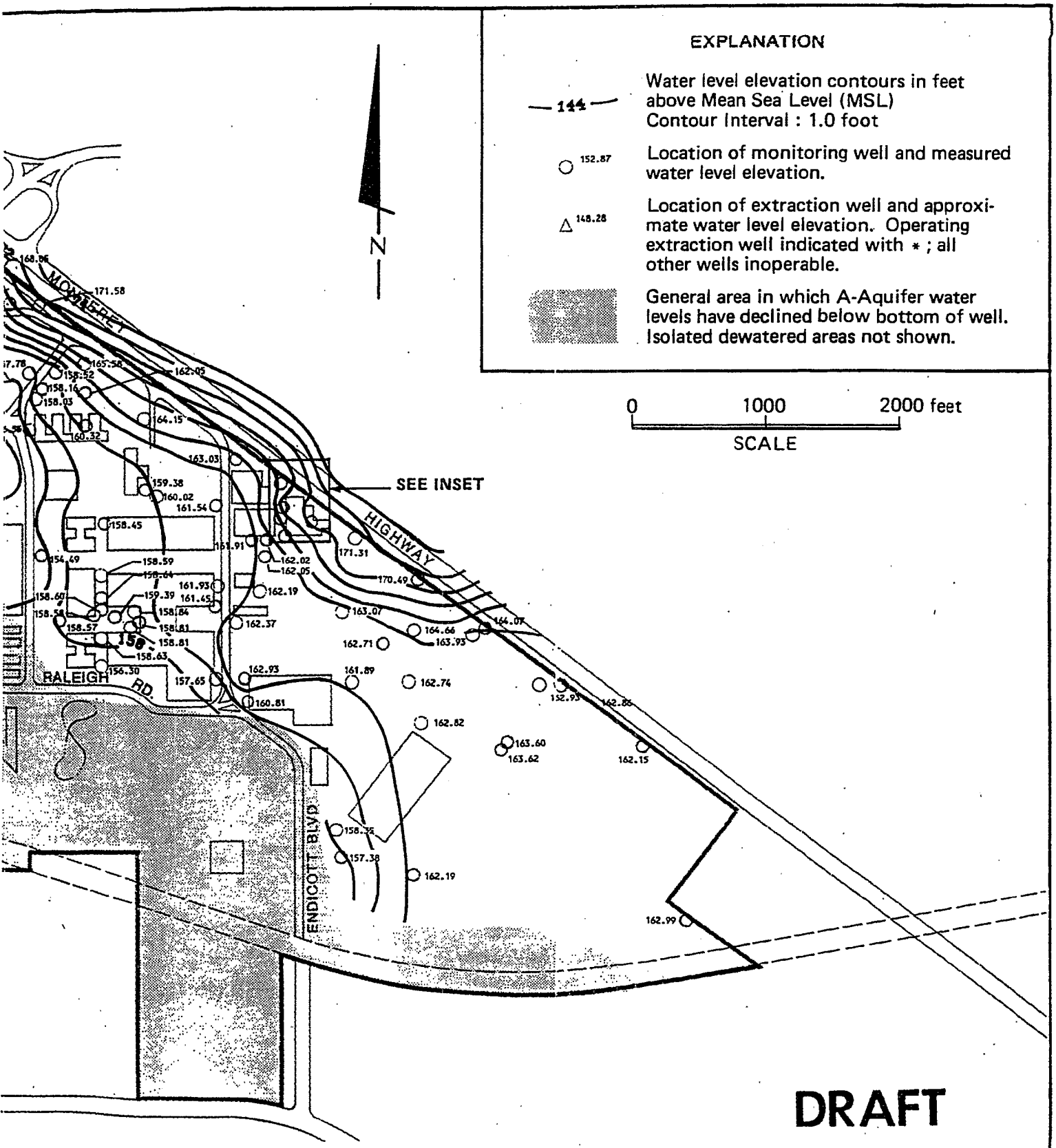
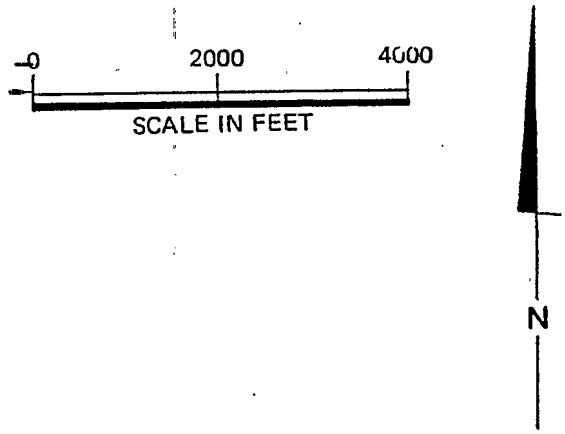
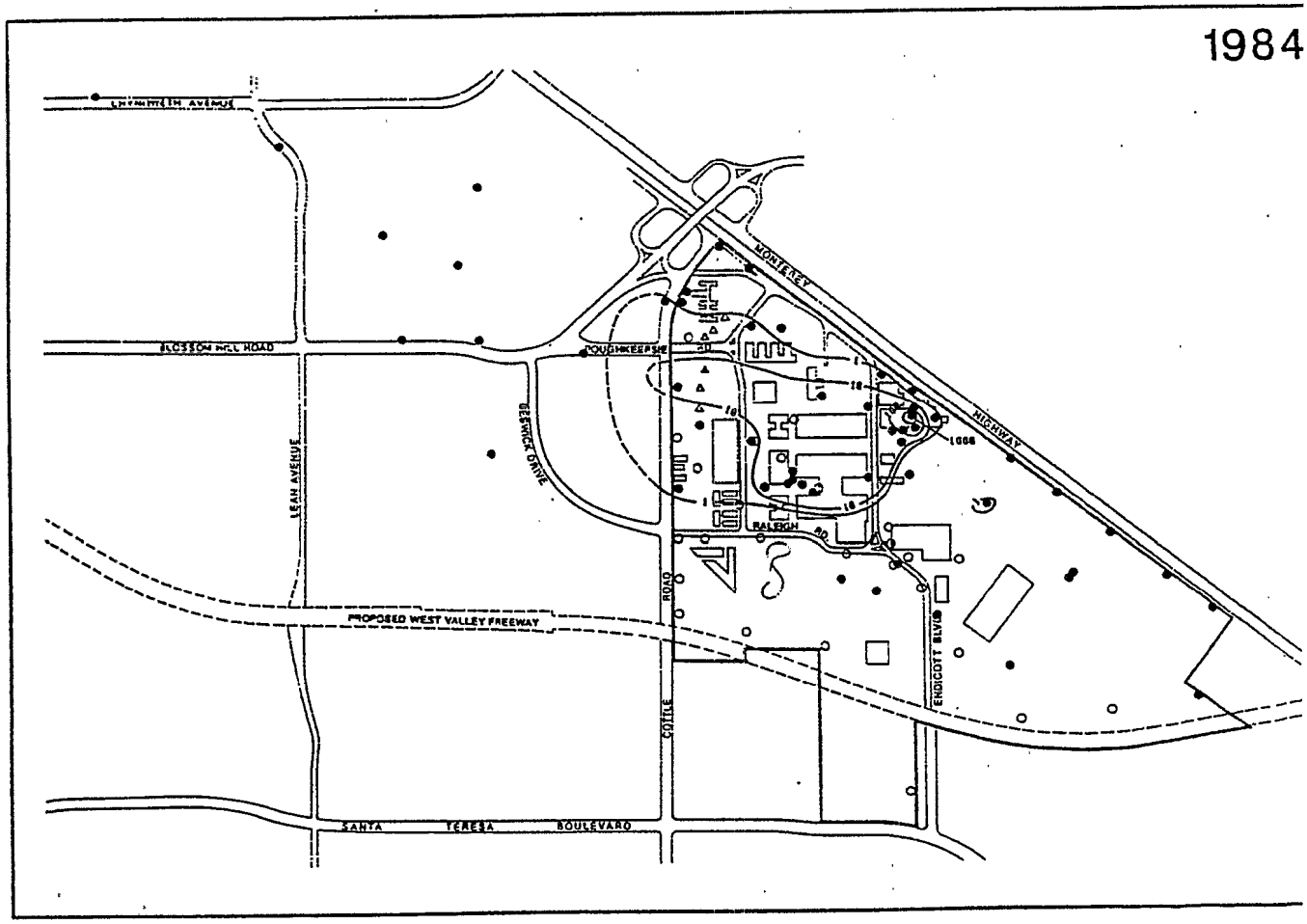


Figure 12
WATER LEVEL ELEVATIONS IN THE A-AQUIFER ZONE, JUNE 1986
IBM-SAN JOSE SITE

Source: HLA. June, 1987. Appendix B: Summary of Hydrogeologic Studies, Draft Comprehensive Plan, IBM Groundwater Restoration Program.





Source: HLA. June, 1987. Appendix B: Summary of Hydrogeologic Studies, Draft Comprehensive Plan, IBM Groundwater Restoration Program.

EXPLANATION

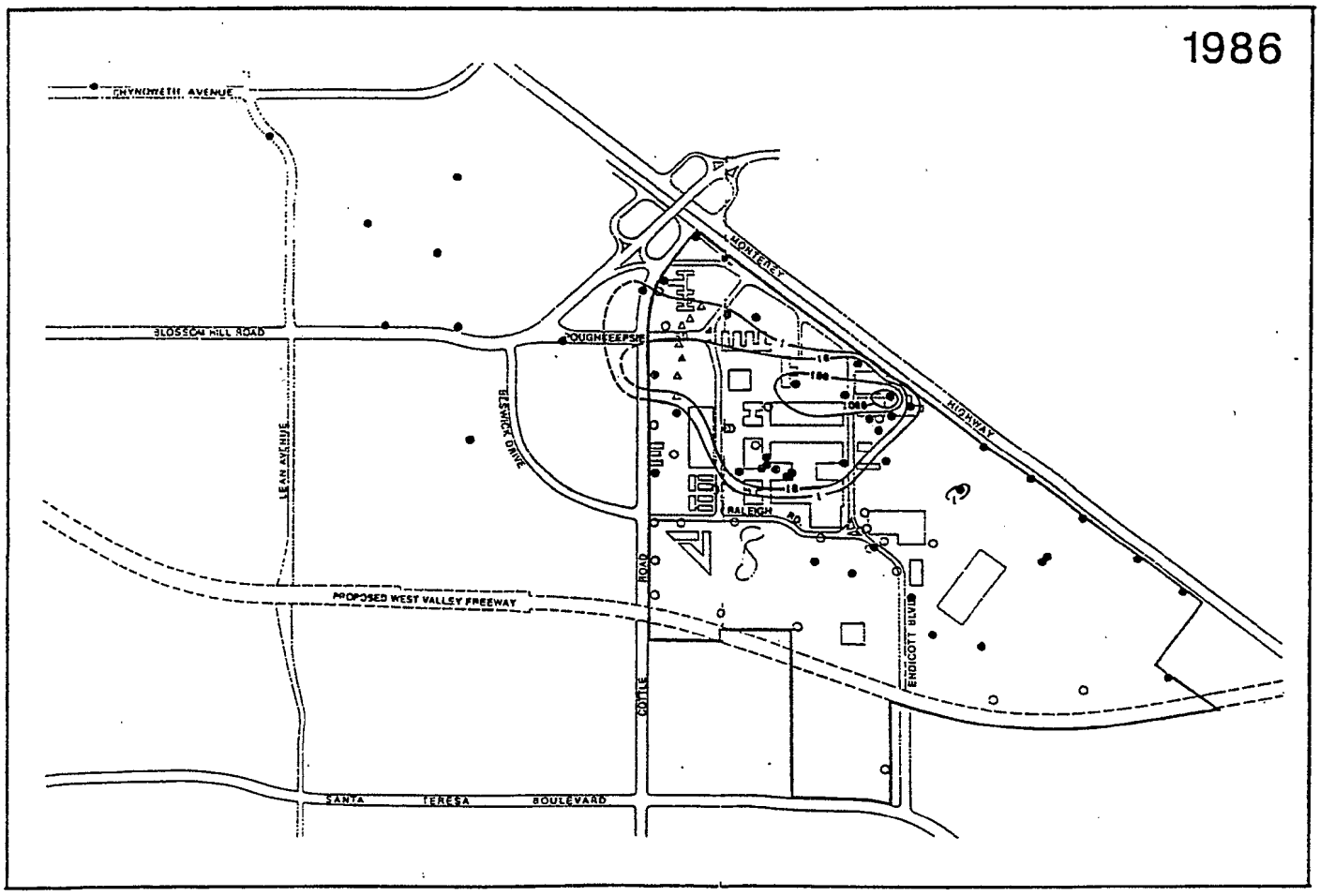
Chemical concentration contours in ppb, based on mean concentrations in samples collected from monitoring and extraction wells during the period specified in the title.

Location of monitoring well from which samples were collected.

Location of extraction well from which samples were collected.

Location of monitoring well from which no samples were collected or well installed subsequent to the period specified in the title.

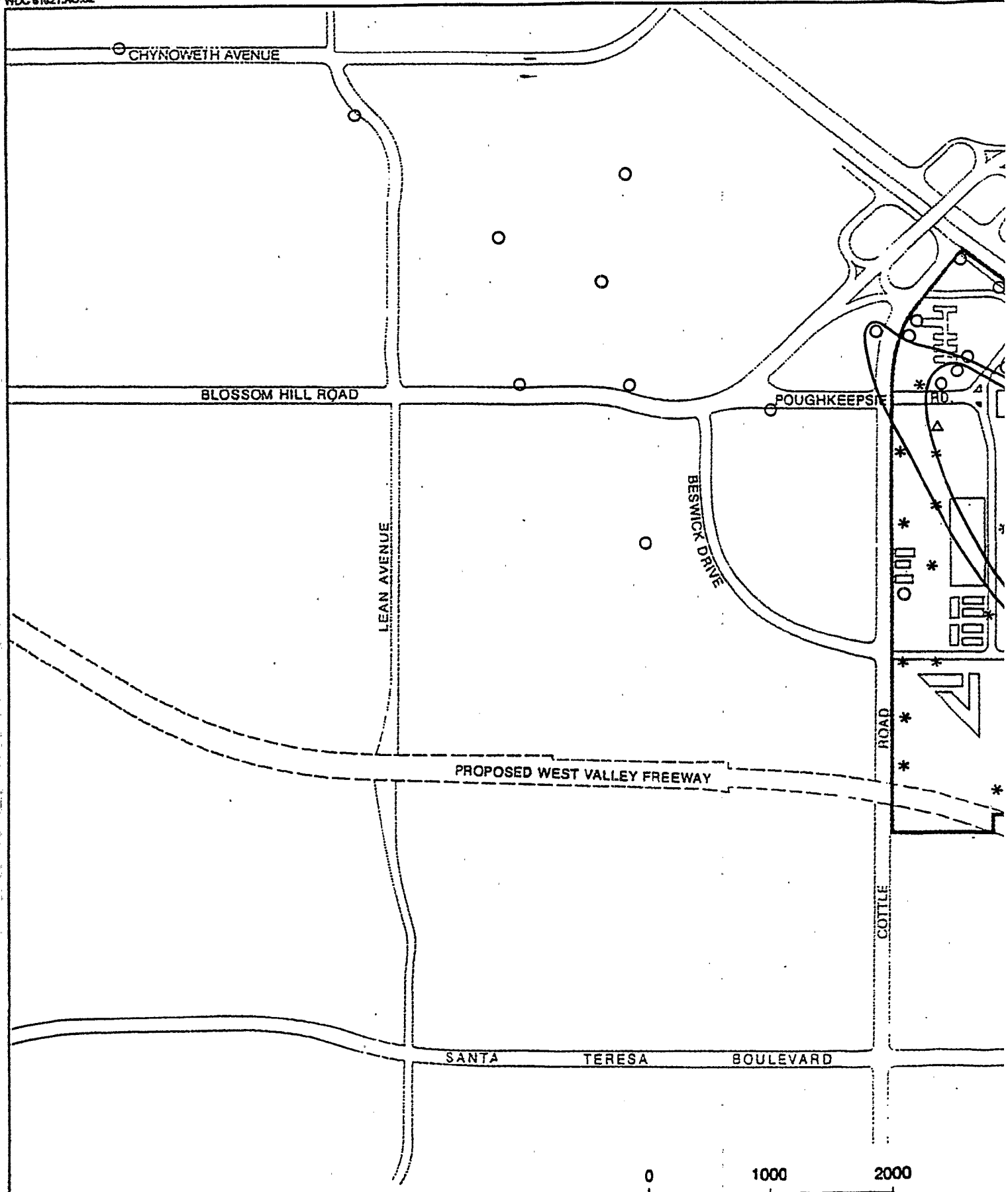
Location of extraction well from which no samples were collected or well installed subsequent to the period specified in the title.



DRAFT

Figure 14
TCA IN THE A-AQUIFER ZONE, SECOND QUARTER 1984 AND SECOND QUARTER1986
IBM-SAN JOSE SITE

WDC 61621.A0.JJZ



Source: HLA. January, 1989. Quarterly Report, September 1988 through December 1988, IBM Groundwater Restoration Program.

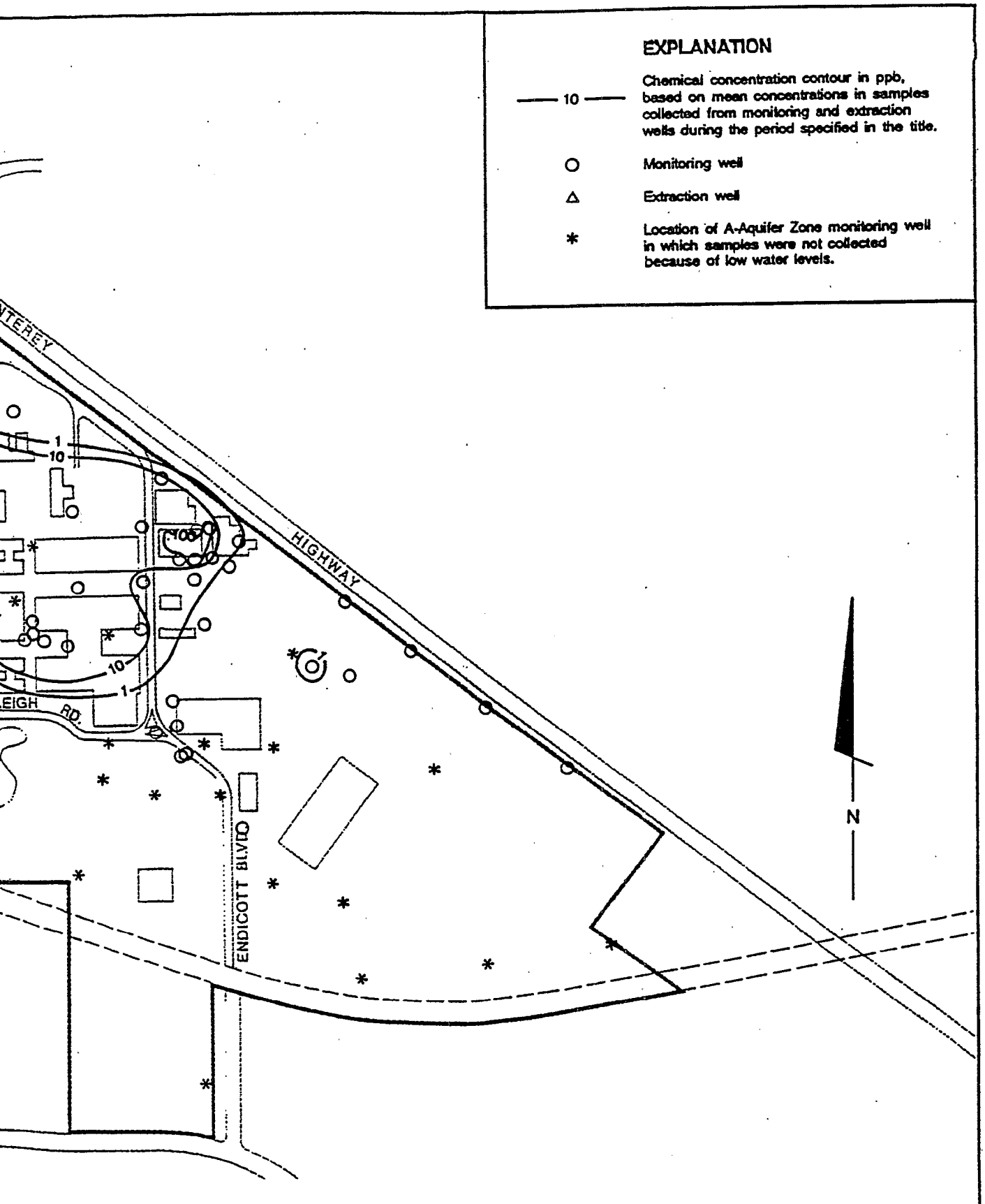
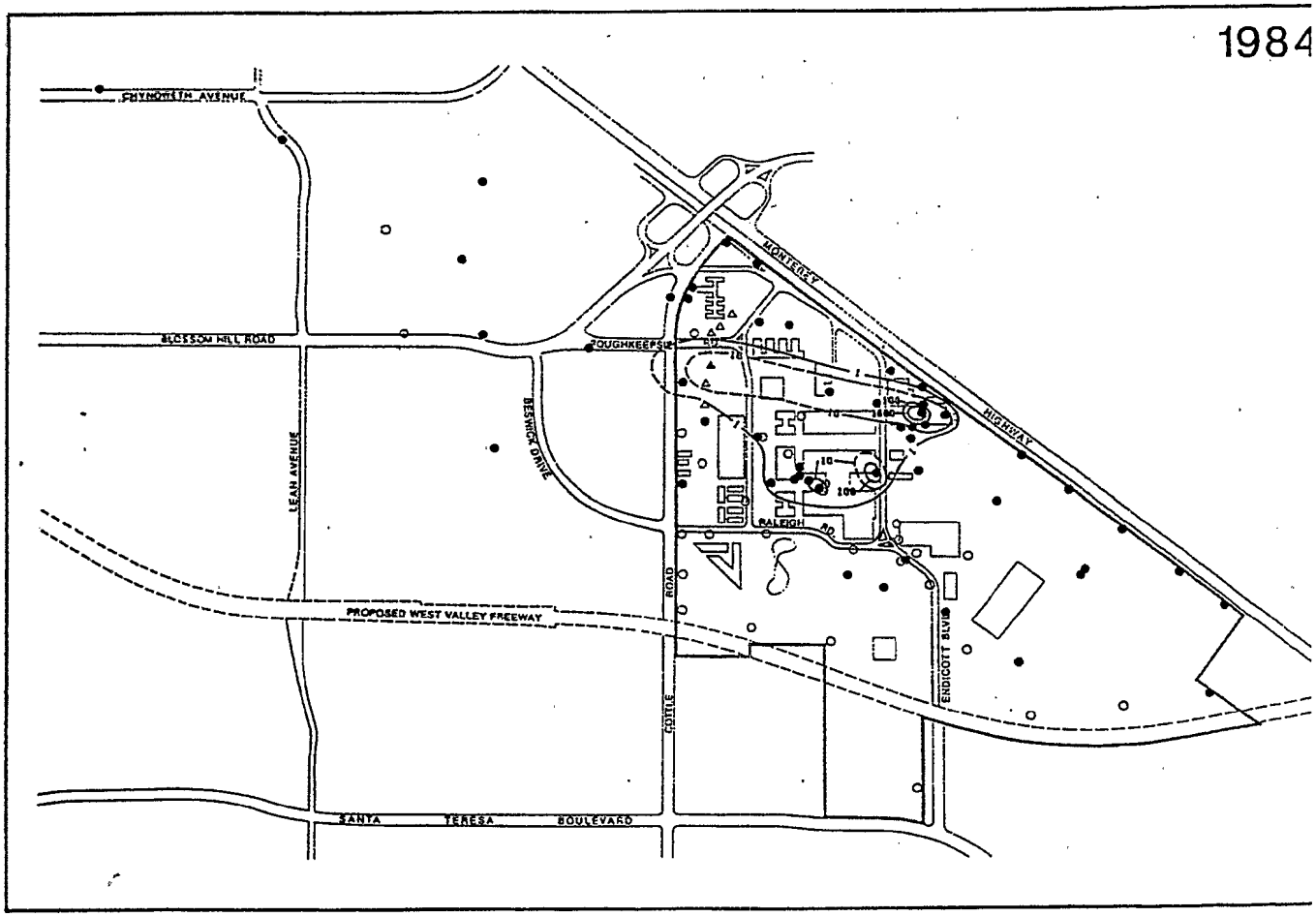


Figure 15
TCA IN THE A-AQUIFER ZONE
DURING THE PERIOD 9/26/88 - 12/30/88
IBM-SAN JOSE SITE

WDC 61621.AO.02



Source: HLA. June, 1987. Appendix B: Summary of Hydrogeologic Studies, Draft Comprehensive Plan, IBM Groundwater Restoration Program.

EXPLANATION

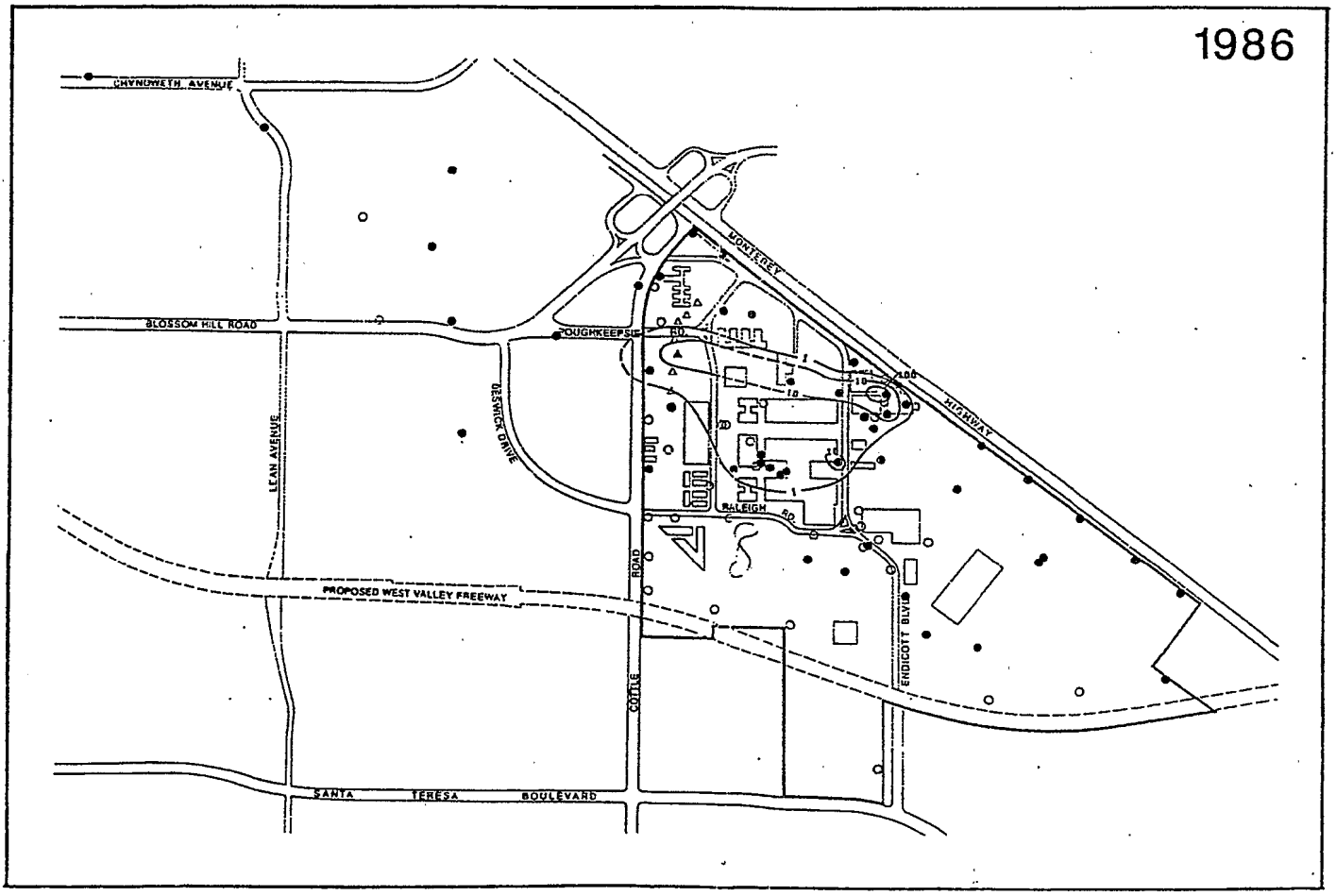
Chemical concentration contours in ppb, based on mean concentrations in samples collected from monitoring and extraction wells during the period specified in the title.

Location of monitoring well from which samples were collected.

Location of extraction well from which samples were collected.

Location of monitoring well from which no samples were collected or well installed subsequent to the period specified in the title.

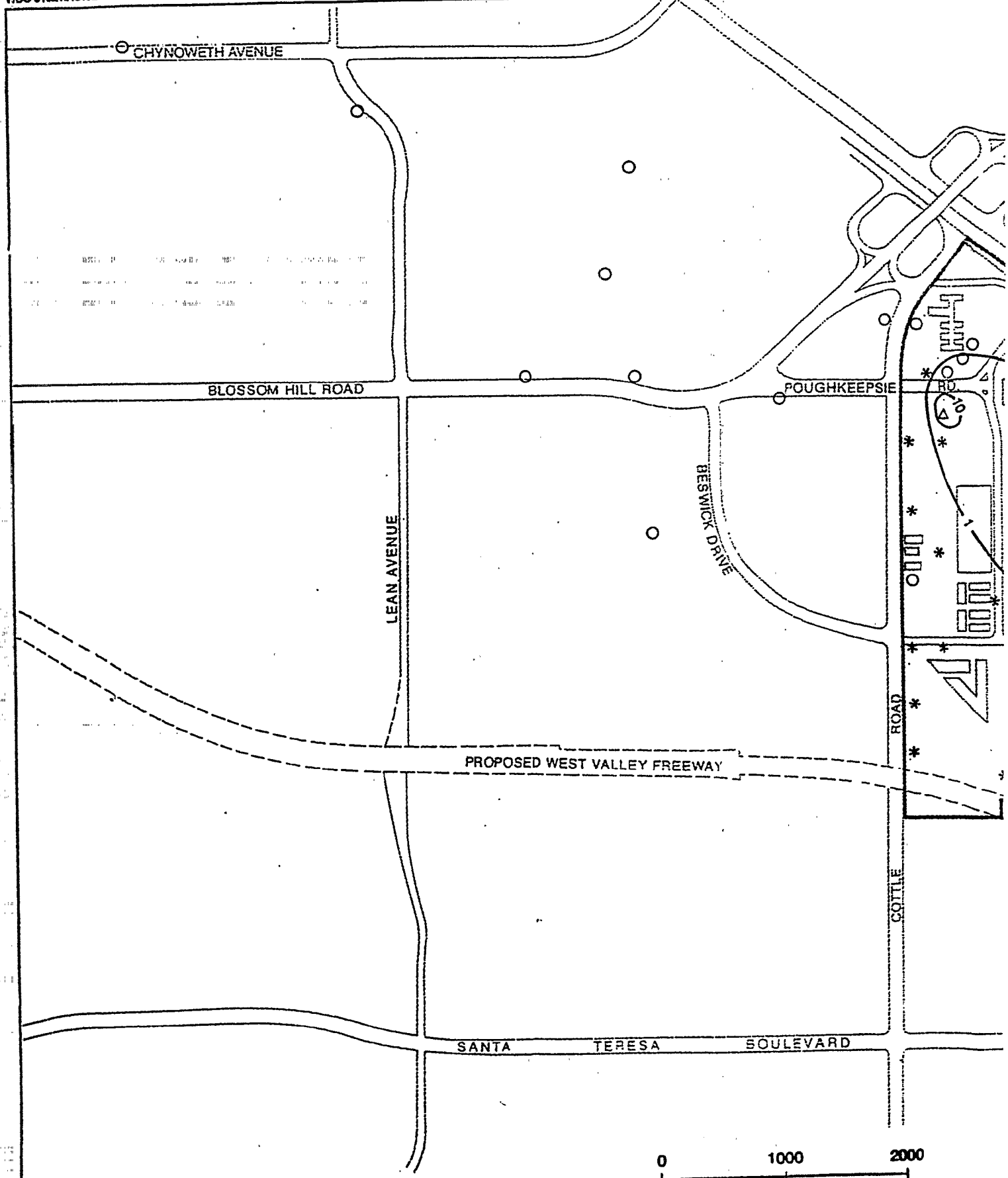
Location of extraction well from which no samples were collected or well installed subsequent to the period specified in the title.



DRAFT

Figure 16
1,1-DCE IN THE A-AQUIFIER ZONE, SECOND QUARTER 1984 AND SECOND QUARTER 1986
IBM-SAN JOSE SITE

WDC 61821.AO.02



Source: HLA. January, 1989. Quarterly Report, September 1988 through December 1988, IBM Groundwater Restoration Program.

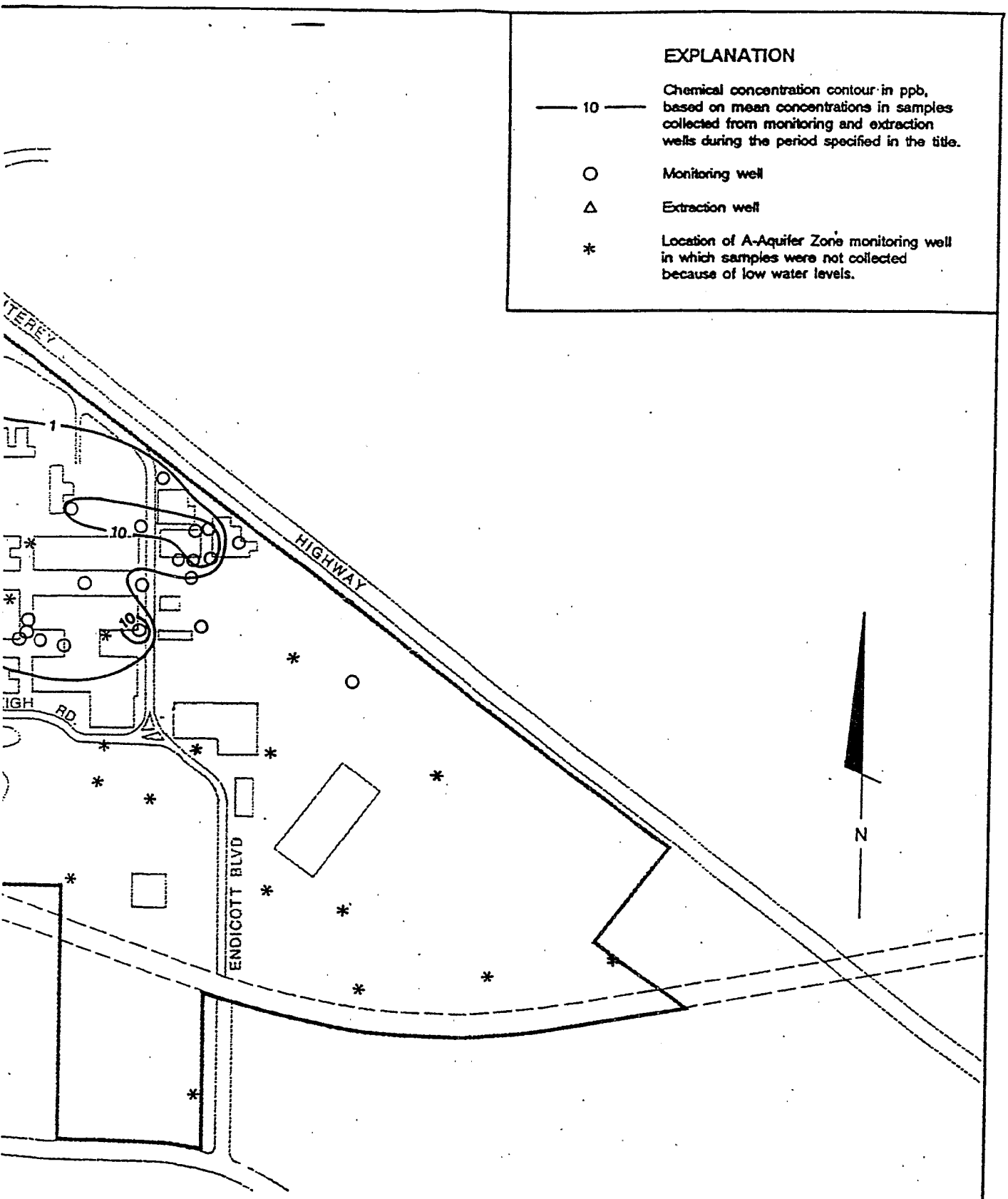
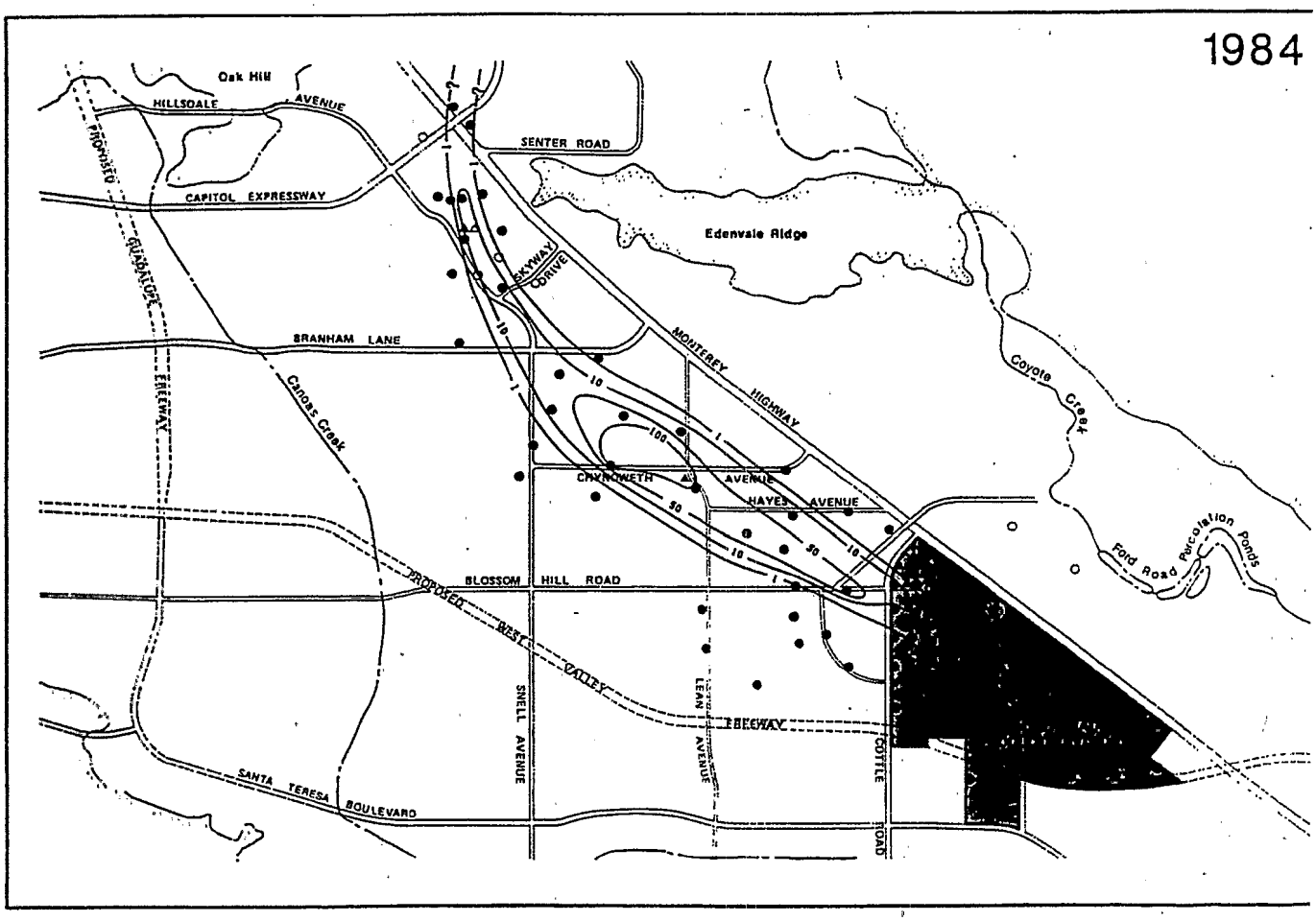


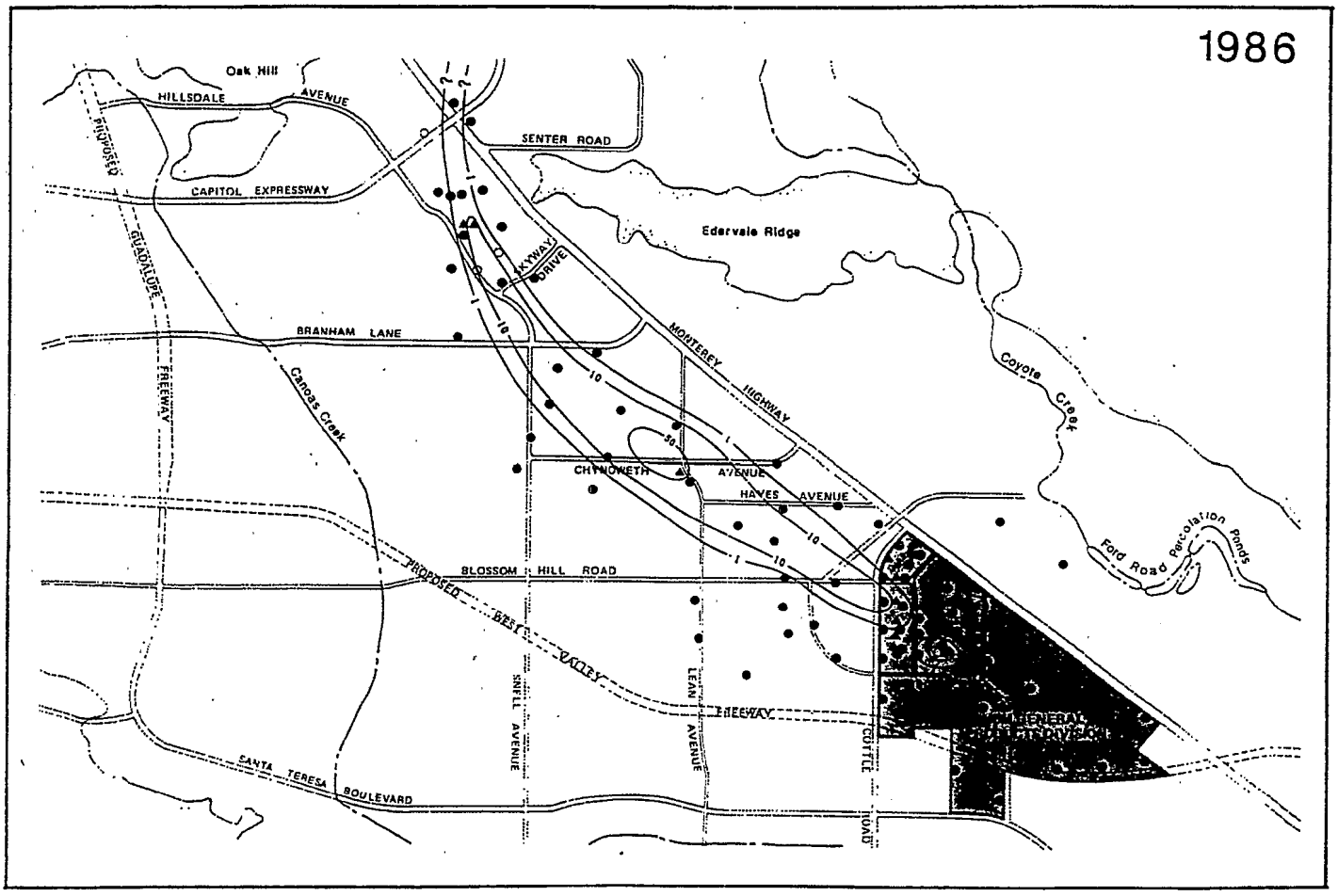
Figure 17
1,1-DCE IN THE A-AQUIFER ZONE, DURING THE PERIOD 9/26/88 - 12/30/88
IBM-SAN JOSE SITE



Source: HLA. June, 1987. Appendix B: Summary of Hydrogeologic Studies, Draft Comprehensive Plan, IBM Groundwater Restoration Program.

EXPLANATION

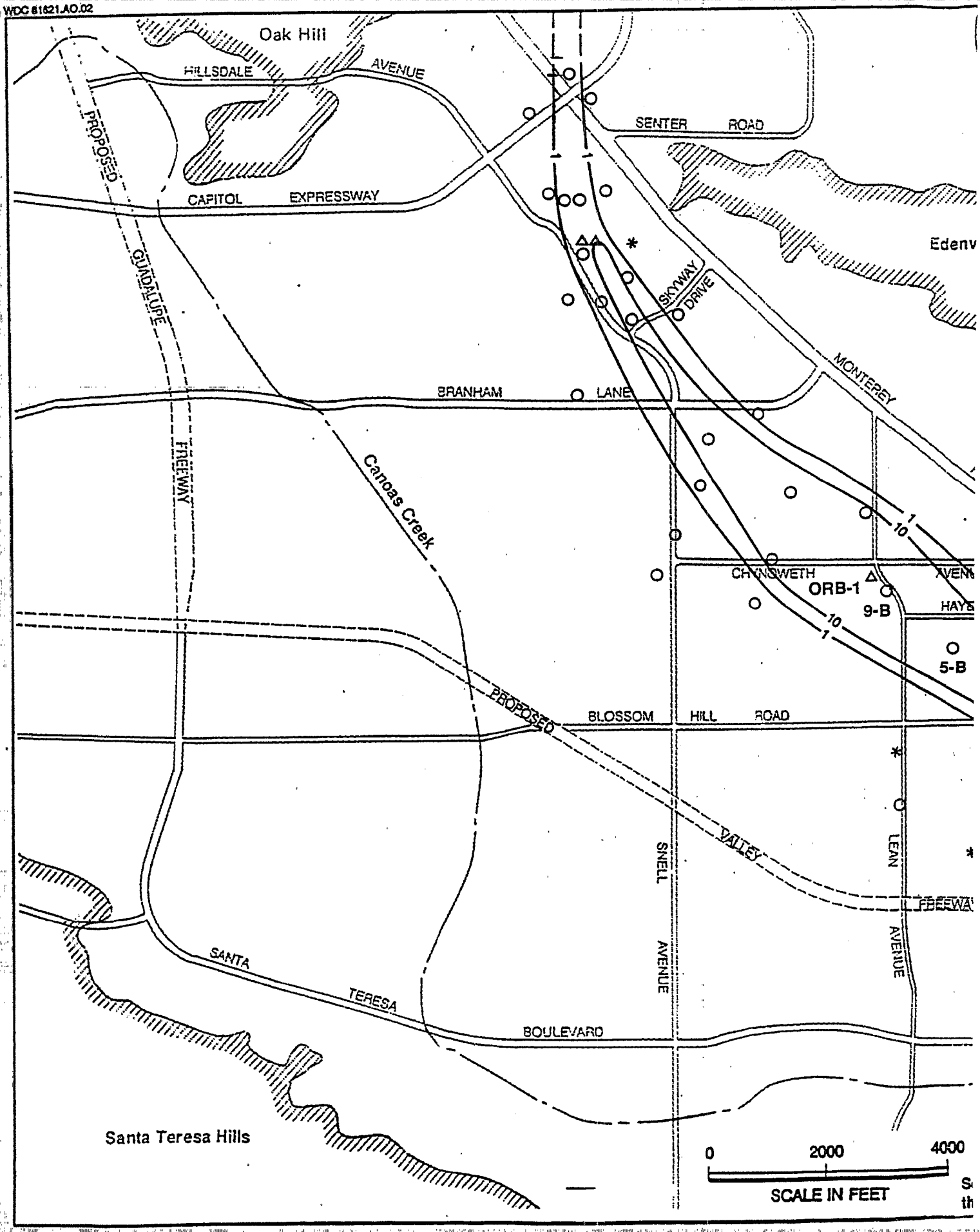
- Chemical concentration contours in ppb, based on mean concentrations in samples collected from monitoring and extraction wells during the period specified in the title.
- • Location of monitoring well from which samples were collected.
- ▲ Location of extraction well from which samples were collected.
- ○ Location of monitoring well from which no samples were collected or well installed subsequent to the period specified in the title.
- △ Location of extraction well from which no samples were collected or well installed subsequent to the period specified in the title.

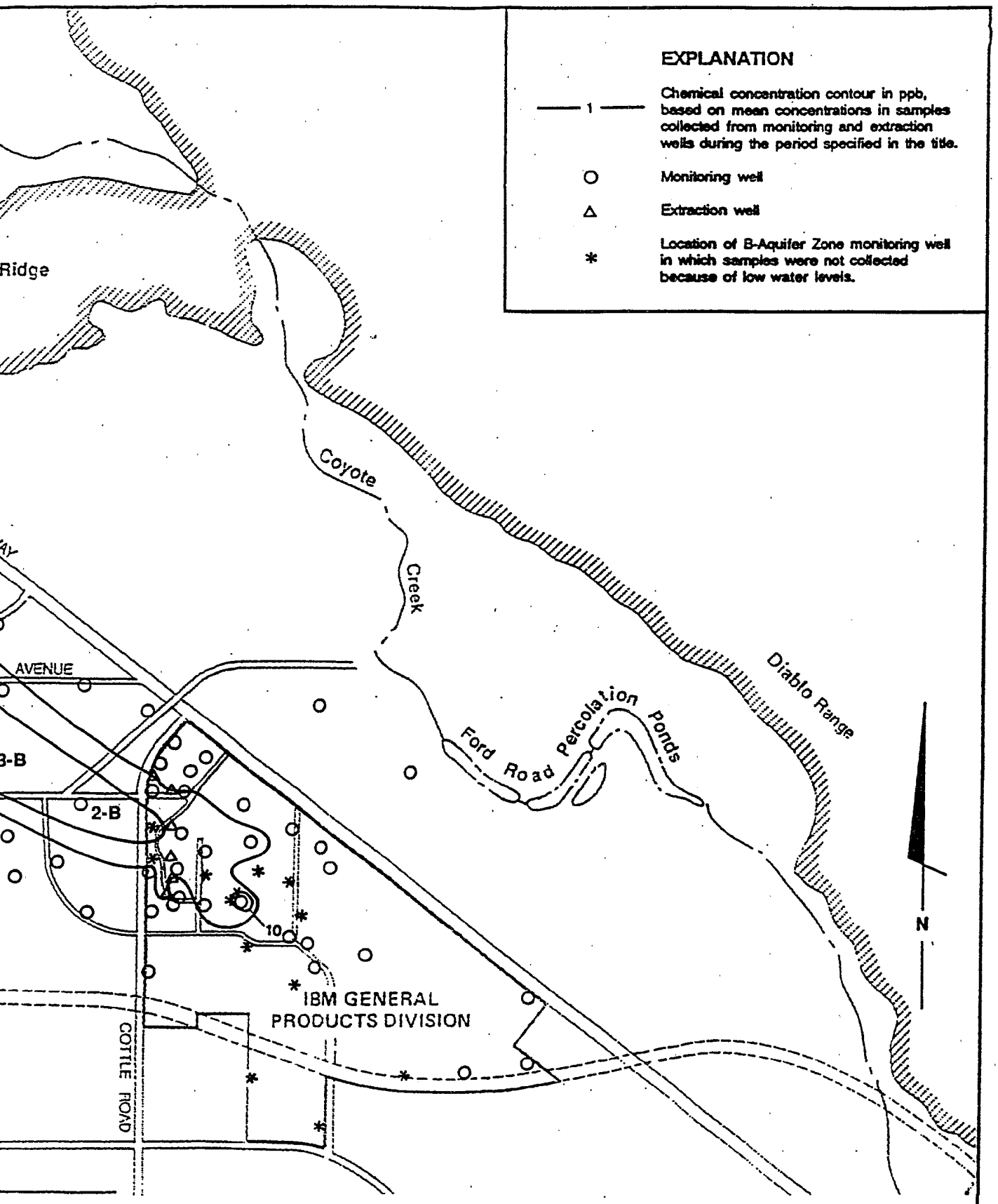


DRAFT

Figure 18
TCA IN THE B-AQUIFIER ZONE, SECOND QUARTER 1984 AND SECOND QUARTER 1986
IBM-SAN JOSE SITE

WDC 61621.AO.02





: HLA. January, 1989. Quarterly Report, September 1988
n December 1988, IBM Groundwater Restoration Program.

Figure 19
TCA IN THE B-AQUIFIER ZONE, DURING THE PERIOD 9/26/88 - 12/30/88
IBM-SAN JOSE SITE

EXPLANATION

Chemical concentration contours in ppb, based on mean concentrations in samples collected from monitoring and extraction wells during the period specified in the title.

Location of monitoring well from which samples were collected.

Location of extraction well from which samples were collected.

Location of monitoring well from which no samples were collected or well installed subsequent to the period specified in the title.

Location of extraction well from which no samples were collected or well installed subsequent to the period specified in the title.

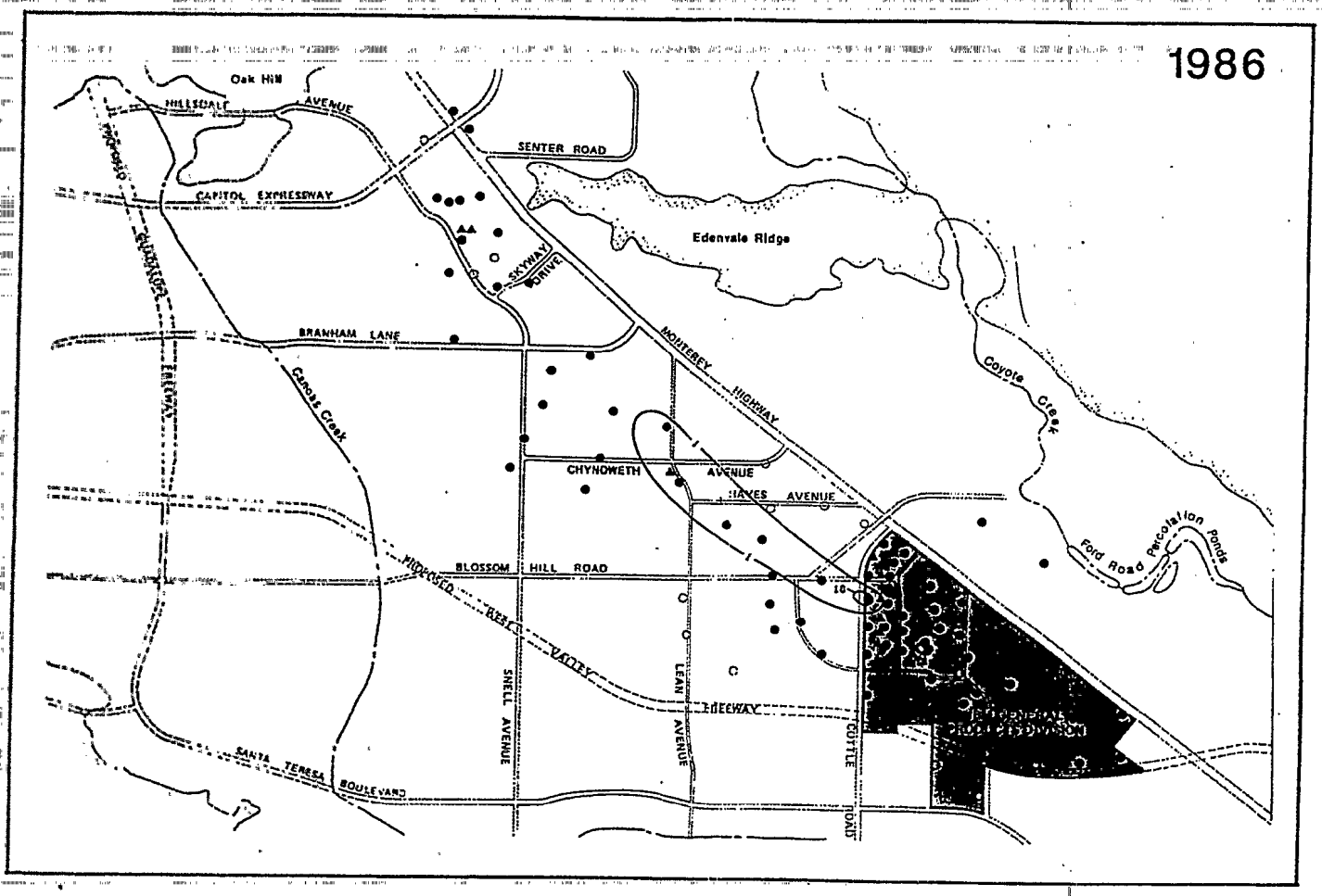
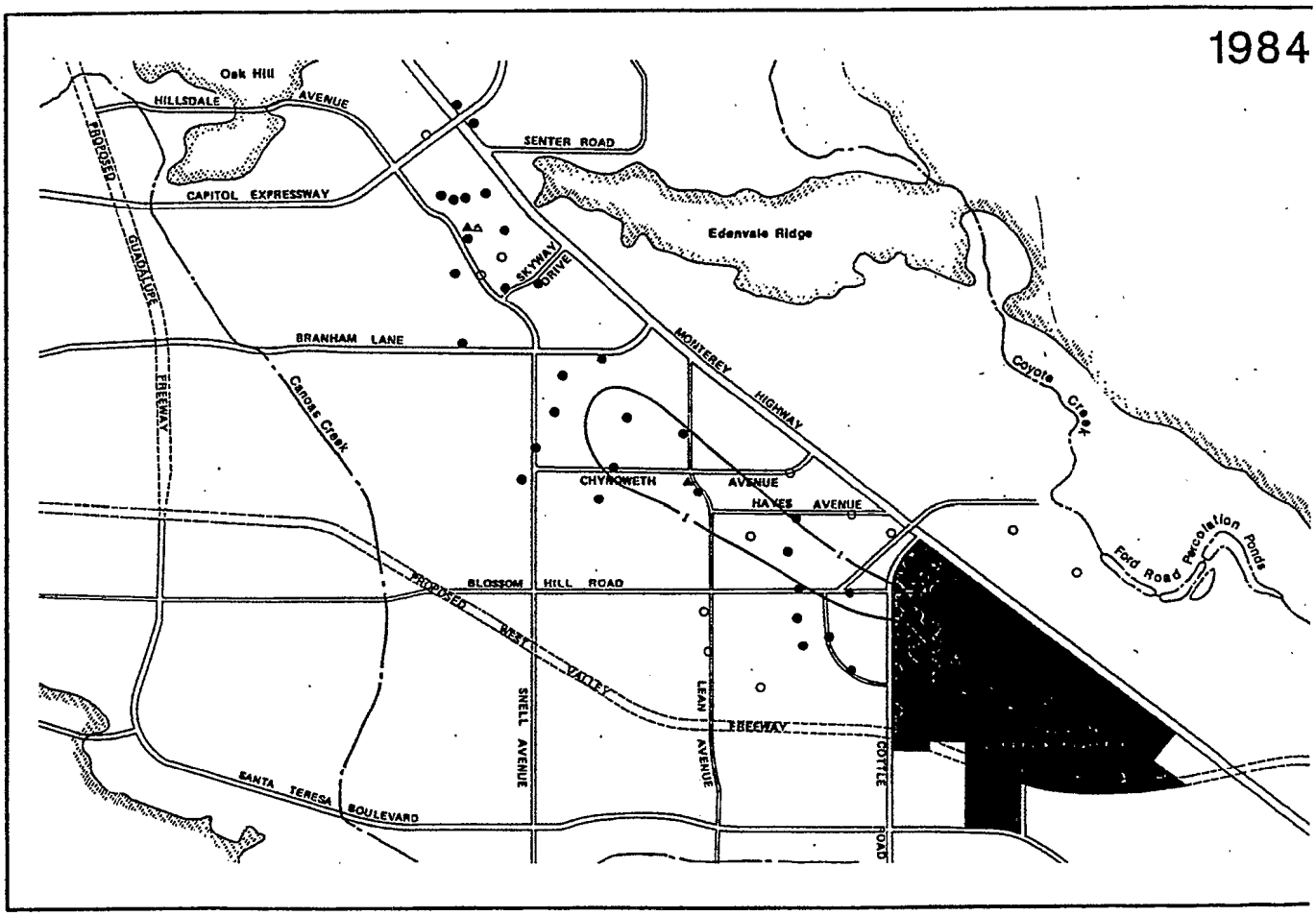
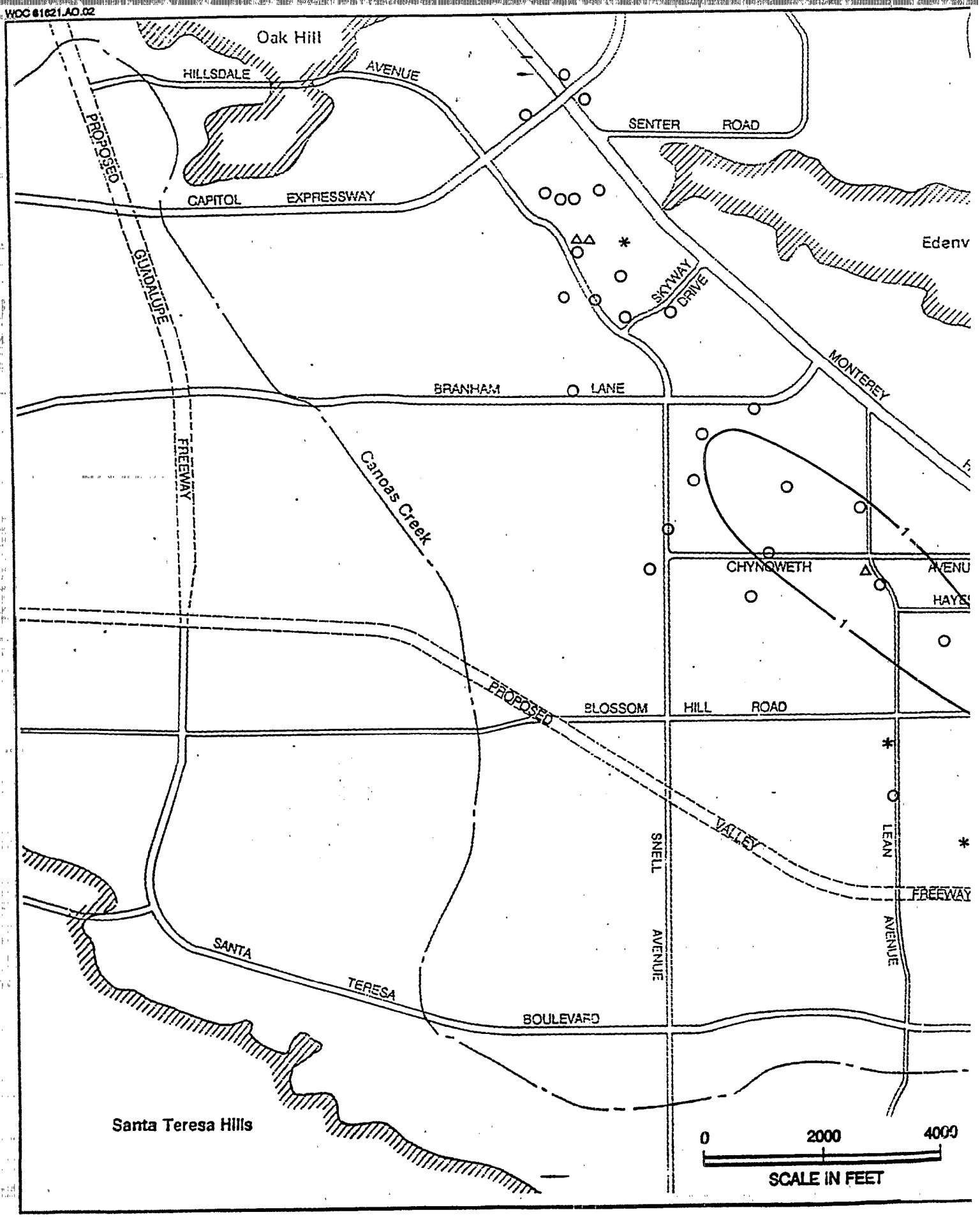


Figure 20
1,1-DCE IN THE B-AQUIFIER ZONE, SECOND QUARTER 1984 AND SECOND QUARTER 1986
IBM-SAN JOSE SITE



Source: HLA. June, 1987. Appendix B: Summary of Hydrogeologic Studies, Draft Comprehensive Plan, IBM Groundwater Restoration Program.

WOC 61621.A0.02



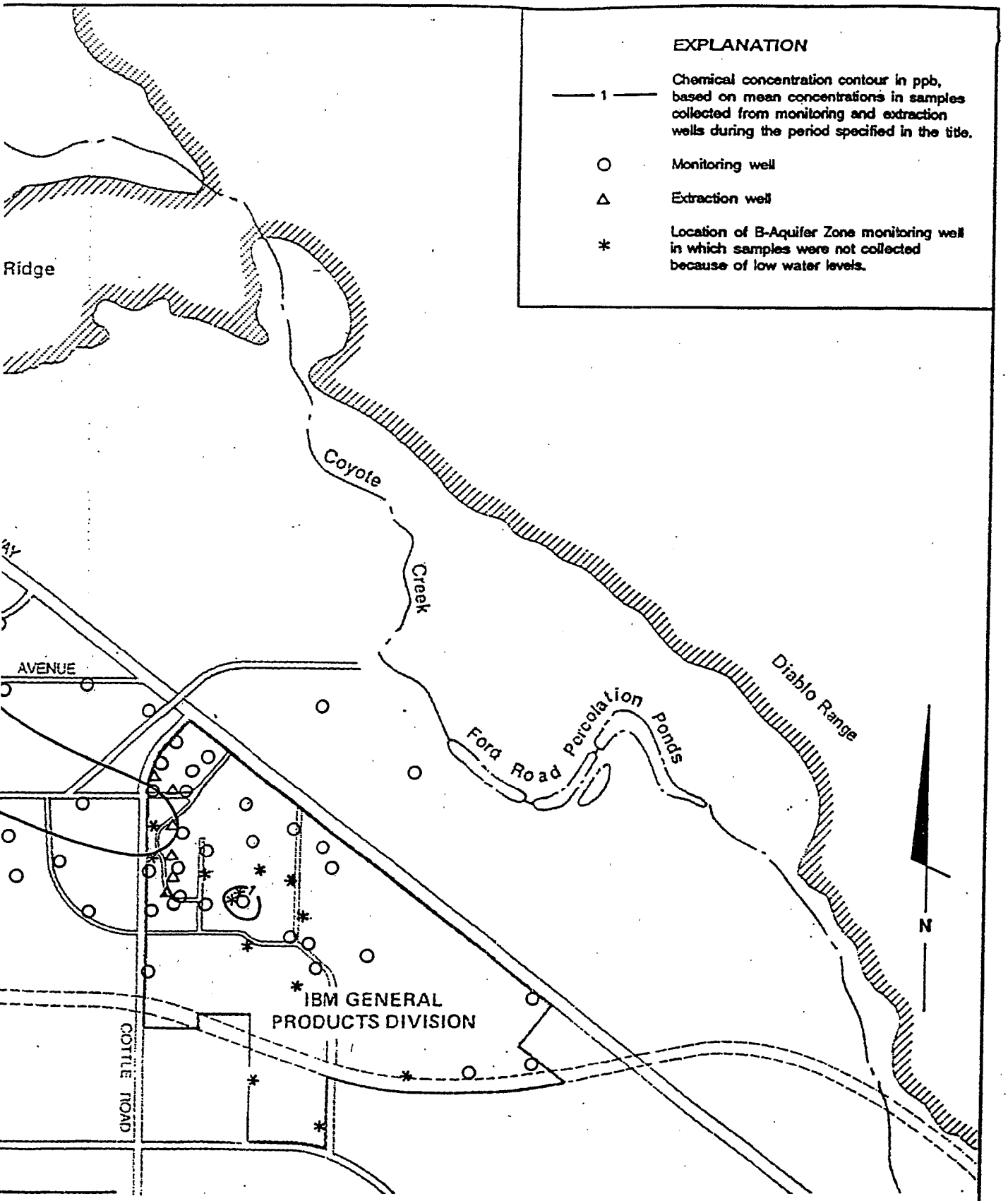
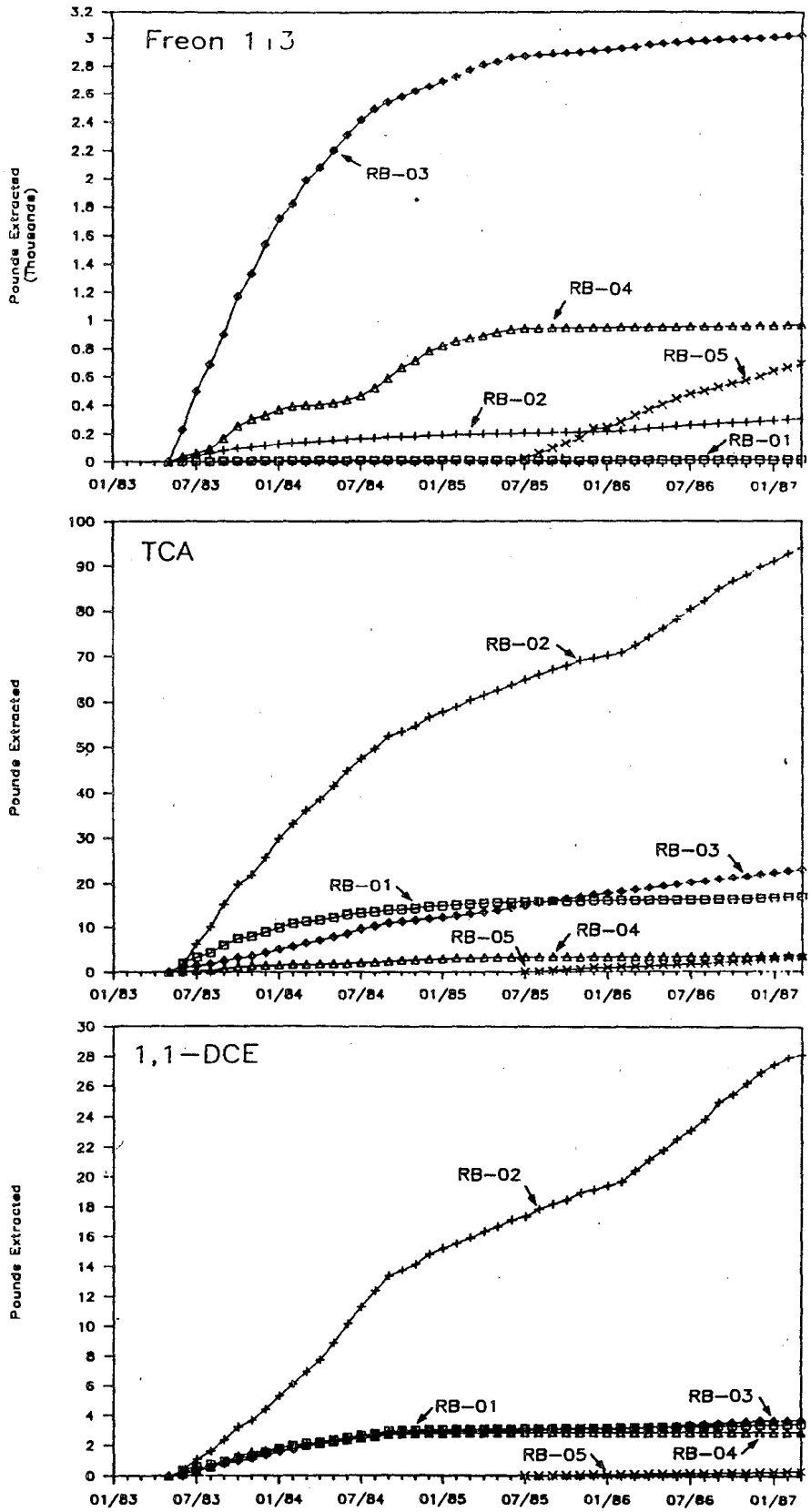


Figure 21
1,1-DCE IN THE B-AQUIFER ZONE, DURING THE PERIOD 9/26/88 - 12/30/88
IBM-SAN JOSE SITE

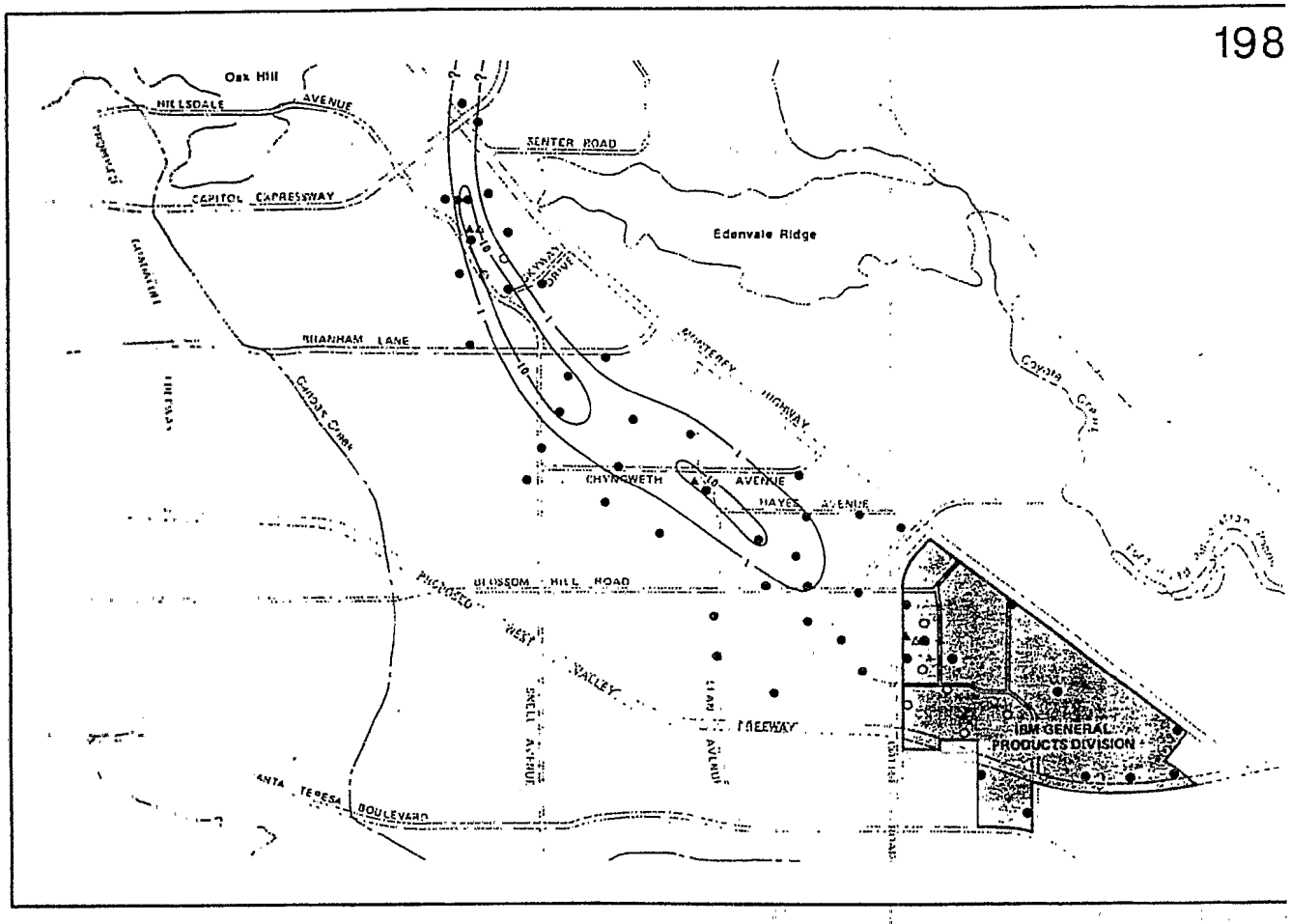
rce: HLA. January, 1989. Quarterly Report, September 1988 ugh December 1988, IBM Groundwater Restoration Program.



DRAFT

Source: HLA. June, 1987. Appendix B: Summary of Hydrogeologic Studies, Draft Comprehensive Plan, IBM Groundwater Restoration Program.

Figure 22
CHEMICAL MASS EXTRACTED B-AQUIFER ZONE BOUNDARY EXTRACTION SYSTEM
IBM-SAN JOSE SITE



Source: HLA. June, 1987. Appendix B: Summary of Hydrogeologic Studies, Draft Comprehensive Plan, IBM Groundwater Restoration Program.

EXPLANATION

Chemical concentration contours in ppb, based on mean concentrations in samples collected from monitoring and extraction wells during the period specified in the title.

Location of monitoring well from which samples were collected.

Location of extraction well from which samples were collected.

Location of monitoring well from which no samples were collected or well installed subsequent to the period specified in the title.

Location of extraction well from which no samples were collected or well installed subsequent to the period specified in the title.

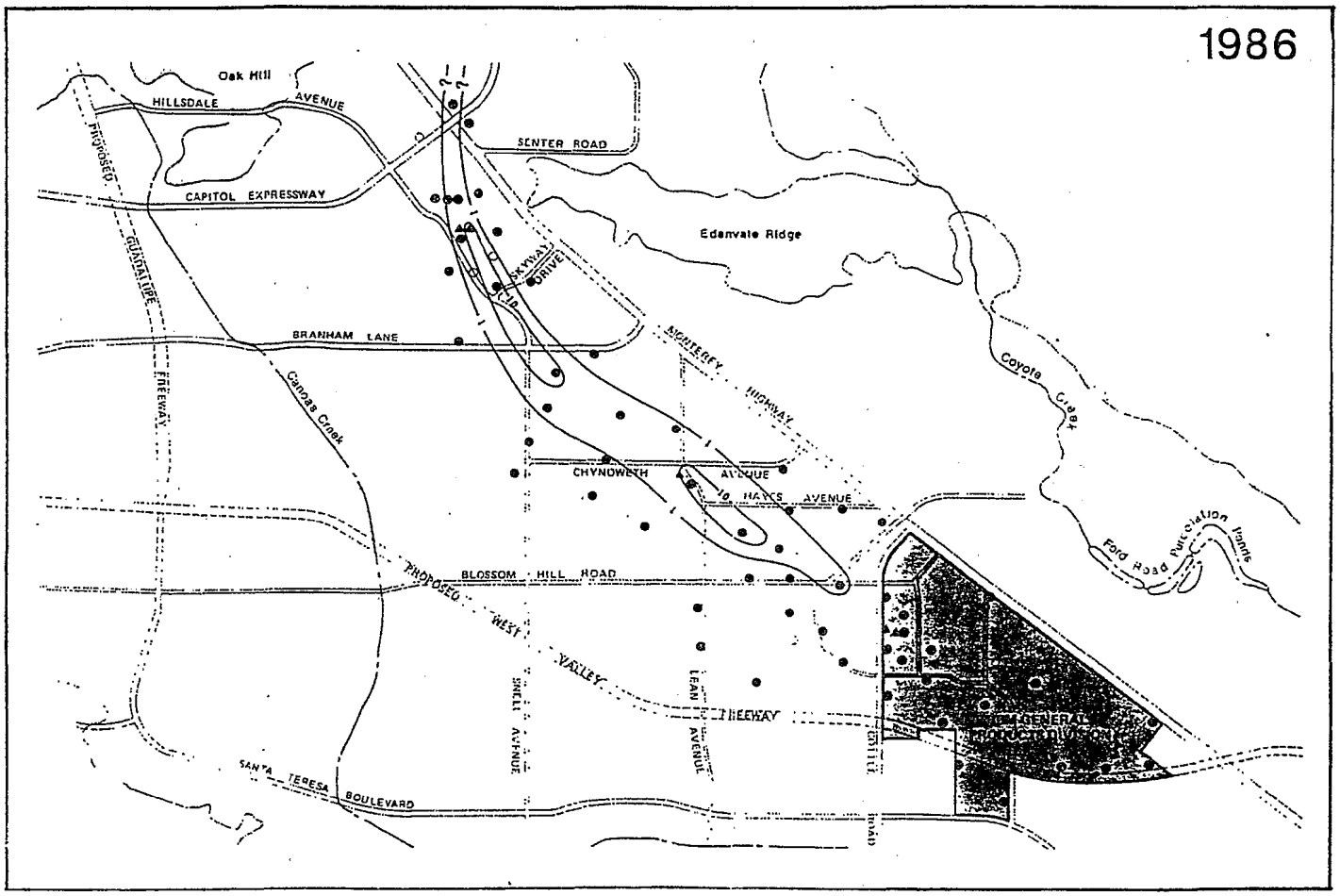
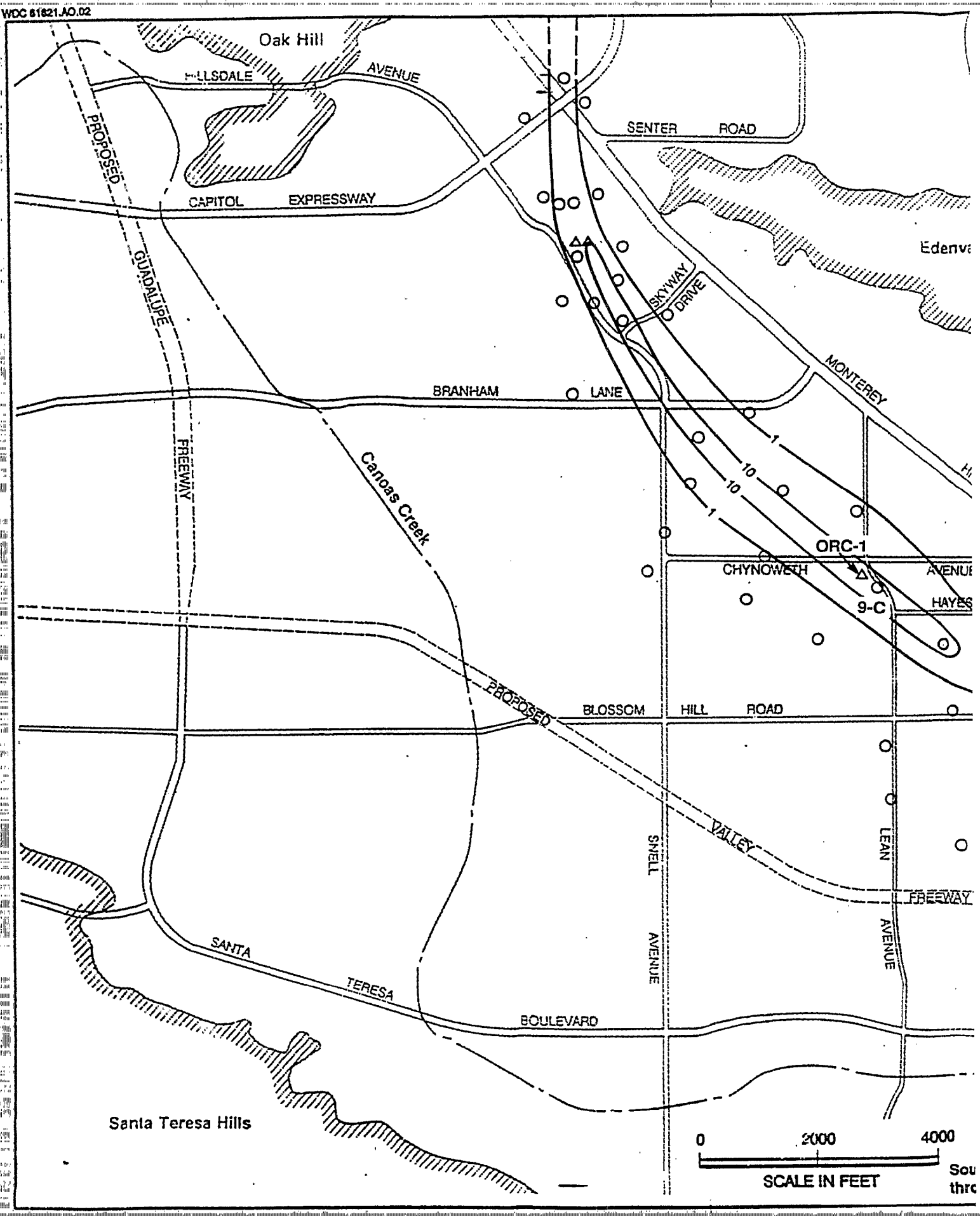


Figure 23
TCA IN THE C-AQUIFIER ZONE, SECOND QUARTER 1984 AND SECOND QUARTER 1986
IBM-SAN JOSE SITE

WDC 61621.AO.02



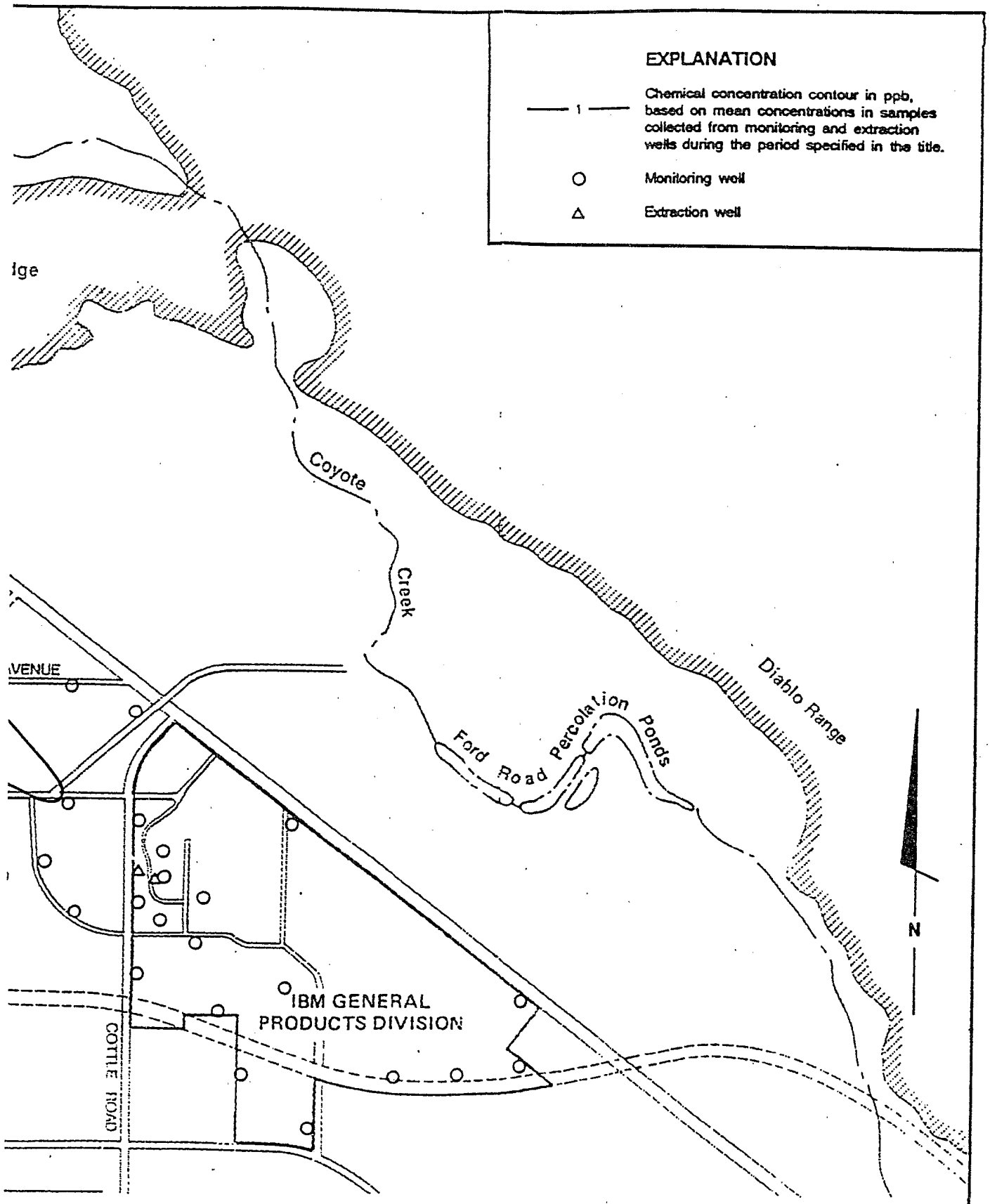


Figure 24
1,1-DCE IN THE C-AQUIFER ZONE, DURING THE PERIOD 9/26/88 - 12/30/88
IBM-SAN JOSE SITE

ILA. January, 1989. Quarterly Report, September 1988 ecember 1988, IBM Groundwater Restoration Program.

Table 6
SUMMARY OF GROUND-WATER EXTRACTION AND CHEMICAL MASS REMOVED

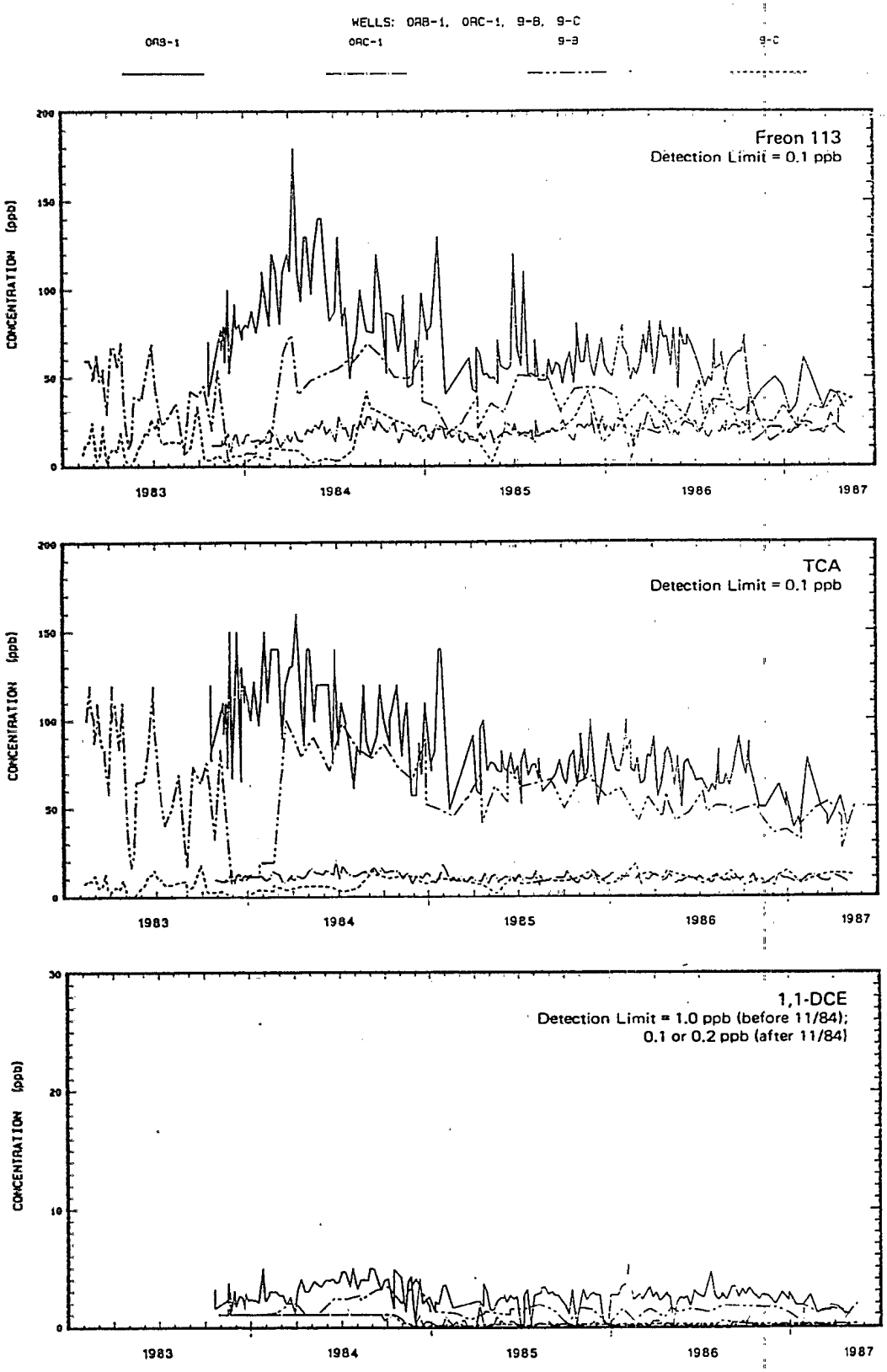
		Freon 113		1,1,1-TCA		1,1-DCE	
	Millions of Gallons*	Pounds Removed	Total Mass Removal Rate (Pounds/ Million Gals.)	Pounds Removed	Total Mass Removal Rate (Pounds/ Million Gals.)	Pounds Removed	Total Mass Removal Rate (Pounds/ Million Gals.)
1983**	735	2,121	2.885	75	0.102	17	0.023
1984	2,150	2,038	0.948	284	0.132	32	0.015
1985	2,865	1,000	0.349	215	0.075	9	0.003
1986	3,154	914	0.290	219	0.070	15	0.005
1987	3,243	564	0.174	165	0.051	11	0.003
	12,147	6,637		958		84	

	Total Pounds Removed***	1,1,1-TCA + 1,1-DCE Pounds Removed
1983**	2,213	92
1984	2,354	316
1985	1,224	224
1986	1,148	234
1987	740	176
	7,679	1,043

*Ground water extracted by all operating extraction wells
**For the period June through December 1983
***Chemical mass removed by extraction wells (Freon 113, 1,1,1-TCA, and 1,1-DCE)

WDR428/045

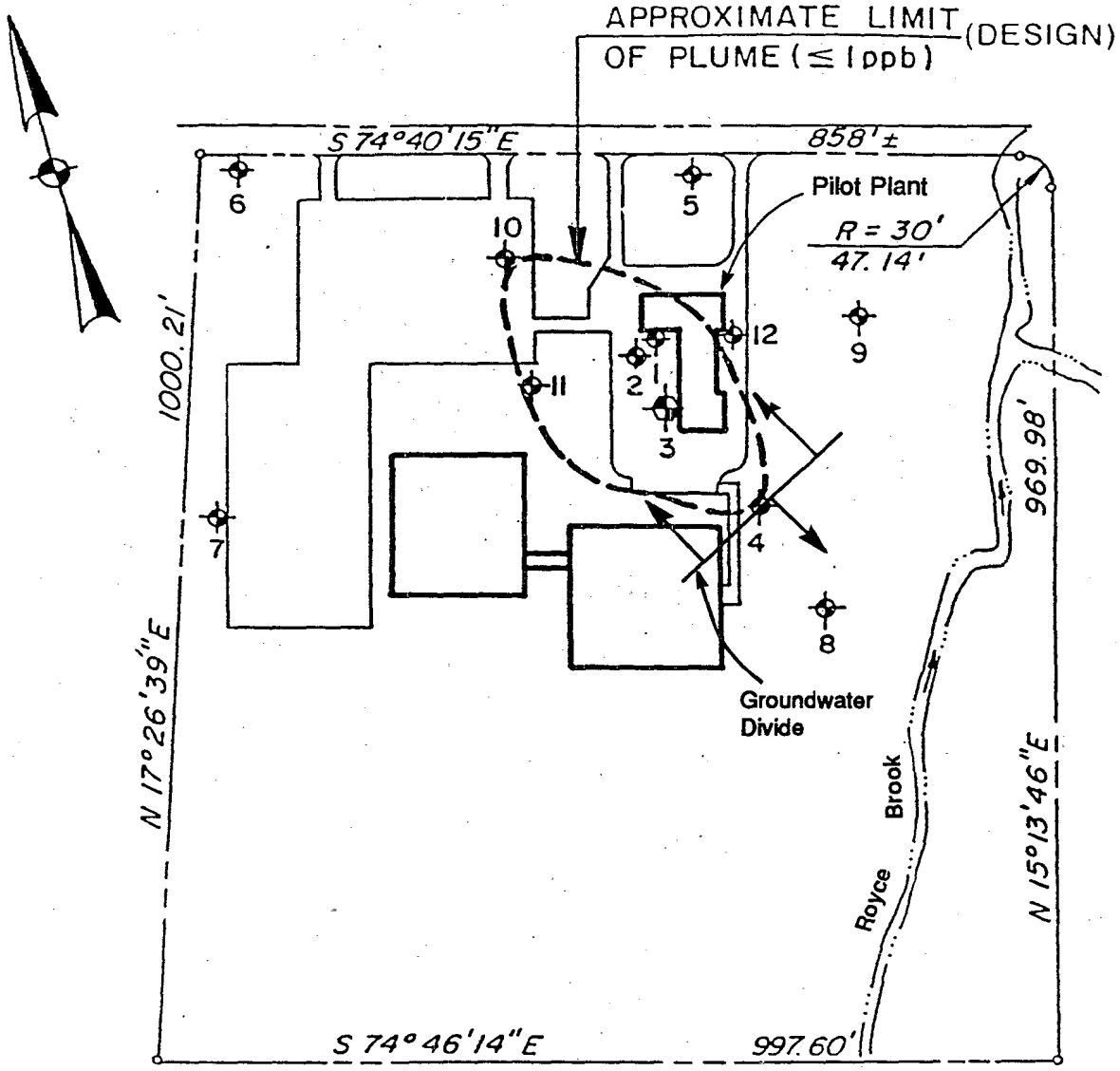
WDC 61621.A0.02



DRAFT

Source: HLA. June, 1987. Appendix B: Summary of Hydrogeologic Studies, Draft Comprehensive Plan, IBM Groundwater Restoration Program.

Figure 25
CHEMICAL CONCENTRATION TRENDS
WELLS ORB-1, ORC-1, 9-B AND 9-C
IBM-SAN JOSE SITE



LEGEND:

MONITORING WELL

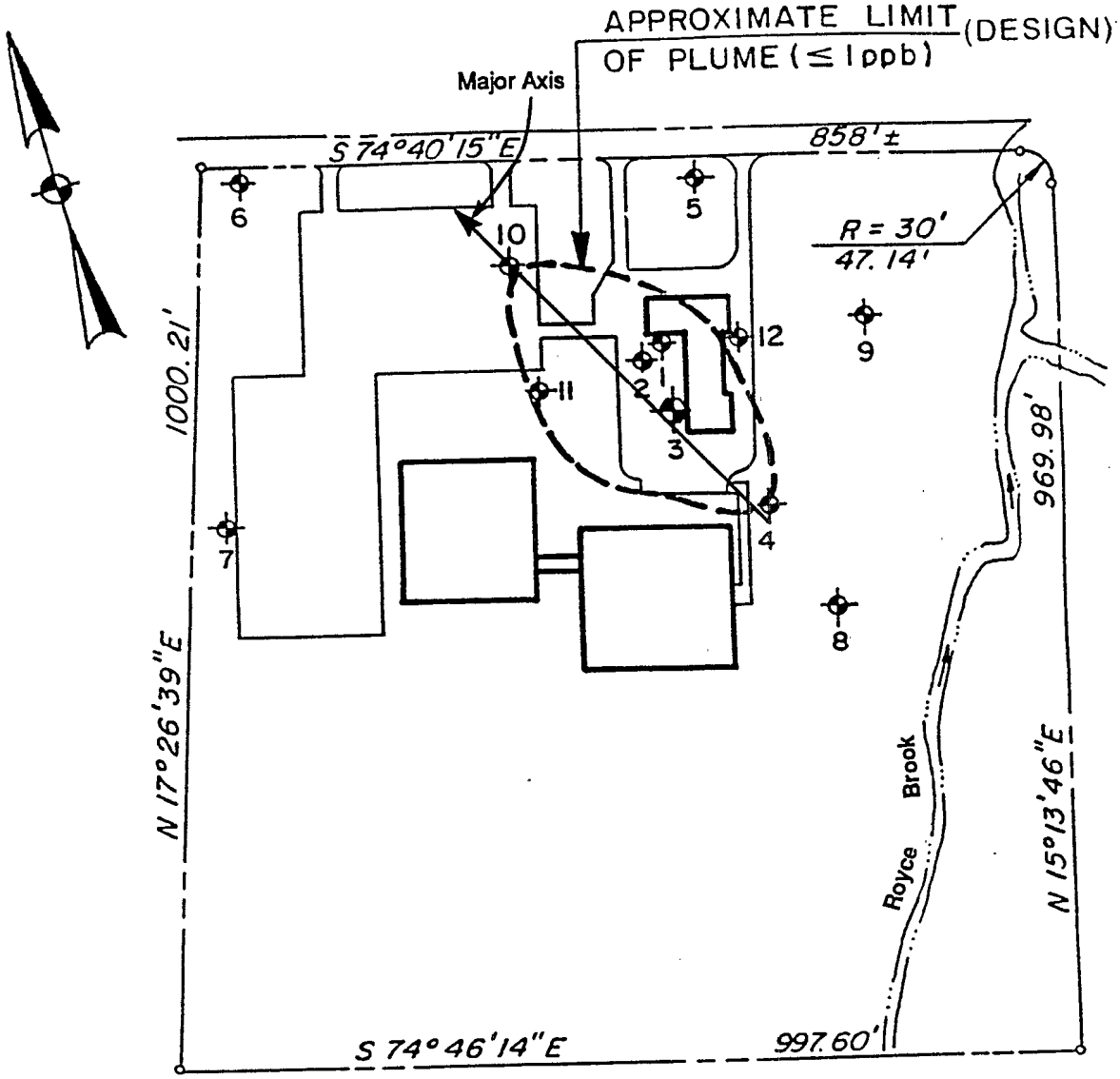
RECOVERY WELL

Figure 1
MONITORING WELL LOCATION MAP SHOWING GROUND-WATER DIVIDE

NICHOLS ENGINEERING SITE

Source: Storch Engineers. September, 1988.

WDC 61621.AO.02



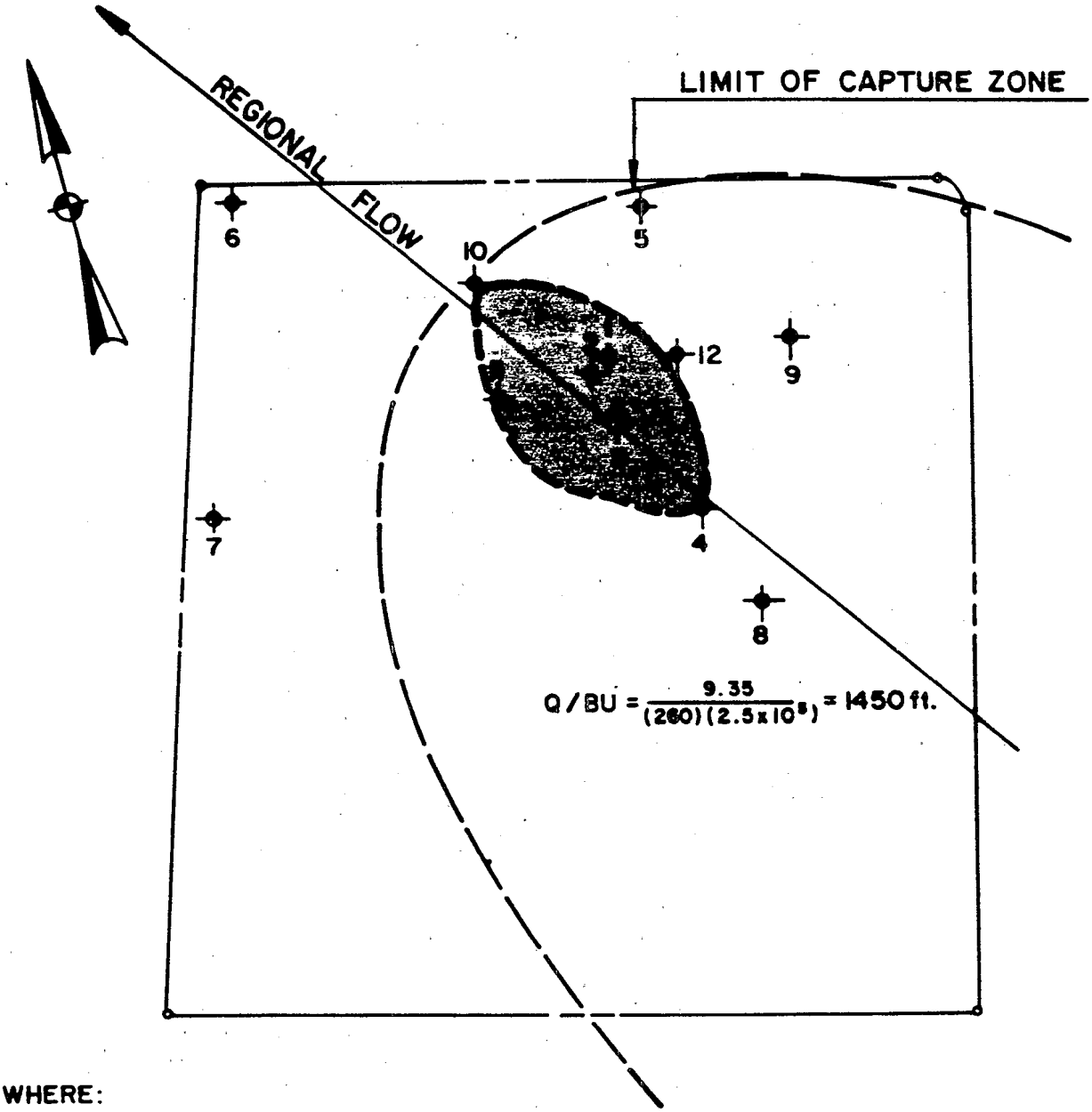
LEGEND:

MONITORING WELL

RECOVERY WELL

Figure 2
MONITORING WELL LOCATION MAP
SHOWING MAJOR AXIS OF TRANSMISSIVITY
NICHOLS ENGINEERING SITE

Source: Storch Engineers. September, 1988.



WHERE:

Q/BU = MAXIMUM DIMENSION OF CAPTURE ZONE PERPENDICULAR TO GROUND WATER FLOW (ft)

Q = RECOVERY WELL PUMPING RATE (ft^3/ min.) = 9.35 (70 gpm)

B = ESTIMATED AQUIFER THICKNESS (ft) = 260

U = Ki = DARCIAN VELOCITY (ft / min.) = 2.5×10^{-5}

K = HYDRAULIC CONDUCTIVITY (ft/min.) = 3×10^{-3}

i = HYDRAULIC GRADIENT (ft/ft) = 0.008

LEGEND:

✦ MONITORING WELL

⊕ RECOVERY WELL

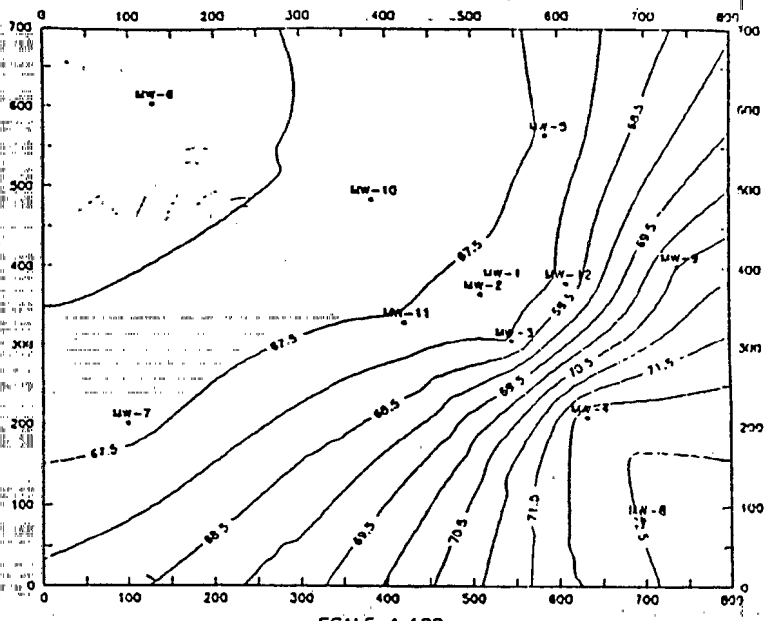
Figure 3
CAPTURE ZONE TYPE CURVE ANALYSIS
FOR MW-3 AS RECOVERY WELL

Source: Storch Engineers. September, 1988.

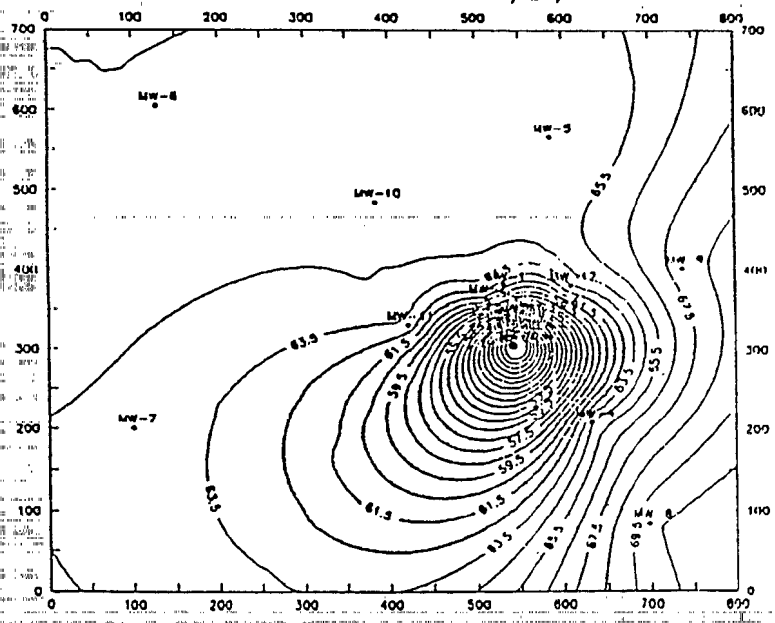
NICHOLS ENGINEERING SITE

WDC 61621.AO.02

POTENTIOMETRIC SURFACE 01/22/88



POTENTIOMETRIC SURFACE 07/21/88



Source: Storch Engineers. September, 1988.

Figure 4
POTENTIOMETRIC SURFACE
(JANUARY VS. JULY 1988)

NICHOLS ENGINEERING SITE

Table 4

SUMMARY OF ANALYTICAL RESULTS

(concentration in ppb)

Parameter	MW-1 1	MW-1 2	MW-1 3	MW-1 4	MW-1 5	MW-1 6	MW-1 7	MW-1 8	MW-1 9	MW-2 1	MW-2 2	MW-2 3	MW-2 4	MW-2 5	MW-2 6	MW-2 7	MW-2 8	MW-2 9
Chloroform	ND	17.0	19.0	6.8	10.0	12.0	9.3	12.0	5.6	21.0	17.0	15.0	9.0	9.3	14.0	13.0	7.3*	7.7
Toluene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Methylene Chloride	ND	ND	1.8 z	1.4 z	37.0 @	ND	3.8 *	32.0	2.9 z	ND	ND	3.9 z	ND	1.7 z	ND	3.2 *	32.0	ND
Carbon Tetrachloride	1980.0	420.0	410.0	150.0	260.0	260.0	230.0	270.0	98.0	610.0	310.0	310.0	180.0	190.0	210.0	290.0	120.0	120.0
Trichloroethene	ND	1.7 *	1.6 *	1.5 *	ND	ND	ND	ND	ND	ND	1.7 *	1.9 *	ND	1.1 *	ND	1.4 *	ND	ND
Tetrachloroethene	ND	14.0	13.0	5.1	9.8 *	7.7	7.3	7.2*	3.0 *	ND	11.0	9.4	4.7	5.5	8.7	9.4	ND	4.5 *
1,1,1-Trichloroethane	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Vinyl Acetate	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

Parameter	MW-3 1	MW-3 2	MW-3 3	MW-3 4	MW-3 5	MW-3 6	MW-3 7	MW-3 8	MW-3 9	MW-4 1	MW-4 2	MW-4 3	MW-4 4	MW-4 5	MW-4 6	MW-4 7	MW-4 8	MW-4 9
Chloroform	1.6	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	NA	NA	NA	ND	NA
Toluene	1.7	ND	ND	ND	ND	ND	ND	ND	ND	9.1	ND	ND	ND	NA	NA	NA	ND	NA
Methylene Chloride	2.4	1.5 @	12.0	ND	1.3 z	ND	3.6 *	5.8	4.6 z	ND	2.9 @	9.4	1.4 *	1.3 z	NA	NA	10.0 @	NA
Carbon Tetrachloride	1.8	ND	ND	ND	ND	ND	ND	ND	ND	2.6	1.0 *	ND	1.9 *	1.3 *	NA	NA	ND	NA
Trichloroethene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	NA	NA	ND	NA
Tetrachloroethene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	NA	NA	ND	NA
1,1,1-Trichloroethane	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	NA	NA	ND	NA
Vinyl Acetate	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	NA	NA	ND	NA

Parameter	MW-5 1	MW-5 2	MW-5 3	MW-5 4	MW-5 5	MW-5 6	MW-5 7	MW-5 8	MW-5 9	MW-6 1	MW-6 2	MW-6 3	MW-6 4	MW-6 5	MW-6 6	MW-6 7	MW-6 8	MW-6 9
Chloroform	ND	NA	NA	NA	NA	NA	NA	ND	ND	ND	ND	ND	ND	ND	NA	NA	ND	NA
Toluene	8.2	NA	NA	NA	NA	NA	NA	ND	ND	ND	ND	ND	ND	ND	NA	NA	ND	NA
Methylene Chloride	1.4 *	NA	NA	NA	NA	NA	NA	1.1 z	7.2 z	3.5 *	8.8 @	1.2 z	ND	1.5 z	NA	NA	10.0 z	NA
Carbon Tetrachloride	1.6 *	NA	NA	NA	NA	NA	NA	7.4	7.0	ND	ND	ND	ND	ND	NA	NA	ND	NA
Trichloroethene	ND	NA	NA	NA	NA	NA	NA	ND	ND	2.4	ND	ND	ND	ND	NA	NA	ND	NA
Tetrachloroethene	ND	NA	NA	NA	NA	NA	NA	ND	ND	ND	ND	ND	ND	ND	NA	NA	ND	NA
1,1,1-Trichloroethane	ND	NA	NA	NA	NA	NA	NA	ND	ND	ND	ND	ND	ND	ND	NA	NA	ND	NA
Vinyl Acetate	ND	NA	NA	NA	NA	NA	NA	ND	ND	ND	ND	ND	ND	2.5 @	NA	NA	ND	NA

NA= Not Analyzed
ND= Not Detected
*= Trace concentrations below the reporting limit
@= Analyte also detected in ERCO Procedural Blank
z= Both trace concentrations detected below the reporting limit and analyte detected in ERCO Procedural Blank

DC: 1395MARV

Sampling Dates:
1= January 6, 1988 (MW-6, MW-7, MW-8, MW-9)
January 7, 1988 (MW-1, MW-2, MW-3, MW-4, MW-5, MW-10, MW-11, MW-12)
2= February 8, 1988
3= February 22, 1988
4= March 21, 1988
5= April 19, 1988
6= May 19, 1988
7= June 21, 1988
8= July 21, 1988
July 22, 1988
9=October 6, 1988

Table 4 (continued)

(concentration in ppb)

Parameter	MW-7 1	MW-7 2	MW-7 3	MW-7 4	MW-7 5	MW-7 6	MW-7 7	MW-7 8	MW-7 9	MW-8 1	MW-8 2	MW-8 3	MW-8 4	MW-8 5	MW-8 6	MW-8 7	MW-8 8	MW-8 9
Chloroform	ND	NA	NA	NA	NA	NA	NA	ND	NA	ND	NA	NA	NA	NA	NA	NA	ND	NA
Toluene	1.6 *1	NA	NA	NA	NA	NA	NA	ND	NA	ND	NA	NA	NA	NA	NA	NA	ND	NA
Methylene Chloride	2.4 *1	NA	NA	NA	NA	NA	NA	16.0 z1	NA	2.5 *1	NA	NA	NA	NA	NA	NA	3.0 z1	NA
Carbon Tetrachloride	ND	NA	NA	NA	NA	NA	NA	ND	NA	ND	NA	NA	NA	NA	NA	NA	ND	NA
Trichloroethene	ND	NA	NA	NA	NA	NA	NA	ND	NA	ND	NA	NA	NA	NA	NA	NA	ND	NA
Tetrachloroethene	ND	NA	NA	NA	NA	NA	NA	ND	NA	ND	NA	NA	NA	NA	NA	NA	ND	NA
1,1,1-Trichloroethane	ND	NA	NA	NA	NA	NA	NA	ND	NA	ND	NA	NA	NA	NA	NA	NA	ND	NA
Vinyl Acetate	ND	NA	NA	NA	NA	NA	NA	ND	NA	ND	NA	NA	NA	NA	NA	NA	ND	NA

Parameter	MW-9 1	MW-9 2	MW-9 3	MW-9 4	MW-9 5	MW-9 6	MW-9 7	MW-9 8	MW-9 9	MW-10 1	MW-10 2	MW-10 3	MW-10 4	MW-10 5	MW-10 6	MW-10 7	MW-10 8	MW-10 9
Chloroform	ND	NA	NA	NA	NA	NA	NA	ND	NA	1.7 *1	1.6 *1	1.4 *1	ND	ND	NA	NA	ND	ND
Toluene	ND	NA	NA	NA	NA	NA	NA	ND	NA	4.2	ND	ND	ND	ND	NA	NA	ND	ND
Methylene Chloride	ND	NA	NA	NA	NA	NA	NA	2.4 z1	NA	1.8 *1	2.4 *1	7.4	ND	ND	NA	NA	1.1*	ND
Carbon Tetrachloride	ND	NA	NA	NA	NA	NA	NA	ND	NA	9.8	ND	ND	2.8	3.0	NA	NA	1.4*	1.4 *1
Trichloroethene	ND	NA	NA	NA	NA	NA	NA	ND	NA	ND	ND	ND	ND	ND	NA	NA	ND	ND
Tetrachloroethene	ND	NA	NA	NA	NA	NA	NA	ND	NA	ND	ND	ND	ND	ND	NA	NA	ND	ND
1,1,1-Trichloroethane	ND	NA	NA	NA	NA	NA	NA	ND	NA	ND	ND	ND	ND	ND	NA	NA	ND	ND
Vinyl Acetate	ND	NA	NA	NA	NA	NA	NA	ND	NA	ND	ND	ND	ND	ND	NA	NA	ND	ND

Parameter	MW-11 1	MW-11 2	MW-11 3	MW-11 4	MW-11 5	MW-11 6	MW-11 7	MW-11 8	MW-11 9	MW-12 1	MW-12 2	MW-12 3	MW-12 4	MW-12 5	MW-12 6	MW-12 7	MW-12 8	MW-12 9
Chloroform	3.6	5.4	2.6	3.8	4.4	2.9	5.0	4.2	4.6 *1	ND	NA	NA	NA	NA	NA	NA	ND	NA
Toluene	6.7	ND	ND	ND	ND	ND	ND	ND	ND	3.2	NA	NA	NA	NA	NA	NA	ND	NA
Methylene Chloride	1.5 *1	ND	3.9 *1	1.5 *1	1.8 z1	1.9	2.4	3.0*	5.7 z1	3.0 *1	NA	NA	NA	NA	NA	NA	ND	NA
Carbon Tetrachloride	15.0	15.0	8.1	10.0	12.0	15.0	17.0	17.0	12.0	ND	NA	NA	NA	NA	NA	NA	ND	NA
Trichloroethene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	NA	NA	NA	NA	NA	NA	ND	NA
Tetrachloroethene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	NA	NA	NA	NA	NA	NA	ND	NA
1,1,1-Trichloroethane	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	NA	NA	NA	NA	NA	NA	ND	NA
Vinyl Acetate	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	NA	NA	NA	NA	NA	NA	ND	NA

NA= Not Analyzed
ND= Not Detected
*= Trace concentrations below the reporting limit
@= Analyte also detected in ERCO Procedural Blank
z= Both trace concentrations detected below the reporting limit and analyte detected in ERCO Procedural Blank

DC: 1395MARV

Sampling Dates:
1= January 6, 1988 (MW-6,MW-7,MW-8,MW-9)
January 7, 1988 (MW-1,MW-2,MW-3,MW-4,MW-5,MW-10,MW-11,MW-12)
2= February 8, 1988
3= February 22,1988
4= March 21, 1988
5= April 19, 1988
6= May 19, 1988
7= June 21, 1988
8= July 21, 1988
July 22, 1988
9=October 6, 1988

Table 4 (continued)

(concentration in ppb)

	FIELD BLANKS											TRIP BLANKS										
	1a	1b	2	3	4	5	6	7	8a	8b	9	1a	1b	2	3	4	5	6	7	8a	8b	9
Toluene	16.0	19.0	1.3 *	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Methylene Chloride	7.4	8.0	2.8 z	27.0	5.6	11.0 @	ND	6.3	9.1 @	2.7 @	12.0 z	2.3 *	1.9 *	ND	4.4 *	10.0	11.0	ND	4.2 *	1.6 *	2.9 *	6.8 z
Chloromethane	ND	5.5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,1,1-Trichloroethane	ND	ND	ND	ND	ND	3.2	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	2.0	ND	ND	ND	ND
Chloroform	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Carbon Tetrachloride	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Tetrachloroethene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	3.9	ND	ND	ND	ND	ND
Trichloroethene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

NA= Not Analyzed
ND= Not Detected
*= Trace concentrations below the reporting limit
@= Analyte also detected in ERCO Procedural Blank
z= Both trace concentrations detected below the reporting limit and analyte detected in ERCO Procedural Blank
NOTE: Acetone, used to decontaminate field sampling equipment, was detected in the field blank collected on October 6, 1988, at a concentration of 38 ppb. Field and trip blanks had not previously been analyzed for acetone.

Sampling Dates:
1a= January 6, 1988
1b=January 7, 1988
2= February 8, 1988
3= February 22, 1988
4= March 21, 1988
5= April 19, 1988
6= May 19, 1988
7= June 21, 1988
8a= July 21, 1988
8b= July 22, 1988
9= October 6, 1988

QC:MARV2

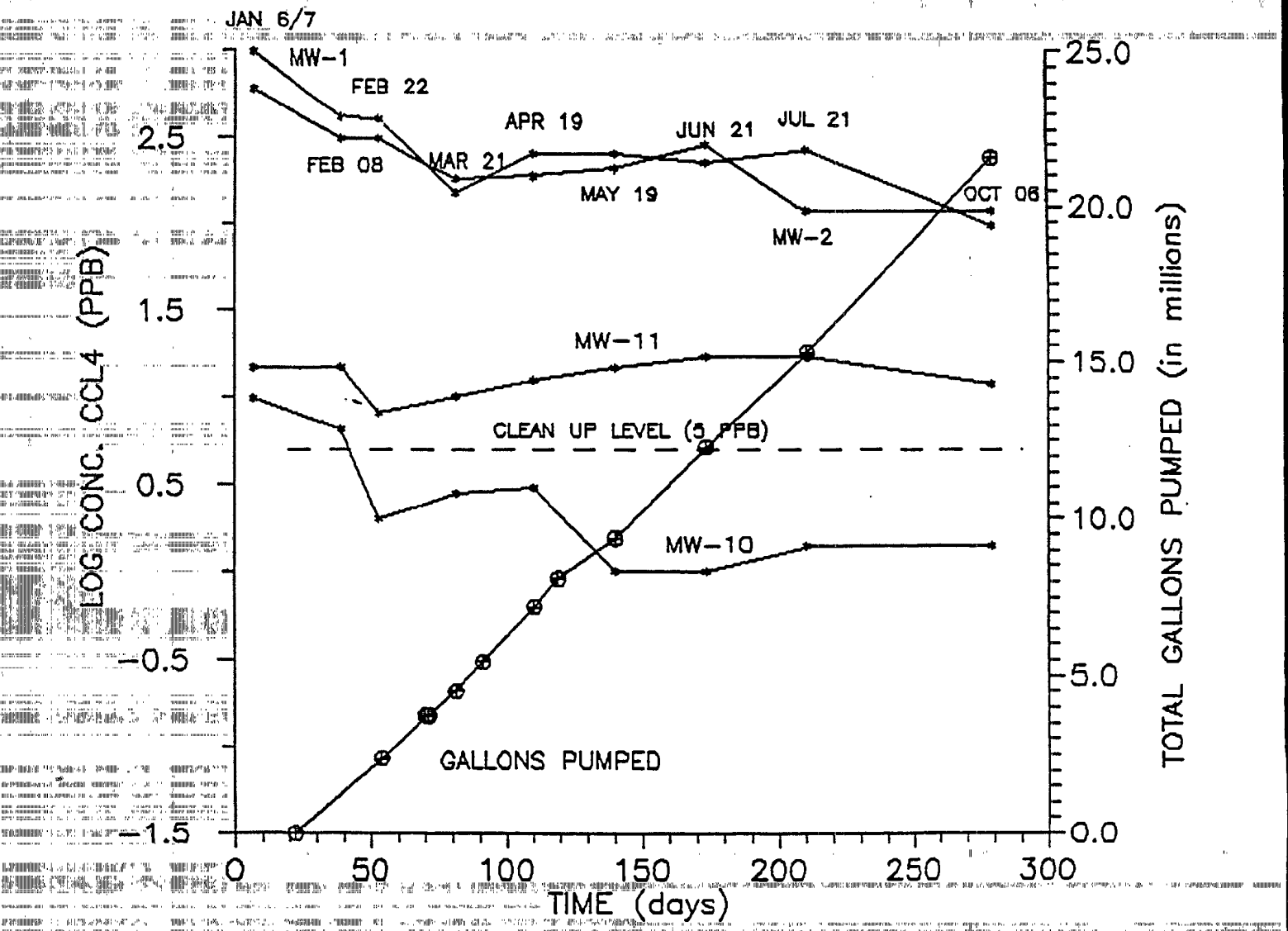
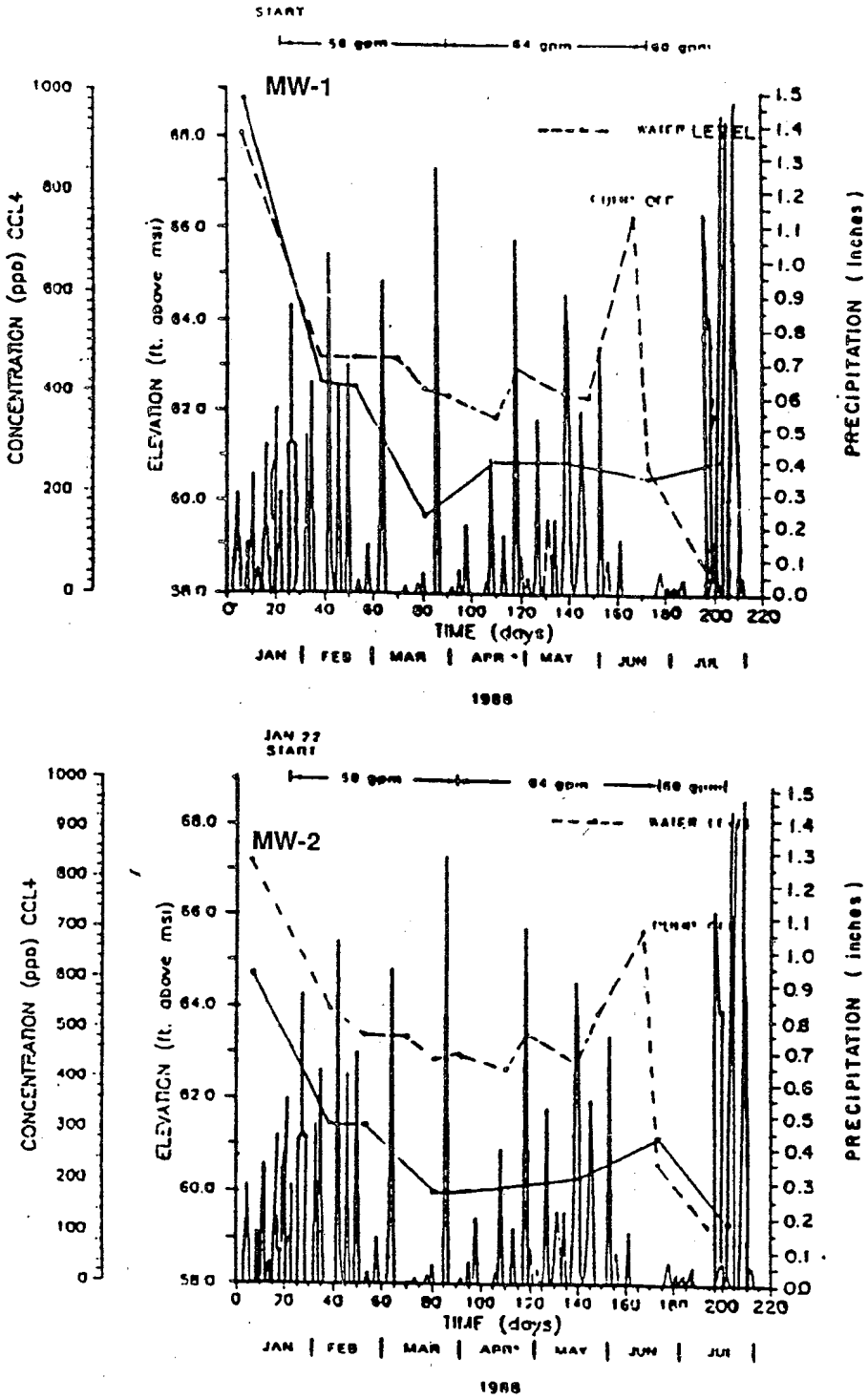


Figure 5
CCL_4 CONCENTRATION VS. DISCHARGE VOLUME

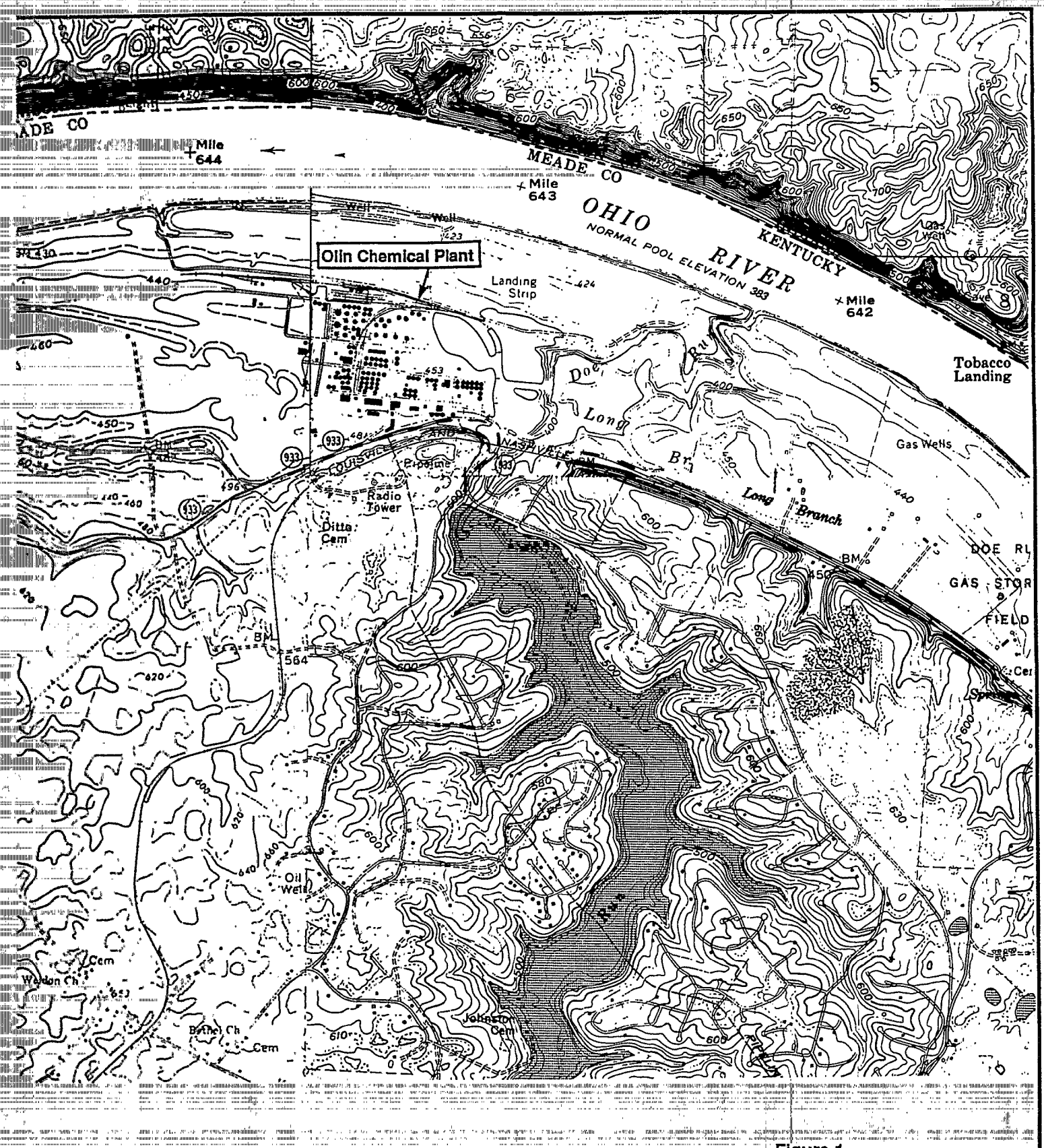
Source: Storch Engineers. November, 1988.

NICHOLS ENGINEERING SITE



Source: Storch Engineers. September, 1988.

Figure 6
RELATIONSHIP BETWEEN CCL_4 CONCENTRATION, WATER LEVEL, AND PRECIPITATION FOR MW-1, MW-2
NICHOLS ENGINEERING SITE



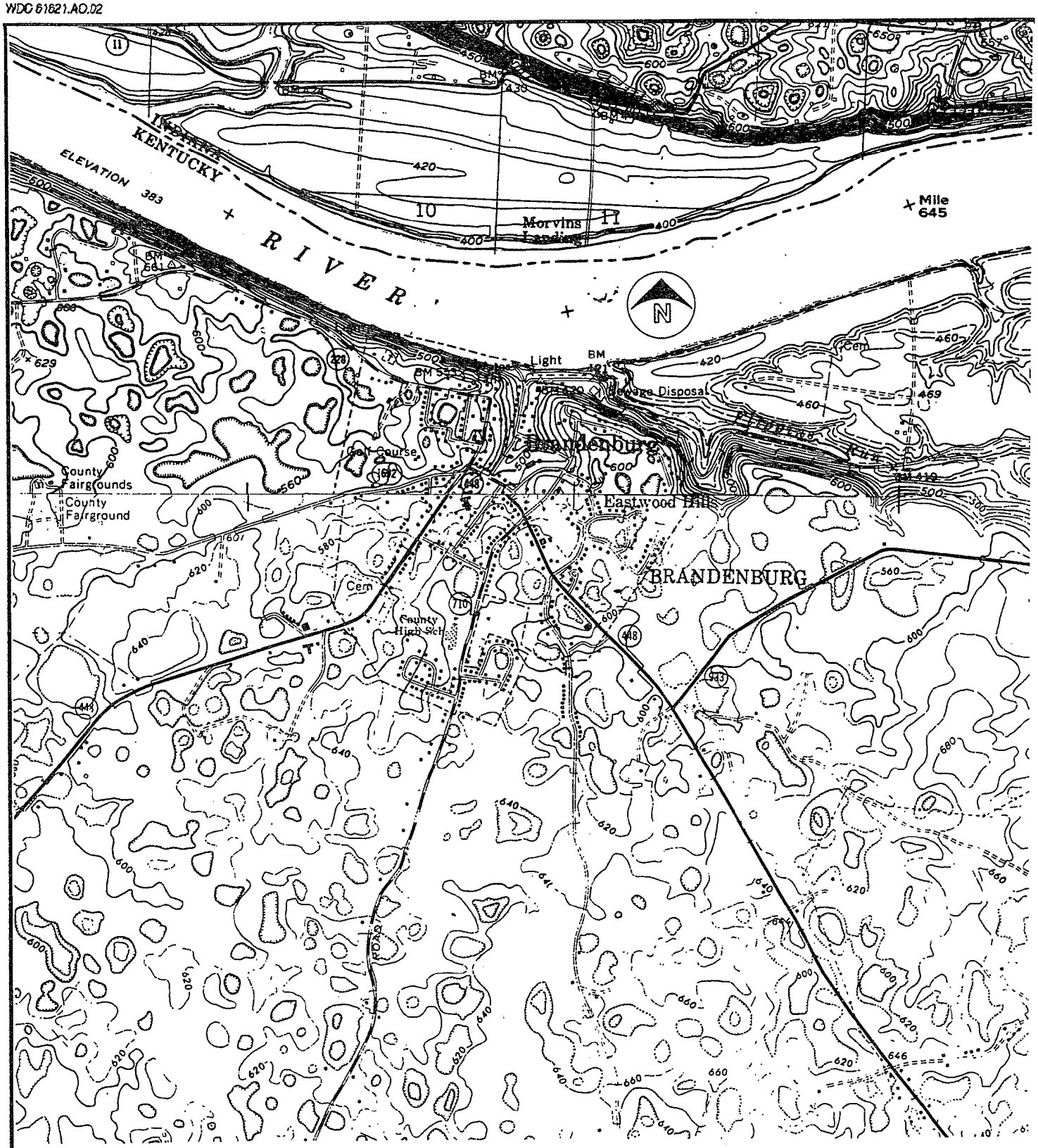
SCALE 1:24 000

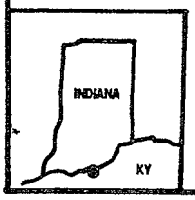
0 — 1 MILE

0 — 2000 — 3000 — 4000 — 5000 — 6000 — 7000 FEET

0 — 1 KILOMETER

Figure 1
SITE LOCATION MAP
OLIN CHEMICALS GROUP
DOE RUN PLANT
BRANDENBURG, KENTUCKY





Source: Olin Chemical. September, 1986. A Ground-water Assessment of Olin Chemicals Group Doe Run Plant, Brandenburg, Kentucky

WDC 61621.AO.02

Source: Olin Chemical. September, 1986. A Ground-water Assessment of Olin Chemicals Group Doe Run Plant, Brandenburg, Kentucky

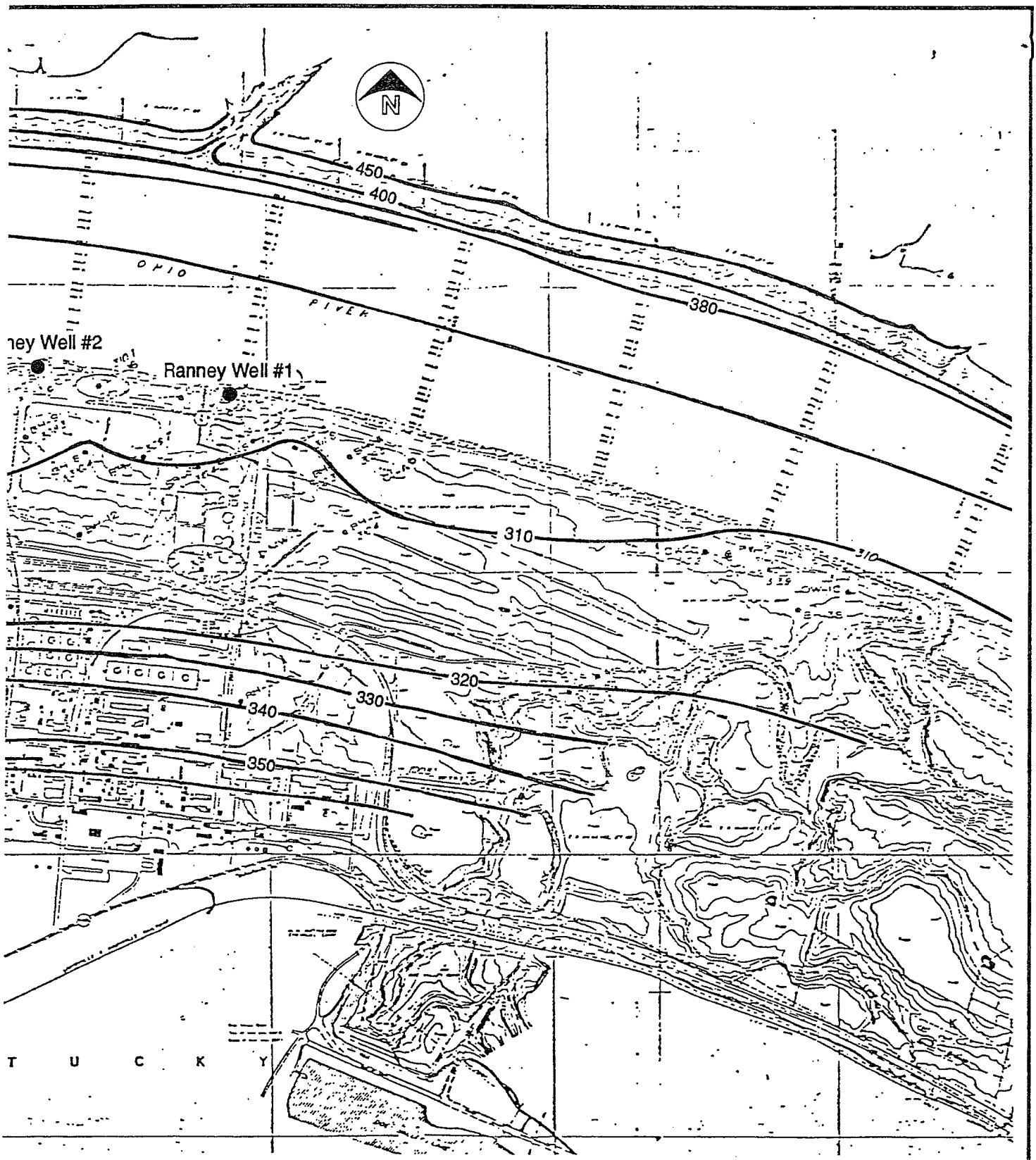
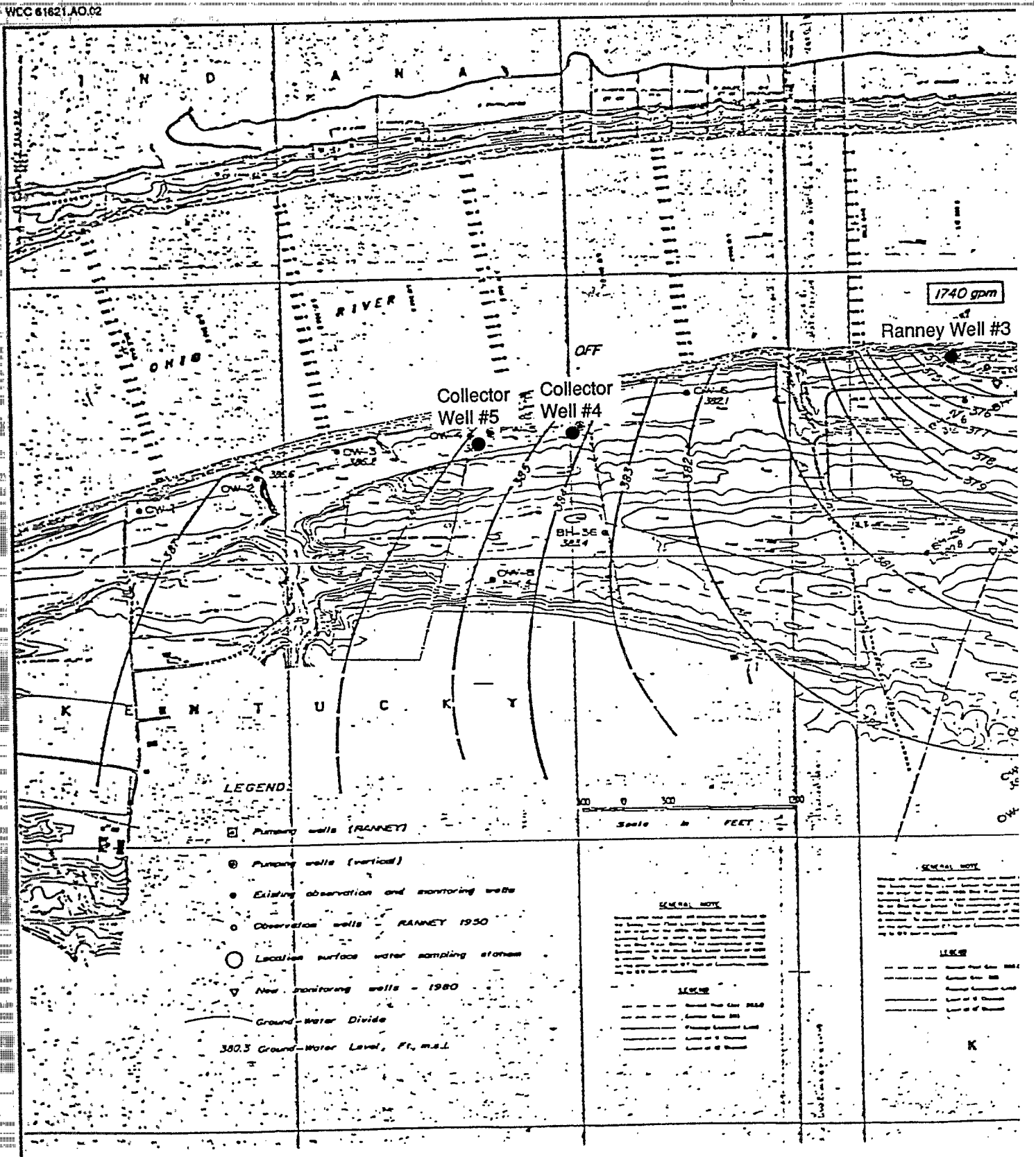


Figure 2
BEDROCK SURFACE ELEVATION MAP
OLIN CHEMICALS GROUP
DOE RUN PLANT

WCC 61621.AO.02



Source: Olin Chemical. September, 1986. A Ground-water Assessment of Olin Chemicals Group Doe Run Plant, Brandenburg, Kentucky

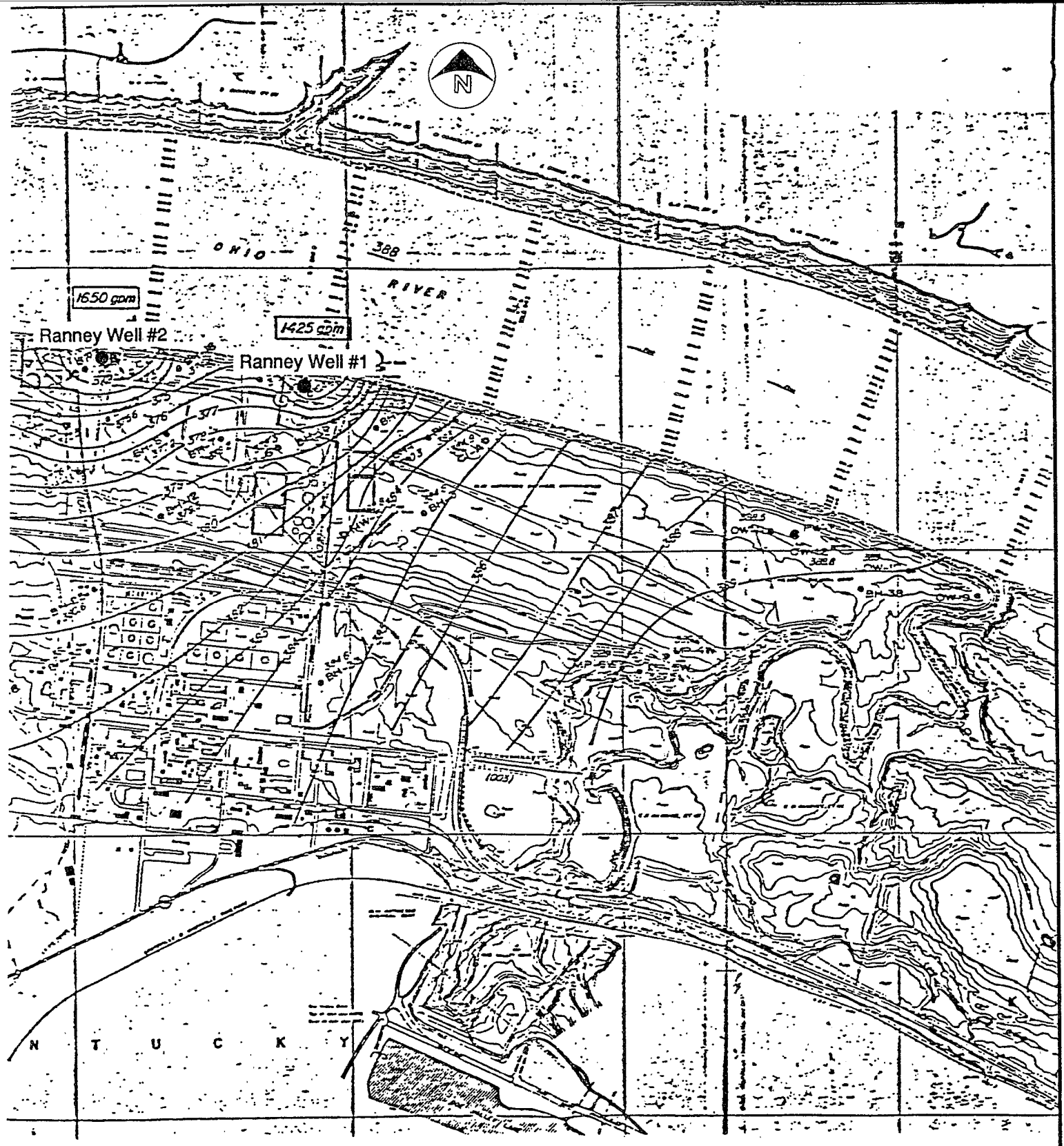
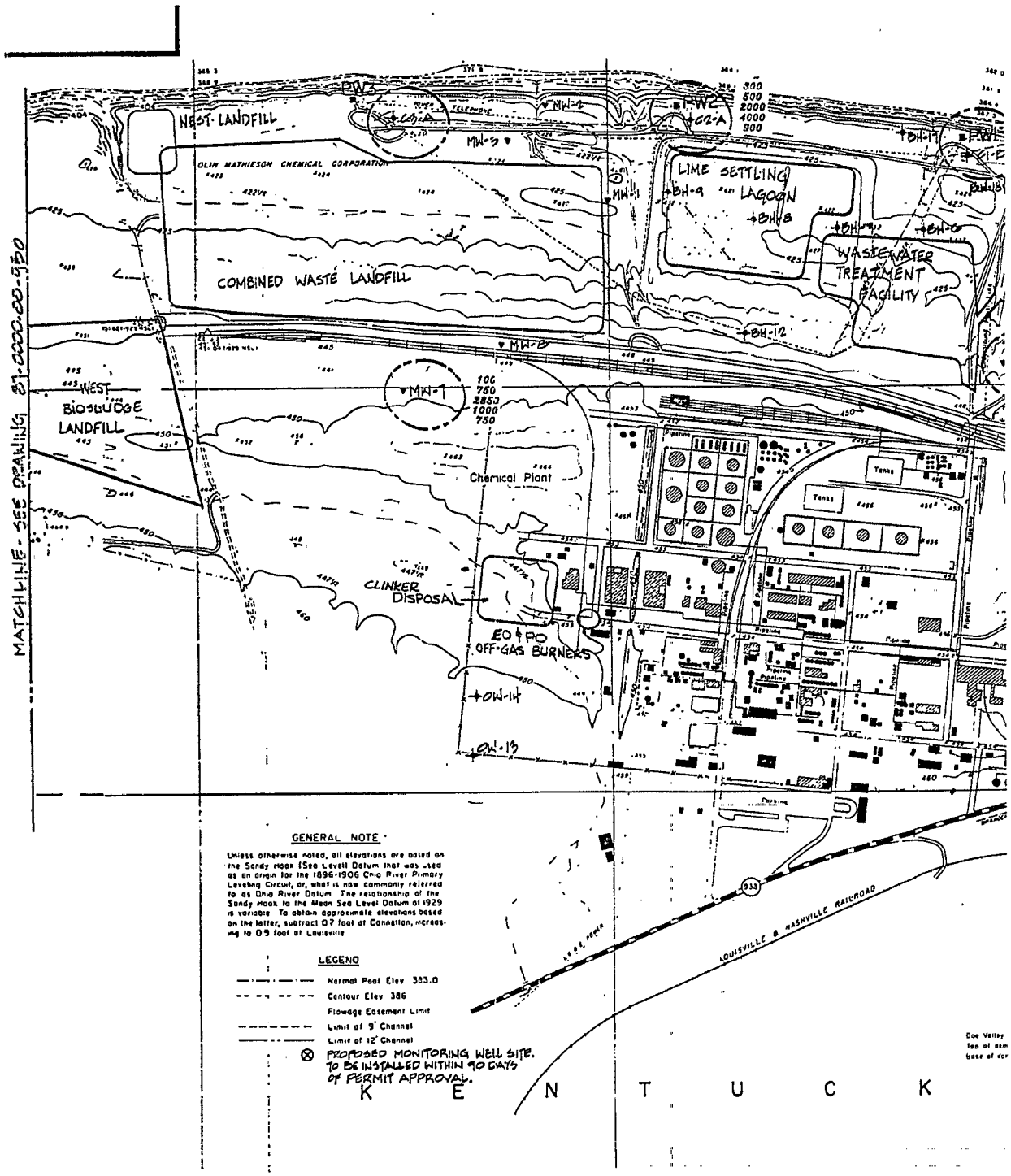


Figure 3
POTENTIOMETRIC SURFACE MAP
MAY 1980
OLIN CHEMICALS GROUP
DOE RUN PLANT



Source: Olin Chemical. March 7, 1988. Assessment of Need for Corrective Action at the Olin Chemicals Doe Run Plant, Brandenburg, Kentucky

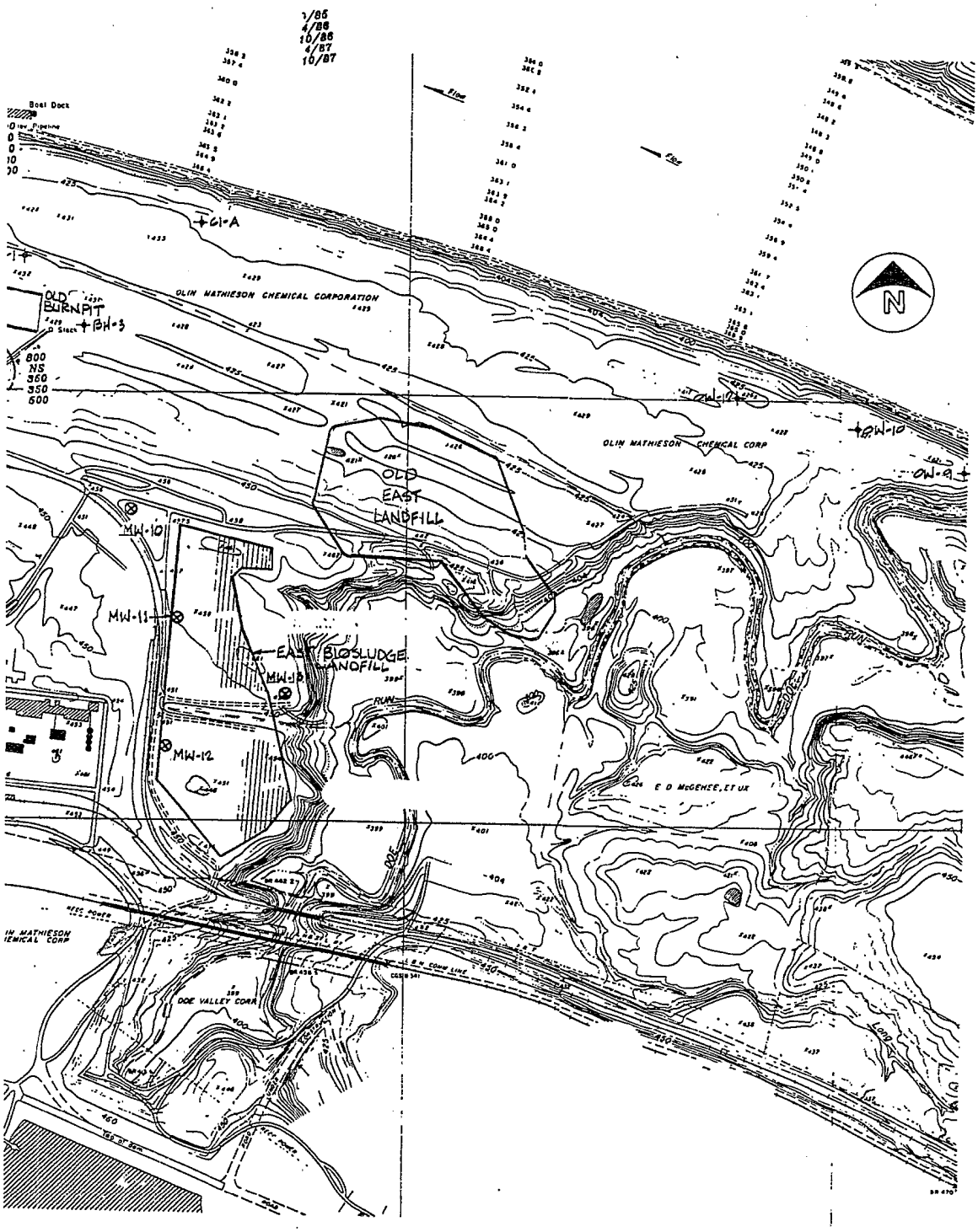
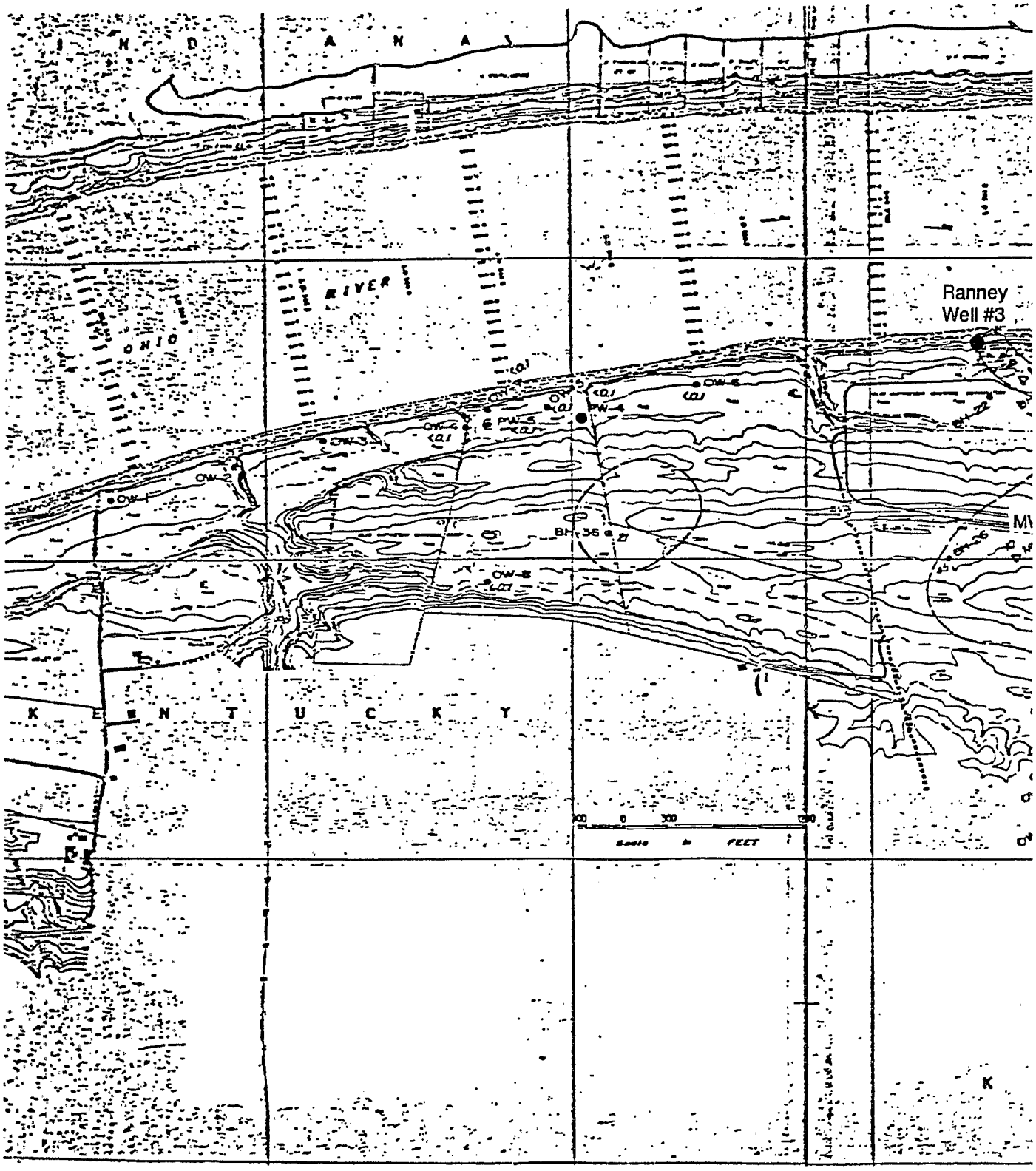


Figure 4
LOCATION OF SOLID WASTE MANAGEMENT UNITS
OLIN CHEMICALS GROUP
DOE RUN PLANT

WOC 61621.AO.02



Note: Shaded areas show locations of highest concentration.

Source: Olin Chemical. September, 1986. A Ground-water Assessment of Olin Chemicals Group Doe Run Plant, Brandenburg, Kentucky

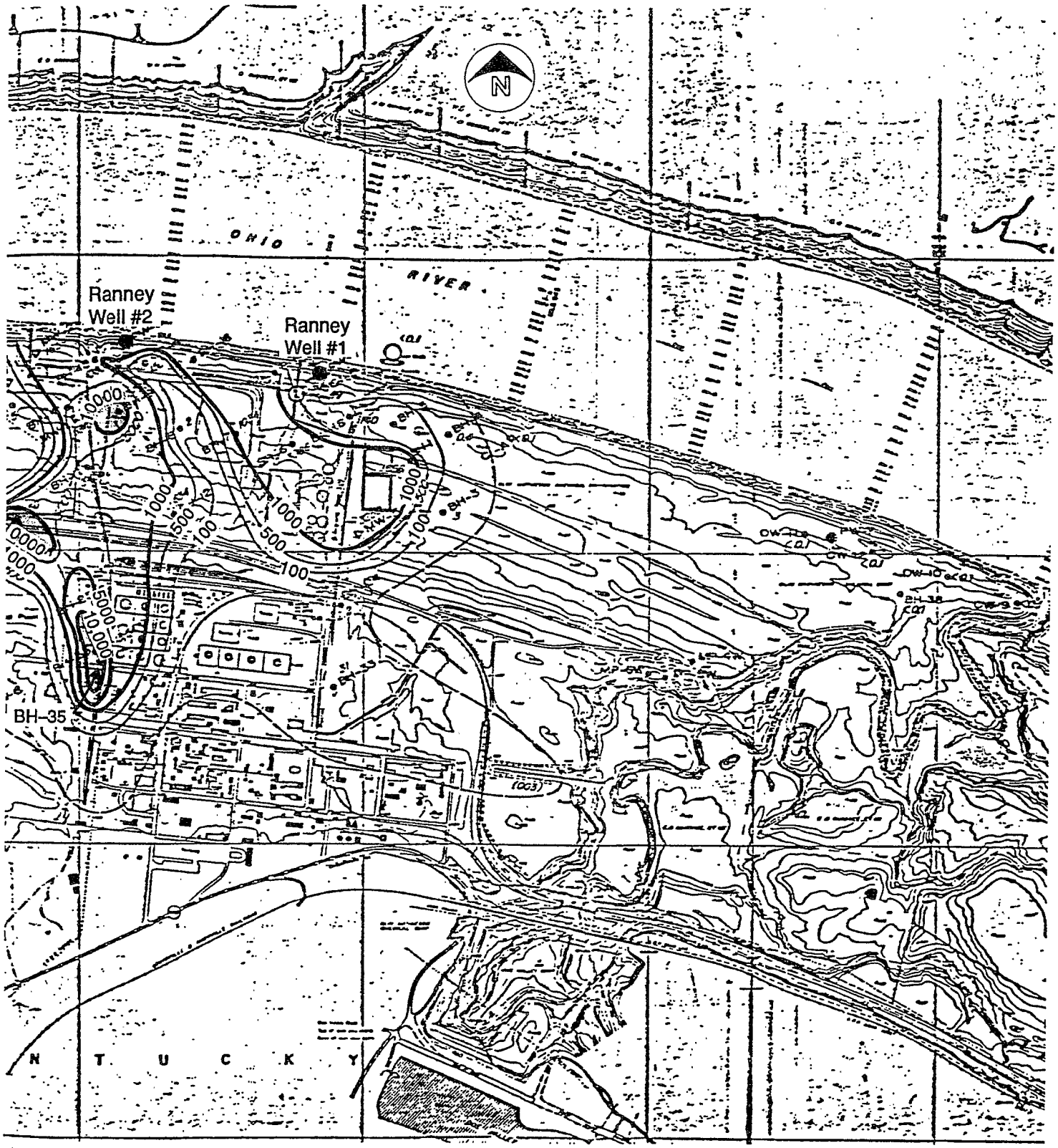


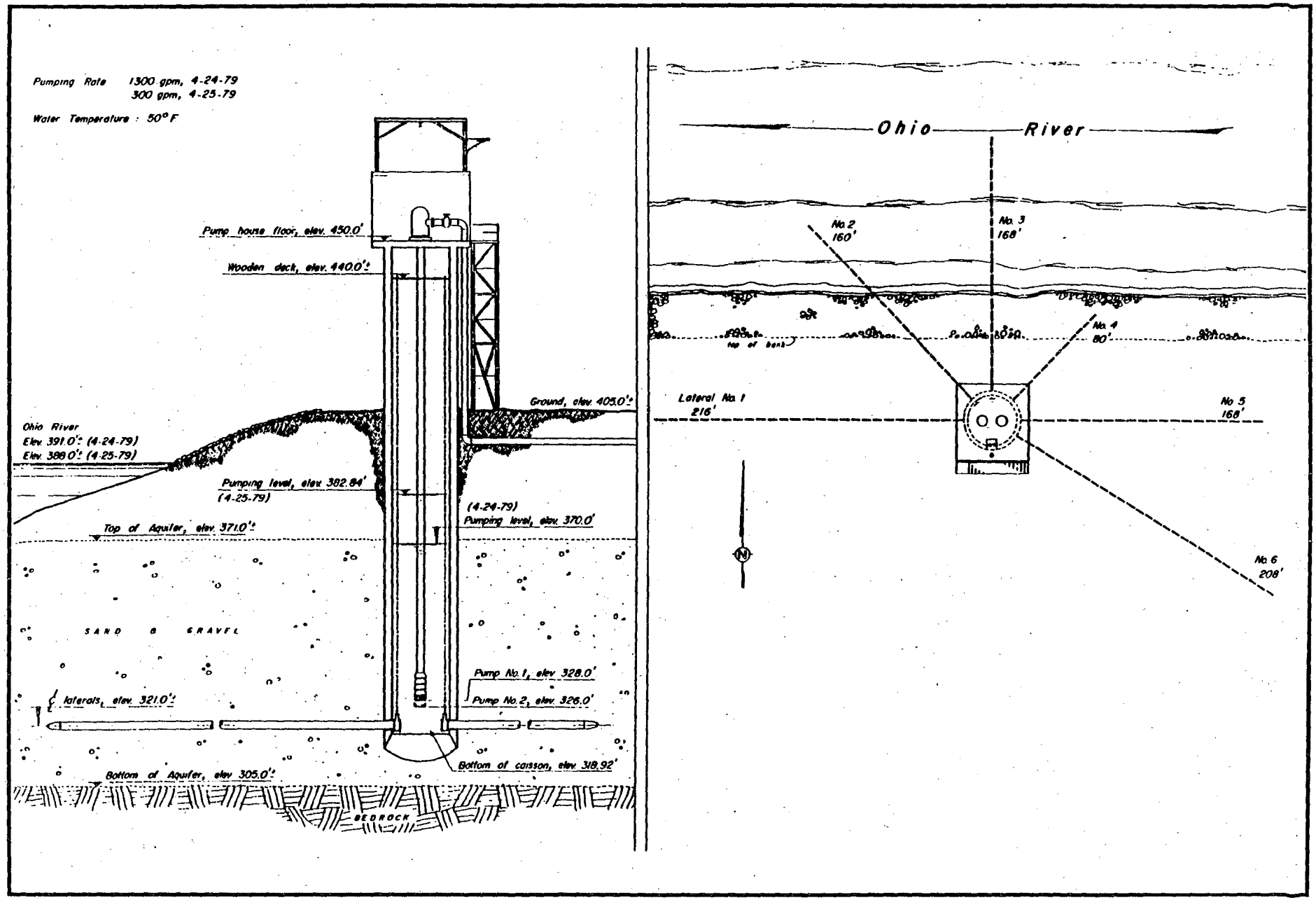
Figure 5
DISTRIBUTION OF DCEE IN GROUND WATER, MAY-JUNE 1980.
OLIN CHEMICALS GROUP
DOE RUN PLANT

WOC 61621.AO.02

Note: Shaded areas show locations of highest

Source: Olin Chemical. September, 1986. A Ground-water Assessment of Olin Chemicals Group Doe Run Plant, Brandenburg, Kentucky

Figure 6
DISTRIBUTION OF DCIPE IN GROUND WATER, MAY 1980.
OLIN CHEMICALS GROUP
DOE RUN PLANT



Source: Olin Chemical. March 7, 1988. Assessment of Need for Corrective Action at the Olin Chemicals Doe Run Plant, Brandenburg, Kentucky

Figure 7
SECTION AND PLAN VIEW OF A RANNEY WELL
OLIN CHEMICALS GROUP
DOE RUN PLANT

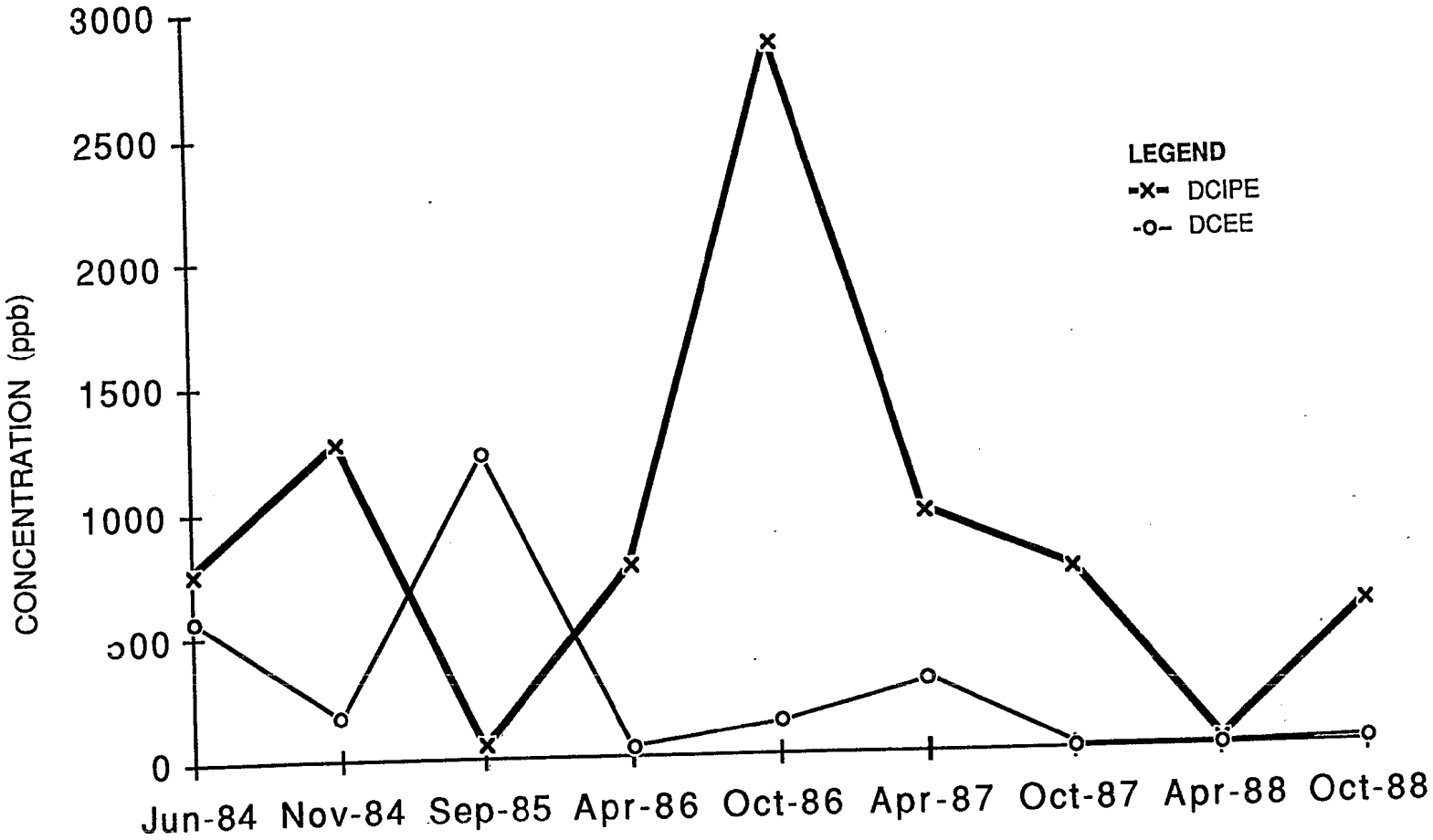


Figure 8
ETHER CONCENTRATIONS IN MW-7
OLIN CHEMICAL GROUP
DOE RUN PLANT

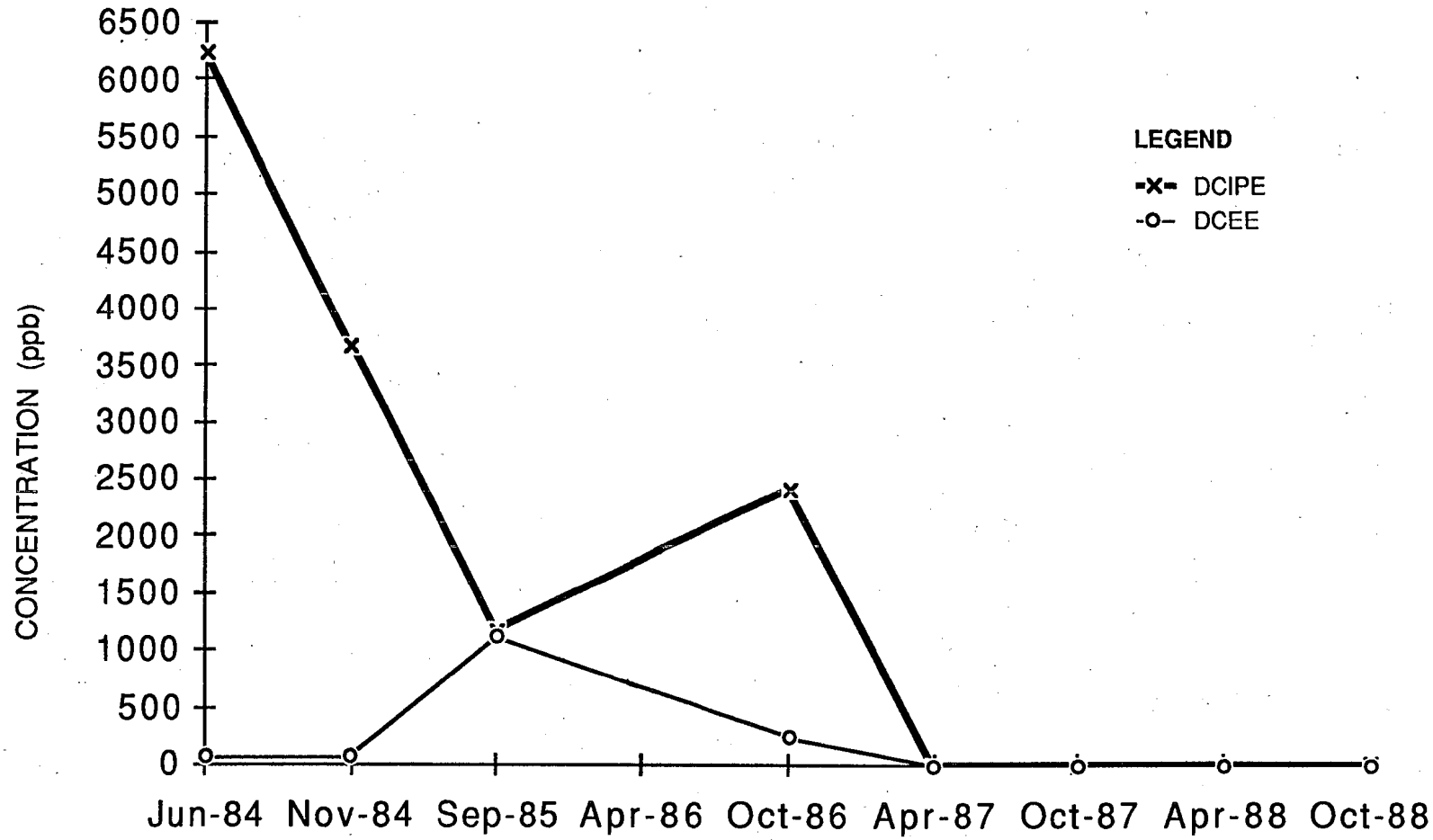


Figure 9
ETHER CONCENTRATIONS IN BH-1
OLIN CHEMICALS GROUP
DOE RUN PLANT

WDC 61621.A0.02

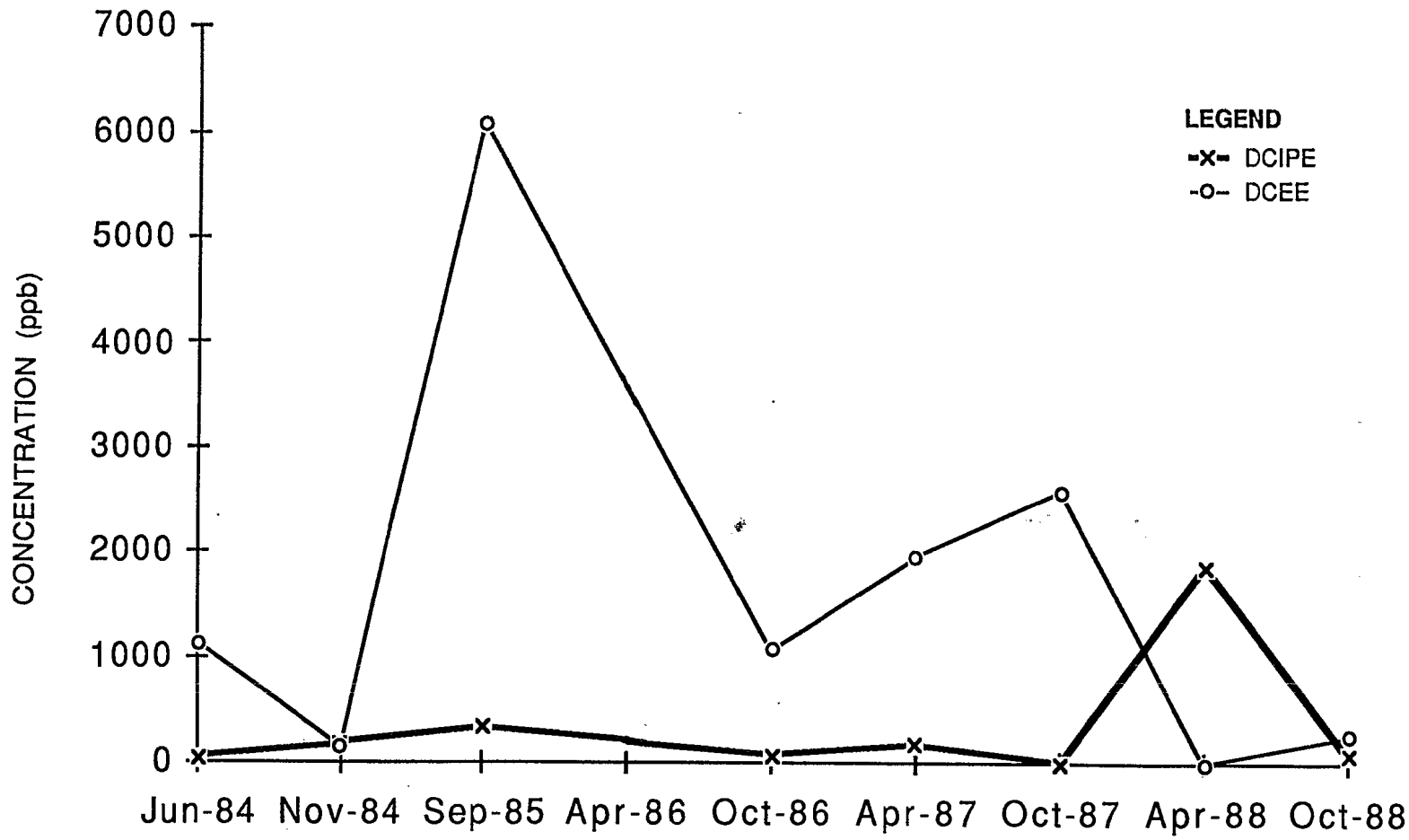
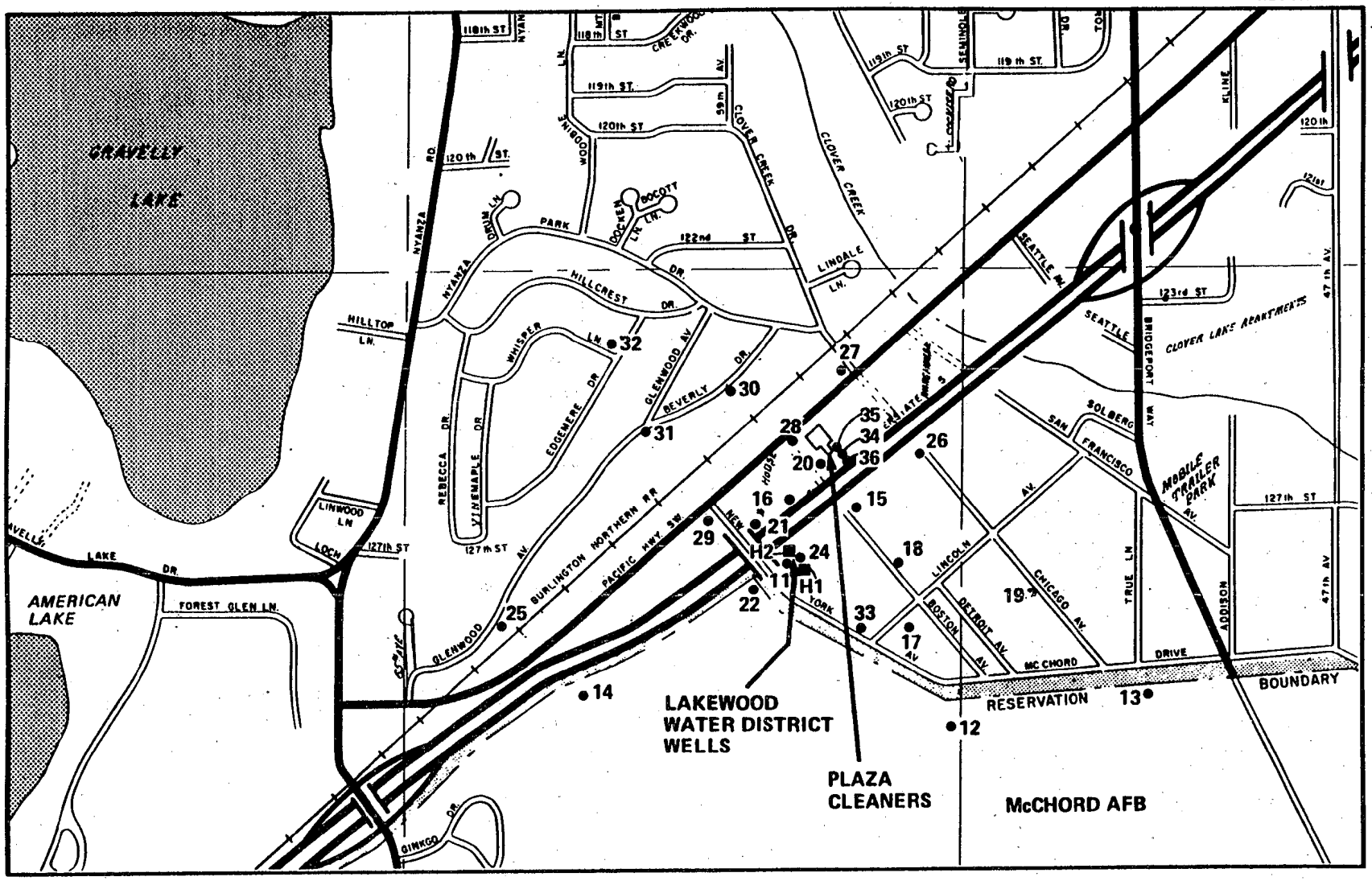


Figure 10
ETHER CONCENTRATIONS IN MW-2
OLIN CHEMICALS GROUP
DOE RUN PLANT

WDC 61621.AO.02

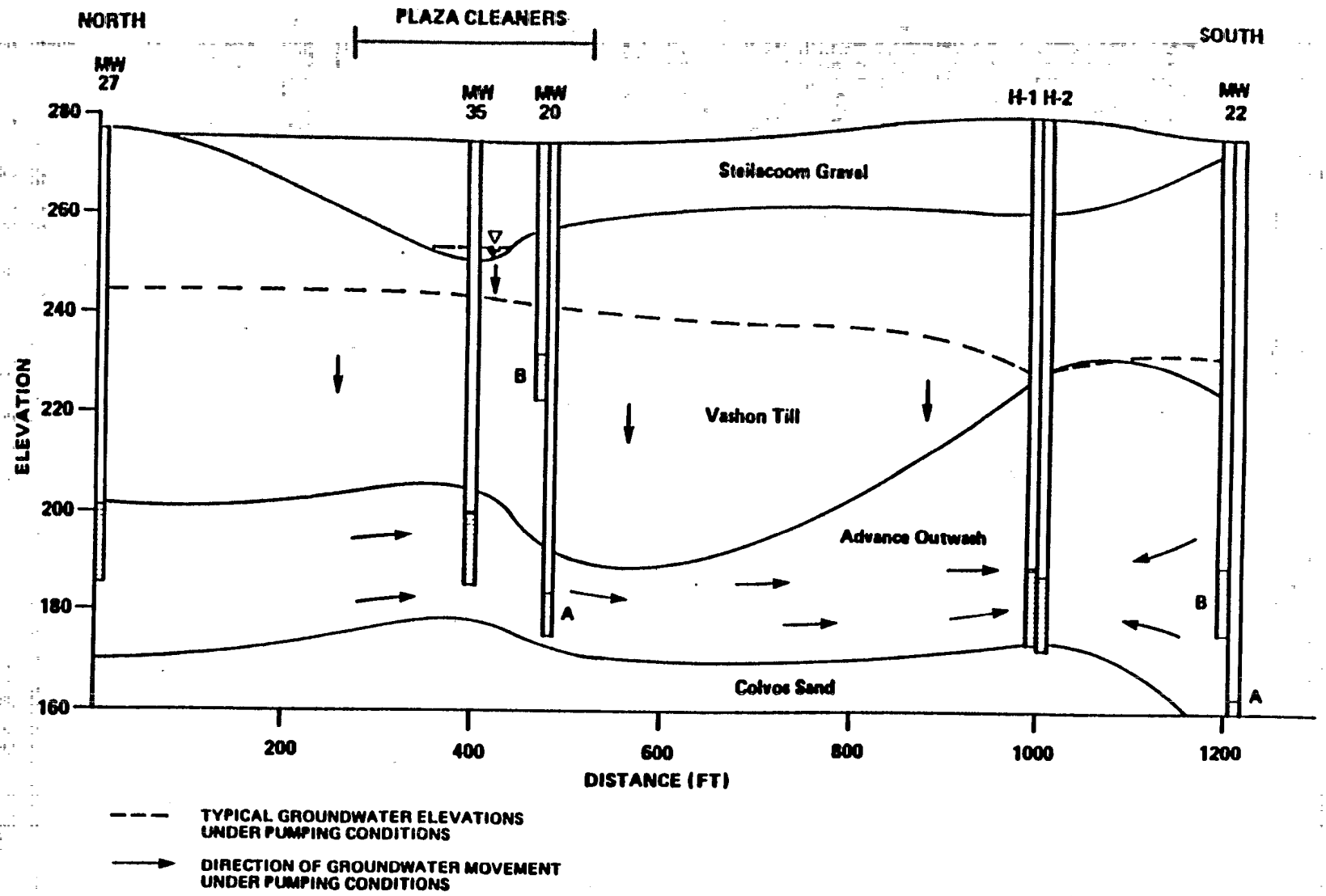


Based on CH2M HILL, Predesign Report, April 1987. EPA-62-ON22.

LEGEND

- ● MONITORING WELL
- ■ TEST OR PRODUCTION WELL

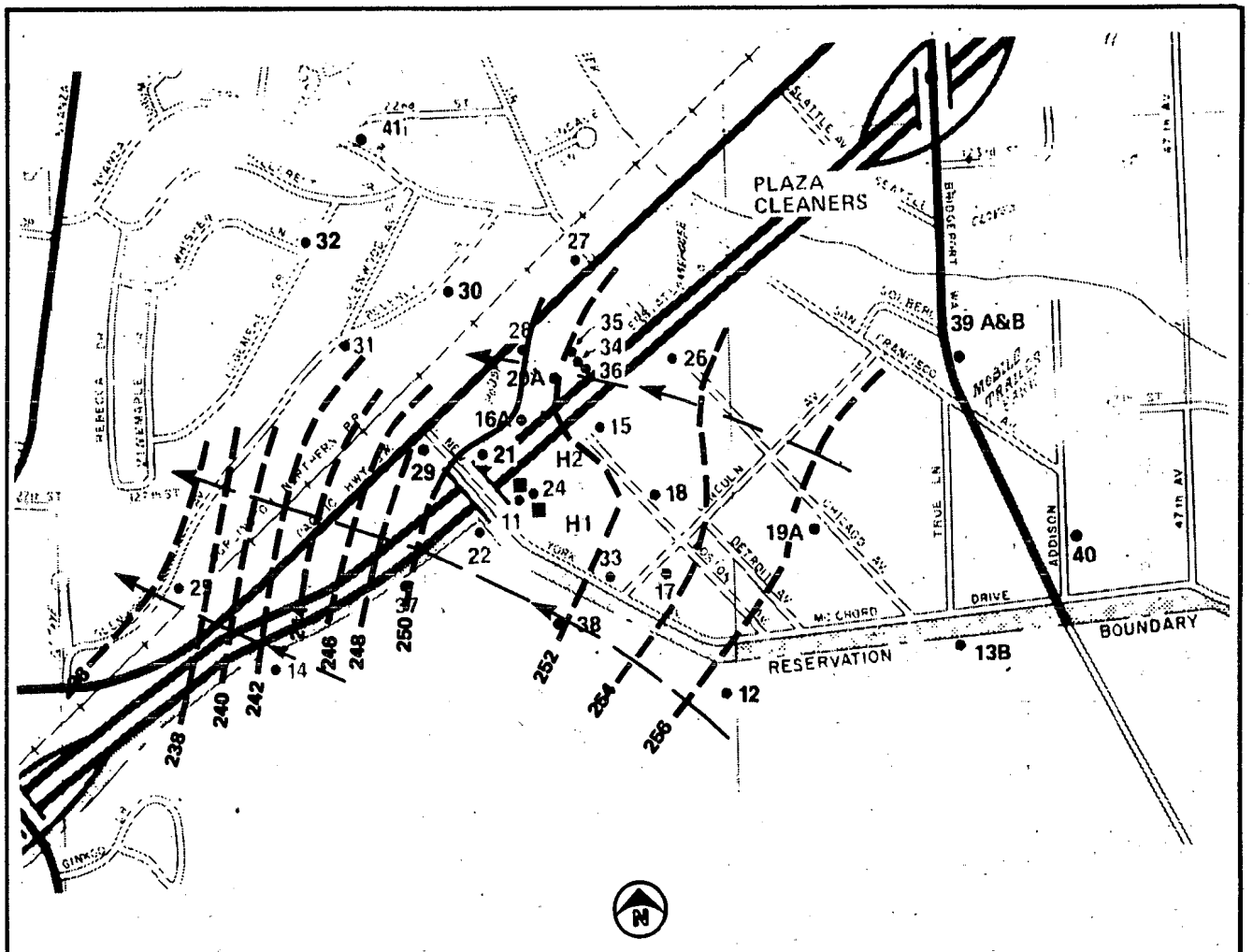
Figure 1
SITE LOCATION MAP
PONDERS CORNER SITE
LAKEWOOD, WASHINGTON



Based on EPA, Record of Decision, Remedial Alternative Selection, September 1985.

Figure 2
NORTH-SOUTH GEOLOGIC CROSS SECTION BETWEEN PLAZA CLEANERS AND WELLS H1 AND H2
PONDERS CORNER SITE

WDC61621.A0.02

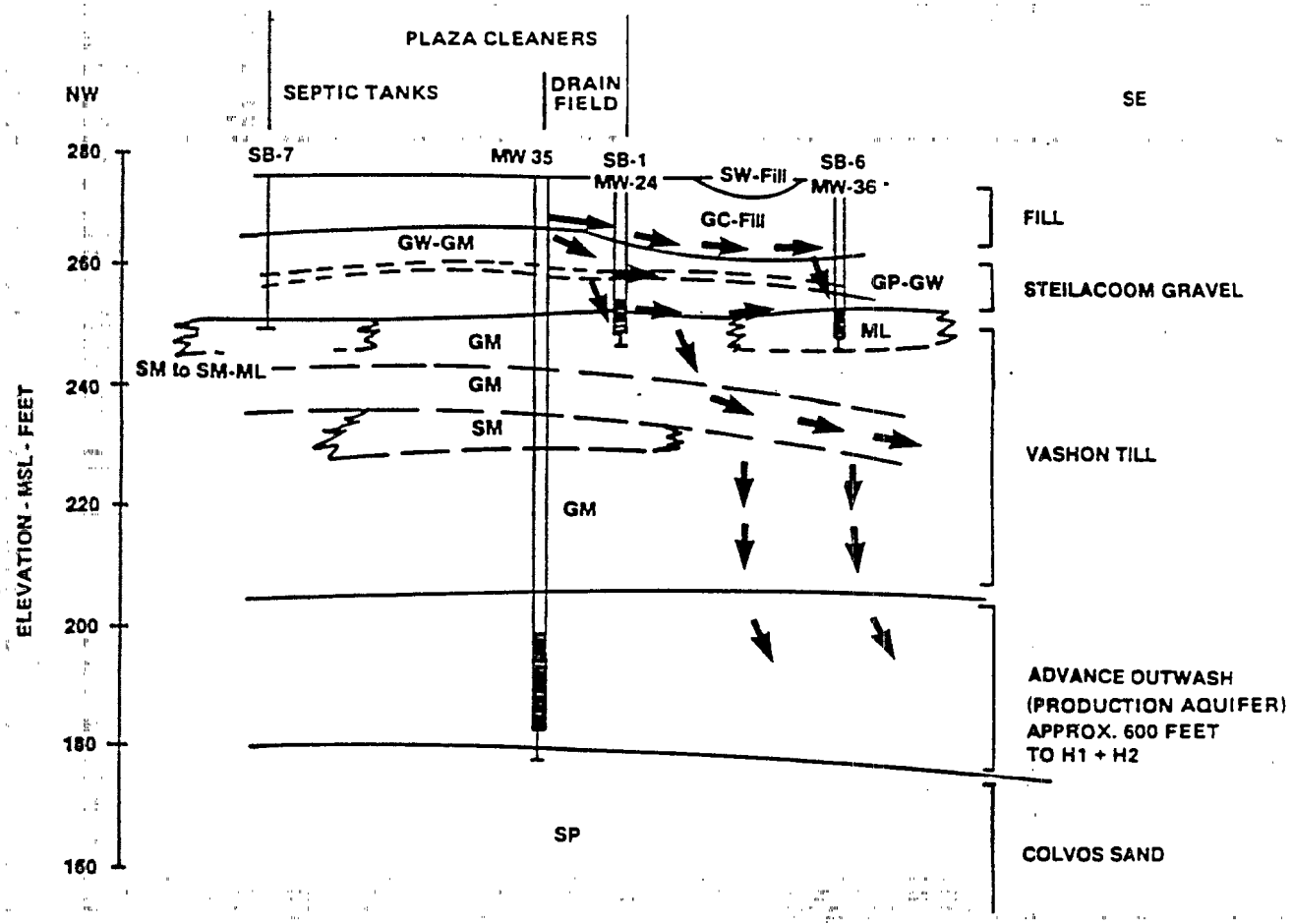


Based on EPA, Record of Decision, Remedial Alternative Selection, September 1985.

LEGEND

- ● MONITORING WELL
- ■ TEST OR PRODUCTION WELL
- WATER LEVEL-CONTOUR. SOLID WHERE APPROXIMATE, DASHED WHERE INFERRED. ELEVATION IN FEET ABOVE MEAN SEA LEVEL.
- → GROUNDWATER FLOW DIRECTION

Figure 3
WATER LEVEL CONTOUR MAP OF THE ADVANCE OUTWASH AQUIFER, JULY 23, 1984.
PONDERS CORNER SITE



0 20 40 60
Feet

DIRECTION OF CONTAMINANT MIGRATION

GW	GRAVEL, WELL GRADED
GP	GRAVEL, POORLY GRADED
GM	SILTY GRAVEL
GC	CLAYEY GRAVEL
SW	SAND, WELL GRADED
SP	SAND, POORLY GRADED
SM	SILTY SAND
ML	SILT, LOW LIQUID LIMIT

Based on CH2M HILL, Final Aquifer Cleanup Assessment Report, February 1988.

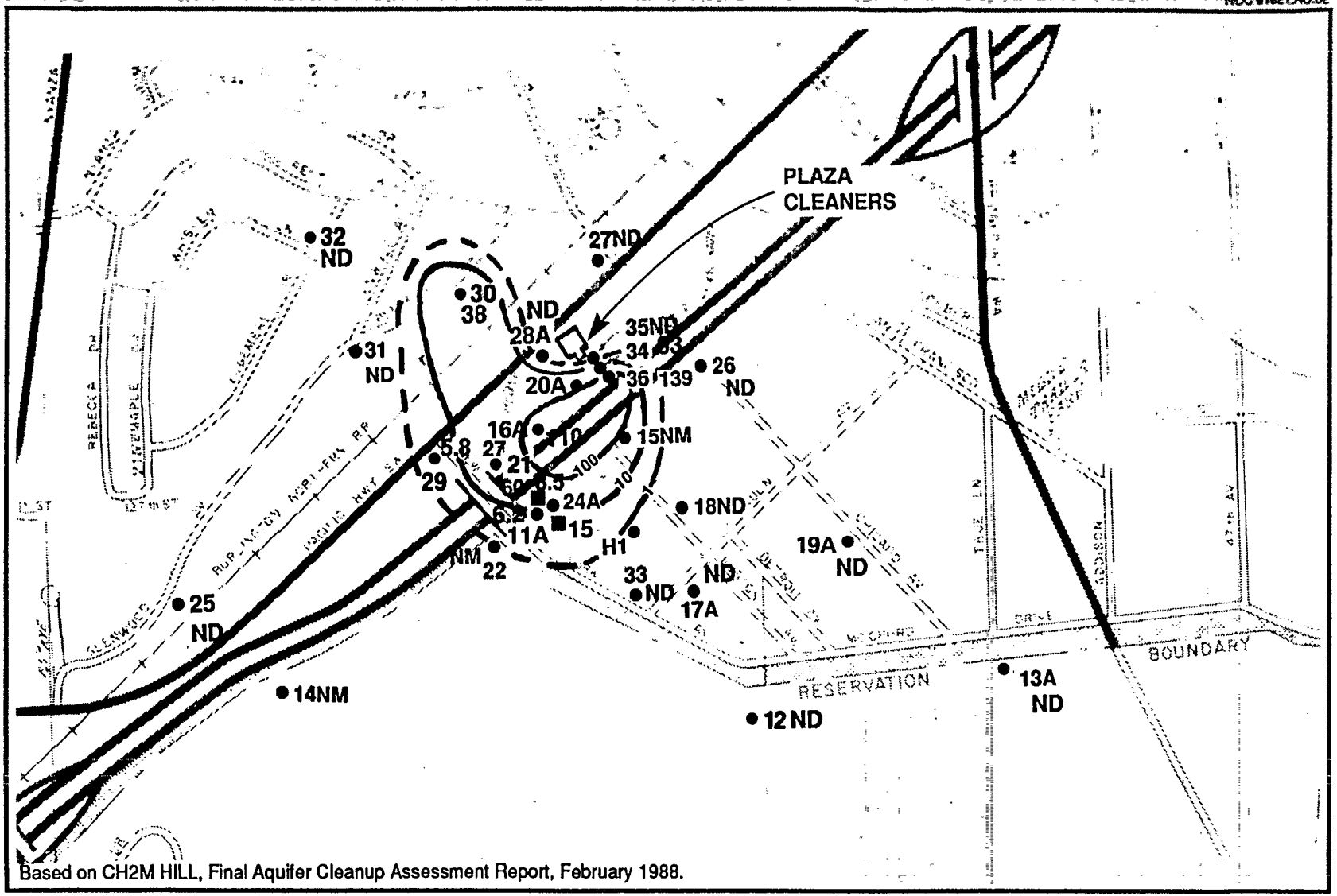
Figure 4
CROSS SECTION VIEW OF CONTAMINANT MIGRATION
PONDERS CORNER SITE

Table 1
ESTIMATED QUANTITIES OF CONTAMINATION IN EACH ZONE
OF THE GROUNDWATER UNIT, FEBRUARY TO MAY 1985
(SOLID AND LIQUID PHASE)

	Steilacoom Gravel (MW34 and MW36 only)			Vashon Till (MW 20B only)			Advance Outwash		
	1,2-DCE	TCE	PCE	1,2-DCE	TCE	PCE	1,2-DCE	TCE	PCE
Average Concentration (ug/L)	ND	42	111	ND	58	2,500	ND	3	16
Number of Observations	--	1	2	--	2	3	--	5	28
Minimum/Maximum Concentration (ug/L)	--	--	83/139	--	12/103	570/4,866	--	1.5/6.3	0.5/110
Total Volume of Contaminated Media (cu ft)	7.5×10^5	7.5×10^5	7.5×10^5	2.0×10^6	2.0×10^6	2.0×10^6	4.5×10^7	4.5×10^7	4.5×10^7
Approximate Mass of Contamination (lb)	--	4	20	--	14	1,300	--	16	180

ND = not detected.
1,2-DCE = 1,2-dichloroethylene.
TCE = trichloroethylene.
PCE = tetrachloroethylene.
ug/L = micrograms per liter.
Source: EPA, ROD, Remedial Alternative Selection, 1985.
Wells MW20B, MW34, and MW36 are within 150 feet of Plaza Cleaners.
Well MW20B was the only well in Vashon till with contamination.
Wells MW34 and MW36 were screened in both Vashon till and Steilacoom gravel.

WDCR218/018.50



LEGEND

240.2 ● 24	Monitoring Well Number and PCE Concentration in ug/l
■	Test or Production Well
— — — —	Approximate Concentration Contour
ND	Below Detection Limit
NM	Not Measured

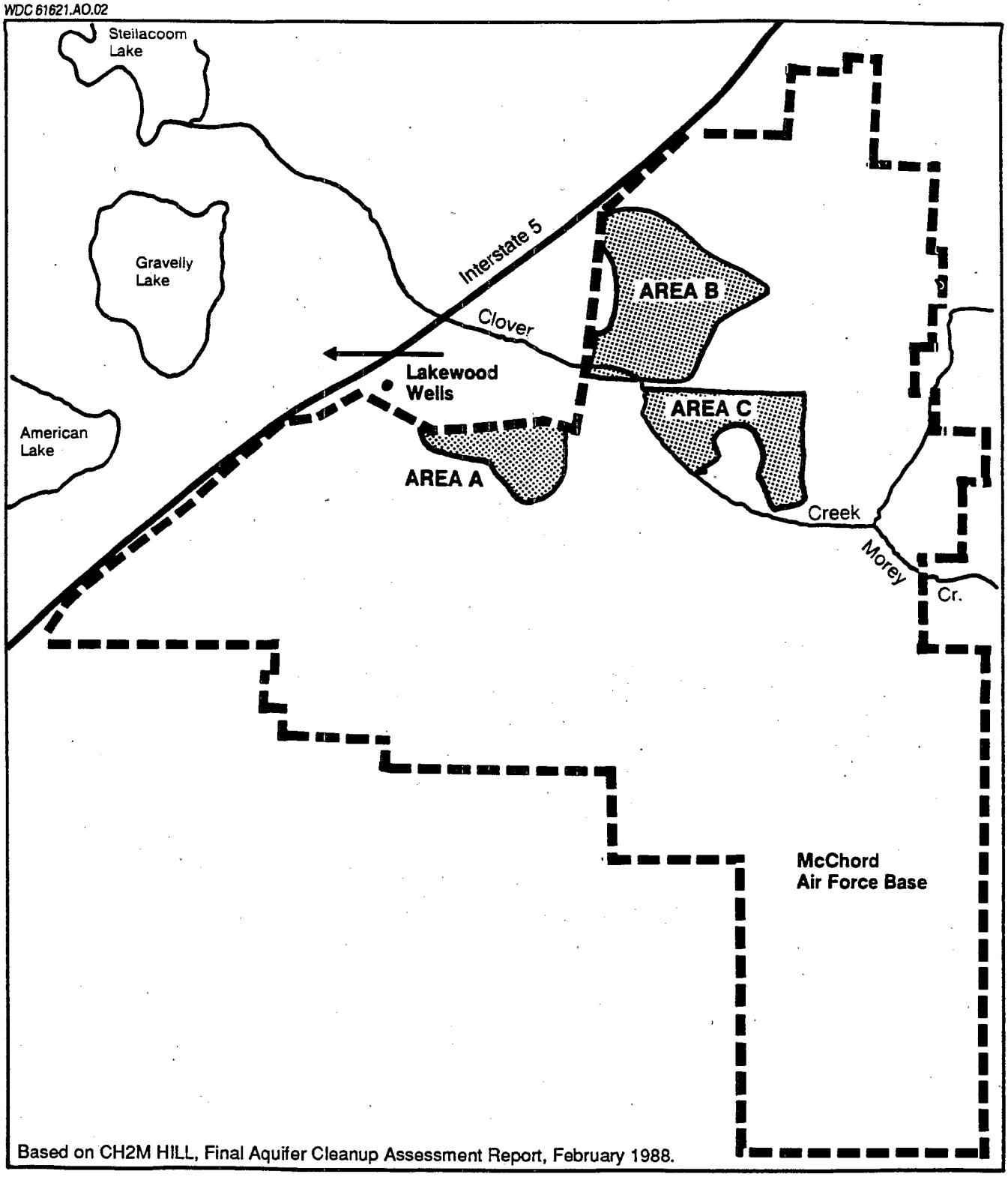
N

0 500 1000

SCALE IN FEET

Figure 5
CONTOUR MAP OF PCE CONCENTRATION, FEBRUARY, 1985.
PONDERS CORNER SITE

WDC 61621.AO.02



N

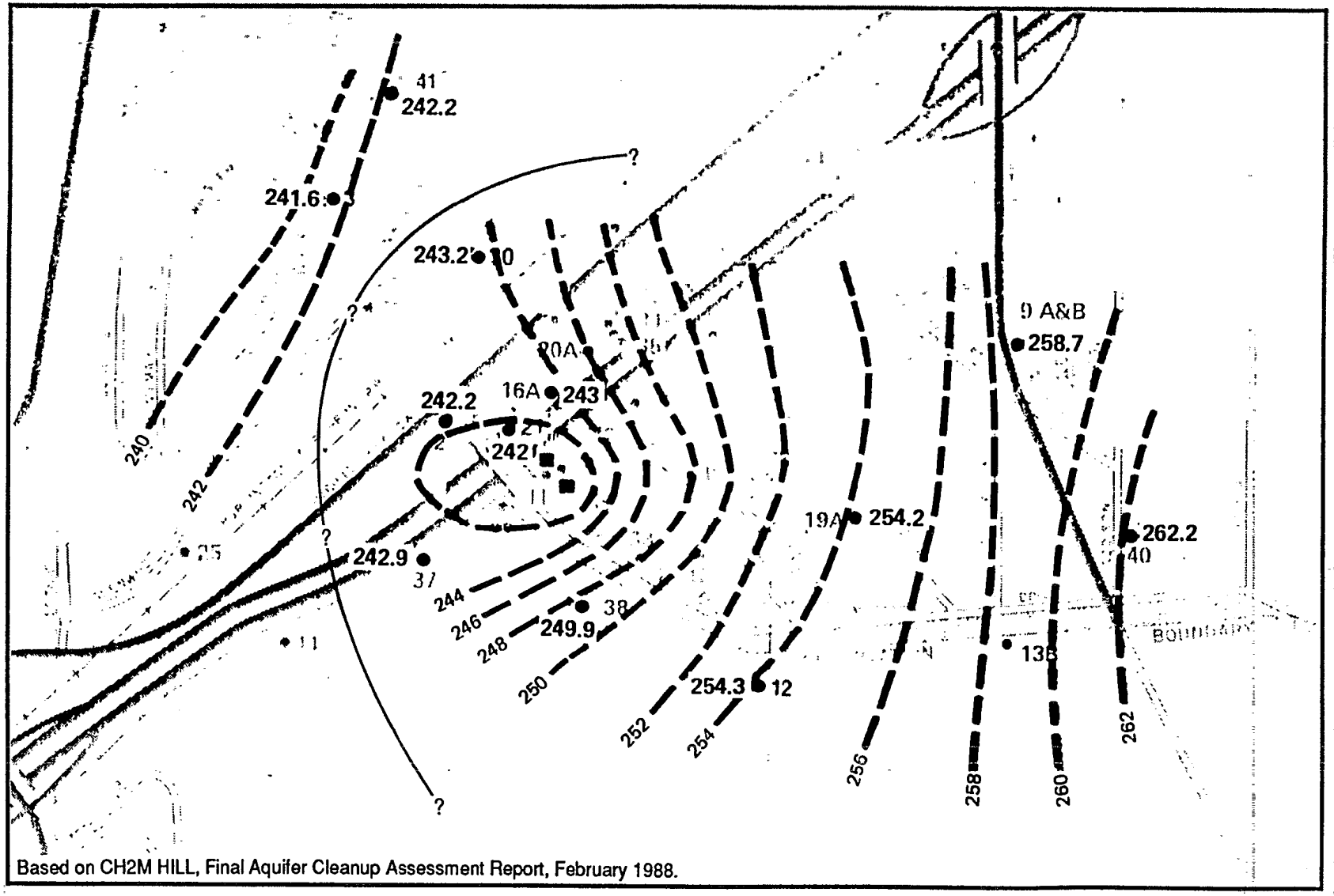
0 1

SCALE in MILES

Groundwater Flow Direction

Note: Monitoring Well Locations Not Included

Figure 6
POTENTIAL CONTAMINANT SOURCES AT McCHORD AIR FORCE BASE
PONDERS CORNER SITE



Based on CH2M HILL, Final Aquifer Cleanup Assessment Report, February 1988.

LEGEND

240.2 ● Monitoring Well Number and Water Level Elevation

■ Test or Production Well

— — — Approximate Water Level Elevation Contour

——?—— Approximate Limit of Zone of Capture of Production Wells

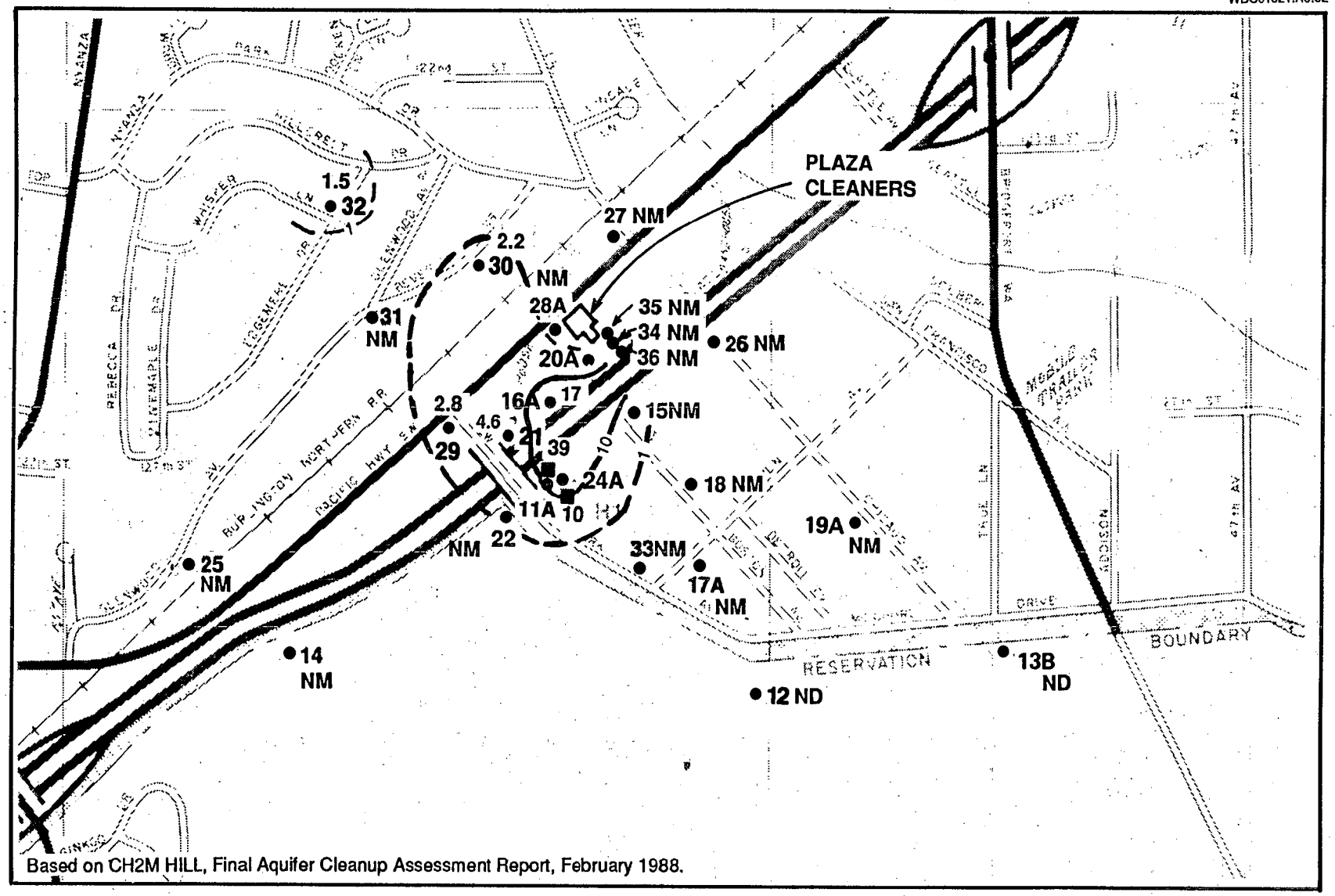
N

0 500 1000

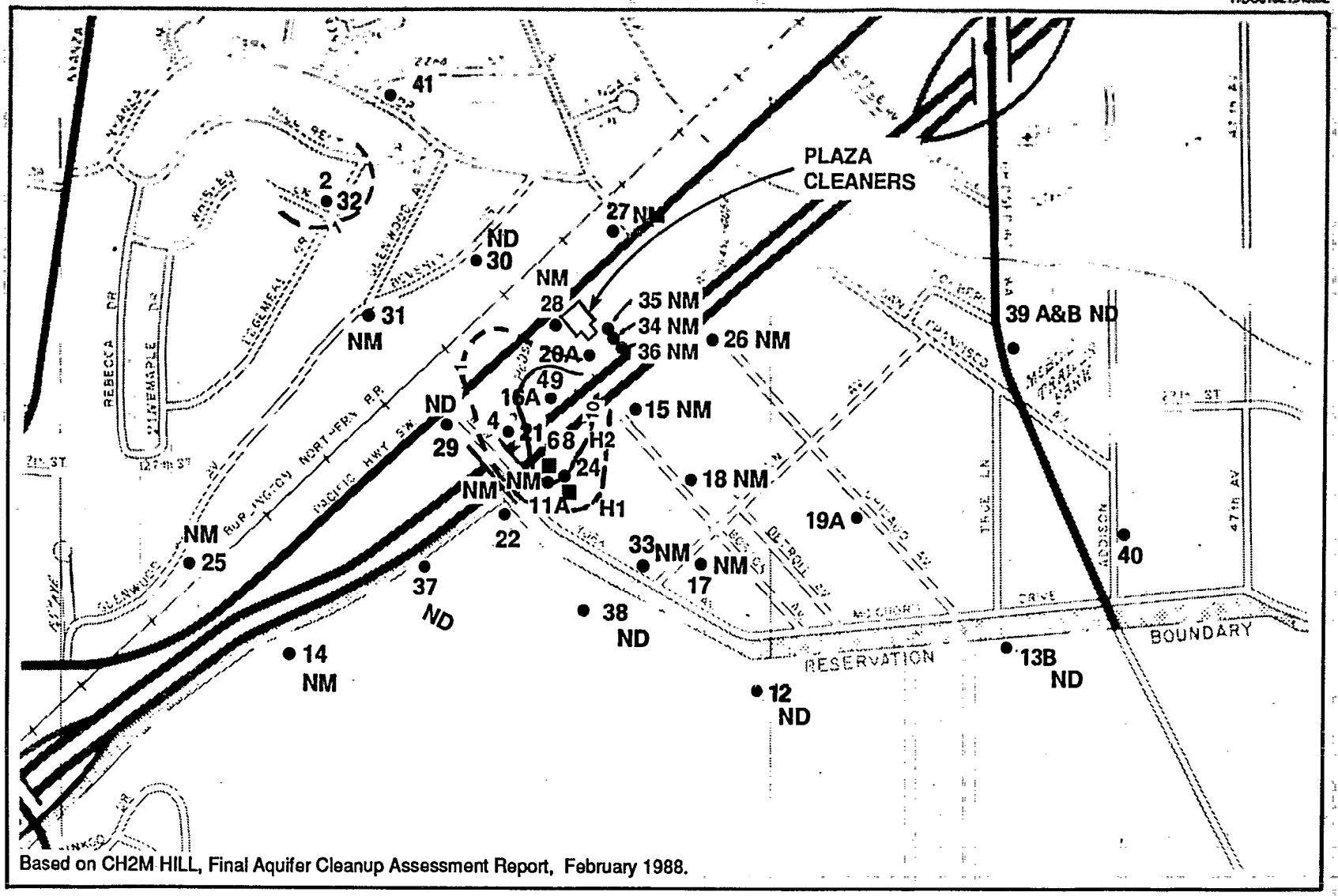
SCALE IN FEET

Figure 7
WATER LEVEL CONTOUR MAP OF THE ADVANCE OUTWASH AQUIFER, MARCH 1987.
PONDERS CORNER SITE

WDC61621.A0.02


PLAZA
CLEANERS
1.5
32
2.2
30
NM
27 NM
28A
35 NM
34 NM
36 NM
26 NM
20A
31
NM
16A
17
15NM
2.8
4.6
21
39
29
24A
18 NM
11A
10
22
NM
33NM
17A
NM
19A
NM
25
NM
14
NM
12 ND
13B
ND
RESERVATION
BOUNDARY
RUPPINGTON NORTHERN P.R.
PACIFIC HWY S.N.
ROSEWOOD
ROSEMARY
ROSEMARY LN
ROSEMARY DR
ROSEMARY CT
ROSEMARY PL
ROSEMARY WAY
ROSEMARY CIR
ROSEMARY DRIVE
ROSEMARY ROAD
ROSEMARY LANE
ROSEMARY COURT
ROSEMARY PLACE
ROSEMARY WAY
ROSEMARY CIRCLE

WDC61821.A0.02



Based on CH2M HILL, Final Aquifer Cleanup Assessment Report, February 1988.

LEGEND

240.2 ● 24	Monitoring Well Number and PCE Concentration in ug/l
■	Test or Production Well
— — — —	Approximate Concentration Contour
ND	Below Detection Limit
NM	Not Measured

N

0 500 1000

SCALE IN FEET

Figure 9
CONTOUR MAP OF PCE CONCENTRATION, MARCH 1987.
PONDERS CORNER SITE

Table 2
PERC CONCENTRATIONS MEASURED IN MONITORING WELLS
Ponders Corner, Washington

Well No.	02/12/85 Through 02/14/85	03/18/85 Through 03/22/85	04/25/85	05/16/85 Through 05/20/85	6/17/85 Through 6/21/85	8/20/85 Through 8/23/85[a]	11/5/85 Through 11/7/85[a]	8/25/86 Through 8/28/86	12/16/86 Through 12/17/87	3/17/87 Through 3/20/87	7/7/87
11A	6.2	5.6	NM	6.1	2.7	4.3	2	1.4	NM	NM	NM
11B	NM	NM	NM	NM	NM	2.4	NM	NM	NM	NM	NM
12	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
13A	ND	ND	ND	ND	ND	NM	NM	NM	NM	NM	NM
13B	NM	NM	NM	NM	NM	ND	ND	ND	ND	ND	ND
14	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
15A	NM	0.5	NM	ND	ND	ND	ND	ND	NM	NM	NM
15B	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
16A	110	70	NM	46	33	20/11[b]	19	16	17	49	NM
16B	NM	15	NM	13	5	NM	4[c]	4.5	NM	NM	NM
17A	ND	ND	NM	ND	ND	ND	ND	NM	NM	NM	NM
17B	NM	ND	NM	ND	ND	ND	ND	NM	NM	NM	NM
18	ND	ND	NM	ND	ND	D	ND	ND	NM	NM	NM
19A	ND	ND	NM	ND	ND	ND	ND	ND	NM	ND	ND
19B	NM	ND	NM	ND	ND	ND	ND	ND	NM	NM	NM
20A	NM	5.1	NM	NM	2.8	4.0	ND	2.1	1.5	ND	NM
20B	NM	4,866	2,200	570	1,220	1,060	350	745	NM	NM	NM
21	27	2.2	NM	13	11	10	ND	ND	4.6	4	NM
22	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
24A	8.5	4.5	NM	7.2	4.4	16	NM	NM	NM	NM	NM
24B	NM	9.5	NM	0.9	4.0	4.9	ND	2.9	NM	NM	NM
25	ND	ND	NM	ND	ND	ND	13	ND	NM	NM	NM
26	ND	ND	NM	NM	ND	ND	9	ND	NM	NM	NM
27	ND	NM	NM	NM	ND	ND	ND	ND	NM	NM	NM
28A	ND	0.7	NM	ND	ND	NM	ND	ND	NM	NM	NM
29	5.8	0.9	NM	5.4	1.1	3.4	ND	2	2.8	ND	NM
30	38	24.1	NM	17.2	13	NM	10	5.3	2.2	ND	NM
31	ND	ND	NM	ND	ND	ND	ND	ND	NM	NM	NM
32	ND	4.3	5	6.9	3.3	3.7	ND	2	1.5	2	NM
33	ND	ND	NM	ND	ND	ND	ND	ND	NM	NM	NM
34	83	NM	NM	NM	NM	1.2	NM	NM	NM	NM	NM
35	ND	ND	NM	ND	ND	ND	ND	ND	NM	NM	NM
36	139	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
37[d]										ND	ND
38[d]										ND	ND
39A[d]										ND	ND
39B[d]										ND	ND
40[d]										ND	ND
41[d]										ND	ND

ND = not detected.

D = detected, not quantified.

NM = not measured.

Note: Units in µg/l.

[a]Exceeded acceptable holding time.

[b]Duplicate analysis.

[c]Estimated value. Compound present but at less than the specified detection limit.

[d]Well constructed 2/87 through 3/87

Based on CH2M HILL, Final Aquifer Cleanup Assessment Report, February 1988.

Table 3

TCE CONCENTRATIONS MEASURED IN MONITORING WELLS
Ponders Corner, Washington

Well No.	02/12/85 Through 02/14/85	03/18/85 Through 03/22/85	04/25/85	05/16/85 Through 05/20/85	6/17/85 Through 6/21/85	8/20/85 Through 8/23/85[a]	11/5/85 Through 11/7/85[a]	8/25/86 Through 8/28/87	12/16/86 Through 12/17/86	3/17/87 Through 3/20/87	7/7/87
11A	ND	ND	NM	ND	ND	D	ND	ND	NM	NM	
11B	NM	NM	NM	NM	NM	ND	NM	NM	NM	NM	
12	ND	ND	ND	ND	ND	ND	ND	1[d]	ND	ND	ND
13A	NM	ND	ND	ND	ND	NM	NM	NM	NM	NM	NM
13B	NM	NM	NM	NM	NM	D	ND	1[d]	1[d]	2	ND
14	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
15A	ND	ND	NM	ND	ND	ND	ND	ND	NM	NM	NM
15B	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
16A	6.3	3.9	NM	3.4	2.0	D/D[b]	2[d]	1[d]	1[d]	ND	NM
16B	NM	ND	NM	ND	ND	NM	NM	ND	NM	NM	NM
17A	ND	ND	NM	ND	ND	ND	ND	NM	NM	NM	NM
17B	NM	ND	NM	ND	ND	ND	ND	NM	NM	NM	NM
18	ND	ND	NM	ND	ND	ND	ND	NM	NM	NM	NM
19A	ND	ND	NM	ND	ND	ND	ND	ND	NM	ND	ND
19B	NM	ND	NM	ND	ND	ND	ND	ND	NM	NM	NM
20A	NM	ND	NM	NM	ND	D	ND	ND	ND	ND	NM
20B	NM	103	32	12	ND	D[c]	29	100	NM	NM	NM
21	1.5	ND	NM	ND	ND	D	6	1[d]	1[d]	1[d]	NM
22	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
24A	ND	ND	NM	ND	ND	1.2	NM	NM	NM	NM	NM
24B	NM	ND	NM	ND	ND	D	ND	ND	NM	NM	NM
25	ND	ND	NM	ND	ND	ND	ND	ND	NM	NM	NM
26	ND	ND	NM	ND	ND	ND	ND	ND	NM	NM	NM
27	ND	NM	NM	ND	ND	ND	ND	ND	NM	NM	NM
28A	ND	ND	NM	ND	ND	NM	ND	ND	NM	NM	NM
29	ND	ND	NM	ND	ND	ND	ND	ND	1[d]	ND	NM
30	1.6	ND	NM	ND	D	NM	ND	1[d]	ND	ND	NM
31	ND	ND	NM	ND	ND	ND	ND	ND	NM	NM	NM
32	ND	ND	ND	ND	ND	D	ND	1[d]	ND	ND	NM
33	ND	ND	NM	ND	ND	ND	ND	ND	NM	NM	NM
34	ND	NM	NM	NM	NM	ND	NM	NM	NM	NM	NM
35	ND	ND	NM	ND	ND	ND	ND	ND	NM	NM	NM
36	42	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
37[e]										ND	ND
38[e]										15	ND
39A[e]										1	ND
39B[e]										ND	ND
40[e]										ND	ND
41[e]										ND	

NM = not measured.

ND = not detected.

D = detected, not quantified.

Note: Units in parts per billion.

[a] Exceeded acceptable holding time.

[b] Duplicate analysis.

[c] Detection limit = 100 µg/l.

[d] Estimated value. Compound present but at less than the specified detection limit.

[e] Wells constructed 2/87 through 3/87

Based on CH2M HILL, Final Aquifer Cleanup Assessment Report, February 1988.

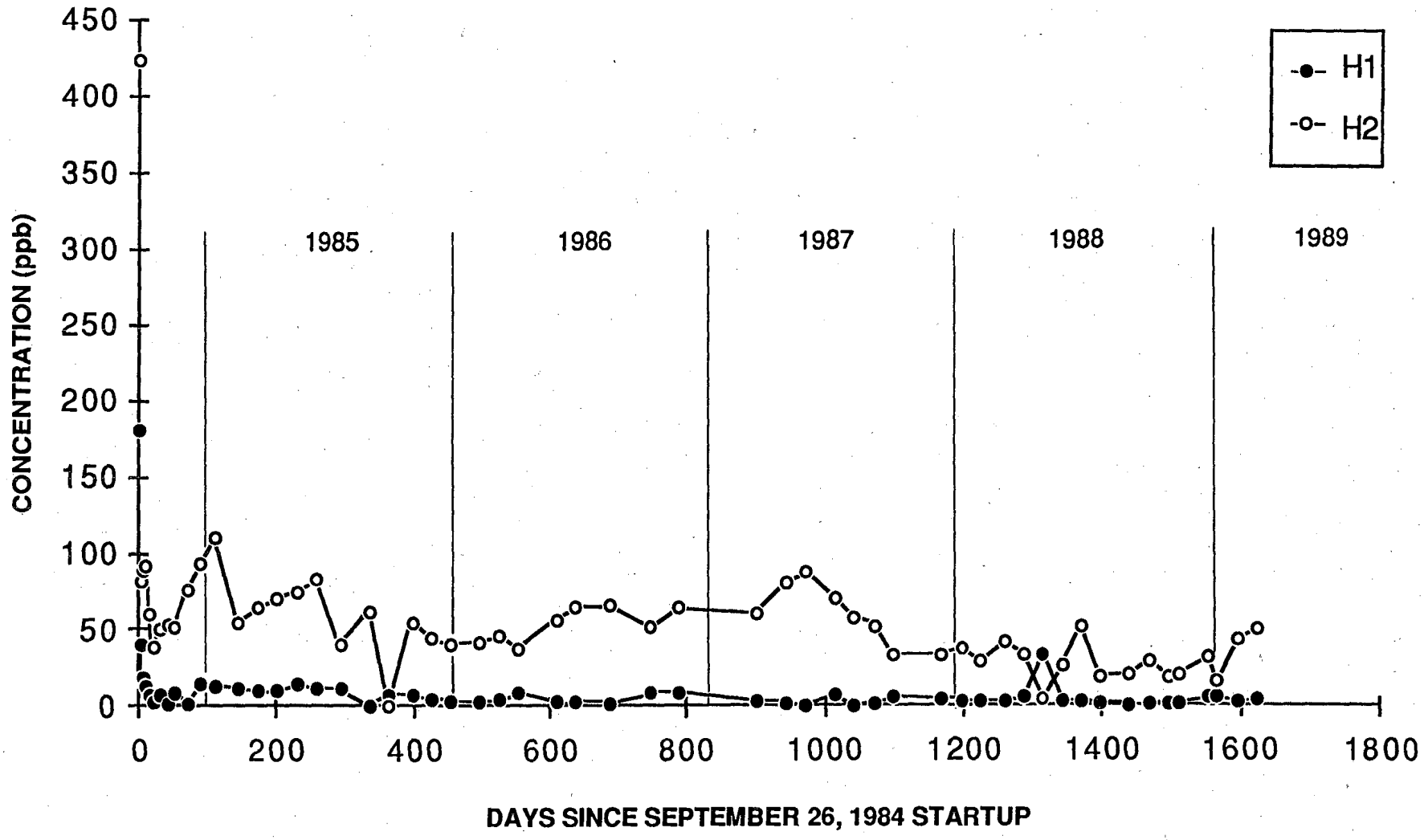


Figure 10
TIME SERIES PLOT OF PCE CONCENTRATION IN RECOVERY WELLS H1 AND H2
PONDERS CORNER SITE

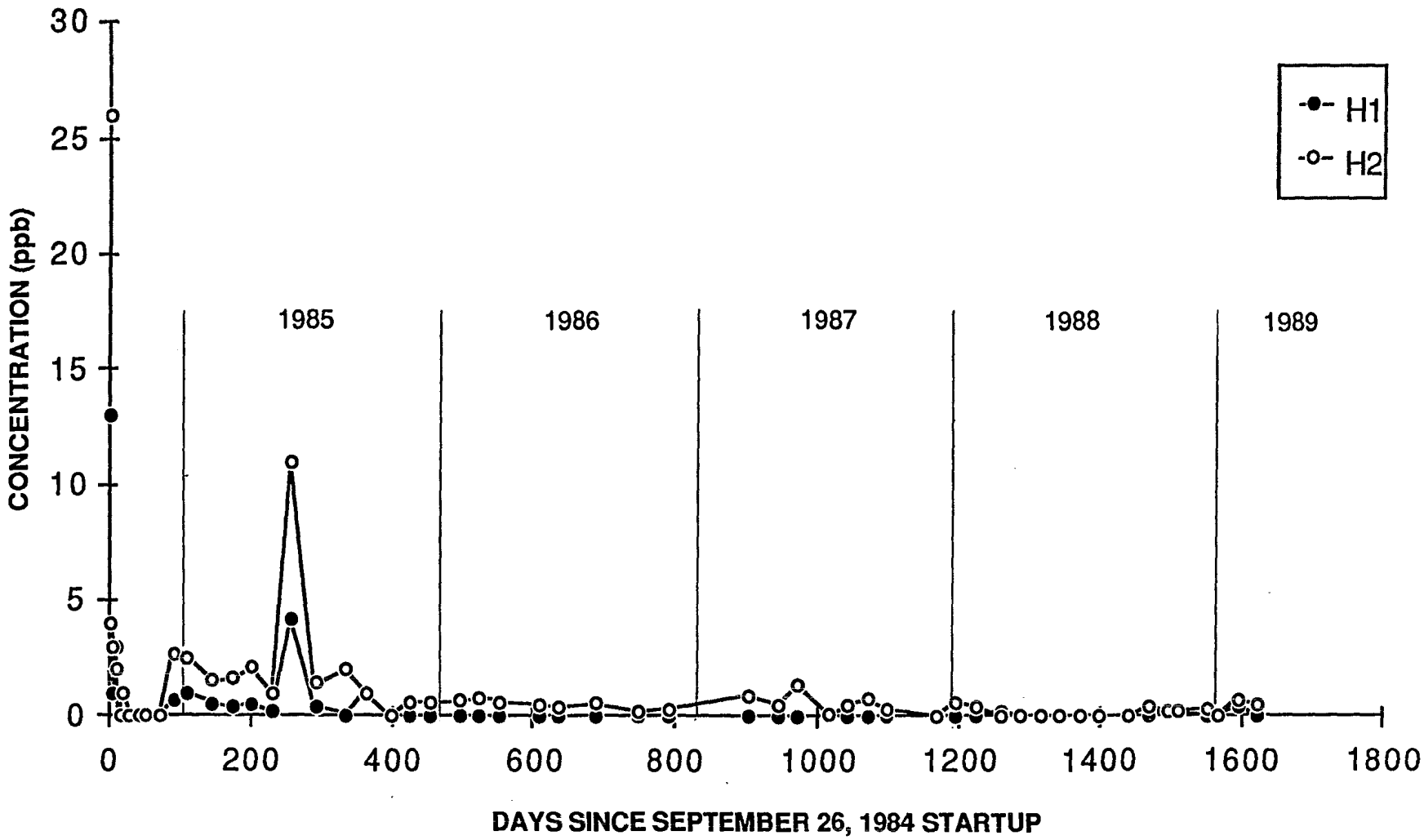


Figure 11
TIME SERIES PLOT OF TCE CONCENTRATION IN RECOVERY WELLS H1 AND H2
PONDERS CORNER SITE

WDC 61621.AO.02

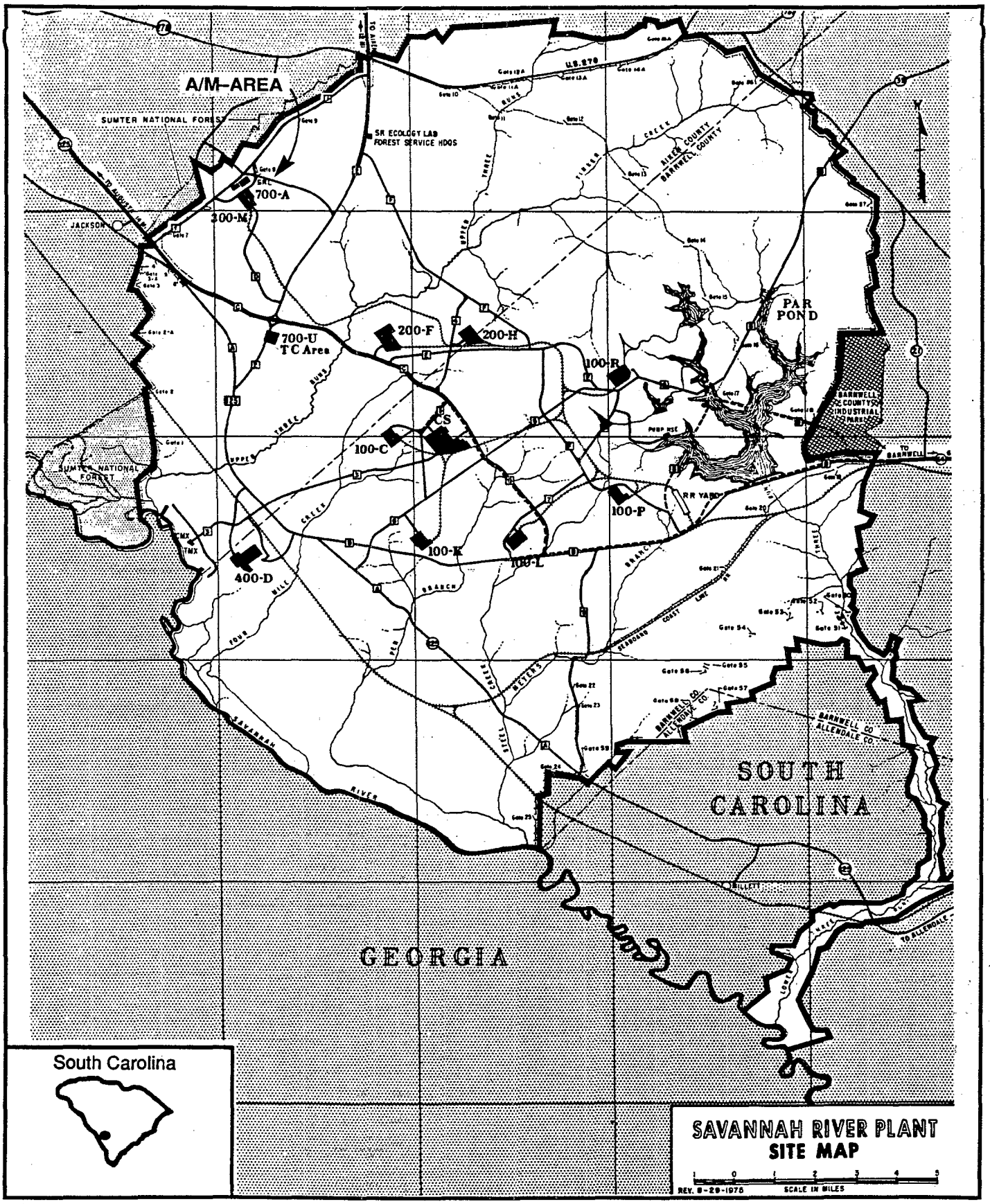
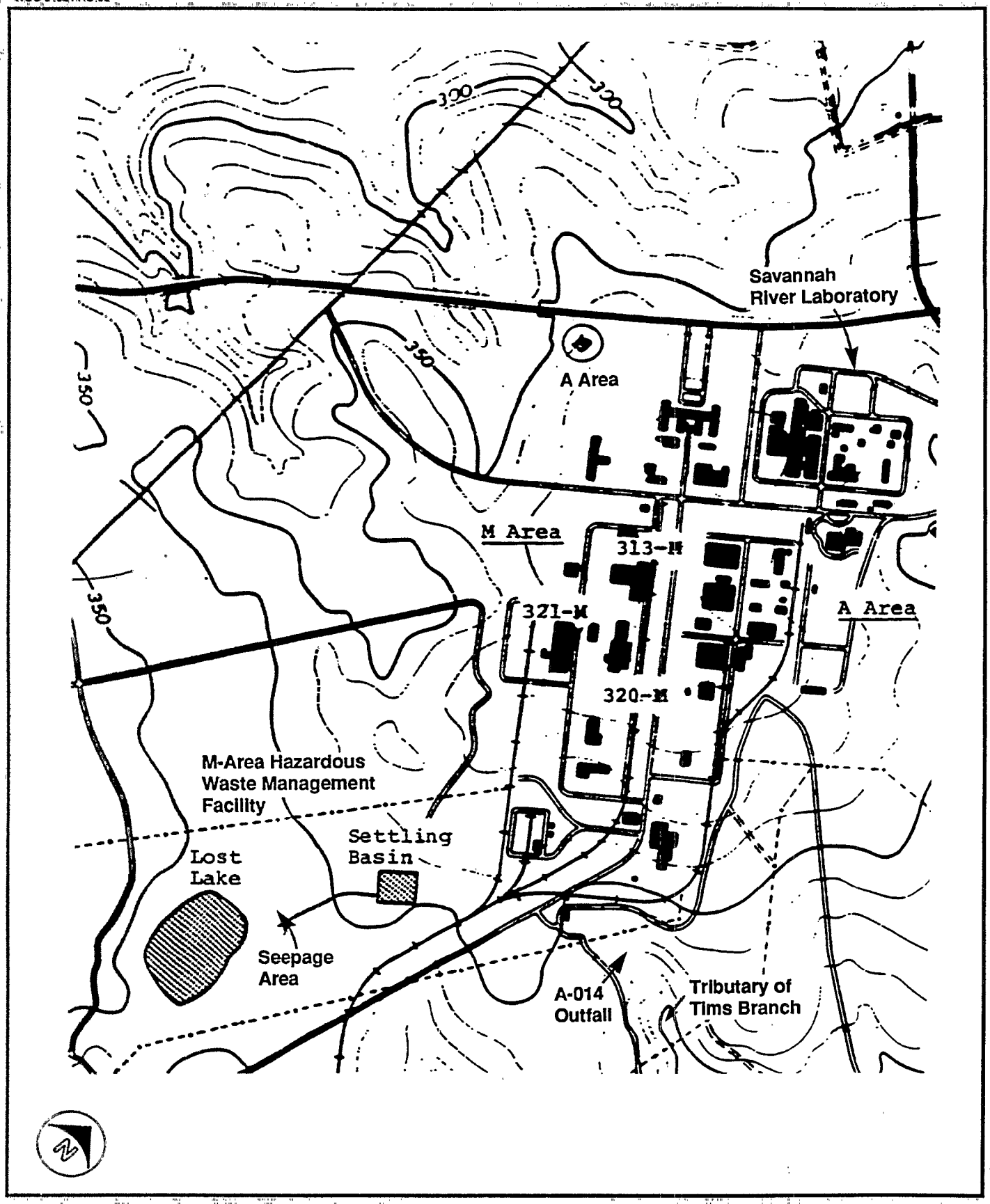
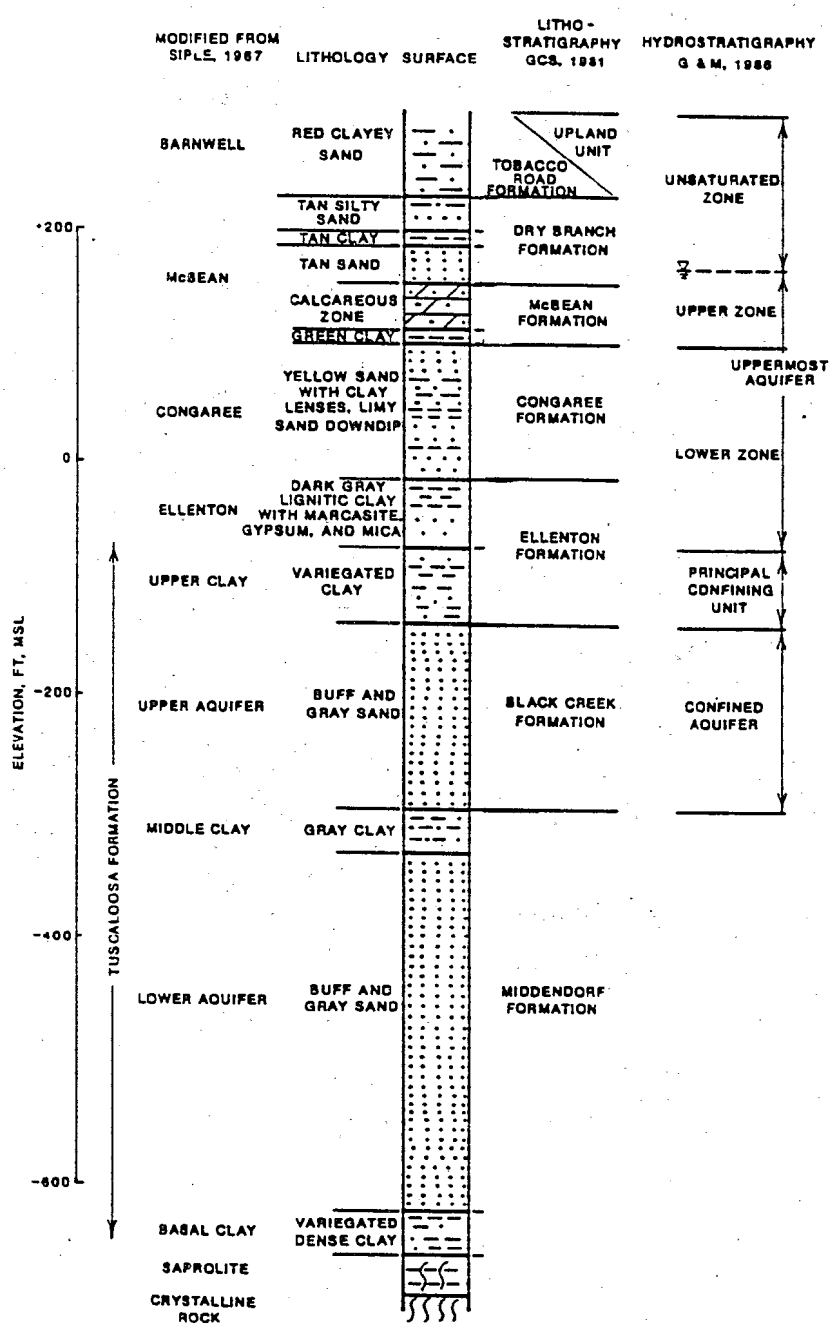


Figure 1
MAP SHOWING LOCATION OF THE A/M-AREA AT THE SAVANNAH RIVER PLANT
SAVANNAH RIVER PLANT A/M-AREA SITE
AIKEN, SOUTH CAROLINA



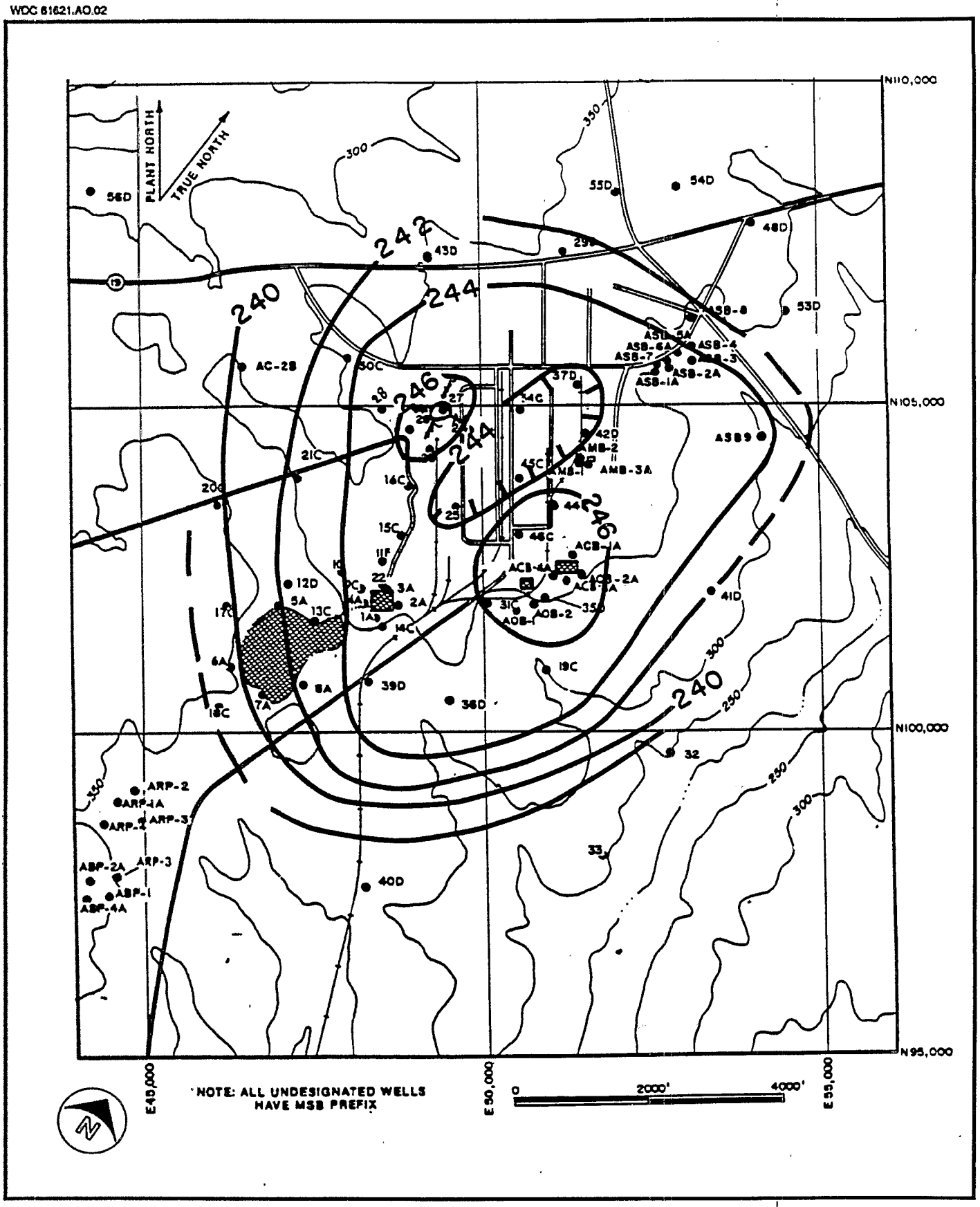
Source: USDOE, July 1986. Application for a Post-Closure Permit, A/M-Area Hazardous Waste Management Facility, Volume III, Revision No. 1, Savannah River Plant.

Figure 2
MAP OF A/M-AREA
SRP A/M-AREA SITE



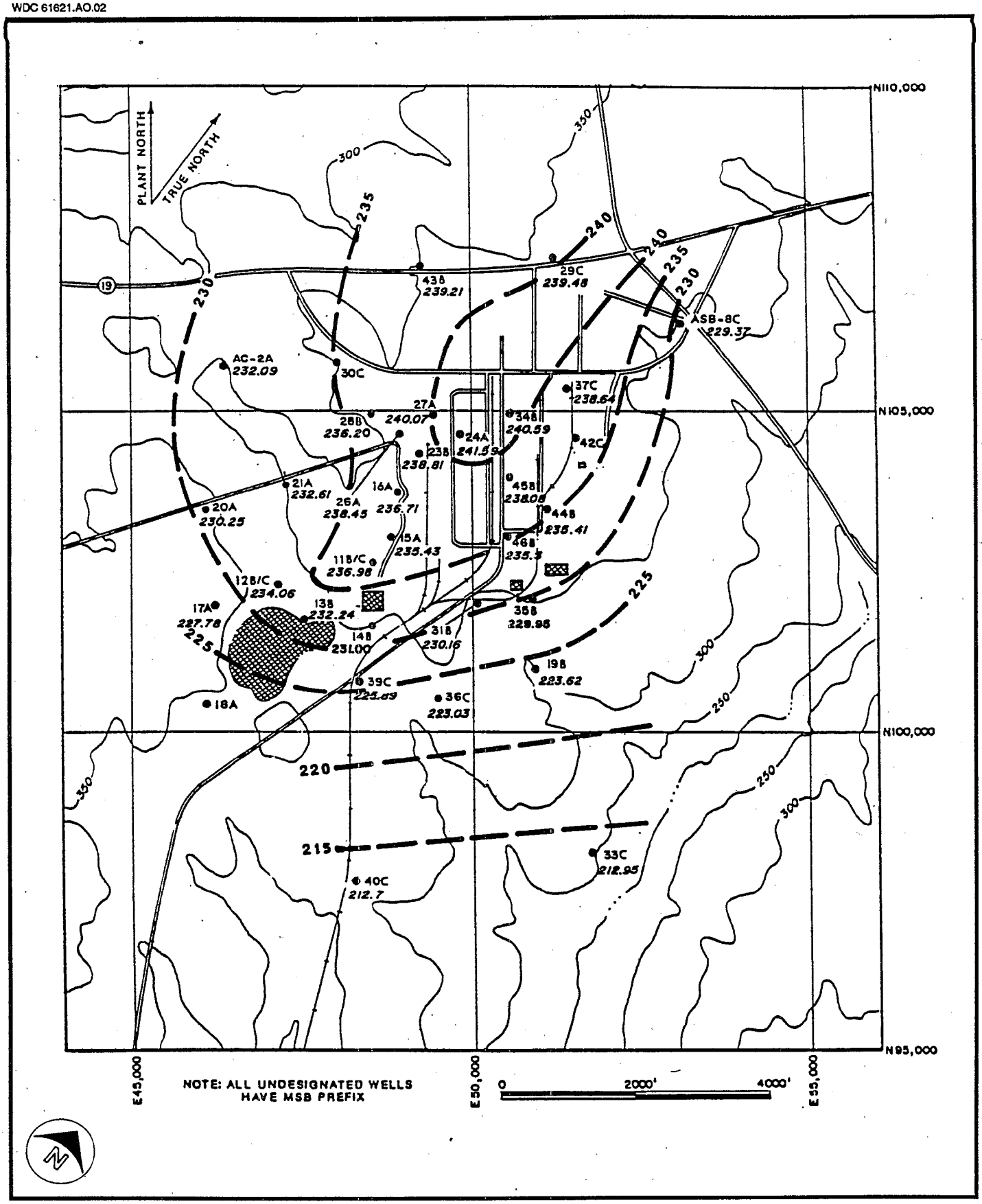
Source: USDOE. July 1986. Application for a Post-Closure Permit, A/M-Area Hazardous Waste Management Facility, Volume III, Revision No. 1, Savannah River Plant.

Figure 3
GENERALIZED GEOLOGIC COLUMN OF THE A/M-AREA
SRP A/M-AREA SITE



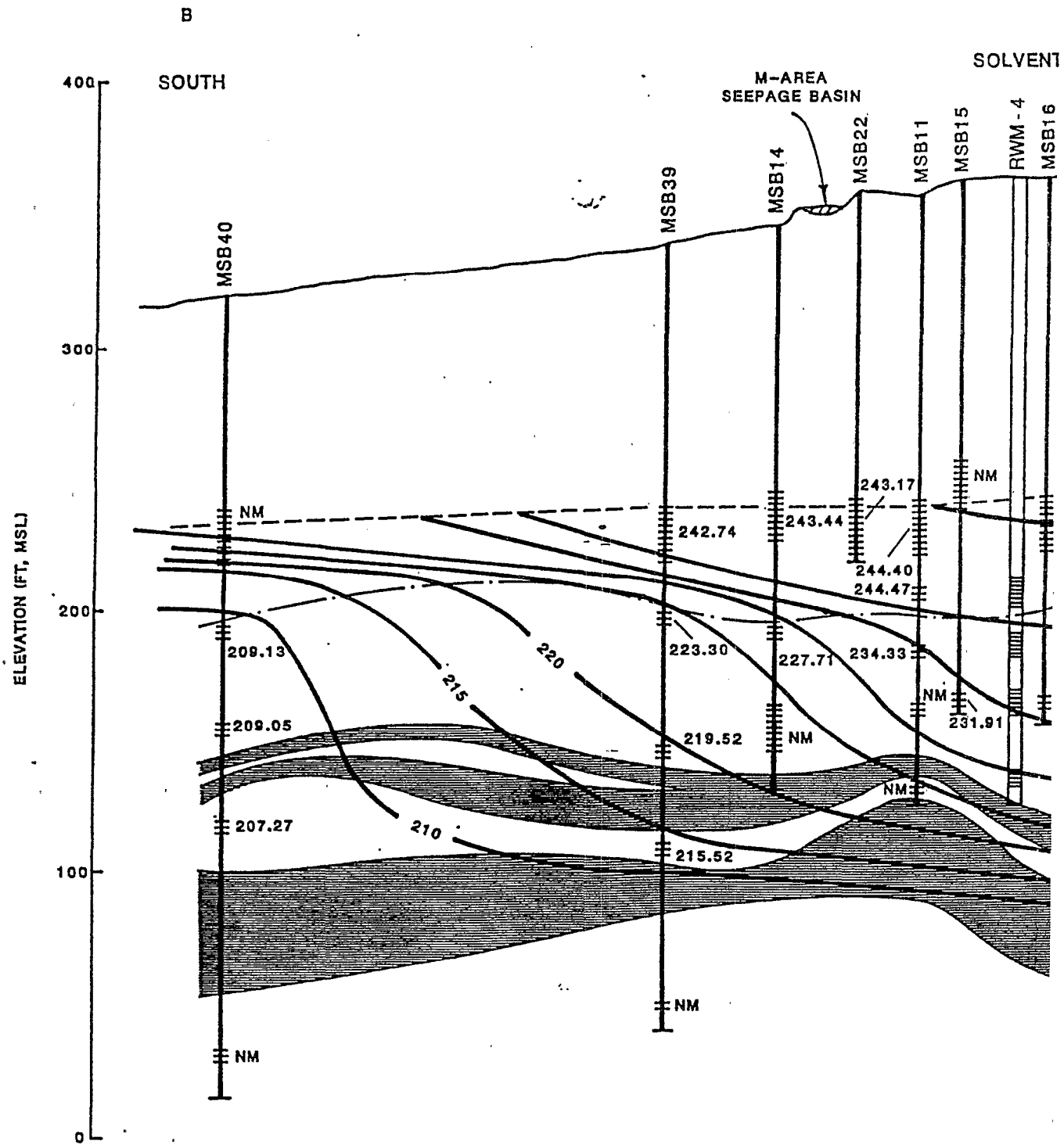
Source: Colven et al. February 1987. Draft First Year Report, Effectiveness of the A/M-Area Remedial Action Program, September 1985 to September 1986.

Figure 4
POTENTIOMETRIC SURFACE MAP OF THE WATER-TABLE UNIT, FIRST QUARTER 1985
SRP A/M-AREA SITE

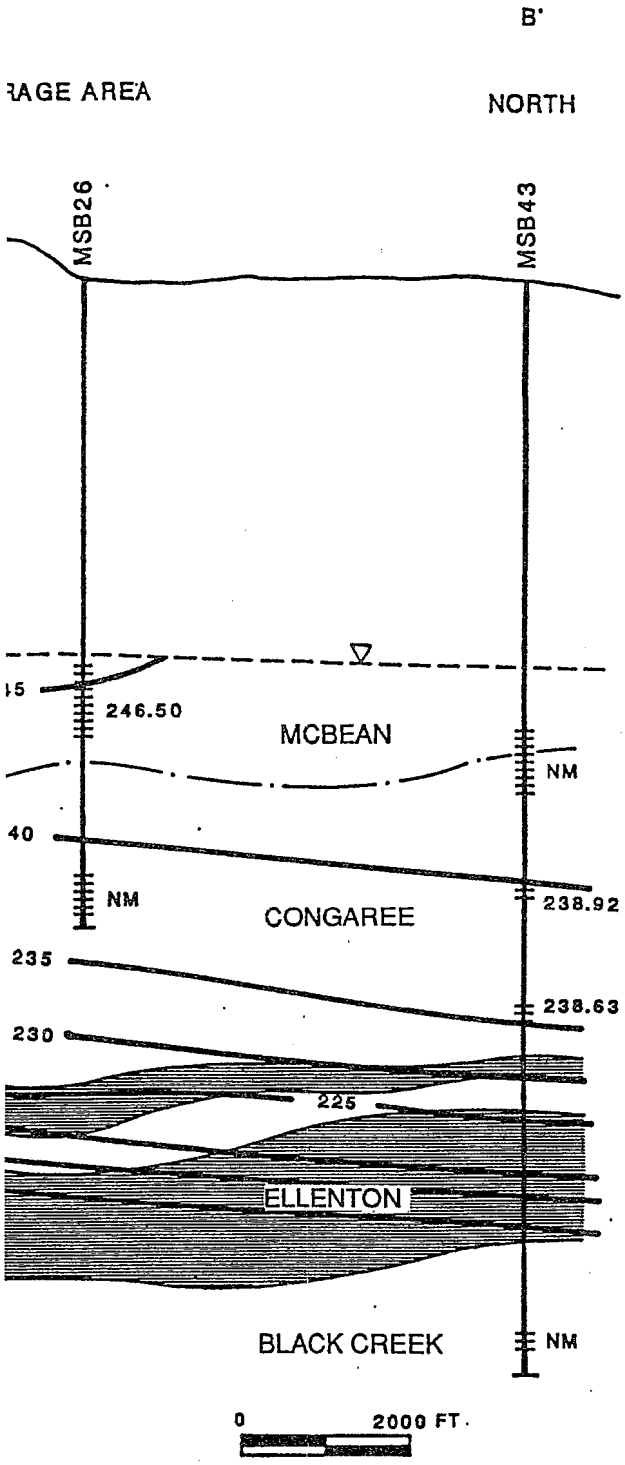


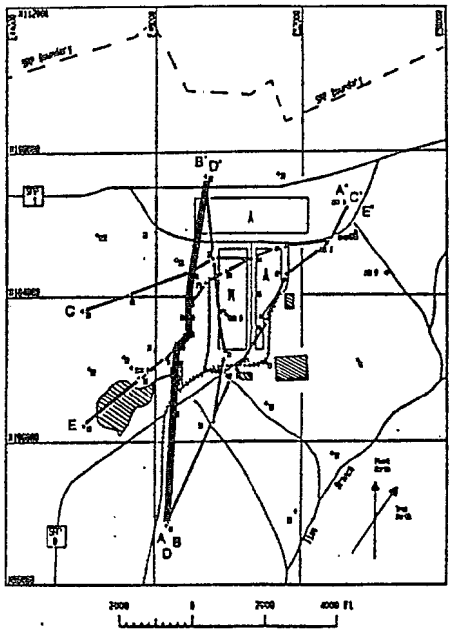
Source: Colven et al. February 1987. Draft First Year Report Effectiveness of the A/M-area Remedial Action Program, September 1985 to September 1986.

Figure 5
POTENTIOMETRIC SURFACE MAP OF THE UPPER CONGAREE FORMATION, FOURTH QUARTER 1986
SRP A/M-AREA SITE



Source: USDOE. July 1986. Application for a Post-Closure Permit, A/M-Area Hazardous Waste Management Facility, Volume III, Revision No. 1, Savannah River Plant.





EXPLANATION

THIRD QUARTER 1985

240.51 — MONITOR WELL SCREEN ZONE WITH POTENTIOMETERIC ELEVATION (FT, MSL)

RECOVERY WELL SCREEN ZONE

245 — POTENTIOMETRIC CONTOUR

WATER TABLE

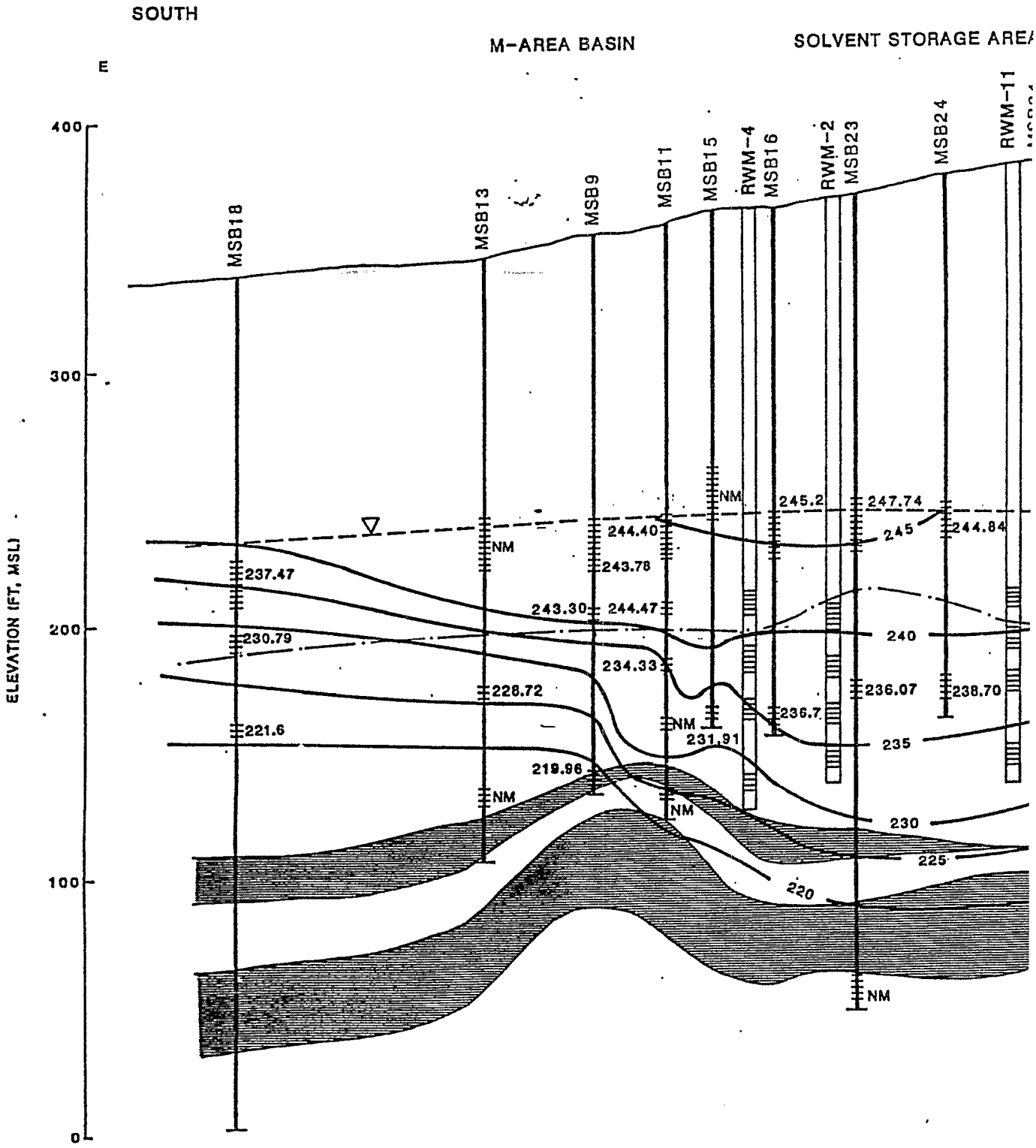
ELLENTON CLAY

McBEAN/CONGAREE CONTACT

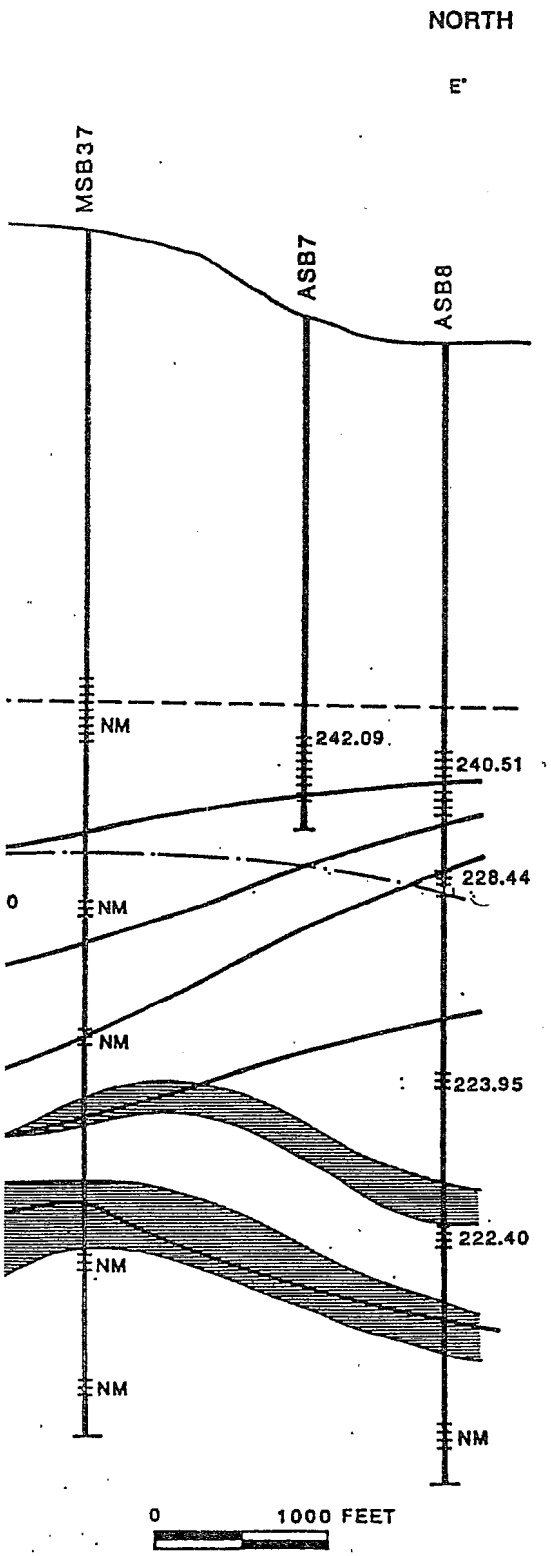
NM — NOT MEASURED

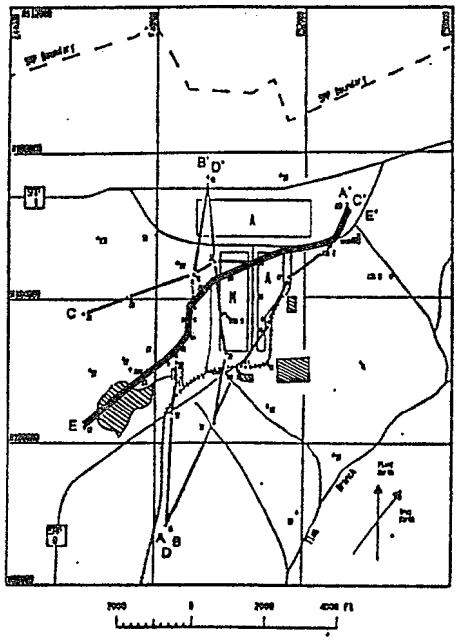
NOTE: VERTICAL EXAGGERATION = 40 TIMES.

Figure 6
HYDROGEOLOGIC CROSS SECTION B-B', THIRD QUARTER 1985
SRP A/M-AREA SITE



Source: USDOE. July 1986. Application for a Post-Closure Permit, A/M-Area Hazardous Waste Management Facility, Volume III, Revision No. 1, Savannah River Plant.





EXPLANATION

THIRD QUARTER 1985

240.51 — MONITOR WELL SCREEN ZONE WITH POTENTIOMETERIC ELEVATION (FT, MSL)

RECOVERY WELL SCREEN ZONE

245 — POTENTIOMETRIC CONTOUR

WATER TABLE

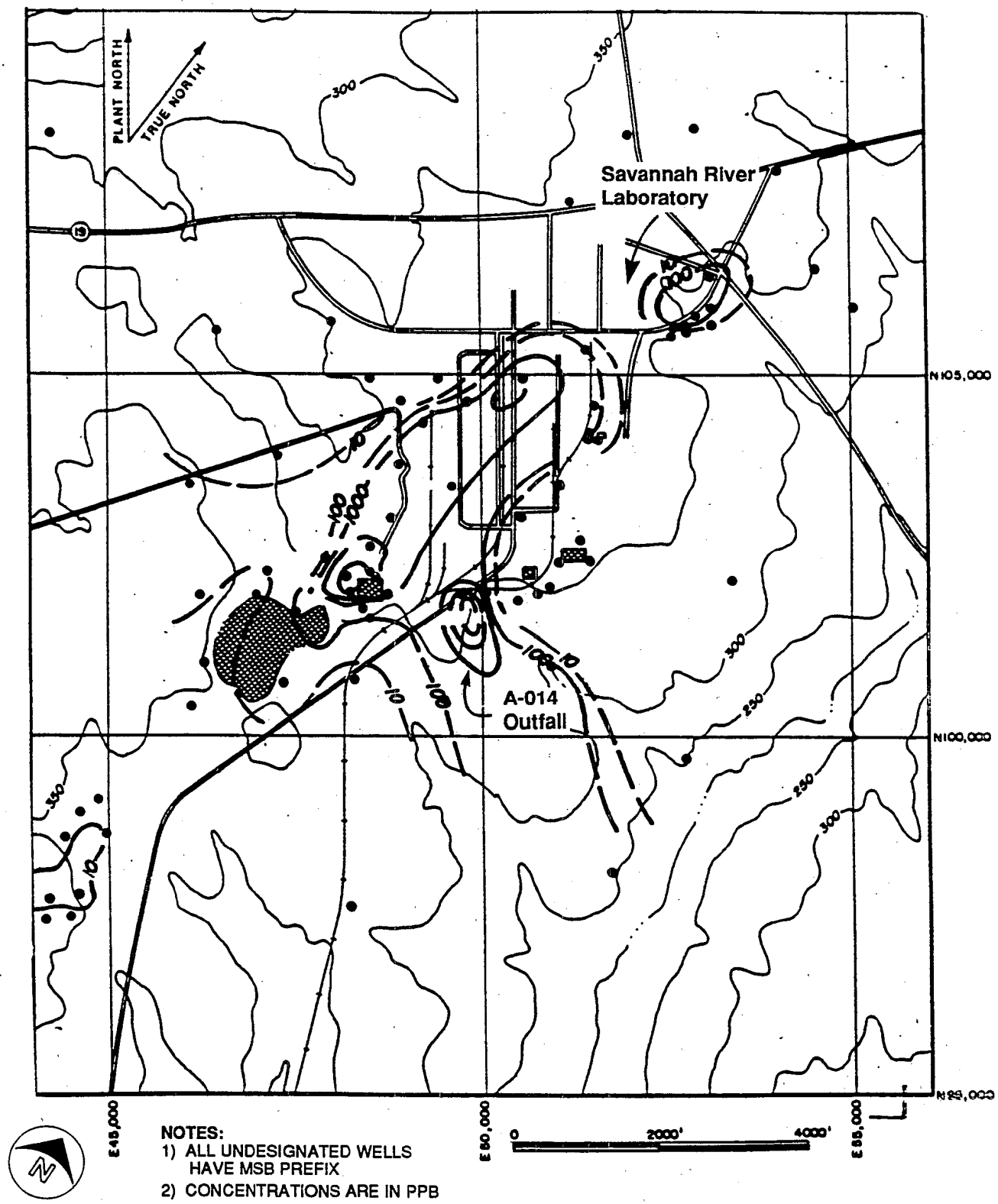
ELLENTON CLAY

McBEAN/CONGAREE CONTACT

NM — NOT MEASURED

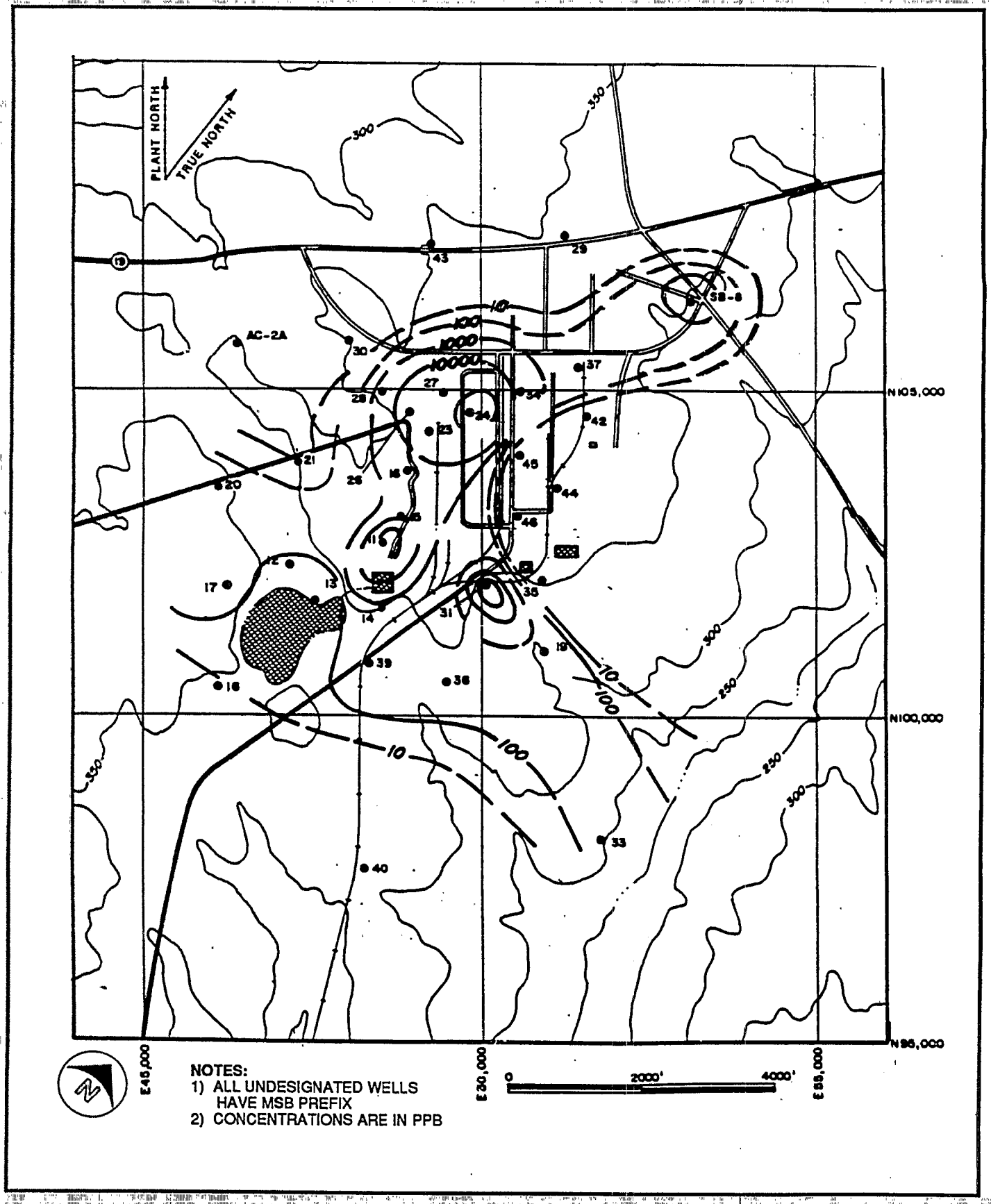
NOTE: VERTICAL EXAGGERATION = 20 TIMES.

Figure 7
HYDROGEOLOGIC CROSS SECTION E-E', THIRD QUARTER 1985
SRP A/M-AREA SITE



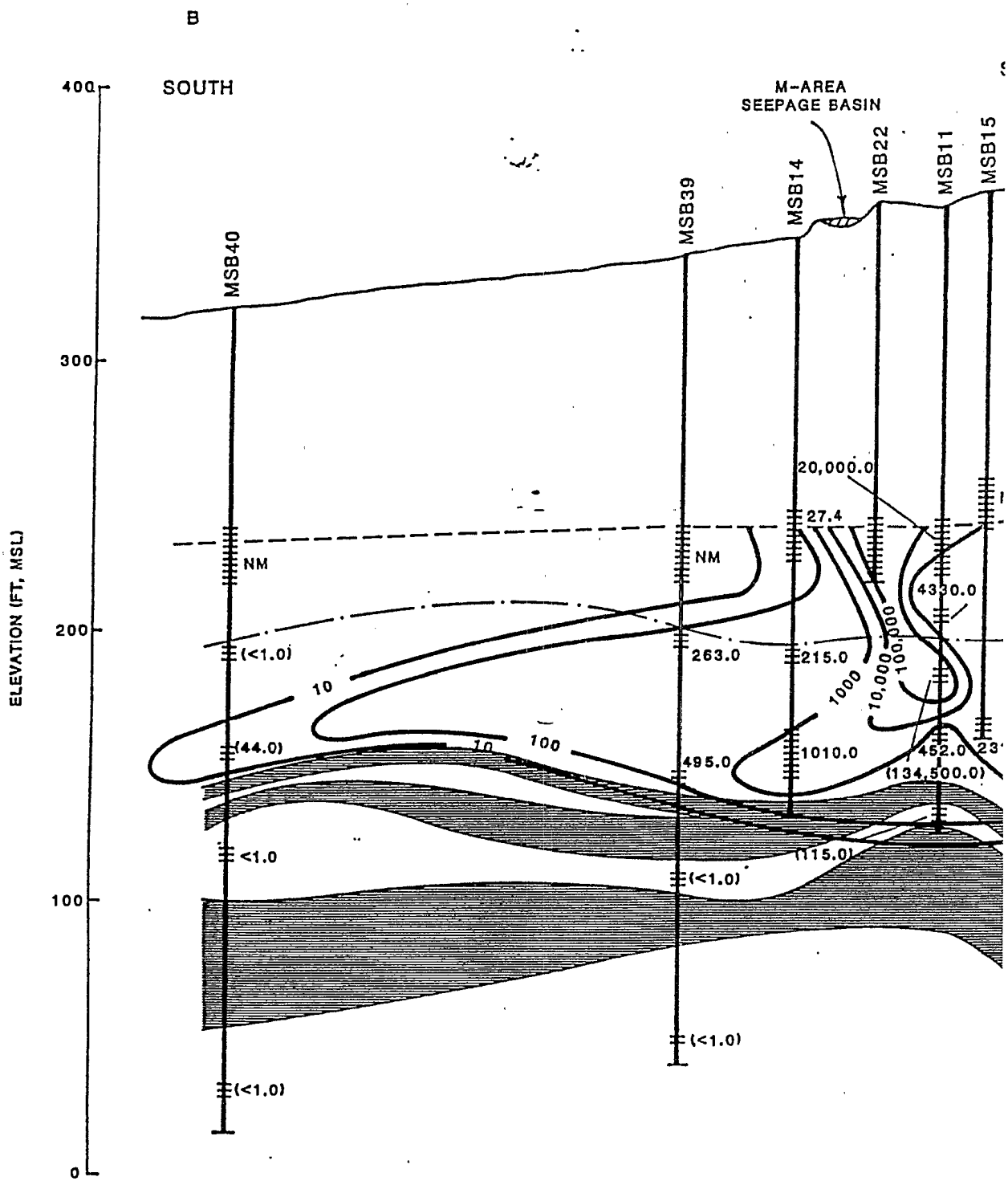
Source: Colven et al. February 1987. Draft First Year Report, Effectiveness of the A/M-Area Remedial Action Program, September 1985 to September 1986.

Figure 8
CONTOUR MAP OF TCE CONCENTRATIONS IN THE WATER-TABLE UNIT, THIRD QUARTER 1985
SRP A/M-AREA SITE

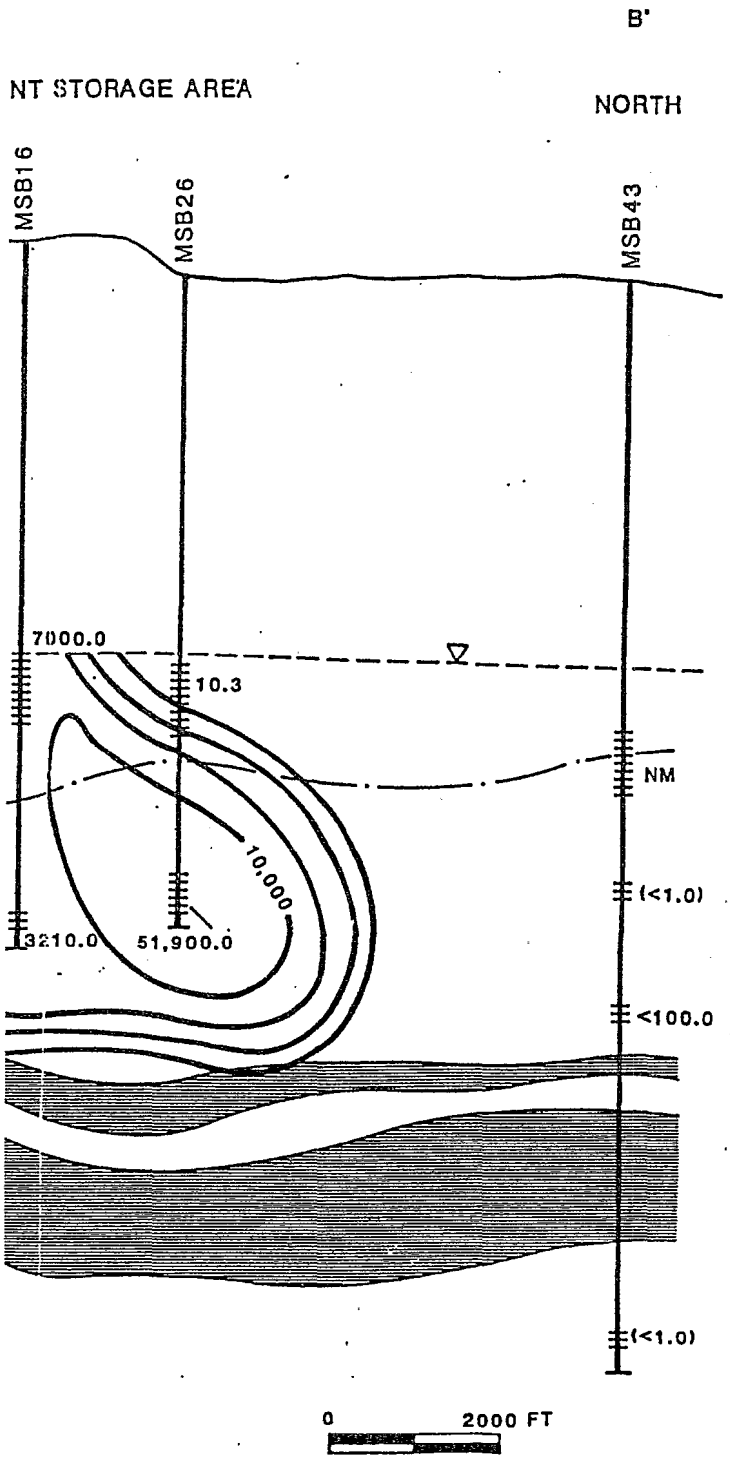


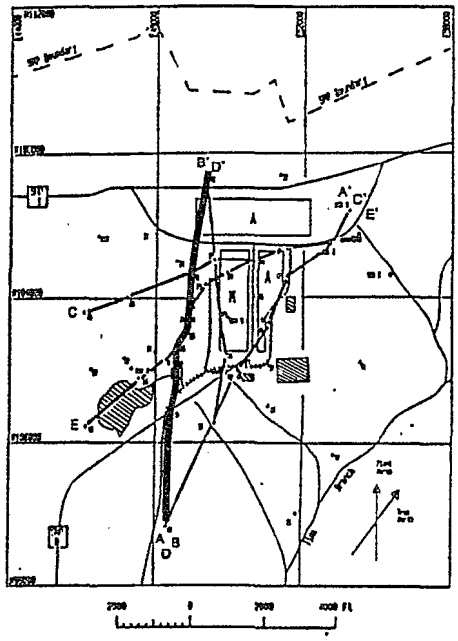
Source: Colven et al. February 1987. Draft First Year Report, Effectiveness of the A/M-Area Remedial Action Program, September 1985 to September 1986.

Figure 9
CONTOUR MAP OF TCE CONCENTRATIONS IN THE UPPER CONGAREE FORMATION, THIRD QUARTER 1985
SRP A/M-AREA SITE



Source: USDOE. July 1986. Application for a Post-Closure Permit, A/M-Area Hazardous Waste Management Facility, Volume III, Revision No. 1, Savannah River Plant.





EXPLANATION

THIRD QUARTER 1985

263.0 MONITOR WELL SCREEN ZONE WITH TRICHLOROETHYLENE CONCENTRATION (ug/l)

RECOVERY WELL SCREEN ZONE

10 ISOCONCENTRATIONAL CONTOUR

WATER TABLE

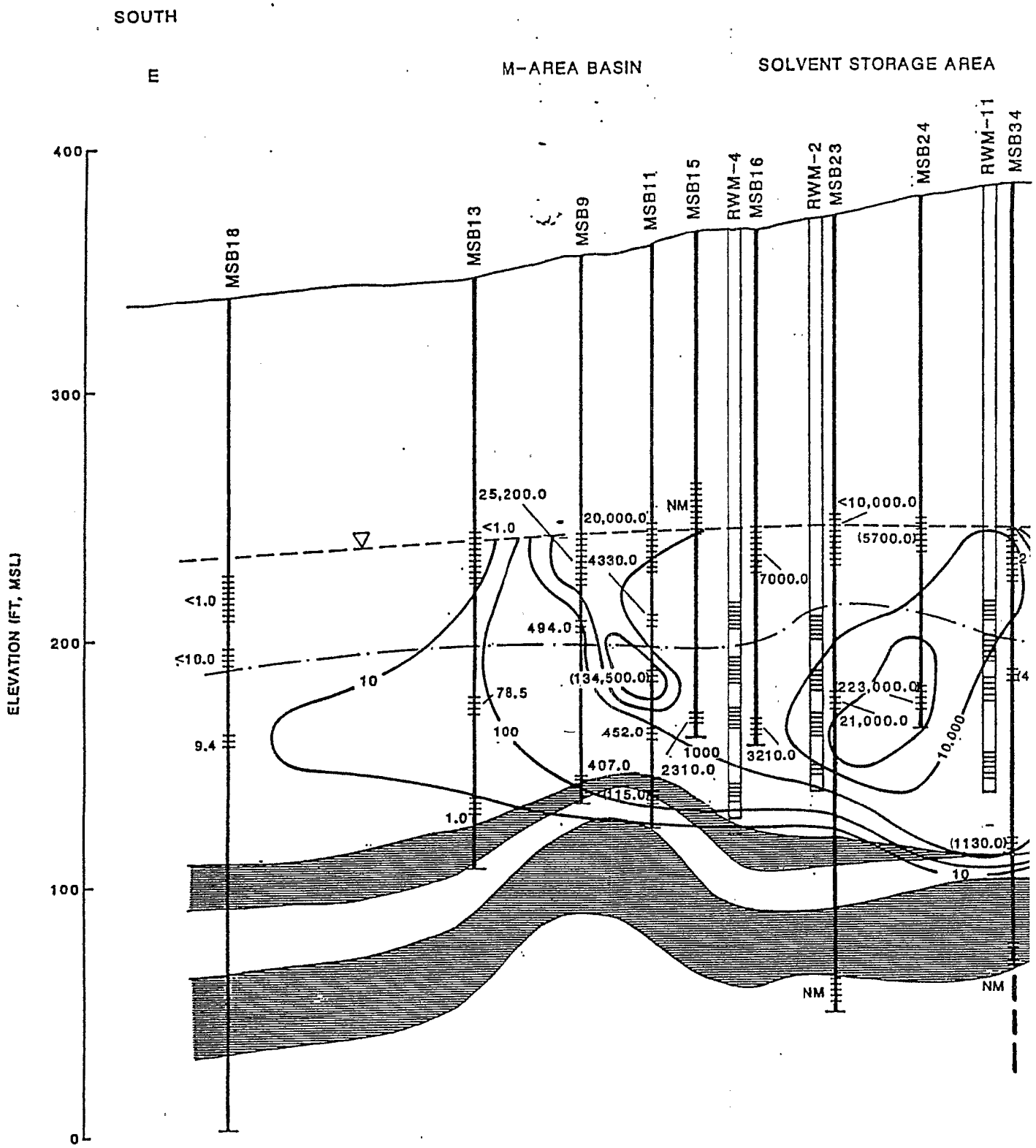
ELLENTON CLAY

McBEAN/CONGAREE CONTACT

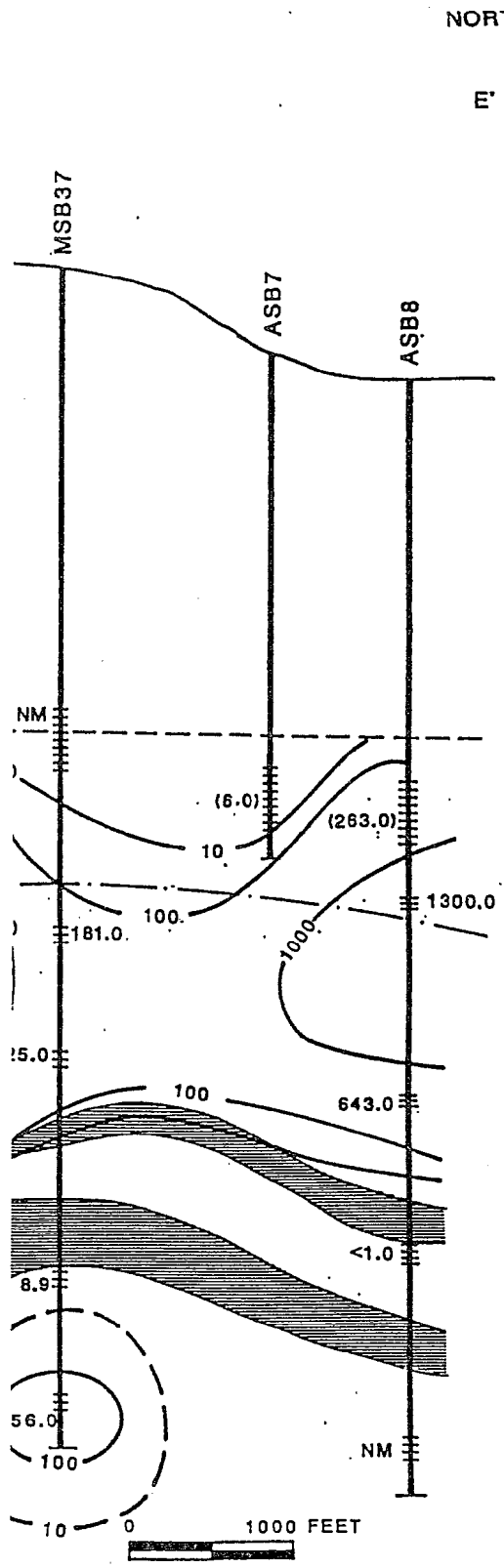
NM NOT MEASURED

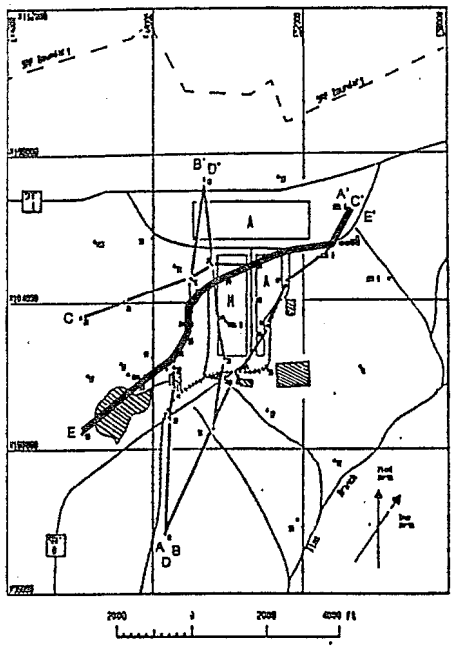
If concentration for third quarter not available, last available concentration is shown in parentheses.

Figure 10
TCE CONTAMINATION ALONG CROSS SECTION B-B', THIRD QUARTER, 1985
SRP A/M-AREA SITE



Source: USDOE. July 1986. Application for a Post-Closure Permit, A/M-Area Hazardous Waste Management Facility, Volume III, Revision No. 1, Savannah River Plant.





EXPLANATION

THIRD QUARTER 1985

263.10 — MONITOR WELL SCREEN ZONE WITH TRICHLOROETHYLENE CONCENTRATION (ug/l)

RECOVERY WELL SCREEN ZONE

10 — ISOCONCENTRATIONAL CONTOUR

WATER TABLE

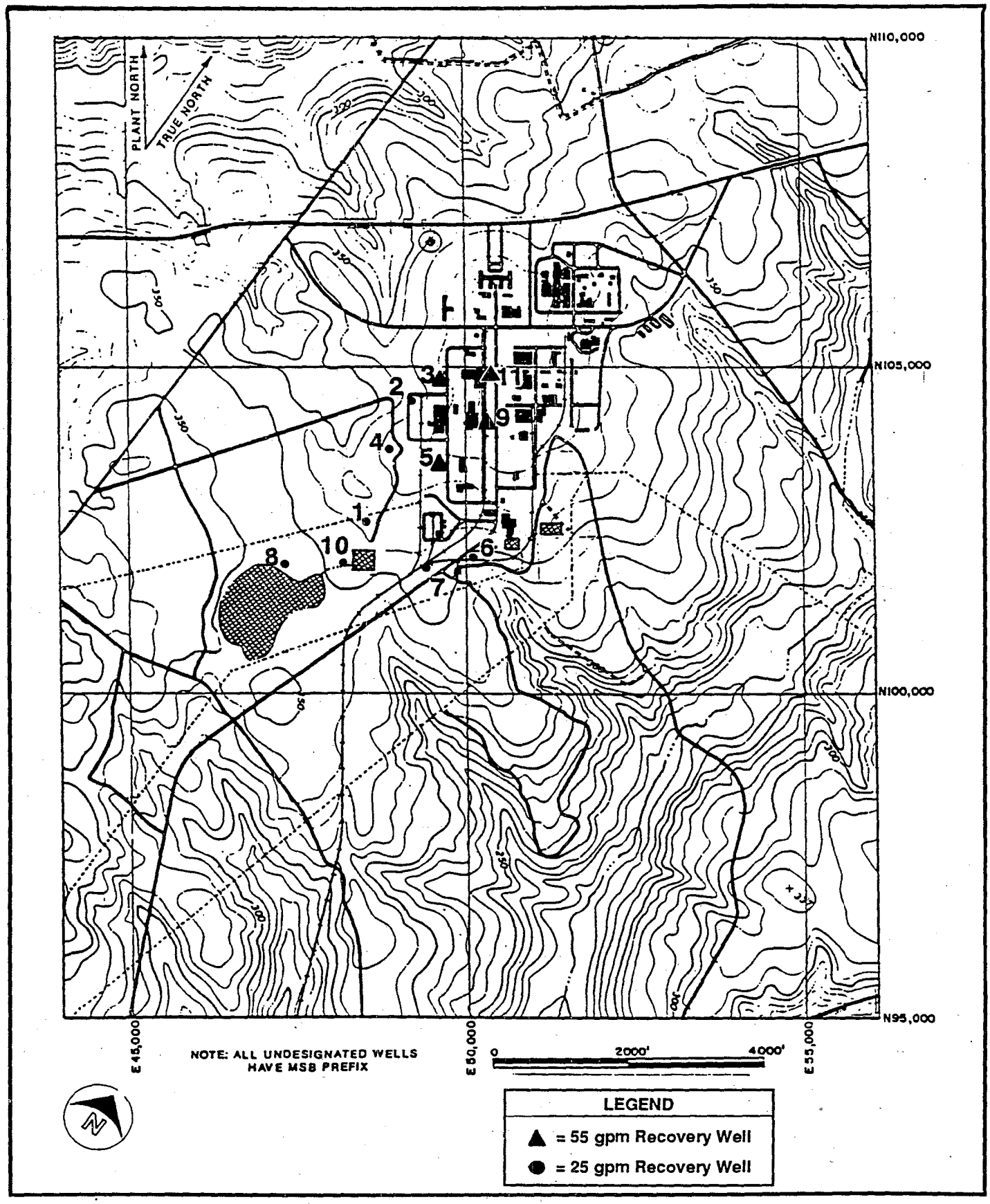
ELLENTON CLAY

McBEAN/CONGAREE CONTACT

NM — NOT MEASURED

If concentration for third quarter not available, last available concentration is shown in parentheses.

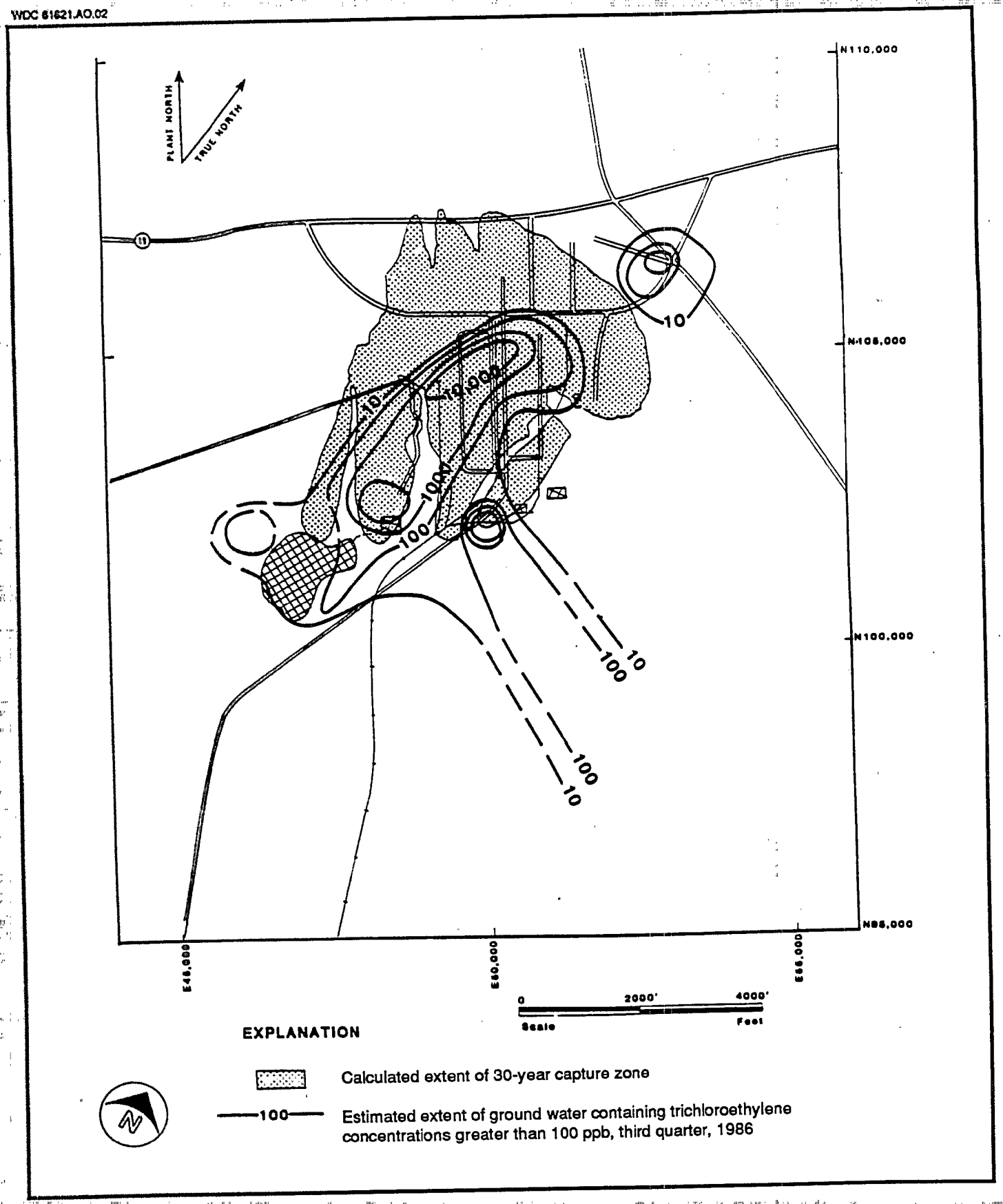
Figure 11
TCE CONCENTRATION ALONG CROSS SECTION E-E' THIRD QUARTER, 1985
SRP A/M-AREA SITE



Source: USDOE. July 1986. Application for a Post-Closure Permit, A/M-Area Hazardous Waste Management Facility, Volume III, Revision No. 1, Savannah River Plant.

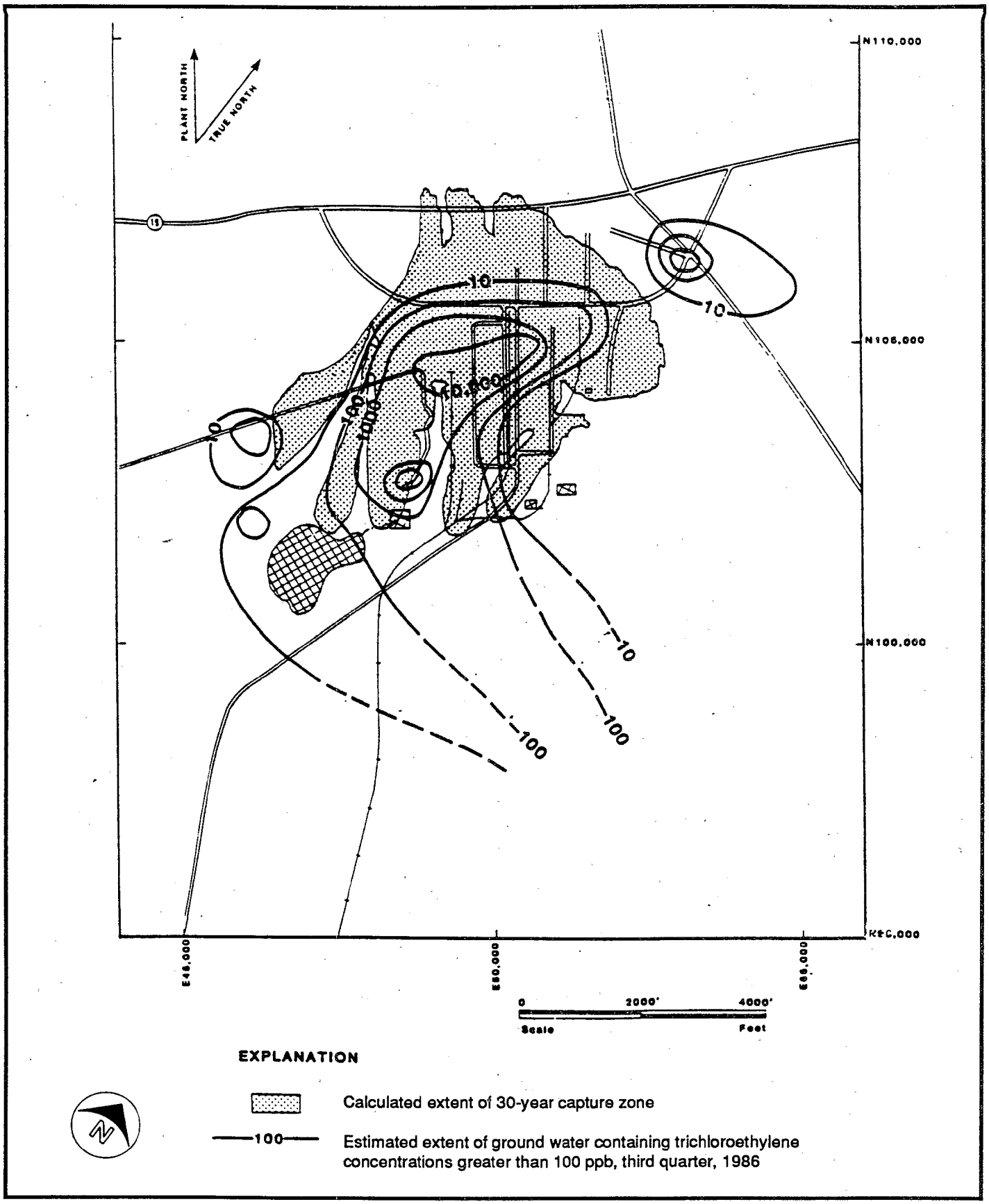
Figure 12
RECOVERY WELL LOCATION MAP
SRP A/M-AREA SITE

WDC 61621.AO.02



Source: Colven et al. February 1987. Draft First Year Report, Effectiveness of the A/M-Area Remedial Action Program, September 1985 to September 1986.

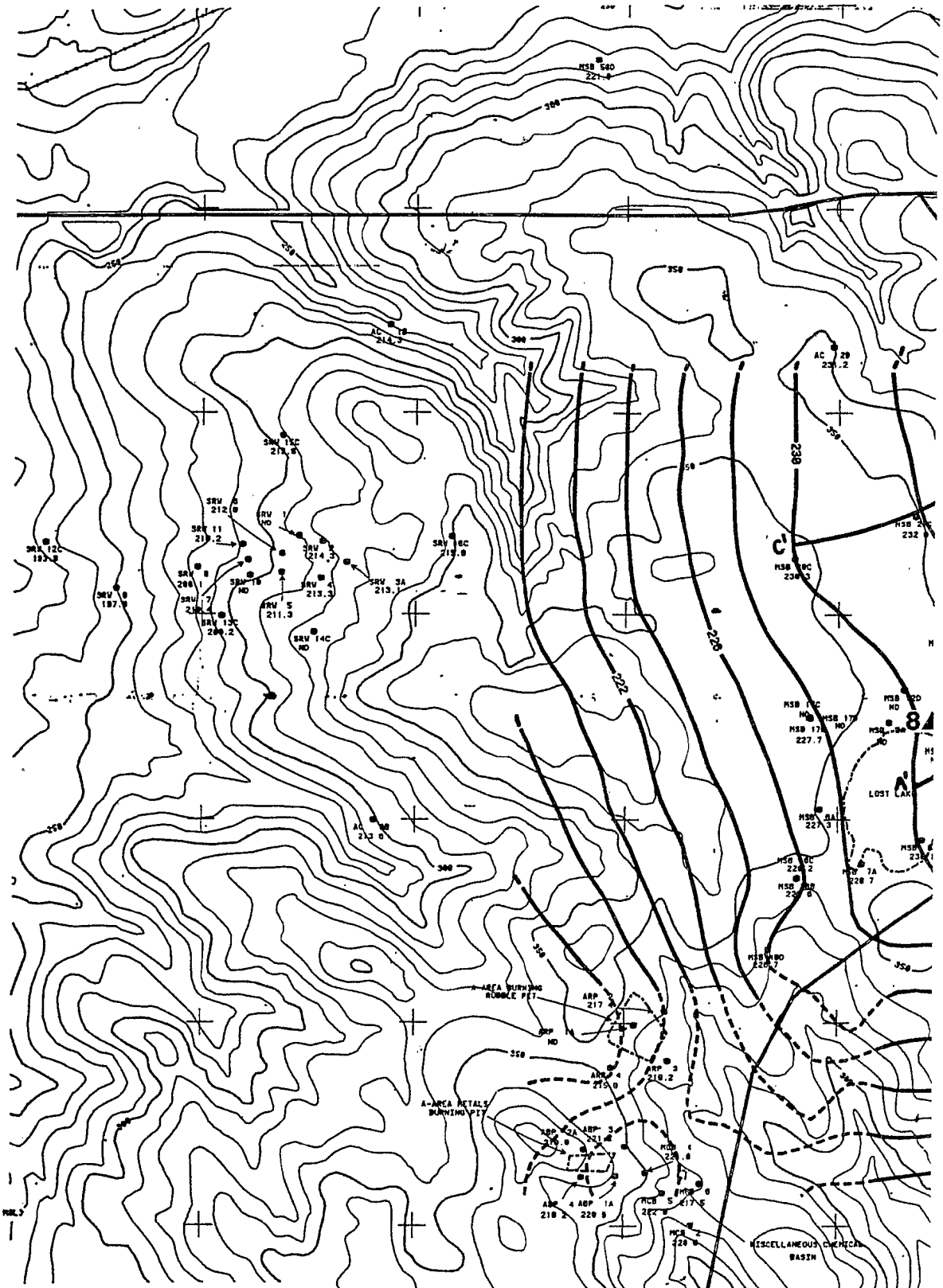
Figure 13
30-YEAR ZONE OF CAPTURE IN THE WATER-TABLE UNIT
SRP A/M-AREA SITE



Source: Colven et al. February 1987. Draft First Year Report, Effectiveness of the A/M-Area Remedial Action Program, September 1985 to September 1986.

Figure 14
30-YEAR ZONE OF CAPTURE IN THE UPPER CONGAREE FORMATION
SRP A/M-AREA SITE

WDC 61621.AO.02



Source: USDOE. March 1989. A/M-Area Hazardous Waste Management Facility Post-Closure Care Permit, Groundwater Monitoring and Corrective Action Program, Savannah River Plant, 1988 Annual Report.

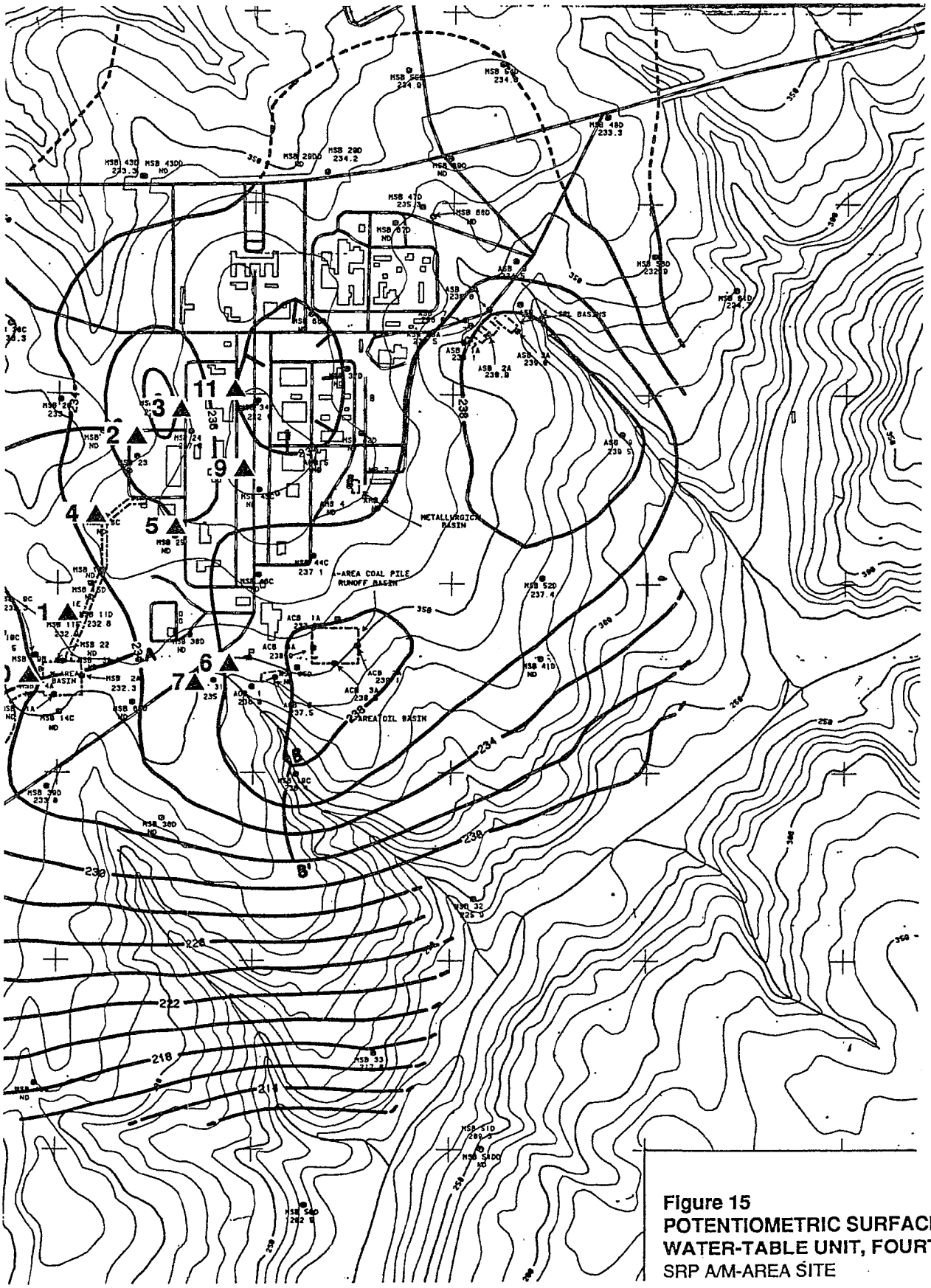
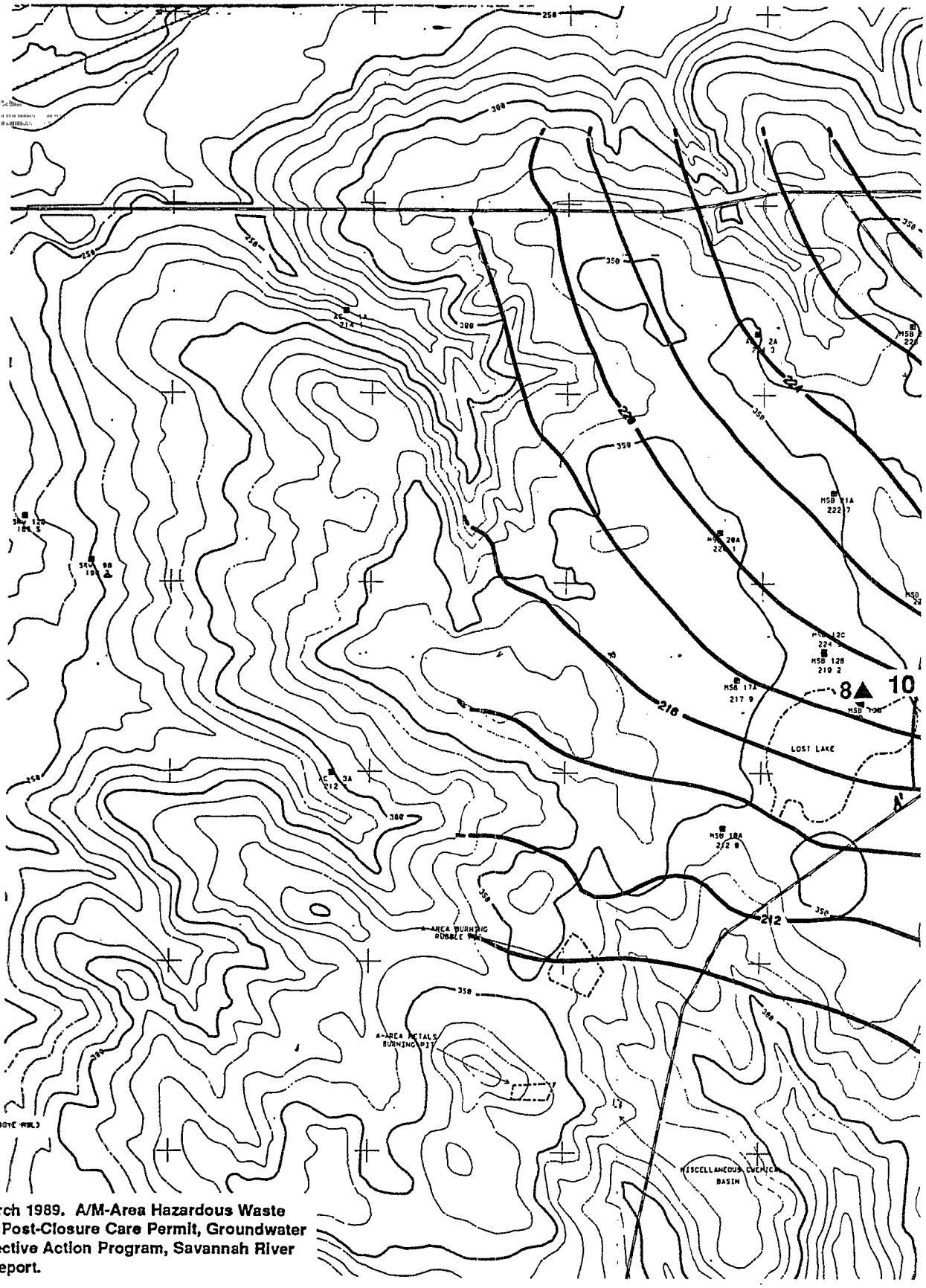


Figure 15
POTENTIOMETRIC SURFACE MAP OF THE WATER-TABLE UNIT, FOURTH QUARTER 1988
SRP A/M-AREA SITE



Source: USDOE. March 1989. A/M-Area Hazardous Waste Management Facility Post-Closure Care Permit, Groundwater Monitoring and Corrective Action Program, Savannah River Plant, 1988 Annual Report.

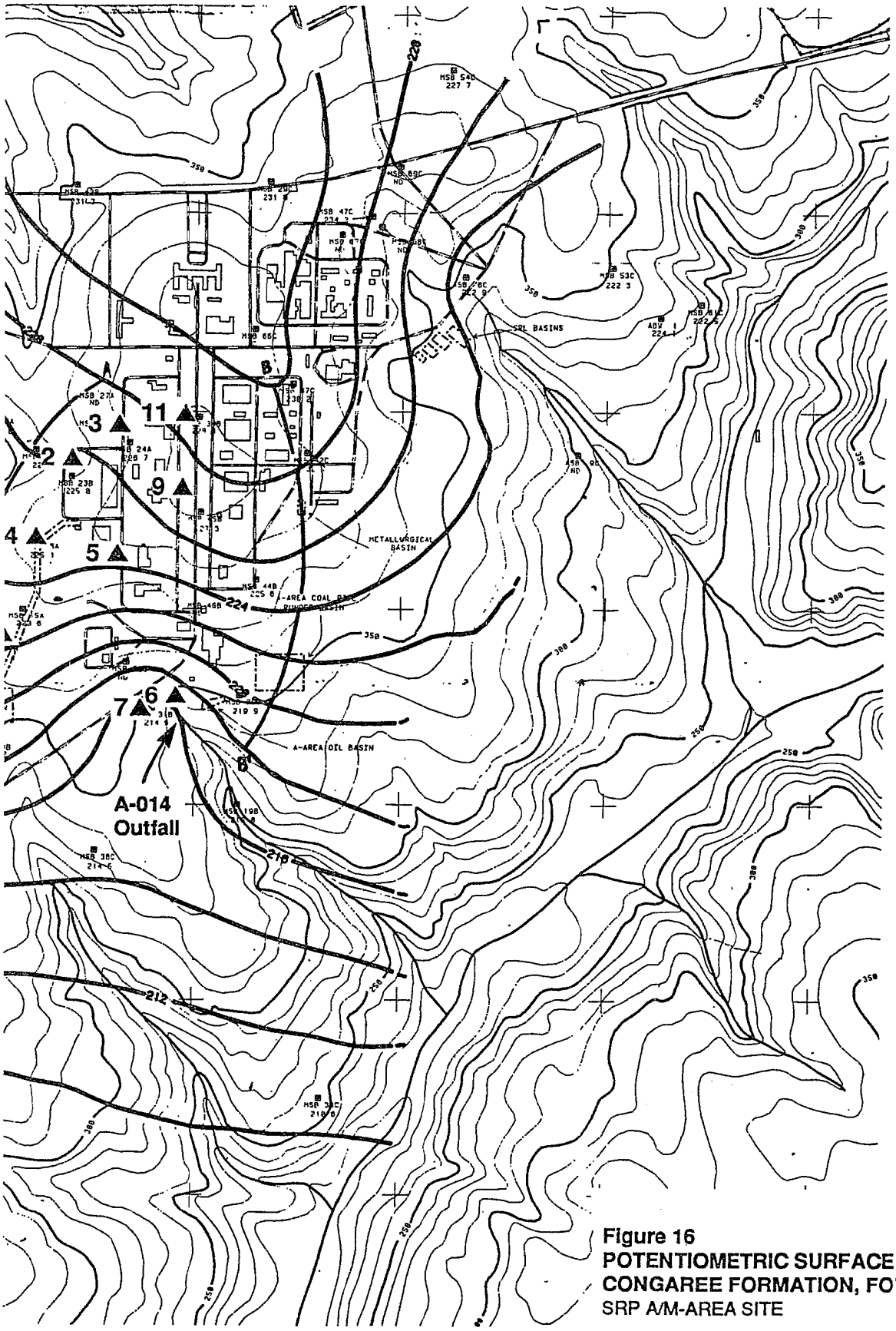
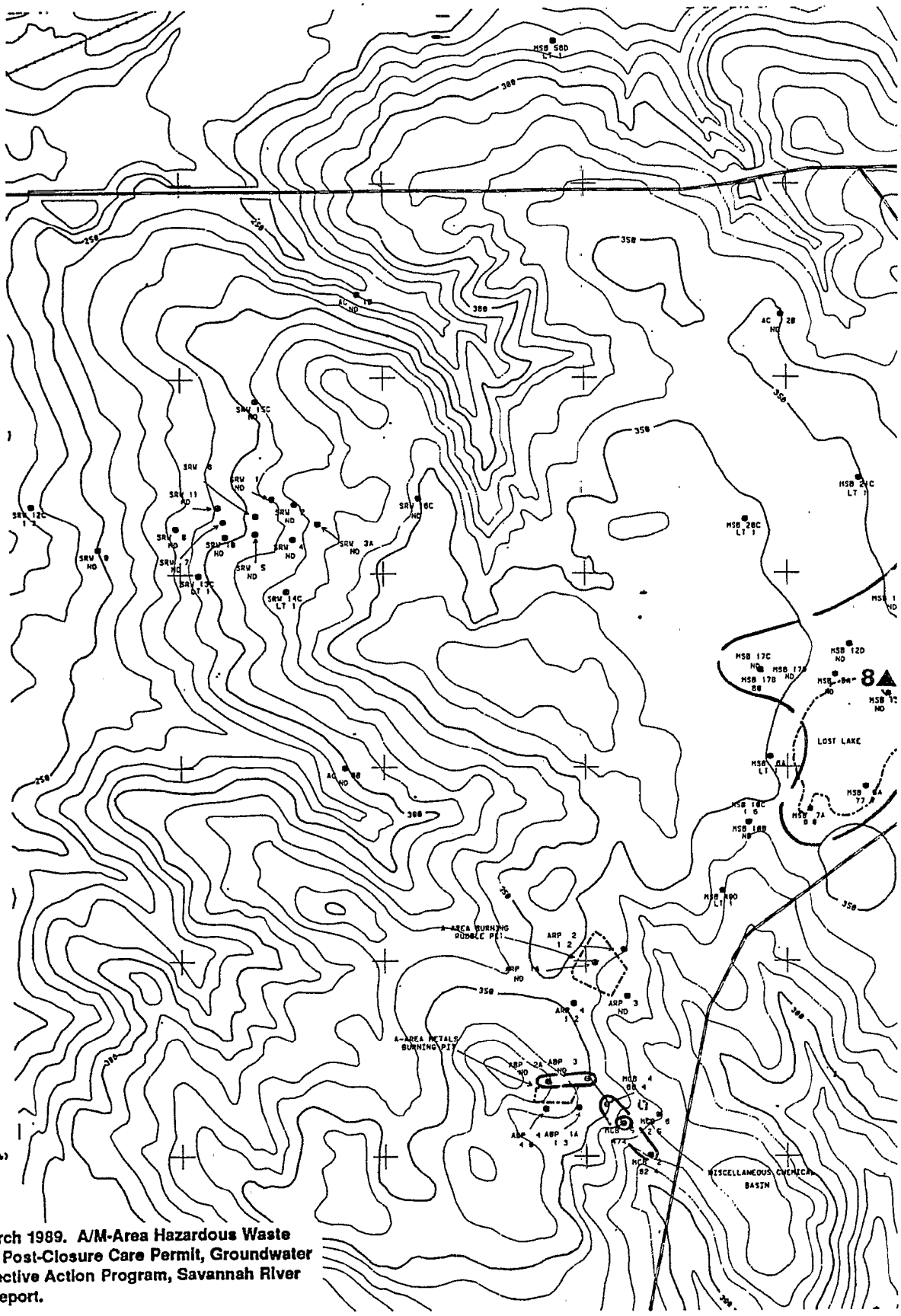


Figure 16
POTENTIOMETRIC SURFACE MAP OF THE UPPER CONGAREE FORMATION, FOURTH QUARTER 1988
SRP A/M-AREA SITE

WDC 61621.AO.02



Source: USDOE. March 1989. A/M-Area Hazardous Waste Management Facility Post-Closure Care Permit, Groundwater Monitoring and Corrective Action Program, Savannah River Plant, 1988 Annual Report.

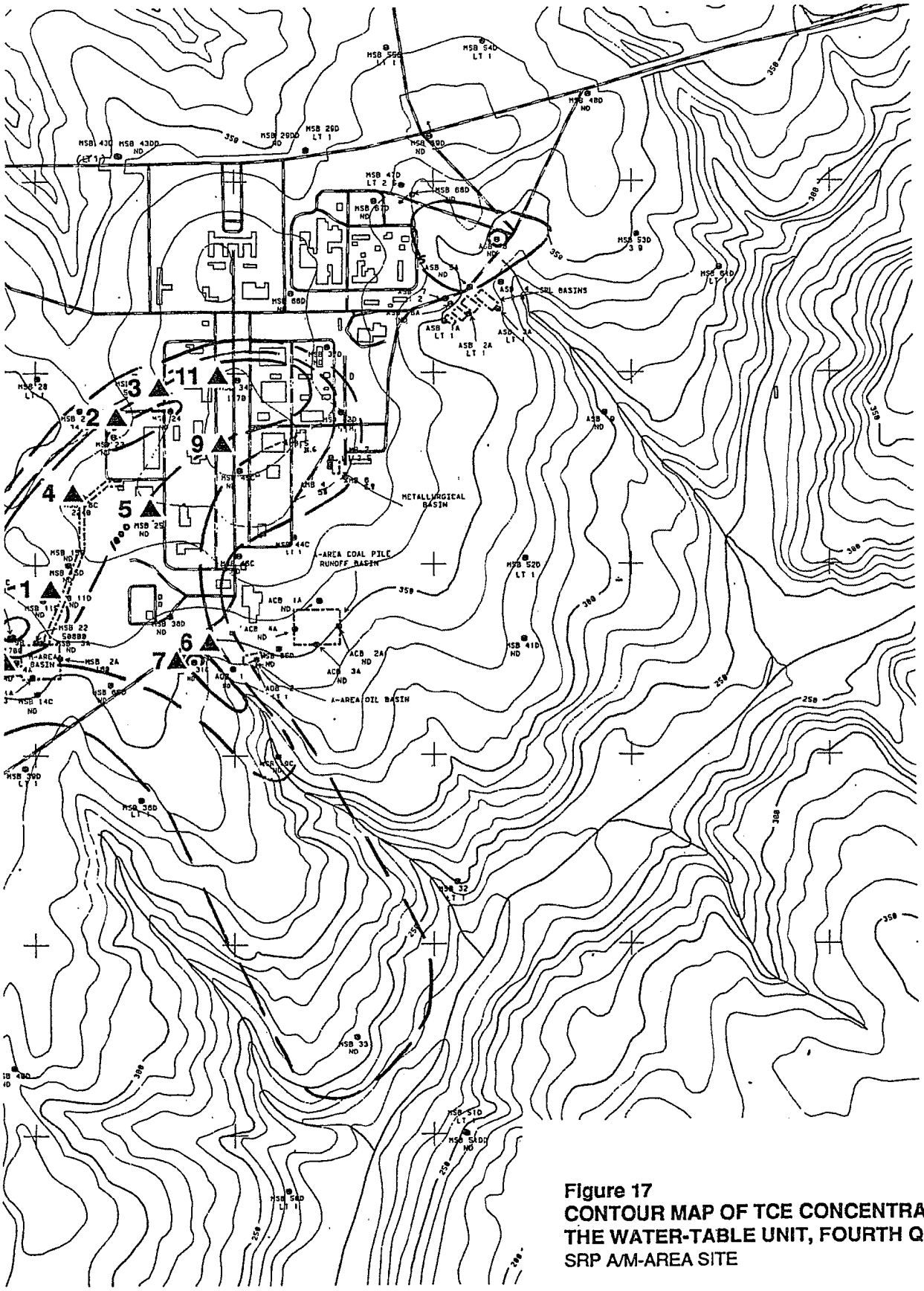
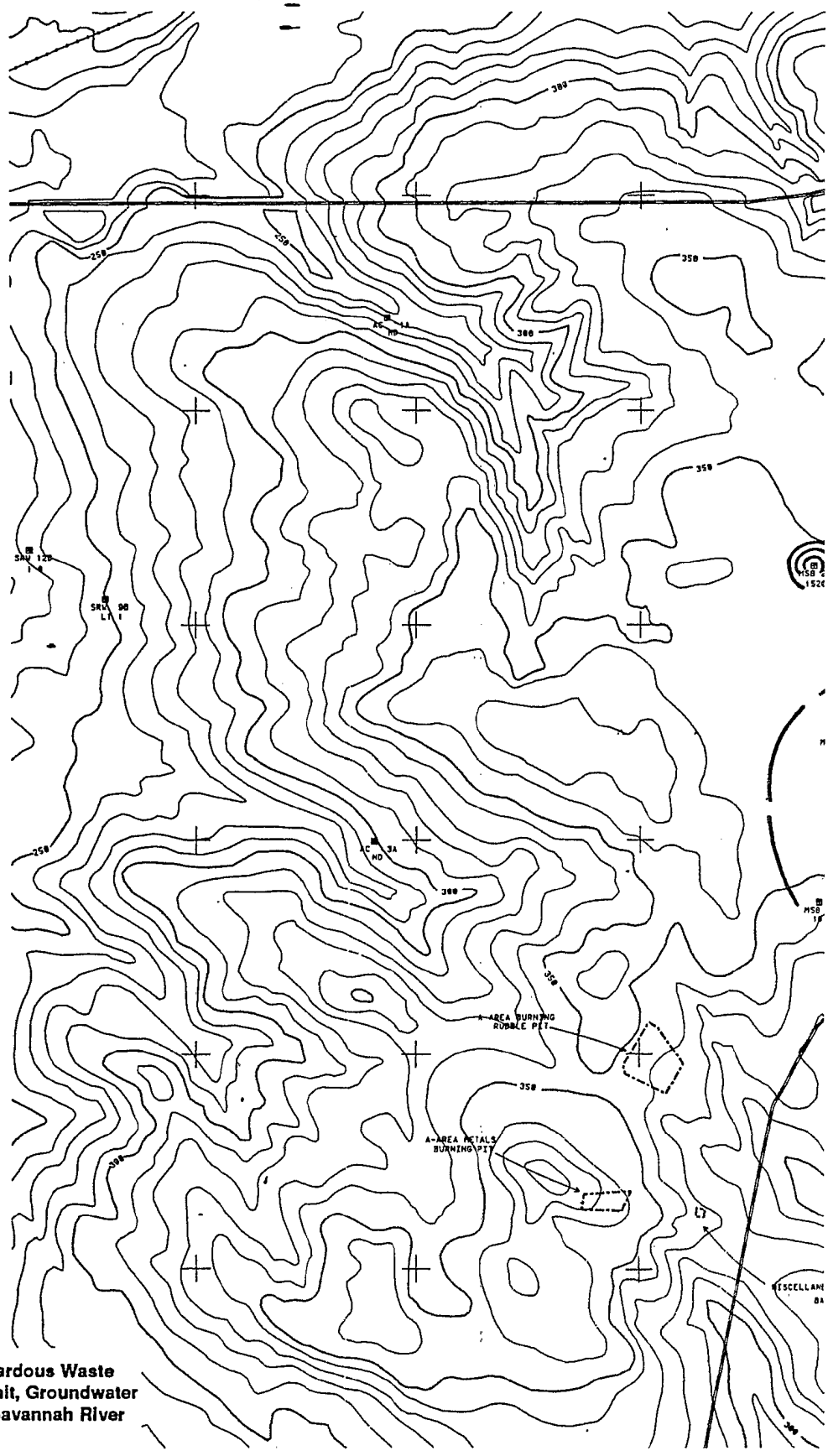
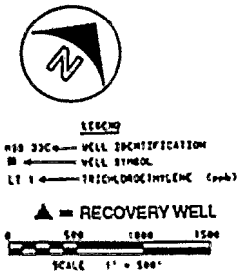


Figure 17
CONTOUR MAP OF TCE CONCENTRATIONS IN THE WATER-TABLE UNIT, FOURTH QUARTER 1988
SRP A/M-AREA SITE





Source: USDOE. March 1989. A/M-Area Hazardous Waste Management Facility Post-Closure Care Permit, Groundwater Monitoring and Corrective Action Program, Savannah River Plant, 1988 Annual Report.

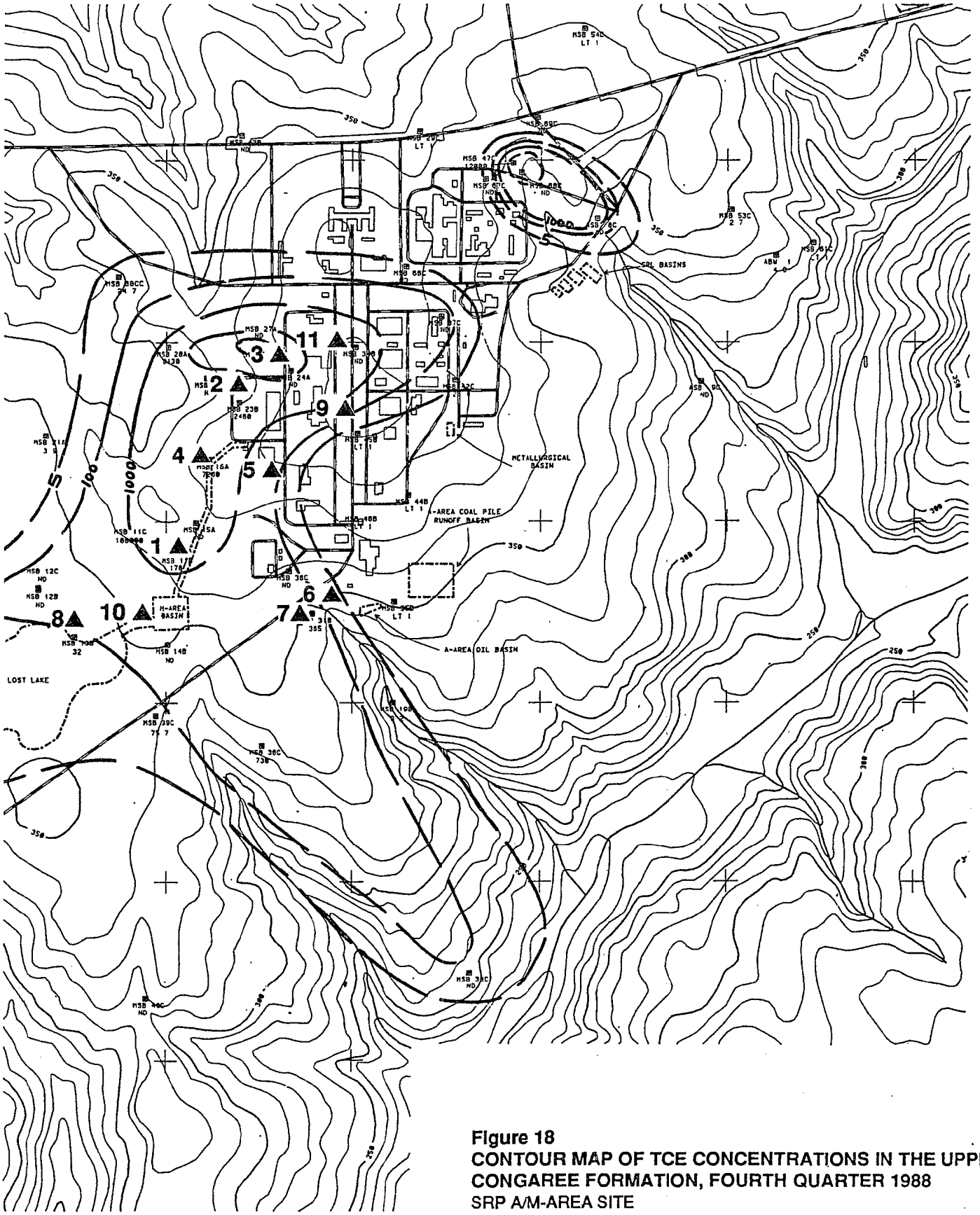
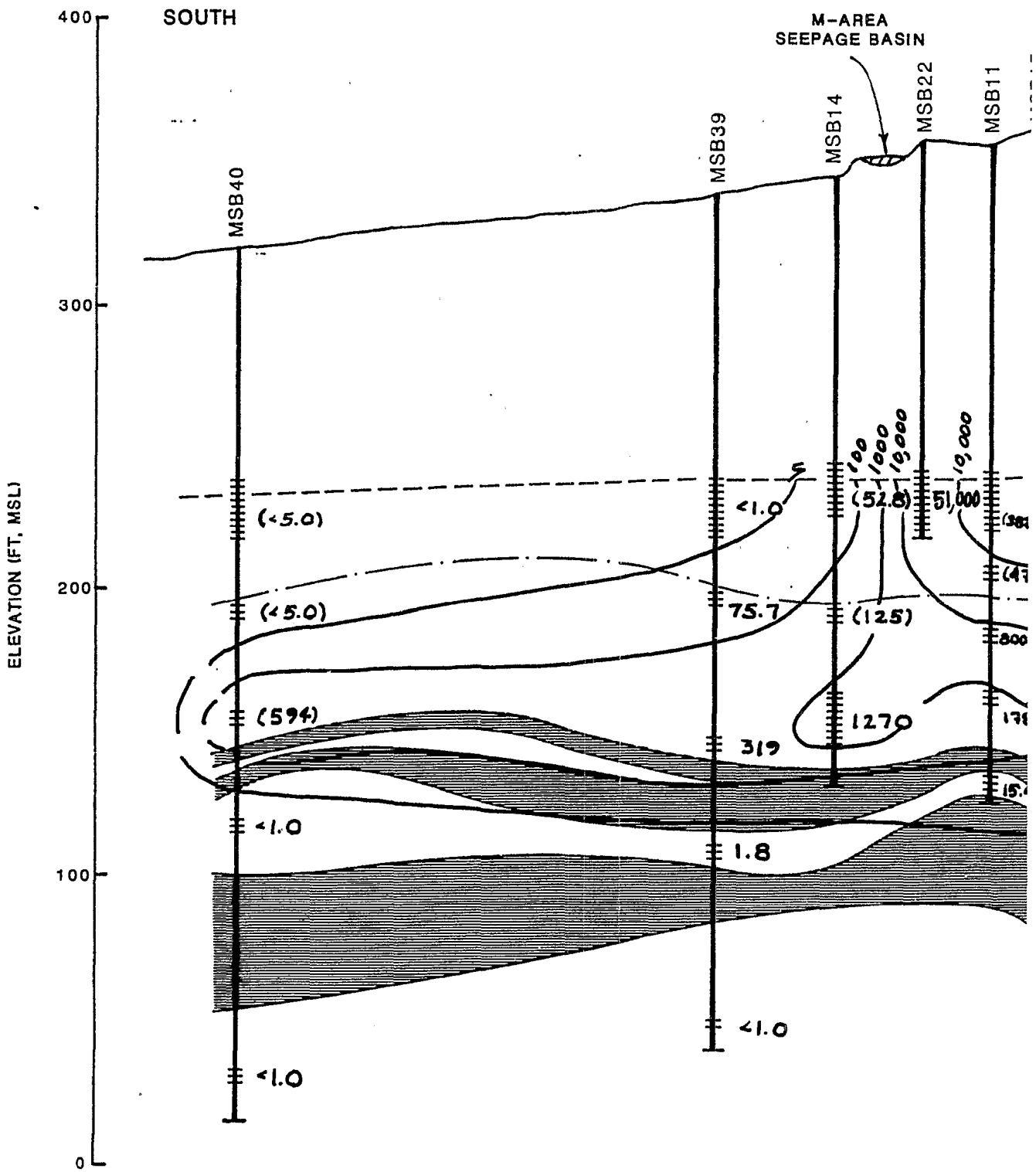
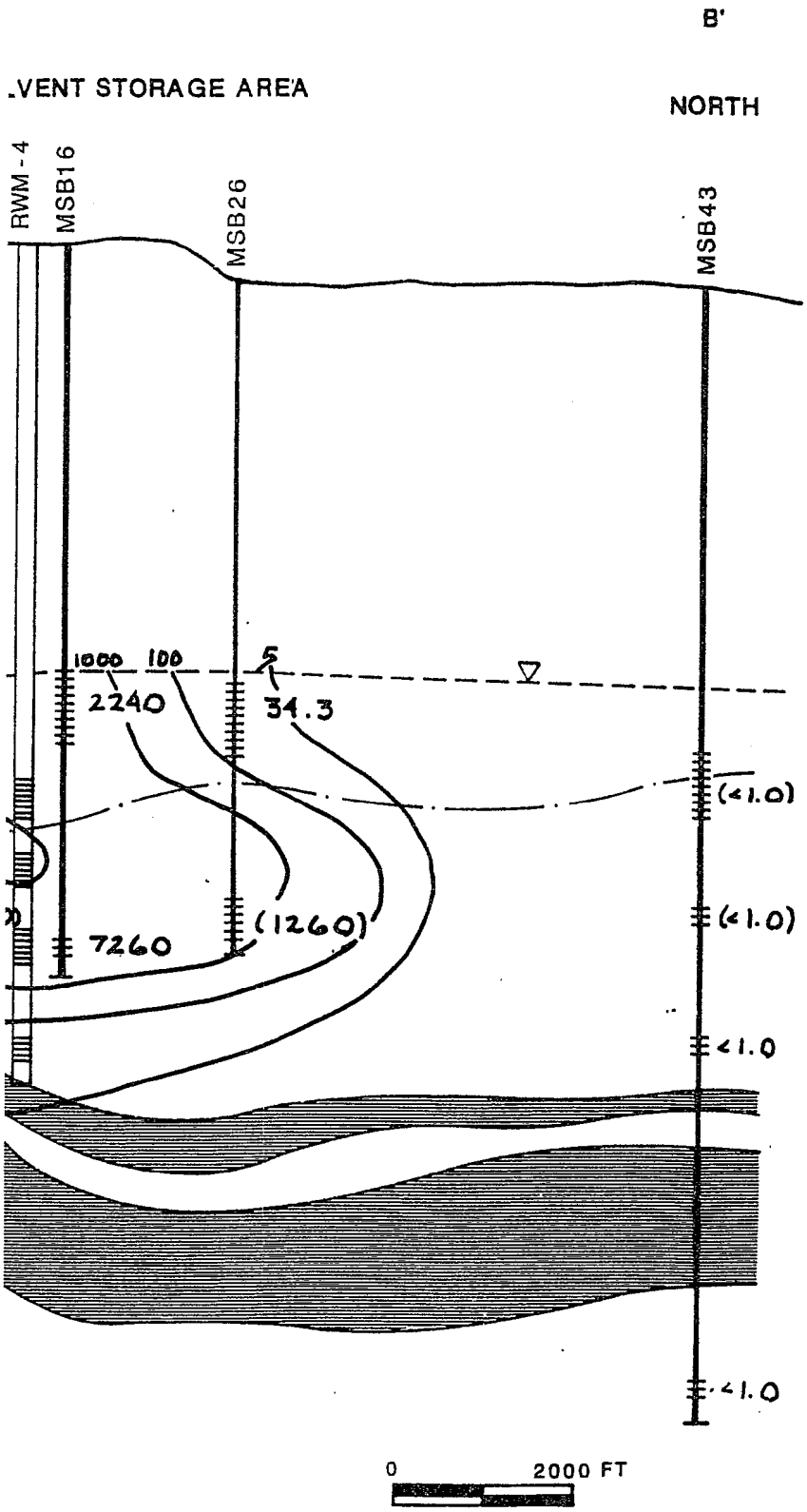
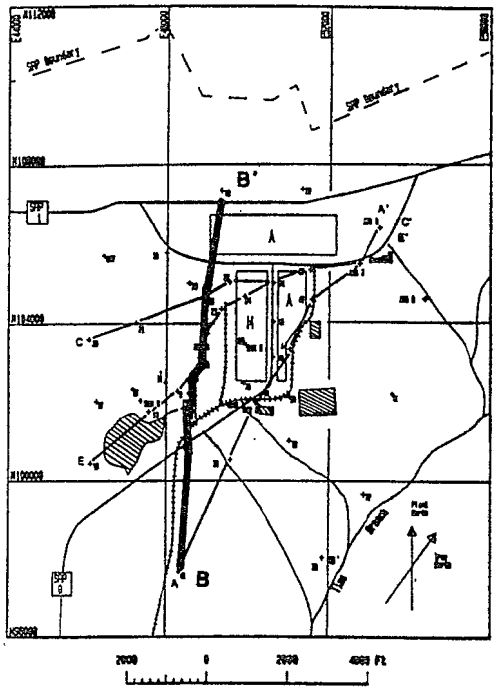


Figure 18
CONTOUR MAP OF TCE CONCENTRATIONS IN THE UPPER CONGAREE FORMATION, FOURTH QUARTER 1988
SRP A/M-AREA SITE



Source: USDOE. March 1989. A/M-Area Hazardous Waste Management Facility Post-Closure Care Permit, Groundwater Monitoring and Corrective Action Program, Savannah River Plant, 1988 Annual Report.





EXPLANATION

Fourth Quarter 1988

58,500.0 MONITOR WELL SCREEN ZONE WITH TRICHLOROETHYLENE CONCENTRATION (ug/l)

RECOVERY WELL SCREEN ZONE

10 ISOCONCENTRATIONAL CONTOUR

WATER TABLE

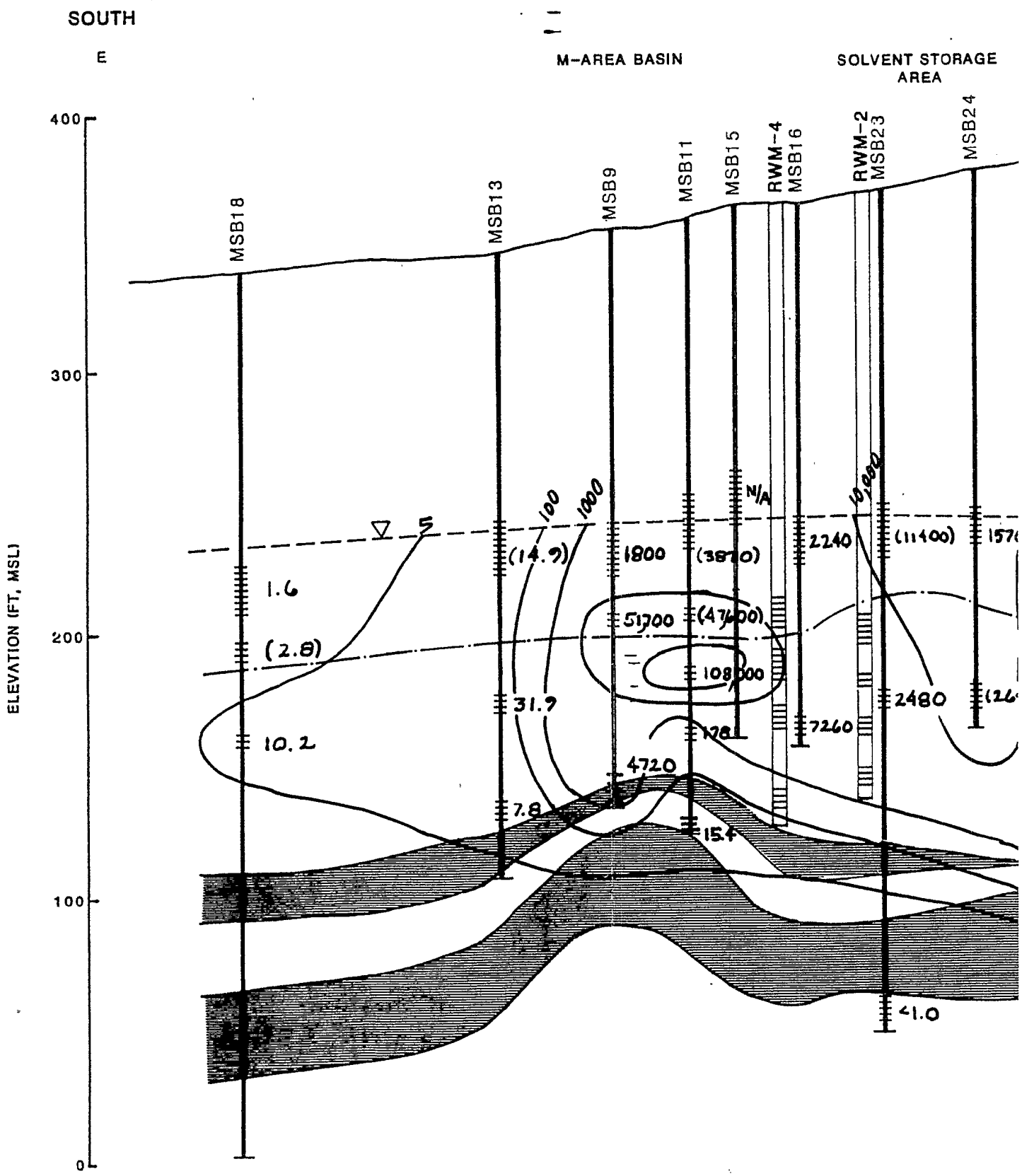
ELLENTON CLAY

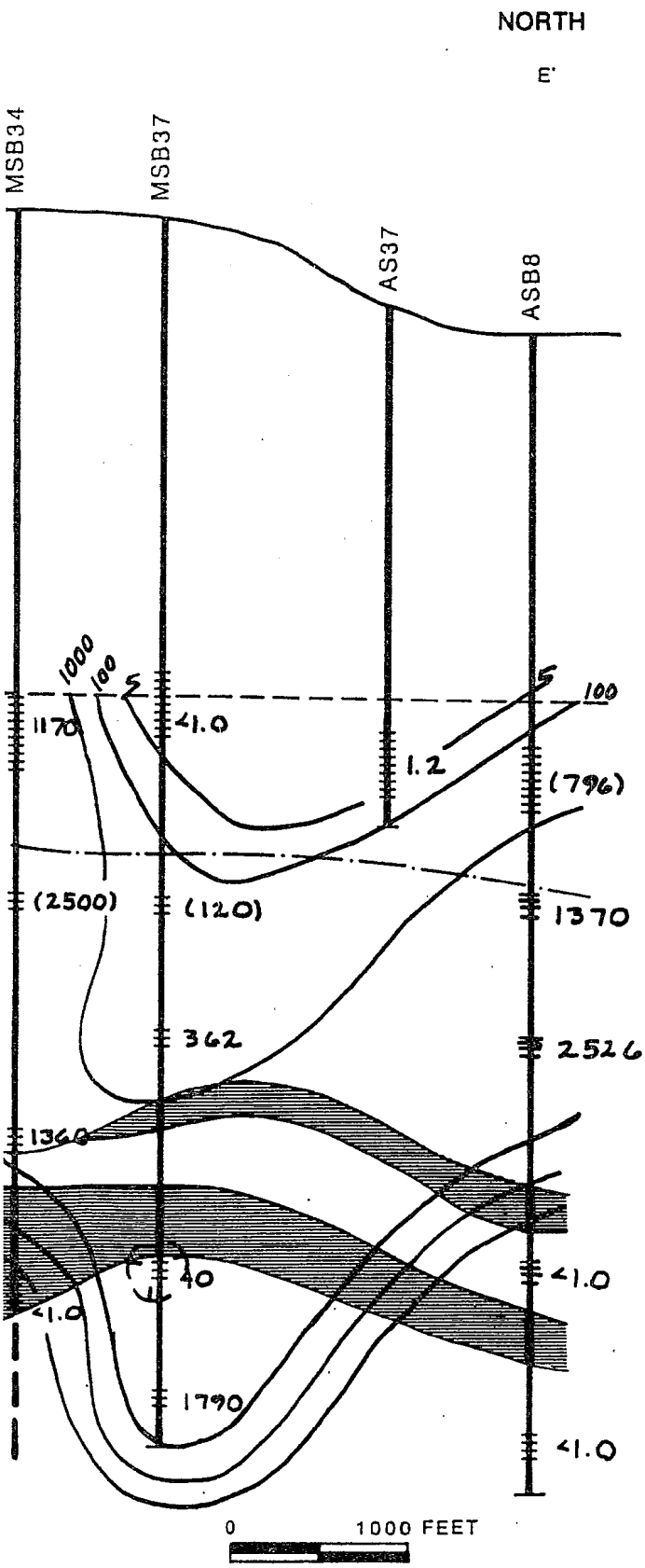
McBEAN/CONGAREE CONTACT

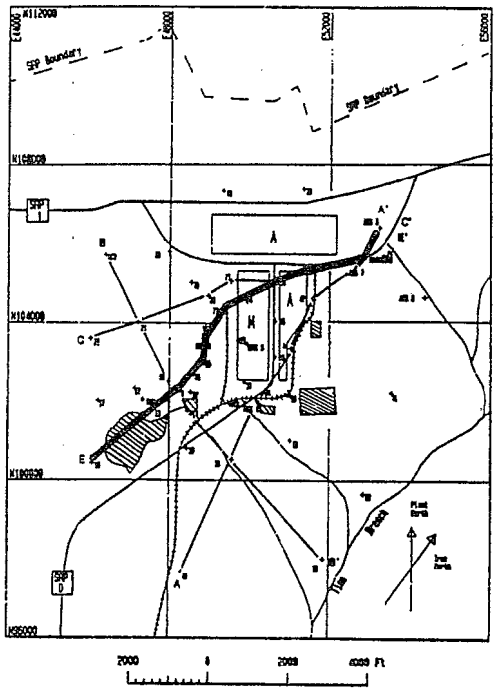
NM NOT MEASURED

If concentration for fourth quarter not available, last available concentration is shown in parentheses.

Figure 19
TCE CONCENTRATIONS ALONG CROSS SECTION B-B', FOURTH QUARTER 1988
SRP A/M-AREA SITE


SOUTH
E
M-AREA BASIN
SOLVENT STORAGE AREA
MSB18
MSB13
MSB9
MSB11
MSB15
RWM-4
MSB16
RWM-2
MSB23
MSB24
ELEVATION (FT, MSL)
400
300
200
100
0
5
100
1000
10,000
N/A
1.6
(2.8)
10.2
(14.9)
31.9
7.8
1800
51700
108,000
4720
178
15.4
(38710)
2240
7260
(11400)
2480
41.0





EXPLANATION

Fourth Quarter 1988

58,500.0 — MONITOR WELL SCREEN ZONE WITH TRICHLOROETHYLENE CONCENTRATION (ug/l)

RECOVERY WELL SCREEN ZONE

10 — ISOCONCENTRATIONAL CONTOUR

WATER TABLE

ELLENTON CLAY

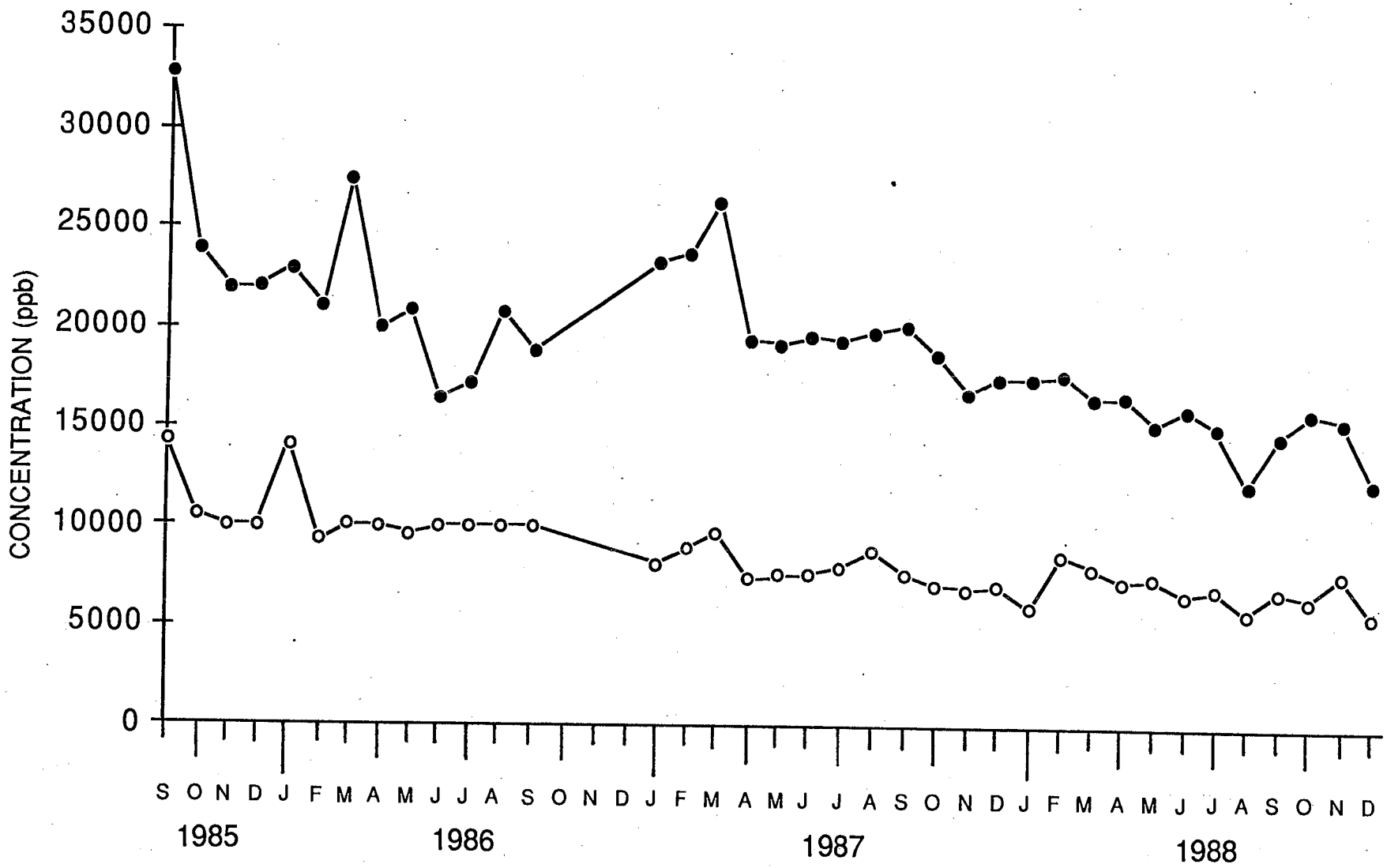
McBEAN/CONGAREE CONTACT

NM — NOT MEASURED

If concentration for fourth quarter not available, last available concentration is shown in parentheses.

Figure 20
TCE CONCENTRATIONS ALONG CROSS SECTION E-E', FOURTH QUARTER 1988
SRP A/M-AREA SITE

WDC 61621.AO.02

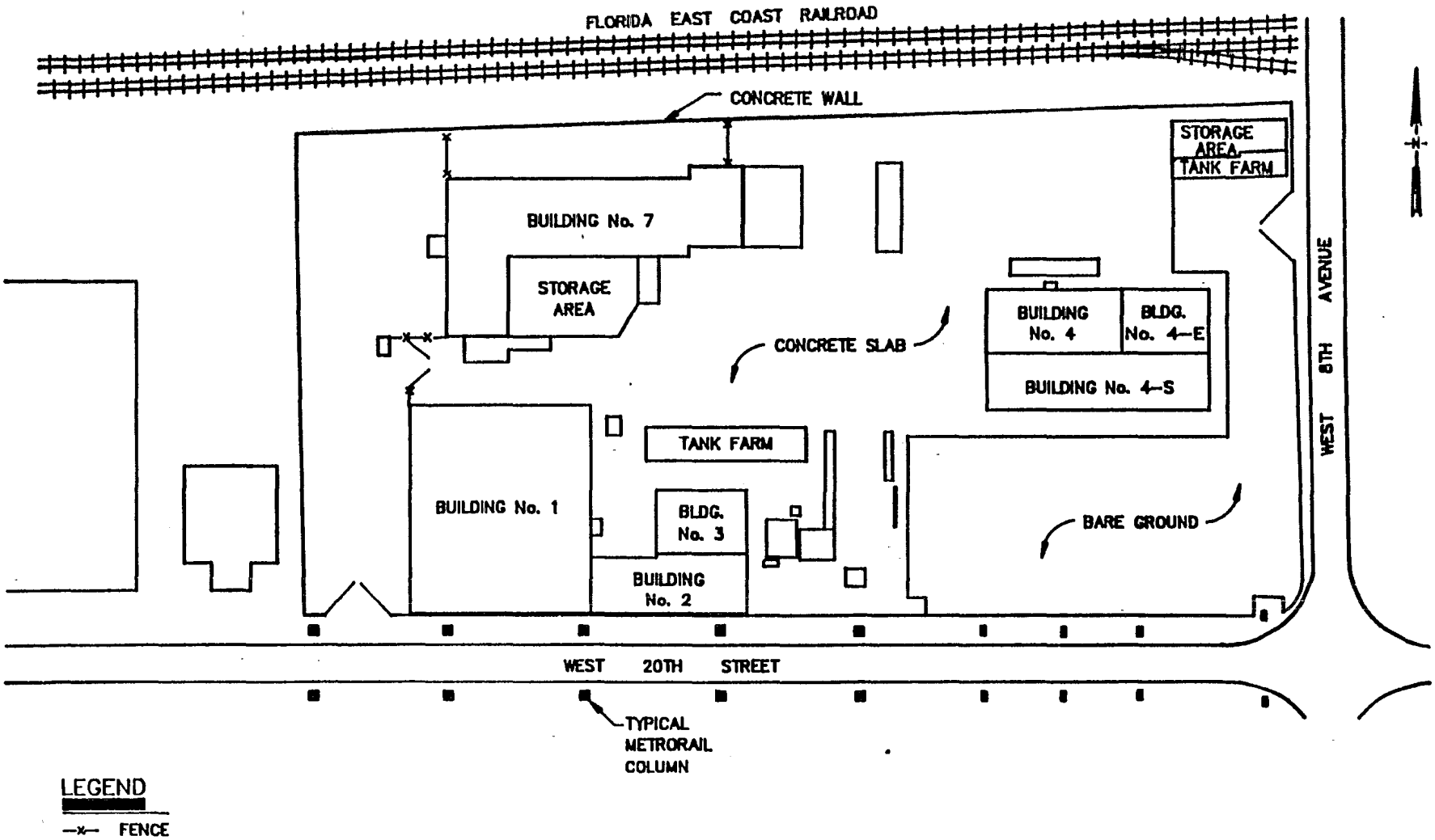


LEGEND

-●- TCE
-o- PCE

Figure 21
TIME SERIES PLOT OF TCE AND PCE CONCENTRATIONS IN THE AIR STRIPPER INFLUENT
SAVANNAH RIVER PLANT A/M-AREA SITE
AIKEN, SOUTH CAROLINA

WDC 61621 A0.02



LEGEND

—x— FENCE

Figure 1
MAP OF SITE A
SOUTH FLORIDA

WDC 61621. A0.02

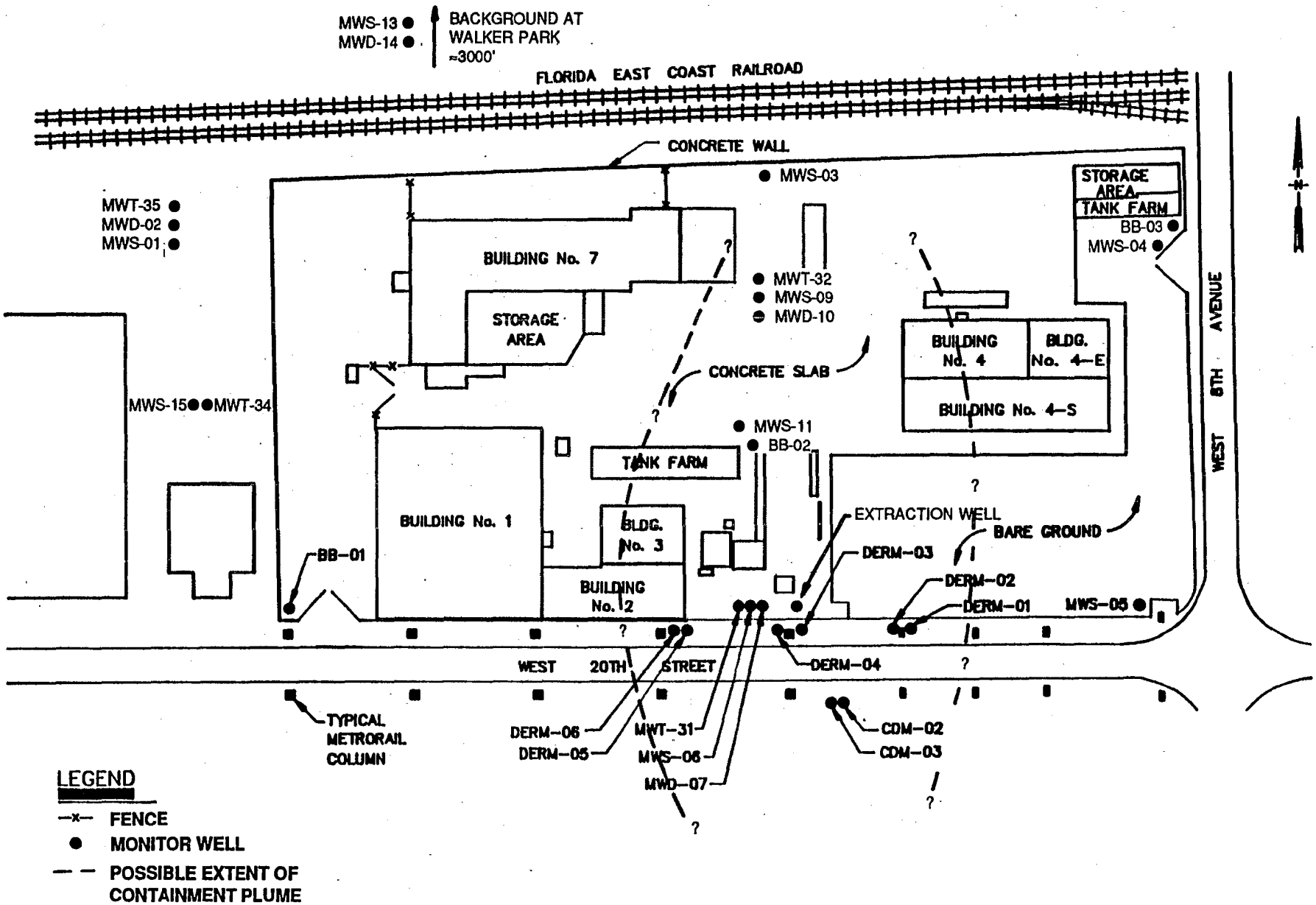
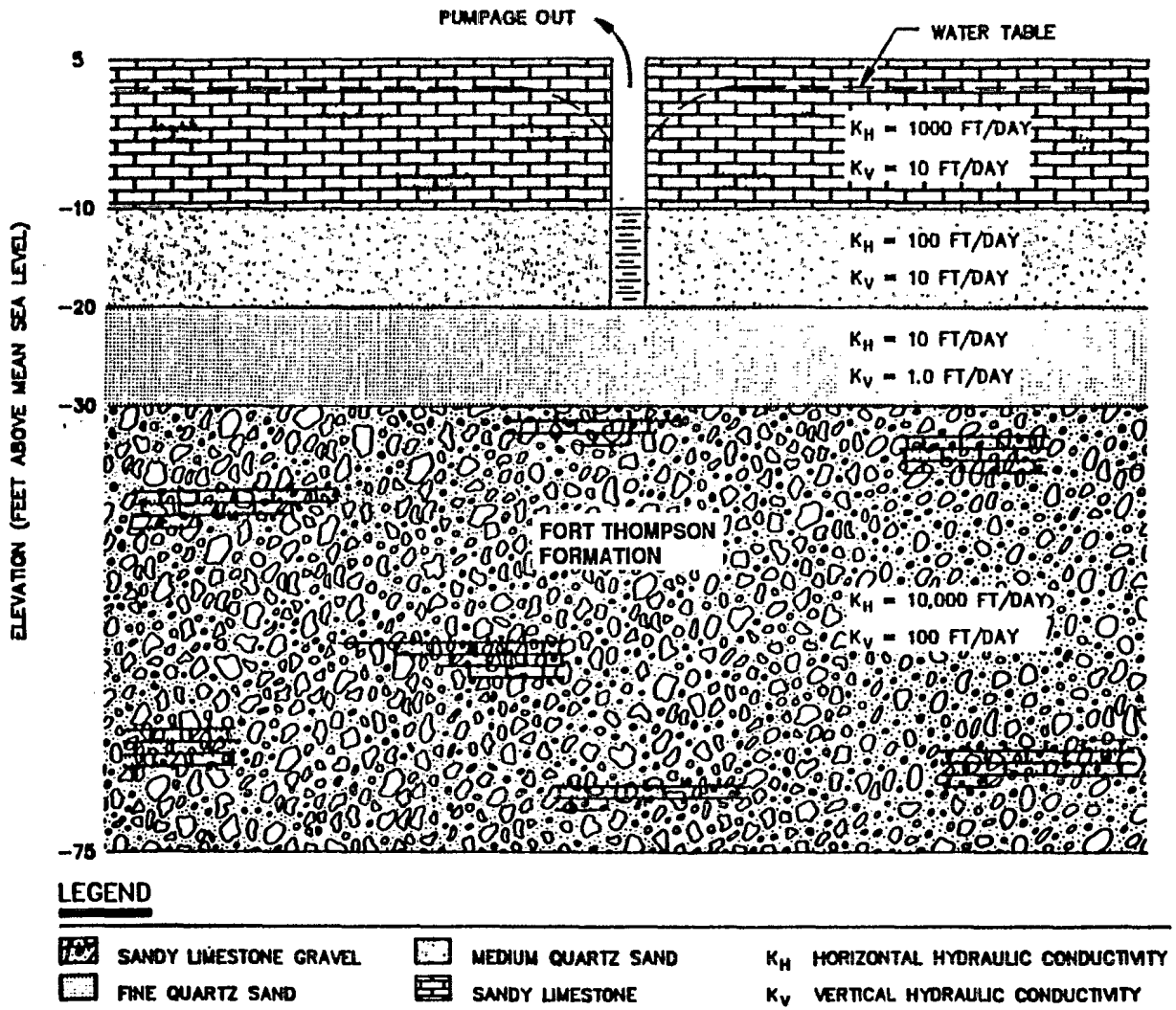


Figure 2
MONITORING WELL LOCATIONS
SITE A



LEGEND

SANDY LIMESTONE GRAVEL
FINE QUARTZ SAND
MEDIUM QUARTZ SAND
SANDY LIMESTONE
K_H HORIZONTAL HYDRAULIC CONDUCTIVITY
K_V VERTICAL HYDRAULIC CONDUCTIVITY

Figure 3
IDEALIZED HYDROGEOLOGIC CROSS SECTION OF SITE A

TABLE 1

APPLICABLE OR RELEVANT AND APPROPRIATE REQUIREMENTS (ARARs)
FOR INDICATOR CHEMICALS
SITE A

Chemical	Drinking Water Limits, ug/l		
	USEPA's MCLG[a]	USEPA's MCL[b]	Florida MCL
Benzene	0	5[c]	1
Bis(2-chloroethyl)ether	-	-	-
Bis(2-ethylhexyl)phthalate	-	-	-
Chlorobenzene	60[c]	-	-
Chloroform	-	100	-
1,4-Dichlorobenzene	0[c]	5[c]	-
1,1-Dichloroethylene	7	7[c]	-
Trans-1,2-Dichloroethylene	70[c]	-	-
Phenol	-	-	1[d]
Vinyl chloride	0	1[c]	1

[a] MCLG = Maximum Contaminant Level Goal.
[b] MCL = Maximum Contaminant Level.
[c] Proposed value.
[d] Dade County Department of Environmental Management DERM) MCL.

WDCR321/051.50

WDC 61821 A0.02

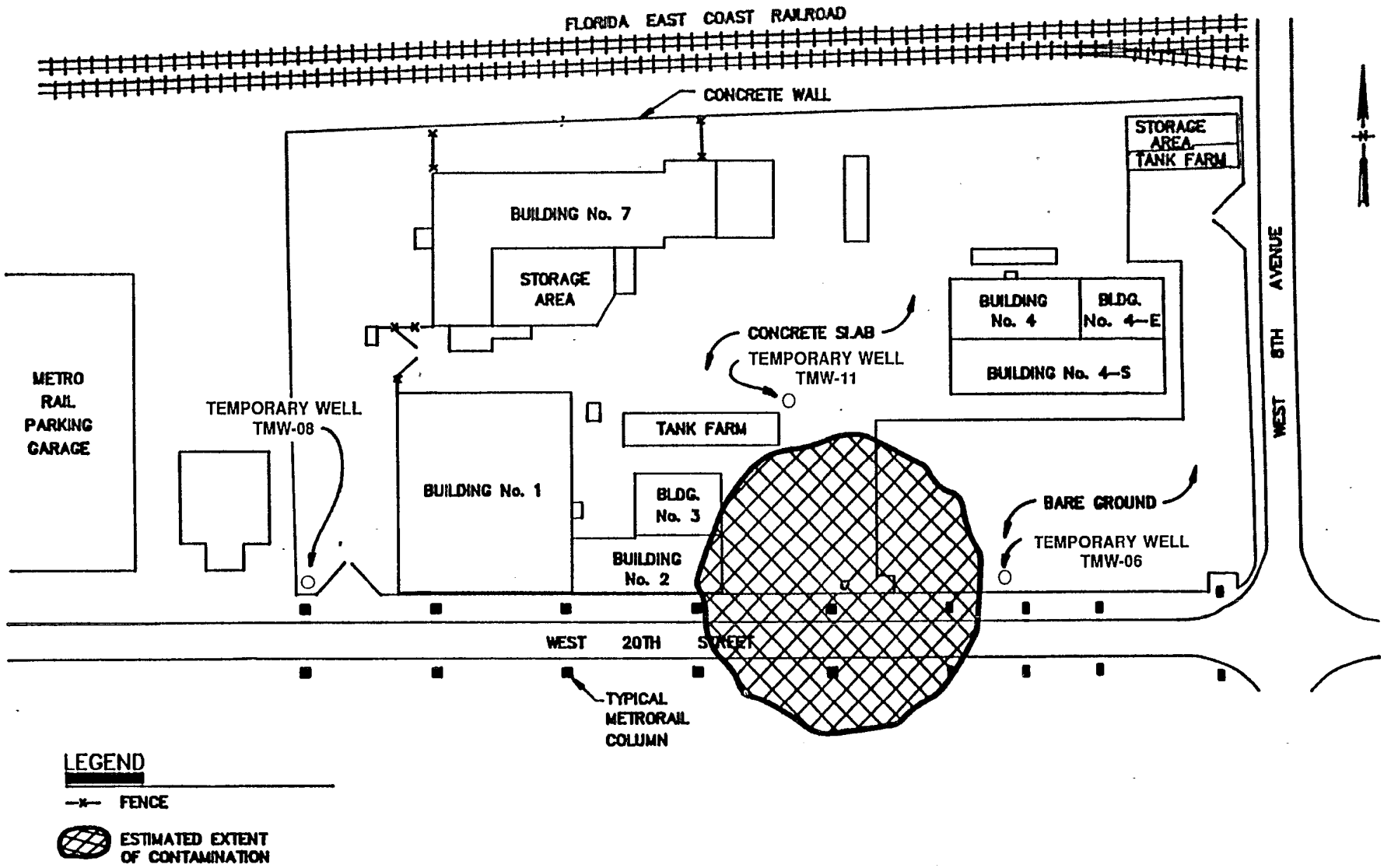


Figure 4
EXTENT OF CONTAMINATION ESTIMATED BY CONTRACTOR
SITE A

Table 2
ANALYTICAL RESULTS FROM SAMPLING OF GROUP A MONITORING WELLS

Monitor Well Number	Depth (ft)	Sample Date	Days After Startup	Benzene Goal=1	Chlorobenzene Goal=60	1,4-dichlorobenzene Goal=5	trans-1,2-DCE Goal=70	Vinyl Chloride Goal=1	Total VOCs
CDM-02	20	1/19/88	0	8.2	200	88	360	14	893
		9/14/88	17	4.5	49	5.7	8.6	6.7	118
		10/12/88	45	7.6	52	21	21	13	147
		11/02/88	66	6.5	38	13	16	12	103
		11/09/88	73	7.6	41	0.5	22	19	110
		12/07/88	101	14	38	0.5	8.4	6	71
		1/11/89	136	15	44	10	4.8	0.5	78
		1/25/89	150	11	45	0.5	2	0.5	62
		2/17/89	171	5.6	31	0.5	3.3	0.5	46
		3/02/89	186	3.1	23	0.5	1.8	1.1	30
		3/15/89	199	2.8	22	0.5	1.3	0.5	29
CDM-03	55	1/19/88	0	0.5	5.2	0.5	3.8	2.1	15
		9/14/88	17	0.5	4.2	0.5	0.5	0.5	4
		10/12/88	45	0.5	3.4	0.5	0.5	1.6	5
		11/09/88	73	0.5	2.3	0.5	0.5	0.5	4
		12/07/88	101	0.5	2.3	0.5	0.5	0.5	2
		1/11/89	136	3.2	14	0.5	0.5	0.5	17
		1/25/89	150	0.5	2	0.5	0.5	0.5	13
		3/02/89	186	0.5	2.4	0.5	0.5	0.5	2
		3/15/89	199	0.5	0.5	0.5	0.5	0.5	1
MWS-06	20	1/19/88	0	5.7	140	110	33	23	324
		9/14/88	17	2.3	180	160	14	2.4	498
		10/12/88	45	0.5	56	10	1.6	0.5	90
		11/09/88	73	1.5	20	42	0.5	0.5	70
		12/07/88	101	1.8	13	3.6	1.3	0.5	20
		1/11/89	136	1.8	37	0.5	0.5	0.5	41
		1/25/89	150	0.5	29	2.8	0.5	0.5	37
		3/02/89	186	0.5	18	2.5	0.5	0.5	23
		3/15/89	199	0.5	12	2.4	0.5	0.5	14
MWS-11	20	1/19/88	0	2.5	23	0.5	20	74	160
		9/14/88	17	3	21	0.5	0.5	0.5	28
		10/12/88	45	7.9	34	6.2	0.5	0.5	48
		11/02/88	66	3.3	36	20	3.4	0.5	64
		11/09/88	73	3.4	49	25	0.5	0.5	96
		12/07/88	101	3.3	56	4.6	0.5	0.5	75
		1/11/89	136	3	63	14	0.5	0.5	86
		1/25/89	150	3.4	67	1.1	0.5	0.5	77
		2/17/89	171	6.2	63	1.4	0.5	0.5	76
		3/02/89	186	6.6	78	0.5	0.5	0.5	89
		3/15/89	199	4.2	58	0.5	0.5	0.5	63

Table 2
(Continued)

Monitor Well Number	Depth (ft)	Sample Date	Days After Startup	Benzene Goal=1	Chlorobenzene Goal=60	1,4-dichlorobenzene Goal=5	trans-1,2-DCE Goal=70	Vinyl Chloride Goal=1	Total VOCs
MWT-31	8	1/19/88	0	7	0.5	4.9	40	36	195
		9/14/88	17	3.8	180	120	11	56	733
		10/12/88	45	2.2	66	17	3.9	2.1	140
		11/09/88	73	1.1	27	5.5	0.5	0.5	43
		12/07/88	101	0.5	12	2.6	1.3	0.5	20
		1/11/89	136	0.5	33	7.3	0.5	0.5	42
		1/25/89	150	0.5	27	2.6	0.5	0.5	36
		3/02/89	186	0.5	11	2.8	0.5	0.5	15
		3/15/89	199	0.5	8.1	0.5	0.5	0.5	9
DERM-05	19	1/19/88	0	8.4	32	0.5	210	240	520
		9/14/88	17	1.8	34	64	69	100	288
		10/12/88	45	1.5	28	360	66	94	615
		11/02/88	66	0.5	10	86	2.4	8.7	116
		11/09/88	73	0.5	16	0.5	10	14	63
		12/07/88	101	0.5	13	0.5	6.6	5	40
		1/11/89	136	0.5	19	0.5	26	10	102
		1/25/89	150	0.5	18	0.5	22	27	116
		2/17/89	171	0.5	13	0.5	21	6	91
		3/02/89	186	0.5	9.4	0.5	33	18	100
		3/15/89	199	0.5	11	0.5	20	0.5	67
DERM-06	10	1/19/88	0	6.4	25	15	21	48	127
		9/14/88	17	0.5	9.9	29	4.4	19	66
		10/12/88	45	0.5	18	140	17	7.5	204
		11/02/88	66	0.5	13	130	2.8	5	171
		11/09/88	73	0.5	8	0.5	4.2	0.5	37
		12/07/88	101	0.5	8.4	0.5	1.3	3.6	24
		1/11/89	136	0.5	12	0.5	6.3	11	47
		1/25/89	150	0.5	15	0.5	5.9	8.7	60
		2/17/89	171	0.5	12	0.5	13	6.2	53
		3/02/89	186	0.5	7.6	0.5	13	6.4	54
		3/15/89	199	0.5	9.5	0.5	12	0.5	44

Notes: 1. All concentrations are expressed in ug/l.
2. The laboratory detection limit for these compounds is 1.0 ug/l.
3. Laboratory results reported as below 1.0 ug/l are shown here as 0.5 ug/l.

WDCR321/052.50

Table 3
ANALYTICAL RESULTS FROM SAMPLING OF GROUP B MONITORING WELLS

Monitor Well Number	Depth (ft)	Sample Date	Days After Startup	Benzene Goal=1	Chlorobenzene Goal=60	1,4-dichlorobenzene Goal=5	trans-1,2-DCE Goal=70	Vinyl Chloride Goal=1	Methylene Chloride	Total VOCs
MWS-08	20	1/19/88	0	0.5	0.5	0.5	0.5	0.5	0.5	0.5
		9/28/88	31	0.5	0.5	0.5	0.5	0.5	0.5	6.0
		10/26/88	59	0.5	0.5	0.5	0.5	0.5	0.5	1.0
		11/21/88	84	0.5	0.5	0.5	0.5	0.5	0.5	0.5
		12/20/88	113	0.5	0.5	0.5	0.5	0.5	2.6	3.0
		1/25/88	148	0.5	0.5	0.5	0.5	0.5	0.5	0.5
MWS-09	20	1/19/88	0							
		9/28/88	31	0.5	4.2	14	1.3	0.5	0.5	20.0
		10/26/88	59	0.5	2.1	3.7	0.5	0.5	0.5	6.0
		11/21/88	84	0.5	2.7	0.5	0.5	0.5	0.5	3.0
		12/20/88	113	0.5	1.8	2.5	1.5	0.5	0.5	6.0
		1/25/88	148	0.5	1.8	0.5	0.5	0.5	0.5	2.0
MWS-12	20	1/19/88	0	0.5	0.5	0.5	0.5	0.5	0.5	4.0
		9/28/88	31	0.5	0.5	0.5	0.5	0.5	0.5	3.0
		10/26/88	59	0.5	0.5	0.5	0.5	0.5	0.5	0.5
		11/21/88	84	0.5	0.5	0.5	0.5	0.5	0.5	0.5
		12/20/88	113	0.5	0.5	0.5	0.5	0.5	0.5	0.5
		1/25/88	148	0.5	0.5	0.5	0.5	0.5	0.5	0.5
MWT-32	7	1/19/88	0							
		9/28/88	31	0.5	10	57	0.5	0.5	0.5	113.0
		10/26/88	59	1.8	6.6	63	0.5	0.5	1.5	136.0
		11/21/88	84	0.5	4.9	0.5	0.5	0.5	0.5	5.0
		12/20/88	113	0.5	4.4	0.5	0.5	0.5	0.5	4.0
		1/25/88	148	0.5	5.3	0.5	0.5	0.5	0.5	5.0
MWT-33	7	1/19/88	0							
		9/28/88	31	0.5	0.5	0.5	0.5	0.5	0.5	6.0
		10/26/88	59	0.5	0.5	0.5	0.5	0.5	2.6	7.0
		11/21/88	84	0.5	0.5	0.5	0.5	0.5	0.5	0.5
		12/20/88	113	0.5	0.5	0.5	0.5	0.5	1.7	2.0
		1/25/88	148	0.5	0.5	0.5	0.5	0.5	0.5	0.5
DERM-01	19	1/19/88	0	0.5	0.5	0.5	0.5	0.5	0.5	5.0
		10/12/88	45	0.5	10	0.5	0.5	0.5	0.5	10.0
		10/26/88	59	1.7	13	0.5	0.5	0.5	0.5	16.0
		11/02/88	66	1.6	12	0.5	0.5	0.5	0.5	14.0
		11/21/88	84	0.5	8	0.5	0.5	0.5	0.5	8.0
		12/20/88	113	0.5	1.8	0.5	0.5	0.5	0.5	2.0
		1/25/89	148	0.5	4.1	0.5	0.5	0.5	0.5	6.0
DERM-02	10	1/19/88	0	0.5	8.3	0.5	0.5	0.5	0.5	10.0
		10/12/88	45	0.5	6.7	0.5	0.5	0.5	0.5	7.0
		10/26/88	59	0.5	7	4.5	0.5	0.5	0.5	20.0
		11/21/88	84	0.5	1	0.5	0.5	0.5	0.5	1.0
		12/20/88	113	0.5	4	0.5	0.5	0.5	0.5	4.0
		1/25/89	148	0.5	6.8	0.5	0.5	0.5	0.5	8.0

Notes: 1. All concentrations are expressed in ug/l.
2. The laboratory detection limit for these compounds is 1.0 ug/l.
3. Laboratory results reported as below 1.0 ug/l are shown here as 0.5 ug/l.

WDCR321/053.50

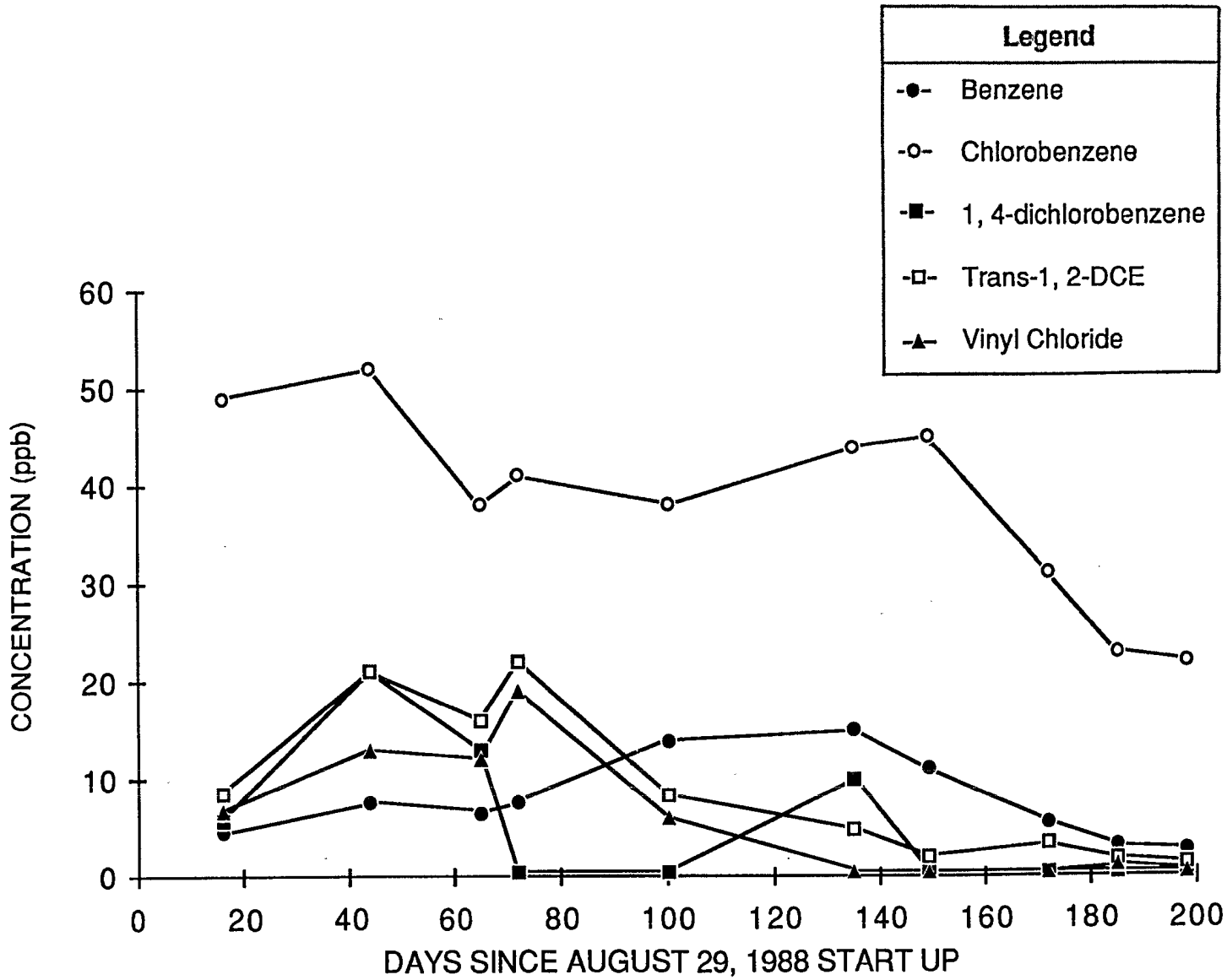


Figure 5
GROUND-WATER QUALITY IN WELL CDM-02, CONCENTRATION VS. TIME
SITE A

WDC 61621. A0.02

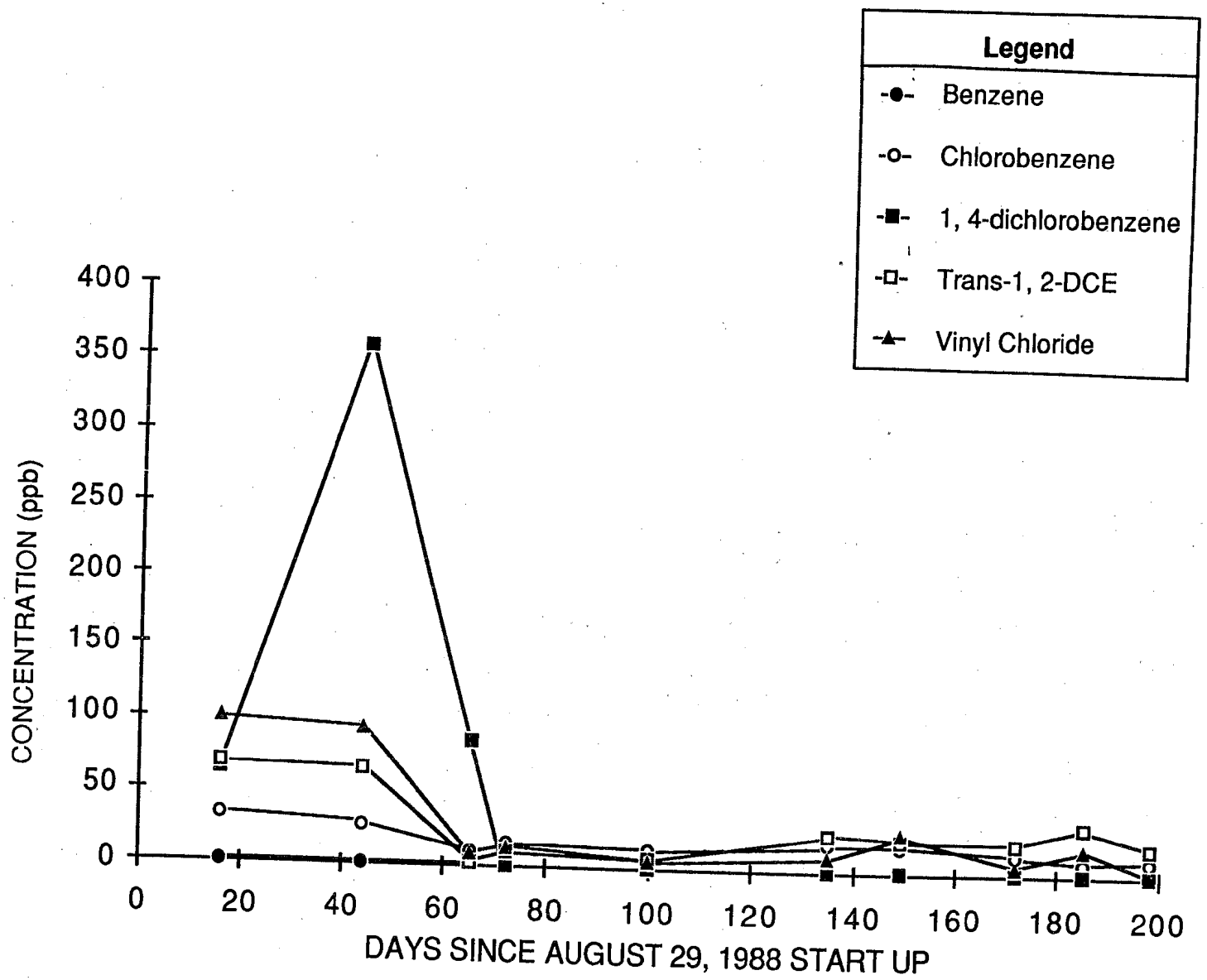


Figure 6
GROUND-WATER QUALITY IN WELL DERM-05, CONCENTRATION VS. TIME
SITE A

WDC 51521. A0.02

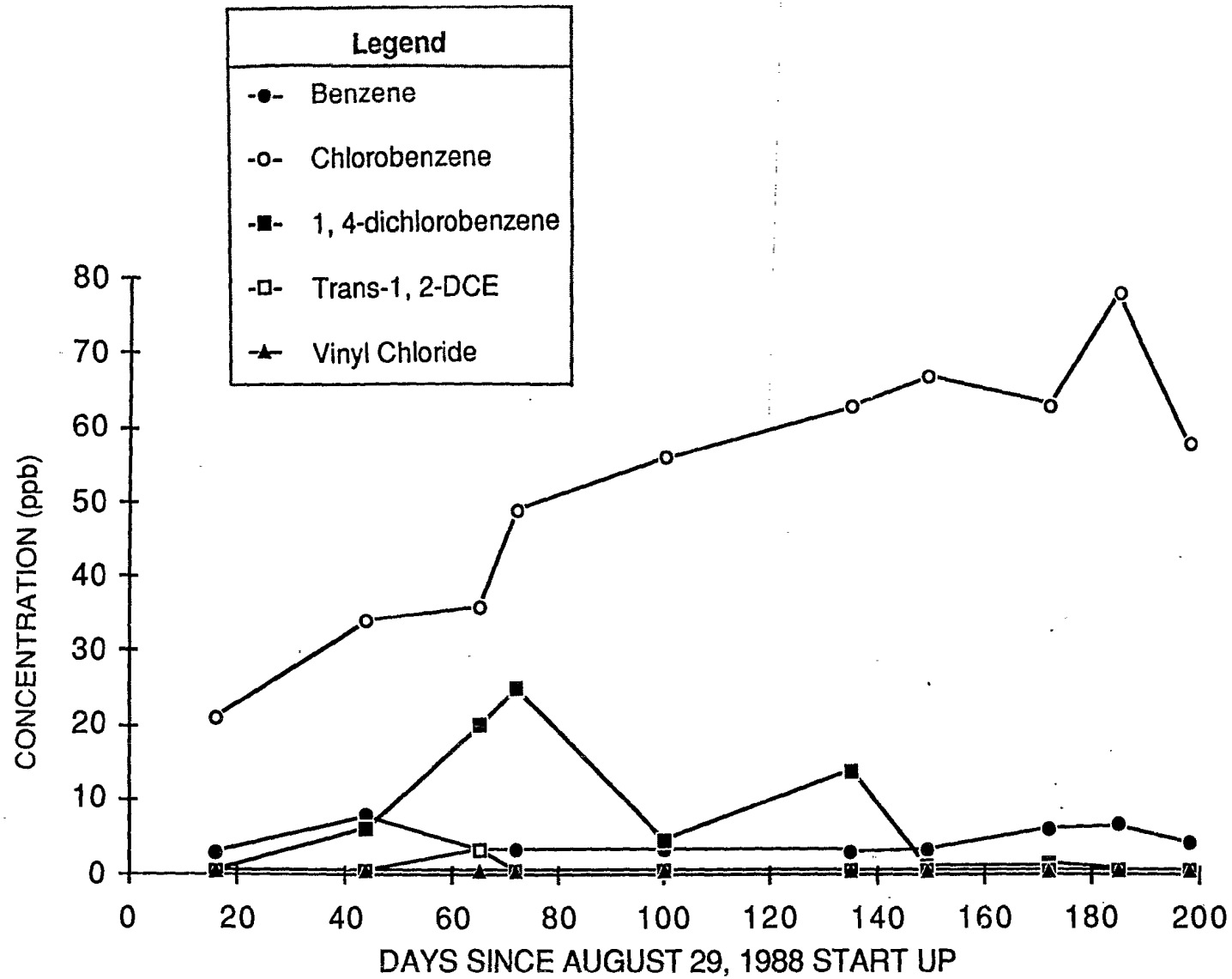


Figure 7
GROUND-WATER QUALITY IN WELL MWS-11, CONCENTRATION VS. TIME
SITE A

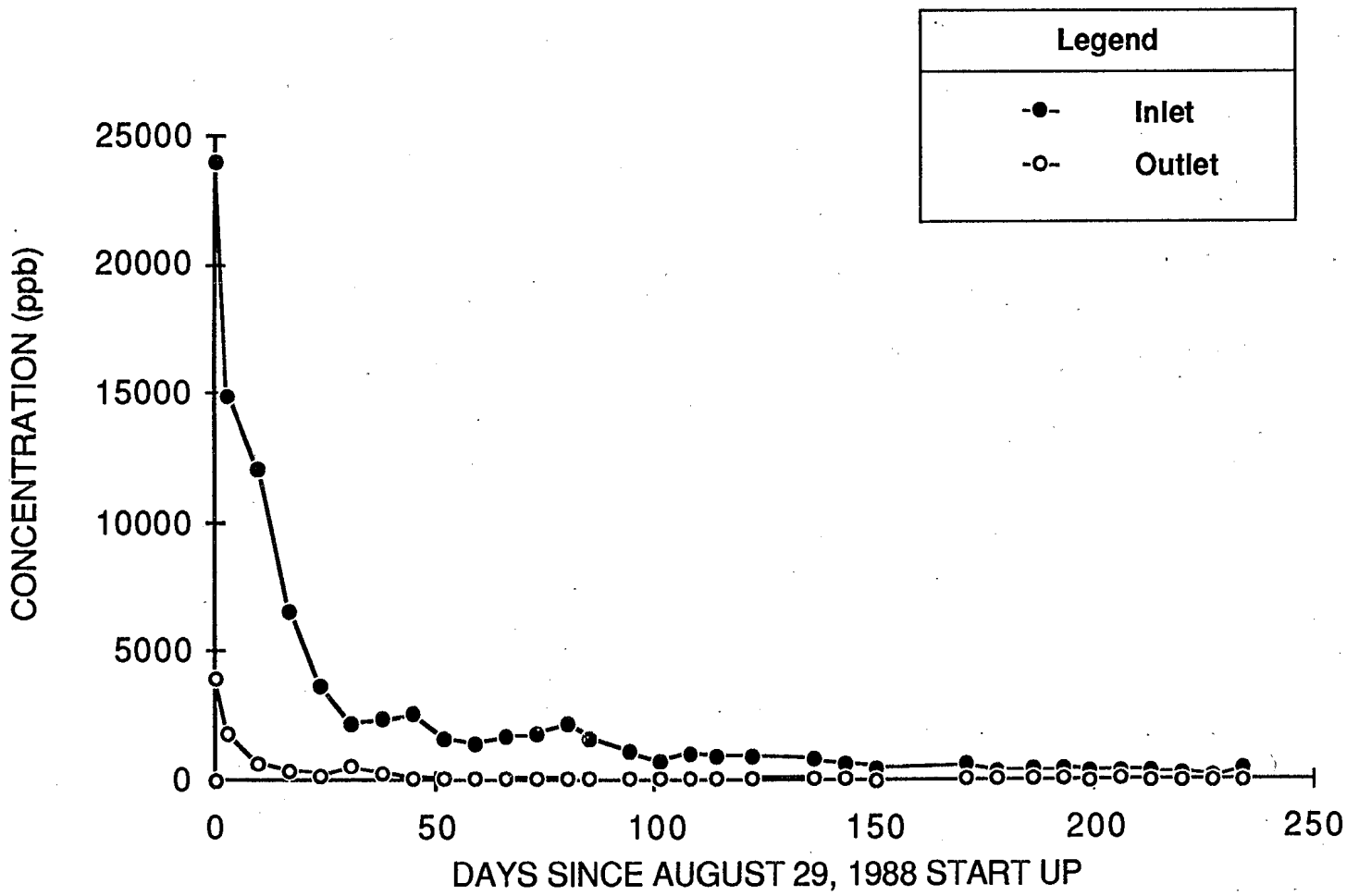
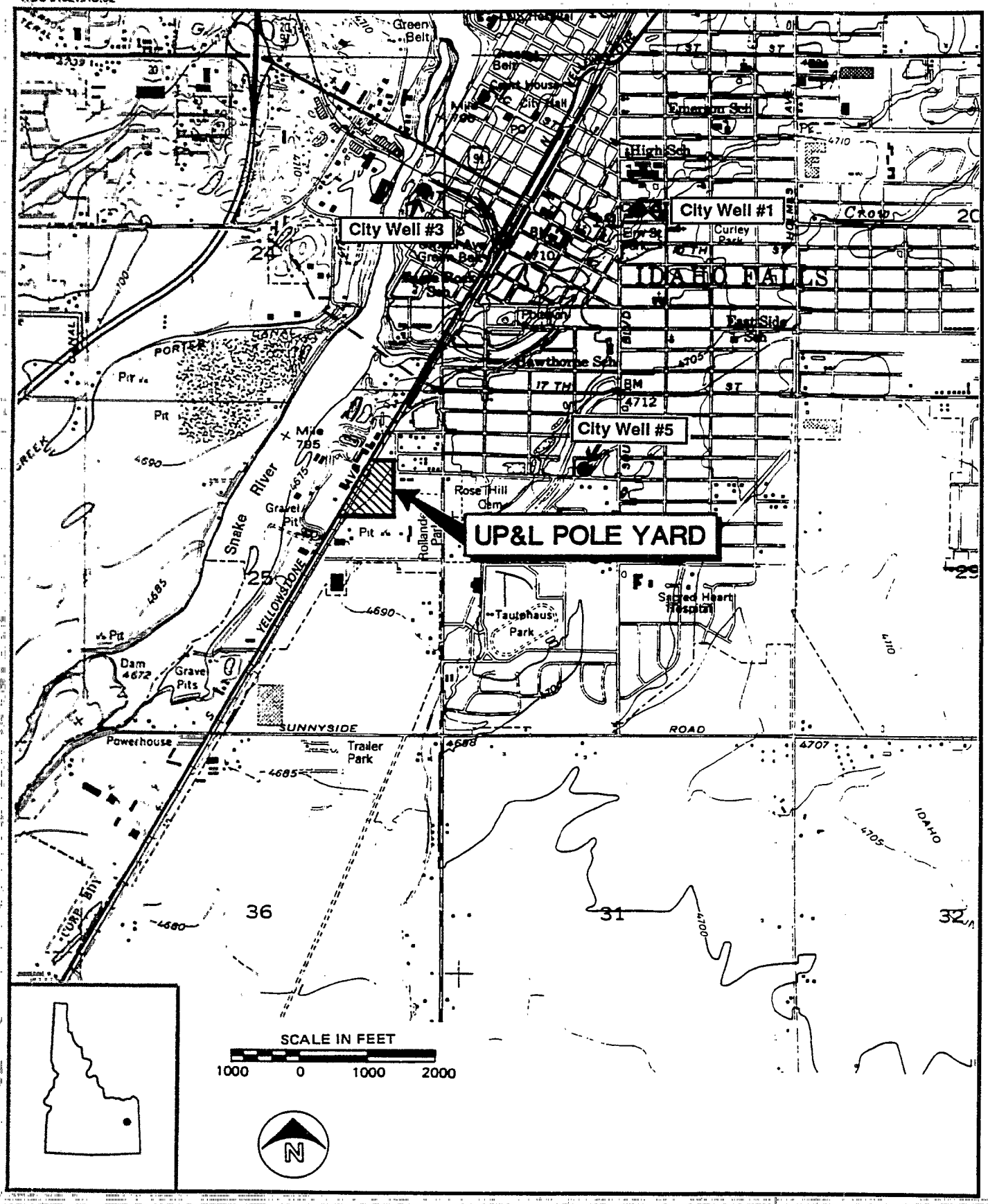


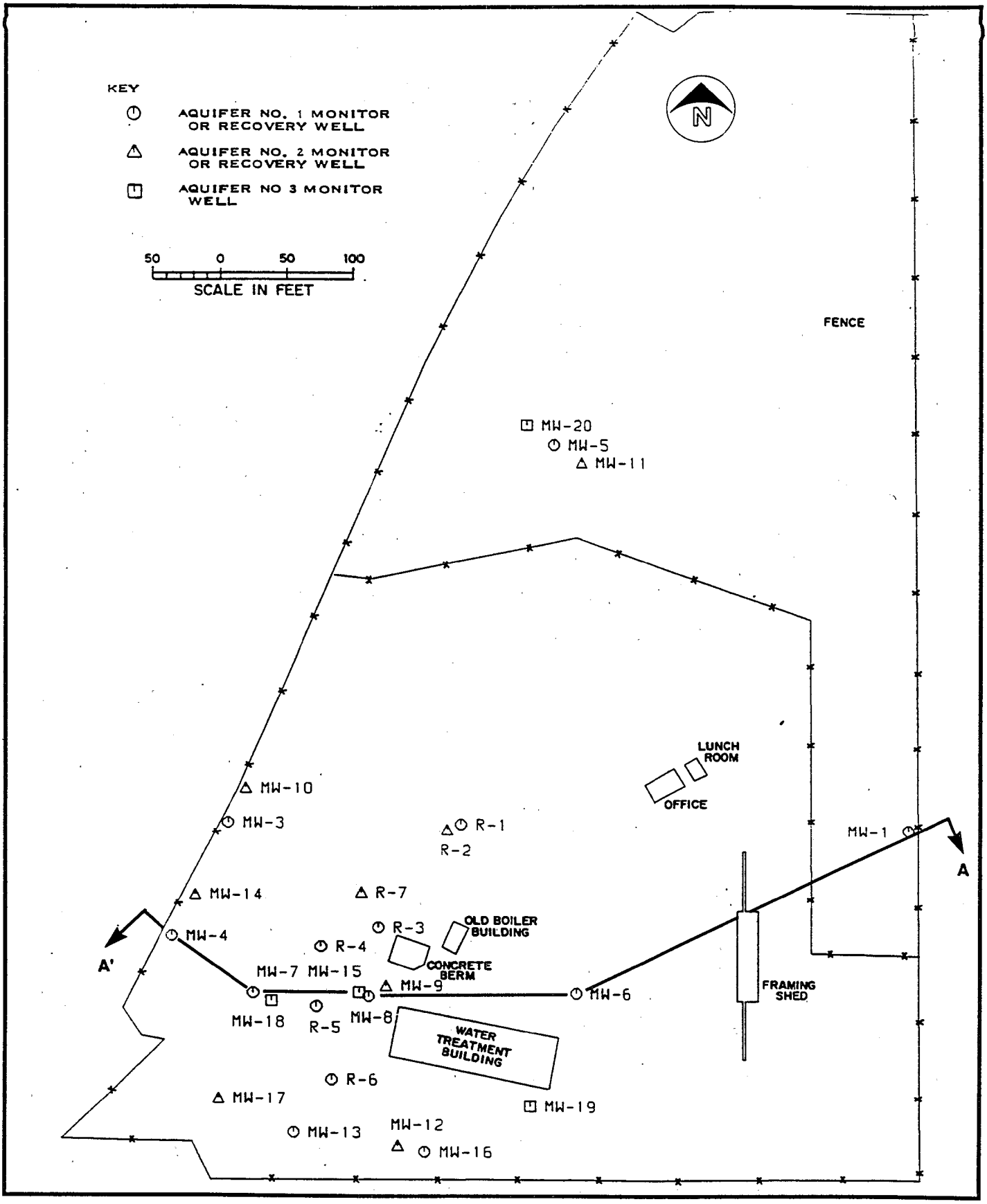
Figure 8
AIR STRIPPER INFLUENT AND EFFLUENT CONCENTRATION, TOTAL VOCS
SITE A

WDC 81621.AO.02



Source: CH2M HILL, October 1987, Groundwater Treatment Phase 2 Interim Report, UP & L Pole Treatment Yard, Idaho Falls, Idaho.

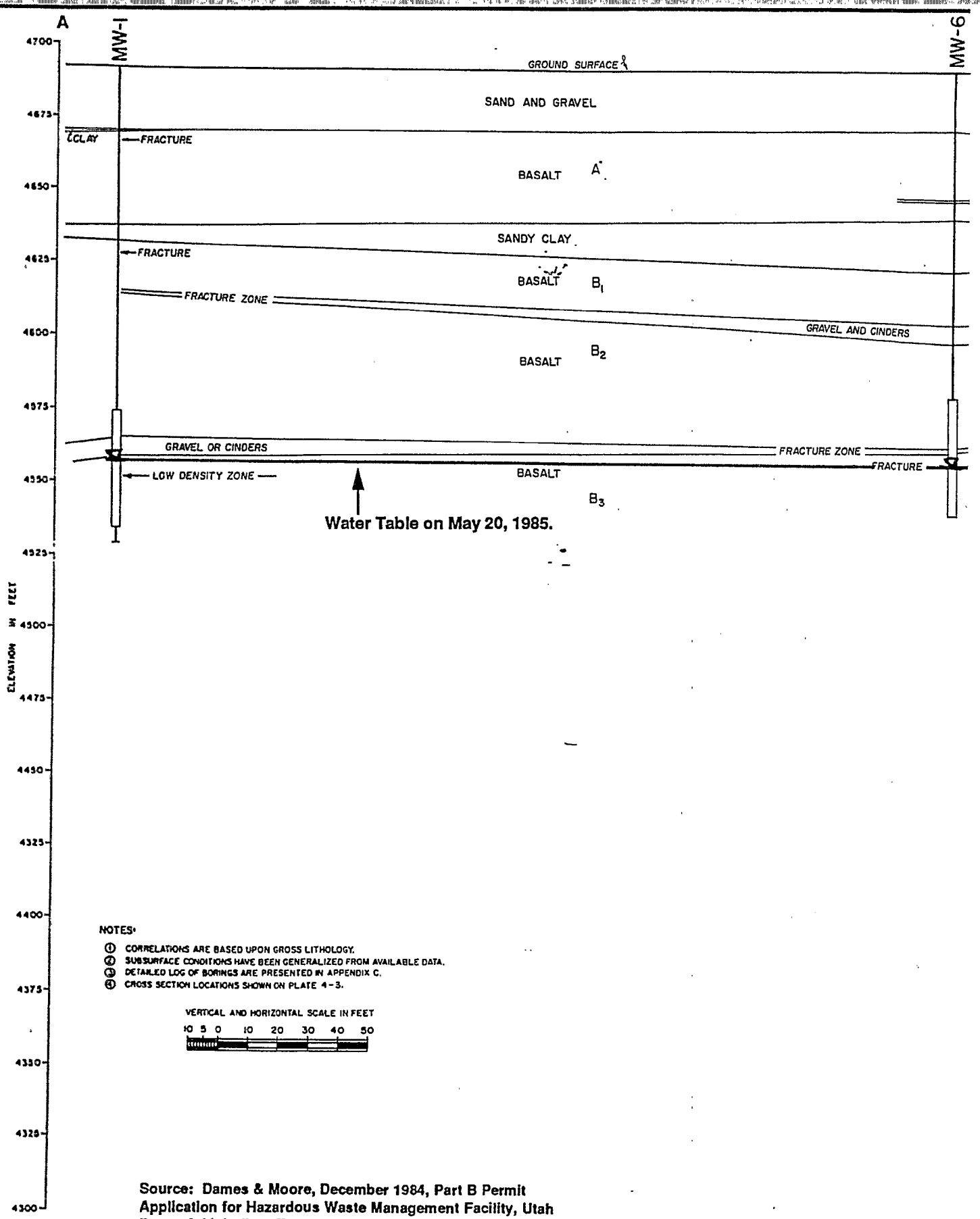
Figure 1
SITE LOCATION MAP
UTAH POWER AND LIGHT SITE
IDAHO FALLS, IDAHO



Source: Dames & Moore, January 1988, Installation of Aquifer #3 Monitoring Wells, Pole Treatment Yard, Idaho Falls, Idaho

Figure 2
SITE PLAN WITH WELL LOCATIONS, JANUARY 1988
UTAH POWER AND LIGHT SITE

WDC 81621.A0.02



Source: Dames & Moore, December 1984, Part B Permit Application for Hazardous Waste Management Facility, Utah Power & Light Pole Treatment Facility, Idaho Falls, Idaho, Volume 4.

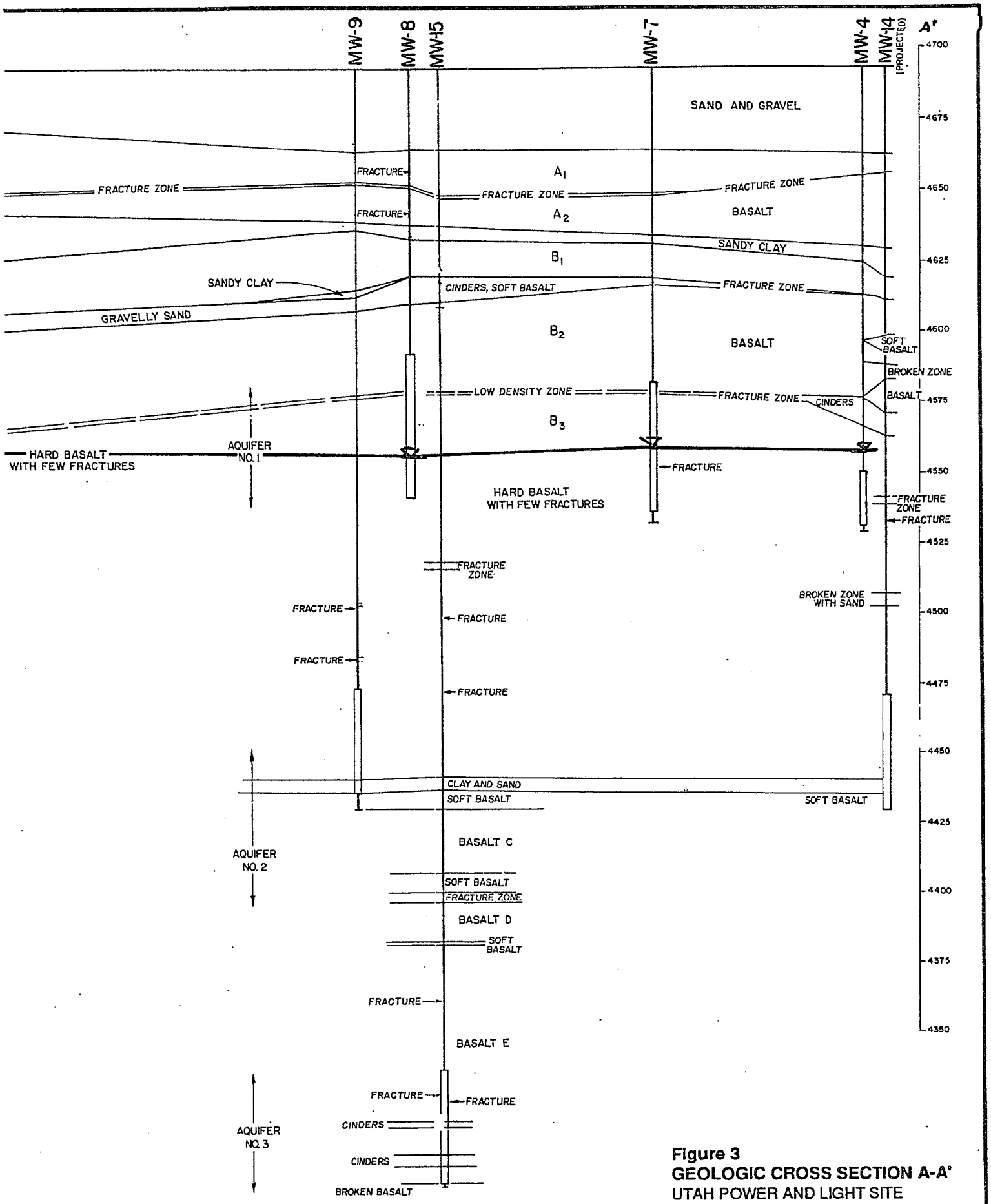
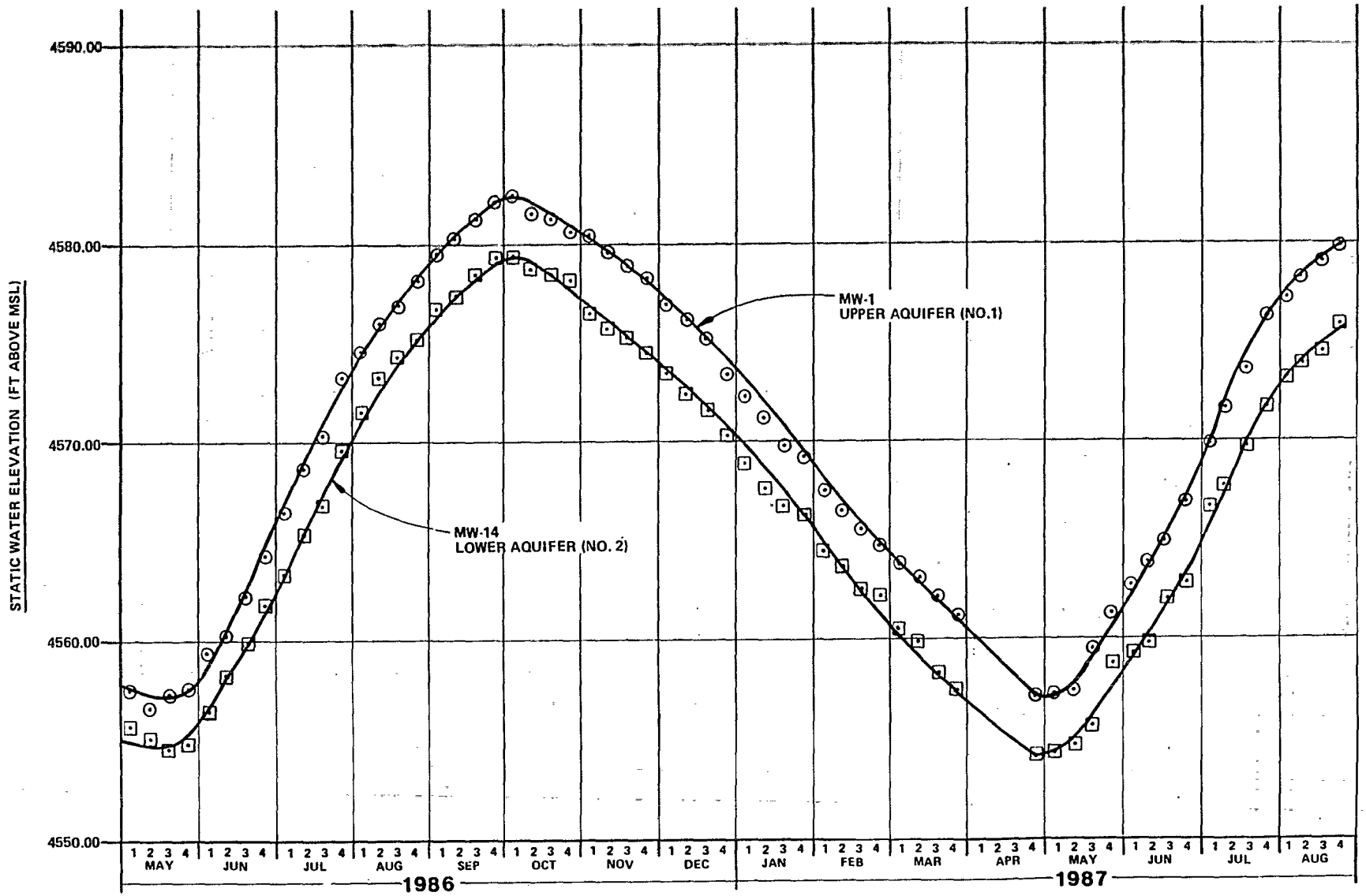


Figure 3
GEOLOGIC CROSS SECTION A-A'
UTAH POWER AND LIGHT SITE

Table 1
SPECIFIC CAPACITY AND AQUIFER TEST RESULTS
FOR ONSITE WELLS

Well	Aquifer	Specific Capacity (gpm/ft)	Transmissivity (gpd/ft)	Leakance (day^{-1})
NW-1	1	610 - 1,100		
MW-2a				
MW-3	1	190 - 610	260,000 - 950,000	NR
MW-4	1	22 - 1,200		
MW-5	1	110 - 550		
MW-6	1	90 - 550		
MW-7	1	<0.2 - 1.9		
MW-8	1	0.015		
MW-13	1	3.3 - 4.4	2,250 - 14,300	0.0029 - 0.013
MW-16	1			
R-1	1	610		
R-3	1	<180		
R-4	1	6.3		
R-5	1	0.56	1,100 - 6,400	0.0072 - 0.018
R-6	1	4.3		
MW-9	2	1.2 - 1.5	20,400 - 30,400	0.015 - 0.029
MW-10	2	55 - 65		
MW-11	2	150 - 370		
MW-12	2	16 - 17	28,400 - 29,800	NR
MW-14	2	2.9		
MW-17	2	0.4		
R-2	2	8.9	25,500 - 29,800	0.0068 - 0.012
R-7	2	3.5		
MW-15	3	>1,180		
MW-18	3	100		
MW-19	3	100		
MW-20	3	110		

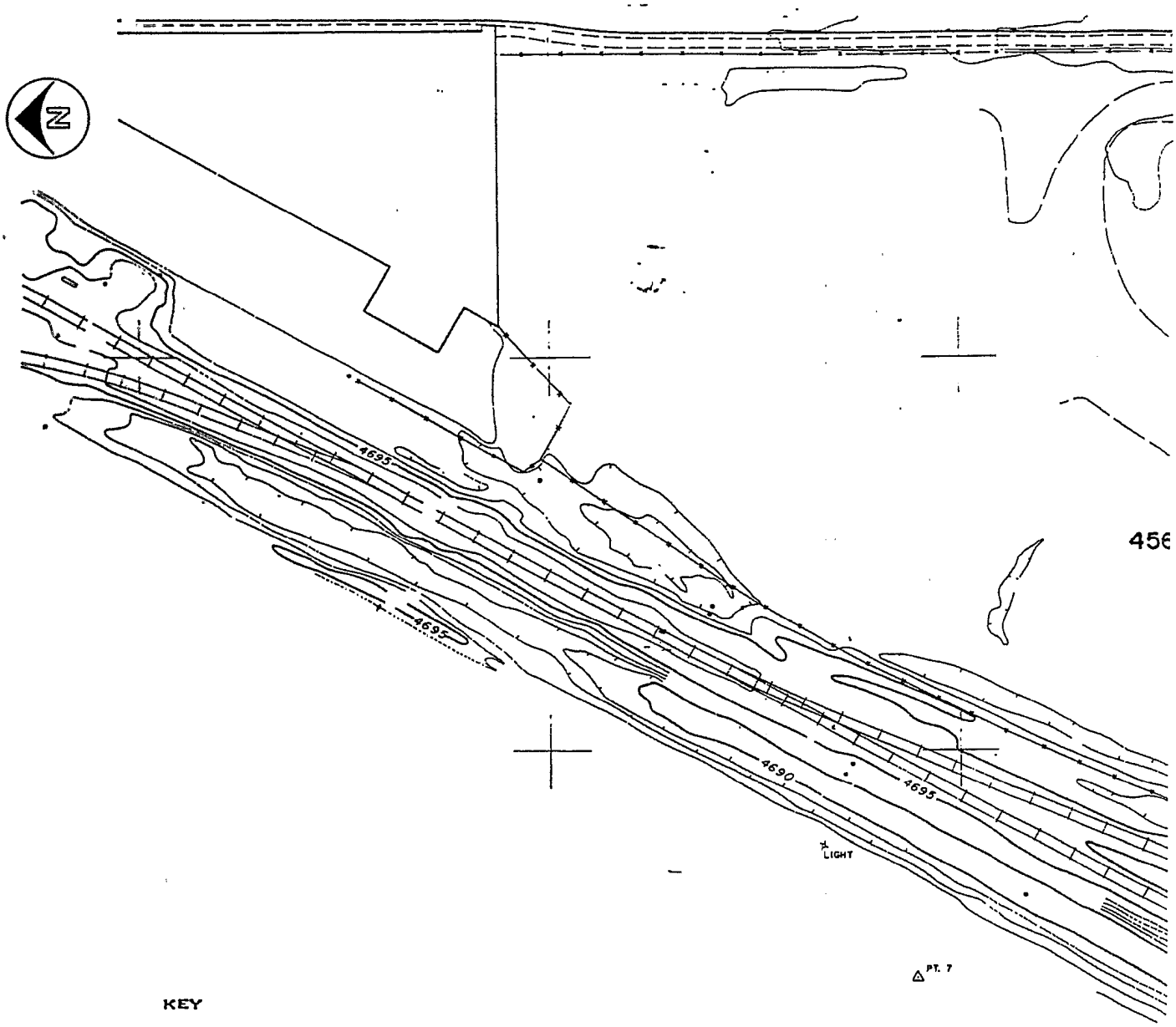
WDCR436/071.50



Source: CH2M HILL, October 1987, Groundwater Treatment Phase 2 Interim Report, UP & L Pole Treatment Yard, Idaho Falls, Idaho.

Figure 4
WATER TABLE FLUCTUATIONS, IN AQUIFERS #1 AND #2, 1986 AND 1987
UTAH POWER AND LIGHT SITE

WDC 61621.AO.02



KEY

⇨	IDEALIZED GROUND WATER FLOW PATH
—4566—	ELEVATION CONTOUR OF POTENTIOMETRIC SURFACE ASSOCIATED WITH THE UPPERMOST AQUIFER
△	MONITOR WELL IN THE UPPERMOST AQUIFER WITH MEASURED ELEVATION OF POTENTIOMETRIC SURFACE
○	MONITOR WELL IN A DEEPER AQUIFER WITH MEASURED ELEVATION OF POTENTIOMETRIC SURFACE
X	PRESENTLY ABANDONED MONITOR WELL IN UPPER AQUIFER WITH MEASURED ELEVATION OF THE POTENTIOMETRIC SURFACE

SCALE IN FEET

40 0 40 80

Source: Dames & Moore, April 1986, Hydrologic Investigations and Design Recommendations, Well Field for Creosote Recovery, Pole Treatment Yard, Idaho Falls, Idaho.

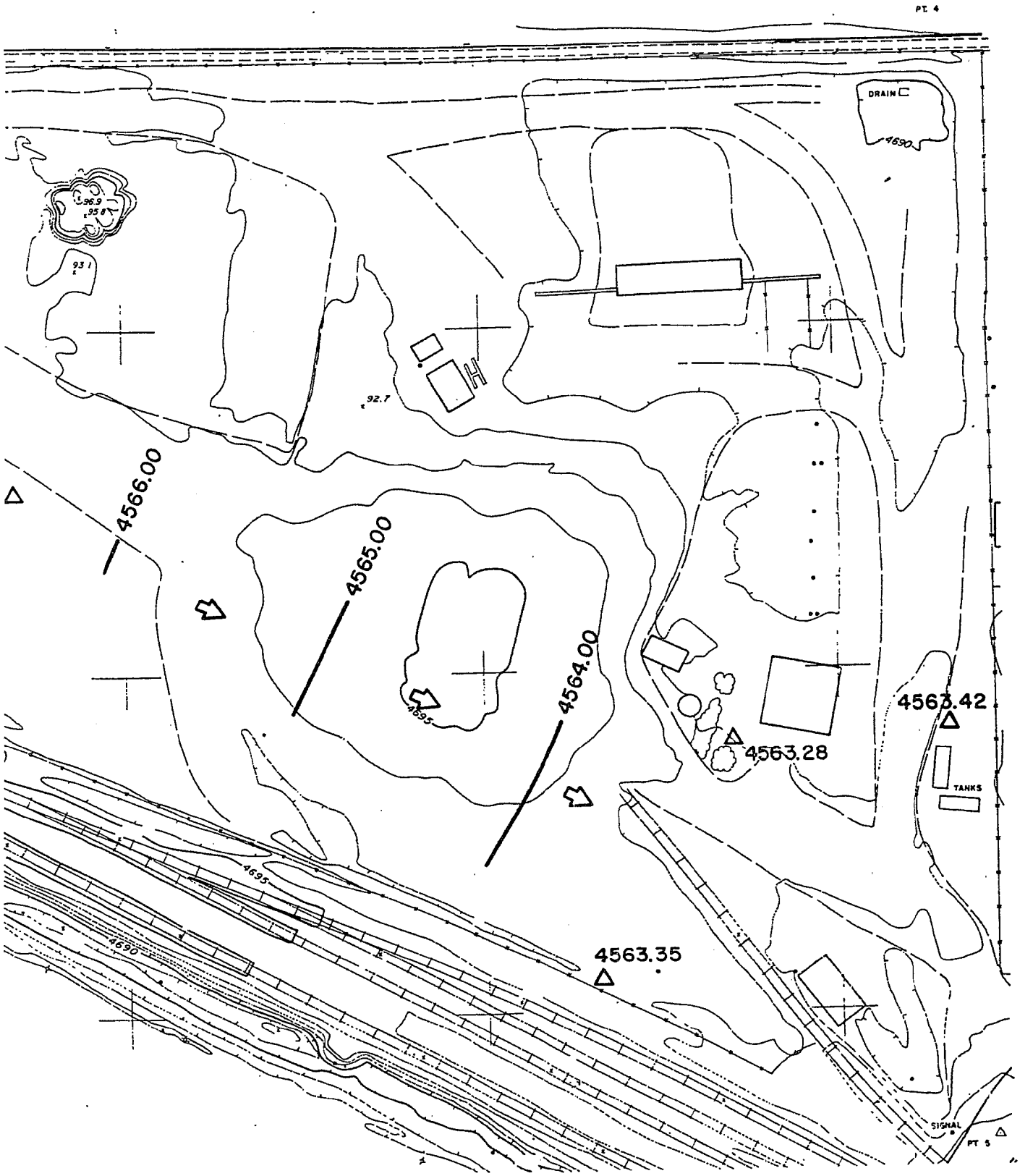
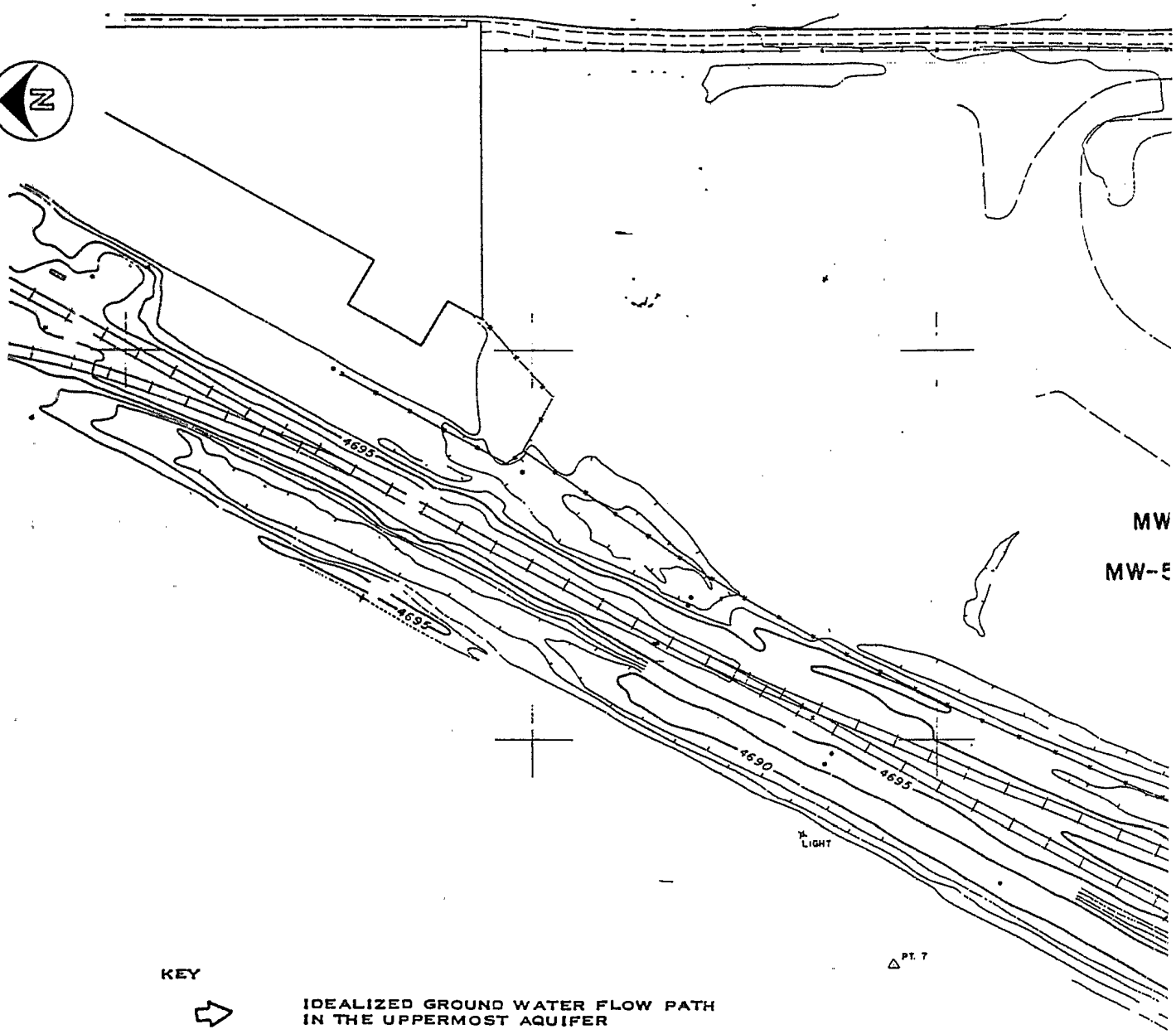


Figure 5
POTENTIOMETRIC HEAD IN AQUIFER #2, FEBRUARY 13, 1985
UTAH POWER AND LIGHT SITE



KEY

- IDEALIZED GROUND WATER FLOW PATH IN THE UPPERMOST AQUIFER
- —4566— ELEVATION CONTOUR OF POTENTIOMETRIC SURFACE ASSOCIATED WITH THE UPPERMOST AQUIFER
- △ MONITOR WELL IN THE UPPERMOST AQUIFER WITH MEASURED ELEVATION OF POTENTIO-METRIC SURFACE
- ○ MONITOR WELL IN A DEEPER AQUIFER WITH MEASURED ELEVATION OF POTENTIOMETRIC SURFACE
- X PRESENTLY ABANDONED MONITOR WELL IN UPPER AQUIFER WITH MEASURED ELEVATION OF THE POTENTIOMETRIC SURFACE

SCALE IN FEET

40 0 40 80

Source: Dames & Moore, April 1986, Hydrologic Investigations and Design Recommendations, Well Field for Creosote Recovery, Pole Treatment Yard, Idaho Falls, Idaho.

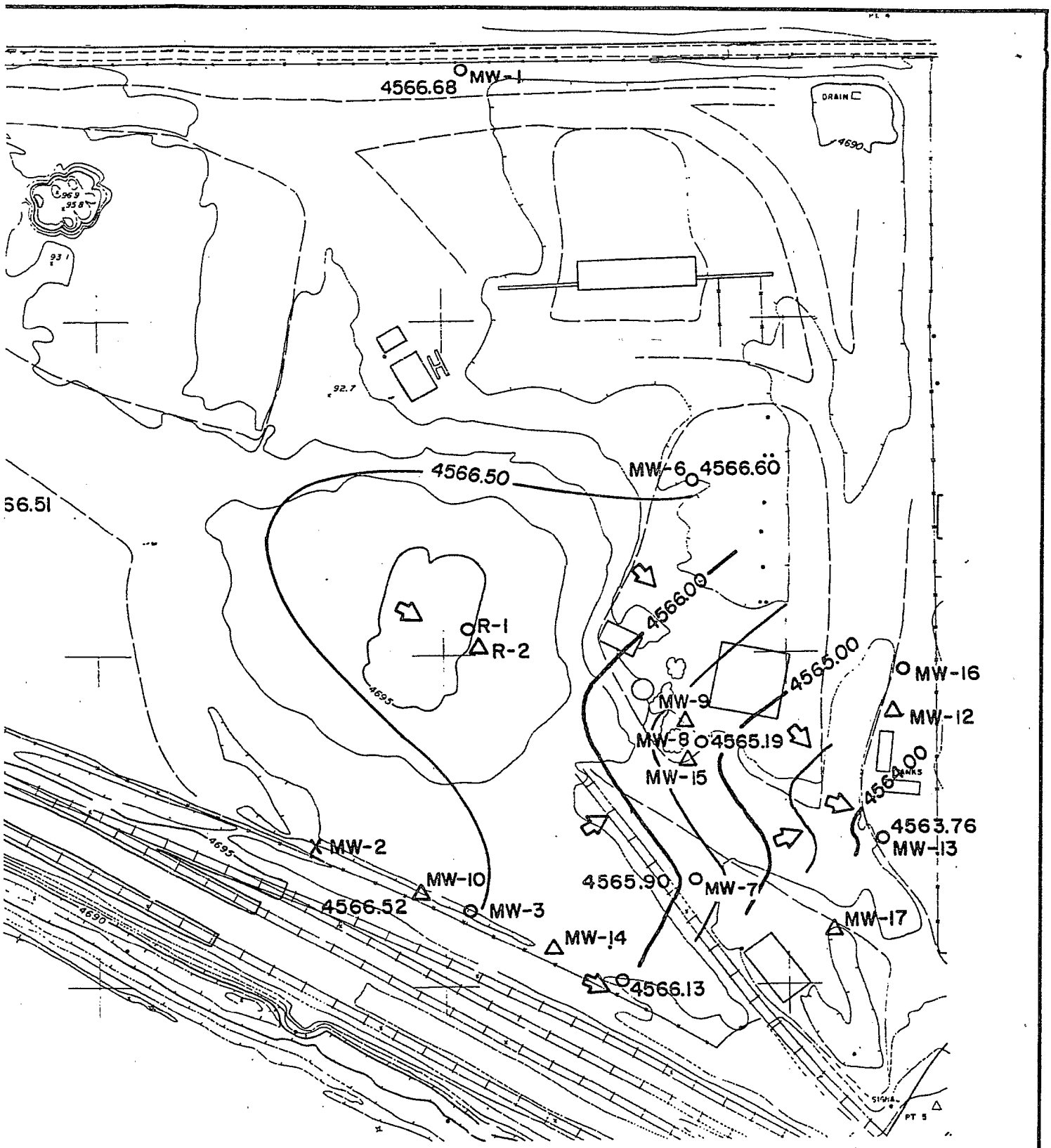
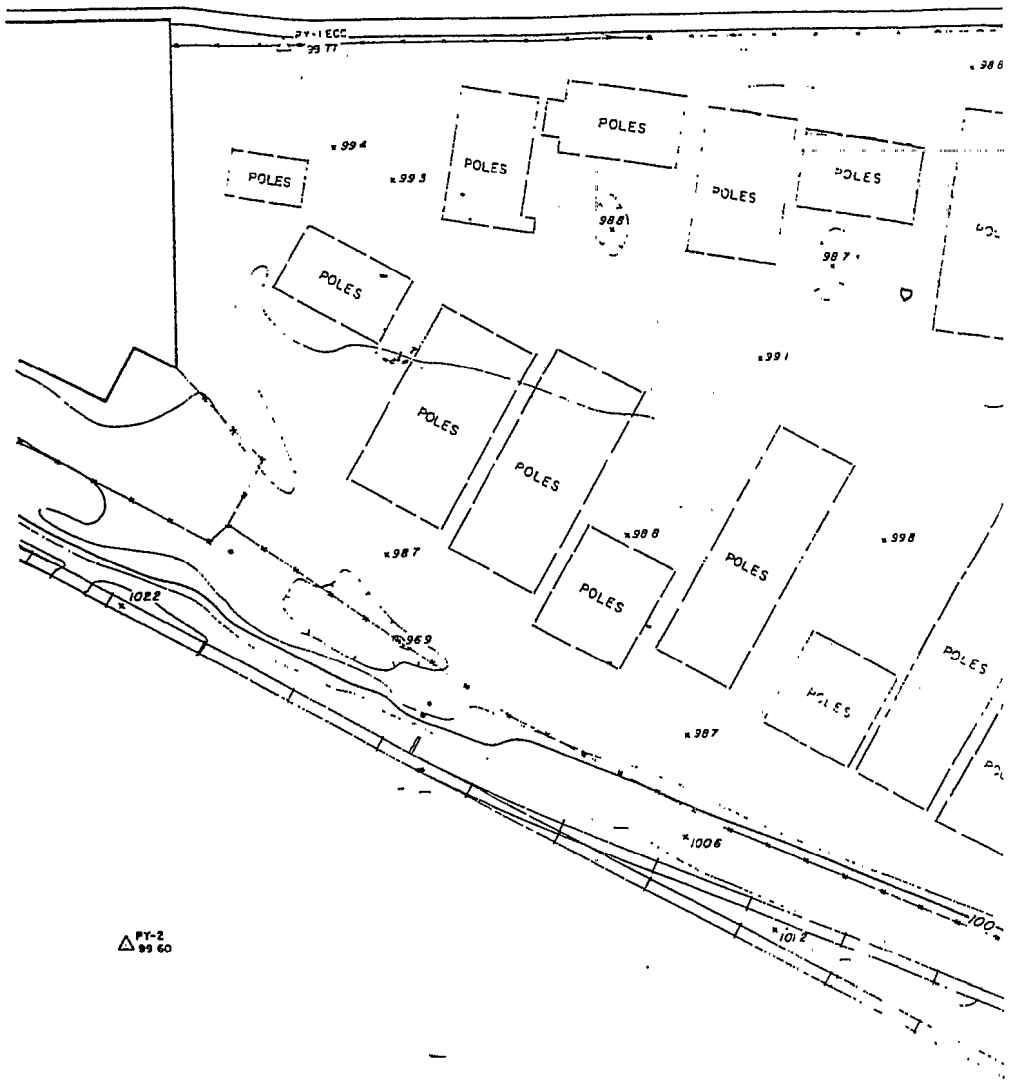


Figure 6
POTENTIOMETRIC HEAD IN AQUIFER # 1,
FEBRUARY 13, 1985
UTAH POWER AND LIGHT SITE



ELEVATIONS SHOWN ARE BASED ON AN ARBITARY DATUM– 4984.09 SHOULD BE ADDED TO ALL ELEVATIONS TO OBTAIN ACTUAL ELEVATIONS BASED ON THE CITY OF IDAHO FALLS DATUM.

KEY

⊗#13 — BORING LOCATIONS (UP&L)

▼8DUP — SURFACE SAMPLE (UP&L AND EPA)

FEET

40 0 40 80

Source: Dames & Moore, December 1984, Part B Permit Application for Hazardous Waste Management Facility, Utah Power & Light Pole Treatment Facility, Idaho Falls, Idaho, Volumes 1, 2, and 3.

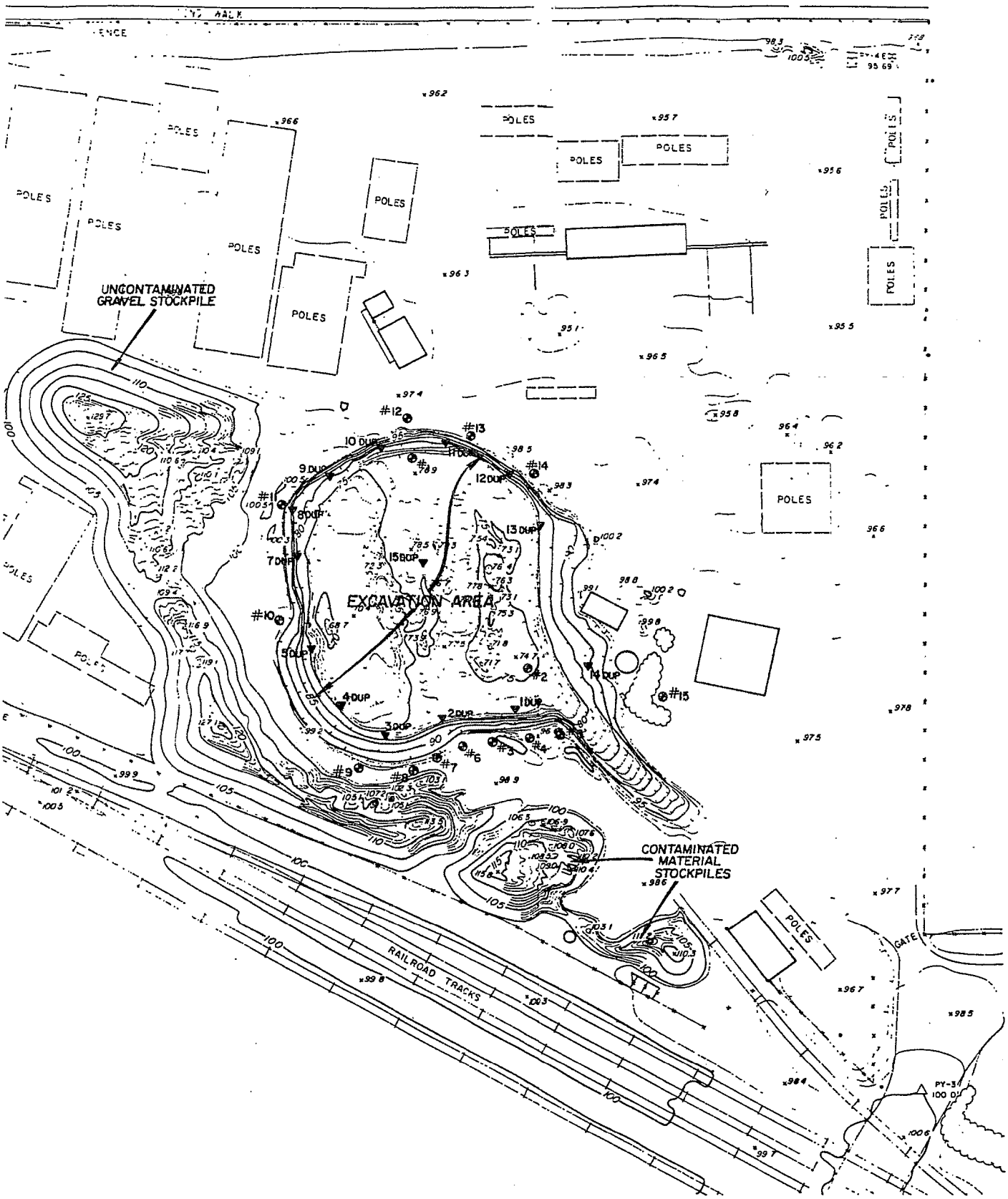


Figure 7
EXCAVATION AND SAMPLING OF CONTAMINATED SURFACE SOILS
UTAH POWER AND LIGHT SITE

	Mean Concentration µg/L				
	MW-7[a]	MW-8[b]	MW-9[c]	MW-13[d]	Composite[e]
Naphthalene*	2,480	8,600	2,804	750	1,923
Acenaphthylene*	7	32	15	5	10
Acenapthene*	692	3,550	1,035	395	726
Fluorene*	326	1,886	421	120	288
Phenanthrene*	568	4,522	818	74	487
Anthracene*	67	811	58	21	48
Fluoranthene*	212	2,019	248	5	150
Pyrene*	188	1,776	180	5	116
Bis(2-ethylhexyl)phthalate	4	4	4	<1	3
Chrysene*	33	334	28	<1	19
Benzo(a)anthracene*	41	409	34	<1	23
Di-n-octylphthalate	3	2	1	<1	1
Benzo(k)fluoranthene*	19	198	18	<1	12
Benzo(a)pyrene*	2	181	8	<1	5
Indeno(1,2,3-c,d)pyrene*	1	38	4	<1	2
Benzo(g,h,i)perylene*	1	41	2	<1	2
2-Nitrophenol	<1	3	12	<1	6
Phenol	3	63	31	<1	14
2,4-Dimethylphenol	43	186	116	3	58
Dibenzofuran	257	1,438	373	130	259
2-Methylnaphthalene	594	2,104	622	175	438
2-Methylphenol	16	258	81	<1	38
4-Methylphenol	12	286	121	<1	54
Total Base, Neutral & Acid Extractables, Sum (Above Parameters)	5,570	28,741	7,034	1,695	4,681
Total Phenols	87	790	8	39	37
Total Organic Carbon	24,400	47,550	16,925	12,275	16,312
Total Organic Halide (as Cl)	31	47	34	9	23
Total Dissolved Solids (mg/L)	403	433	355	390	378
C-Alkalinity (mg/L)	<1	<1	<1	2	1
B-Alkalinity (mg/L)	250	285	235	260	248
Conductivity (µmhos/cm)	691	706	539	566	617
pH (units)	7.3	7.2	7.4	7.4	

[a]Based on five sampling events; 8/15/84, 9/14/84, 10/17/84, 11/15/84, and 2/13/85. Standard Deviation 2,449 µg/L.

[b]Based on five sampling events; 8/27/84, 9/14/84, 10/17/84, 11/15/84, and 2/13/85. Standard deviation, 7,326 µg/L.

[c]Based on four sampling events; 8/16/84, 9/14/84, 10/17/84, and 11/15/84. Standard Deviation, 4,008 µg/L.

[d]Based on two sampling events; 11/15/84 and 2/13/85. Standard Deviation, 1,060 µg/L.

[e]Composite computed assuming that all four wells were in operation; MW-7, MW-8, MW-9, and MW-13, pumping at capacity, i.e., 30, 1, 80, and 80 gpm, respectively.

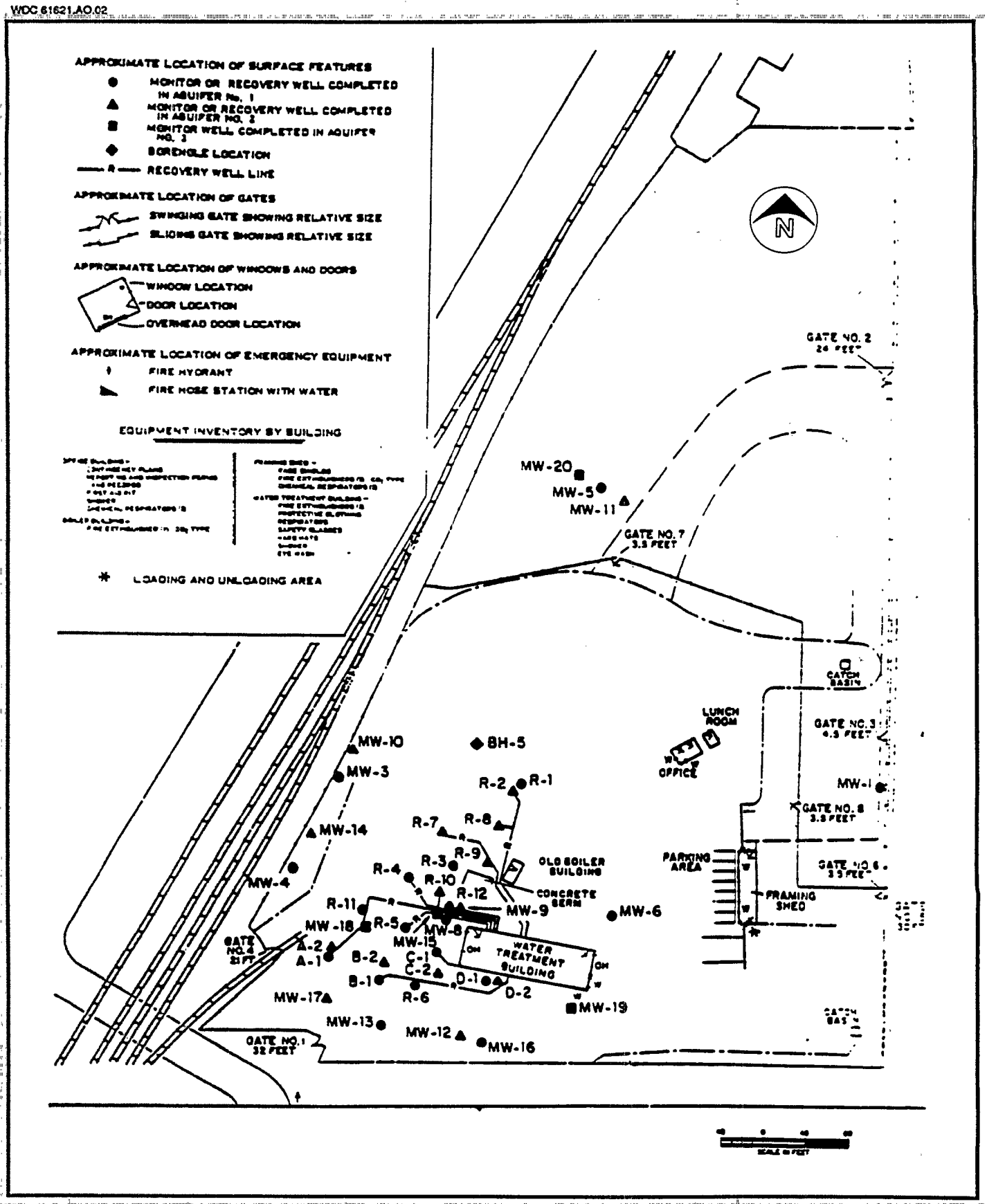
*Polynuclear Aromatic Hydrocarbons.

Note: In calculating mean concentrations, values below the detection limit were considered to be equal to half that limit. Only mean values below 1 µg/L were recorded as <1 µg/L.

Source: CH2M HILL, June 1986, Groundwater Treatment Pilot Plant Report at the Utah Power and Light Pole Treatment Yard, Idaho Falls, Idaho.

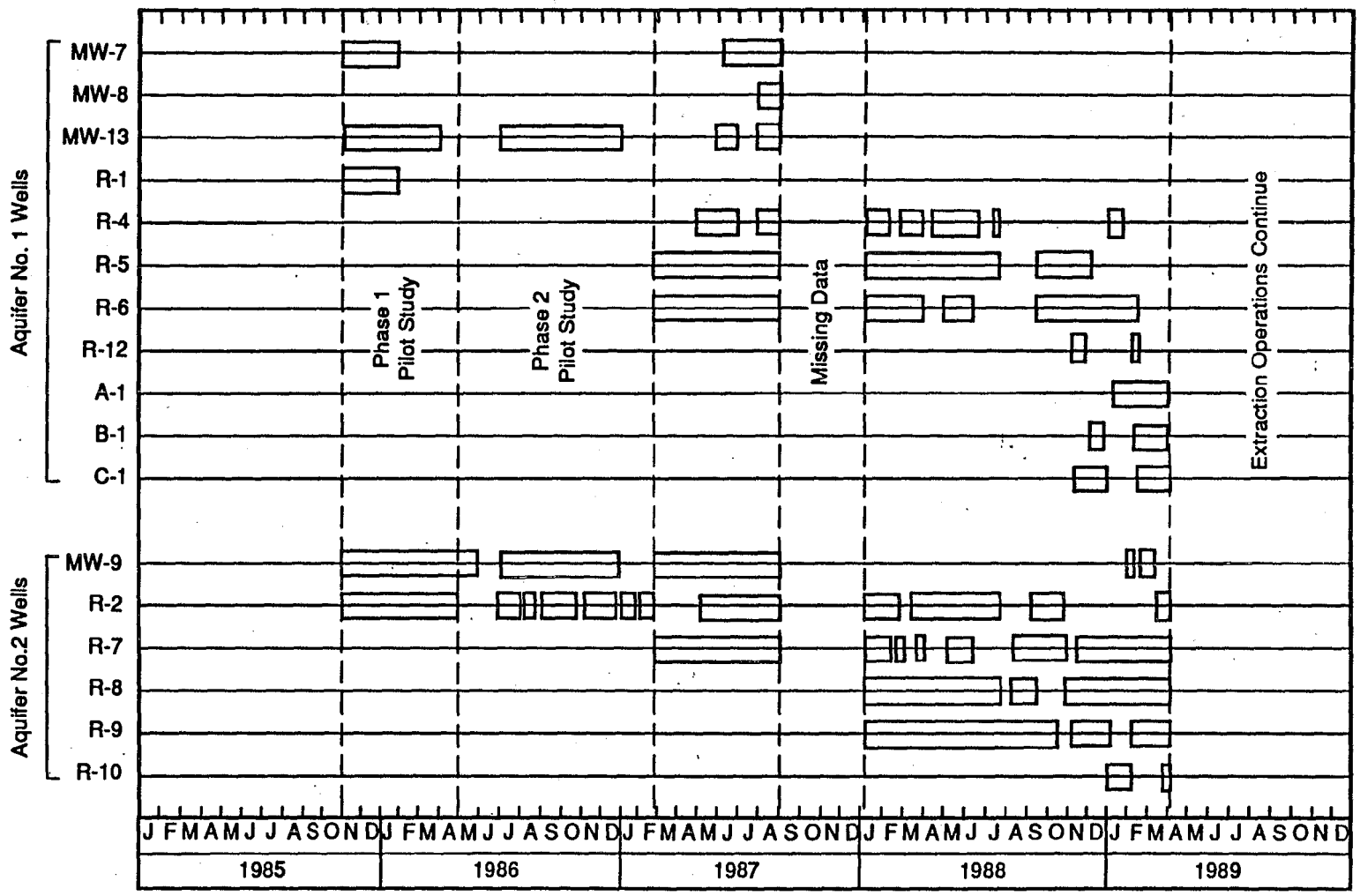
Table 4
INITIAL GROUND-WATER TEST RESULTS
UTAH POWER AND LIGHT SITE

WDC 61621.AO.02



Source: Pacific Power, May 1989, Utah Power & Light/ Pacific Power & Light Idaho Falls Pole Yard, RCRA Post Closure Semi-Annual Report for October 1988 thru March 1989.

Figure 8
EXTRACTION AMD MONITORING WELL SYSTEM, MARCH 1989
UTAH POWER AND LIGHT SITE



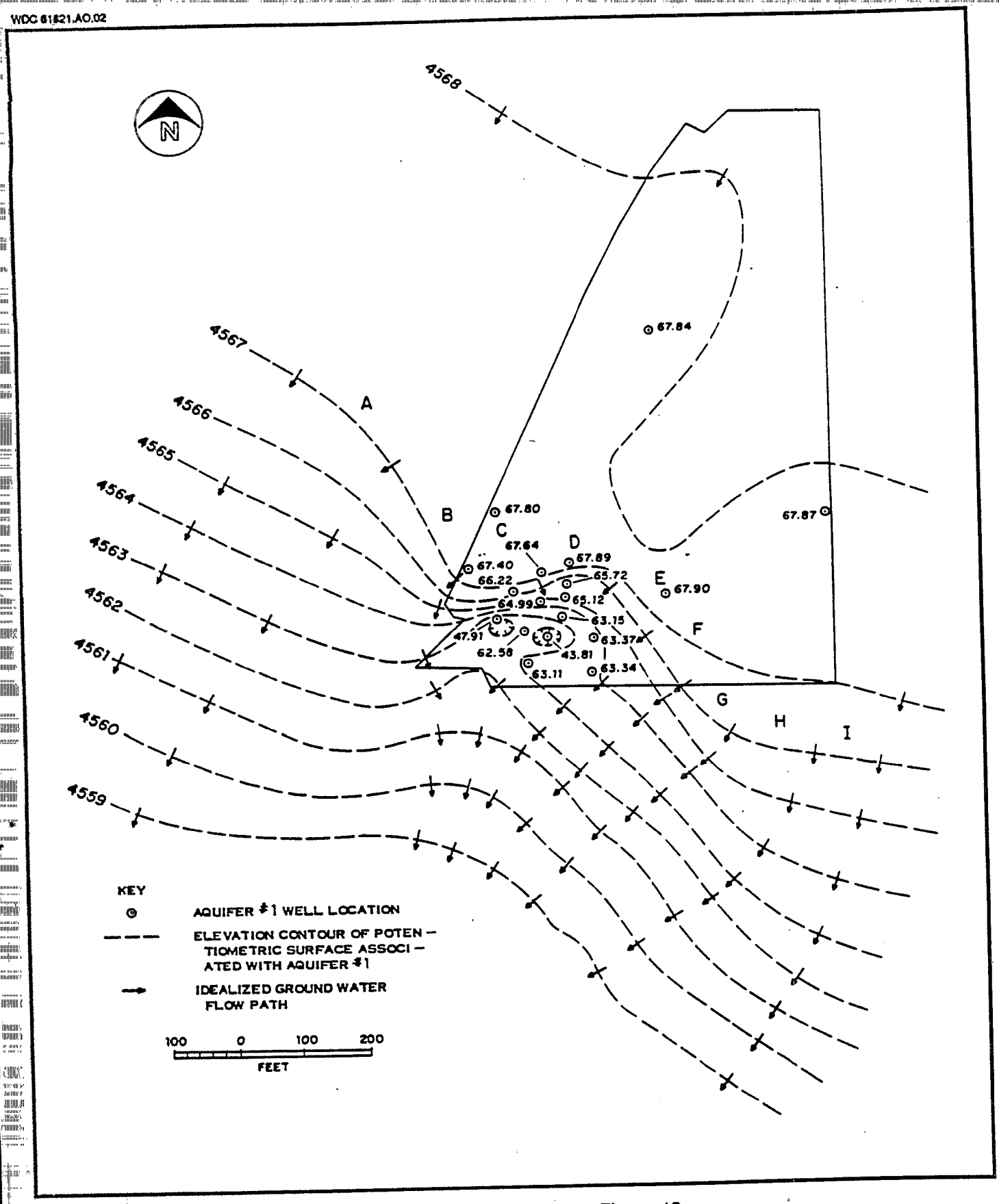
Key:

Period of Well Operation

Note: Wells may not be pumped 24 hours a day during operational periods. Breaks in operation of less than 4 days are not shown.

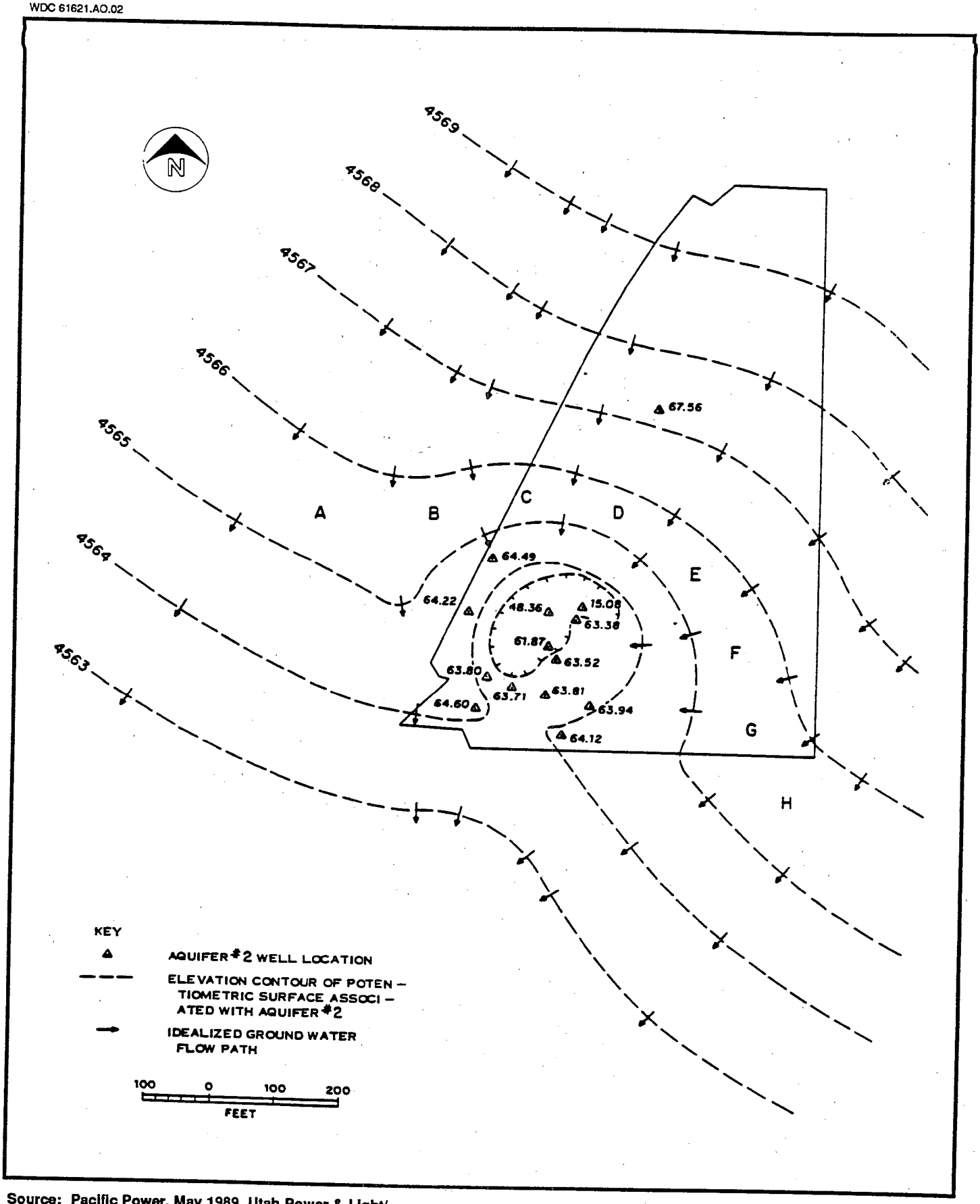
Figure 9
RECORD OF RECOVERY WELL OPERATIONS
UTAH POWER AND LIGHT SITE

WDC 61821.AO.02



Source: Pacific Power, May 1989, Utah Power & Light/ Pacific Power & Light Idaho Falls Pole Yard, RCRA Post Closure Semi-Annual Report for October 1988 thru March 1989.

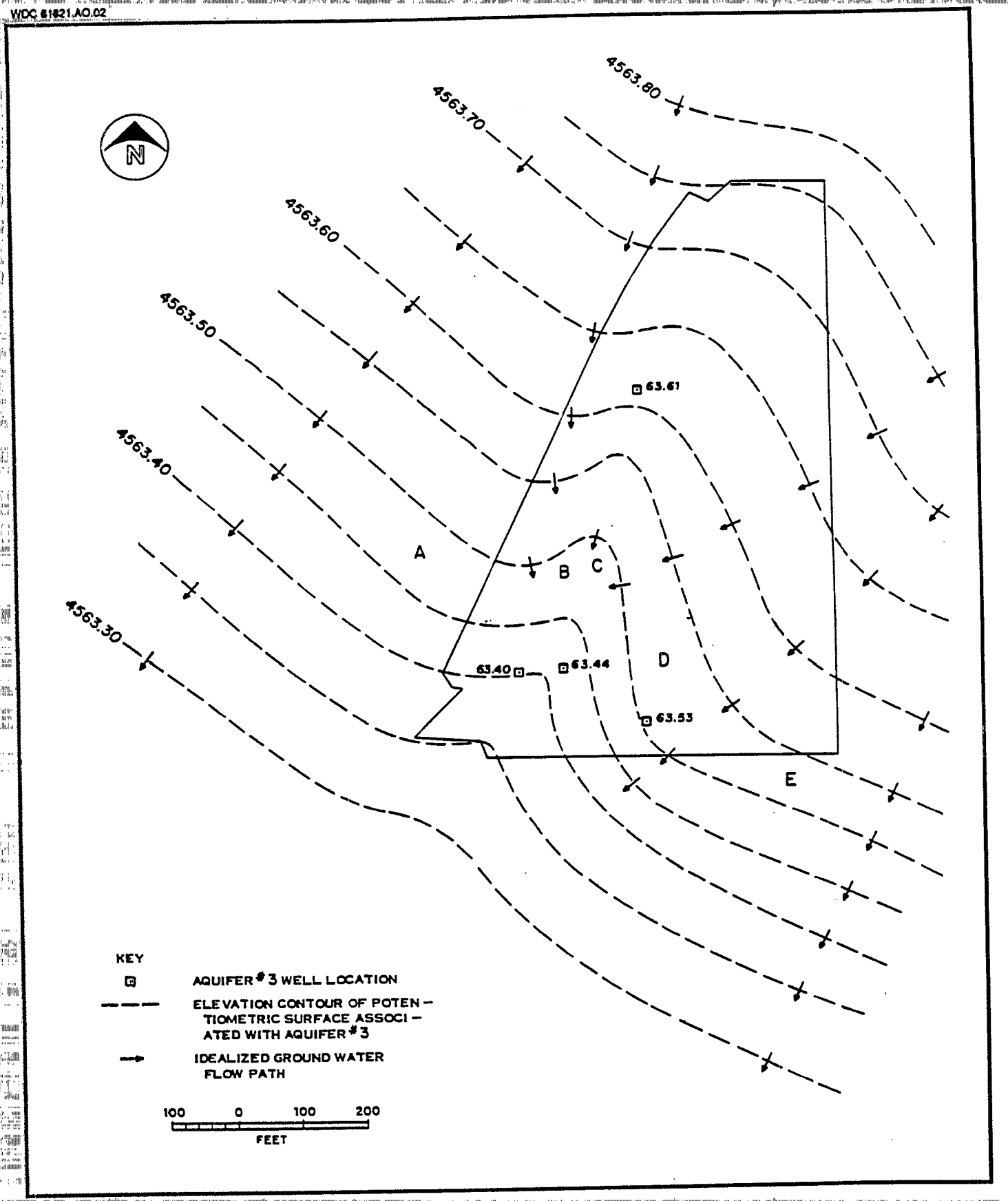
Figure 10
POTENTIOMETRIC SURFACE IN AQUIFER #1, JANUARY 26, 1989
UTAH POWER AND LIGHT SITE



Source: Pacific Power, May 1989, Utah Power & Light/ Pacific Power & Light Idaho Falls Pole Yard, RCRA Post Closure Semi-Annual Report for October 1988 thru March 1989.

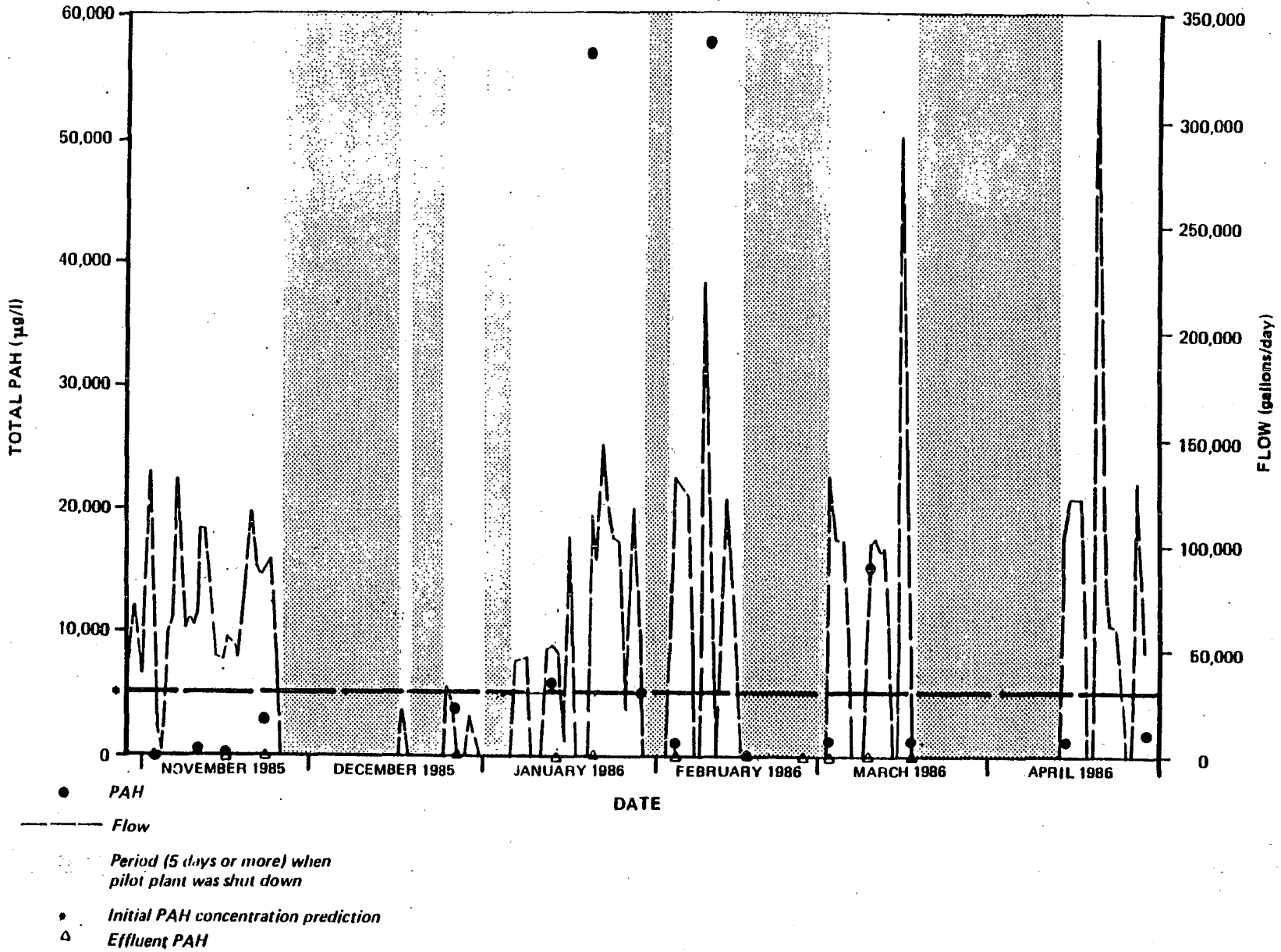
Figure 11
POTENTIOMETRIC SURFACE IN AQUIFER #2, JANUARY 26, 1989
UTAH POWER AND LIGHT SITE

WDC 61821.AO.02



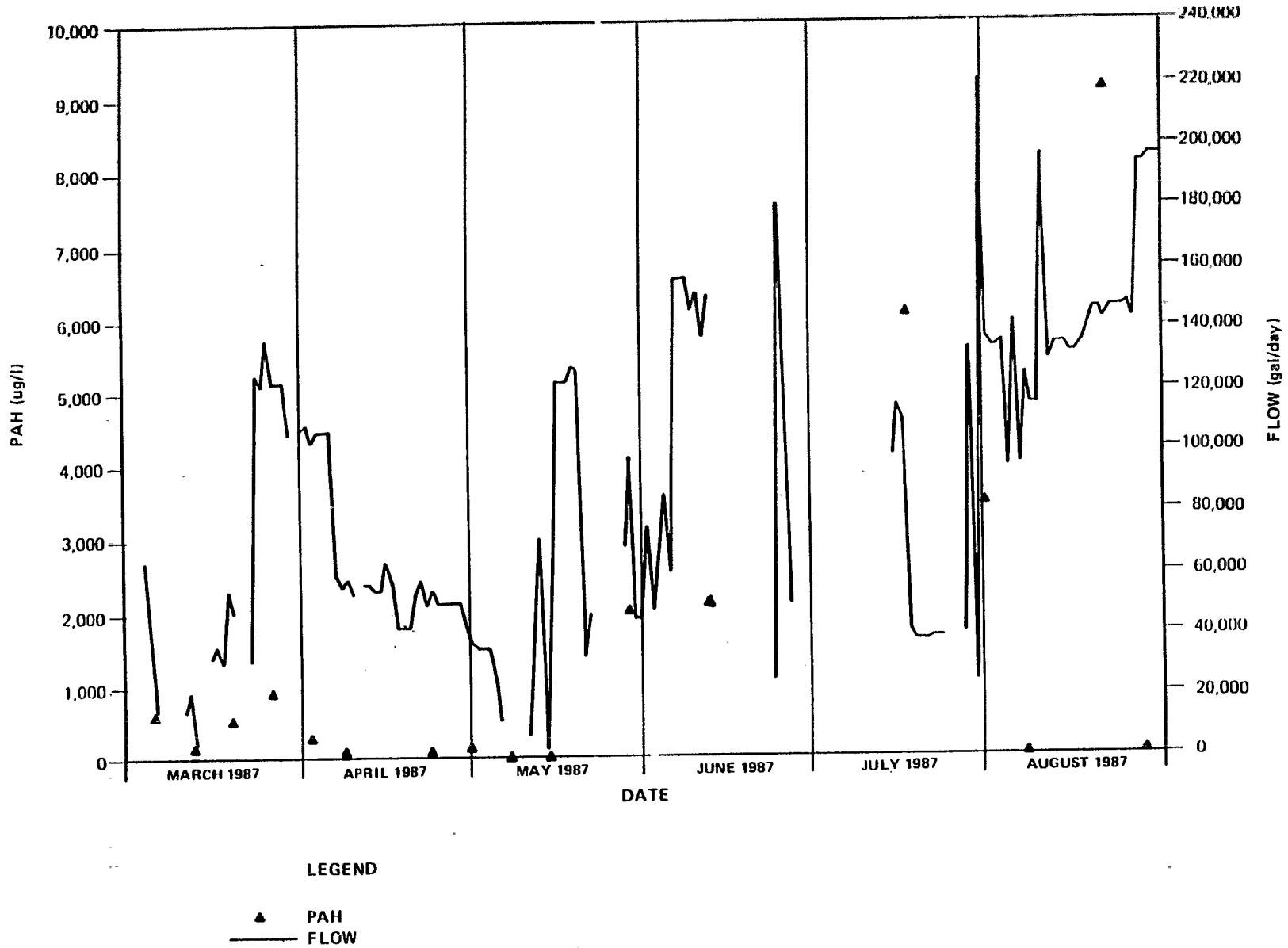
Source: Pacific Power, May 1989, Utah Power & Light/ Pacific Power & Light Idaho Falls Pole Yard, RCRA Post Closure Semi-Annual Report for October 1988 thru March 1989.

Figure 12
POTENTIOMETRIC SURFACE IN AQUIFER #3, JANUARY 26, 1989
UTAH POWER AND LIGHT SITE



Source: CH2M HILL, June 1986, Groundwater Treatment Pilot Plant Report at the Utah Power and Light Pole Treatment Yard, Idaho Falls, Idaho.

Figure 13
RECORD OF COMPOSITE INFLUENT FLOW RATE AND TOTAL PAH CONCENTRATION AT THE TREATMENT PLANT, PHASE 1 PILOT STUDY
UTAH POWER AND LIGHT SITE



Source: CH2M HILL, October 1987, Groundwater Treatment Phase 2 Interim Report, UP & L Pole Treatment Yard, Idaho Falls, Idaho.

Figure 14
RECORD OF COMPOSITE INFLUENT FLOW RATE AND TOTAL PAH CONCENTRATION AT THE TREATMENT PLANT, PHASE 2 PILOT STUDY
UTAH POWER AND LIGHT SITE

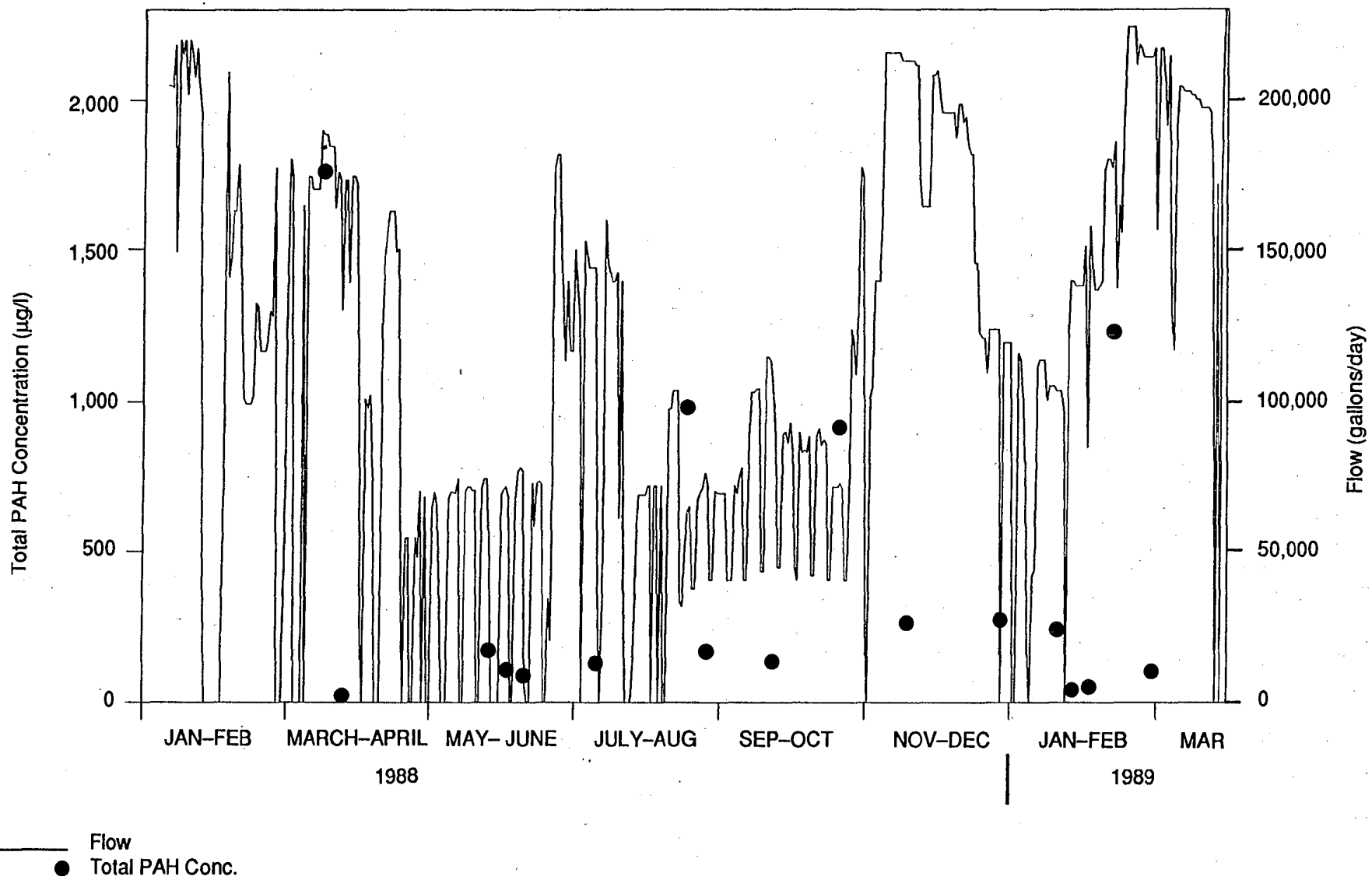


Figure 15
RECORD OF COMPOSITE INFLUENT FLOW RATE AND TOTAL PAH CONCENTRATION AT THE TREATMENT PLANT, 1988 and 1989 OPERATING PERIOD
UTAH POWER AND LIGHT SITE

WDC 61621.AO.02

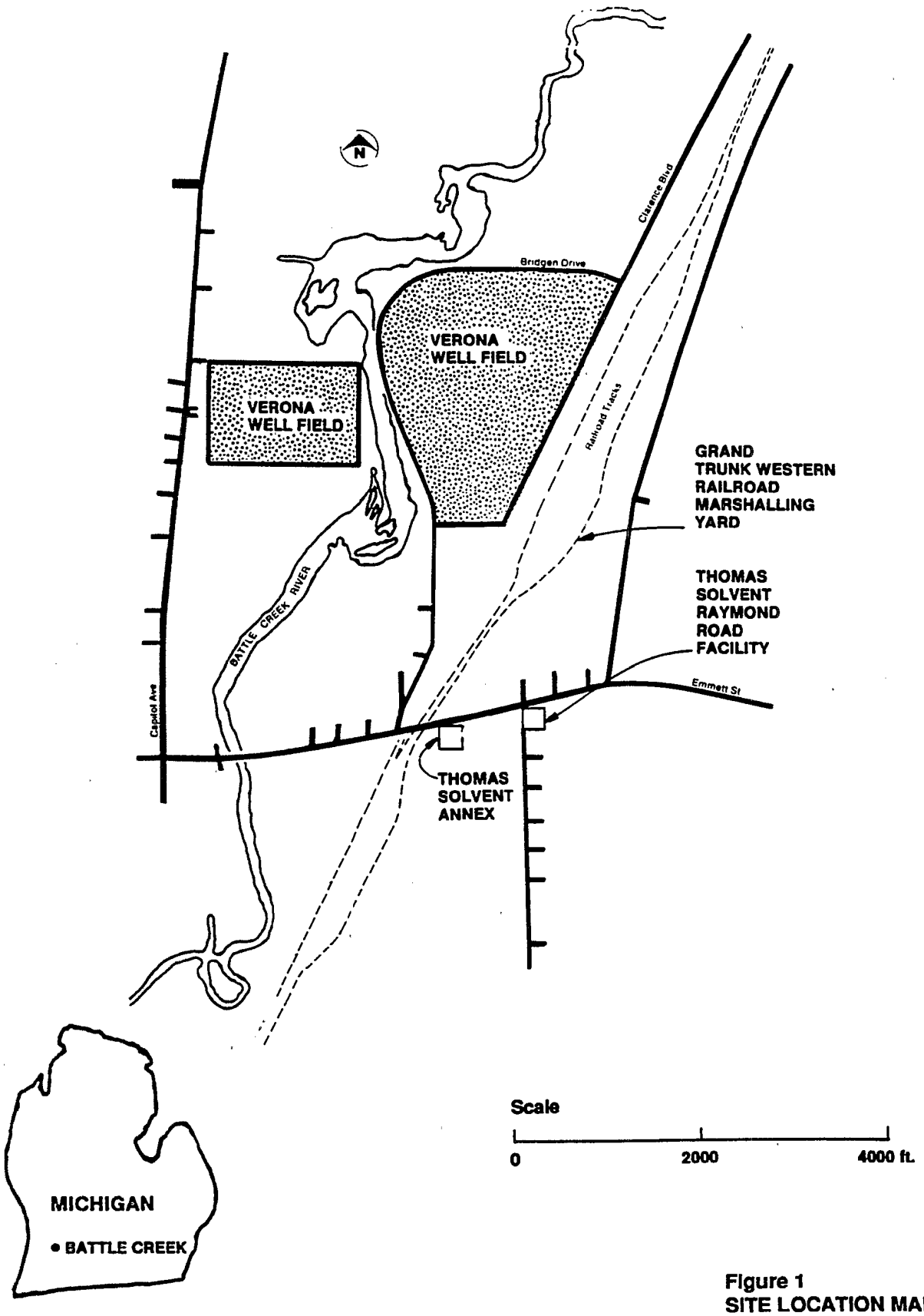
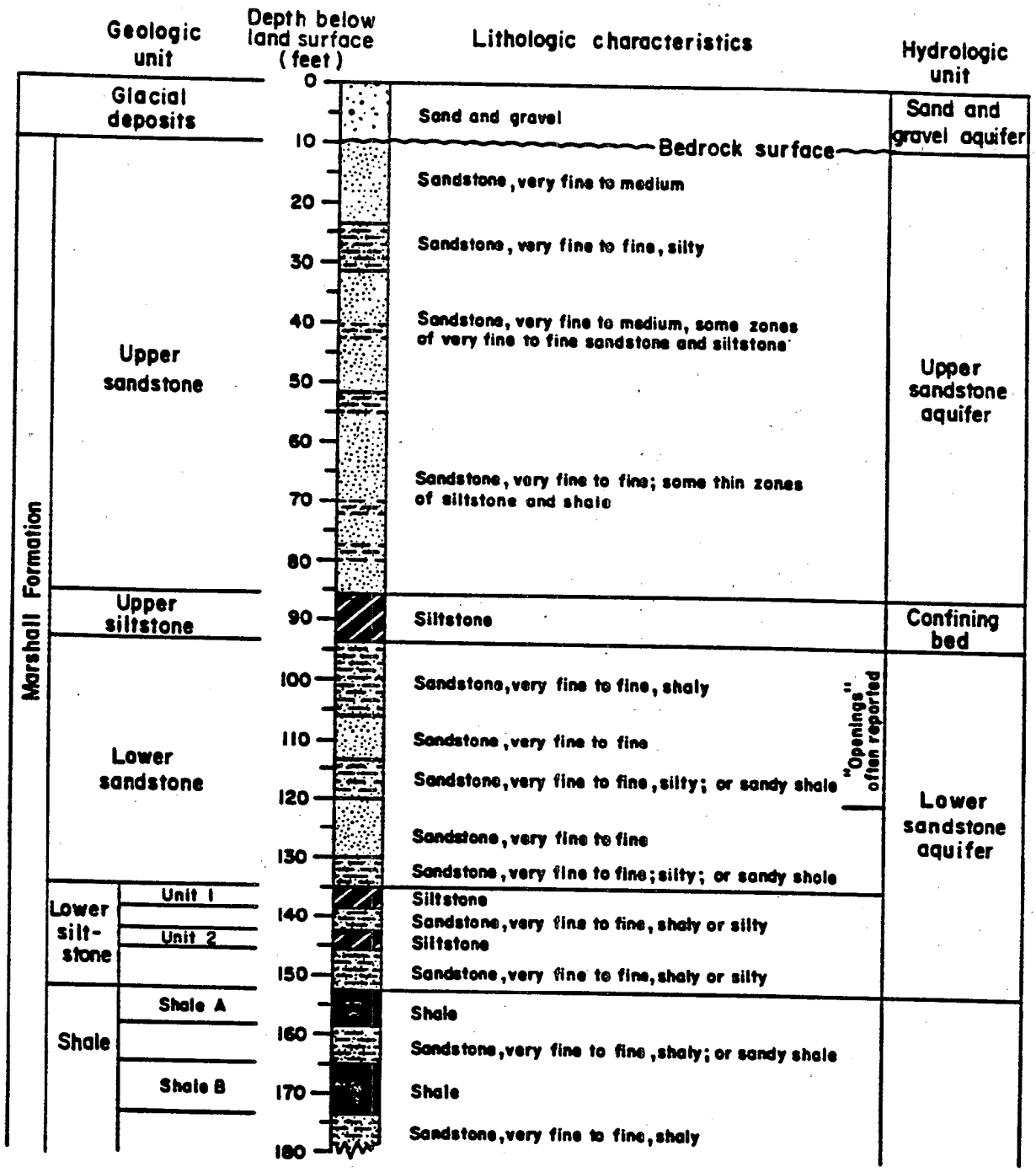


Figure 1
SITE LOCATION MAP
VERONA WELL FIELD SITE
BATTLE CREEK, MICHIGAN

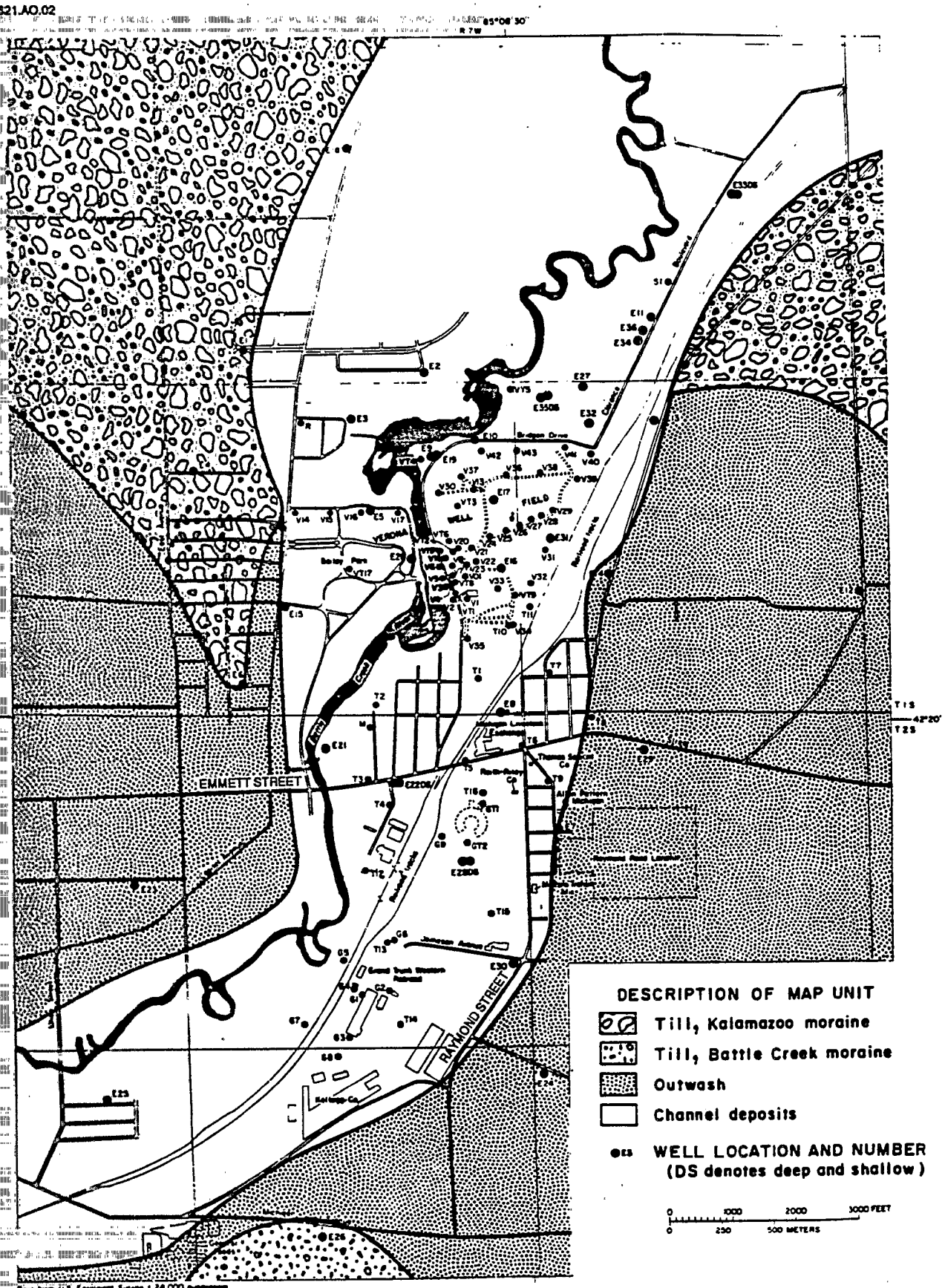
Source: Verona well field final RI/FS work plan. May, 1988.



Source: RCRA handbook on ground-water remediation technologies. January, 1988.

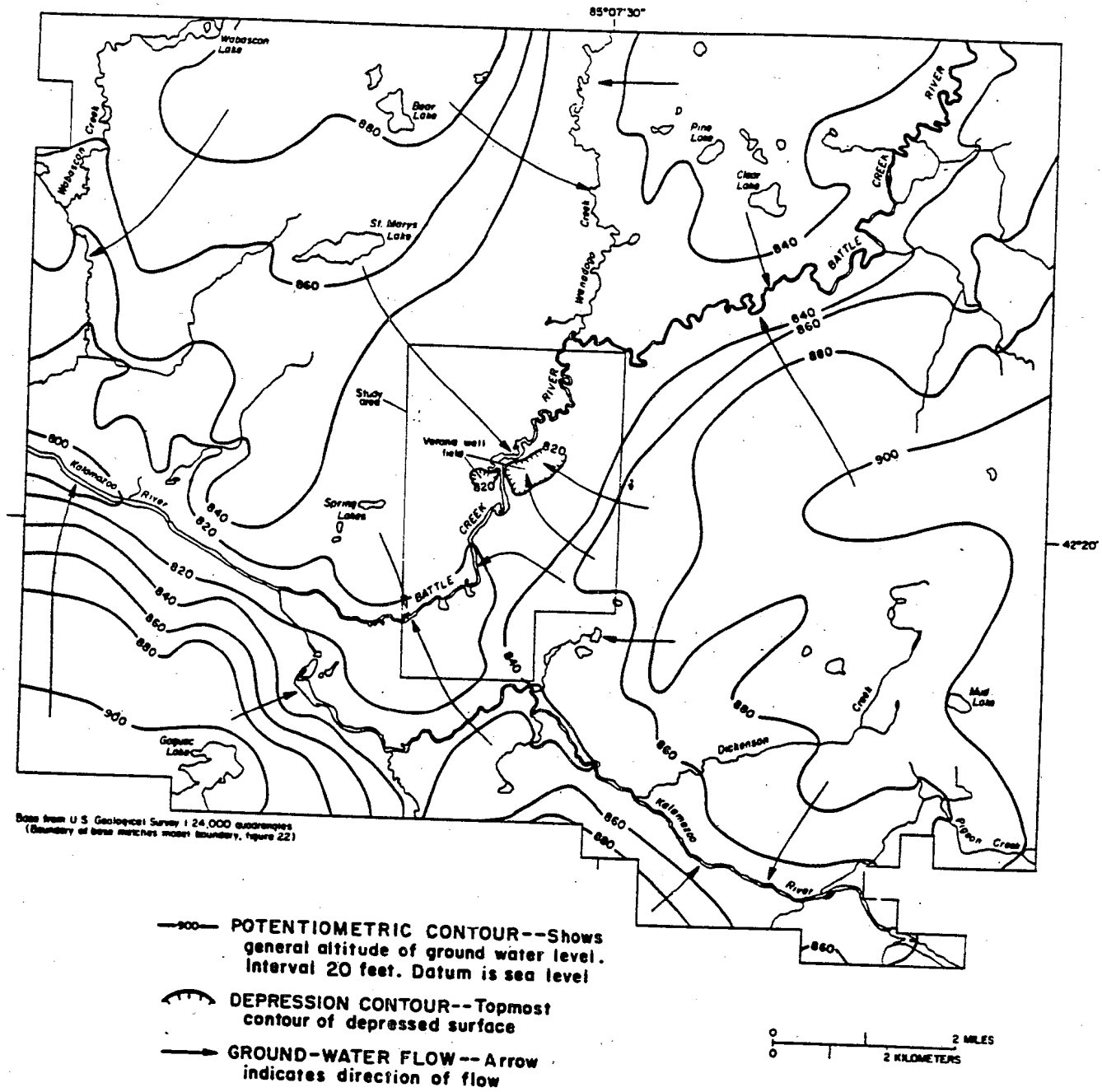
Figure 2
LITHOLOGIC COLUMN OF THE MARSHALL FORMATION IN THE VERONA WELL FIELD AREA
VERONA WELL FIELD SITE

WDC 61621.AO.02



Source: RCRA handbook on ground-water remediation technologies. January, 1988.

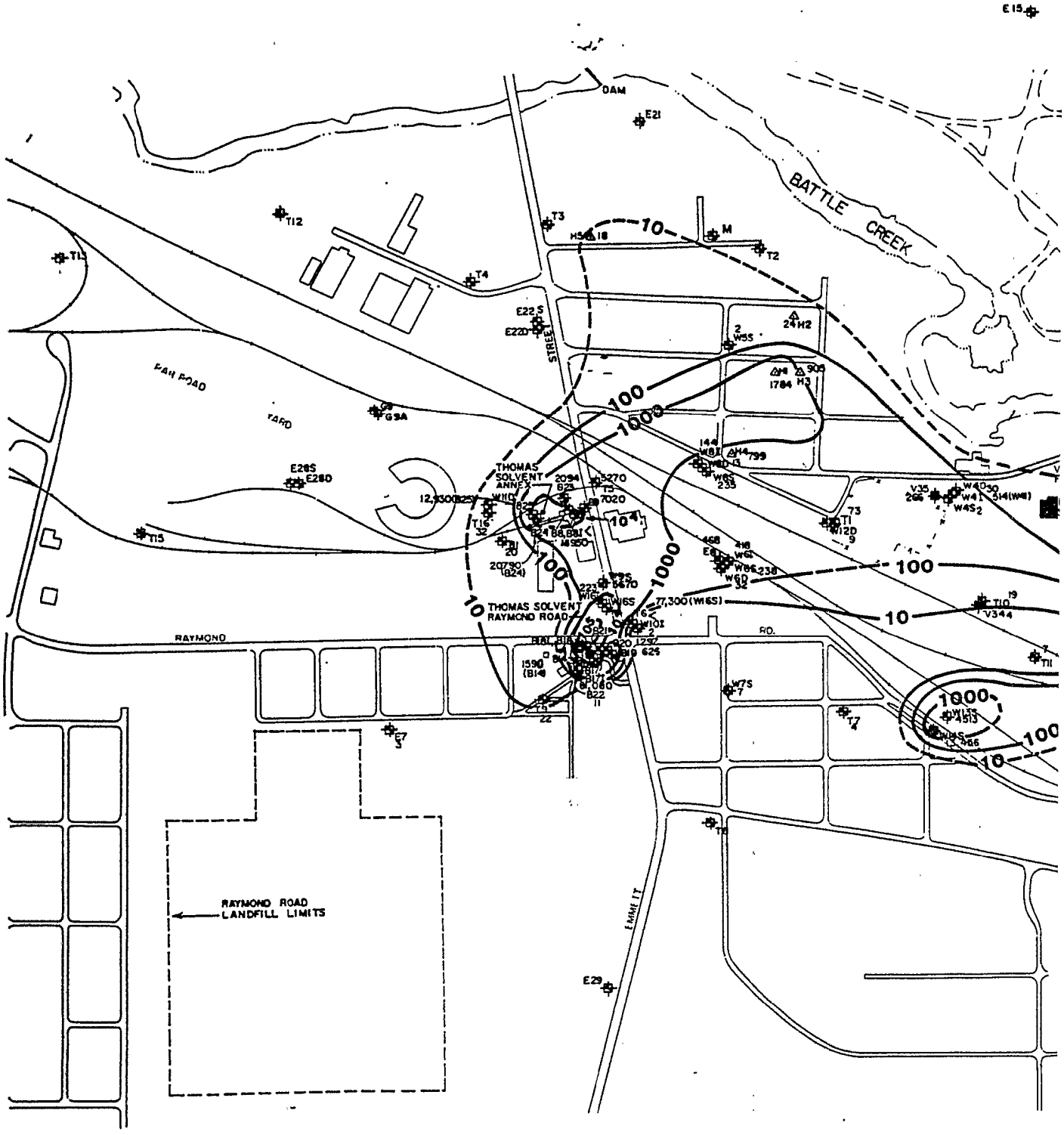
Figure 3
UNCONSOLIDATED SURFACE DEPOSITS IN THE BATTLE CREEK MICHIGAN AREA.
VERONA WELL FIELD SITE



Source: RCRA handbook on ground-water remediation technologies, Jan. 1988.

Figure 4
GROUND-WATER LEVEL CONTOUR MAP OF BATTLE CREEK AREA.
VERONA WELL FIELD SITE

WDC 81621.AO.0"



Source: RCRA handbook on ground-water remediation technologies. January, 1988.

E4

LEGEND

—10— ISOCONCENTRATION CONTOUR (CONTOUR INTERVAL IS SHOWN IN POWERS OF TEN e.g. 10^4 = 10,000 ug/l DASHED WHERE INFERRED, <-INDICATES BELOW DETECTION)

V16 < W61 125 > WELL LOCATION AND NUMBER WITH CONCENTRATION IN ug/l

NOTES

1. REFER TO FIGURE 2 (DRAWING NO.C11185-B26) FOR ADDITIONAL NOTES AND LEGEND.

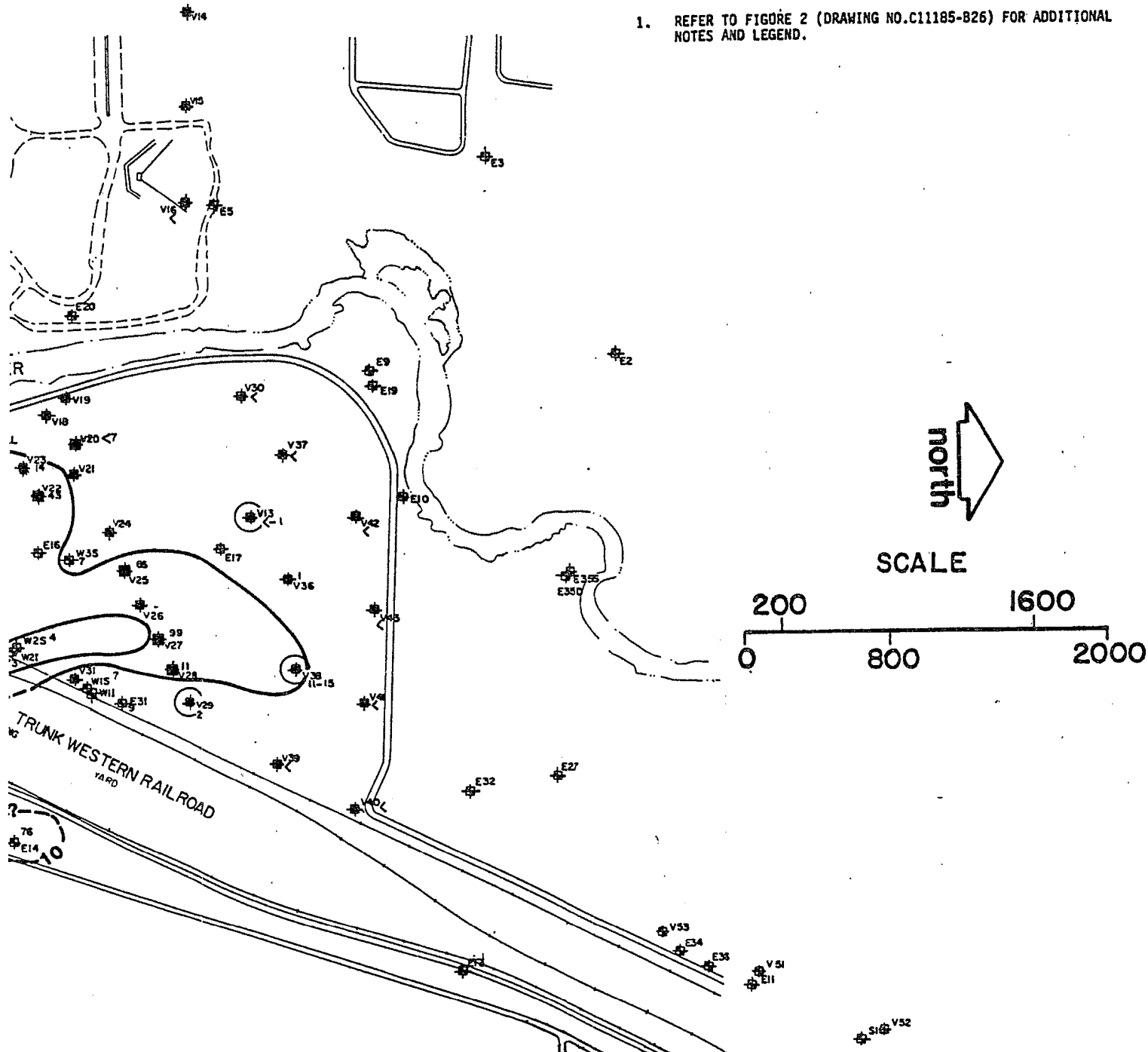
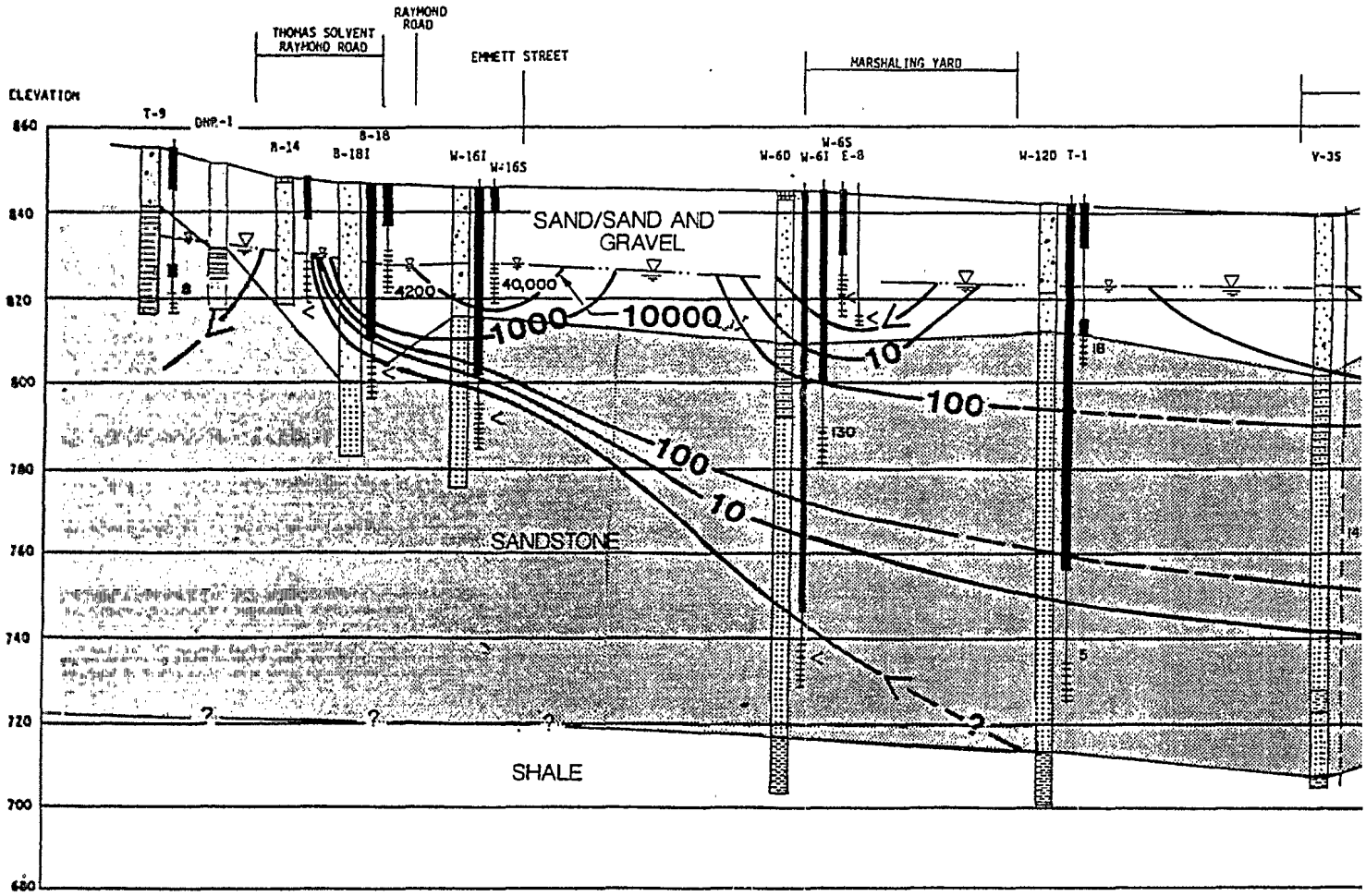
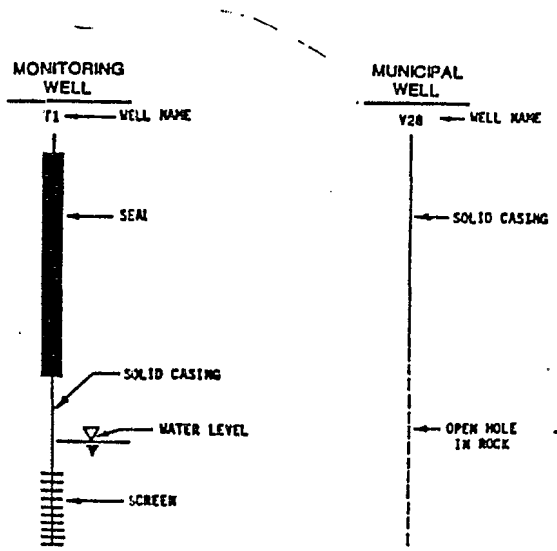


Figure 5
TOTAL VOLATILE ORGANIC COMPOUNDS ISOCONCENTRATION MAP, AUGUST 1984
VERONA WELL FIELD SITE



NOTES

1. THE GEOLOGIC CROSS SECTIONS ARE GENERAL IN NATURE AND DO NOT PURPORT TO BE AN EXACT REPRESENTATION OF SUBSURFACE CONDITIONS BETWEEN BORINGS.
2. QUESTION MARKS BETWEEN GEOLOGIC UNITS INOICATES THE CONTACT IS INFERRED.
3. AT EACH GROUNDWATER MONITORING WELL OR GEOLOGIC BORING LOG LOCATION THE BORING LOG IS ACCURATELY LOCATED WITH RESPECT TO HORIZONTAL LOCATION AND VERTICAL DEPTHS OF GEOLOGIC UNITS. THE GEOLOGIC UNITS HAVE BEEN GENERALIZED. DETAILED DESCRIPTIONS ARE PRESENTED IN THE BORING LOGS IN THE ACCOMPANYING TEXT MANUSCRIPT.
4. ALL GEOLOGIC UNIT CONTACTS AND THE WATER TABLE SURFACE ARE SHOWN TO THE CENTER OF THE BORING LOG. ALL HORIZINTAL DISTANCES ARE MEASURED WITH RESPECT TO THE CENTER OF EACH BORING LOG.
5. WELL DEPTHS AND SCREENED OR OPEN INTERVALS ARE SHOWN FOR ILLUSTRATIVE PURPOSES. REFERENCE REPORT APPENDICES FOR WELL CONSTRUCTION DETAILS AND BORING LOGS FOR RECENT W & B SERIES WELLS AND BORINGS. MUNICIPAL WELL LOGS OBTAINED FROM THE CITY OF BATTLE CREEK.
6. GROUNDWATER LEVELS (▽) DETERMINED FROM WATER LEVEL MEASUREMENTS OBTAINED ON AUGUST 11,1984.
7. THESE CROSS SECTIONS ARE EXAGERRATED VERTICALY 10 TIMES.



TYPICAL WELL DETAIL

LEGEND

TOPSOIL

FILL

BROWN FINE TO M
FINE TO COARSE

BROWN FINE SAND

BROWN, GREEN, TO
WEATHERED SANDST

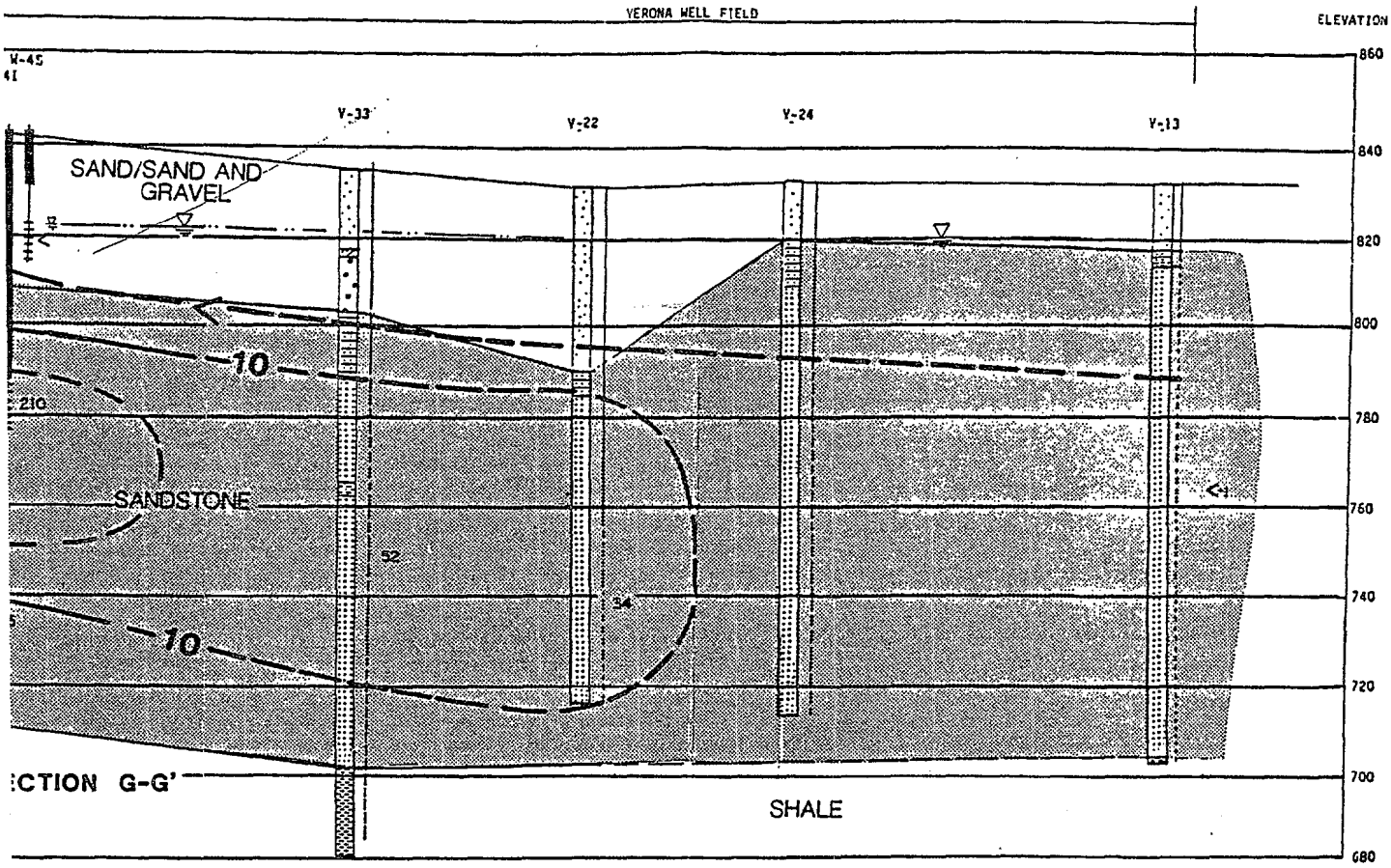
GRAY FINE TO MED

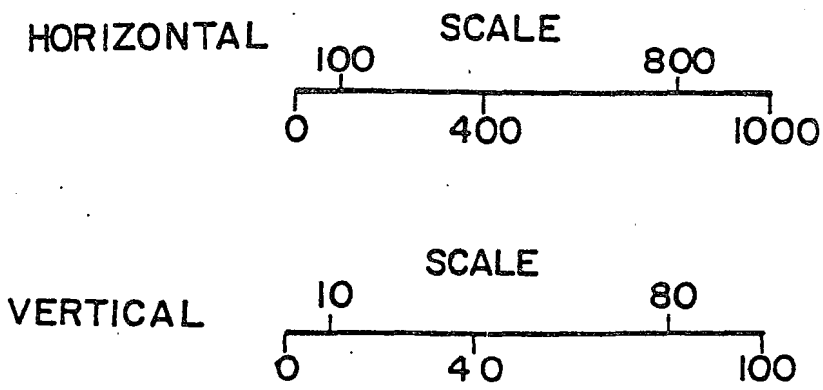
DARK GRAY TO BLA

LEGEND

—100— CONCENTRATION CONTOUR (DASHED WHERE INFERRED)

Source: RCRA handbook on ground-water remediation technologies. January, 1988.





), TRACE TO LITTLE SILT, TRACE TO LITTLE
), SP-SM, SM).

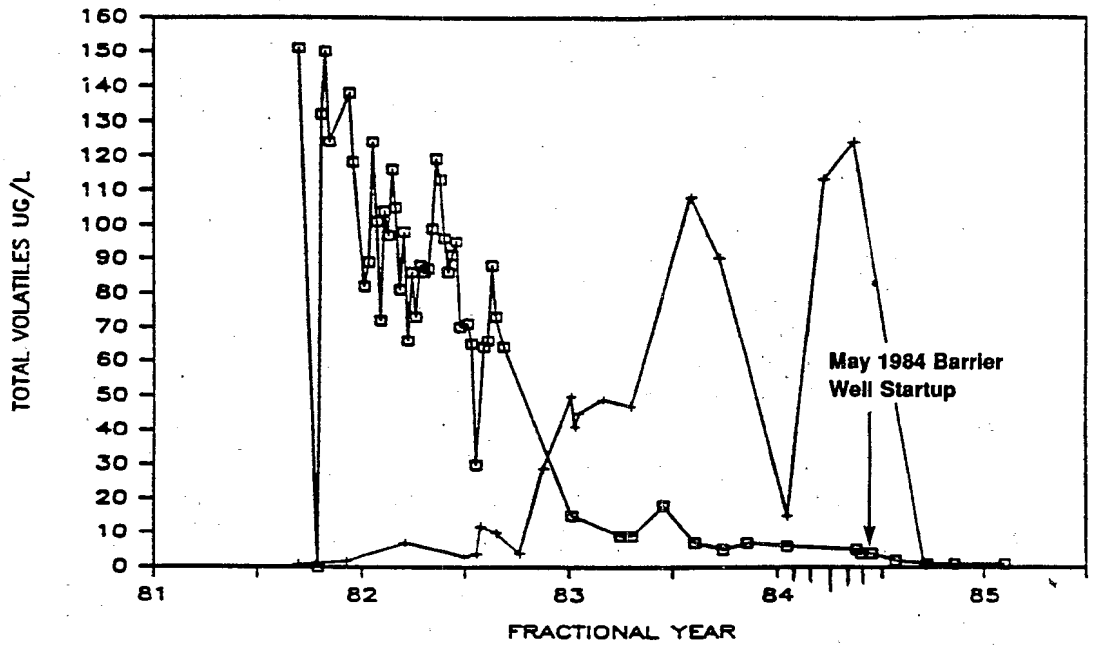
LAYERS (SP, ML, SM)

F FINE TO MEDIUM SAND, SOME SILT,
M,SM).

TONE.

WITH SANDSTONE AND SILTSTONE LAMINATIONS.

Figure 6
VERTICAL DISTRIBUTION OF 1, 2-DICHLOROETHYLENE CONCENTRATION (ppb) IN GROUND-WATER AT THE THOMAS SOLVENT RAYMOND ROAD SITE, AUGUST 1984—
VERONA WELL FIELD SITE

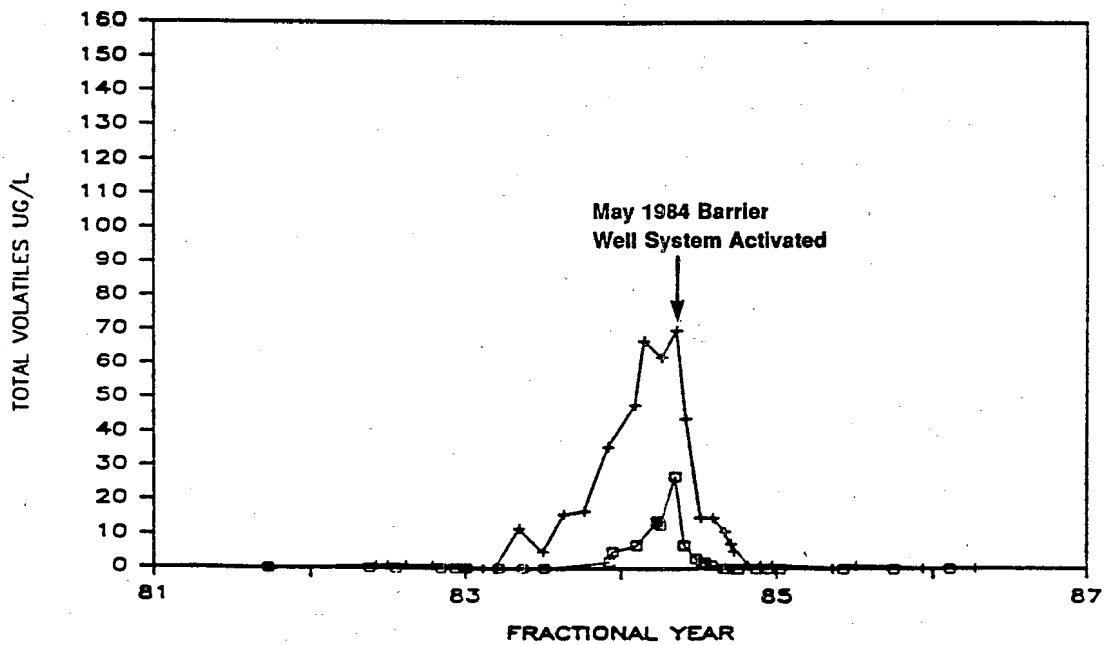


LEGEND

+ WELL V-29

□ WELL V-32

Figure 7
HISTORIC TOTAL VOLATILE ORGANICS WELL V-29 AND V-32
VERONA WELL FIELD
BATTLE CREEK, MICHIGAN



LEGEND

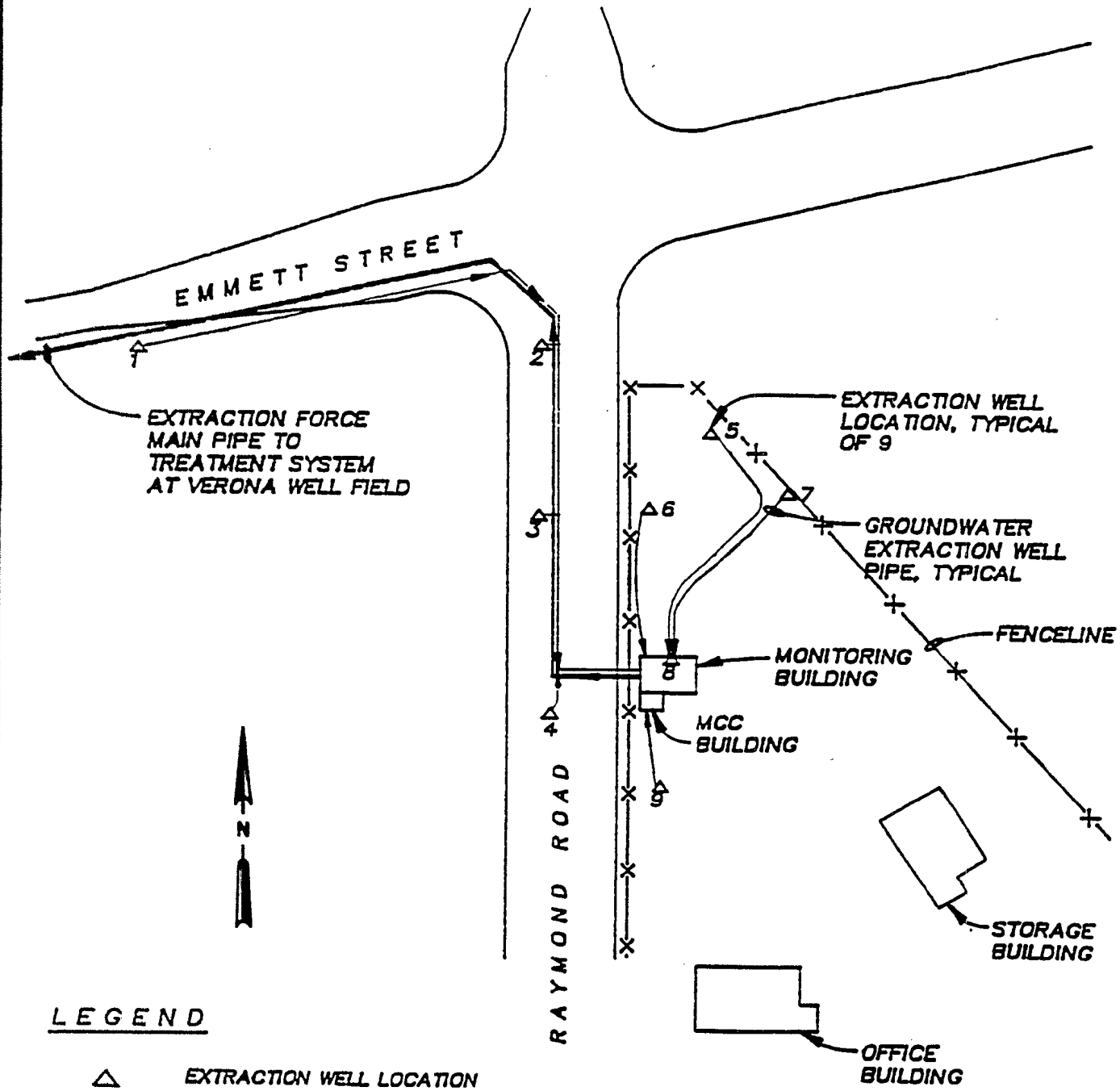
+ WELL V-38

□ WELL V-13

Source: Verona well field final RI/FS work plan. May, 1988.

Figure 8
HISTORIC TOTAL VOLATILE ORGANICS WELL V-13 AND V-38
VERONA WELL FIELD
BATTLE CREEK, MICHIGAN

WDC 61621.AO.02



LEGEND

△ EXTRACTION WELL LOCATION

—EW1— PIPE ROUTING FROM EXTRACTION WELL #1 (TYPICAL)

EXTRACTION FORCE MAIN

Source: Thomas Solvent Raymond Road Groundwater Extraction Well Treatment System Monitoring Report. June, 1988.

Figure 9
THOMAS SOLVENT RAYMOND ROAD EXTRACTION SYSTEM
VERONA WELL FIELD SITE. BATTLE CREEK, MICHIGAN

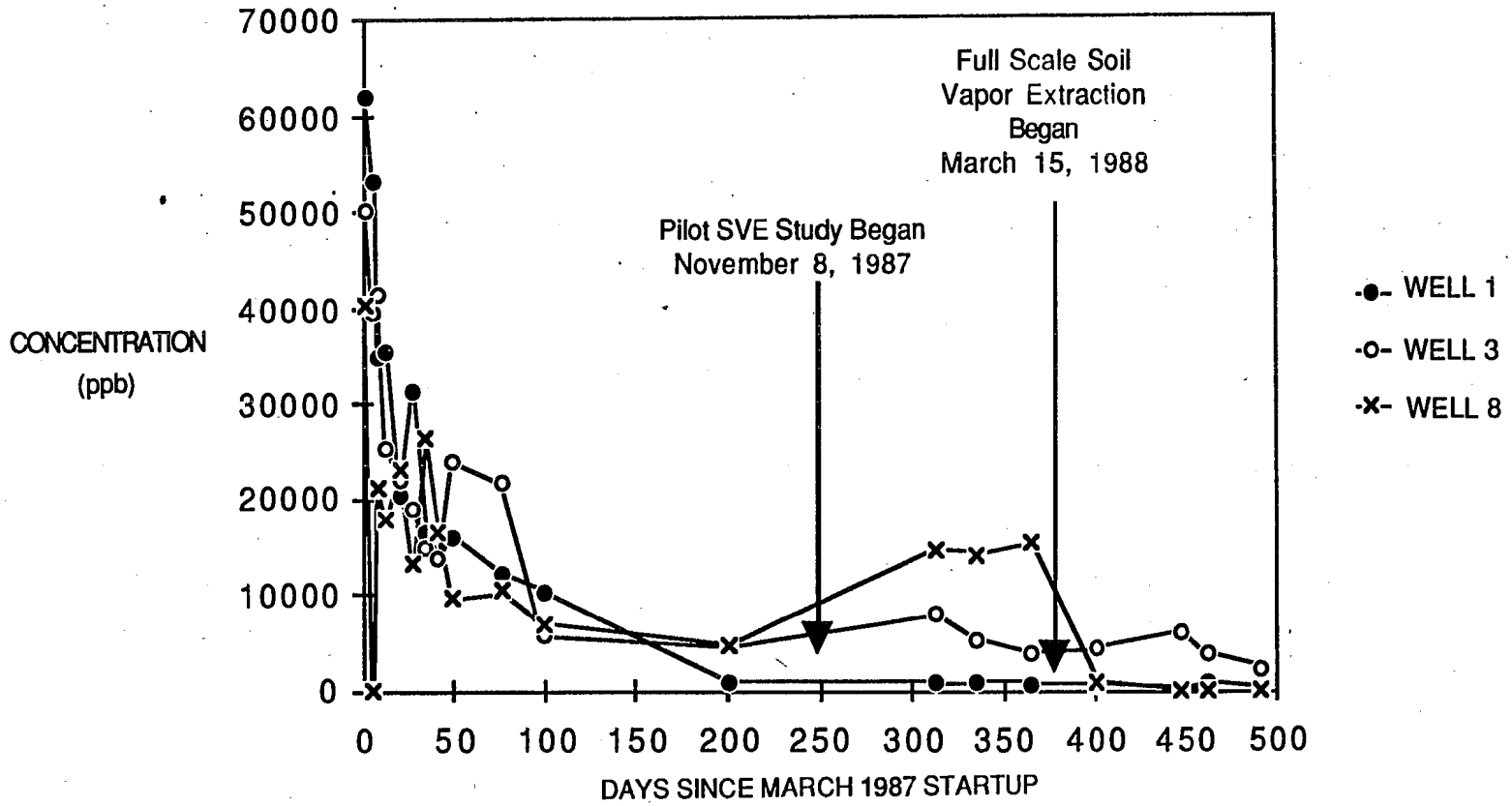


Figure 10
TOTAL VOCS IN TSRR EXTRACTION WELLS 1, 3, AND 8
VERONA WELL FIELD
BATTLE CREEK, MICHIGAN

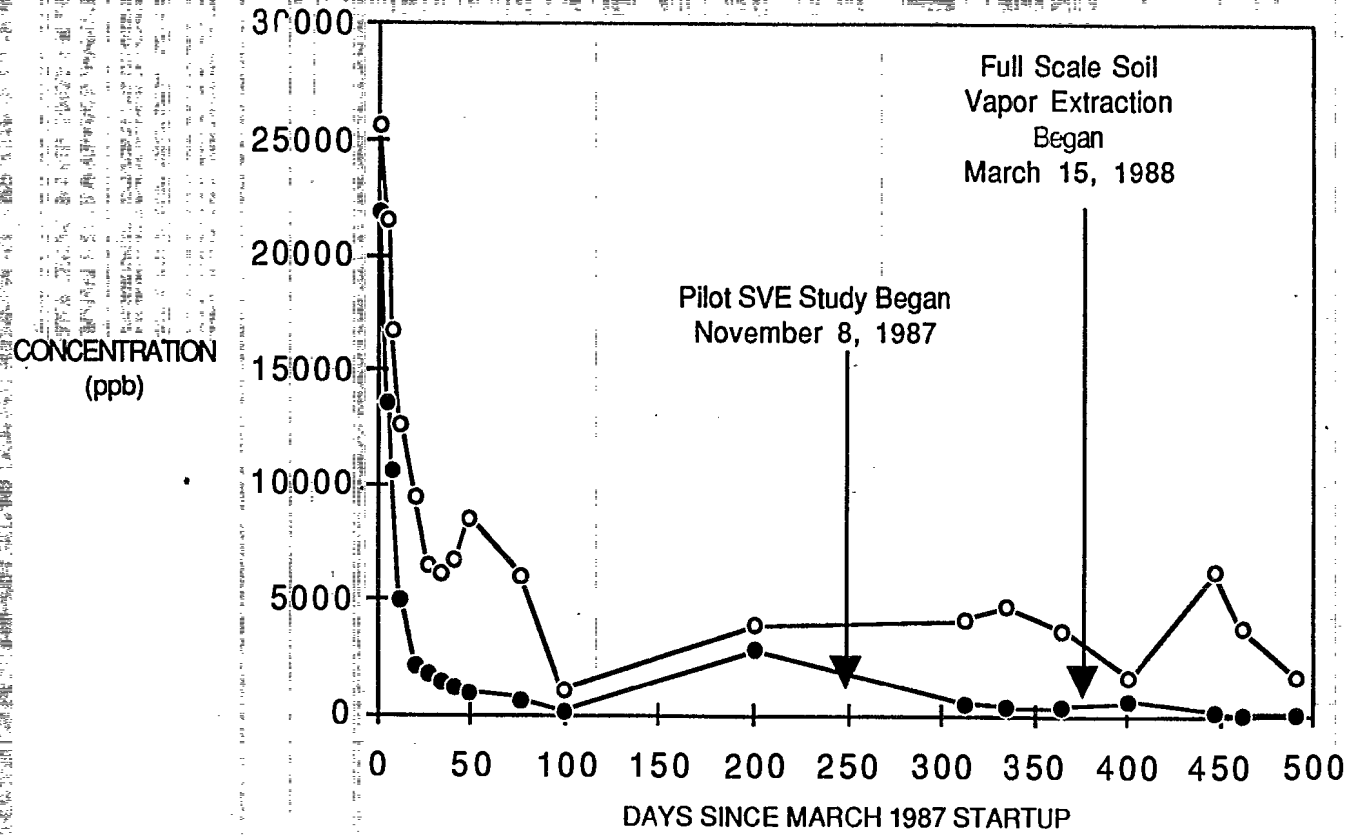


Figure 11
TOTAL VOCS IN TSRR EXTRACTION WELLS 4 AND 6
VERONA WELL FIELD
BATTLE CREEK, MICHIGAN

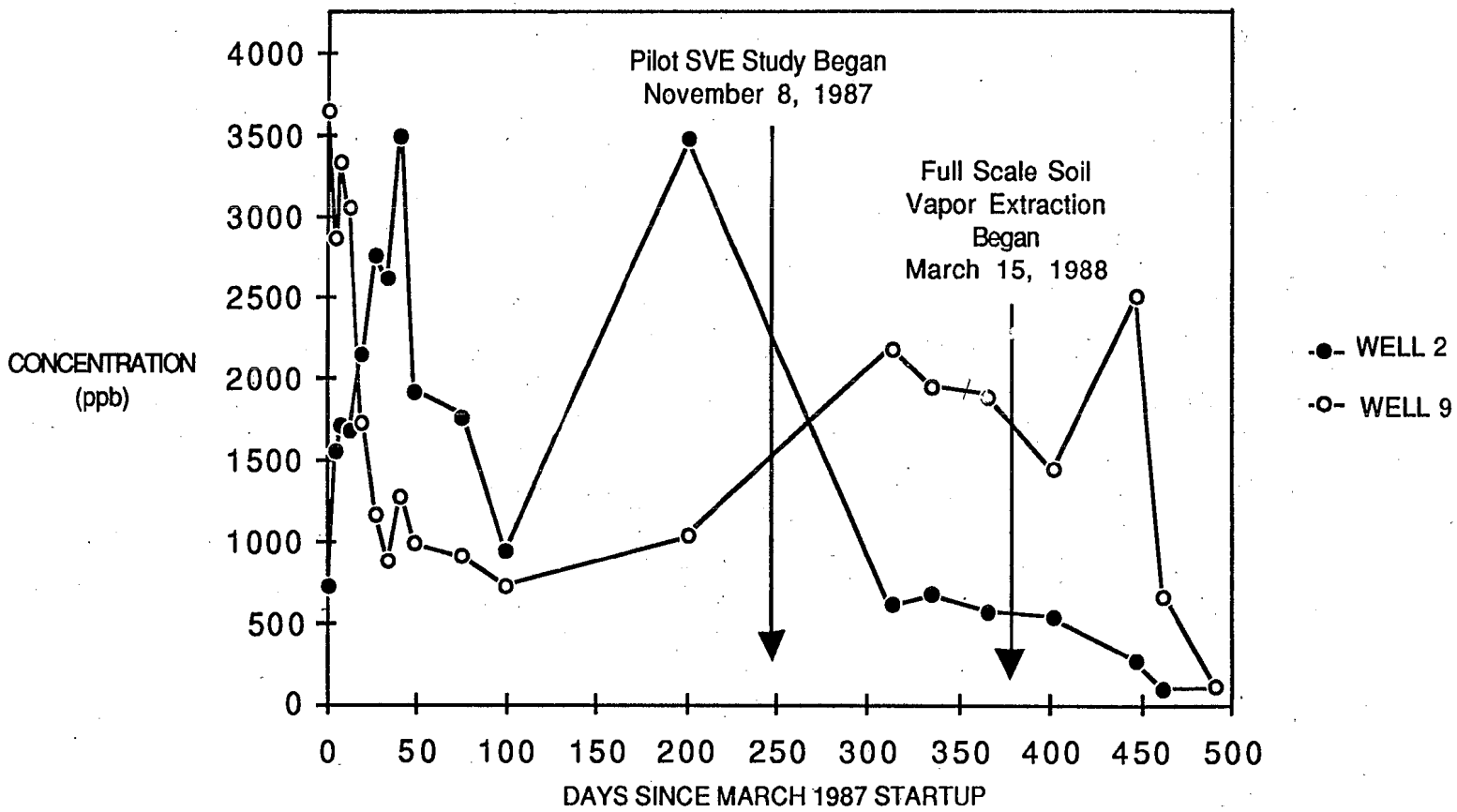


Figure 12
TOTAL VOCS IN TSRR EXTRACTION WELLS 2 AND 9
VERONA WELL FIELD
BATTLE CREEK, MICHIGAN

WDC 61621/AO.02

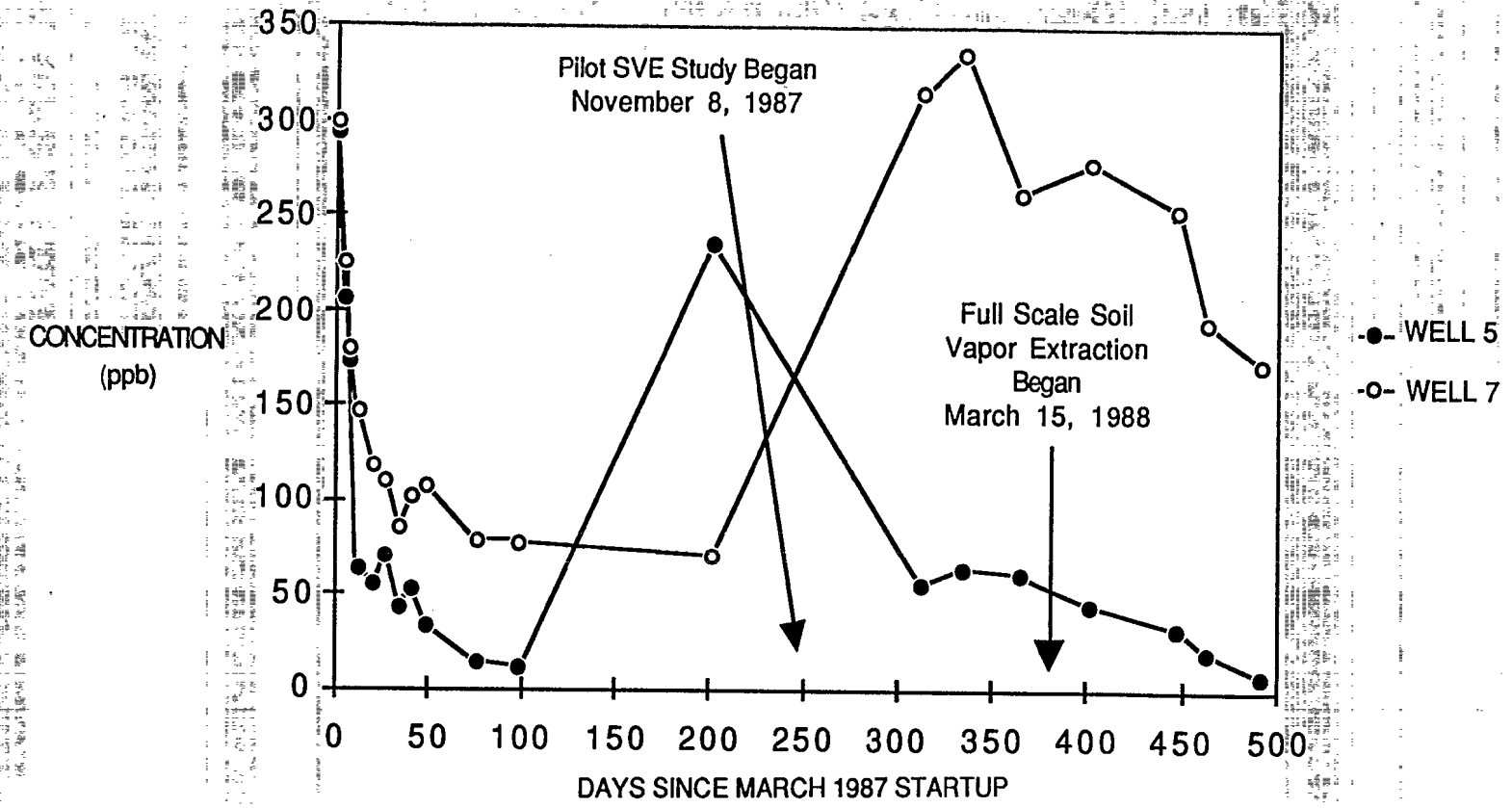


Figure 13
TOTAL VOCS IN TSRR EXTRACTION WELLS 5 AND 7
VERONA WELL FIELD
BATTLE CREEK, MICHIGAN

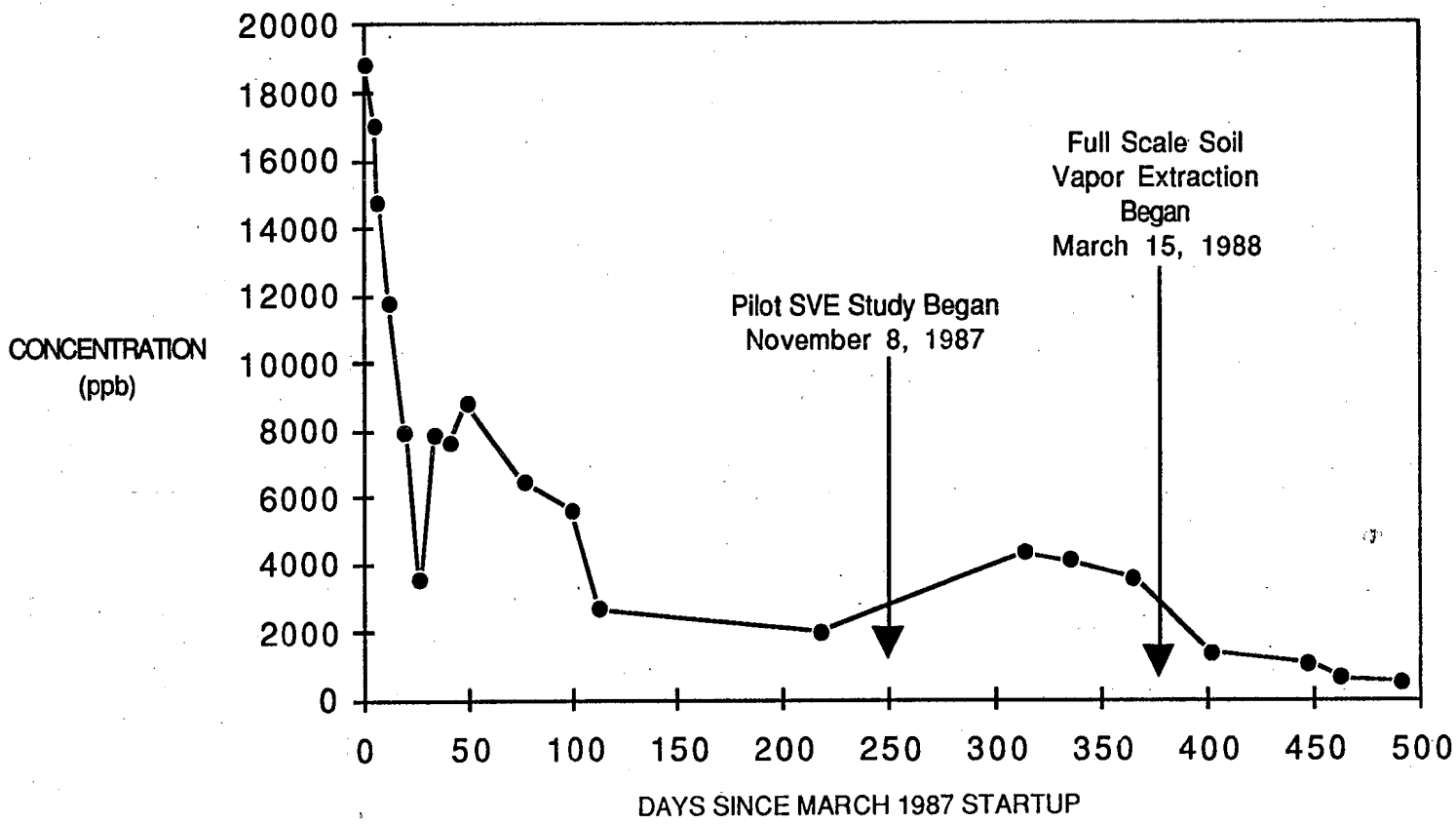


Figure 14
TOTAL VOCS IN TSRR COMBINED EXTRACTION WELLS
VERONA WELL FIELD
BATTLE CREEK, MICHIGAN

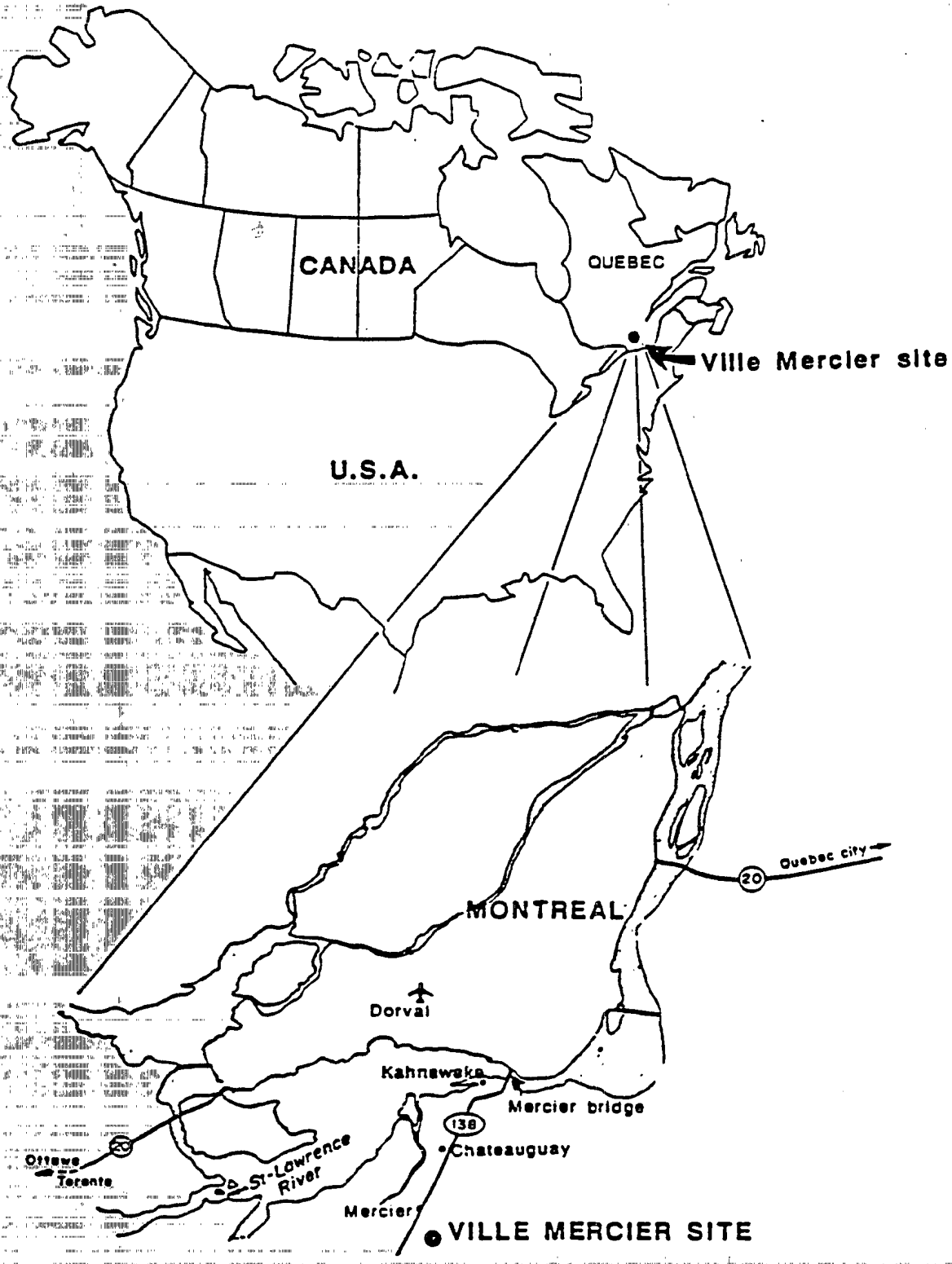


Figure:1 LOCATION MAP OF THE VILLE MERCIER SITE

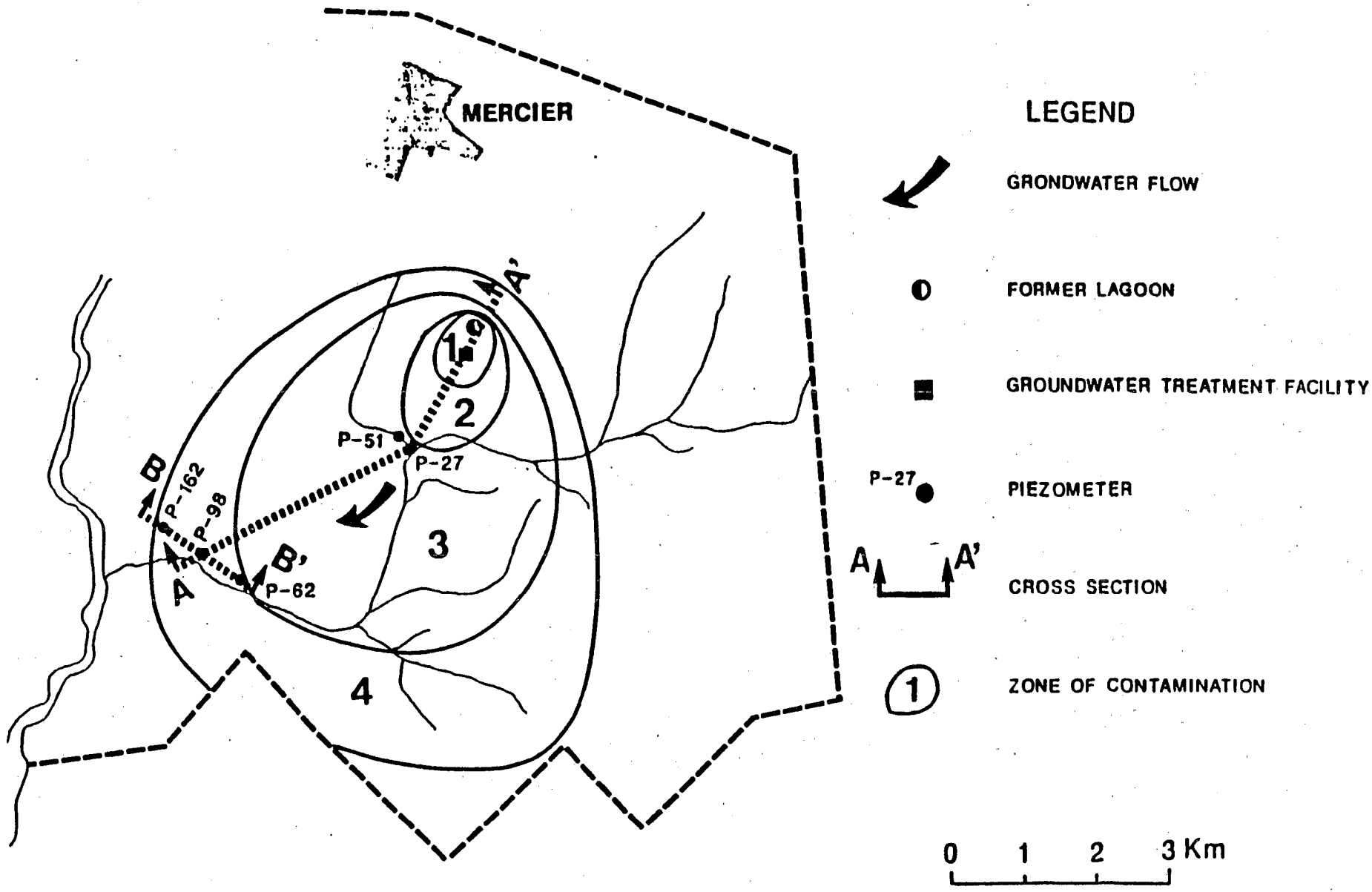


FIGURE : 2 EXTENT OF GROUNDWATER CONTAMINATION AND LOCALISATION OF CROSS SECTIONS

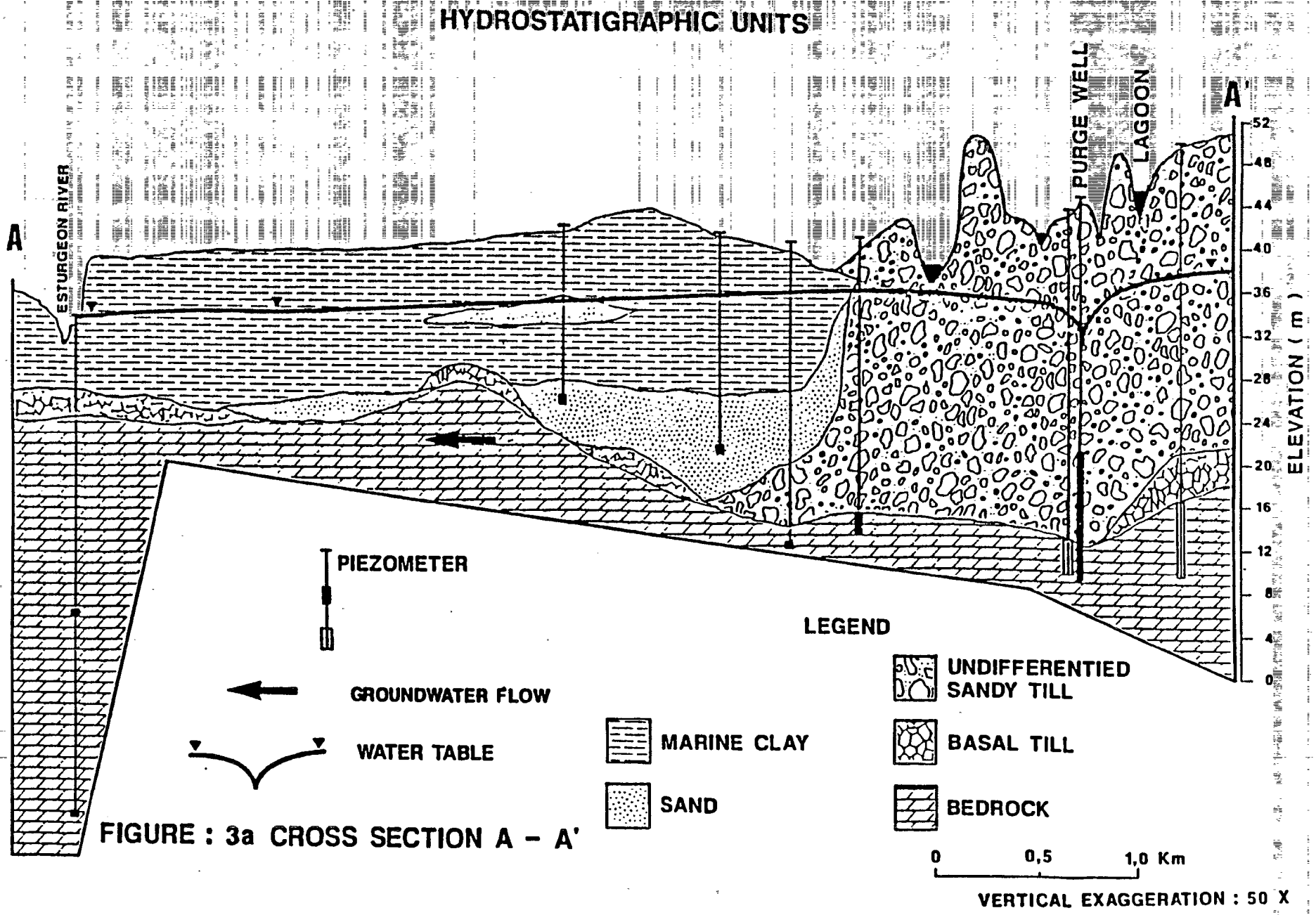


FIGURE : 3a CROSS SECTION A – A'

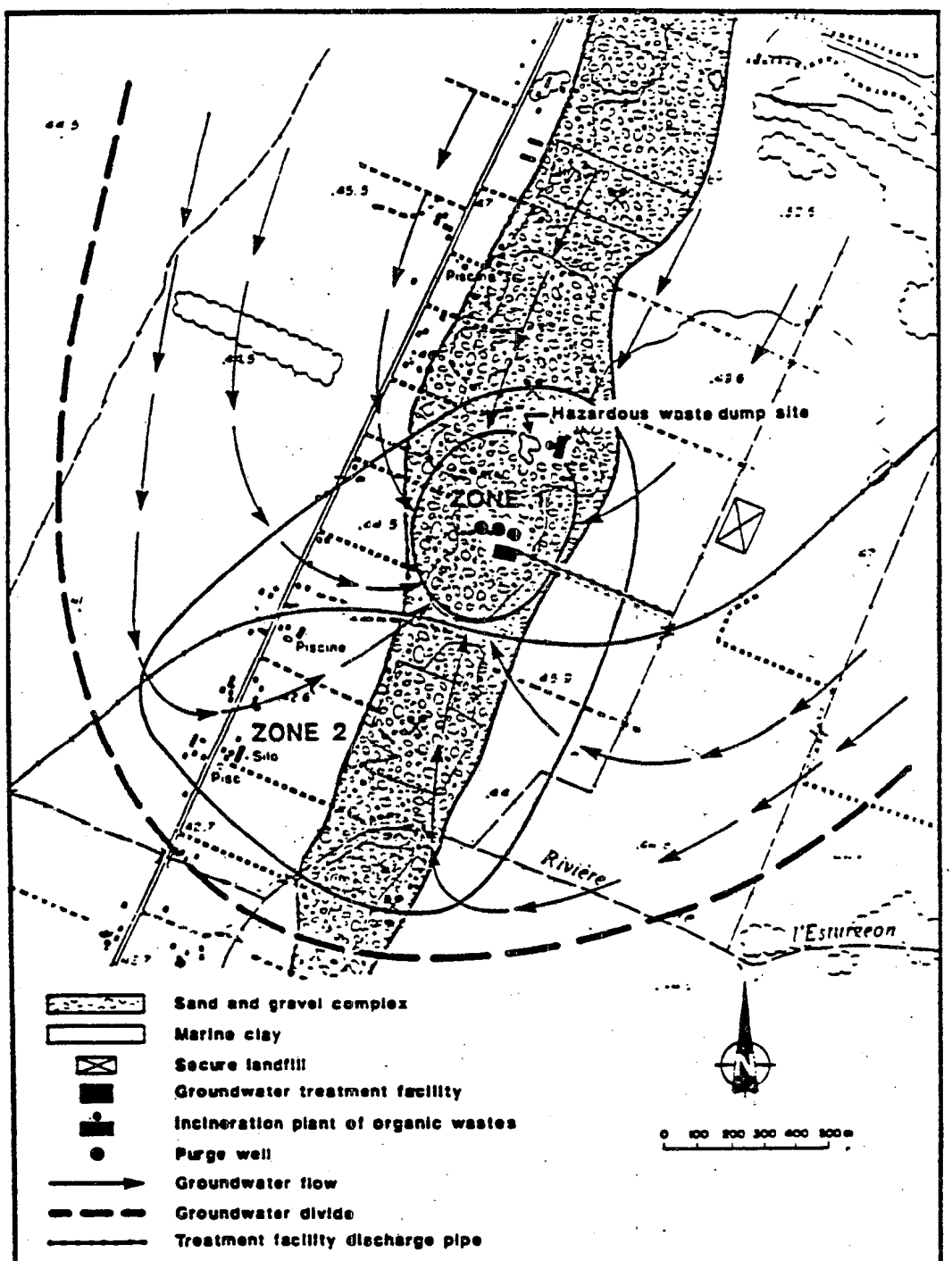


FIGURE : 3b HYDROGEOLOGICAL SETTING OF THE VILLE MERCIER RESTORATION SITE

(From Simard et Lanctôt, 1987)

TABLE 1a
VOLATILE ORGANIC COMPOUNDS
CONCENTRATION OF HALOGENATED HYDROCARBONS IN THE RAW WATER OF VILLE MERCIER

HALOGANATED HYDROCARBONS	CONCENTRATION (ug/l)	SOLUBILITY (mg/l)	DENSITY (g/cm^3)	DRINKING WATER GDL. (ug/l)
1,2 dichloroethane	1 050	8 690	1,23	5 ***
1,1,2 trichloroethane	450	4 500	1,44	
1,1,2 trichloroethylene	160	1 100	1,49	50 ***
Vinyl chloride	160	N.A.	0,92	2 **
Tetrachloroethene	58,8	150	1,63	10 *
Trans 1,2 dichloroethylene	55	600	1,28	
1,1 dichloroethylene	53	400	1,22	7 **
1,2 dichloroethylene	50	N.A.	1,27	
1,1 dichloroethane	49	5 500	1,17	
1,4 dichlorobutene	30	N.A.	1,14	
Chloroform	8,3	8 200	1,50	30 *
1,1,2,2 tetrachloroethane	8,1	2 900	1,60	
1,2 dichlorobutane	6,0	N.A.	1,11	
2,3 dichlorobutane	3,0	N.A.	1,11	
Dichloromethane	3,0	N.A.	1,33	50 ***
1,1,1 trichloroethane	2,3	720	1,34	200 **
1,2 dichloropropane	1,4	2 700	1,16	
Trans 1,3 dichloropropene	1,03	N.A.	1,22	
Bromodichloromethane	0,87	4 500	1,98	
Bromoform	0,3	3 010	2,89	
Carbon tetrachloride	0,06	785	1,59	5 ***

Σ HHs - 86% of TOCs

N.A. no data available
* WHO - World Health Organization
** US EPA - United State Environmental Protection Agency
*** HWC - Health and Welfare Canada
Data from the Merck index (1976) and Sax (1984)

TABLE 1b

VOLATILE ORGANIC COMPOUNDS

CONCENTRATION OF MONOCYCLIC AROMATIC HYDROCARBONS IN THE WATER OF VILLE MERCIER

MONOCYCLIC AROMATIC HYDROCARBONS	CONCENTRATION (ug/l)	SOLUBILITY (mg/l)	DENSITY (g/cm^3)	DRINKING WATER GDL. (ug/l)
Toluene	114	470	0,87	
Xylene	65	N.A.	0,86	
Benzene	47	1 780	N.A	5 ***
Chlorobenzene	23,4	500	1,11	80 ***
Ethyl benzene	17,6	140	0,87	

$\sum$MAHs - 11% of TOCs

N.A. no data available
*** HWC - Health and Welfare Canada
Data from the Merck index (1976) and Sax (1984)

TABLE 2a

NON VOLATILE ORGANIC COMPOUNDS

CONCENTRATION OF POLYCYCLIC AROMATIC HYDROCARBONS IN THE RAW WATER OF VILLE MERCIER

POLYCYCLIC AROMATIC HYDROCARBONS	CONCENTRATION (ug/l)	SOLUBILITY (ug/l)	DENSITY (g/cm^3)	DRINKING WATER GDL. (ug/l)
2-Methylnaphtalene	7,3	N.A.	1,01	
Napthtalene	4,1	34 400	1,16	
Phenanthene	2,2	1 290	1,79	
Benzo (b+k) anthracene	1,6	N.A.	N.A.	
Pyrene	1,1	140	1,27	
Benzo (a) anthracene	1,1	14	N.A.	
Benzo (g,h,i) perylene	1,1	0,26	N.A.	
Dibenzo (a,h) anthracene	1,0	0,5	N.A.	
Benzo (a) pyrene	0,9	3,8	1,35	0,01 ***
Fluoranthene	0,8	260	1,25	
Fluorene	0,8	1 980	1,20	
Indeno (1,2,3,- cd) pyrene	0,6	620	N.A.	
Acenaphtene	0,6	3 400	N.A.	
Anthracene	0,6	73	1,25	
Acenaphtylene	0,2	3 920	N.A.	

Σ PAHs = 1% of TOCs

N.A. no data available

*** HWC - Health and Welfare Canada

Data from CNRC (1983), the Merck index (1976) and Sax (1984)

TABLE 2b

NON VOLATILE ORGANICS COMPOUNDS

CONCENTRATION OF PHENOLIC COMPOUNDS IN THE RAW WATER OF VILLE MERCIER

PHENOLIC COMPOUNDS	CONCENTRATION (ug/l)	SOLUBILITY (mg/l)	DENSITY (g/cm^3)	DRINKING WATER GDL. (ug/l)
2,4 dimethylphenol	13,0	N.A.	N.A.	
Phenol	6,2	82 000	1,07	
4-nitrophenol	2,1	N.A.	1,27	
Pentachlorophenol	0,8	N.A.	N.A.	60 ***
2- chlorophenol	0,4	28 500	1,26	
2- nitrophenol	0,4	N.A.	1,49	
4- chloro 3- methylphenol	0,4	N.A.	N.A.	
2- methylphenol	0,3	N.A.	1,5	
2,4- dinitrophenol	0,3	N.A.	N.A.	70 ***
4,6- dinitrophenol	0,3	N.A.	N.A.	
2,4- dinitrophenol	0,1	N.A.	N.A.	

$\sum$ PCs = 1% of TOCs

*** HWC - Health and Welfare Canada

N.B. In Quebec the Drinking Water Standard for Phenolic Compounds is 2 ug/l.

Data from the Merck index (1976) and Sax (1984)

TABLE 2c

NON VOLATILE ORGANIC COMPOUNDS

CONCENTRATION OF MONOCYCLIC AROMATIC HYDROCARBONS, HALOGENATED HYDROCARBONS AND OTHERS IN THE RAW WATER OF VILLE MERCIER

MONOCYCLIC AROMATIC HYDROCARBONS	CONCENTRATION (ug/l)	SOLUBILITY (mg/l)	DENSITY (g/cm^3)	DRINKING WATER STD. (ug/l)
2 nitroaniline	14,0	N.A.	N.A.	
Nitrobenzene	3,1	N.A.	1,20	
1,2 dichlorobenzene	0,6	N.A.	1,30	200 ***
1,4 dichlorobenzene	0,4	N.A.	1,25	5 ***
HALOGENATED HYDROCARBONS				
Hexachloroethane	7,2	N.A.	2,09	
Hexachlorobutadiene	1,4	N.A.	N.A.	
OTHERS				
Isophrone	4,1	N.A.	0,92	
N- nitroso- DIN-propylamine	0,7	N.A.	N.A.	
Dibenzofuran	0,5	N.A.	N.A.	$15X10^{-6}$***

Σ(MAHs + HHs + OTHERS)= 1% of TOCs

Data from the Merck index (1976) and Sax (1984)

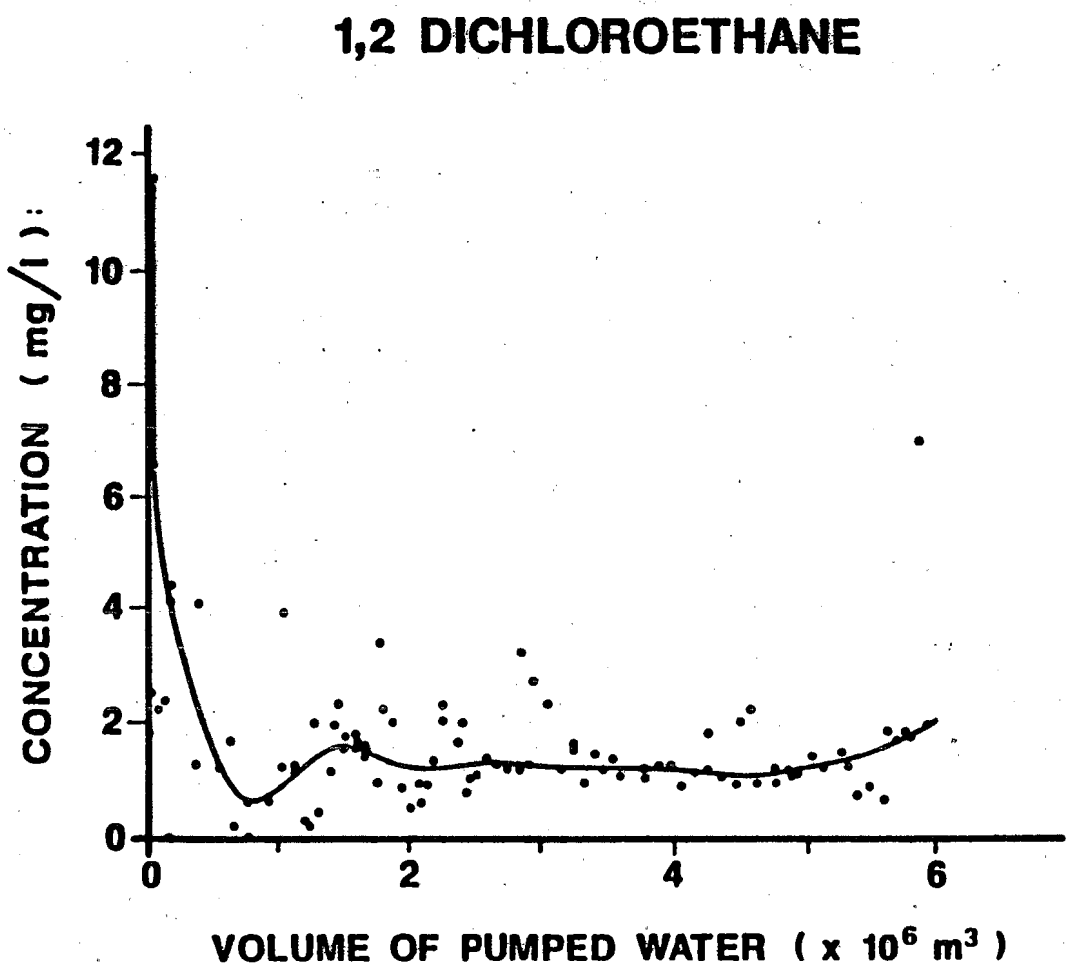


FIGURE : 4 CONCENTRATION OF 1,2 DICHLOROETHANE VERSUS VOLUME OF PUMPED WATER

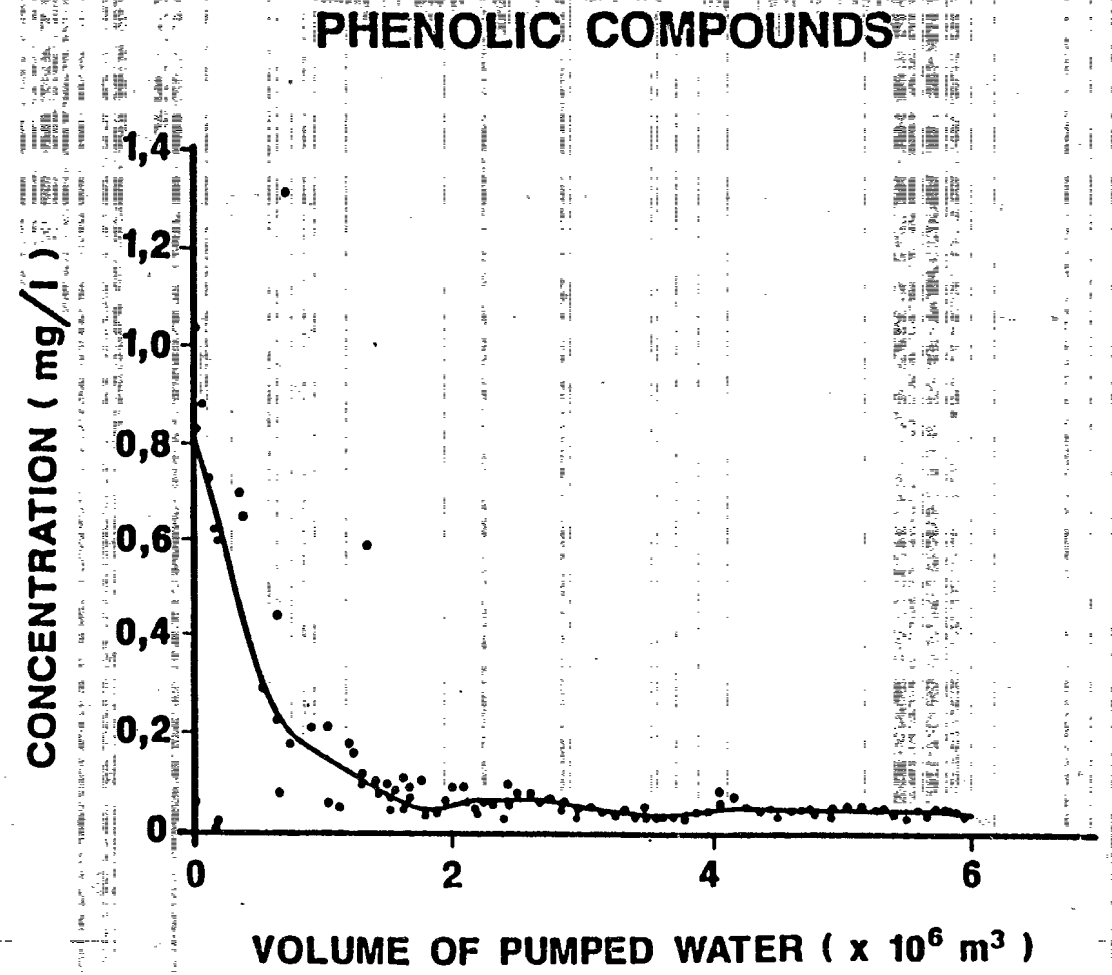


FIGURE : 5 CONCENTRATION OF PHENOLIC COMPOUNDS VERSUS VOLUME OF PUMPED WATER

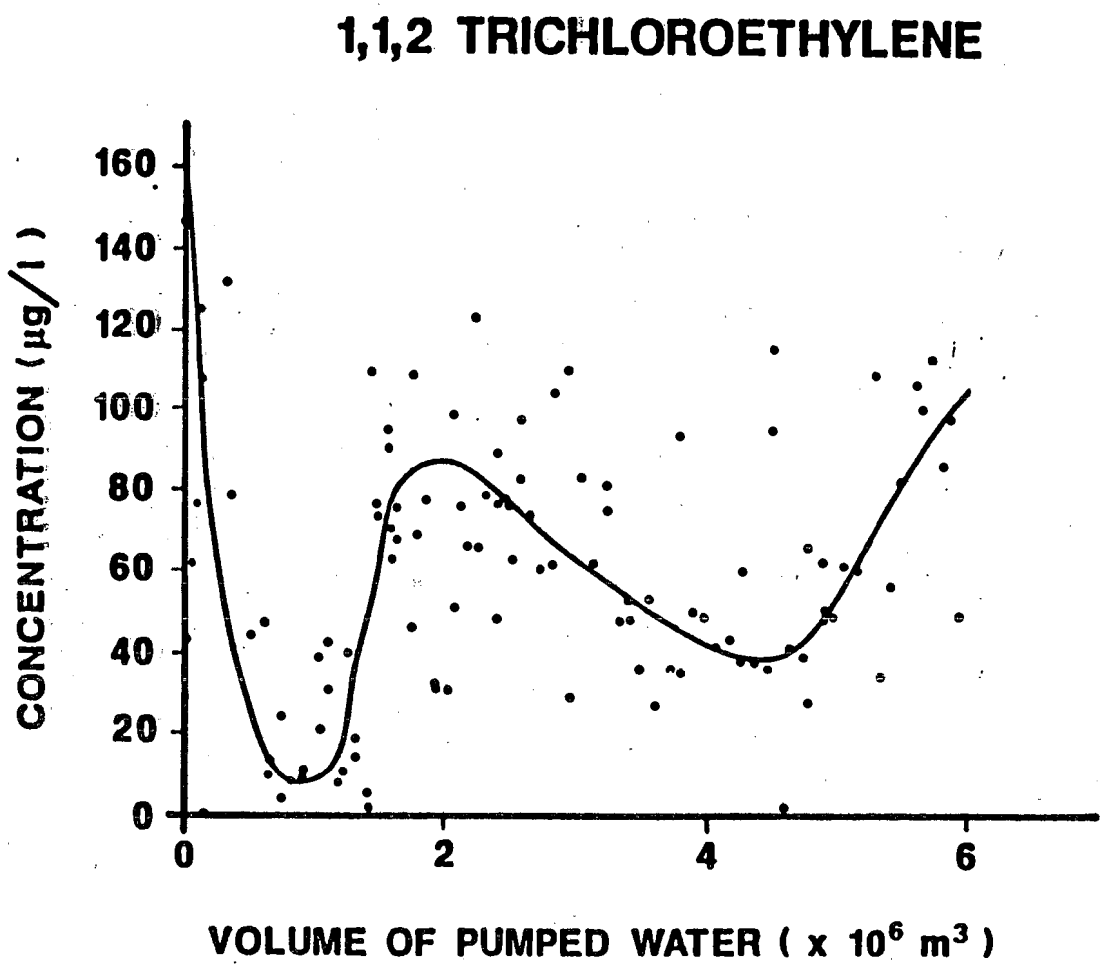


FIGURE : 6 CONCENTRATION OF 1,1,2 TRICHLOROETHYLENE VERSUS VOLUME OF PUMPED WATER

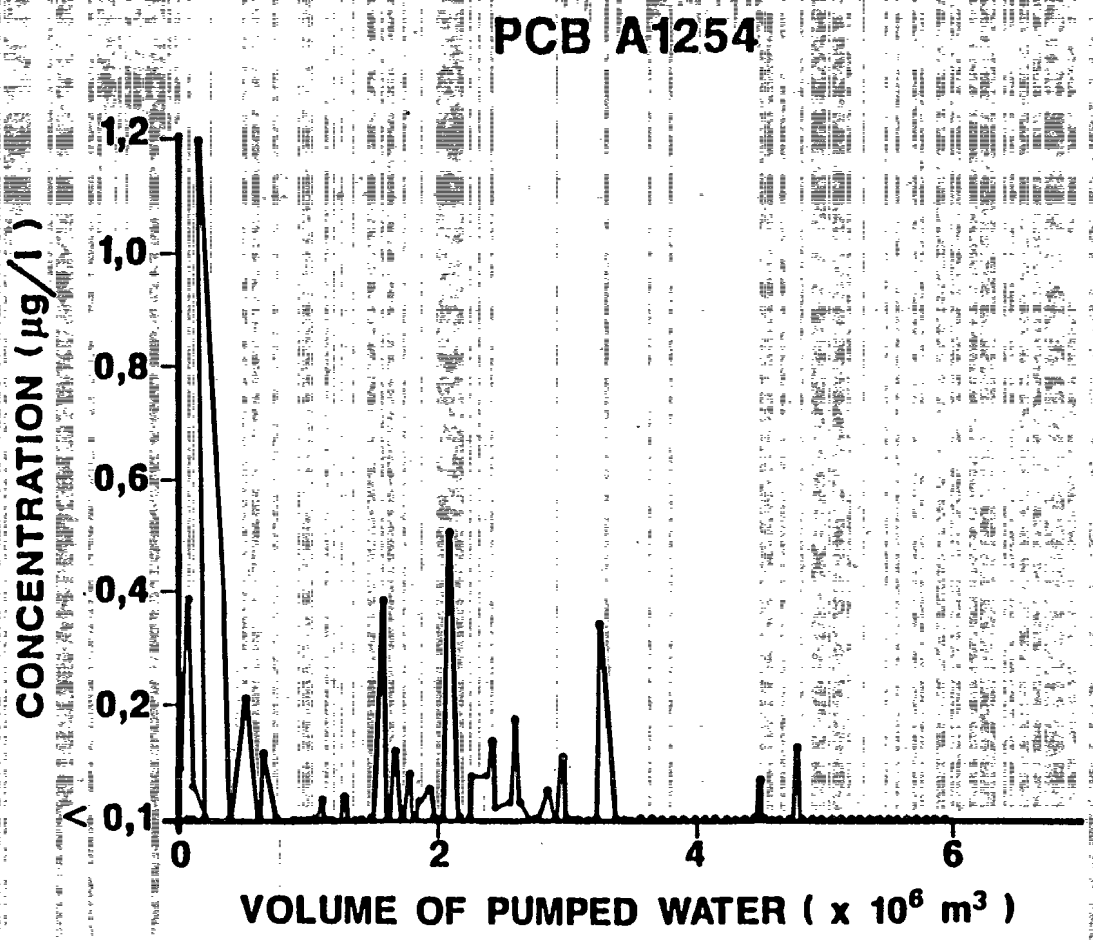


FIGURE : 7 CONCENTRATION OF A1254 VERSUS VOLUME OF PUMPED WATER

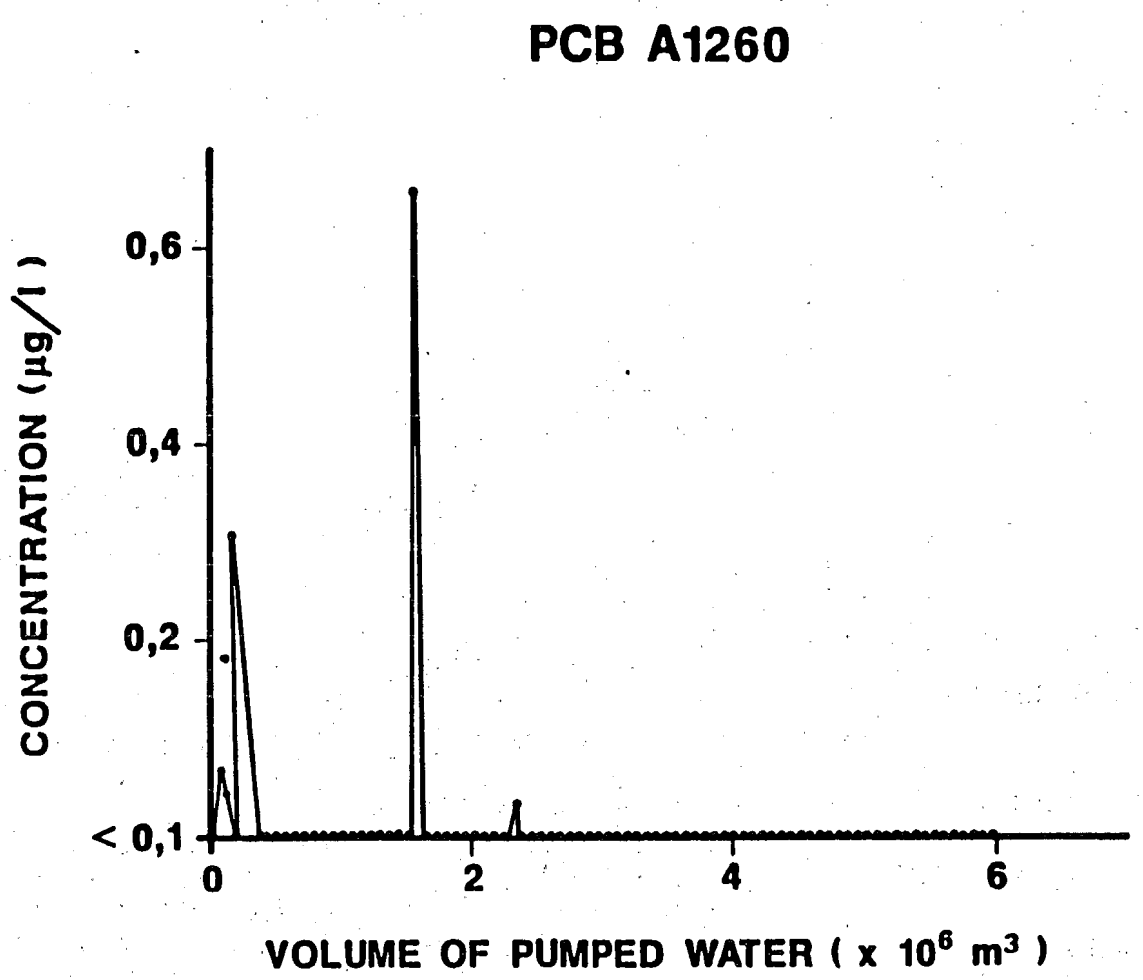


FIGURE : 8 CONCENTRATION OF A1260 VERSUS VOLUME OF PUMPED WATER

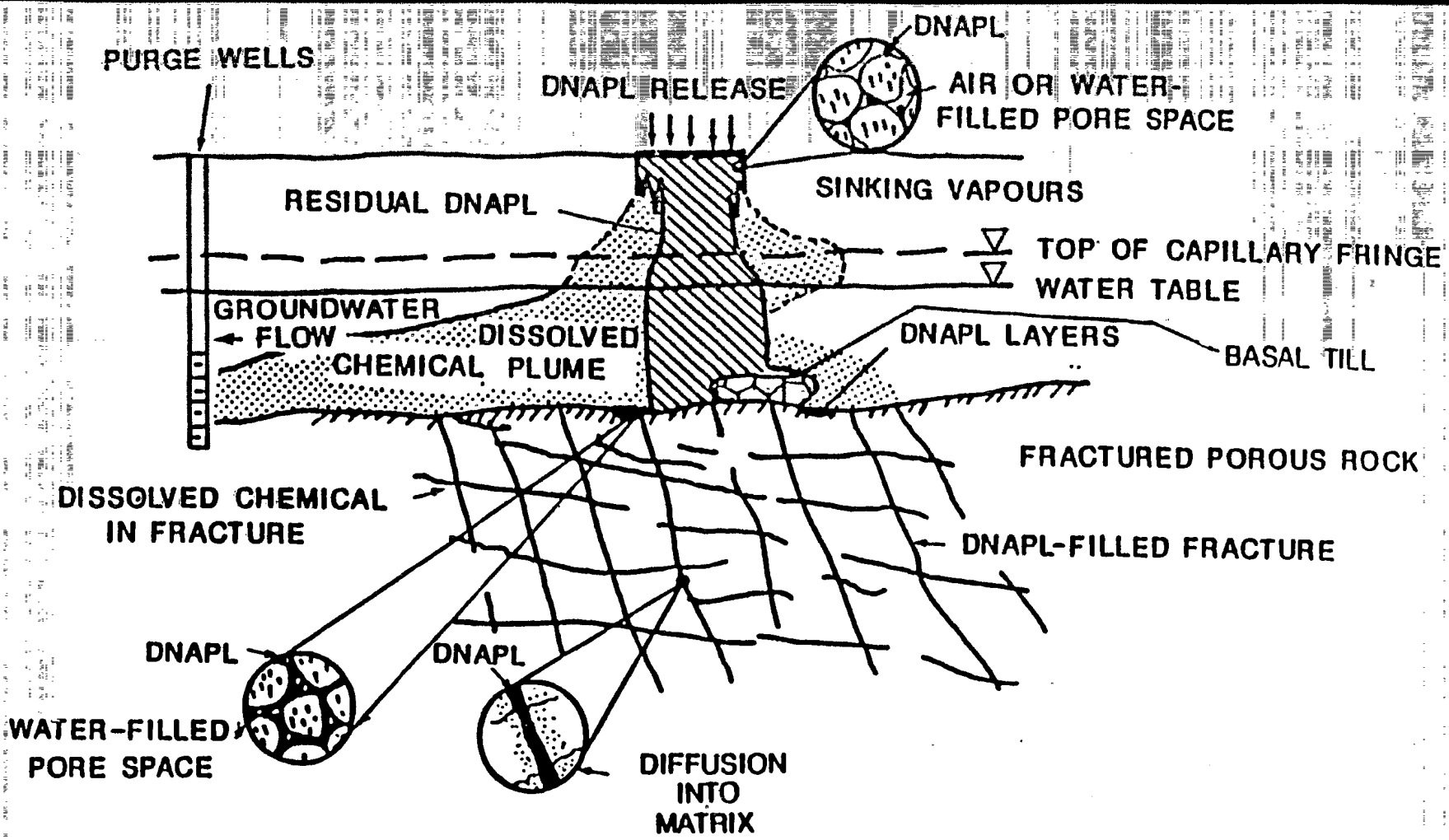
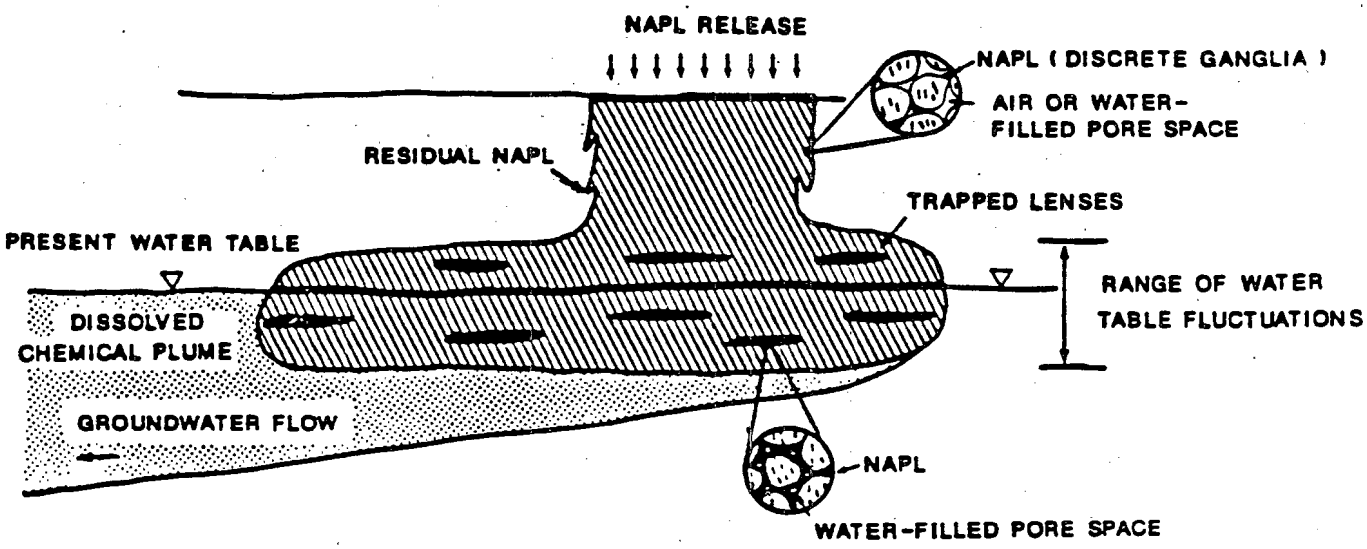


FIGURE : 9 GROUNDWATER CONTAMINATION FROM RESIDUAL DNAPL AND DNAPL POOLS

(MODIFIED FROM FEENSTRA AND CHERRY, 1988)



(MODIFIED FROM HUNT ET AL, 1988)

FIGURE : 10 GROUNDWATER CONTAMINATION FROM RESIDUAL NAPL AND NAPL POOLS IN THE WATER TABLE FLUCTUATION ZONE

TABLE 3

Concentration of organic compounds in piezometer of the sampling campaign of May 1988.

Organic compounds	Concentrations (ug/l)				
	P-98	P-162	P-62	P-27	P-51
HHs					
1,2 dichloretane	34,0	0,92			
1,1,2 trichloroethane	15,3				
Dichloromethane	4,2				
1,1,2 trichloroethylene	0,65				
1,1,2,2 tetrachloroethane	0,23				
Tetrachloroethylene	0,20				
1,1 dichloroethane	0,15				
Chloroform	0,08	0,11		0.13	
1,1 dichlorethylene				0,21	
MAHs					
Chlorobenzene	1,60				
Benzène	1,20	0,25		0,35	
Toluene	0,60	0,20		0,12	
Ethyl benzene	0,10	0,17			
PCs					
Phenol	1,0				
4-methylphenol	0,1				
PAHs					
Benzo (a) anthracene	0,6				
Benzo (g,h,i) perylene	0,3				
Phenanthrene	0,1				
Fluoranthene	0,1				
Pyrene	0,1				
Benzo (b+k) fluoranthene	0,1				
Benzo (a) pyrene					

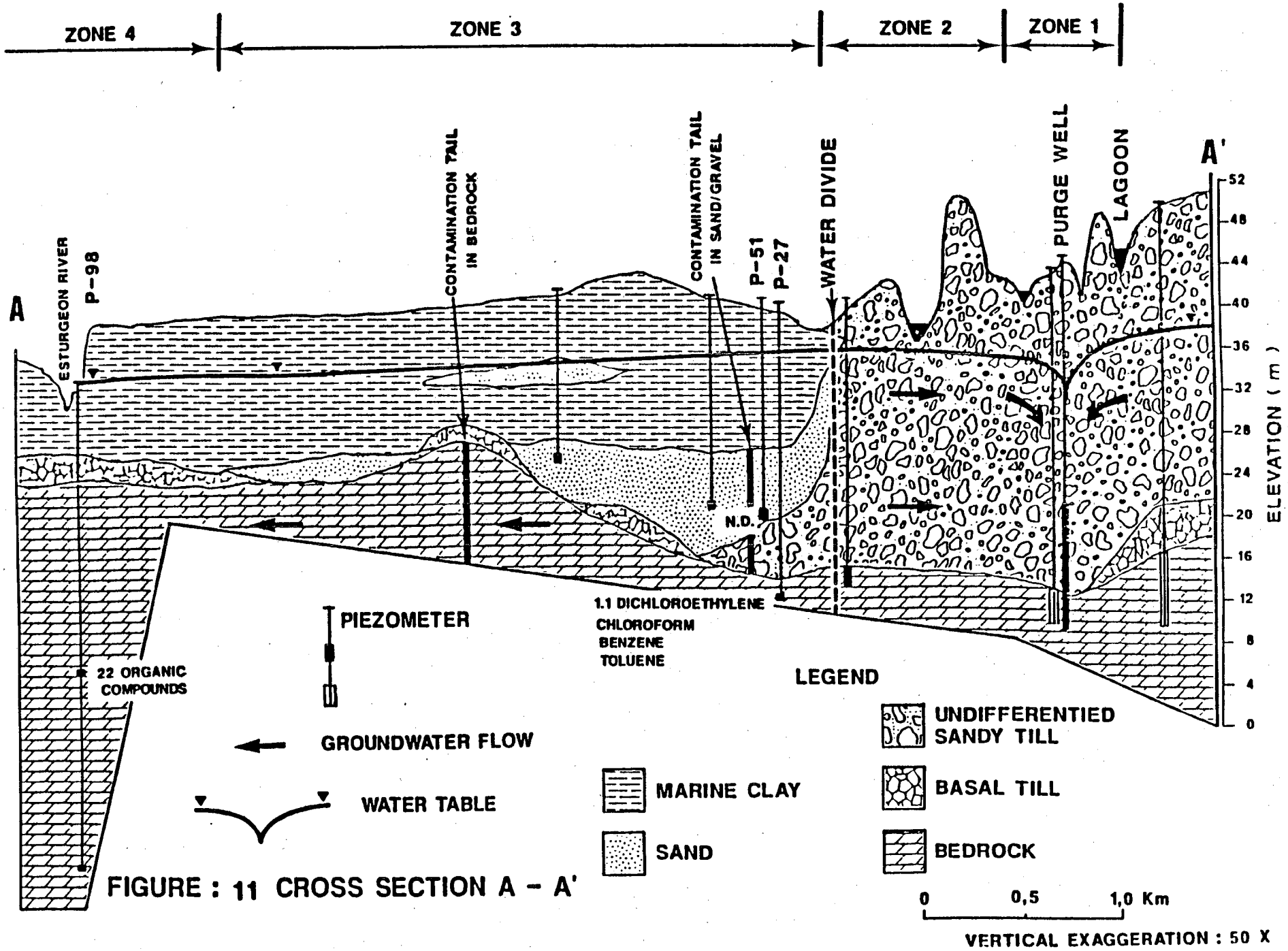


FIGURE : 11 CROSS SECTION A - A'

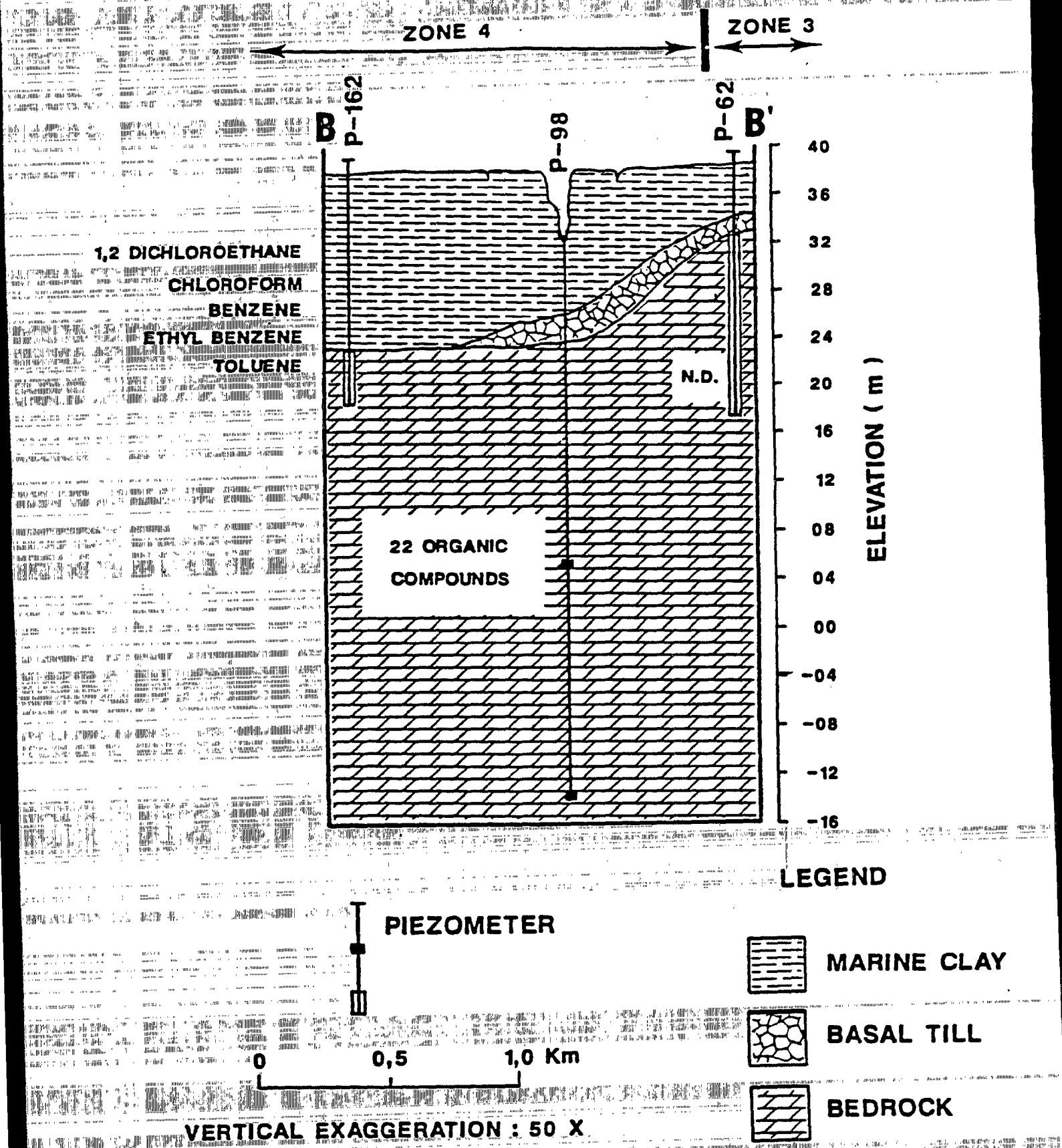


FIGURE :12 CROSS SECTION B – B'

*US GOVERNMENT PRINTING OFFICE:1990-748-159/20411

United States
Environmental Protection
Agency

Center for Environmental Research
Information
Cincinnati OH 45268

Official Business
Penalty for Private Use, $300

Please make all necessary changes on the above label, detach or copy, and return to the address in the upper left-hand corner

If you do not wish to receive these reports CHECK HERE ☐; detach, or copy this cover, and return to the address in the upper left-hand corner.

EPA/540/2-89/054b