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REMEDIAL INVESTIGATION/ ALTERNATIVES REPORT

BROOKLYN CENTER WOOD TREATING SITE

Prepared For

JOSLYN CORPORATION

January 1986

By

BARR ENGINEERING CO.

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REMEDIAL INVESTIGATION/
ALTERNATIVES REPORT
Brooklyn Center Wood Treating Site

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I hereby certify that this report was prepared by me or under my direct supervision and that I am a duly Registered Professional Engineer under the laws of the State of Minnesota.

Allan Gebhard

Allan Gebhard

Date: 1/2/86 Reg. No. 9421

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EXECUTIVE SUMMARY

REMEDIAL INVESTIGATION/ALTERNATIVES REPORT
JOSLYN BROOKLYN CENTER TREATING FACILITY SITE

EXECUTIVE SUMMARY

This report summarizes the results from a remedial investigation of the site of Joslyn Corporation's former wood treating facility in Brooklyn Center, Minnesota, and an evaluation of alternative remedial action plans that could be used to manage contaminated groundwater and soil identified at the site.

This report is intended to fulfill the requirements of Task C - Part VI and Task B - Part VII of Exhibit A, to the May 30, 1985 Response Order by Consent for the site between the Minnesota Pollution Control Agency and Joslyn Corporation. The remedial investigation was carried out in conformance with the January, 1985 Work Plan for the investigation prepared by Joslyn and approved by the Minnesota Pollution Control Agency.

REMEDIAL INVESTIGATION

The remedial investigation defines the impacts of past facility operations and waste management practices on public health and the environment. The investigation involved the placement of 23 monitoring wells and four deep borings at the site. Exploratory excavations and shallow borings were used to define the extent and characteristics of contaminated soil in the waste disposal areas and former operating area on the site. Several sets of water samples were collected from the monitoring wells, from an existing well at the site, from two off-site private wells, and from the Twin Lakes, which is located west of the site. The water samples and representative samples of the contaminated soil from the site were analyzed for specific phenolic compounds including pentachlorophenol, specific polyaromatic hydrocarbon (PAH) compounds which are primary constituents of creosote, and copper, chromium and arsenic. These were the primary contaminants in the wood preservatives used at the facility.

Criteria used by the Minnesota Pollution Control Agency to guide the clean up at other wood treating sites were used to estimate the volume of contaminated soil that exists at the Joslyn site. Contaminated soil was defined based on visual appearance and on the results of the analyses of representative soil samples. It is estimated that 40,000 cubic yards of contaminated soil is present on the site. Most of the contaminated soil is located in the vicinity of the former operating area of the facility and beneath a wastewater disposal pond that was used during the last 15 years of site operations.

Two groundwater aquifers have been identified below the site. The upper aquifer is a shallow sand located at the ground surface and the lower aquifer consists of the St. Peter Sandstone, dolomitic formations of the Prairie du Chien Group and a buried sand and gravel unit that fills a buried bedrock valley located below the western one-third of the site. The surface of the saturated zone in the upper aquifer is approximately 10 feet below the ground surface over most of the site. The saturated thickness of the upper aquifer is from 38 to 45 feet below the site. Groundwater moves from west to east through the upper aquifer, from Twin Lakes to the Mississippi River. The rate of lateral movement in the upper aquifer is estimated to be 400 to 700 feet per year.

The lower aquifer beneath the eastern two-thirds of the site consists of the St. Peter Sandstone and dolomitic formations in the Prairie du Chien Group, along with an overlying thin stratum of gravel. A vertical gradient of approximately 2-1/2 feet exists from the upper aquifer to the lower aquifer in the eastern two-thirds of the site. Below this portion of the site, the upper and lower aquifers are separated by a middle confining unit, which consists of several units of silt, sandy clay till, silty clay and silty sand. The middle confining unit varies from 20 to 60 feet thick beneath this portion of the site. The vertical movement of water through the middle confining unit is very slow (estimated at 0.4 to 0.004 feet per year) due to small pressure difference that exists across the unit and the low permeability of the unit.

The middle confining unit and the St. Peter Sandstone are not present below the western one-third of the site. It is probable that these units have been eroded away creating a north/south trending buried bedrock valley below the western one-third of the site. The buried bedrock valley cuts through the St. Peter and into the Prairie du Chien bedrock unit. The middle confining unit and the St. Peter have been replaced with a valley fill unit consisting of sand and gravel. The vertical rate of movement through this valley fill is likely greater than the rate of movement through the middle confining unit.

The results from the analyses of samples from the monitoring wells placed in the top of the upper sand aquifer show the presence of a plume of pentachlorophenol and PAH compounds. No metals in excess of EPA drinking water criteria were detected in the contaminant plume. The plume originates in the former operating area and in the vicinity of Pond A and extends in an easterly direction. The plume extends approximately 2,000 feet downgradient of the eastern boundary of the site, although contaminant concentrations are very low outside of the immediate vicinity of the former operating and waste disposal areas on the site.

The results from the analysis of samples collected from monitoring wells screened at the base of the upper aquifer show substantially lower concentrations of pentachlorophenol and PAH compounds at the base of the aquifer than are present in the top of the aquifer. The low concentrations at the base of the upper aquifer show that the plume is primarily confined to the upper portion of the groundwater system below the site.

The results from the analyses of samples from monitoring wells in the lower aquifer show that the lower aquifer does not contain detectable concentrations of pentachlorophenol or significant concentrations of creosote related compounds.

The monitoring of Twin Lakes indicates that the lake has not been impacted by the site. Although the lake water contains detectable PAH compounds, the presence of these compounds at varying concentrations at several background stations in the lake suggests that they originate from sources such as motorboat traffic rather than from the site.

Several private wells are located within the area of shallow groundwater contamination from the wood treating site. All but two of these wells are reportedly not used for potable purposes. The two wells that are used for water supply purposes are reportedly deep and are not likely influenced by the site.

FEASIBILITY ASSESSMENT

The purpose of the feasibility assessment is to evaluate the cost and effectiveness of several technically feasible remedial action plans that will mitigate existing and potential impacts from the contaminated soil and groundwater at the site. The first step in this portion of the investigation was to define technologies that are available to control and treat soil and groundwater contaminated with creosote and pentachlorophenol compounds. The technically feasible technologies were then combined into several alternative remedial action plans that were designed to achieve one of several possible levels of mitigation for the site. The four levels of mitigation that were used were:

I. SOURCE CONTROL: Remedial action plans at this level of protection are designed to minimize the further release of contaminants from the contaminated soil to the saturated zone.

II. SOURCE GROUNDWATER CONTROL: Remedial action plans at this level of protection are designed to minimize the further release of contaminants to the saturated zone <u>and</u> minimize the further migration of contaminated groundwater from the areas of heaviest soil and groundwater contamination on the site.

III. SITE GROUNDWATER CONTROL: Remedial action plans at this level of protection are designed to minimize the further migration of contaminated groundwater from the site.

A total of 9 remedial action plans were evaluated for the site. The estimated capital, annual and 30-year present worth costs for the various remedial action plans are summarized in the table at the end of this summary. The present worth costs are based on a 6 percent net interest rate and 30 years of operation.

Alternatives I.A. through I.D. are remedial action plans designed to contain or remove contaminated soil and thereby minimize the further release of contaminants to the saturated zone. Alternatives I.A. and I.B. are directed at managing only the contaminated soil above the surface of the saturated zone, while Alternatives I.C. and I.D. remove or contain all contaminated soil on the site. Alternative I.A., which involves grading the site to cover contaminated soil and provide surface drainage, will be less effective than Alternative I.B., which involves placing a low permeability cap over the contaminated soil at the site. The capital cost of the site grading alternative is estimated to be $0.3 million with a 30-year present worth cost of $2.2 million. The estimated capital cost of the capping alternative is $1.1 million, with an estimated 30-year present worth cost of $3.1 million. Most of the annual cost of these alternatives is the routine quarterly groundwater monitoring at the site. The estimated cost of routine site monitoring is $140,000 per year.

Alternative I.C., which involves the construction of an on-site vault for the contaminated soil and Alternative I.D., which involves the on-site incineration of the contaminated soil, are of equivalent effectiveness. Both of these alternatives are considered more effective than capping the contaminated soil. The capital cost of the on-site vault alternative is estimated to be $3.2 million and the 30-year present worth cost is estimated to be $5.1 million. The capital cost of the on-site incineration alternative is estimated to be $10.6 million and the 30-year present worth cost is estimated to be $12.1 million.

Alternatives II.A., II.B., and II.C. are remedial action plans designed to minimize the further release of contaminants to the saturated zone <u>and</u> minimize further migration of contaminated groundwater from the areas of greatest soil and groundwater contamination on the site. Alternative II.A. involves the construction of a slurry wall around the former operating area of the facility. The capital cost of this alternative is estimated to be $2.1 million and the 30-year present worth cost is estimated to be $4.1 million. Alternative II.B. involves placing a cap over the contaminated soil and constructing a groundwater pump-out system in the former operating area of the facility. The discharge from the pump-out system is assumed to be pretreated and discharged to the sanitary sewer system. The capital cost of this alternative is $1.9 million and the estimated 30-year present worth cost is estimated to be $7.6 million. A significant portion of the annual operating cost of this alternative is the cost of pretreatment and disposal of the contaminated groundwater to the sanitary sewer system. Alternative II.C. involves placement of all contaminated soil in an on-site vault and the construction of a groundwater pump-out system in the former process area of the facility. The capital cost of this alternative is estimated to be $3.9 million and the 30-year present worth cost is estimated to be $8.6 million. This alternative also includes the high annual operating cost associated with the discharge of pretreated groundwater to the sanitary sewer system. Alternative II.A. is considered to be slightly more effective than Alternatives II.B. and II.C. due to the anticipated lower rate of vertical seepage to the lower aquifer under Alternative II.A.

Alternatives III.A. and III.B. are remedial action plans designed to minimize the further migration of contaminated groundwater from the site. Alternative III.A. involves construction of groundwater pump-out systems in the area of highest groundwater contamination on the site and at the downgradient site boundary. The capital cost of this alternative is estimated to be $1.5 million and the 30-year present worth cost is estimated to be $7.7 million. Alternative III.B. involves containing contaminated groundwater on-site with a slurry wall that generally follows the boundary of the site. This slurry wall alternative also includes a groundwater pump-out system that must pump at a relatively high rate of discharge since the slurry wall cannot be keyed into the middle confining unit along its entire length. The estimated capital cost of this alternative is $4.5 million and the 30-year present worth cost is estimated to be $10.2 million. Alternatives III.A. and III.B. are considered to be equally effective at minimizing the further migration of contaminated groundwater off-site.

RECOMMENDATIONS

Data in this investigation show that contamination from the site is confined to the upper portion of the shallow aquifer and has not impacted water supply aquifers underlying the site. If not remediated, the potential exists for the contamination in the shallow groundwater to slowly migrate into the lower aquifer below the site.

It is recommended that the following measures be taken to mitigate the current impacts of the site on the shallow groundwater aquifer and reduce the potential for future impact on the lower aquifer:

1) The principle objective of the remedial action plan at the site should be to control the future lateral and vertical movement of the contaminated groundwater that exists in the former operating area of the facility.

2) Alternative II.A., which involves construction of a slurry wall around the former operating area of the site and the excavation of contaminated soil outside the slurry wall, is the most cost-effective remedial action plan to meet the remedial action objective. The next step in implementing a remedial action plan for the site should be to prepare a detailed design of the slurry wall containment system.

3) During the 1986 construction season, the water in Pond A should be drained and discharged to the sanitary sewer system. Contaminated soil in Pond A should be removed and either placed in the slurry wall containment area (if that portion of the remedy is under construction) or temporarily stockpiled on the site. The Pond A area should then be filled and graded.

4) Residents identified in the well search conducted for this investigation as still using groundwater for potable supply purposes should be required to connect to the city water system.

Consumption of water from private wells is inappropriate in a highly urbanized area where the groundwater is subject to contamination from a wide variety of potential contaminant sources. The Minnesota Plumbing Code, MN. Rules 1984 Section 4715.0310 requires connection to public water distribution systems for new premises and also for altered, renovated or replaced plumbing facilities. The principles of the Minnesota Plumbing Code strongly encourage connection to public water supply system.

5) Routine groundwater monitoring should be continued at the site. It is recommended that routine site monitoring consist of the following during the next 12-month period:

   a) quarterly sampling of Wells 10, 112, 121, 122, 123, 124, 125, 126, 301, 307 and the plant well 6+9, 212, 223

   b) annual sampling of the remaining wells on the site

   c) analysis of all samples for the PAH and phenolic compounds in Table 2 of this report. Analysis of one set of samples from all wells for the metals in Table 2.

It is also recommended that additional monitoring wells be constructed southwest of the site to verify that contamination from the site is not migrating to the southwest toward private wells in this area that are still being used for potable water supply purposes. These additional monitoring wells should be monitored quarterly for representative PAH and phenolic compounds.

EXCSUM/316,10

SUMMARY OF ALTERNATIVE REMEDIAL ACTION COSTS
CAPITAL, ANNUAL, AND PRESENT WORTH

Alternative	ESTIMATED COST ($ Millions) Capital	Annual	Present Worth
I. SOURCE CONTROL - Restricts Further Leaching From Contaminated Soil			
I.A. Site Grading	$ 0.3	0.14	2.2
I.B. Cap Contaminated Soil	1.1	0.14	3.1
I.C. On-Site Vault	3.2	0.16	5.1
I.D. On-Site Incineration	10.6	0.13	12.1
II. SOURCE AREA CONTROL - Controls Soil and Groundwater in Vicinity of Contaminated Soil Areas			
II.A. Slurry Wall Containment	2.1	0.17	4.1
II.B. Cap and Source Groundwater Pump-out System	1.9	0.44	7.6
II.C. On-site Vault and Source Groundwater Pump-out System	3.9	0.37	8.6
III. SITE GROUNDWATER CONTROL - Minimizes Off-Site Migration of Contaminated Groundwater			
III.A. Groundwater Plume Control	1.5	0.54	7.7
III.B. Groundwater Plume Contain-	4.5	0.44	10.2

SUMM31610

Section 1

INTRODUCTION

REMEDIAL INVESTIGATION/ALTERNATIVES REPORT
JOSLYN BROOKLYN CENTER WOOD TREATING SITE

SECTION 1
INTRODUCTION

This report summarizes the results from a remedial investigation and an assessment of potentially feasible remedial action alternatives for the Joslyn Corporation wood treating site located in Brooklyn Center, Minnesota. The report is intended to satisfy the requirements of Task C, Part VI and Task B, Part VII of Exhibit A to the May 30, 1985 Response Order by Consent for the site between the MPCA and Joslyn.

The remedial investigation was conducted according to the January, 1985 work plan titled "Remedial Investigation Scope of Work, Joslyn Wood Preserving Site". The work plan was prepared by Barr Engineering Co. for Joslyn and was approved on February 26, 1985 by the MPCA with several minor modifications.

The Remedial Investigation portion of this report (Section 2): 1) summarizes the data collected during the remedial investigation, 2) describes the geologic and hydrogeologic settings of the site, 3) estimates the volume and characteristics of waste and contaminated soil at the site, 4) assesses the extent and magnitude of groundwater contamination, 5) assesses the magnitude and extent of contamination in Twin Lakes due to the site, 6) defines the locations and condition of existing private wells in the vicinity of the site, 7) provides information on the actual or potential public health or environmental impacts from the site and 8) provides information necessary to evaluate remedial actions appropriate for the site. Section 2 of the report is intended to provide the information required by Task C, Section VI of Exhibit A to the May 30, 1985 Response Order.

Section 3 of the report: 1) identifies several technologies that could be used to remedy present and potential future impacts from the site and

2) assesses the technologies to determine their feasibility for application at the site. Section 4 of the report evaluates the most promising remedial action plans for the site in terms of cost, effectiveness, and implementation schedule. Sections 3 and 4 are intended to provide the information required by Task B, Section VII of Exhibit A to the May 30, 1985 Response Order.

The final section of the report (Section 5) provides recommendations regarding the most cost-effective remedial action plan for the site. This section also provides recommendations for a program of routine monitoring at the site for the twelve month period beginning with the fourth quarter of 1985.

Section 2

REMEDIAL INVESTIGATION

SECTION 2

REMEDIAL INVESTIGATION

OVERVIEW OF FACILITY OPERATIONS

The Joslyn Corporation wood treating facility was once operated on a 29-acre site in Section 10, T118N, R21W in the City of Brooklyn Center, Hennepin County, Minnesota. The location of the site on which the wood treating facility was formerly operated is shown in Figure 1.

Wood treating operations began at the site in the 1920's. Very little information is available on early operations at the facility. The facility was originally owned and operated by Naugle Pole and Tie Company. The property was purchased in the 1940's by Consolidated Pole Treating Company, of which Joslyn was a part owner. Joslyn obtained sole ownership of the property in the early 1960's and operated the facility until operations ceased in 1980.

Operations at the facility consisted of the treating of poles, posts, railroad ties, timbers and other wood products with preservatives. Creosote, pentachlorophenol and water soluble metal salts were used at one time or another at the site as wood preservatives. A thermal treating process that primarily used creosote as the treating solution was used until 1965. The thermal process consisted of dipping poles, ties and other products in tanks of heated wood preservative. Pentachlorophenol was also used as a wood preservative in the thermal process during the early 1960's.

Several areas on the site were apparently used to dispose of boiler blowdown water and sludge generated by the cleaning of the storage, reclaim and thermal treating tanks. Two waste disposal ponds, referred to in site investigations as Ponds B and C, were apparently used to dispose of boiler blow down water prior to about 1965. The locations of these two disposal areas are shown in Figure 2.

In 1965, the thermal treating process at the facility was converted to a pressure treating process. The pressure treating process primarily used pentachlorophenol and soluble metal salts (copper, chromium, and arsenic) as the treating solutions. Creosote was also used for a brief period in the early years of the pressure treating process. The locations of the storage tanks, working tanks, thermal treating tanks, pressure cylinders and other facilities on the site as identified from a 1975 aerial photograph are shown in Figure 2.

From 1965 until the facility was closed in September 1980, wastewater from the pressure treating cylinders drained to a reclaim system located in the building immediately west of the cylinders. From the reclaim system, the wastewater was pumped through a series of baffles and skimmers to a disposal pond (called Pond A in site investigations), located as shown in Figure 2. Pond A was constructed to accommodate the larger volumes of wastewater generated by the pressure treating cylinders. Oil and wood preservatives recovered by the reclaim system were reused in the pressure treating cylinders. A 1976 report prepared for Joslyn by SERCO Laboratories estimated that the inflow to Pond A averaged 219,000 gallons per year at the time of their investigation.

Results from interviews with former facility employees indicated that sludge from the cleaning of process tanks, storage tanks, thermal treating tanks, and treating cylinders was disposed of at several locations on the site. Spills of wood treating solutions reportedly occurred at the site in the late 1950's or early 1960's and again in 1968.

From 1976 until the facility closed in 1980, sludge generated by tank and cylinder cleaning was shipped to out-of-state hazardous waste disposal facilities. Following the end of facility operations, the treating tanks were removed and MPCA approval was obtained to fill the excavations.

In December 1981, approximately 30,000 gallons of wood treating solution were removed from the facility and shipped out of state. Approximately 6,500 gallons of sludge was shipped to a hazardous waste disposal facility in Texas in May, 1982.

The site has been leased to another company that uses the site for the temporary storage and distribution of lumber products.

Sand fill was apparently placed over much of the site during construction and/or operation of the wood treating facility. The western limits of the fill are shown in Figure 2. A 2-foot contour interval topographic map developed from an April, 1980 aerial photograph of the site is shown in Figure 3.

CHARACTERISTICS OF WOOD PRESERVATIVES

The following paragraphs provide general information about the nature of the wood preservatives used at the Joslyn wood treating facility.

PENTACHLOROPHENOL

Pentachlorophenol is a synthetic organic compound with a melting point of approximately 190 C. Pentachlorophenol is thus a solid at normal temperatures unless dissolved in a solvent. It has a relatively low vapor pressure at ambient temperatures and significant quantities of pentachlorophenol will not volatilize under normal conditions. Pentachlorophenol is a weak acid and its water solubility is strongly pH dependent. Under normal pH conditions (pH 6 to 8) the solubility of pentachlorophenol in water is in the range of 10 to 1,000 milligrams per liter (mg/L). Because it is an acid, the solubility of pentachlorophenol increases with increasing pH. The recently published EPA proposed recommended maximum contaminant level (RMCL) for drinking water for pentachlorophenol of 0.22 mg/L is based on its chronic toxicity. This proposed RMCL is lower than the drinking water criteria formerly used by EPA, which was 1.01 mg/L. The EPA also indicates (November 28, 1980 Federal Register) that acute and chronic toxicity to freshwater aquatic life occurs at concentrations as low as 0.055 and 0.003 mg/L, respectively. The MPCA has used a pentachlorophenol chronic toxicity level of 0.008 mg/L in the past.

Pentachlorophenol must be dissolved in a liquid carrier solvent to be used in wood preserving. The liquid carrier solvent is usually a petroleum based solvent, such as No. 2 fuel oil. Fuel oil is less dense than water and pentachlorophenol has a density greater than water. The density of a pentachlorophenol/fuel oil mixture will depend on the concentration of the pentachlorophenol in the oil. In most instances, a pentachlorophenol/fuel oil mixture will be lighter than water.

Recently available information from the EPA and from pentachlorophenol manufacturers indicates that commercially manufactured pentachlorophenol used for wood preserving contains hexa, hepta and octachloro-dibenzo-p-dioxins. The concentrations of these dioxin compounds in the pentachlorophenol treating solution depend on the manufacturer of the pentachlorophenol and the time that the pentachlorophenol was manufactured. Although these dioxin compounds are much less toxic than tetrachlorodibenzo-p-dioxin, their presence must be considered when developing a remedial action plan for the site.

CREOSOTE

Creosote is a product of coal tar distillation and is a complex mixture of organic compounds. Most of the 200 or more compounds in creosote are polynuclear aromatic hydrocarbon (PAH) compounds. Polynuclear aromatic hydrocarbons are a class of organic compounds made up of a series of two or more fused carbon rings. Only a limited number of PAH compounds (less than 20) are typically present in creosote at concentrations greater than 1 percent.

The major components of creosote are shown in Table 1. The composition of creosote varies from manufacturer to manufacturer and from time to time from the same manufacturer due to variations in the composition of the coal tar used in the manufacturing process. Also present in lesser quantities in creosote are nitrogen, sulfur and oxygen heterocyclic compounds. This class of organic compounds is similar to the class of PAH compounds, except that there is a non-carbon atom (nitrogen, sulfur or oxygen) within one of more of the ring structures. Creosote is heavier than water and spilled creosote reaching the groundwater in high concentrations will sink.

The water solubility of the PAH compounds in creosote ranges from the low microgram per liter (ug/L) level for the five and six member ring compounds to the low milligram per liter (mg/L) level for the two member ring compounds.

With a boiling point of 218°C, the PAH compound naphthalene can be considered to be slightly volatile. Other PAH compounds are less volatile than naphthalene because of their higher boiling points.

The EPA drinking water level for PAH compounds is based on the potentially carcinogenic nature of certain PAH compounds. The MPCA has informally developed drinking water levels for potentially carcinogenic and non-carcinogenic PAH and heterocyclic compounds. The potentially carcinogenic and non-carcinogenic PAH and heterocyclic compounds used by the MPCA to implement the informal drinking water levels are shown in List 1 and List 2 in Table 2. The informal MPCA drinking water level for the potentially carcinogenic PAH and heterocyclic compounds is that the sum of the concentrations of the PAH and heterocyclic compounds in List 1 of Table 2 must not exceed .028 ug/L. The informal MPCA drinking water level for non-carcinogenic PAH and heterocyclic compounds is that the sum of the concentrations of the PAH and heterocyclic compounds in List 2 of Table 2 must not exceed 0.30 ug/L.

The MPCA has also applied informally developed water quality (aquatic life) levels to regulate the discharge of PAH compounds to surface waters. The water quality level that has been applied most consistently in the past by the MPCA is that the sum of the concentrations of the List 1 compounds in Table 2 must not exceed 0.311 ug/L. The water quality levels that have been applied in the past for other compounds depend on such characteristics of the receiving water as the 10-year frequency low flow, the amount of mixing that is anticipated, and the use of the receiving water.

METAL SALTS

A mixture of copper chromate and copper arsenate salts was also used as a wood preservative at the facility. These salts are water soluble and were mixed with water to make the wood treating solution. The chemical characteristics of the copper cation and the arsenate and chromate anions are described in the following paragraphs.

Copper

Copper is a metal with an average atomic weight of 63.5. The EPA secondary maximum contaminant level (drinking water criterion) for copper is 1.0 mg/L (40CFR 143 - July 19, 1979 Federal Register) and the recently published EPA proposed RMCL for copper is 1.3 mg/L. As is true with most heavy metal cations, the most important attenuation mechanisms for copper are adsorption, ion exchange and chemical precipitation. Copper has two potential valence states, +1 and +2. The +2 valence state is the most common in the environment and is the valence state of copper in the wood preservative once used at the facility. Copper will be removed from groundwater by adsorption as the groundwater contacts clay particles in the soil. Attenuation studies indicate that copper removal will vary with clay type and that pH is the most important factor controlling removal with a given adsorbant. Adsorbtion at a pH below 5 is negligible but increases to a maximum at pH 6 or 7 and decreases at a pH of 8 and above. It is generally believed that the amount of copper that will be removed from solution is related to, but less than, the cation exchange capacity of the clay minerals in the soil.

Chromium

Chromium is a transition metal with an average atomic weight of 52. Common aqueous forms include the +3 and +6 oxidation states. In the chromate anion (CrO_4^{-2}), chromium is in the +6 oxidation state. This is the anion in the wood preservative once used at the site. The EPA primary drinking water standard for chromium is 0.05 mg/L. The recently published EPA-proposed RMCL for chromium is 0.12 mg/L.

Adsorption, chemical precipitation and reduction-oxidation changes are the key mechanisms for chromium removal in soil systems, with the importance of each mechanism dependent on the form of the chromium. The oxidized chromium ion is hexavalent ($Cr,^{+6}$) and is anionic ($CrO_4,^{-2}$ or $CR_2O_7,^{-2}$) in form. The reduced chromium ion ($Cr,^{+3}$) is cationic in form. Very little has been published about the chemistry of chromium in soils, although the dominant species appears to be $Cr,^{+3}$. Chromium removal by a combination of adsorption and precipitation will effectively attenuate the migration of $Cr,^{+3}$ in soil systems. At pH exceeding 6, migration will be controlled by precipitation as an oxide, carbonate or sulfide. Soil material that will contribute to attenuation of chromium includes organic matter, clay minerals, and hydrous metal oxides. More rapid transport can be expected in coarse-textured soils than in fine-textured soils because of the larger pores, faster movement of water and smaller amounts of clay minerals.

Arsenic

Arsenic has an average atomic weight of 75. The EPA primary drinking water standard for arsenic is 0.05 mg/L and the EPA-proposed RMCL is also 0.05 mg/L. Arsenic most commonly exists in either the +3 or +5 oxidation states in the environment. The most important mechanism for the attenuation of arsenic in soils is adsorption on soil colloids, including clay and hydrous metal oxides. At the low concentrations normally found in leachates from waste disposal sites and other aqueous waste streams, chemical precipitation of arsenic is unlikely, except perhaps as an impurity in a phosphorus precipitate. In aqueous systems, arsenic is available in the anionic forms of arsenate ($AsO_4,^{-3}$), with oxidized arsenic ($As,^{+5}$) or as arsenite. Where reducing conditions prevail as a result of poor drainage and/or microbial activity, arsenate will be reduced to arsenite. A return to oxidizing conditions can result in reconversion of arsenite to arsenate through biological oxidation. It is likely that the principal removal mechanism for arsenic is anion exchange, both for $As,^{+5}$

as $H_2AsO_4^{-1}$, and for various arsenite species. Fine-grained soils will probably be most effective in reducing arsenate and arsenite concentrations, due to their larger clay mineral content.

OVERVIEW OF GEOLOGIC SETTING

BEDROCK GEOLOGY

Bedrock geology in the general vicinity of the site has been mapped by Schwartz (1936), Payne (1965), and Bloomgren (1985). A general west to east geologic cross section extending from Twin Lakes on the west to the Mississippi River on the east is shown in Figure 4. This cross section illustrates the relative position of the various bedrock and surficial geologic units discussed in this report. The location of the cross section is shown in Figure 5.

The uppermost bedrock unit beneath the Joslyn site is the St. Peter Formation, a fine to medium grained sandstone with basal shale beds. The St. Peter can be up to 160 feet thick in the area. Beneath the St. Peter is the Prairie du Chien Group, which is made up of the Shakopee Formation, a sandy dolomite underlain by a basal sandstone, and the Oneota Formation, a finely crystalline dolomite. The Prairie du Chien Group ranges from about 125 to 140 feet in thickness in the Twin Cities metropolitan area. The Jordan Sandstone Formation, an 80 to 100-foot thick medium grained sandstone, underlies the Prairie du Chien Group. Together, the Prairie du Chien and the Jordan Sandstone form an important aquifer in the metropolitan area. The St. Lawrence Formation is present below the Jordan Sandstone. The St. Lawrence Formation is a dolomitic siltstone and sandstone and is considered to be an aquitard which separates groundwater flow in the Jordan and overlying aquifers from groundwater flow in the underlying units.

Erosion of the bedrock surface has reduced the thickness of the St. Peter Sandstone in the vicinity of the Joslyn site. Up to 80 feet of relief on the bedrock surface is indicated by well logs in the area, primarily in the form of narrow, steep-sided buried bedrock valleys

(Bloomgren, 1985). There seem to be three buried bedrock valleys in the vicinity of the Joslyn site. The largest valley trends north-northwest/south-southeast beneath the western portion of the site and underlies Twin and Crystal Lakes. Smaller buried bedrock valleys, one west of Twin Lakes trending southeast/northwest, and the other east of Brooklyn Boulevard, trending north/south, probably join the larger valley. The inferred locations of these bedrock valleys are described in detail in the October, 1981 report entitled "Groundwater Investigation - Brooklyn Center Facility" prepared for Joslyn by Barr Engineering Co. (Barr Engineering Co., 1981a).

The potentiometric surface in the St. Peter Sandstone slopes to the east in the area indicating that groundwater movement in this aquifer is toward the Mississippi River. The direction of groundwater movement is similar in the Prairie Du Chien Group, with the potentiometric surface approximately at Elevation 850 MSL directly west of Twin Lakes and decreasing to Elevation 800 MSL at the Mississippi River (Norvitch, et al., 1972). The Mississippi River acts as the regional discharge point for groundwater in both the St. Peter and Prairie Du Chien bedrock units.

GLACIAL GEOLOGY

Up to 150 feet of glacial overburden overlies bedrock in the vicinity of the site (Norvitch, et al., 1972). The overburden is up to 200 feet thick in some of the buried bedrock valleys. The glacial overburden was deposited during and shortly after the late Wisconsin stage advances of the Superior Lobe and Grantsburg Sublobe of the Laurentide Ice Sheet. The glacial geologic setting of the area between the site and the Mississippi River is also described in the October, 1981 report.

McBride (1974) developed a groundwater flow model for the area between Twin Lakes and the Mississippi River. McBride identified the following three glacial units above bedrock in the area: 1) Mississippi River valley train outwash, 2) Grantsburg Sublobe till, and 3) proglacial lacustrine deposits. McBride described the outwash, which is the uppermost of these units, as a well sorted, medium to coarse grained sand averaging about 40 feet in thickness. The sand forms the upper aquifer in the area, including the Joslyn site. A pumping test conducted by McBride (1974) indicated that the permeability coefficient of the sand was 2x10-^{1} cm/sec, but this was thought to be greater than the permeability coefficient of the sand unit on a regional basis. The water table in the upper sand aquifer slopes eastward towards the Mississippi River, with an average gradient of about 50 feet in 2.5 miles (3.8 x 10^{-3} feet/foot). The Mississippi River acts .0038 ft as the regional discharge point for groundwater flow in the upper sand aquifer.

The upper sand aquifer was thought to rest predominantly on clay till (Grantsburg Sublobe till) which is locally sandy or interbedded with sand and gravel. McBride estimated a hydraulic conductivity of 3x10-^{7} cm/sec for this till. Laminated lacustrine silt lies beneath the till in lows in the bedrock surface, and acts as a further confining layer in local areas. The till and lacustrine silt were absent in some of the well logs McBride used to define the area geology, and in those areas the upper sand aquifer was concluded to be in direct contact with subcropping St. Peter Sandstone.

Barr Engineering (1980) conducted a groundwater and soil contamination investigation at the site of a chemical fire at the Howe, Inc. facility located approximately 1/2 mile east of the Joslyn site. Borings placed as part of that investigation indicated that the upper sand aquifer is underlain in part by clay which is possibly till, and also contains inclusions of organic soil and lacustrine clay.

DATA COLLECTION ACTIVITIES

Data collection activities for the remedial investigation at the Joslyn site consisted of a waste and contaminated soil investigation, a groundwater investigation, and a surface water investigation. Two Barr Engineering Co. reports previously prepared for Joslyn -- the October, 1981 Groundwater Investigation referenced earlier, and a December, 1981 study entitled "Hazardous Waste Investigation - Disposal Sites A, B, and C - Brooklyn Center Facility" (Barr Engineering Co., 1981b) -- also provided data for the remedial investigation.

The investigation of waste and contaminated soil consisted of:

- Interpretation of aerial photographs
- Review of past site maps
- Exploration excavations
- Shallow soil borings
- Analysis of representative waste and contaminated soil samples

The groundwater investigation consisted of:

- Review of existing groundwater and geologic information
- Placement of deep borings and bedrock corings
- Installation of shallow and deeper monitoring wells
- Collection and analysis of samples from the monitoring wells
- Video, gamma, and magnetic logging of the water supply well used during operations at the site
- Testing and sampling of the plant well
- Sampling of two private bedrock wells
- Permeability testing of representative soil samples
- Water level measurements
- Off-site well search

The surface water investigation consisted of the collection and analysis of water samples from Twin Lakes.

WASTE AND CONTAMINATED SOIL INVESTIGATION

Aerial photographs of the vicinity of the treating facility site were reviewed to establish a historical record of the locations of operating ares, possible waste disposal areas, and areas of visibly discolored surface soil. Aerial photographs of the facility taken in 1951, 1962, 1965, 1967, and 1980 were located and reviewed. Site maps of the treating facility that were available from Joslyn were used to help identify the locations of process and disposal areas at the site. Discussions with former site operating personnel were also used to help verify the locations of these areas.

Exploratory Excavations

Exploratory excavations have been placed at the treating facility site at two different times to help define the locations, extent and characteristics of waste and contaminated soil at the site. All of the exploratory excavations were placed with a tractor-mounted backhoe.

In September, 1982, a total of 18 test excavations were placed in Areas 1, 3, 4, 5, 6, 7, 8, and 9 shown in Figure 6. The area designations are the same as those used by the MPCA staff in an October 2, 1981 letter to Joslyn. Placement of these excavations was observed by the MPCA staff and their observations are summarized in an October 15, 1982 MPCA memorandum.

The results from the September, 1982 exploratory excavations were used along with the aerial photographs and other available site information to locate an additional 40 exploratory excavations in the vicinity of known or suspected waste disposal areas, spill areas, process areas, and areas of discolored soil. These excavations were placed in December, 1984 and were also observed by the MPCA staff. The locations of the December, 1984 exploratory excavations are shown in Figure 6 and logs of the excavations are in Appendix A-1.

The December, 1984 exploratory excavations ranged up to 10 feet deep and were at least 3 feet wide. Observations were made of the color, texture, odor and oil content of the encountered soils. Samples were collected from the walls of the excavations and representative samples were analyzed for the PAH and phenolic compounds in Table 2. Descriptions of the samples submitted for chemical analysis and the results from the analysis of the samples are in Table 3. The sampling locations within the various exploratory excavations are shown on the exploratory excavation logs in Appendix A-1.

Several PAH and heterocyclic compounds were present in the visibly contaminated soil samples. Pentachlorophenol was the only phenolic compound that was detected. As shown in Table 3, a generally good correlation was obtained between the PAH and pentachlorophenol concentrations in the soil and the visual estimate of the oil content in the soil. The visible appearance of the oil content of the soil is thus a useful indicator of the magnitude of soil contamination at the site.

Shallow Soil Borings

In May, June and July of 1981, 10 core samples were collected from the bottom sediment in Pond A. The sampling locations are shown in Figure 6. The core samples were obtained by driving a 3-foot long, 3-inch diameter thin wall sampler a distance of 3 feet into the bottom sediment. The cores were used to estimate the volume of sludge and contaminated soil in Pond A. Samples from the cores were used for aquatic and oral toxicity testing to help determine if any of the bottom sediment was a hazardous waste under the MPCA hazardous waste rules applicable at the time of that investigation. Samples of the cores were also analyzed for arsenic and chromium and were subjected to leaching tests, with the leachate analyzed for arsenic and chromium. Three samples from the cores were also analyzed for pentachlorophenol and the broad group of phenolic compounds measured by the 4-aminoantipyrene (4-AAP) method. The results from the 1981 Pond A sediment testing program are described in Barr Engineering Co. (1981b). The testing identified approximately 800 cubic yards of bottom sediment in Pond A that would have been classified as a hazardous waste under the MPCA hazardous waste rules applicable at the time of the investigation.

In July, 1981, four borings were placed in former Ponds B and C. The locations of these borings are also shown in Figure 6. The borings were placed to a depth of 20 feet and soil samples were collected at about 2-foot intervals. One boring (Boring B-1) was placed in Pond B and three borings (Borings C-1, C-2 and C-3) were placed in Pond C. Samples from the 6-to 8-foot and 8-to 10-foot depths in Pond B and the surface samples and samples from the 4-to 6-foot and 6-to 8-foot depths in Pond C were analyzed for oral and aquatic toxicity and for chromium and arsenic. The results from the analyses of these samples are also discussed in Barr Engineering Co. (1981b). The results of this investigation showed virtually no detectable arsenic and only very low (less than 40 parts per million) concentrations of chromium in the soil samples from the borings placed in Pond C, with only slightly higher concentrations in the sample from the 2-foot depth in Pond B. The Barr Engineering Co. report concluded that Ponds B and C contained no hazardous waste under the MPCA rules applicable at the time of the investigation.

In February, 1985, two borings were placed in Areas 5 and 6 of the site to help determine the vertical extent of contaminated soil at these locations. The locations of these borings are shown in Figure 6. Boring PB-4 was placed adjacent to Exploratory Excavation TP34 and Boring PB-5 was placed adjacent to Exploratory Excavation TP11. Samples were collected at 2 1/2 foot intervals to a depth of 5 feet below any visibly contaminated soil. Representative samples from the borings were analyzed for the PAH and phenolic compounds in Table 2 and the results of these analyses are in Table 3. Boring logs and the drilling report for the borings are in Appendices A-2 and A-3, respectively.

Analyses of the samples from the exploratory excavations and shallow borings showed that the highest concentrations of wood treating chemicals were found in soils from the former process area (Area 6) of the site, Pond A, and from other waste disposal and spill areas that have been identified at the site (Areas 4 and 8). The largest volumes of contaminated soil are located beneath the former process area and Pond A.

Pond A Water

Pond A, which was the last disposal area used at the site, still contains about 10,000 to 20,000 gallons of water. This is probably the result of precipitation on the surface of the pond and the low permeability of the bottom sediment. The limit and thus the volume of the water in the pond expands and contracts during the year as a result of precipitation and evaporation. Samples of the water in Pond A were collected in January,

1985. A 1-gallon sample was collected of the ice that had formed on Pond A and a sample was collected of the water beneath the ice. Approximately 18 inches of ice and 4 inches of water were present in Pond A at the time the samples were collected. Both samples were analyzed for the metals in Table 2 and the liquid sample was also analyzed for the PAH/heterocyclic and phenolic compounds in Table 2. Results of the analyses of the ice and water samples from Pond A are in Table 4. The results suggest that freezing of the water in the pond caused a concentration of the organics in the liquid phase.

GROUNDWATER INVESTIGATION

The investigation of groundwater conditions at the Joslyn site began in 1979. The Barr Engineering Co. (1981a) report summarizes the results from the groundwater investigation through August, 1981. Additional upper aquifer and lower aquifer monitoring wells were placed during 1984 and 1985. The well construction data for all monitoring wells now at the site are in Table 5. Well logs and drilling reports for the wells placed in 1984 and 1985 are in Appendices A-2 and A-3, respectively.

Shallow Monitoring Wells

Nine shallow monitoring wells were placed at the treating facility site during 1978-1981. These wells are designated Wells 1 through 7, 9, and 10 and their locations are shown in Figure 7. These wells were a "mixed bag" of plastic, stainless steel, screen lengths and diameters. Several of these wells were damaged or destroyed by late 1984. Wells 1 and 4 appeared to have been accidentally pulled from the ground and destroyed by equipment at the site. These wells were replaced by Wells 101 and 104, located as shown in Figure 7. Well 3 was damaged by equipment at the site and abandoned by grouting with neat cement in December, 1984. Well 3 was located adjacent to Well 9 and was not replaced. Wells 2, 5-7, 9, and 10 were used in the remedial investigation described in this report. Well 2 has of a 3-foot long 2-inch diameter ABS plastic screen and riser. Wells 5 and 7 have 5-foot long 2-inch diameter stainless steel screens with galvanized steel riser pipe. Well 6 has a 5-foot long stainless steel screen and a PVC riser pipe. Wells 9 and 10 have 10-foot long 4-inch diameter galvanized steel screens and galvanized steel riser pipe. The screens of wells extend only a short distance into the saturated zone.

Five new shallow monitoring wells were installed on the site in 1985. The new shallow wells are identified as Wells 101, 104, 111, 112, and 113 and their locations are shown in Figure 7. As described previously, Wells 101 and 104 replaced wells that had been destroyed. Each shallow well placed in 1985 has a 2-inch diameter 10-foot long, #10 slot stainless steel screen set 7 to 8 feet into the saturated zone. The wells have stainless steel riser pipes. The new wells were installed using a hollow stem auger. Attempts were made to develop the wells by pumping with a centrifugal pump until they produced clear water but the fine sand in the upper aquifer made this impractical in some cases.

ix shallow monitoring wells were placed downgradient (east) of the site in 1985. These are identified as Wells 121, 122, 123, 124, 125, and 126 in Figure 7. The design and construction of the off-site shallow monitoring wells was identical to the design and construction of the new on-site shallow wells placed in 1985. Well logs and drilling reports for the wells placed in 1985 are in Appendices A-2 and A-3.

The shallow monitoring wells were used to: 1) provide water level data necessary to define groundwater gradients and flow directions in the upper portion of the upper aquifer and 2) allow for the collection of groundwater samples to define the quality of groundwater in the upper portion of the upper aquifer.

Deep Borings

Three deep borings have been placed on-site. The locations of the deep borings are shown in Figure 7. These borings were placed to obtain information on the locations and characteristics of the glacial units beneath the site. Borings PB-1 and PB-2 were placed as pilot borings for deeper wells at these locations. Boring PB-3 was used to define the stratigraphy of the glacial units in the area southeast of Pond A. The drilling log and soil samples collected from the borehole used to place the lower aquifer piezometer (Well 8) during the investigation of the site summarized in the Barr Engineering Co. (1981a) report were also used to define the stratigraphy of the glacial units below the site.

The deep borings were placed using a hollow stem auger and tricone mud rotary methods and samples were collected at 5-foot intervals. Wire line coring was used in Boring PB-2 to obtain core samples of the bedrock. Boring logs and drilling reports for the deep borings are also in Appendices A-2 and A-3.

Mid-Depth Monitoring Wells

Monitoring wells with screens located at the base of the upper sand aquifer were installed at the site in 1985. In most cases, these "mid-depth" wells were placed near shallow monitoring wells to establish a vertical profile of observation points in the upper aquifer. These wells were used to investigate the presence of a contaminant plume with a density greater than the density of water. Such a contaminant plume could sink through the upper aquifer and concentrate above the uppermost confining unit below the site.

Each mid-depth well is identified in Figure 7 by a three-digit number, beginning with the number 2. Wells 206, 207 and 209 were installed at the base of the upper aquifer using a hollow stem auger. Each of these wells is constructed of a 2-inch diameter, 5-foot long, #10 slot stainless steel screen and 2-inch diameter stainless steel riser pipe. Well 201 was installed at the base of the upper aquifer but no confining unit was identified at this location. This well was installed using cable tool and is constructed of a 3 1/2-inch diameter, 10-foot long, #10 slot galvanized steel screen and 4-inch diameter steel riser pipe. Well 201 also has 8-inch and 12-inch diameter outer casings which were used to minimize the potential for the downward migration of surface contaminants during well installation. Well 201 was developed by pumping with a submersible pump until it yielded clear water. Because Wells 206, 207 and 209 had static water levels near the suction limit of the pump, they were developed by bailing and pumping with a piston pump. Well logs and drilling reports for the mid-depth wells are in Appendices A-2 and A-3.

Deep Monitoring Wells

Two deep monitoring wells were placed at the site during the remedial investigation. The locations of these wells (Wells 301 and 307) are shown in Figure 7. Well 301 is screened in the valley fill sand just above Prairie du Chien bedrock in the northwestern portion of the site. Well 307 is screened in the upper portion of the St. Peter Sandstone in the southwestern portion of the site. Each deep monitoring well was installed by cable tool and consists of a 3 1/2-inch diameter galvanized steel screen and 4-inch diameter steel riser pipe. Well 301 has a 20-foot long, #10 slot screen. Because of drilling difficulties, Well 307 has approximately 5 feet of #6 slot screen exposed. An 8-inch diameter and a 14-inch diameter outer casings were used in both wells to minimize the potential for contamination during well installation. Well logs and drilling reports for Wells 301 and 307 are in Appendices A-2 and A-3. The deep wells were developed by pumping with a submersible pump and by jetting until they yielded clear water.

The well located on the Joslyn site that was once used for plant operations is open to the St. Peter Sandstone from Elevation 741 to Elevation 712 and to the Prairie du Chien from Elevation 712 to Elevation 672. The location of the plant well is shown in Figure 7, and is referred to in this investigation as Well 300. The plant well was video and gamma logged in December, 1984. The well was found to be constructed of 10-inch diameter steel casing to Elevation 738. A 9 7/8-inch diameter or larger open borehole extends from the bottom of the casing through the St. Peter Sandstone and into the Prairie du Chien to Elevation 672. The original log for the plant well shows an open hole in the Prairie du Chien Group to Elevation 580. The video log showed that the plant well contains part of a vertical turbine pump and is sediment filled below Elevation 672 (Appendix A-3). In April, 1985, a 5-foot long inflatable packer was installed between Elevations 720 and 725 in the plant well. This elevation interval is a shale zone near the base of the St. Peter Sandstone. Water levels were measured above the packer and water samples were collected above and below the packer.

The groundwater investigation summarized in the Barr Engineering Co. (1981a) report included the installation of a piezometer into the St. Peter Sandstone on the site. This piezometer, shown as Well 8 in Figure 7, was damaged by equipment on the site and was abandoned by grouting with neat cement in December, 1984.

Water Level Measurements

The water levels in the monitoring wells and in the plant well were measured prior to sample collection in the fourth quarter of 1984 and first and second quarters of 1985. During the second quarter of 1985, water levels were also measured in several pump-out and monitoring wells that were once used in the investigation and subsequent remedial action at the site of the Howe, Inc. fire. These wells (P01, P02, P03, P12, and P23) are located about 1/2 mile east of the Joslyn site, as shown in Figure 7. The water level was also measured in the packed-off St. Peter portion of the plant well before pumping began. Due to an equipment malfunction, the static water level could not be measured in the packed-off Prairie du Chien portion of the well.

Permeability Measurements

The permeability coefficients of soil samples from the upper sand aquifer and underlying confining units were measured using laboratory tests. The grain size distributions of samples of the valley fill sand and sandstone residuum were also determined from samples collected from the deep borings and the permeability coefficients of these samples were estimated using Hazen's approximation. The estimated permeability coefficients for the geologic units underlying the site are summarized in Table 7. The supporting grain size distributions and laboratory permeability results are in Appendix A-4.

A pumping test was performed in April, 1985 in the packed-off St. Peter Sandstone portion of the plant well to define the aquifer characteristics of the St. Peter. The aquifer characteristics calculated from this pumping test are also shown in Table 7 and the pumping test procedure is described in Appendix A-4.

Water Sample Collection and Analysis

Samples collected from Wells 1 through 7, 9 and 10 during the period 1979 through 1981 were analyzed for a representative number of PAH compounds using HPLC (high pressure liquid chromatography). This method was found to produce highly variable data that were prone to false positive and inconsistent results. The use of HPLC was discontinued after 1981 due to difficulties in producing consistent results.

The groundwater samples collected as part of this remedial investigation were analyzed for the PAH and phenolic compounds in Table 2 using gas chromatograpy/mass spectrometry (GC/MS) with a modified version of EPA Method 625. The method is described in Appendix B-1. Only the results from the GC/MS analyses were used in the preparation of this report.

Procedures used to collect the groundwater samples in this remedial investigation are described in Appendix B-1. Because of the very low detection limits of the methods used to analyze the samples for PAH and phenolic compounds, extensive quality control procedures were used during sample collection and analysis to provide confidence that reliable data were being generated. The quality control procedures used in the remedial investigation are described in Appendix B-2. Field blank samples and duplicate samples were analyzed as described in Appendix B-2 to check the effectiveness of the quality control program. The results from the analyses of the quality control samples indicate that reliable data were obtained.

The collection of samples for the remedial investigation began in the fourth quarter of 1984 with the sampling of the shallow monitoring wells that existed on the site at that time. The original wells and the new shallow monitoring wells were sampled in the first and second quarters of 1985. Samples were also collected in the second quarter of 1985 from three of the groundwater pump-out and monitoring wells installed during the 1980 investigation and remedial action at the site of the Howe, Inc. fire. The locations of these wells (P02, P03, and P23) are shown in Figure 7.

At least three volumes of water were removed and a stabilization test was performed at each well prior to the collection of samples. Samples were collected from the shallow wells using stainless steel bailers. Samples for metals analysis collected in the fourth quarter of 1984 and the first quarter of 1985 were filtered and preserved. Hexavalent chromium was initially analyzed by Standard Method 312B. However, EPA Method 218.5 was used to analyze the samples collected in the second quarter of 1985 to obtain a lower detection limit. Metals samples collected in the second quarter of 1985 were filtered and preserved in the field, with the exception of the samples for hexavalent chromium analysis, which was filtered in the laboratory and analyzed within 24 hours of collection. The results from the analysis of the samples from the shallow monitoring wells are in Table 8.

Prior to sampling of the mid-depth wells (Wells 201, 206, 207, and 209), five volumes of water were removed or the well was pumped until a stabilization test indicated that consistent quality water was being removed from the well. Samples were collected from Wells 206, 207, and 209 with stainless steel bailers and from Well 201 with a submersible pump. The results from the analyses of the samples from the mid-depth monitoring wells are in Table 9.

The deep monitoring wells (Wells 301 and 307) were pumped until three to five well volumes of water had been removed. A stabilization test was then performed. Samples were collected from the pump outlet or with a stainless steel bailer. The results from the analyses of the samples from the deep monitoring wells are in Table 10. During the last quarter of 1984 and first quarter of 1985, samples were collected from the plant well using a jet pump that was in the well. The intake of the jet pump was at a depth of about 45 feet. The results from the analyses of these samples are also in Table 10. Water samples were collected above and below the packer that was placed in the plant well in April, 1985 and the results from the analyses of these samples, referred to as 300PDC (sample from Prairie du Chien) and 300STP (sample from St. Peter Sandstone) are in Table 10.

Samples From Private Wells

Two private wells, one located northeast of the site and the second located southeast of the site, were sampled on two occasions in 1985. These wells are identified by their Minnesota Geological Survey unique well numbers (203571 and 203574) and their locations are shown in Figure 5. The drilling logs for these wells are in Appendix A-3. Well 203574, which is located southeast of the site, is 4 inches in diameter and 195 feet deep. This well is finished with 27 feet of open hole in the Prairie du Chien. The well was sampled from an outside tap after the pump was operated for about 10 minutes. The well is currently used for lawn watering. Well 203571, which is located northeast of the site, is 4 inches in diameter and 134 feet deep. This well is estimated to be finished in the St. Peter Sandstone. The existing inoperable submersible pump was removed from the well and the well was pumped with a portable submersible pump. The samples were collected from the pump outlet after a stabilization test had been performed. The results from the analyses of the samples from these two wells are in Table 10.

Off-Site Well Search

A program was completed to identify the location, use, depth and condition of other private wells in the vicinity of the site. The search area was bounded on the north by 51st Avenue North (west of France Avenue) and 50th Avenue North (east of France Avenue), on the east and west by the Brooklyn Center city limits, and on the south by Lakeside Avenue and 47th Avenue North. The limits of the well search area are shown in Figure 8. The Minnesota Department of Health conducted a well search east of the

Joslyn site in 1980 following the fire at the Howe, Inc. site. This well search was conducted immediately east of the Joslyn well search area.

Preliminary information on the locations and uses of wells in the search area was obtained from the Brooklyn Center city engineer, the supervisor of the Brooklyn Center Water Department, and from records of the Minnesota Department of Health and the Brooklyn Center Health Department. No drilling logs for wells in the search area were on file at the Minnesota Geological Survey. Addresses of residences and commercial/industrial facilities in the well search area were obtained from the Brooklyn Center Planning Department. A cross reference directory was then used to obtain the names of the residence and business owners for each address.

A total of 141 private wells were identified in the well search area. The addresses of the properties in the area with wells and the status and use of the wells are shown in Appendix C. The locations of the wells are shown in Figure 9. All of the information collected in the well search is contained in the October, 1985 report entitled "Well Search - Brooklyn Center Site" (Barr Engineering Co., 1985) completed by Barr Engineering Co. for Joslyn.

A total of 44 functioning wells were identified in the search area, of which 38 are used on a routine basis. The 38 wells that are routinely used include six that are used as a potable supply, one that is used as a non-potable supply (i.e., for toilet flushing and washing), one that is used as an industrial supply, and 30 that are used for lawn and garden watering. Six wells in the area reportedly still function, but are not routinely used. Of the 99 non-functioning wells, 29 have inoperable pumps, 40 are capped, and 30 are buried or otherwise inaccessible.

All but six residential properties and one business property in the search area are connected to the city water system. City of Brooklyn Center records indicate that city water was installed after most of the homes in the area had been constructed, which accounts for the large number of wells in the area.

Virtually no useful information is available on the depth or other characteristics of the wells in the search area. As stated previously, no drilling logs are available for any of the wells. Reliable information on the depth of the pump intake was obtained on two wells (4110 Lake Breeze Avenue and 3615 - 48th Avenue); however, this does not provide information on the depth of the well. Many property owners indicated that their well is "shallow" or "deep" or "about 40 feet deep" but this information is based on recollections and cannot be verified.

SURFACE WATER INVESTIGATION

Surface water samples were collected from Twin Lakes in January and May, 1985. The samples were collected from the six sampling sites shown in Figure 10. Station LS-1 is located in the southern portion of Twin Lakes, approximately 10 feet from shore and 300 feet north of the railroad tracks. Station LS-2 is also located in this portion of Twin Lakes, about 10 feet from shore and 300 feet south of the railroad tracks. Station LS-3 is located 10 feet from the east bank of the north end of the channel between the southern and northern portions of Twin Lakes, north of the Soo Line railroad bridge. Station LS-4 is located in the northern portion of Twin Lakes, approximately 20 feet from the east side of the southernmost island. Station LS-5 is located about 20 feet west of the swimming beach in the southern portion of Twin Lakes. Station LS-6 was located about 10 feet from the east bank of the northern end of the channel beneath the Highway 100 bridge.

Samples from the lake stations were analyzed for the PAH compounds, heterocycles, and phenolics in Table 2. Results from the analyses of the lake samples are in Table 11.

VOLUME AND CHARACTERISTICS OF WASTE AND CONTAMINATED SOIL

This section of the report summarizes the quantity and characteristics of the waste and contaminated soil at the Joslyn site. Contaminated and uncontaminated soils were differentiated on the basis of the soil's visual appearance, odor, and the results from the chemical analysis of representative samples collected from exploratory excavations and borings.

Three types of wastes were identified in the waste and contaminated soil investigation:

1. Heavily Contaminated Soil -- Oily cinders and sand with a strong fuel oil or creosote odor and fine grained black sediment at the bottom of Pond A

2. Lightly Contaminated Soil -- Black or brown discolored sand with a discernible fuel oil or creosote odor

3. Pond A Water -- Liquid in Pond A in the northwestern portion of site.

The results from the analysis of a broad range of visibly contaminated and not visibly contaminated soil samples collected from the December, 1984 exploratory excavations show good agreement between the visual appearance of the soil and the PAH and pentachlorophenol concentrations (Table 3).

The estimated limits of the areas on the site that were found to contain visibly contaminated soil are shown in Figure 11. Estimated volumes of the two categories of contaminated soils are shown in Table 12.

<u>Pond A</u> -- A total of 12,000 cubic yards of heavily contaminated soil have been identified in the vicinity of Pond A. This contaminated soil surrounds and underlies Pond A from the ground surface to a depth of approximately 7 feet. Exploratory Excavation (TP) 19, placed within the dike but outside of the water in the pond, was used to estimate the limits of the discolored oily sand. From immediately below the ground surface to the bottom of TP19 at a depth of 5 feet below the water table (9 feet below the water in Pond A), a strong creosote odor was observed in the excavation. Water flowing into the excavation had an oily appearance.

The sample of the water collected from Pond A in January, 1985 showed high concentrations of PAH/heterocyclic compounds. The concentrations of these compounds in the liquid from Pond A appeared to be influenced by freezing.

Area West of Pond A -- TP48, TP49 and TP50 were placed on the western side of Pond A, just east and south of the wetland tributary to Twin Lakes. The excavations showed soils with similar characteristics -- a foot of sandy fill over a seam of contaminated silty sand-like material, mixed with wood debris and treated wood. The seam was approximately 1 1/2 to 2 feet thick, exhibited a strong creosote odor during excavation, and was oily when wetted. Beneath the seam was a sand with little or no oil sheen and an odor of decaying organic matter. Water entered the excavation at the contact between the contaminated soil and the underlying sand at TP49 and TP50. The water did not appear to be oily. Water samples from Monitoring Well 101, which is located within this area, have shown only moderate concentrations of PAH and phenolic compounds. It is estimated that 800 cubic yards of heavily contaminated soil exist in this area.

Pond B -- TP20 was placed through Pond B. This exploratory excavation identified a zone of black oily sand and wood debris between depths of 3 1/2 and 5 feet. Boring B-1 was placed through Pond B in 1981 and encountered a zone of black oily sand, gravel and debris between depths of 2 and 6 feet. It is estimated that 2,000 cubic yards of heavily contaminated soil are present in the Pond B area. Groundwater beneath Pond B exhibits a strong creosote odor. The exploratory excavation and borings show that Pond B was excavated below the surface of the saturated zone.

Area 1 -- TP45, TP46 and TP47 were placed in the building foundation in Area 1. Discolored sand with a slightly oily sheen and a slight to moderate creosote odor was encountered between depths of 0.5 and 7.5 feet in TP45. Sand with only a slight oil sheen and odor which decreased significantly with depth was identified in TP46 in the southeastern corner of the foundation. No contaminated soil was identified in TP47. Shallow samples taken in the center of the building foundation showed approximately

3 inches of blackened wood chips which may represent the "bark pile" identified in the MPCA's October, 1982 memorandum. Of the three test pits placed in this area, only TP45 showed any evidence of contamination. Because of the limited extent of the contamination in Area 1, this area is considered to not be a significant source of potential groundwater contamination nor to contain any contaminated soil.

Area 3 -- Exploratory excavations placed in Area 3 encountered little visible contamination. The soil in the test pits had relatively little odor or oil sheen. Test excavations placed west of TP22 and TP23 in 1982 identified 1 1/2 to 2 feet of green and black contaminated soil. It is estimated that 500 cubic yards of heavily contaminated soil may exist in Area 3. This contaminated soil also does not appear to be a significant source of potential groundwater contamination.

Area 4 -- TP13 through TP18 were placed in Area 4. TP13, TP14, TP18 and the north half of TP17 indicated discolored sand with a moderate to strong creosote odor. The soil in these pits was discolored from the surface to depths of 5 to 10 feet. A black, shiny cohesive material was found in a distinct layer at a depth of 8.5 to 9.5 feet in TP13. Beneath the discolored sand and black material, the soils appeared to be uncontaminated, with little or no discoloration and only a slight creosote odor. TP15, TP16 and the southern half of TP17 did not encounter contaminated soil. Based on the estimated areal extent of the contamination in Area 4 and the depths of contamination found in TP13, TP14, TP17 and TP18, it is estimated that 5,500 cubic yards of heavily contaminated soil exist in this area.

Area 5 -- Area 5 is located south of the former process area of the site. The area receives surface runoff from the area east and south of the former thermal treating tanks. Boring PB-5 was placed in Area 5 to better establish the depth of contaminated soil identified in the exploratory excavations. The boring identified a peat deposit at a depth of about 16 feet. A portion of Area 5 contains 2 to 5 feet of black oily cinders and gravel near the ground surface. Water flowing into the test excavations in this area had an oily sheen and a creosote odor. The area may have been used for the disposal of soil which had become contaminated from spills or operations at the thermal treating tanks. The cinders and gravel are underlain by brown discolored sand. The exploratory excavation could not be extended below this discolored sand because groundwater rapidly filled the excavation. Boring P-5 indicated that the discolored sand extended to a depth of 6 feet. A grey sand with a slight oil sheen and creosote odor was identified beneath the discolored sand. This grey sand extends to the top of the peat deposit. The analysis of a sample of the sand from directly above the peat (PB5-4) showed very low concentrations of PAH and phenolic compounds. The oil saturated sand at a depth of about 6 feet seems to retard infiltrating groundwater and causes groundwater mounding in this area. It is estimated that 3,000 cubic yards of heavily contaminated soil exist in the upper 6 feet of the depression in Area 5. It is estimated that 500 cubic yards of lightly contaminated soil exist around the perimeter of the heavily contaminated soil in Area 5.

Area 6 -- Two zones of contaminated soil were identified in Area 6. The first is made up of isolated zones of black and dark brown oily sand located around the former thermal treating and reclaim tanks. The surficial soil in much of Area 6 was disturbed during closure of the treating facility and contains discolored soil and isolated pockets of oily black soil. The second zone of contaminated soil is located below a depth of about 5 feet under most of the area beneath the former reclaim tanks and pipes. Empty pipes extend at a depth of about 5 1/2 feet from the former concrete reclaim tanks located just west of the former plant office. An oil-saturated sand exhibiting a strong creosote odor is present below these pipes and above the surface of the saturated zone. This zone of oil saturated sand was found in TP31, TP37, TP38 and in Boring PB-4. The oil-saturated sand does not extend as far as TP40, TP41, TP44 and the south half of TP~~31~~ 32. The estimated limits of this heavily contaminated soil within Area 6 are shown in Figure 11. Soil samples from Boring PB-4 showed the highest PAH concentrations of any soil samples analyzed during the investigation. The samples were collected from the oil-saturated zone in Area 6. The soil samples from Area 6 had low pentachlorophenol concentrations indicating that the oil is primarily creosote. The volume of heavily contaminated soil in Area 6 is estimated to be 10,000 cubic yards. Additional oil-saturated sand may exist beneath the reclaim piping outside of Area 6. It is estimated that 3,500 cubic yards of lightly contaminated soil and debris exists above and adjacent to the heavily contaminated soil in Area 6.

Area 7 -- No visible discoloration, oil sheen, or odor was detected in the soil exposed in TP30. The September, 1982 excavations in Area 7 identified 0.5 to 1.5 feet of contaminated soil near the surface that had a slight pentachlorophenol odor. Area 7 is not considered to be a significant source of groundwater contamination or contaminated soil.

Area 8 -- A 1/2 foot thick seam of black, oil-saturated sand was found at a depth of approximately 2 feet in TP27 and TP29. Sand below this seam did not appear to be visibly contaminated. It is estimated that 1,000 cubic yards of heavily contaminated soil and 1,000 yards of lightly contaminated soil exist in Area 8.

Burning Pit -- TP20 was placed in the location of a former burning pit north of Pond B. The excavation encountered wire, steel sheets, wood, metal and metal bands. Most of the waste appearing burned or charred and mixed with sand. Little or no oil sheen or creosote odor was observed in the soil samples. The burning pit area is not considered to contain contaminated soil.

HYDROGEOLOGIC CONDITIONS

Information collected during the remedial investigation along with other available information was used to define the geologic and hydrogeologic settings of the Joslyn site. The site is located on an 80-foot to 140-foot thick sequence of unconsolidated sediment that overlies the St. Peter and Prairie du Chien bedrock units. The glacial geology is complicated by the discontinuous nature of the fine-grained glacial units below the site. The bedrock geology is complicated by the variations caused by the buried bedrock valley beneath the western portion of the site.

GEOLOGIC SETTING

The characteristics of the various glacial and bedrock units below the site are described in the following paragraphs. The relationships between the major overburden units -- the upper sand and the middle confining unit -- and the lower aquifer are illustrated in the geologic cross sections in Figures 12 and 13. The locations of the cross sections are shown in Figure 14.

Upper Sand

Most of the site is covered with sand fill which likely was placed as part of the construction and/or operation of the wood treating facilities at the site. This fill contains demolition debris, metal bands, and waste in the former process area of the site.

The uppermost glacial unit is a sand which ranges from 26 to 50 feet in thickness in borings placed on the site. The sand is fine to coarse grained, stratified, and contains some gravel lenses. The unit is continuous over the site and contains deposits of peat, organic rich lacustrine deposits, and sandy silt adjacent to Twin Lakes and associated wetland. The sand has a moderate topsoil development in areas adjacent to the site, but very little topsoil or vegetation is present on the site because of the placement of sand fill over the site. The sand unit is probably fluvial or lacustrine in origin, deposited by meltwater as the Grantsburg Sublobe blocked drainage to the south.

Middle Confining Unit

The middle confining unit consists of an upper silty clay, silty sand, lower silt, and basal sandy clay subunits.

Upper Silty Clay Subunit -- The lower portion of the upper sand unit becomes progressively finer grained and contains interbedded silt and silty clay. This transitional zone grades laterally and vertically into a silty clay, which ranges from 5 to 20 feet in thickness. The silty clay subunit slopes to the northwest and decreases in thickness to the south and west. The silty clay is absent directly above the buried bedrock valley in the western portion of the site. The upper silty clay was probably deposited in a deeper water glacio-lacustrine environment during the retreat of Grantsburg Sublobe ice.

Silty Sand Subunit -- A 6-foot to 10-foot thick deposit of silty sand exists below the silty clay in the eastern two-thirds of the site. This subunit grades laterally into a coarse-grained sand and gravel deposit over the buried bedrock valley in the western portion of the site.

Lower Silt Subunit -- A 13-foot to 26-foot thick silt subunit lies below the silty sand. This lower silt subunit contains lenses of silty sand and low plasticity clay and slopes slightly to the west. The lower silt subunit is also absent directly over the buried bedrock valley in the western portion of the site.

Basal Sandy Clay Subunit -- A 5 to 6-foot thick sequence of brown and reddish brown sandy clay containing clasts of limestone and shale was encountered in Borings PB-2 and PB-3. The sandy clay probably represents a thin discontinuous mantle of till above bedrock in the eastern portion of the site.

Lower Aquifer

The lower aquifer consists of a valley fill sand, a bedrock residuum unit, the St. Peter Sandstone and the Prairie du Chien.

Valley Fill Sand -- A stratified, very dense, reddish-brown fine to medium grained sand with gravel and cobbles fills the deepest portions of the buried bedrock valley below the western portion of the site. The sand and gravel was probably deposited by meltwater before the advance of Grantsburg Sublobe ice over the site, either as outwash from the Superior Lobe or as reworked Superior Lobe material deposited by Grantsburg Sublobe meltwater.

Bedrock Residuum -- A 6 to 9-foot thick, fine to medium grained, white to tan silty sand residuum rests on the St. Peter in the vicinity of Borings PB-2 and PB-3. Boring PB-1 encountered loose pieces of dolomite with about 2 feet of sand and fine gravel residuum above the Prairie du Chien.

St. Peter Sandstone -- The St. Peter Sandstone encountered in Borings PB-2 and PB-3, the boring for Well 8, and the plant well is a fine to medium grained, well sorted quartz sandstone. Thin shale beds were observed at Elevations 727, 722, 716, and 712 MSL in the video and gamma logs of the open borehole of the plant well. The St. Peter is estimated to be up to 75 feet thick east of the site and is not present in the bedrock valley located beneath the western portion of the site. The sandstone was poorly cemented in cores obtained from Boring PB-2.

Prairie du Chien -- The Shakopee Formation of the Prairie du Chien was encountered at Elevation 715 in Boring PB-1 and at Elevation 712 in the log of the plant well. The Prairie du Chien exhibited well-developed horizontal solution-enhanced channels in the video log of the plant well.

HYDROGEOLOGIC SETTING

The surficial sand unit acts as an unconfined upper aquifer beneath the treating facility site. The St. Peter, Prairie du Chien and associated bedrock residuum and the valley fill sand act as a lower aquifer below the site. Beneath the eastern portion of the site, the upper aquifer is separated from the lower aquifer by the fine-grained silt and silty clay subunits of the middle confining unit. Beneath the western portion of the site over the buried bedrock valley, the subunits of the middle confining unit are absent and no significant fine grained unit separates the upper and lower aquifers. The sand and gravel which fills the bedrock valley acts as an aquifer and is connected to the overlying upper aquifer and the underlying Prairie du Chien.

The following paragraphs describe the major hydrogeologic units beneath and downgradient of the site.

Upper Aquifer

The upper aquifer is unconfined and is recharged directly by precipitation. Sparse vegetation, minimal topsoil, and local ponding of surface water at the treating facility site all enhance recharge from precipitation. Recharge from precipitation at the treating facility site is estimated to average 10 inches per year. The groundwater contours in the western portion of the site and in the vicinity of Pond A along with the water surface elevations of Twin Lakes and Pond A indicate that the upper aquifer is also recharged by seepage from Twin Lakes and Pond A.

As shown by the water table contours in Figures 15 and 16, the dominant direction of flow in the upper aquifer is from the west-northwest to the east-southeast in the western portion of the site and generally to the east in the eastern portion of the site and downgradient. The east-southeast direction of groundwater flow in the western portion of the site likely reflects recharge of the upper aquifer from Twin Lakes.

The surface of the saturated zone in the upper aquifer is from 1 to 15 feet below the ground surface at the site. Perched zones or groundwater mounds have developed above zones of oily soil. The saturated thickness of the upper aquifer ranges from 38 feet to 45 feet across the site, but decreases to 15 feet in Well 125 about 1400 feet downgradient of the site.

The lateral groundwater gradient in the upper aquifer ranges from 1×10^{-3} feet/foot in the western portion of the site to 6×10^{-4} feet/foot in the eastern portion of the site. This is slightly less than the gradient of 3.8×10^{-3} feet/foot assumed by McBride (1974), perhaps because the saturated thickness of the upper aquifer at the site is greater than in the larger area studied by McBride.

The differences in water levels measured in the nested wells during this remedial investigation are summarized in Table 13. There does not seem to be a significant difference in lateral gradient and groundwater flow directions in the upper and lower portions of the upper aquifer. No significant water level differences between the upper and lower portions of the upper aquifer (on the order of 0.1 feet or less) were measured at Well Nest 6/206, Well Nest 7/207 or Well Nest 9/209. A water level difference of 0.3 feet was measured in May, 1985 between the top and the base of the upper aquifer at the location of Well Nest 101/201 in the northwestern portion of the site. The middle confining unit is not present below this portion of the site.

Estimates of the permeability coefficient of the upper aquifer range from 2 x 10^{-3} cm/sec to 2 x10^{-1} cm/sec (Table 7). Assuming a permeability coefficient of 2 x 10^{-1} cm/sec, the velocity of lateral groundwater flow in the upper aquifer across the site is on the order of 400 to 700 ft/year, based on the above gradients and an estimated porosity of 30 percent. This flow velocity equates to an estimated flow rate of 80 to 120 gallons per minute (gpm) from west to east across the 900-foot width of the site.

The groundwater surface contours in the upper aquifer in the western portion of the site and the water surface elevation of Twin Lakes indicate that a portion of the water flowing through the upper aquifer comes from Twin Lakes. Comparing the estimated groundwater flow rate of 80 to 120 gpm across the 900-foot width of the site to the estimated precipitation recharge to the groundwater of 10 inches per year suggests that more than three-fourths of the water moving through the upper aquifer beneath the site is from Twin Lakes.

Groundwater levels in the upper aquifer increased by approximately 0.5 to 0.7 feet over most of the site between March, 1985 and May, 1985 due to higher lake levels and the recharge of spring snowmelt and rainfall.

The saturated thickness of the upper sand aquifer decreases downgradient of the site, as shown by the log for Well 203574, and by borings placed for the groundwater investigation associated with the fire at the Howe, Inc. site. Fine grained soils were present in the logs of each of these borings at the elevations shown in Figure 4. McBride (1974) indicates that the upper sand aquifer may be in direct contact with the St. Peter Sandstone at places between Twin Lakes and the Mississippi River. As shown in Figure 4, the middle confining unit appears to be continuous at least to the Howe, Inc. site.

Middle Confining Unit

Where present, the fine-grained subunits of the middle confining unit act as a confining bed between the upper and lower aquifers. As described previously, the middle confining unit is not continuous across the site, being absent above the bedrock valley in the western portion of the site. The middle confining unit is 5 to 20 feet thick in borings placed east of Pond A and in the former process area of the site. The middle confining unit is not present in Boring PB-1, west of Pond A.

Vertical groundwater gradients between wells finished above and below the silty clay and other subunits of the middle confining unit averaged 2×10^{-3} feet/foot indicating a slight downward gradient through the units (Table 13). The vertical gradients between the upper and lower aquifers measured at locations underlain by the middle confining unit were approximately 10 times larger than the vertical gradient between these two units measured in the well nest located where the middle confining unit is not present.

Remolded samples of the silty clay and the silty sand subunits of the middle confining unit had permeability coefficients of 3.8×10^{-7} cm/sec and 8.4×10^{-7} cm/sec respectively when tested using a constant head permeameter (Table 7 and Appendix A-4). These permeability coefficients are similar to the 3×10^{-7} cm/sec estimate used by McBride (1974). Assuming an average vertical permeability coefficient of 6×10^{-7} cm/sec and a porosity of 30 percent for the silty clay and silty sand, the downward velocity through the middle confining unit under the average observed gradient would be on the order of 4×10^{-3} feet/year, which is negligible. If the actual permeability of the middle confining unit is two orders of magnitude higher than the permeability coefficients of the remolded samples, the downward velocity would be on the order of 0.4 feet/year. In either case, the middle confining unit appears to be a significant barrier to downward groundwater movement.

Lower Aquifer

The lower aquifer is comprised of the Prairie du Chien, St. Peter sandstone, overlying bedrock residuum, and the valley fill sand. The lower aquifer is confined by the silt, silty clay, and sandy clay till subunits of the middle confining unit in the eastern portion of the site, but is in contact with the upper aquifer below the western portion of the site.

Based on the water levels measured in Well 307 and the plant well (W300), the lateral flow direction in the lower aquifer seems to be to the east, similar to that of the upper aquifer. The lateral gradient between Well 307 and the plant well averaged 2.5×10^{-3} feet/foot, which is within the range of lateral gradients measured in the upper aquifer. Similar gradients were measured between Well 301 and Well 307 (3×10^{-3} feet/foot) and Well 301 and the plant well (4×10^{-3} feet/foot).

A pumping test conducted in the packed-off St. Peter portion of the plant well indicated an average permeability coefficient of 2.8×10^{-1} cm/sec for the St. Peter. This value is about an order of magnitude higher than McBride's (1974) estimate for the permeability of the St. Peter (2×10^{-2} cm/sec).

The silty sandstone residuum encountered in Borings PB-2 and PB-3 lies between the St. Peter and the middle confining unit in the eastern portion of the site. A permeability coefficient of 2.5×10^{-3} cm/sec was estimated for the sandstone residuum using the grain size distribution of a sample collected from Boring PB-2 and Hazen's approximation.

The grain size distribution of a sample obtained from Boring PB-1 indicated that the permeability coefficient of the valley fill sand is on the order of 7×10^{-3} cm/sec.

Seasonal changes in the potentiometric level in the lower aquifer ranged from 0.5 feet in Well 301 to less than 0.1 feet in the plant well. Because the closest identified lower aquifer wells are used only intermittently, the response of the water level in the lower aquifer on-site to pumping of off-site wells is anticipated to be negligible.

Downward groundwater gradients between the upper and lower aquifers in the western portion of the site were measured at Well Nest 101/201/301 (Table 13). The latter well nest is over the bedrock valley where the upper and lower aquifers are directly connected. The downward gradient from Well 201 to Well 301 was 3 x 10^{-3} feet/foot in March and May, 1985. If the vertical permeability coefficient of the valley fill sand is assumed to be equal to the permeability coefficient estimated using Hazen's approximation (7 x 10^{-3} cm/sec), the downward flow velocity through the valley fill sand would be on the order of 70 feet/year. It is anticipated that the vertical permeability coefficient of the valley fill sand is substantially less than the permeability coefficient estimated by Hazen's approximation, since the material was placed by an alluvial process and is horizontally stratified. If the vertical permeability coefficient of the valley fill sand is an order of magnitude lower than the permeability coefficient estimated by Hazen's approximation, the downward velocity would be on the order of 7 feet/year. If the vertical permeability coefficient is two orders of magnitude lower, the vertical velocity would be on the order of 0.7 feet/year. In any event, the vertical rate of movement from the upper aquifer to the lower aquifer is likely greater over the buried valley than in the portion of the site underlain by the middle confining unit.

The higher rate of lateral groundwater movement in the upper aquifer compared to the rate of downward movement over the buried valley is anticipated to be sufficient to carry any PAH and phenolic compounds that are present in the upper portion of the upper aquifer over the bedrock valley to the portion of the site that is underlain by the middle confining unit before the contaminants reach the base of the upper aquifer. This is confirmed by the relatively low concentrations of PAH compounds and

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pentachlorophenol in the samples from the mid-depth wells located in the western portion of the site (Wells 201 and 207).

The higher potentiometric level in the valley fill sand (Well 301), compared to the potentiometric level in the bedrock portion of the lower aquifer indicates that groundwater in the valley fill probably discharges to the bedrock portion of the lower aquifer through the valley floor and walls. The valley fill sand may be separated from the bedrock in places by a fine-grained unit along the valley wall.

The packed-off St. Peter portion of the plant well had a slightly higher static water level than did the open borehole as a whole (0.1 feet). This suggests that a slight downward gradient may exist between the St. Peter and the Prairie du Chien.

GROUNDWATER QUALITY

This section of the report discusses the results from groundwater quality monitoring at the Joslyn site.

Upper Sand Aquifer

Samples obtained from the sixteen shallow monitoring wells placed in the vicinity of the site indicate that PAH/heterocyclic compounds are present in the groundwater in the upper portion of the upper aquifer. Pentachlorophenol is the only detectable phenolic compound in the upper aquifer. The concentrations of PAH compounds and pentachlorophenol measured in the shallow groundwater downgradient of the areas of contaminated soil on the site are generally lower than those found at other wood treating sites in Minnesota.

Contours of equal pentachlorophenol concentration in the upper portion of the upper aquifer are shown in Figure 17. These contours are based on the average concentration in samples from each shallow well sampled in this remedial investigation. The average pentachlorophenol concentrations in samples from the various wells are shown in Table 14. The pentachlorophenol concentration contours indicate that a plume of pentachlorophenol extends from the Pond A and former process area on the site to a point about 2,000 feet downgradient of the site. Highest pentachlorophenol concentrations are present in the vicinity of Well 113 which is located near the former thermal treating and reclaim tanks. Off-site pentachlorophenol concentrations in the shallow groundwater are below the EPA proposed RMCL of 220 ug/L (0.22 mg/L).

Several PAH and heterocyclic compounds are also present in the shallow groundwater on the site. The contours of total PAH/heterocyclic compound concentration (sum of List 1 and List 2 compounds) are shown in Figure 18. These are also average concentrations from the remedial investigation. The average concentrations are shown in Table 14. The concentration contours in Figure 18 show that a plume of PAH/heterocyclic compounds also extends from Pond A and the process area of the site to the east. As with pentachlorophenol, highest concentrations are present in the vicinity of the former thermal treating and reclaim tanks. Very low concentrations of some List 2 PAH compounds have moved off-site and may have reached Well P23. PAH and heterocyclic compounds could not be detected in samples from Wells P02 or P03, possibly because of analytical interference from the high concentrations of atrazine which was found in the samples from these wells. The most prevalent PAH/heterocyclic compounds in the shallow groundwater are naphthalene, 1-methylnaphthalene, 2-methylnaphthalene, benzo(b)-thiophene, 2,3-dihydroindene, indene, and perylene, which are among the most mobile of the PAH compounds. It is significant to note that the potentially carcinogenic PAH/heterocyclic compounds (List 1 compounds) are not migrating from the areas of heaviest soil contamination on the site.

An oil phase was found on the surface of the groundwater in the samples collected from Well 113 and in test pits placed around the former process area. This oil may be the reason for the high concentrations of PAH compounds and pentachlorophenol in the samples from Well 113.

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The PAH/heterocyclic compounds in the shallow groundwater beneath the site seem to be originating in the former process area and perhaps in Pond A. Relatively high pentachlorophenol concentrations in samples from Wells 6 and 7 suggest that the source of pentachlorophenol on the site extends further to the west than does the source of PAH compounds. Although the concentration contours in Figures 17 and 18 suggest that the plume of PAH/heterocyclic compounds has traveled further to the east than has the plume of pentachlorophenol, this may be due to the lower detection limits for the PAH/heterocyclic compounds in comparison to pentachlorophenol. The apparent difference in the extent of migration may also be due to the fact that creosote (the source of the PAH compounds) was in use for a much longer time at the facility than was pentachlorophenol.

All arsenic, chromium and copper concentrations in the monitoring well samples were within EPA primary drinking water standards, adopted secondary maximum contaminant levels and proposed EPA RMCLs. Arsenic concentrations in water samples collected from the shallow monitoring wells in the vicinity of the site decreased between the first and second quarters of 1985 by an average of 7 ug/L. Smaller decreases were noted in copper and chromium concentrations over the same period. The low concentrations of metals in the shallow groundwater are not considered a threat to public health or the environment.

Samples from the three wells screened at the base of the upper aquifer (mid-depth wells) contained much lower concentrations of PAH/heterocyclic and pentachlorophenol compounds than did samples from the adjacent shallow monitoring wells. The average total concentration of the List 1 and List 2 PAH/heterocyclic compounds and the average concentration of pentachlorophenol in samples from the nested wells are shown in Table 14 and on the cross sections in Figures 19 and 20. Samples from all three of the mid-depth wells had pentachlorophenol concentrations 20 to 750 times lower than the concentrations in samples from the nearby shallow wells. The concentrations of the PAH/heterocyclic compounds were similarly low in samples from Wells 206 and 209. Samples from Well 207 had slightly higher PAH concentrations than did shallow monitoring Well 7 (Figure 20), possibly because Well 207 is located directly beneath the area of heavily contaminated soil in the former process area and Well 7 is located south of the area of heaviest soil contamination.

Samples from Well 201, which is completed in a coarse sand and gravel zone within the valley fill sand, did not show detectable pentachlorophenol or detectable List 1 PAH/heterocyclic compounds. Low concentrations of List 2 PAH/heterocyclic compounds, primarily naphthalenes, were present in samples from this well.

Lower Aquifer

Samples from the lower aquifer monitoring wells completed in the bedrock (Well 307 and the plant well) and samples from the lower aquifer well finished in the valley fill sand (Well 301) showed no detectable concentrations of pentachlorophenol. Samples from the two bedrock monitoring wells and the well in the valley fill sand did show low concentrations of several PAH and heterocyclic compounds. The average concentrations of the List 1 and List 2 PAH/heterocyclic compounds in the lower aquifer wells are shown in Table 14. The average concentrations of the List 1 and List 2 PAH/heterocyclic compounds in samples from Well 301 and the plant well are "slightly greater" than the concentrations in samples from Well 201, but are still well within the informal MPCA recommended drinking water levels. The concentrations of the PAH/heterocyclic compounds in samples collected from the St. Peter and Prairie du Chien portions of the borehole for the plant well did not differ significantly. Average concentrations of the List 1 PAH/heterocylic concentrations in samples from Well 307 are also well within the informal MPCA drinking water levels, but the concentrations of the List 2 compounds are slightly greater than MPCA recommended levels for drinking water wells.

Samples from the two private bedrock wells that were monitored in the vicinity of the site indicated that the water from these wells is within the MPCA recommended drinking water levels for PAH/heterocyclic compounds. No pentachlorophenol or other phenolic compounds were detected in the samples from these wells.

SURFACE WATER QUALITY

Surface water samples collected from Twin Lakes showed no detectable concentrations of pentachlorophenol or other phenolics. Detectable concentrations of List 1 and List 2 PAH/heterocyclic compounds were found in samples from all of the lake sampling stations. The highest concentrations were found at Station LS4 on the northern portion of the lake. This station was intended to be a background station and is not located near the Joslyn site. Samples collected in January, 1985 at Station LS4 contained relatively high concentrations (compared to other lake stations) of several List 2 PAH/heterocyclic compounds which were not present in significant concentrations in groundwater beneath the treating facility site. PAH compounds are a known constituent in the exhaust from internal combustion engines (e.g., outboard motors) and motor fuels and lubricants. Similar compounds were found in the January sampling from Station LS1, which is located in the lower portion of the lake just west of the treating facility site. Because of the chemical signature of these samples and the location of Station LS4 relative to the site, it is likely that the PAH compounds detected in the January sample were of typical background quality in lakes with extensive motorboat traffic and not from the site.

POTENTIAL IMPACTS OF SITE

GROUNDWATER USE

PAH/heterocycles and pentachlorophenol have entered the shallow groundwater beneath the Joslyn site as the result of spills, waste disposal, and other releases in the former process area and waste disposal areas on the site. Highest concentrations are present in the shallow groundwater near and immediately downgradient of the former thermal treating, reclaim and storage tanks and Pond A. Analyses of samples from off-site shallow monitoring wells have shown that low concentrations of List 2 PAH/heterocycles and pentachlorophenol have moved off-site. The direction and extent of off-site movement and the concentrations that have been measured are consistent with the locations of contaminated soil on the site and the groundwater gradients in the upper aquifer. The most mobile contaminants moving through the groundwater away from the areas of heaviest soil contamination are the non-carcinogenic (List 2) PAH and heterocyclic compounds.

Samples from wells screened at the base of the upper aquifer have shown only very low concentrations of PAH/heterocyclic compounds and pentachlorophenol, in comparison to nearby shallow wells. This indicates that a contaminant plume with a density greater than water is not present at this site. The reasons for the low concentrations of wood preservatives at the base of the upper aquifer are thought to be the low specific gravity of the wood treating chemicals used at the site and the lack of significant downward groundwater movement. The deeper groundwater in the upper aquifer below the site is also primarily derived from recharge from Twin Lakes and, therefore, has not been in contact with the contaminated soils located above the surface of the saturated zone on the site.

Lower aquifer monitoring wells located at the site indicate that the lower aquifer has not been significantly impacted by PAH and pentachlorophenol in the upper aquifer. Samples from Well 307, located adjacent to the former process area on the site, suggest that groundwater in the vicinity of this well may slightly exceed the MPCA's informal drinking water levels for the non-carcinogenic PAH/heterocyclic (List 2) compounds, however, these levels are extremely protective. The low concentrations of wood treating chemicals in the lower portion of the upper sand aquifer and the very long travel time through the middle confining unit have protected the quality of the lower aquifer.

Without site remediation, the concentrations of pentachlorophenol and PAH compounds in the upper aquifer in the vicinity of the areas of heaviest soil contamination are not expected to decrease in the short-term. The most highly contaminated groundwater, which is still confined to the former operating areas on the site, will continue to move to the east. The rate of contaminant movement is estimated to be 100 feet per year or less, assuming a pentachlorophenol and PAH compound retardation factor of 5 or greater. Continued movement of the low concentrations of pentachlorophenol and PAH compounds to the east of the site is not expected to significantly affect groundwater use in the area. The shallow groundwater east of the Howe, Inc. facility is contaminated with atrazine and perhaps other pesticides and the available information indicates that the shallow groundwater is not being used in the area east of the site.

not true
conc are
above
criteria

PAH compounds and pentachlorophenol will also tend to continue to slowly move vertically to the underlying lower aquifer below the site. The future vertical migration of these compounds to the lower aquifer would seem to be a more significant potential impact to the public health than would the continued lateral migration to the east. The reason for this conclusion is that the lower aquifer below the site is used by a few water supply wells in the vicinity of the site and is used by high capacity water supply wells on a regional basis.

sinking
plume

A total of 78 wells were identified in the area downgradient of the site within the estimated limits of the 0.3 ug/L total PAH/heterocyclic concentration contour. The estimated location of the 0.3 ug/L PAH/heterocyclic concentration contour in relation to the wells downgradient of the site is shown in Figure 21. The location of this contour is based on results from the analysis of samples collected from shallow monitoring wells installed as part of the remedial investigation, and is applicable only to groundwater in the shallow portion of the upper aquifer. Of the 78 wells in this area, two are used as potable supplies, one is used as an industrial supply, and 17 are used for lawn and garden watering. The owners of the two potable water supply wells within the 0.3 ug/L PAH/heterocyclic concentration contour indicated that their wells are finished in either deep sand or in bedrock. The remaining 58 wells within the 0.3 ug/L PAH/heterocyclic concentration contour are not used.

Samples from a limited number of private wells located south and east of the site by the Minnesota Department of Health in 1961, Brooklyn Center in 1978, and the MPCA in 1980 showed low, but detectable, levels of phenolics. The previous samples from private wells east of the site suggest that low concentrations of organics from the site may be impacting shallow wells located within the 0.3 ug/L concentration contour shown in Figure 21. These wells are not used for potable supply purposes and no present impact on public health is anticipated.

TWIN LAKES

The results from the analyses of the surface water samples collected from Twin Lakes indicate that low concentrations of PAH compounds are present in the lake; however, the distribution of the data indicate that measurable concentrations are not the result of past operations at the Joslyn site. The elevated concentrations of PAH compounds in Twin Lakes could be the result of motorboat traffic on the lake or dust fall from anthropogenic sources in the Twin Cities metropolitan area. Because water in the shallow groundwater flows east, away from Twin Lakes, it is unlikely that the contaminated groundwater in the upper aquifer below the site will impact Twin Lakes in the future.

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Section 3

ASSESSMENT OF ALTERNATIVE TECHNOLOGIES

SECTION 3

ASSESSMENT OF ALTERNATIVE REMEDIAL ACTION TECHNOLOGIES

INTRODUCTION

Soil and shallow groundwater beneath a portion of the Joslyn site is contaminated with pentachlorophenol and PAH compounds as a result of wood treating operations at the site. The extent and magnitude of this soil and groundwater contamination has been defined in the previous section of this report. Contamination in the shallow groundwater is moving to the east at an estimated rate of 100 feet per year or less. The potential exists for the PAH compounds and pentachlorophenol in the shallow groundwater to eventually move vertically to the lower aquifer which underlies the site. The lower aquifer below the site has not been significantly affected by wood preservatives in the shallow groundwater. The lower aquifer includes bedrock units that are used by a limited number of private wells in the vicinity of the site and by municipalities surrounding the site. No municipal water supply wells are, however, located within 1-1/2 miles of the site. All but two residences in the area of shallow groundwater contamination are served by city water. The two residences without city water reportedly have deep wells. Shallow wells in the area are used primarily for lawn watering.

The contaminated water and contaminated surficial soil in Pond A on the site is a risk to people trespassing on the site that come in contact with this waste. Access to Pond A is controlled by a temporary fence.

The purpose of this section of the report is to evaluate various remedial action technologies that could be used to mitigate the potential impacts of the soil and groundwater contamination at the Joslyn site. Potential impacts of the soil and groundwater contamination at the site can be mitigated by eliminating the contaminated water and soil in Pond A and 1) restricting the leaching of additional contaminants from the contaminated soil to the groundwater and/or 2) restricting the further migration of contaminated shallow groundwater.

Restricting the further leaching of contaminated soil will virtually eliminate the supply of additional contaminants to the shallow groundwater. Further releases from the contaminated soil can be controlled by removing or containing the contaminated soil. This approach will prevent the contaminants in the surficial groundwater from increasing in concentration. With such an approach, the contaminants in the shallow groundwater will eventually diminish in concentration by diffusion and dilution. Due to the number and complexity of the variables that affect the rate of change in contaminant concentrations, however, an accurate estimate of the time rate of change in groundwater contaminant concentrations is not possible. It is anticipated that decades will be required for substantial groundwater improvement to occur under remedial actions that restrict the further leaching of contaminated soil.

Another approach to mitigating site impacts is to restrict the migration of the contaminated groundwater by establishing some type of barrier to groundwater flow. Groundwater flow barriers can be either a physical restriction such as a slurry wall or a hydraulic restriction such as a pumping system that intercepts and removes the contaminated groundwater. With this approach, contaminants that enter the upper aquifer are intercepted or blocked by the groundwater control system. A groundwater control system will have to be maintained for decades to restrict the movement of contaminated groundwater unless leaching from the large mass of contaminated soil on the site is somehow also controlled.

This section of the report evaluates several potentially feasible remedial action technologies that are designed to mitigate the impacts from the contaminated soil and groundwater on the site. The potentially feasible remedial action technologies are evaluated on the basis of their technical feasibility and cost and effectiveness in abating the release or threatened release of contaminants from the site.

Potentially feasible remedial action technologies that were investigated were selected on the basis of 1) the List of Feasible Alternative Response Actions submitted in response to Task A.1.b of Exhibit A to the May 30, 1985 Response Order between Joslyn and the MPCA and 2) the

August 14, 1985 letter from the MPCA regarding modifications to the list of feasible response actions submitted by Joslyn. The technologies that are investigated include those designed to reduce the further release of contaminants from the contaminated soil at the site and those designed to control the further movement of contaminants that have reached the groundwater in the upper aquifer.

CONTAMINATED SOIL CONTROL TECHNOLOGIES

Contaminated soil control technologies are designed to remove, contain or treat the contaminated soil either on-site or at an off-site facility. Many of the contaminated soil treatment technologies that are allegedly available are proprietary and/or are not fully developed and their application and reliability has not been demonstrated. Use of such technologies at the Joslyn site would require considerable bench and pilot scale testing. Off-site treatment and containment facilities may be available for the contaminated soil, but it is difficult to obtain a long-term commitment from such facilities to take the waste when the remedial action plan is implemented. In addition, off-site facilities are generally thought to present more risk of future liabilities than do on-site treatment or containment alternatives, since the waste generator has no control over, but significant liability for, management methods used at off-site facilities.

Potentially feasible contaminated soil control technologies are:

1) Capping
2) On-Site Containment with Vault
3) On-Site Containment with Slurry Wall
4) Solidification
5) On-Site Incineration
6) Composting
7) Conventional Land Treatment
8) Off-Site Containment
9) Off-Site Incineration

Technologies that are available to dispose of the water in Pond A were evaluated along with the contaminated soil control technologies. The only potentially feasible technology for the water in Pond A is to discharge it to the sanitary sewer after any necessary pretreatment.

CONTAMINATED GROUNDWATER CONTROL TECHNOLOGIES

Contaminated groundwater control technologies are designed to contain or recover contaminated groundwater. These technologies can be used to reduce the lateral migration of pentachlorophenol and PAH compounds through the upper aquifer and reduce the vertical migration of these contaminants to the lower aquifer below the site.

Potentially feasible contaminated groundwater control technologies are:

1) Slurry Wall Containment
2) Groundwater Interception and
    a) surface water discharge
    b) sanitary sewer discharge

ASSESSMENT OF POTENTIALLY FEASIBLE TECHNOLOGIES

The applicability and estimated unit costs of the potentially feasible remedial action technologies are described in this portion of the report. The costs should be viewed as "first-cut" estimates (-30 percent to +50 percent) of the actual cost of implementing the technology at the site. The costs should primarily be used as indicators of the relative costs of the various technologies. Many of the costs are very sensitive to such assumptions as the quantity of contaminated soil, the quality and quantity of contaminated water that must be treated, and the amount of monitoring or administrative cost required to implement the remedy. The unit costs presented in this section includes an added 10 percent for contractor mobilization, 20 percent for contingencies, and 20 percent for engineering, design and administration.

CONTAMINATED SOIL CONTROL TECHNOLOGIES

Two general approaches can be used to control the further leaching of contaminated soil on the site. These are: 1) containment and 2) treatment.

Caps, vaults, and slurry walls are examples of the containment approach. Incineration, solidification, composting and conventional land treatment are examples of the treatment approach. Containment or treatment of contaminated soil can be performed on-site or off-site. This report emphasizes the on-site application of contaminated soil control technologies because of the uncertain availability and potential liabilities associated with virtually all off-site approaches. Most, but not all, of the contaminated soil control technologies require that the contaminated soil be excavated prior to containment or treatment.

The technical feasibility, cost and general effectiveness of each of the potentially feasible contaminated soil control technologies are summarized in the following paragraphs.

Contaminated Soil Excavation

Unit costs were estimated for: 1) excavation of contaminated soil above the surface of the saturated zone such as is anticipated over most of the site and 2) excavation of contaminated soil from below the surface of the saturated zone such as is anticipated in the Pond A area and in the former process area on the site.

Excavation of Waste Above Saturated Zone -- The cost to excavate, load, move and unload contaminated soil excavated above the surface of the saturated zone is estimated to be $11 per cubic yard. This includes mobilization, contingencies, and engineering. Soils contaminated with PAH compounds and pentachlorophenol must be excavated in a manner consistent with applicable safety precautions, but such work is feasible and can be done safely by most contractors with appropriate safety training. The cost of backfilling the excavation, including obtaining the backfill from an on-site location and placing, grading and compacting the backfill is estimated at an additional $11 per cubic yard. This work can be carried out using standard construction practices.

Excavation of Soil In Saturated Zone -- Some heavily contaminated soil in the Pond A area and in the former process area of the site is located below the surface of the saturated zone. This is probably due to groundwater mounding above the contaminated soil as a result of the relatively low permeability of the oil-saturated soil. Due to the difficulty of excavating more than 1 to 2 feet below the saturated zone without dewatering, it will not be possible to excavate the contaminated soil from below the surface of the saturated zone unless groundwater is removed. Although the high permeability of the upper sand unit makes dewatering of an excavation difficult and expensive, dewatering is more effective than dredging in removing the contaminated soil from the upper 5 to 10 feet of the saturated zone. Water removed during excavation of contaminated soil would most logically be discharged to the sanitary sewer after any necessary pretreatment. For cost estimating purposes, it was assumed that flocculation would be used for pretreatment prior to discharge to the sewer. This level of treatment was used to satisfactorily treat the dewatering discharge from the excavation of soil contaminated with wood preserving wastes at the National Pole and Treating Co. site in Fridley. It was assumed that the water would be batch treated in pools where the flocculant would be mixed and allowed to settle. The floc (sludge) would periodically be removed from the pools and managed with the excavated contaminated soil. This form of pretreatment can be expected to generate about 10 pounds of sludge (dry weight) per 1,000 gallons of treated water.

The estimated cost of excavating contaminated soil below the surface of the saturated zone is $40 per cubic yard. This cost includes dewatering the excavation, excavating the contaminated soil, backfilling the excavation with clean soil from an on-site source, pretreating the water by flocculation, and disposing of the water in the sanitary sewer. Dewatering during excavation of contaminated soil will also remove part of the contaminated groundwater present in and around the contaminated soil. This is an advantage over excavating without dewatering.

Capping

Contaminated soil could either be capped in place or excavated and moved to another location on-site and capped. The following capping strategies are assessed: clay soil, multi-layer, synthetic membrane and asphalt.

- Clay Cap -- After grading, a single compacted clay layer could be placed directly over the area to be capped. The clay layer would then be covered by topsoil and vegetated. Since clay is a natural material, a long life can be expected. In addition, no joint seaming is required. Clay tends to be "self-healing" if differential settling occurs. Standard design practice usually uses a 2-foot thickness of compacted clay to provide assurance that a layer of low permeability material is placed across the capped area. The cost of using clay as a cap is obviously dependent on clay availability. The estimated capital cost of a clay cap is $90,000 per acre. The estimated annual maintenance cost is $1,500 per acre per year. These costs include contractor mobilization, contingencies, and engineering.

- Multi-Layer Cap -- The typical multi-layer cap system consists of the following layers from top to bottom:

  - Cover Soil -- An upper layer of soil which will support vegetation and enhance surface runoff, consisting of 18 to 24 inches of cover soil.

  - Flow Zone -- A middle layer which serves as the designed drainage path, consisting of 18 to 24 inches of high permeability gravel.

- Low Permeability Layer -- A bottom layer of low permeability clay which serves as a boundary to restrict infiltration, consisting of 24 inches of clay.

The multi-layer cap system is generally the most expensive of the capping systems. With proper placement, however, it can also be the most effective. The grading, vegetation, cover soil, flow zone and low permeability layers all combine to minimize infiltration. All construction materials are natural, consequently a long life and low maintenance costs can be expected. The estimated capital cost of a multi-layer cap is $100,000 per acre. The estimated annual maintenance cost is $1,500 per acre per year.

- Synthetic Membrane -- A synthetic membrane will provide a relatively low cost cap which can be highly efficient. Membrane installation typically includes: subbase grading, placement of clean soil or sand, placement of the membrane, placement of topsoil over the membrane, and vegetation of the topsoil. otential drawbacks of membranes include uncertain long-term life, uncertain waste/liner compatibility, possible punctures during installation, and uncertain integrity of seaming. The MPCA now requires that any synthetic membrane used as a cap be placed below the frost zone.

  The estimated capital cost of a 100 mil synthetic membrane is $100,000 per acre. The estimated annual maintenance cost is $1,500 per acre per year. The estimated capital cost of a 60 mil synthetic membrane is $90,000 per acre, with the same annual cost for maintenance.

- Asphalt -- The initial cost of an asphalt cap is often less than the initial cost of a multi-layer or synthetic membrane cap. Due to the physical properties of asphalt, however, the long-term maintenance cost will be substantially higher than that of other capping materials. Long-term effects of differential settlement,

> sun aging, creep subgrade movement, and freeze/thaw will combine to reduce the effectiveness of the cap. An asphalt cap will crack and if not repaired the cracks will allow subsurface infiltration. The maximum expected life of an asphalt cap is about 10 years. Because of the high maintenance and short life expectancy, asphalt was not given further consideration as a capping material.

On an overall performance basis, the multi-layer cap and the synthetic membrane cap represent the two most effective and technically feasible capping approaches for the Joslyn site.

On-Site Containment with Vault

The objective of the on-site containment of the contaminated soil in a containment vault is to isolate the waste from the upper aquifer. The containment vault would be constructed according to RCRA Subtitle C (hazardous waste) regulations.

The design of a RCRA containment vault involves: a double liner system of two layers of synthetic membrane over a clay base, a leachate collection system over the primary liner, a leak detection system between the primary and secondary liners, and a synthetic membrane or clay cap over the contaminated soil.

The following paragraphs summarize the details and cost of constructing a RCRA containment vault at the Joslyn site. The design of the vault bottom liner, starting from the top layer of the liner is:

- geotextile fabric
- leachate collection system
- primary liner -- 100 mil membrane
- leak detection system
- secondary liner -- 60 mil membrane
- 36 inches of compacted clay.

The design of the vault cap, starting with the top layer of the cap is:

- vegetation cover
- 2 feet of sand/topsoil
- 3 feet of clean fill
- geotextile fabric
- 12 inches of sand
- 100 mil membrane
- 24 inches of compacted clay
- 12 inches of sand.

Internal and external side slopes were assumed to be 4 horizontal to 1 vertical. External side slopes were assumed to be sodded. The cap surface was assumed to be sloped at 2 percent. The design used for cost estimating purposes assumed that the base of the liner system would be 11 feet below the ground surface. The construction cost for a RCRA vault with capacities in the range of 20,000 to 50,000 cubic yards is estimated to be $35 per cubic yard. The annual operating and maintenance cost for a vault is estimated to be $2,000 per year which includes periodic inspections, repair of any erosion that occurs on the side slopes or cap, monitoring of the leak detection system and groundwater monitoring wells, and removal and disposal to the sanitary sewer of any leachate that is collected. Preliminary indications are that a high density polyethylene membrane material will be compatible with the contaminants in the soil at the Joslyn site. Compatibility testing may be necessary if the use of synthetic membranes is part of the remedial action plan for the site.

On-Site Containment with Slurry Wall

Slurry wall containment technology involves the construction of a low permeability barrier (slurry wall) around the contaminated soil or groundwater. The slurry wall is constructed of a mixture of bentonite, sand and fines. A low permeability clay or synthetic membrane cap would typically be placed over the area surrounded by the slurry wall to minimize the infiltration of precipitation into the area surrounded by the wall.

Slurry walls are constructed by excavating a trench filled with a slurry of clay and water and then backfilling the trench with a soil-bentonite backfill mix. Most commonly, the slurry wall is keyed into an underlying geologic unit of low permeability. A slurry wall at the Joslyn site would logically be keyed into the middle confining unit below the site. Where the middle confining unit is not present, an inward hydraulic gradient would have to be used to provide the containment. An inward hydraulic gradient is achieved by maintaining a lower water level inside the area surrounded by the slurry wall than exists outside the area. The most obvious way to maintain a lower interior water level is to pump water from the interior of the containment area and limit recharge into the containment area with a low permeability cap.

The bentonite slurry is used to support the trench walls during excavation of the slurry wall to allow the trench to extend well below the water table. The bentonite in the slurry is forced into the soil matrix on the trench walls to form a low permeability filter cake. When a portion of the trench has been keyed into the underlying low permeability unit or has otherwise been excavated to the desired depth, that portion of the trench is backfilled with a soil and clay mixture (soil-bentonite backfill mix) as excavation of the trench continues. The process continues until the wall is complete. The result is a low permeability wall keyed into a low permeability layer or carried to the desired depth.

The extent to which the groundwater and soil characteristics will influence the long-term integrity of the wall material can be investigated by a variety of preconstruction tests. A properly designed and installed slurry wall can be effective for many decades with little or no maintenance. A high level of quality control is necessary during construction to build an effective wall and a specialty contractor is required.

The typical capital cost of a soil-bentonite slurry wall is $9.00 to $12.00 per square foot of wall area. A slurry wall at the Joslyn site could be as much as 60 feet deep, which may require some excavation with a crane and clamshell bucket. This is a much less efficient method than using a backhoe. A unit cost of $11.00 per square foot of wall area was used for cost estimating purposes in this investigation.

The vibrated beam method is another technology used to construct a slurry wall. This is a proprietary technology that requires the use of a special beam connected to a powerful vibrator. The beam is locked into a guide frame for positioning and stabilized by a hydraulic foot that provides guidance and aids in keeping the beam vertical. Slurry is injected into the soil under pressure through nozzles located at the base of the vibrating beam as the beam is pulled out of the ground. At the completion of each panel, the vibrator and beam are moved along the wall alignment and a new panel is constructed. The new panel is overlapped with the previous panel to provide continuity. The method is reportedly applicable to depths as great as 80 feet. Saturated loose granular soils are best suited for the vibrated beam technology, although layers of clay and silt can reportedly be penetrated without difficulty. Disadvantages of the vibrated beam technology compared to the excavated trench technology are 1) possible uncertainty about the continuity of the wall at depth and 2) the substantial variability in lateral penetration of the slurry due to the geotechnical properties of the soil into which the slurry is injected. The cost of a vibrated beam slurry wall is usually quoted at about $9.00 per square foot of wall area. Although slightly less costly than the excavated slurry wall technology, the vibrated beam technology is considered less reliable and was not considered further.

Contaminated Soil Treatment

Solidification, incineration, composting, and conventional land treatment technologies were evaluated for the on-site treatment of the contaminated soil at the Joslyn site.

Solidification -- The objective of waste solidification is to create a hard, stable mass either by surrounding the waste with a solidifying agent or by mixing the waste with a solidifying agent to form a chemically fixed material. A number of proprietary and non-proprietary solidification technologies have been commercially available for the last few years and additional technologies are now in various stages of development. The potential for using commercially available solidification technologies on the contaminated soil at the Joslyn site is limited by the unknown leachability of solidified wood treating wastes. Because commercial suppliers of the available solidification technologies lack confidence in the ability of the available processes to treat wood preserving wastes, solidification is not considered at this time to be a technically feasible method to treat the contaminated soil at the site and was not considered further.

On-Site Incineration -- The burning of contaminated soil containing PAH compounds and pentachlorophenol in an on-site incinerator is a technically possible method of treatment. If the temperature and the retention time in the incinerator can be maintained at proper levels, thermal destruction of pentachlorophenol and PAH compounds will occur. Because contaminated soil has a low BTU content, a supplemental fuel source will be required. In addition, measures would have to be incorporated into the design of the incinerator to control the emissions of NO_x, SO_2, HCL, dioxins, and furans. A portable, circulating bed incinerator was selected for evaluation. In this system, acid gas emissions are controlled by the addition of granular limestone to the combustion chamber. Particulates are removed from the flue gas by a baghouse filter. Emissions of NO_x are low because of the retention period achieved in the combustion chamber.

The following assumptions were made to estimate the cost of applying this technology to the contaminated soil at the Joslyn site:

- 40,000 cubic yards of contaminated soil would be incinerated
- the heating value of the contaminated soil would be negligible

- a heat input of 4 million BTU will be required per ton of contaminated soil incinerated

- use of the incinerator would occur over a 24-month period

- the limestone requirement will be 20 percent of the waste inflow (by weight)

- ash from the incinerator will be used as clean fill in a demolition landfill type of disposal on-site.

The feasibility of this option depends on receiving all necessary permits and approvals to operate the incinerator. To obtain all needed approvals, it will be necessary to demonstrate that the stack emissions from the incinerator meet state and federal air pollution regulations. A test burn will be required to demonstrate such compliance. The feasibility of this option also depends on obtaining local acceptance of the incineration of the contaminated soil on-site.

The cost of incinerating the waste is estimated to be $250 per cubic yard. This includes the cost to purchase and operate the incinerator, perform test burns and pilot burns, secure permits, monitor during incineration, and dispose of the ash on-site as clean fill. The cost of this treatment technology used in this assessment is dependent upon the production of an ash that meets the MPCA's criteria for disposal as an on-site clean fill.

Composting -- Composting is a biological treatment process in which aerobic thermophilic decomposition of organic compounds occurs. The process is enhanced by maintaining moisture content, oxygen concentration, carbon/nitrogen ratio, temperature and pH within recommended ranges. A porous, stable material that is capable of sustaining biological decomposition is produced by mixing bulking agents (recycled compost or wood chips) and nutrients with the waste. Inoculation of the mixture with a microbial population will likely be required.

An extended aeration form of compost pile was assumed to minimize land requirements for the composting operation. In this design, aerobic conditions are maintained by drawing air through the piping network at the base of the pile. This induces air to flow into the pile. The temperature inside the pile can be controlled by adjusting the aeration rate.

The following design assumptions were used to evaluate the application of composting technology to the contaminated soil at the Joslyn site:

- wood chips would be used as the bulking agent
- bulking agent to waste ratio of 1:1
- a 1-year composting cycle will achieve 95 percent reduction of pentachlorophenol and PAH compounds
- 4,000 cubic yards of contaminated soil would be processed annually (project life of 10 years)
- unprocessed waste would be stored in a temporary on-site vault
- an asphalt pad would be used to collect leachate and runoff
- nutrients would be added to the compost mixture
- the compost mixture would be inoculated with pentachlorophenol and PAH acclimated bacteria
- the compost product would be used as topsoil for revegetation on-site.

For this treatment technology to be used, the material produced by this process must be able to be disposed of on-site as topsoil or clean fill. No literature was found on the composting of PAH and pentachlorophenol contaminated soil, so a pilot study would be required to evaluate the effectiveness of this technology in treating contaminated soil. Because the feasibility of composting soils contaminated with PAH compounds and pentachlorophenol has not been demonstrated at this time, this treatment technology was not be considered further.

Conventional Land Treatment -- In conventional land treatment, destruction of PCP and PAH compounds occurs through photo-oxidation and biodegradation of excavated contaminated soil that has been applied to designated areas of the site. The applied waste is managed to maximize the oxidation and degradation rates. Waste application rates would be limited to minimize leaching of contaminants below the treatment zone.

Microbial assimilation of pentachlorophenol and PAH compounds can be enhanced using the following management techniques:

- pH adjustment
- nutrient addition to maintain the organic carbon:nitrogen:phosphorus ratio within a recommended range
- control of soil moisture
- substrate addition to increase microbial activity
- inoculation of the waste with pentachlorophenol and PAH acclimated bacteria.

A pilot-scale study would be required to define the recommended application rate and the optimum conditions for waste treatment.

State hazardous waste regulations would have to be followed in designing and operating a land treatment system for wastes containing pentachlorophenol and PAH compounds. Under these regulations, all transformation and degradation of waste constituents must occur within a treatment zone which is limited to a maximum depth of 5 feet. In addition, the minimum distance between the bottom of the treatment zone and the seasonal high groundwater table must be 3 feet or more. Unsaturated zone monitoring, including soil monitoring and soil-pore liquid monitoring would be required immediately below the treatment zone to verify that contaminants are not leaching from the treatment zone.

Information on the effectiveness of the land treatment of pentachlorophenol-contaminated wood treating waste was not identified. Preliminary data were obtained from a demonstration study on the land treatment of creosote waste at a wood treating facility in northern Minnesota. A decrease in the concentrations of two-, three-, and the less complex four-ring (fluoranthene, pyrene, and chrysene) PAH compounds was observed in data collected during the three-month period used in this study. Degradation of more complex PAH compounds was not observed in this study, but has been shown to occur in other work.

Although degradation of pentachlorophenol and certain PAH compounds could be achieved using conventional land treatment at the Joslyn site, it may be difficult to meet regulatory requirements concerning the treatment zone at this site because of the high permeability and low adsorptive capacity of the sand in the upper sand unit. Land treatment at the Joslyn site was not given further consideration for this reason.

Off-Site Commercially Available Facilities

The implications of recent changes to the Federal hazardous waste legislation and regulations regarding the disposal of pentachlorophenol wastes have made operators of commercially available hazardous waste disposal facilities cautious about accepting these wastes. Changes to 40 CFR 261 and 264, (January 14, 1985 Federal Register) defined certain pentachlorophenol wastes and contaminated soil as acutely hazardous. This definition presently includes only manufacturing and not wood preserving uses of pentachlorophenol; however, operators of hazardous waste facilities fear that the definition might be expanded to include wood preserving wastes. Waste defined as acutely hazardous can be managed only at a fully permitted facility and not at facilities with interim permit status. Also of significance to facility operators is that pentachlorophenol wastes are a candidate for being banned from land disposal in two years. Facility operators and regulatory agencies also recognize that pentachlorophenol wastes contain dioxins. Facilities require extensive testing to define the dioxin concentrations in a pentachlorophenol waste before the waste is accepted for disposal. If dioxin is found in the waste, commercially available facilities will be hesitant to accept the waste due to potential regulatory and local opposition issues.

Off-Site Land Disposal -- Only one fully permitted hazardous waste land disposal facility presently exists in the United States. Operators of this facility, located in Arlington, Oregon, will reportedly not accept wastes from outside of the Pacific Northwest and Intermountain West. Land disposal facilities with interim permit status which could accept the contaminated soil from the Joslyn site are hesitant to commit to accepting the waste. The unit costs for disposal of contaminated soil in a secure landfill range from $380 to $760 per cubic yard, with typical costs around $600 per cubic yard. This includes the cost of testing, transportation, and disposal.

The most significant problems associated with the off-site land disposal of the contaminated soil are 1) the lack of willingness of such facilities to commit to accepting the waste when it is excavated and 2) the continued legal liability to Joslyn for the waste even after disposal at an off-site facility. The continued liability issue is considered to be greater than that associated with an on-site facility since Joslyn has no control over the continued management of the waste at an off-site facility. Based on the high cost, lack of reliability, and the added liability associated with the use of an off-site land disposal facility, this option was not considered further.

<u>Off-Site Incineration</u> -- As discussed previously, pentachlorophenol and PAH compounds can be destroyed in an incinerator fitted with the equipment and controls necessary to accomplish efficient destruction of the waste. In discussions with technical representatives of a hazardous waste incinerator in Chicago, it was learned that it is not practical to commercially incinerate contaminated soil. The following reasons were given:

- The large quantity of ash remaining after incineration will still require disposal in a hazardous waste landfill unless the waste can be delisted. It is typically not feasible to delist the ash unless a very large quantity is being incinerated. The cost to transport and dispose of the ash at a secure landfill greatly increases the overall cost of incineration, making this option impractical for contaminated soil.

- A large alternate fuel source must be maintained to destroy pentachlorophenol and PAH compounds because of the low Btu content of the contaminated soil. Fuel costs make this impractical.

In addition, soil contaminated with pentachlorophenol is likely to also contain dioxin compounds and commercially available facilities are not interested in wastes containing dioxins at the present time.

An estimate of the cost to incinerate soil contaminated with pentachlorophenol and PAH compounds at a commercial facility is $1,000 per ton if a facility can be found to accept the waste. This equates to $1,500 per cubic yard, at an assumed density of 1.5 tons per cubic yard. Based on the lack of interest expressed in the waste by the available facilities, future regulatory constraints on the incineration of pentachlorophenol wastes from wood preserving, the probable need to manage the ash as a hazardous waste or go through an expensive and time consuming delisting process, and the high cost of off-site incineration, this technology was not considered further.

Contaminated Surface Water Disposal

The contaminated surface water in Pond A should be discharged to the sanitary sewer. The cost of such a discharge is expected to be on the order of $1 per 1,000 gallons. If the quality of the water in Pond A is unacceptable for direct discharge to the sanitary sewer, pre-treatment could be provided. The surface water could be batch-treated with a flocculant at a cost of approximately $0.20/gallon. The sludge produced would be managed with the contaminated soil at the site.

CONTAMINATED GROUNDWATER CONTROL TECHNOLOGIES

The following two remedial control technologies have been identified for the contaminated shallow groundwater below and downgradient of the site: 1) slurry wall containment and 2) groundwater interception. Groundwater interception options will necessitate disposal of the water either to surface waters or the sanitary sewer. In the case of a surface water discharge, the need for treatment will depend on the quality of the water removed by pumping, the point of discharge, and the cost-effectiveness of technologies available to treat the discharge. In the case of a discharge to the sewer system, the need for treatment will depend on the quality of the pumped water, the rate of discharge, Metropolitan Waste Control Commission (MWCC) rules regarding the discharge and the cost-effectiveness of technologies to treat the discharge. Different effluent limitations and, therefore, different treatment technologies will likely apply to each discharge option. Much more stringent effluent limitations will be applicable to a surface water discharge than to a sanitary sewer discharge.

Slurry Wall Containment

Slurry walls are fixed underground barriers formed by pumping a slurry (usually a cement or bentonite and water mixture) into a trench as excavation proceeds and backfilling the trench with a designed mix of low permeability material. Cost and design considerations for slurry walls were described previously in the portion of this section that describes contaminated soil control technologies. Slurry wall containment systems used for groundwater control are often covered with a low permeability cap to minimize the recharge to the groundwater within the area surrounded by the slurry wall. Cost and design considerations for several low permeability caps are described in the portion of this section describing contaminated soil control technologies.

An alternative to providing a cap over the area surrounded by the slurry wall would be to use pump-out wells or a similar technique to lower the groundwater level in the area surrounded by the wall. Since only a slight downward vertical groundwater gradient exists at the Joslyn site, maintaining a slightly lower groundwater level than presently exists within the slurry wall containment area would result in an upward gradient at the base of the wall. This would result in the confinement of all contaminated groundwater within the slurry wall containment area, whether or not the base of the slurry wall is keyed into a low permeability formation. Water removed from the interior of the containment area may have to be pretreated prior to being discharged to the sanitary sewer or more completely treated prior to discharge to surface waters. Several pretreatment and treatment technologies are described in a latter portion of this section.

Groundwater Pump-Out

Groundwater pump-out wells or groundwater collection drains can be used to remove contaminated groundwater from the upper sand aquifer. Such a system would stop the further lateral migration of PAH compounds and pentachlorophenol within the capture zone of the system, reduce the vertical migration of organic compounds to the lower aquifer in the immediate vicinity of the groundwater pump-out system by lowering the water level in the upper aquifer, and eventually remove much of the contamination upgradient of the wells or drains. The choice between a system of pump-out wells or a system of drains will be made in final design if a groundwater pump-out system is used.

Two groundwater interception systems were used in the various remedial action plans evaluated in the feasibility assessment at the Joslyn site. These systems are 1) a system of wells or drains in the upper sand aquifer immediately downgradient of the areas of heaviest soil contamination on the site and 2) a system of wells or drains in the upper sand aquifer generally paralleling France Avenue near the downgradient boundary of the site. The locations of these groundwater pump-out systems are shown in Figure 22.

The anticipated pumping rates from the two groundwater pump-out systems are 80 gallons per minute (gpm) from the system immediately downgradient of the area of heaviest soil contamination on the site and 110 gpm from the system at the downgradient boundary of the site. The anticipated capture zones for the two pump-out systems are shown in Figure 22.

The capital cost of the pump-out system immediately downgradient of the areas of heaviest soil contamination soil on the site is estimated to be $570,000 and the annual operating and maintenance cost of this system is estimated to be $15,000 per year. The estimated capital cost of the groundwater pump-out system located along the eastern boundary of the site is also $570,000 and the annual operating and maintenance cost is estimated to be $15,000 per year. The capital cost includes furnishing and installing the wells or drains, pumps, and piping. The annual operating and maintenance cost includes electricity, monitoring prior to treatment, pump replacement, and reporting. Neither the capital nor the annual cost includes any treatment of the water prior to discharge. The annual cost assumes that the operation of the groundwater pump-out systems will not be affected by iron floc, iron bacteria or other physical and biological factors that could impair the performance of the system. The costs of the two groundwater pump-out systems are summarized in Table 15.

Groundwater Treatment -- Surface Water Discharge

It is anticipated that contaminated groundwater removed from the upper sand aquifer by a pump-out system would require rather extensive treatment prior to discharge to surface waters. The feasibility and cost of several potentially applicable treatment technologies was assessed using the following design assumptions:

1) Flow Rate: The flow rate from the various pump-out schemes evaluated at the site could vary from a maximum of about 200 gpm to a minimum of 80 gpm. A flow rate of 100 gpm was used in this assessment to compare technologies and to provide a "first-cut" unit cost for the assessment of remedial action plans.

2) Inflow Quality: The average quality of samples from Wells 113 and 2 located immediately downgradient of the former process area and Pond A was selected as being representative of the quality of groundwater removed by the pump-out system located immediately downgradient of the areas of heaviest soil contamination on the site. The average quality of samples from Well 112 in the eastern portion of the site divided by three was selected as being representative of the quality of the groundwater removed by the pump-out system located along the eastern boundary of the

site. A factor of three was applied to the quality of the water from the well located near the center of the contaminant plume at the location of the eastern boundary pump-out system to account for the fact that the groundwater at the edges of the capture zone of this pump-out system is anticipated to be significantly lower in PAH compound and pentachlorophenol concentrations than the groundwater at the well in the center of the plume. The assumed quality of the discharge from each pump-out system is summarized in Table 16.

3) Level of Treatment: Groundwater discharged to surface water would be required to meet the following effluent limitations:

- pentachlorophenol: 8 ug/L
- PAH compounds - List 1: 311 ug/L.

The pentachlorophenol criterion is based on the effluent limitations in a recently issued NPDES permit involving the clean-up of groundwater at another wood preserving site and the PAH criterion is based on the State of Minnesota's informal water quality level for potentially carcinogenic PAH compounds.

Because of the stringent effluent requirements assumed for the discharge of treated groundwater to surface waters, it is concluded that the groundwater will need to be treated with activated carbon or filtration and ozone/UV prior to discharge to surface waters. A number of pretreatment technologies were evaluated to reduce the cost of carbon treatment. Oil removal will be necessary from the discharge from the pump-out system immediately downgradient of the most heavily contaminated soil areas on-site.

The results of the investigations of several biological, chemical and physical pretreatment processes are summarized in the following paragraphs.

Biological Treatment Processes -- The available literature was reviewed on the biodegradation of water containing pentachlorophenol and PAH contaminated wood treating waste. Various laboratory studies have verified that pentachlorophenol is biodegradable in aqueous systems (Kirch and Etzel, 1973; Dust and Thompson, 1973). In addition, several studies have documented the degradation of pentachlorophenol by soil microorganisms (Suzuki and Nose, 1970; Watanabe and Hayashi, 1972, Watanabe, 1977). Only two references were found describing the biological treatment of pentachlorophenol contaminated wood treating wastewater in pilot scale systems (USEPA, 1976; Environment Canada, 1980). No literature studies were identified describing the biodegradation of PAH compounds in wood treating wastewaters.

The following critical factors that tend to limit the biological degradation of pentachlorophenol and PAH compounds were identified in the literature:

1) Nutrients -- The low concentrations of nitrogen and phosphorus in wood treating wastewater can limit the growth of microorganisms capable of assimilating pentachlorophenol. To increase microbial activity, nitrogen and phosphorus may have to be added to the water in sufficient quantities to maintain a BOD_5:nitrogen: phosphorus ratio of 100:5:1 (WPCF, 1977).

2) Growth Inhibitors -- Organic compounds capable of inhibiting microbial activity may be present in water contaminated with wood preservatives. Although no single compound may be present at a toxic concentration, the cumulative effect of several compounds may be sufficient to limit microbial activity.

3) Acclimation Period -- The acclimation of a microbial community to water contaminated by wood preservatives is necessary for the organic compounds in the water to be treated. The acclimation period is dependent upon the strength and composition of the water.

A treatability test, performed at the University of Minnesota using contaminated water containing pentachlorophenol and PAH compounds from another wood preserving site in Minnesota, demonstrated that biological treatment is a technically viable means of reducing PAH and pentachlorophenol concentrations in wastewater. Assuming that the results of a similar treatability investigation show that the biological treatment of contaminated groundwater at the Joslyn site is technically feasible, the following specific biological pretreatment processes thought to have potential application at the site were evaluated:

1) Activated Sludge
2) Aerated Stabilization.

These processes are briefly described below.

Activated Sludge -- In the activated sludge process, a microbial population capable of degrading organic compounds is maintained in an aeration tank. The hydraulic detention time in the aeration tank may vary from 4 to 24 hours, depending upon the activated sludge process being used. Solids separation is accomplished in a clarifier, with the collected sludge either returned to the aeration tank or removed from the system for disposal. For treatment of waters having low concentrations of nitrogen and phosphorus, nutrient addition may be required to maintain the organic carbon:nitrogen:phosphorus ratio of the mixed liquor at a level which will stimulate microbial activity.

Although pilot scale studies have demonstrated that pentachlorophenol removal can be achieved by an activated sludge process (Environment Canada, 1980), USEPA, 1976), insufficient data are available to derive values for parameters necessary to design an activated sludge pretreatment system for groundwater from the Joslyn site. The composition and temperature of the contaminated groundwater at the site is substantially different from the process water used in the two pilot studies described in the literature. Because of the lack of design information and the differences in wastewater composition, it would be necessary to operate a pilot scale system at the wood preserving site to determine values for critical design parameters.

Aerated Stabilization -- Microbial degradation of the waste occurs in the aeration basin where aerobic conditions are sustained by surface aerators. In addition, the aerators keep the water in the basin mixed and the microbial floc in suspension. In most applications, the aerated basin is sized to provide a hydraulic detention time greater than 10 days. Solids separation is accomplished in a clarifier. Since sludge is not recycled back to the aeration basin, the solids retention time of the system is equal to the hydraulic detention time.

As with any other biological treatment process, nutrient addition may be required to treat wastewater deficient in nitrogen and phosphorus.

Biological treatment processes for groundwater removed by the pump-out system assumed at the Joslyn site would require a capital investment in excess of $1,000,000 and require annual operating costs on the order of $200,000 to $300,000 per year to maintain the treatment facility and manage the sludge. The effluent would also require treatment with activated carbon. In view of the other treatment technologies available, biological treatment was dropped from further consideration.

Chemical Oxidation Processes -- Chemical oxidation can also be used to remove pentachlorophenol and PAH compounds from the contaminated groundwater. Chemical oxidants which were investigated were hydrogen peroxide, ozone and a combination of ozone and ultraviolet irradiation. Although complete oxidation of the contaminants to carbon dioxide and water will not be achieved, compounds may be formed which are easily removed by other treatment processes. If chemical oxidation is evaluated in a pilot study, samples should be analyzed for possible byproducts of the oxidation reaction.

Ozone -- Information in the literature indicates that ozone is an effective oxidant for organic compounds. Bench scale tests on water contaminated with pentachlorophenol and PAH have indicated that ozone is effective at oxidizing pentachlorophenol in contaminated groundwater. Based on the evidence from bench scale testing, a conceptual design of an ozone pretreatment system consisting of an ozone generator, air drier, mixing tank and contact tank was assumed.

Ozone is generated by passing dry air or oxygen between two high voltage electrodes. Since ozone is relatively unstable, it must be produced on-site at the time of use. Ozone is a strong oxidant that reacts rapidly with many organic compounds.

The capital cost for a 100 gpm ozone pretreatment system is estimated to be $400,000. The annual operating and maintenance cost for such a system is estimated to be $120,000 per year.

Ozone-UV -- A variation of ozone oxidation is a process where a combination of ozone and ultraviolet (UV) irradiation is used to degrade organic compounds. In this process, the rate of degradation is faster and the extent of oxidation more complete than with ozonation alone. This is due in part to the cleavage of chemical bonds by the high energy input introduced by UV irradiation. The estimated capital cost for a 100 gpm ozone-UV treatment system is $1,000,000. The annual operating and maintenance cost for this system is estimated to be $300,000 per year.

Hydrogen Peroxide -- Hydrogen peroxide is effective in oxidizing many phenolic compounds under the proper conditions. Oxidation is optimized at a pH between 2.5 and 4.5 when iron is used as a catalyst. Bench scale studies are required to establish optimum operating conditions.

A major disadvantage of this pretreatment process is the large volume of sludge that will be generated during operation. It is estimated that 6,000 lbs. per day of iron hydroxide/calcium carbonate sludge would be produced under 100 gpm design conditions. This high volume of sludge and the anticipated problems with its disposal make this alternative not feasible.

Physical Treatment Processes -- Pentachlorophenol and PAH compounds can be removed from groundwater by physical treatment processes. Using these processes, contaminants are selectively removed based on their physical properties. Physical treatment processes that were investigated were carbon adsorption, wet-air oxidation, and oil removal. Oil removal will be needed as a pretreatment step before any other treatment technology for the discharge from the pump-out system immediately downgradient of the contaminated soil areas on the site.

Carbon Adsorption -- In carbon adsorption treatment, a fixed bed of granular activated carbon serves as the adsorption media. The system could be operated as a downflow gravity system or as an upflow pressure system. Depending upon the quality of water being treated, backwash and surface washing capabilities may be required which would necessitate a pressure system. Carbon adsorption units can be operated as a single unit or combined in series or in parallel.

The efficiency of a carbon adsorption unit depends upon:

- flow rate
- column height
- contaminant concentrations
- pH
- competition for adsorption sites by individual contaminants
- affinity of the contaminant for the carbon surface.

The following conditions were assumed for full-scale design purposes:

- flow rate of 100 gpm
- no pretreatment of contaminated groundwater except oil removal
- four units (each containing 20,000 pounds GAC) in series
- carbon burn rate of 3.7 pounds of GAC per 1,000 gallons treated.

Based on these assumptions, the capital cost of a 100 gpm granular activated carbon treatment system is estimated to be $470,000 and the annual operating and maintenance cost is estimated to be $400,000 per year.

Carbon treatment of wood preserving wastewater has recently become less attractive than it was previously. Pentachlorophenol contaminated soil and groundwater has been found to carry trace concentrations of various dioxins and activated carbon suppliers are refusing to regenerate the spent carbon. Alternate disposal methods must then be found for the spent carbon. The available options include on-site containment, on-site regeneration or disposal in a fully permitted hazardous waste facility.

Wet-Air Oxidation -- Wet-air oxidation is the oxidation of soluble organic compounds by air, under pressure, at temperatures between 350°F and 700°F. The efficiency of the process is dependent upon the quantity of air supplied and the temperature maintained. The treated effluent, consisting of water, carbon dioxide, hydrochloric acid, organic acids and inert ash will require additional treatment prior to discharge. According to a manufacturer of wet-air oxidation units, the economic feasibility of this process is dependent on solids content, volatile organic content, and the organic loading of the waste to be treated. In general, wet-air oxidation can be feasible for a waste containing 1 to 10 percent solids. The capital cost of a unit capable of treating 55 mg/L COD at 10 gpm is approximately $2.45 million. The annual operating and maintenance cost is about $650,000 per year. Due to the relatively high capital and operating costs required for a unit capable of treating groundwater contaminated with pentachlorophenol and PAH compounds, this process was eliminated from further consideration.

Oil Removal -- Oil removal will be needed for the groundwater from the pump-out system located near the areas of heavily contaminated soil on the site prior to treatment by other treatment technologies. Oil separation should be able to provide at least 50 percent removal of the PAH compounds and pentachlorophenol from the water in the discharge from that pump-out system. Oil separation can be accomplished with a gravity oil separator. The most typical design is the American Petroleum Institute (API) separator. The features of this separator include oil skimming, sludge collection, and detention times of 20 to 60 minutes to allow for the gravity separation of the oil. Oil separation may be enhanced by the use of coagulants to induce the coalescing of the oil particles.

Oil screen filtration can also be used for oil removal. This method will separate suspended oil from a liquid stream on the basis of differential surface tension. The process has been successfully applied to many types of oil water mixtures in oil spill clean-up and oil scavenger well applications. The applicability of the oil screen technique on the oil-water mixture in the vicinity of the areas of most heavily contaminated soil on the site will require bench scale and/or pilot scale testing prior to final design. The capital and operating costs for oil screen filtration is likely to be similar to that of an API separator. The screens may also be used in addition to an API separator to enhance oil removal, reduce the amount of water contained in the oil waste, and thereby reduce the total cost of the oil separation.

Additional features of an oil separation system include oil handling and storage facilities, sludge handling and storage facilities, coagulant mixing tank, chemical handling equipment, automatic controls, and a treatment building. The collected oil will have to be disposed of, probably by incineration at a hazardous waste incinerator. The oily water should be collected so as to minimize the amount of emulsification that occurs. If the oil is emulsified, a de-emulsifier step will be needed, which will greatly increase costs. The estimated capital cost of an oil removal system for a 100 gpm discharge from the pump-out system located immediately downgradient of the most contaminated areas on the site is $400,000. The estimated annual operating and maintenance cost is $150,000 per year.

Summary -- The capital, annual operating and 30-year present worth costs of the various groundwater treatment technologies available for a surface water discharge of 100 gpm are compared in Table 17. It is technically feasible but extremely expensive to treat the contaminated groundwater to a level suitable for discharge to surface waters. Given the assumptions that were used in preparing the cost estimates, the long-term costs for granular activated carbon alone and granular activated carbon with ozone/UV pretreatment are about the same. From a practical standpoint, if a surface water discharge is necessary, granular activated carbon treatment should initially be used with oil separation. After the groundwater pump-out wells and the granular activated carbon treatment system are in place, a much better evaluation of the cost-effectiveness of pretreatment could be made. With the pump-out system in place, there would be a good estimate of inflow quality and flow rate, both of which would influence the cost-effectiveness of pretreatment.

Treatment of Contaminated Groundwater -- Sanitary Sewer Discharge

If permission can be obtained from the Metropolitan Waste Control Commission (MWCC), the groundwater removed from the upper sand aquifer could be discharged directly to the sanitary sewer without pretreatment. Such direct discharges from groundwater contamination clean-up projects have occurred in the past. The PAH compounds and pentachlorophenol in the groundwater below the site should be effectively removed at the MWCC metro sewage treatment plant. Due to a change in policy or for some other reason, pretreatment may be required for all or a portion of the water from a groundwater pump-out system prior to the discharge of the groundwater to the sanitary sewer.

For purposes of evaluating the cost and feasibility of various pretreatment technologies applicable to a sanitary sewer system discharge, it was assumed that the only pump-out system discharge that would require pretreatment would be the discharge from the system located immediately downgradient of the areas of heaviest soil contamination on the site. Oil removal would probably be the only treatment technology investigated in the preceding portion of this section that would be applicable to a sanitary sewer discharge.

The estimated capital cost for the construction and startup of an oil removal system is $400,000. The annual operating and maintenance cost for the oil removal system is estimated to be $150,000 per year.

too high by factor of 10?

The annual operating and maintenance cost includes the cost of discharging the groundwater to the sewer system. It was assumed that this cost would be $1 per 1,000 gallons. This amounts to a cost of approximately $50,000 per year for a discharge of 100 gpm. Bench testing of the technologies would be needed to establish the effectiveness and to define the design and operating parameters of such a system.

The costs for groundwater treatment are based on an assumed constant inflow quality and flow rate. If a groundwater pump-out system is installed, the concentrations of pentachlorophenol and PAH compounds as well as the pumping rate from the system will likely decrease with time. The decrease in concentrations and flow rate will result in lower annual operating and maintenance costs for the treatment system and for the cost of discharging to the sanitary sewer. Since it is not possible to accurately estimate the time-rate of decrease in concentrations or flow rate, use of a fixed inflow concentration and flow rate is appropriate for cost comparison purposes at this level of investigation.

A significant issue with any groundwater pump-out system is the likelihood that effluent limitations imposed by the regulatory agencies (MPCA and MWCC) will change in the future. Possible changes to effluent limitations makes it difficult to plan for future operating costs and to select the most cost-effective remedial action plan.

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Section 4

ALTERNATIVE REMEDIAL ACTION PLANS

SECTION 4

ALTERNATIVE REMEDIAL ACTION PLANS

INTRODUCTION

The remedial investigation in Section 2 of this report identified contaminated soil in the former operating areas of the site and a plume of contaminated groundwater in the upper portion of the upper aquifer extending downgradient of the areas of contaminated soil. The remedial investigation also identified the potential for the slow downward migration of the PAH compounds and pentachlorophenol into a lower aquifer under the site. This lower aquifer is connected to aquifers that are used by residential wells in the vicinity of the site and municipal wells regionally. No water supply aquifer has been affected by contaminants from the site at this time. The contaminated soil at the site continues to release PAH compounds and pentachlorophenol to the shallow groundwater and the potential exists for the continued lateral and vertical migration of these contaminants.

The technically feasible and potentially effective technologies defined in Section 3 of this report are combined into several alternative remedial action plans in this section. The alternative remedial action plans defined in this section are grouped into three general levels of control (degree of protection) over the contaminated soil and groundwater contamination at the site. The general levels of control are as follows:

I. SOURCE CONTROL: Remedial action plans at this level of control are designed to minimize the further release of contaminants to the saturated zone.

II. SOURCE GROUNDWATER CONTROL: Remedial action plans at this level of control are designed to minimize the further release of contaminants to the saturated zone and minimize the further migration of contaminated groundwater from the areas of heaviest soil contamination on the site.

III. SITE GROUNDWATER CONTROL: Remedial action plans at this level of control are designed to minimize the further migration of contaminated groundwater from the site.

The alternative remedial action plans within each level of control are designed to provide similar levels of protection, although some differences in effectiveness are apparent. The most cost-effective remedy for the site balances the degree of protection appropriate to the site with the cost of imposing that protection.

The remaining portion of this section provides a description, effectiveness assessment, technical evaluation and cost estimate of a wide range of possible remedial action plans for the site. The description of each remedial action plan explains each of the major elements of the plan. This description also summarizes the assumptions on which the cost estimate and effectiveness assessment are based. The effectiveness assessment evaluates the extent of clean-up that can be anticipated from the plan. The technical evaluation of each remedial action plan discusses the plan's reliability, constructability, implementation schedule, and site benefits.

> Reliability is defined as the remedy's expected durability and consistency of performance over time and under changing conditions. Features that add to the remedy's effectiveness or to the ease of monitoring are highlighted.
>
> Constructability is defined as the need for special capabilities or technology to implement the remedy, important techniques or practices involved in the remedy, and any negative short-term environmental impacts that are likely during implementation of the remedy. All construction activities at the site have the potential to cause noise, dust, odor and may temporarily interfere with use of the site adjacent to the construction area. These impacts can be mitigated by prohibiting noisy work during evenings and weekends, using dust and odor control measures, and planning construction sequences to minimize disruption to the neighbors and the existing use of the site. Release of sediment to Twin Lakes during construction can be minimized by using standard erosion control measures such as temporary diking. These impacts and mitigative measures are not described separately for each remedial action plan.
>
> Implementation schedule is a general estimate of the time required to implement the remedial action plan once a remedy has been approved. The implementation schedule includes the engineering design and

construction of the remedial actions activities as well as a reasonable time period to obtain necessary permits and approvals. Delays due to agency approvals, public hearings, permitting, and other administrative activities that could occur in the process of selecting and securing authorization to implement the remedy are not included in the implementation schedule. The estimated time needed to construct a remedy assumes that the construction season begins April 15 and ends November 15.

Site benefits are the advantages gained from implementation of the remedial action plan that are beyond the objectives of the remedy as it is designed to function. Land use benefits are the primary site benefits noted.

The cost estimates provide the estimated cost of engineering, permitting, administration and construction of the remedial action plan in January, 1986 dollars. Annual costs of operation and maintenance are also included. The cost of future monitoring of the site is included in the annual cost of operation and maintenance. Judgement was used to define a level of future monitoring that would be consistent with the level of protection provided by the remedial action plan. Annual costs are converted to present worth cost using a 6 percent net interest rate and a 30-year time period. Annual costs for remedial action plans that are expected to operate for time periods of less than 30 years, such as on-site incineration, are converted to a present worth cost using a net interest rate of 6 percent and the time period for which the remedy is anticipated to operate. The present worth of the annual cost is added to the capital cost of the remedial action to obtain the total 30-year present worth cost of each remedial action.

I. SOURCE CONTROL ALTERNATIVES

The objective of the alternative remedial action plans designed to achieve this level of protection is to minimize the further release of contaminants to the saturated zone. Remedial action plan alternatives at this level of control will result in the eventual improvement in the quality of the groundwater due to dilution, dispersion, and attenuation. Not acceptable

The remedial action plans that are designed to provide this level of protection are:

I.A. Site Grading - grading contaminated soil areas.
I.B. Capping - capping contaminated soil areas.
I.C. On-Site Vault - containment of contaminated soil.
I.D. On-Site Incineration - incineration of contaminated soil.

ALTERNATIVE I.A.: SITE GRADING

Description

The site grading alternative is designed to eliminate the presence of contaminated soil and surface water at the ground surface. The important elements of the site grading remedial action plan are shown in Figure 23. Under this alternative, the water in Pond A would be discharged to the sanitary sewer after any necessary pretreatment. Pond A would be filled with soil from the surrounding dikes and the disturbed area would be graded and revegetated. The depression in Area 5 on the site would be filled and revegetated. A drainageway would be constructed to provide surface drainage to the west from this area. All contaminated soil at the ground surface would be covered with at least 1 foot of clean soil obtained from an on-site source.

Under this alternative, it was assumed that routine site monitoring would consist of the quarterly monitoring of 15 upper aquifer wells and five lower aquifer wells for PAH and phenolic compounds for a period of 30 years.

Effectiveness

Site grading will reduce but not eliminate the infiltration of precipitation through the contaminated soil above the surface of the saturated zone. The contaminated soil on the site would continue to release contaminants to the shallow groundwater, but the rate of contaminant release would be less than it is now. Pond A and the former process area of the site currently have no surface water drainage outlet. Precipitation on these areas now evaporates or infiltrates to the upper aquifer. Grading will encourage runoff from these areas by establishing an outlet and providing a sloped surface. It is estimated that grading will reduce infiltration in these areas by 50 percent. If contaminant release is proportional to infiltration, this will result in a 50 percent reduction in contaminant release to the groundwater from the contaminated soils above the saturated zone in these areas. No reduction in contaminant leaching would occur under this alternative from contaminated soil located below the groundwater table or above the groundwater in areas that are not graded. No measurable reduction in the rate of lateral movement of contaminants already in the groundwater is expected with this plan. No change is expected in the potential for contaminant migration to the lower aquifer under this plan.

Technical Evaluation

Reliability. Site grading is a low maintenance remedial action, requiring only regular mowing and annual inspection. The sloped ground surface enhances runoff and reduces infiltration for most typical rainfall or snowmelt events. The need for maintenance or improvement to the graded surface would be obvious by depressions or ponding at the ground surface. The reliability of the remedy is high provided that the grading and vegetation are maintained.

Constructability. The construction activities associated with this alternative require standard construction techniques.

Implementation Schedule. It is anticipated that this alternative could be constructed in three months during the construction season, provided that a 2-month lead time is provided for engineering design prior to the beginning of construction.

Site Benefits. The potential use of the site would be only slightly enhanced by this remedial action. Contaminated soil would remain at the site. Areas with contaminated soil could be developed for such uses as open space, recreation, and parking since the soil would be covered by clean material, but such areas would generally not be suitable for new construction.

Cost

The estimated cost of this remedial action is summarized in Table 18. The total estimated capital cost is $290,000 and the estimated annual operating and maintenance cost is $141,000 per year, which is primarily site monitoring. The total 30-year present worth cost of this remedial action is $2,240,000.

ALTERNATIVE I.B.: CAP CONTAMINATED SOIL

Description

This remedial action plan involves placing a low permeability cap over all contaminated soil on the site. The important elements of this remedial action plan are shown in Figure 24.

The multi-layer cap or the 100 mil synthetic membrane cap described in the previous section of this report was assumed in this alternative. The cap would be sloped to promote drainage. A drainageway would be cut to the west to promote surface water drainage from the capped area.

The contaminated soil in the portion of the site not covered by the cap shown in Figure 24 would be excavated and placed under the cap. It is estimated that 18,000 cubic yards of contaminated soil, including 8,000 cubic yards from below the surface of the saturated zone in the vicinity of Ponds A and B, would be excavated and moved under the cap. Groundwater encountered during excavation of the contaminated soil would be discharged to the sanitary sewer after pretreatment. Sludge generated by pretreatment would be dewatered and placed beneath the cap. The surface water in Pond A would be discharged to the sanitary sewer before excavation of the contaminated soil in Pond A.

As with the previous alternative, it was assumed that routine site monitoring would consist of the quarterly monitoring of 15 upper aquifer wells and five lower aquifer wells for PAH and phenolic compounds for a period of 30 years.

Effectiveness

It is anticipated that capping will reduce infiltration of precipitation through the contaminated soil above the saturated zone by more than 90 percent, from an estimated 10 inches per year to less than 1 inch per year. If contaminant leaching is proportional to infiltration, capping will result in about a 90 percent reduction in contaminant release to the groundwater from the contaminated soil above the saturated zone. Thus, this remedial action plan would be significantly more effective in minimizing the further release of contaminants to the upper aquifer than would the previous alternative. In addition, contaminated groundwater encountered during excavation of contaminated soil outside the capped area would be removed which makes this alternative more effective than capping. Leaching from the contaminated soil located below the groundwater table in the capped area will be unaffected under this plan. A reduction in the concentrations of PAH compounds and pentachlorophenol in the groundwater beneath and downgradient of the site can be expected over the long-term with this alternative. Accurate predictions cannot be made of the rate of improvement in groundwater quality due to the cap. Excavation activities may mobilize some PAH compounds and pentachlorophenol, resulting in a temporary increase in groundwater contaminant concentrations immediately downgradient of the excavation areas. No change is expected in the potential for contaminant migration to the lower aquifer under this alternative in the short-term, however, over the long term a reduction in vertical contaminant migration can be expected as the quality of the upper aquifer improves due to dilution, dispersion and attenuation.

Technical Evaluation

Reliability. A cap is a reliable long-term, low-maintenance cover for the contaminated soils. The cap material, whether synthetic membrane or clay would be resistant to attack by contaminated soil. The cap cannot be expected to eliminate all infiltration through the soil, but will achieve a substantial reduction in leachate production even with imperfections and some loss of integrity with time. Annual inspection and regular maintenance of the cover over the cap will improve the long-term reliability of the cap. It is difficult to determine that a cap is functioning correctly and a major flaw in construction could seriously reduce the cap's effectiveness. Monitoring the groundwater around the cap will not be useful in defining the cap's effectiveness because the underlying groundwater is contaminated before cap placement.

Constructability. Cap construction is unusual in the heavy construction industry, but does not require a specialized contractor. Care and attention to detail must be paid when placing and covering the synthetic membrane. Any necessary pretreatment of contaminated water from Pond A or groundwater removed during excavation of contaminated soil is also unusual in construction. The other construction activities require standard construction techniques.

Implementation Schedule. It is anticipated that this remedial action plan could be constructed in one construction season, provided that a lead time of 4 months is allowed for engineering design and related field work prior to the beginning of the construction season.

Site Benefits. The potential use of the site would be substantially enhanced by this remedial action plan. The majority of the site would be cleared of contaminated soil which could interfere with site use. The capped area would be usable as open space, recreation or parking.

Cost

The estimated cost of this alternative is summarized in Table 19. The total estimated capital cost is $1,110,000 and the total estimated annual operating and maintenance cost is $141,000, for a total 30-year present worth cost of $3,060,000.

ALTERNATIVE I.C.: ON-SITE VAULT

Description

This remedial action plan involves excavating all contaminated soil on the site and placing the soil into a secure containment vault constructed on-site. The key elements of this remedial action plan are shown in Figure 25.

The vault would be constructed with a double liner and leachate collection/detection systems as described in Section 3 of this report. The vault would be designed to contain 40,000 cubic yards of contaminated soil, but could be made larger or smaller depending on the volume of contaminated soil actually encountered.

All contaminated soil would be excavated and placed in the vault. The estimated volume of contaminated soil includes 15,000 cubic yards anticipated to exist below the surface of the saturated zone in the vicinity of Ponds A and B and in Areas 4, 5, and 6. Contaminated groundwater encountered during excavation in these areas would be discharged to the sanitary sewer after any necessary pretreatment. Any sludge generated during pretreatment would be placed in the vault. The surface water in Pond A would be discharged to the sanitary sewer after any necessary pretreatment.

The routine site groundwater monitoring program assumed for the previous alternatives (quarterly sampling of 15 upper aquifer wells and five lower aquifer wells) was assumed for the first 10 years following implementation of this alternative. After 10 years of monitoring, it was assumed that semi-annual monitoring of the same number of wells would be required for the next 10 years and that annual monitoring of the same wells would be required for the final 10 years of the 30-year period. The monitoring program assumed for the vault is described in the assessment of this technology in Section 3 of this report.

Effectiveness

The vault will provide effective containment of the excavated contaminated soil and would eliminate the release of contaminants from the contaminated soil on the site. Any infiltration penetrating the vault cap would be collected in the internal leachate collection system. The removal and disposal of contaminated groundwater during excavation of contaminated soil from below the surface of the saturated zone will also remove a significant source of contamination. The control of the contaminant sources under this plan is complete enough that some reduction in PAH and pentachlorophenol concentrations in the groundwater in the contaminated areas of the site can be anticipated within a 5-year period. As with the other plans involving the excavation of contaminated soil, excavation may mobilize some contaminants resulting in a temporary increase in groundwater contaminant concentrations in the excavation area. The long-term potential for contaminant migration to lower aquifers would be reduced due to the reduced concentrations of contaminants in the upper sand aquifer. This remedial action plan is considered more effective than the capping alternative since the contaminated soil and a portion of the contaminated groundwater is removed from below the surface of the saturated zone.

Technical Evaluation

Reliability. A vault is a long-term, low-maintenance container for the contaminated soil. The liners used in the cap and bottom liner would be resistant to attack by the chemicals in the contaminated soil. The leachate collection system will minimize the accumulation of liquid in the vault. Annual inspection and regular maintenance of the vault cap will help prolong the life of the cap. Monitoring of the leachate collection system and the leak detection system can be used to assess the vault's integrity,. Monitoring of the groundwater around the vault will not be helpful in evaluating the vault's effectiveness, because that groundwater is likely contaminated before vault construction.

Constructability. Vault construction is unusual in the construction industry, but does not require a specialized contractor. Care and attention to detail must be paid when placing and constructing the liner and capping systems. The other construction activities require standard construction techniques.

Implementation Schedule. It is anticipated that this alternative could be constructed in one construction season, provided that a lead time of 4 months is provided for engineering design and related field activities prior to the beginning of construction. Implementation could be delayed by difficulties in obtaining local acceptance for the long-term containment of the contaminated soil on-site.

Site Benefits. The potential land use of the site will be substantially enhanced by this remedial action. The site would be cleared of contaminated soil which might interfere with further site use. The vault area would be surrounded by a fence and would likely not be usable unless a special vault design is used to accommodate development.

Cost

The estimated cost of this alternative is summarized in Table 20. The total estimated capital cost is $3,250,000, the total estimated annual operating and maintenance cost is $162,000 for the first 10 years, $114,000 for the next 10 years, and $90,000 for the final 10 years of the 30-year period. The total 30-year present worth cost of this alternative is $5,140,000.

ALTERNATIVE I.D.: ON-SITE INCINERATION

Description

This remedial action plan involves the excavation and on-site incineration of all contaminated soil on the site. The key elements in this remedial action plan are shown in Figure 26. The incinerator would be a portable facility which would be removed from the site upon completion of the project. The incinerator that was evaluated in this investigation is capable of processing 5 tons of contaminated soil per hour. It was assumed that the residual ash from the incineration of the contaminated soil would be used as clean fill on-site. Contaminated soil awaiting incineration would be stored on a temporary pad with a low permeability base and covered with a synthetic membrane. Any leachate collected from the pad would be treated if necessary and discharged to the sanitary sewer.

It is anticipated that all 40,000 cubic yards of contaminated soil would be excavated. Groundwater encountered during excavation would be pretreated as necessary and discharged to the sanitary sewer. The surface water in Pond A would be discharged to the sanitary sewer, after any necessary pretreatment.

The same routine site groundwater monitoring program assumed for the on-site vault alternative (Alternative I.C.) was assumed for this option. The monitoring program assumed for the incinerator is described in the assessment of this technology in Section 3 of this report.

Effectiveness

Incineration provides complete destruction of contaminants in the soil, thus eliminating the future source of contaminants to the groundwater. A reduction in the concentration of contaminants in the groundwater equal to that achieved under the on-site vault alternative is expected. As with the other alternatives involving excavation, excavation may mobilize some contaminants that would not otherwise have been mobilized, resulting in a temporary increase in groundwater contaminant concentrations downgradient of the excavation areas. The long-term potential for contaminant migration to lower aquifers would be reduced with this plan due to the reduced concentrations of contaminants in the upper aquifer. The effectiveness of this alternative is considered equivalent to the effectiveness of the on-site vault (Alternative I.C.).

Technical Evaluation

Reliability. An incinerator is a dependable technology for destroying the contaminants at the site. Performance can be reasonably assumed by the temperature and residence time in the combustion chamber and monitored by testing samples of the incinerated material and the incinerator emissions.

Constructability. The incinerator is supplied by a vendor who installs and tests the equipment, runs pilot tests to assure that required destruction efficiencies and air emission standards can be met, and trains an operator to operate the incinerator. The other construction activities associated with this remedial action plan can be completed with standard construction techniques.

The operation of the incinerator may cause some noise but should not cause dust or odors. Proper siting and screening of the equipment can reduce the disruption to neighbors. If noise levels or other aspects of the incinerator are found to be disruptive, additional mitigative measures are available.

Implementation Schedule. It is anticipated that this alternative could be implemented in two years and completed in four years, provided delivery of an incinerator, pilot testing and approvals to dispose of the incinerated soil can be completed in one year. The incineration of the waste would require two years at a rate of 20,000 cubic yards per year. This alternative has more risk than the previous alternative that the implementation schedule could be delayed by the time needed to secure necessary approvals, permits, authorization for the operation of the incinerator, and on-site disposal of the incinerated soils.

Site Benefits. The potential use of the site will be greatly enhanced by this remedial action. The site would be clear of contaminated soil which might interfere with site use. Once the incinerator has been removed, use of the site would not be restricted by soil contamination or by any long-term containment facility. This remedy also eliminates any risks associated with the long-term containment of the contaminated soil on-site.

Cost

The estimated cost of this alternative is shown in Table 21. The total estimated capital cost is $10,600,000 and the total estimated annual operating and maintenance cost is $134,000 for the first 10 years, $86,000 for the next 10 years, and $62,000 for the final 10 years of the 30-year period. The total 30-year present worth cost of this alternative is $12,080,000. The cost of operating and monitoring of the incinerator and disposing of the ash on-site are shown as a 2-year total in Table 21. This cost was treated as a first year total, and was not adjusted by a present worth calculation. The cost of incineration will increase substantially if the incinerated soil cannot be disposed of on-site as clean fill.

II. SOURCE GROUNDWATER CONTROL

The objective of the alternative remedial action plans designed to achieve this level of protection is to isolate contaminated soil and groundwater in the areas of heaviest soil and groundwater contamination on the site from the other portions of the site. This isolation will greatly reduce the movement of contaminants from the areas of heaviest contamination on-site and eventually slow the lateral and vertical spread of the contaminated groundwater outside the limits of the remedy.

The remedial actions plans that are designed to provide this level of protection are:

II.A. Slurry Wall Containment
II.B. Cap and Source Groundwater Pump-Out System
II.C. Vault and Source Groundwater Pump-Out System

ALTERNATIVE II.A.: SLURRY WALL CONTAINMENT

Description

This remedial action plan involves placing a slurry wall around the areas of heaviest soil and groundwater contamination on the site, excavating any contaminated soil identified outside the area surrounded by the slurry wall, placing the contaminated soil inside the slurry wall containment area, and capping the containment area. The alignment of the slurry wall used in this assessment is shown in Figure 27.

The slurry wall shown in Figure 27 surrounds the contaminated soil in Areas 5 and 6 and extends from the ground surface to a depth of approximately 60 feet. The area surrounded by the slurry wall would be capped with a low permeability membrane. It is anticipated that the slurry wall will be keyed into the middle confining unit along its entire length. Groundwater would be pumped from the containment area at a rate necessary to depress the groundwater surface inside the containment area to a level below the groundwater level outside the containment area. The primary objective of this interior pump-out system is to minimize the vertical migration of contaminants from the containment area. The groundwater removed from the containment area would be discharged to the sanitary sewer, after any necessary pretreatment. It was assumed that oil removal would be required as a pretreatment step prior to discharge of the water to the sanitary sewer.

It is estimated that 22,000 cubic yards of contaminated soil would need to be excavated and placed within the containment area. This includes 9,000 cubic yards from below the surface of the saturated zone in the vicinity of Ponds A and B and in Area 4. Contaminated groundwater encountered during excavation of contaminated soil would be discharged to the sanitary sewer after any necessary pretreatment.

The same level of routine site groundwater monitoring assumed for the on-site vault (Alternative I.C.) and on-site incineration (Alternative

I.D.) was assumed for this alternative. In addition, quarterly monitoring of water levels within the slurry wall containment area and quarterly monitoring of the discharge to the sanitary sewer system was assumed.

Effectiveness

A slurry wall and cap will provide effective control of the contaminated soil and groundwater inside the containment area. The cap over the slurry wall containment area can be expected to reduce infiltration through the contaminated soil above the water table in the containment area by more than 90 percent. Lowering the groundwater level inside the containment area below the groundwater level outside the containment area will effectively stop any vertical migration of contaminants in the containment area to the lower aquifer as well as any leakage of contaminated groundwater through the slurry wall. Implementation of this option will also lead to a reduction in the concentrations of contaminants in the groundwater outside the containment area. This will occur initially as contaminated groundwater is removed during excavation of the contaminated soil and over the long-term as the leaching from contaminated soil is reduced.

Technical Evaluation

Reliability. A slurry wall is a durable, maintenance-free barrier to groundwater flow. The slurry is designed to be resistant to the contaminants being contained. Containment can be assured by maintaining an inward hydraulic gradient across the slurry wall. Capping the slurry wall containment area will virtually eliminate leaching of further contaminants from the unsaturated zone within the containment area. Annual inspection and regular maintenance, of the cap and the monitoring of water levels within the area surrounded by the slurry wall will monitor the effectiveness of the containment system. A major defect in slurry mix design or construction would impair the containment system's reliability, although the effectiveness of the system could still be maintained by depressing the groundwater surface within the containment area with additional pumping.

Constructability. Slurry wall construction is a specialized field in the construction industry. Qualified, experienced contractors are capable of constructing a slurry wall that will meet the requirements of this remedial action alternative. Special equipment will be necessary. Placement of the synthetic membrane is also a specialized activity requiring care and thoroughness to assure continuous coverage without punctures, tears, or other faults.

Implementation Schedule. It is anticipated that this alternative could be constructed in one construction season, provided that a lead time of 6 months is provided for engineering design and any necessary field investigations prior to the beginning of the construction season. Implementation could be delayed by difficulties in obtaining approval to discharge groundwater to the sewer system.

Site Benefits. The potential use of the site would be substantially enhanced by this remedial action. Most of the site would be clear of contaminated soil which might interfere with site use. The exception would be the area surrounded by the slurry wall which would be usable as open space, parking or recreation. This area could also be made suitable for building construction with a specially designed slurry wall and cap.

Cost

The estimated cost of this alternative is summarized in Table 22. The total estimated capital cost is $2,090,000. The total estimated annual operating and maintenance cost is $169,000 for the first 10 years, $121,000 for the next 10 years and $97,000 for the final 10 years of the 30-year period. These costs could increase substantially if further pretreatment of the groundwater than was assumed in this assessment is required prior to discharge to the sanitary sewer of the water pumped from the containment

what happens after 30 yrs?

area. The total 30-year present worth cost of this alternative is $4,070,000.

ALTERNATIVE II.B.: CAP AND SOURCE GROUNDWATER PUMP-OUT SYSTEM

Description

This remedial action plan involves use of a cap over the contaminated soil (Alternative I.B.) and a groundwater pump-out system to remove contaminated groundwater immediately downgradient of the areas of greatest soil and groundwater contamination on the site. The key elements in the cap and source groundwater pump-out system alternative are shown in Figure 28.

As described in the technical description of Alternative I.B., the cap assumed in the evaluation is a 100 mil synthetic membrane with covering soil or a multi-layer cap. The cap would be graded to promote drainage. A drainageway would be cut to carry surface drainage to the west. The contaminated soil from the site would be excavated and placed under the cap. Groundwater encountered during excavation would be discharged to the sanitary sewer after any necessary pretreatment.

A series of shallow wells or collector drains and sumps would be used to collect contaminated groundwater in the upper aquifer immediately downgradient of the former process area and Pond A on the site. The capture zone of the groundwater pump-out system is shown in Figure 28 and includes the portion of the site from Pond A on the north to the former process area on the south. The groundwater removed by the pump-out system would be discharged to the sanitary sewer, after any necessary pretreatment. Pretreatment by oil separation was assumed for cost estimating purposes in this assessment.

The same level of routine site groundwater and discharge monitoring that was assumed for Alternative I.C. and I.D. was assumed for this alternative.

Effectiveness

As discussed in Alternative I.B., the capping of the contaminated soil will substantially reduce the release of additional PAH compounds and pentachlorophenol from the contaminated soil located above the surface of the saturated zone. The continued leaching from contaminated soil located below the surface of the saturated zone will not be reduced by capping. The source groundwater pump-out system downgradient of the areas of greatest soil and groundwater contamination on the site significantly improves the effectiveness of the remedial action over that of the cap alone by intercepting additional contamination that is released from the contaminated soil below the saturated zone beneath the cap. The groundwater pump-out system will also collect the contaminants now in the groundwater. Contaminants that have already moved downgradient of the pump-out system will be isolated from the sources of contamination and the downgradient concentrations will eventually decrease. The potential for contaminant migration from the areas of greatest soil contamination to the lower aquifers will be reduced due to the reduction in the further release of contaminants, the reduced concentrations of contaminants in the upper aquifer, and the reduced downward gradient due to the lowering of water levels in the vicinity of the pump-out system. This alternative is considered to be slightly less effective than the slurry wall containment alternative (Alternative II.A.), due to the expected greater vertical leakage that would occur to the lower aquifer under this alternative in comparison to Alternative II.A.

Technical Evaluation

Reliability. The reliability of the cap over the contaminated soil is described in the evaluation of Alternative I.B. The reliability of the source groundwater pump-out system depends on the long-term performance of the drains or wells and the long-term availability of the sanitary sewer as the discharge location at a reasonable cost. The pumping system is subject to temporary breakdown due to power failure, accidental disruption or inadequate maintenance. Temporary shutdown of the groundwater pump-out system, however, will not reduce the system's reliability because of the relatively long time required for the aquifer to respond to altered conditions. Long-term shutdown of the pump-out system should be avoided by proper maintenance and inspection, although iron bacteria, iron floc, or sediment can cause plugging and loss of efficiency in groundwater pump-out system. The proper functioning of the system can be verified by the monitoring of groundwater levels.

Constructability. The construction of a low permeability cap is unusual in the construction industry, but does not require specialized contractors. Care and attention to detail must be paid when placing and covering the synthetic membrane. Construction of a drain below the surface of the saturated zone will be difficult in the fine sands at the site. The other activities associated with this alternative can be completed with standard construction skills.

Implementation Schedule. It is anticipated that this alternative can be constructed in one season, provided that a lead time of 4 months is provided for engineering design and related field investigations prior to the beginning of the construction season. Implementation may be delayed by the time needed to secure approvals for the long-term discharge of groundwater to the sanitary sewer system.

Site Benefits. The potential use of the site would be substantially enhanced by this remedial action. The site would be clear of waste which might interfere with site use except at the cap location. The capped area would be usable as open space or could be developed for recreation or parking. The locations of needed groundwater pump-out facilities would be determined so that site improvement could be planned around these facilities.

Cost

The estimated cost of this alternative is shown in Table 23. The total estimated capital cost is $1,940,000 and the total estimated annual operating and maintenance cost is $439,000 during the first 10 years, $391,000 during the next 10 years, and $367,000 during the final 10 years of the 30-year period. These costs could increase substantially if further pretreatment of the groundwater than was assumed in this assessment is required prior to discharge to the sanitary sewer. The total 30-year present worth cost of this alternative is $7,630,000.

ALTERNATIVE II.C. ON-SITE VAULT AND SOURCE GROUNDWATER PUMP-OUT SYSTEM

Description

This remedial action involves construction of an on-site vault for all contaminated soil on-site (Alternative I.C.) and construction of a groundwater pump-out system to remove contaminated groundwater immediately downgradient of the areas of greatest soil and groundwater contamination on the site. The groundwater pump-out system used in this alternative is smaller than the system assumed in the previous alternative (Alternative II.B.). The Pond A area is not included in the capture zone of the groundwater pump-out system since all contaminated soil and much of the contaminated groundwater will be removed from the Pond A area under this alternative. The key elements of the vault and source groundwater pump-out system alternative are shown in Figure 29.

The vault would have a double liner and leachate collection/detection system as described in Section 3 and Alternative I.C. in this section. The vault would be designed to contain 40,000 cubic yards of contaminated soil and could be enlarged or reduced in size depending on the volume of contaminated soil actually encountered. Contaminated soil from the site would be excavated and placed in the vault. Groundwater encountered during excavation would be discharged to the sanitary sewer after any necessary pretreatment.

A series of shallow wells or drains and sumps would be placed across the contaminated groundwater plume immediately downgradient of the former process area of the site. The former process area will be the area of greatest remaining soil and groundwater contamination on the site after excavation of the contaminated soil from the Pond A area. The effluent would be discharged to the sanitary sewer after any necessary pretreatment. It was assumed that oil removal would be necessary for pretreatment. The same level of monitoring assumed for the previous alternative (Alternative II.B.) was assumed in this alternative.

Effectiveness

The effectiveness of the on-site vault is described in Alternative I.C. The vault would provide effective containment for the excavated contaminated soil and would eliminate the release of contaminants from contaminated soils on the site.

The groundwater pump-out system will intercept contaminated groundwater immediately downgradient of the major remaining area of contaminated soil and groundwater on the site thus minimizing the migration of contaminants. The potential for contaminant migration to the lower aquifers will be significantly reduced due to the containment of the source, the reduced contaminant concentrations in the upper sand aquifer, and the reduced downward gradient due to the interception system. The effectiveness of this alternative is considered to be similar to the effectiveness of the previous alternative (Alternative II.B.) and slightly less effective than Alternative II.A. The vertical migration of contaminants under this alternative is anticipated to be similar to the vertical migration under Alternative II.B. and slightly greater than that under Alternative II.A.

Technical Evaluation

Reliability. The reliability of an on-site vault is described in the evaluation of Alternative I.B. A vault is considered a long-term, low-maintenance container for contaminated solids. The leak detection system will help verify the vault's effectiveness. The source groundwater pump-out system downgradient of the vault will improve the already high reliability of the vault by intercepting any leaks.

The reliability of the source groundwater pump-out system is described in the evaluation of Alternative II.B. The proper functioning of the groundwater pump-out system will be verified by monitoring groundwater levels upgradient and downgradient of the system.

Constructability. Vault construction is unusual in the heavy construction industry, but does not require specialized contractors. Care and attention to detail must be used when placing and covering the membranes and fabrics of the liner systems.

Implementation Schedule. It is anticipated that this alternative could be constructed in one construction season, provided that a lead time of 4 months is provided for engineering design and related field investigations prior to the beginning of the construction season. Implementation may be delayed by the time necessary to secure approval to continuously discharge groundwater to the sewer system.

Site Benefits. The site benefits of the vault are described in the evaluation of Alternative I.B. The site benefits of the source groundwater pump-out system are described in the evaluation of Alternative II.B. The site benefits of the two remedial actions are additive. Future use of the site will be substantially enhanced with this alternative. The locations of needed groundwater pump-out facilities would be determined so that site improvement could be planned around these facilities.

Cost

The estimated cost of this alternative is summarized in Table 24. The total estimated capital cost is $3,900,000 and the total estimated annual operating and maintenance cost is $370,000 for the first 10 years, $322,000 for the next 10 years, and $298,000 for the final 10 years of the 30-year period. These costs could increase substantially if further pretreatment of the contaminated groundwater than assumed in this assessment is required prior to discharge to the sewer system. The total 30-year present worth cost of this alternative is $8,620,000.

III. SITE GROUNDWATER CONTROL

The objective of the alternative remedial action plans designed to achieve this level of protection is to contain contaminated groundwater on-site. With implementation of the remedial action plans designed to achieve this level of control, the low concentrations of PAH and pentachlorophenol that have previously migrated off-site will gradually move to the east and disperse. Future increases in off-site concentrations of PAH and pentachlorophenol in the shallow groundwater will not occur.

The remedial action plans that are designed to provide this level of protection are:

III.A. Groundwater Plume Pump-Out
III.B. Groundwater Plume Containment with Slurry Wall

ALTERNATIVE III.A.: GROUNDWATER PLUME PUMP-OUT

Description

This alternative involves collecting and removing the contaminated groundwater plume along France Avenue North at the eastern site boundary and intercepting groundwater immediately downgradient of the most heavily contaminated areas on the site. The alignment of the groundwater pump-out systems assumed in this assessment are shown in Figure 30.

The groundwater pump-out system immediately downgradient of the areas of heaviest soil and groundwater contamination is the same as that assumed in Alternative II.B. An 800-foot long drain or shallow well system will also be used to intercept contaminated groundwater in the upper sand aquifer along France Avenue North in this alternative. The estimated pumping rate of 190 gpm from these two systems results in the capture zone shown in Figure 30. Groundwater removed by the two systems will be discharged to the sanitary sewer. It is anticipated that pretreatment consisting of oil removal will be necessary for the water removed from system downgradient of the containment sources, but not for the water removed by the system at the eastern site boundary.

In addition to the construction of the two groundwater pump-out systems, the water in Pond A would be discharged to the sanitary sewer. Pond A would be filled with material from the surrounding dikes, the disturbed area would be covered with soil and revegetated, and the site would be graded as described in Alternative I.A. The depression in Area 5 would be filled and revegetated, and a drainageway would be constructed to provide surface drainage toward the west.

The routine site groundwater monitoring program assumed for Alternatives I.C. and I.D., and II.A through II.C. was used for this alternative. In addition, it was assumed that the discharge to the sanitary sewer would be monitored quarterly.

Effectiveness

This alternative will effectively intercept the contaminated groundwater in the upper aquifer near the downgradient property boundary. The use of a pump-out system immediately downgradient of the most heavily contaminated areas on the site will help minimize the vertical migration of contaminants that would otherwise occur if only the pump-out system at the eastern site boundary is used. Since the low concentrations of PAH compounds and pentachlorophenol that have migrated downgradient of the site will be isolated from the higher concentrations of contaminants on-site, the downgradient concentrations will decrease with time. The potential for contaminant migration to the lower aquifer will be reduced because of the removal of the contaminants from the shallow groundwater by the pump-out systems and because of the lower water levels in the upper aquifer resulting from the removal of groundwater. Site grading will reduce the leaching of additional contaminants from the unsaturated zone by about 50 percent, but will not reduce the contaminant leaching from the below-ground water sources.

Technical Evaluation

Reliability. The reliability of groundwater pump-out systems was discussed in the evaluation of Alternative II.B. The pumping system is subject to temporary shutdown but such a temporary shutdown will not impair the system's reliability. The risks of long-term shutdown of the system can be minimized but exist due to plugging of the drains or well screens. The effectiveness of the system can be verified by monitoring groundwater levels.

Constructability. Construction of the drain system below the normal groundwater level will be difficult but can be completed using standard construction practices. The other construction activities require standard construction techniques. The implementation of this alternative could be difficult due to the need to obtain property or easements to build the groundwater pump-out system along France Avenue North. Joslyn does not own much of the property on which this system must be placed.

Implementation Schedule. It is anticipated that this alternative could be implemented in one construction season, provided that a lead time of 4 months is provided for engineering design and related field activities prior to construction. As with any of the groundwater pump-out options, implementation could be delayed by not receiving timely approval to discharge groundwater to the sanitary sewer.

Site Benefits. The potential use of the site will be only slightly enhanced by this remedial action. Contaminated soil now present in the subsurface will remain. These areas may be developed for such uses as open space, recreation and parking, but will generally not be suitable for new construction. The locations of needed groundwater pump-out facilities would be determined so that site improvement could be planned around these facilities.

Cost

The estimated cost of this alternative is summarized in Table 25. The total estimated capital cost is $1,520,000 and the total estimated annual operating and maintenance cost is $535,000 for the first 10 years, $487,000 for the next 10 years, and $463,000 for the last 10 years of the 30-year period. These annual costs could increase substantially if further pretreatment of the contaminated groundwater than assumed in this assessment is required. The total 30-year present worth cost of this alternatives is $7,370,000.

ALTERNATIVE III.B.: GROUNDWATER PLUME CONTAINMENT WITH SLURRY WALL

Technical Description

This alternative involves the use of a slurry wall to prevent the further migration of contaminated groundwater off-site. The slurry wall alignment assumed in this alternative is shown in Figure 31. The slurry wall configuration in Figure 31 encompasses most of the contaminated groundwater on-site. The wall extends from the ground surface to a depth of approximately 60 feet and is keyed into the middle confining unit where this unit is present. A low permeability cap would not be constructed over the area surrounded by the slurry wall; instead, groundwater would be pumped from the area surrounded by the wall to lower the groundwater level within the containment area. The estimated long-term pumping rate to maintain the water level inside the containment area about one foot lower than inside the containment area is 80 gpm. The pumping rate is high since the wall cannot be keyed into the middle confining unit along its entire length. The groundwater removed from the slurry wall containment area will be discharged to the sanitary sewer. Pretreatment consisting of oil removal was assumed.

Along with construction of the slurry wall and interior pump-out system, this remedial action plan includes discharging the water in Pond A to the sanitary sewer, filling Pond A, covering the disturbed area with topsoil, revegetation and completing the site grading described in

Alternative I.A. The depression in Area 5 would also be filled and revegetated and a drainageway would be constructed to establish surface drainage to the west.

The routine site groundwater monitoring program assumed in the previous six alternatives was also assumed for this alternative.

Effectiveness

The slurry wall will effectively contain the contaminated groundwater on-site. The alignment of the slurry wall shown in Figure 31 will halt the movement of contaminants off-site and cut-off the flow of uncontaminated water into the site from the west. This uncontaminated water now mixes with contaminated groundwater, picks up additional contaminants from the contaminated soil in the saturated zone, and transports the contaminants downgradient to the east. If, as expected, the middle confining unit is not continuous along the alignment of the slurry wall assumed in this alternative, the interior pump-out system will only remove the infiltration through the ground surface surrounded by the slurry wall and maintain a near neutral gradient across the wall. Escape of contaminants through the bottom of the containment area will be negligible, if the interior water level can be maintained lower than the exterior water level. The contaminated groundwater present downgradient of the slurry wall containment area will be isolated from the contaminants on-site and will dissipate with time. The site grading reduces the leaching of additional contaminants to the groundwater from the unsaturated zone, but will not reduce leaching from contaminated soil that is present below the surface of the saturated zone. The effectiveness of this alternative is equivalent to the effectiveness of Alternative III.A.

Technical Evaluation

Reliability. The reliability of a slurry wall is discussed in the description of Alternative II.A. Removal of groundwater from inside the area surrounded by the slurry wall will create a near neutral hydraulic gradient across the slurry wall resulting in no net flow through the wall. A major defect in construction could impair the system's reliability, requiring greater pumping to maintain the required groundwater level within the containment area. The functioning of the system can be reliably monitored by monitoring groundwater levels and pumping rates.

Constructability. Slurry wall construction is a specialized field in the heavy construction industry. Qualified, experienced contractors are capable of constructing a high quality slurry wall that meets the requirement of the remedial action alternative. The other construction activities require standard construction and well drilling techniques.

Implementation Schedule. It is anticipated that this alternative could be implemented in two construction seasons, provided that 6 months lead time is allowed for engineering design and related field investigations prior to the beginning of the first construction season.

Site Benefits. The potential use of the site would only be slightly enhanced by this remedial action. Contaminated soil will remain below the surface of the site. Areas underlain by contaminated soil may be developed for such uses as open space, recreation, and parking, but generally will not be suitable for new construction.

Cost

The estimated cost of this alternative is summarized in Table 26. The estimated capital cost is $4,520,000, the estimated annual operating and maintenance cost is $437,000 for the first 10 years, $389,000 for the next 10 years, and $365,000 for the final 10 years in the 30-year period. These annual costs could increase substantially if additional pretreatment of the groundwater removed from the slurry wall containment area is required prior to discharge to the sanitary sewer. The total 30-year present worth cost of this alternative is $10,170,000.

SUMMARY OF REMEDIAL ACTION ALTERNATIVES

The estimated capital, annual and 30-year present worth costs for the various remedial action plans that were evaluated for the Joslyn site are summarized in Table 27.

Alternatives I.A. through I.D. are remedial action plans designed to contain or remove contaminated soil and thereby minimize the further release of contaminants to the saturated zone. Alternatives I.A. and I.B. are directed at managing only the contaminated soil above the surface of the saturated zone, while Alternatives I.C. and I.D. remove or contain all contaminated soil on the site. Alternative I.A., which involves grading the site to cover contaminated soil and provide surface drainage, will be less effective than Alternative I.B., which involves placing a low permeability cap over the contaminated soil at the site. The capital cost of the site grading alternative is estimated to be $0.3 million with a 30-year present worth cost of $2.2 million. The estimated capital cost of the capping alternative is $1.1 million, with an estimated 30-year present worth cost of $3.1 million. Most of the annual cost of these alternatives is the routine quarterly groundwater monitoring at the site. The estimated cost of monitoring is $140,000 per year.

Alternative I.C., which involves the construction of an on-site vault for the contaminated soil and Alternative I.D. which involves the on-site incineration of the contaminated soil are of equivalent effectiveness. Both of these alternatives are considered more effective than capping the contaminated soil. The capital cost of the on-site vault alternative is estimated to be $3.2 million and the 30-year present worth cost is estimated to be $5.1 million. The capital cost of the on-site incineration alternative is estimated to be $10.6 million and the 30-year present worth cost is estimated to be $12.1 million.

Alternatives II.A., II.B., and II.C. are remedial action plans designed to minimize the further release of contaminants to the saturated zone <u>and</u> minimize further migration of contaminated groundwater from the areas of greatest soil and groundwater contamination on the site. Alternative II.A. involves the construction of a slurry wall around the former operating area of the facility. The capital cost of this alternative is estimated to be $2.1 million and the 30-year present worth cost is estimated to be $4.1 million. Alternative II.B. involves placing a cap over the contaminated soil and constructing a groundwater pump-out system in the former operating areas of the facility. The discharge from the pump-out system is assumed to be pretreated and discharged to the sanitary sewer system. The capital cost of this alternative is $1.9 million and the estimated 30-year present worth cost is estimated to be $7.6 million. A significant portion of the annual operating cost of this alternative is the cost of pretreatment and disposal of the contaminated groundwater to the sanitary sewer system. Alternative II.C. involves placement of all contaminated soil in an on-site vault and the construction of a groundwater pump-out system in the former process area of the facility. The capital cost of this alternative is estimated to be $3.9 million and the 30-year present worth cost is estimated to be $8.6 million. This alternative also includes the high annual operating cost associated with the discharge of pretreated groundwater to the sanitary sewer system. Alternative II.A. is considered to be slightly more effective than Alternatives II.B. and II.C. due to the anticipated lower rate of vertical seepage to the lower aquifer under Alternative II.A.

slurry wall only & pump inside wall

Vault & pumping

Alternatives III.A. and III.B. are remedial action plans designed to minimize the further migration of contaminated groundwater from the site. Alternative III.A. involves construction of groundwater pump-out systems in the area of highest groundwater contamination on the site and at the downgradient site boundary. The capital cost of this alternative is estimated to be $1.5 million and the 30-year present worth cost is estimated to be $7.7 million. Alternative III.B. involves containing contaminated groundwater on-site with a slurry wall that generally follows the boundary of the site. This slurry wall alternative also includes a groundwater pump-out system that must pump at a relatively high rate of discharge since the slurry wall cannot be keyed into the middle confining unit along its entire length. The estimated capital cost of this alternative is $4.5 million and the 30-year present worth cost is estimated to be $10.2 million. Alternatives III.A. and III.B. are considered to be equally effective at minimizing the further migration of contaminated groundwater off-site.

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Section 5

REMEDIAL ACTION RECOMMENDATIONS

SECTION 5

RECOMMENDATIONS

Data in this investigation show that contamination from the site is confined to the upper portion of the shallow aquifer and has not impacted water supply aquifers underlying the site. If not remediated, the potential exists for the contamination in the shallow groundwater to slowly migrate into the lower aquifer below the site.

It is recommended that the following measures be taken to mitigate the current impacts of the site on the shallow groundwater aquifer and reduce the potential for future impact on the lower aquifer:

1) The principle objective of the remedial action plan at the site should be to control the future existing lateral and vertical movement of the contaminated groundwater that exists at the site ~~in the former operating area of the facility~~.

2) Alternative II.A., which involves construction of a slurry wall around the former operating area of the site, is the most cost-effective remedial action plan to meet the remedial action objective. The next step in implementing a remedial action plan for the site should be to prepare a detailed design of the slurry wall containment system.

3) During the 1986 construction season, the water in Pond A should be drained and discharged to the sanitary sewer system. Contaminated soil in Pond A should be removed and either placed in the slurry wall containment area (if that portion of the remedy is under construction) or temporarily stockpiled on the site. The Pond A area should then be filled and graded.

4) Residents identified in the well search conducted for this investigation as still using groundwater for potable supply purposes should be required to connect to the city water system.
No authority.

Consumption of water from private wells is inappropriate in a highly urbanized area where the groundwater is subject to contamination from a wide variety of potential contaminant sources. The Minnesota Plumbing Code, MN. Rules 1984 Section 4715.0310 requires connection to public water distribution systems for new premises and also for altered, renovated or replaced plumbing facilities. The principles of the Minnesota Plumbing Code strongly encourage connection to public water supply system.

5) Routine groundwater monitoring should be continued at the site. It is recommended that routine site monitoring consist of the following during the next 12-month period:

   a) quarterly sampling of Wells 10, 112, 121, 122, 123, 124, 125, 126, 301, 307 and the plant well mid depth

   b) annual sampling of the remaining wells on the site – off site wells?

   c) analysis of all samples for the PAH and phenolic compounds in Table 2 of this report. Analysis of one set of samples for all wells for the metals in Table 2.

It is also recommended that the additional monitoring wells shown in Figure 32 be constructed southwest of the site to verify that contamination from the site is not migrating to the southwest toward private wells in this area that are still being used for potable water supply purposes. These additional monitoring wells should be monitored quarterly for the PAH and phenolic compounds in Table 2 of the report.

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Tables

TABLE 1

MAJOR COMPONENTS OF CREOSOTE

Component	Approximate Percent In Creosote	Boiling Point °C	Melting Point °C	Molecular Weight
Naphthalene	3.0	218	80-81	128.2
2-Methylnaphthalene	1.2	241	24-25	142.2
1-Methylnaphthalene	0.9	244	-22	154.2
Biphenyl	0.8	255	71	154.2
Dimenthylnaphthalenes	2.0	268	8-105	156.2
Acenaphthene	9.0	279	96-97	156.2
Dibenzofuran	5.0	287	86-87	168.2
Fluorene	10.0	293-295	116-117	166.2
Methylfluorenes	3.0	318	46-47	180.2
Phenanthrene	21.0	340	101	178.2
Anthracene	2.0	340	216	178.2
Carbazole	2.0	355	247-248	167.2
Methylphenanthrenes	3.0	354-355	65-123	192.2
Methylanthracenes	4.0	360	81-210	192.2
Fluoranthene	10.0	382	111	202.3
Pyrene	8.5	393	156	202.3
Benzofluorenes	2.0	413	189-190	216.3
Chrysene	3.0	448	255-256	228.3

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TABLE 2

MONITORING PARAMETERS

List 1 - PAH and Heterocycles

Benzo(a)anthracene
Benzo(b)fluoranthene**
Benzo(j)fluoranthene*
Benzo(a)pyrene
Chrysene**
Indeno(1,2,3,cd)pyrene
Benzo(ghi)perylene
Dibenzo(ah)anthracene
Quinoline

List 2 - PAH and Heterocycles

Indene
2,3-Dihydroindene
Naphthalene
1-Methylnaphthalene
2-Methylnaphthalene
Biphenyl
Acenapthylene
Acenaphthene
Fluorene
Phenanthrene
Anthracene
Isoquinoline
Fluoranthene
Pyrene
Benzo(k)fluoranthene**
Benzo(e)pyrene
Perylene
Acridine
Carbazole
2,3-Benzofuran
Benzo(b)thiophene
Dibenzothiophene
Indole
Dibenzofuran
Triphenylene**

Phenolic Compounds

Phenol
o-Cresol
m-Cresol and p-Cresol
2-Chlorophenol
2,4-Dichlorophenol
2,4,6-Trichlorophenol
2,4-Dimethylphenol
4-Chloro-m-cresol
2-Nitrophenol
4-Nitrophenol
2,4-Dinitrophenol
4,6-Dinitro-o-cresol
Pentachlorophenol

Metals

Arsenic
Chromium (Hexavalent and Total)
Copper

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* Cannot be quantified with GC/MS analytical procedure.

** These compounds coelute, are structure isomers (benzo(b)fluoranthene with benzo(k)fluoranthene and chrysene with triphenylene) and, therefore, cannot be individually quantified.

TABLE 3

SOIL QUALITY

(concentration in mg/kg)

Sample Number	5	7	12	25	26	30	31	41
Exploratory Excavation	13	16	19	27	27	31	31	37
Area	4	4	POND A	8	8	6	6	6
Field Description	Discolor. Oily Silty Sand	Backgrd. Sample Tan Sand	Discolor. Oily Sand	Tan Oily Sand	Discolor. Oily Sand	Discolor. Oily Silty Sand	Gray Slightly Oily Sand	Brown Oily Sand
Depth (Ft.)	9.0-10.0	0.0-6.0	5.5-6.0	4.0-4.5	1.8-2.4	5.5-6.0	1.0-2.0	5.5-6.1
LIST 1 PAH/HETEROCYCLES								
Benzo(a)anthracene	<10	<0.1	22	2.1	<10 p	5.1	25	730
Benzo(b)fluoranthene	<10 c	<0.1 c	15 c	<2.0 c	<10 c	5.4 c	19 c	130 c
Benzo(ghi)perylene	<10	<0.1	<5.0	<2.0	<10	<1.0	5.4	36
Benzo(a)pyrene	<10	<0.1	<5.0 p	<2.0	<10	2.3	15	21
Chrysene	<10 c	<0.1 c	24 c	2.5 c	<10 pc	4.6 c	19 c	130 c
Dibenz(ah)anthracene	<10	<0.1	<5.0	<2.0	<10	<1.0	2.5	13
Indeno(1,2,3,cd)pyrene	<10	<0.1	<5.0	<2.0	<10	<1.0	5.6	32
Quinoline	<10	<0.1	7.3	<2.0	<10	<1.0	4.1	<10
Sum List 1	ND	ND	68	4.6	ND	17	96	430
LIST 2 PAH/HETEROCYCLES								
Acenaphthene	19	<0.1	130	24	49	18	32	52
Acenaphthylene	<10	<0.1	<5.0	<2.0	<10	<1.0	<1.0	<10
Acridine	<10	<0.1	<5.0	<2.0	<10	<1.0	<1.0	<10
Anthracene	10	0.2	40	27	24	6.4	16	15
Benzo(k)fluoranthene	<10 c	<0.1 c	c	<2.0 c	<10 c	c	c	c
2,3-Benzofuran	<10	<0.1	<5.0	<2.0	<10	<1.0	<1.0	<10
Benzo(e)pyrene	<10	<0.1	<5.0 p	<2.0	<10	1.9	9.7	61
Benzo(b)thiophene	13	<0.1	8.6	3.2	11	1.3	1.8	<10
Biphenyl	23	<0.1	33	20	57	5.2	6.0	<10
Carbazole	<10	<0.1	<5.0	<2.0	<10	18	13	<10
Dibenzothiophene	48	<0.1	81	77	200	6.5	13	52
Dibenzofuran	32 p	<0.1	120	29	74	13	24	21
2,3-Dihydroindene	<10 p	<0.1	<5.0 p	3.9	24	<1.0	<1.0	<10
Fluoranthene	<10	<0.1	140	10	25	21	85	400
Fluorene	36	<0.1	170	53	110	22	36	<10
Indene	<10	<0.1	5.3	<2.0	<10 p	<1.0	<1.0	<10
Indole	<10	<0.1	<5.0	<2.0	<10	<1.0	<1.0	<10
Isoquinoline	<10	<0.1	<5.0	<2.0	<10	<1.0	8.0	<10
1-Methylnaphthalene	400	<0.1	210	180	510	42	37	13
2-Methylnaphthalene	780	<0.1	420	290	840	9.4	67	<10
Naphthalene	130	<0.1	170	25	120	2.2	28	<10
Perylene	<10	<0.1	<5.0	<2.0	<10	<1.0	2.7	<10 p
Phenanthrene	140	<0.1	340	110	290	45	110	71
Pyrene	14	<0.1	88	10	24	16	59	310
Triphenylene	<10 c	<0.1 c	c	c	<10 pc	c	c	c
Sum List 2	1600	0.2	2000	860	2400	230	560	1000
PHENOLICS								
4-chloro-3-methylphenol	<40	<0.4	<10	<20	<20	<10	<4.0	<20
2-Chlorophenol	<40	<0.4	<10	<20	<20	<10	<4.0	<20
O-Cresol	<40	<0.4	<10	<20	<20	<10	<4.0	<20
M-Cresol	<40	<0.4	<10	<20	<20	<10	<4.0	<20
P-Cresol	<40	<0.4	<10	<20	<20	<10	<4.0	<20
2,4-Dichlorophenol	<40	<0.4	<10	<20	<20	<10	<4.0	<20
2,4-Dimethylphenol	<40	<0.4	<10	<20	<20	<10	<4.0	<20
2,4-Dinitrophenol	<200	<2.0	<50	<100	<100	<50	<20	<100
2-methyl-4,6-dinitrophenol	<200	<2.0	<50	<100	<100	<50	<20	<100
2-Nitrophenol	<40	<0.4	<10	<20	<20	<10	<4.0	<20
4-Nitrophenol	<40	<0.4	<10	<20	<20	<10	<4.0	<20
Pentachlorophenol	3200	<0.4	310	680	2300	330	<4.0	2800
Phenol	<40	<0.4	<10	<20	<20	<10	<4.0	<20
2,4,6-Trichlorophenol	<40	<0.4	<10	<20	<20	<10	<4.0	<20

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c Concentration for coeluting compounds (reported as the List 1 compound). Coeluting compounds are Chrysene/Triphenylene, and Benzo(b)fluoranthene/Benzo(k)fluoranthene

p Small peak in chromatogram below method detection limit.

ND Not Detected.

TABLE 3 (cont.)

SOIL QUALITY

(concentrations in mg/kg)

Sample Number	PB4-4	PB4-9	PB5-4
Shallow Boring Number	4	4	5
Area	6	6	5
Field Description	Discolor. Oily Sand	Gray Oily Sand	Gray-brn. Slightly Oily Sand
Depth (Ft.)	7.0-8.0	14.5-16.0	14.5-15.5
LIST 1 PAH/HETEROCYCLES			
Benzo(a)anthracene	110	220	<0.4
Benzo(b)fluoranthene	60 c	180 c	<0.4 c
Benzo(ghi)perylene	<25	48	<0.4
Benzo(a)pyrene	48	110	<0.4
Chrysene	350 c	190 c	<0.4 c
Dibenz(ah)anthracene	<25	<25	<0.4
Indeno(1,2,3,cd)pyrene	<25	44	<0.4
Quinoline	<25	61	<0.4
Sum List 1	570	850	ND
LIST 2 PAH/HETEROCYCLES			
Acenaphthene	310	540	<0.4
Acenaphthylene	<25	<25	<0.4
Acridine	<25	<25	<0.4
Anthracene	1100	190	<0.4
Benzo(k)fluoranthene	c	c	<0.4 c
2,3-Benzofuran	<25	<25	<0.4
Benzo(e)pyrene	33	86	<0.4
Benzo(b)thiophene	<25	57	<0.4
Biphenyl	36	83	<0.4
Carbazole	400	97	<0.4
Dibenzothiophene	54	86	<0.4
Dibenzofuran	220	360	<0.4
2,3-Dihydroindene	<25	40	<0.4
Fluoranthene	410	780	0.4
Fluorene	350	490	<0.4
Indene	<25	25	<0.4
Indole	<25	<25	<0.4
Isoquinoline	<25	<25	<0.4
1-Methylnaphthalene	97	260	<0.4
2-Methylnaphthalene	170	440	<0.4
Naphthalene	460	1900	<0.4
Perylene	<25	<25	<0.4
Phenanthrene	840	1400	<0.4
Pyrene	290	580	<0.4
Triphenylene	c	c	<0.4 c
Sum List 2	4800	7400	0.4
PHENOLICS			
4-chloro-3-methylphenol	<50	<100	<0.4
2-Chlorophenol	<50	<100	<0.4
O-Cresol	<50	<100	<0.4
M-Cresol	<50	<100	<0.4
P-Cresol	<50	<100	<0.4
2,4-Dichlorophenol	<50	<100	<0.4
2,4-Dimethylphenol	<50	<100	<0.4
2,4-Dinitrophenol	<250	<500	2.0
2-methyl-4,6-dinitrophenol	<250	<500	<2.0
2-Nitrophenol	<50	<100	<0.4
4-Nitrophenol	<50	<100	<0.4
Pentachlorophenol	<50	<100	8.6
Phenol	<50	<100	<0.4
2,4,6-Trichlorophenol	<50	<100	<0.4

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c **Concentrations for coeluting compounds (reported as List 1 compounds). Coeluting compounds are Chrysene/Triphenylene, Benzo(b)fluorathene/Benzo(k)fluoranthene, and M-Cresol/P-Cresol.**

ND Not detected.

TABLE 4

POND A WATER QUALITY

(concentrations in ug/L)

	POND A LIQUID	POND A ICE
	01/24/85	01/24/85
List 1 PAH/Heterocycles		
Benzo(a)anthracene	1100	
Benzo(b)fluoranthene	<1000 c	
Benzo(ghi)perylene	<1000	
Benzo(a)pyrene	<1000	
Chrysene	1900 c	
Dibenz(ah)anthracene	<1400	
Indeno(1,2,3,cd)pyrene	<1700	
Quinoline	<1000	
Sum List 1	3000	
List 2 PAH/Heterocycles		
Acenaphthene	14000	
Acenaphthylene	<1000	
Acridine	<1800	
Anthracene	4200	
Benzo(k)fluoranthene	<1000 c	
2,3-Benzofuran	DLND	
Benzo(e)pyrene	<1000	
Benzo(b)thiophene	2100	
Biphenyl	10000	
Carbazole	<1100	
Dibenzothiophene	64000	
Dibenzofuran	21000	
2,3-Dihydroindene	1600	
Fluoranthene	10000	
Fluorene	35000	
Indene	<1000	
Indole	<2900	
Isoquinoline	DLND	
1-Methylnaphthalene	110000	
2-Methylnaphthalene	180000	
Naphthalene	21000	
Perylene	<1000	
Phenanthrene	86000	
Pyrene	92000	
Triphenylene	c	
Sum List 2	650000	
Phenolics		
4-chloro-3-methylphenol	<5	
2-Chlorophenol	<5	
O-Cresol	<5	
M-Cresol	<5 c	
P-Cresol	<5 c	
2,4-Dichlorophenol	<5	
2,4-Dimethylphenol	<5	
2,4-Dinitrophenol	<25	
2-methyl-4,6-dinitrophenol	<25	
2-Nitrophenol	<5	
4-Nitrophenol	<5	
Pentachlorophenol	780	
Phenol	<5	
2,4,6-Trichlorophenol	<5	
Metals		
Arsenic (filtered)	9	50
Copper (filtered)	14000	34
Chromium, total (filtered)	850	1.3
Chromium, hexavalent	<20	<20

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c Coeluting compound (concentrations reported with the List 1 compound). Coeluting compounds are Chrysene/Triphylene and Benzo(b)fluoranthene/Benzo(k)fluoranthene.

DLND Not detected. Detection limit not determined.

TABLE 5

MONITORING WELL CONSTRUCTION INFORMATION

Well	Well Elevation (MSL)				Well Depth (ft.)	Screen Length (ft.)	Screen Slot Size (in.)	Sandpack Length (ft.)	Well Diameter (in.)	Casing Construction	Screen Construction
	Ground	Casing	Riser	Bottom							
2	856.3	858.82	858.72	845.1	11.2	3	.010	Unknown	2	PVC	ABS
5	860.9	860.96	860.96	845.9	16.0	3	.010	Unknown	2	GS	SS
6	863.6	863.67	863.67	844.2	19.4	3	.010	Unknown	2	PVC	SS
7	861.8	864.05	864.00	838.8	24.0	10	.010	Unknown	2	GS	SS
9	865.5	867.85	867.85	843.9	21.6	10	Unknown	Unknown	4	GS	GS
10	860.2	862.07	862.07	847.2	13.0	10	Unknown	Unknown	4	GS	GS
101	854.4	856.10	856.05	841.6	12.8	10	.010	10	2	SS	SS
104	855.1	857.26	857.14	843.6	11.0	10	.010	10	2	SS	SS
111	859.3	860.94	860.98	842.7	16.4	10	.010	12.5	2	SS	SS
112	865.9	867.86	867.77	841.4	24.5	10	.010	16.0	2	SS	SS
113	863.5	865.59	865.54	845.0	18.5	10	.010	13.0	2	SS	SS
121	865.3	867.10	866.96	841.3	24.0	10	.010	18.5	2	SS	SS
122	864.1	865.83	865.73	840.1	24.0	10	.010	13.5	2	SS	SS
123	857.3	859.43	859.36	840.8	16.5	10	.010	12.5	2	SS	SS
124	865.5	867.76	867.60	838.5	27.0	10	.010	11.0	2	SS	SS
125	864.1	866.17	866.15	839.0	25.0	10	.010	14.5	2	SS	SS
126	857.2	859.34	859.21	838.7	18.5	10	.010	14.5	2	SS	SS
201	854.1	856.04	856.36	787.1	63.0	10	.010	None	4	Iron	GS
206	864.1	865.61	865.45	812.1	52.0	5	.010	10.0	2	SS	SS
207	863.9	865.95	865.81	812.9	51.0	5	.010	26.0	2	SS	SS
209	865.5	867.28	867.25	806.1	59.4	5	.010	11.0	2	SS	SS
301	853.8	855.97	856.28	716.8	137.8	20	.010	None	4	Iron	GS
307	860.9	863.20	863.46	728.9	132.0	4.3	.006	None	4	Iron	GS
Production Well (300)	863.7	865.32	865.61	671.7	192.0	66 (Open Borehole)	--	None	10	Iron	Open Borehole
Howe Inc.											
P12	850.4	851.39	851.39	821.9	28.5	2		Unknown	2	5′ SS/GS	SS
P23	860.5	861.55	861.55	822.0	38.5	2		Unknown	2	5′ SS/GS	SS
P01			852.85	Unknown	Unknown	15		Unknown	6	Iron	LCS
P02			852.00	Unknown	Unknown	15		Unknown	6	Iron	LCS
P03			851.71	Unknown	Unknown	15		Unknown	6	Iron	LCS

Key:

ABS:	ABS Plastic
PVC:	PVC Plastic
GS:	Galvanized Steel
SS:	Stainless Steel
LCS:	Low Carbon Steel
Iron:	Black Iron

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TABLE 6

WATER LEVELS (MSL)

SHALLOW WELLS

Well Number

	W2	W5	W6	W7	W9	W10	W101	W104
Ground Elev:	856.3	860.9	863.6	861.8	865.5	860.2	854.4	855.1
Casing Elev:	858.82	860.96	863.67	864.05	867.85	862.07	856.10	857.26
Riser Elev:	858.72	860.96	863.67	864.00	867.85	862.07	856.05	857.14
01/29/85	850.47	850.28	849.81	850.22	849.67	850.06	851.71	851.00
03/25/85	851.16	850.61	850.32	850.83	850.11	850.67	852.48	853.11
05/06/85	851.52	851.14	850.91	851.32	850.79	851.17	852.08	852.16

Well Number

	W111	W112	W113	W121	W122	W123	W124	W125
Ground Elev:	859.3	865.9	863.5	865.3	864.1	857.3	865.5	864.1
Casing Elev:	860.94	867.86	865.59	867.10	865.83	859.43	867.76	866.17
Riser Elev:	860.98	867.77	865.54	866.96	865.73	859.36	867.60	866.15
01/28/85	--	849.24	--	--	--	--	--	--
01/29/85	850.31	--	--	--	--	--	--	--
03/25/85	850.95	849.56	855.20	849.20	--	849.30	856.2	--
03/26/85	--	--	--	--	848.44	--	--	848.94
05/06/85	851.40	850.22	853.93	849.98	849.02	850.02	848.22	848.85

Well Number

	W126	P01	P02	P03	P12	P23
Ground Elev:	857.2	--	--	--	--	--
Casing Elev:	859.34	--	--	--	--	--
Riser Elev:	859.21	852.85	852.00	851.71	851.94	861.55
03/25/85	848.63	846.1	846.2	847.0	--	--
03/26/85	--	--	--	--	845.4	846.04
05/06/85	848.95	845.93	845.84	846.23	844.67	--

MID-DEPTH & DEEP WELLS

Well Number

	W201	W206	W207	W209	W300	W301	W307
Ground Elev:	854.1	864.1	863.9	865.5	863.7	853.8	860.9
Casing Elev:	856.04	865.61	865.95	867.28	866.10	855.97	863.20
Riser Elev:	853.36	865.45	865.81	867.25	866.10	856.28	863.46
12/02/84	--	--	--	--	847.10	--	--
01/29/85	--	849.64	--	--	--	--	--
03/25/85	851.39	850.28	850.9	850.06	847.35	851.27	848.53
05/06/85	851.90	850.87	851.40	850.68	847.39	851.77	848.80

SURFACE WATER

	TWIN LAKES	RYAN CREEK	RYAN LAKE	POND A
03/25/85	852.27	--	849.59	853.90
03/26/85	--	--	--	--
05/06/85	--	847.2	--	--

TABLE 7

ESTIMATED PERMEABILITY COEFFICIENTS OF GEOLOGIC UNITS

Unit	Permeability Coefficient (cm/sec)	Source
UPPER AQUIFER		
Surficial Sand	2×10^{-1}	Pumping test (McBride, 1974)
	2×10^{-3}	Falling head test on remolded sample (Barr Engineering Co., 1981a)
	2×10^{-2}	Hazen's approximation (Barr Engineering Co., 1981a)
MIDDLE CONFINING UNIT		
Silty Sand	8.4×10^{-7}	Constant head test on remolded sample (Barr Engineering Co., 1981a)
Upper Silty Clay	3.8×10^{-7}	Constant head test on remolded sample (Barr Engineering Co., 1981a)
Lower Silt	5×10^{-7}	Literature Estimate (Freeze & Cherry, 1979)
Sandy Clay Till	3×10^{-7}	McBride, 1974
VALLEY FILL		
Sand	7.2×10^{-3}	Hazen's approximation
LOWER AQUIFERS		
Sandstone Residuum	2.5×10^{-3}	Hazen's approximation
St. Peter Sandstone	2×10^{-2}	McBride, 1974
	2.8×10^{-1}	Barr Pumping Test at Plant Well
Prairie du Chien Group	1.8×10^{-2}	Literature Estimate (Norvitch, et. al., 1972)

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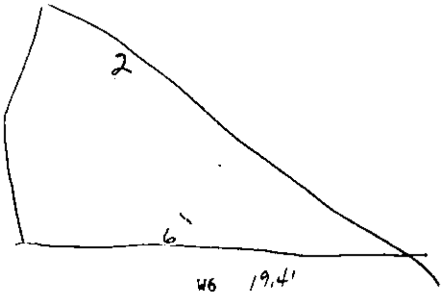

TABLE 8

SHALLOW GROUNDWATER QUALITY

(concentrations in ug/L)

	W2 11.2'			W6 19.4'		
	12/11/84	03/27/85	05/22/85	12/27/84	03/27/85	05/16/85
List 1 PAH/Heterocycles						
Benzo(a)anthracene	<0.025	<0.0010	0.033	<0.20	<0.50	<0.010
Benzo(b)fluoranthene	<0.025 c	<0.0010 c	<0.010 c	<0.20 c	<0.50 c	<0.010 c
Benzo(ghi)perylene	<0.025	<0.0010	<0.010	<0.20	<0.50	<0.010
Benzo(a)pyrene	<0.025	<0.0010	<0.010	<0.20	<0.50	<0.010
Chrysene	<0.025 c	<0.0010 c	0.048 c	<0.20 c	<0.50 c	0.030 c
Dibenz(ah)anthracene	<0.035	<0.0014	<0.014	<0.28	<0.70	<0.014
Indeno(1,2,3,cd)pyrene	<0.043	<0.0017	<0.017	<0.34	<0.85	<0.017
Quinoline	<0.025	<0.0010	0.021	<0.20	<0.5	<0.010
Sum List 1	ND	ND	0.069	ND	ND	0.030
List 2 PAH/Heterocycles						
Acenaphthene	0.150	0.0053	0.60	0.95	1.1	0.11
Acenaphthylene	<0.025	<0.0010	<0.010	1.7	<0.5	<0.010
Acridine	<0.045	<0.0018	<0.018	<0.36	<0.90	<0.018
Anthracene	<0.025	<0.0010	0.027	<0.20	<0.50	0.034
Benzo(k)fluoranthene	<0.025 c	<0.0010 c	<0.010 c	<0.20 c	<0.50 c	<0.010 c
2,3-Benzofuran	0.053	0.0038	0.078	0.25	0.57	0.31
Benzo(e)pyrene	<0.025	<0.0010	<0.010	<0.20	<0.50	<0.010
Benzo(b)thiophene	1.5	0.029	1.3	6.1	23	21
Biphenyl	0.038	<0.0010	0.14	0.32	<0.50	0.044
Carbazole	<0.028	<0.0011	<0.011	0.38	<0.55	0.16
Dibenzothiophene	0.054	DLND	DLND	DLND	DLND	DLND
Dibenzofuran	0.67	<0.0020	0.073	<0.40	<1.0	0.031
2,3-Dihydroindene	0.094	0.0067	0.13	2.0	4.5	1.9
Fluoranthene	0.030	<0.0010	0.31	<0.20	<0.50	0.030
Fluorene	0.065	0.0019	0.59	2.2	<0.70	0.029
Indene	0.12	0.012	0.15	0.74	1.5	0.39
Indole	<0.072	<0.0029	<0.029	<0.58	<1.4	<0.029
Isoquinoline	DLND	DLND	DLND	DLND	DLND	DLND
1-Methylnaphthalene	0.42	0.050	4.3	30	27	3.3
2-Methylnaphthalene	0.45	0.061	3.7	4.2	19	0.58
Naphthalene	0.73	0.11	1.8	2.3	32	0.97
Perylene	<0.025	<0.0010	<0.010	<0.20	<0.50	<0.010
Phenanthrene	0.15	<0.0010	0.44	<0.20	<0.50	0.013
Pyrene	0.025	<0.0010	0.21	<0.20	<0.50	0.023
Triphenylene	<0.025 c	<0.0010 c	c	<0.20 c	<0.50 c	c
Sum List 2	4.5	0.28	10	51	110	29
Phenolics						
4-chloro-3-methylphenol	<5	<100	<10	<250	<50	<5
2-Chlorophenol	<5	<100	<10	<250	<50	<5
O-Cresol	<5	<100	<10	<250	<50	<5
M-Cresol	<5 c	<100 c	<10 c	<250 c	<50 c	<5 c
P-Cresol	<5 c	<100 c	<10 c	<250 c	<50 c	<5 c
2,4-Dichlorophenol	<5	<100	<10	<250	<50	<5
2,4-Dimethylphenol	<5	<100	<10	<250	<50	<5
2,4-Dinitrophenol	<25	<500	<50	<1200	<250	<25
2-methyl-4,6-dinitrophenol	<25	<500	<50	<1200	<250	<25
2-Nitrophenol	<5	<100	<10	<250	<50	<5
4-Nitrophenol	<5	<100	<10	<250	<50	<5
Pentachlorophenol	350	6200	430	12000	4200	2100
Phenol	<5	<100 p	<10	<250	<50	<5
2,4,6-Trichlorophenol	<5	<100	<10	<250	<50	<5
Metals						
	01/24/85			01/24/85		
Arsenic (filtered)	2	3	<1	2	5	<1
Copper (filtered)	6.0	2.3	4.2	1.9	4.2	1.0
Chromium, total (filtered)	1.7	1.1	<0.5	1.8	1.1	<0.5
Chromium, hexavalent	<20	<1	<1	<20	<1	<1

Showing in deep wells

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p Small peak in chromatogram below method detection limit.
c Coeluting compound (concentrations reported with the List 1 compound). Coeluting compounds are Chrysene/Triphylene and Benzo(b)fluoranthene/Benzo(k)fluoranthene.
s Statistical analysis indicates a potential false positive value.
DLND Not detected. Detection limit not determined.
ND Not detected.

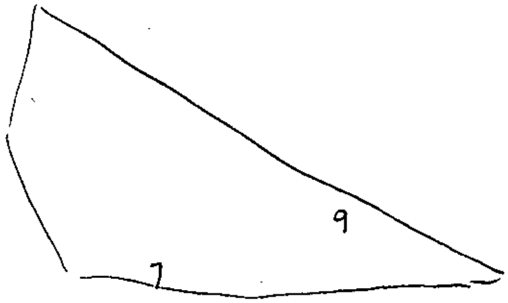


TABLE 8 (cont.)

SHALLOW GROUNDWATER QUALITY

(concentrations in ug/L)

	W7 24'			W9 21.6		
	12/27/84	03/27/85	05/16/85	12/11/84	03/28/85	05/22/85
List 1 PAH/Heterocycles						
Benzo(a)anthracene	<0.010	<0.050	<0.010	<0.040	<0.50	<1.0
Benzo(b)fluoranthene	<0.010 c	<0.050 c	<0.010 c	<0.040 c	<0.50 c	<1.0 c
Benzo(ghi)perylene	<0.010	<0.0050	<0.010	<0.040	<0.50	<1.0
Benzo(a)pyrene	<0.010	<0.0050	<0.010	<0.040	<0.50	<1.0
Chrysene	<0.010 c	<0.050 c	<0.010 c	<0.040 c	<0.50 c	<1.0 c
Dibenz(ah)anthracene	<0.014	<0.0070	<0.014	<0.056	<0.70	<1.0
Indeno(1,2,3,cd)pyrene	<0.017	<0.0085	<0.017	<0.068	<0.85	<1.0
Quinoline	<0.010	<0.050	<0.010	<0.040	<0.50	<1.0
Sum List 1	ND	ND	ND	ND	ND	ND
List 2 PAH/Heterocycles						
Acenaphthene	<0.013	0.17	0.058	30	110	160
Acenaphthylene	<0.010	<0.050	<0.010	0.77	2.3	14
Acridine	<0.018	<0.090	<0.018	<0.072	<0.90	<1.0
Anthracene	<0.010	<0.050	0.027	<0.040	<0.50	1.2
Benzo(k)fluoranthene	<0.010 c	<0.050 c	<0.010 c	<0.040 c	<0.50 c	<1.0 c
✓ 2,3-Benzofuran	0.021	0.051	0.59	1.2	1.5	44
Benzo(e)pyrene	<0.010	<0.0050	<0.010	<0.040	<0.50	<1.0
✓ Benzo(b)thiophene	0.50	5.7	1.2	8.6	9.7	85
Biphenyl	0.013	0.24	0.12	1.9	3.1	23
Carbazole	<0.011	<0.055	0.019	2.0	2.4	14
Dibenzothiophene	DLND	DLND	DLND	0.048	DLND	<1.0
Dibenzofuran	<0.020	0.33	0.14	4.8	10	57
2,3-Dihydroindene	0.031	1.5	0.066	8.8	43	250
Fluoranthene	<0.010	<0.050	0.022	<0.040	<0.50	2.3
Fluorene	<0.014	0.12	0.10	2.3	3.2	21
Indene	0.0083	0.24	0.014	6.6	7.5	130
Indole	<0.029	<0.14	<0.029	<0.12	<1.4	<1.0
Isoquinoline	DLND	DLND	DLND	DLND	DLND	<1.0
✓ 1-Methylnaphthalene	0.047	17	2.7	18	42	98
✓ 2-Methylnaphthalene	0.060	22	3.2	<0.080	<1.0	2.0
✓ Naphthalene	0.051	16	0.80	22	<0.95	340
Perylene	<0.010	<0.0050	<0.010	<0.04	<0.50	<1.0
Phenanthrene	<0.010	0.16	0.044	3.8	5.3	46
Pyrene	<0.010	<0.050	0.022	<0.040	<0.50	1.3
Triphenylene	<0.010 c	<0.050 c	<0.010 c	<0.040 c	<0.50 c	<1.0 c
Sum List 2	0.73	64	9.1	110	240	1300
Phenolics						
4-chloro-3-methylphenol	<5	<25	<5	<5	<25	<25
2-Chlorophenol	<5	<25	<5	<5	<25	<25
O-Cresol	<5	<25	<5	<5	<25	<25
M-Cresol	<5 c	<25 c	<5 c	<5 c	<25 c	<25 pc
P-Cresol	<5 c	<25 c	<5 c	<5 c	<25 c	<25 pc
2,4-Dichlorophenol	<5	<25	<5	<5	<25	<25 p
2,4-Dimethylphenol	<5	<25	<5	<5 p	<25	<25 p
2,4-Dinitrophenol	<25	<125	<25	<25	<125	<125
2-methyl-4,6-dinitrophenol	<25	<125	<25	<25	<125	<125
2-Nitrophenol	<5	<25	<5	<5	<25	<25
4-Nitrophenol	<5	<25	<5	<5	<25	<25
Pentachlorophenol	16	1000	69	570	1300	980
Phenol	<5	<25	<5	<5	<25	<25
2,4,6-Trichlorophenol	<5	<25	<5	<5	25	<25
Metals						
	01/24/85			01/24/85		
Arsenic (filtered)	5	8	<1	3	7	<1
Copper (filtered)	1.3	33	0.8	1.3	5.7	2.4
Chromium, total (filtered)	2.9	2.7	1.0	1.4	2.6	<0.5
Chromium, hexavalent	<20	6	<1	<20	1	<1

---

p Small peak in chromatogram below method detection limit.

c Coeluting compound (concentrations reported with the List 1 compound). Coeluting compounds are Chrysene/Triphylene and Benzo(b)fluoranthene/Benzo(k)fluoranthene.

s Statistical analysis indicates a potential false positive value.

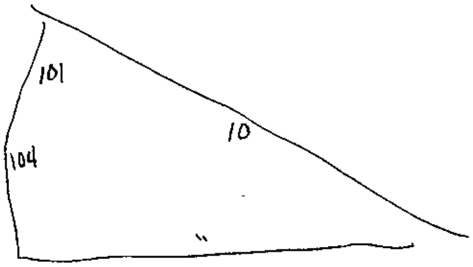
DLND Not detected. Detection limit not determined.

ND Not detected.

TABLE 8 (cont.)

SHALLOW GROUNDWATER QUALITY

(concentrations in ug/L)



12/13/86

	W10 13.' 12/11/84	W10 13.' 03/28/85	W10 13.' 05/16/85	forest duplicate	W101 12.8' 01/24/85	W101 12.8' 05/16/85	W104 11.' 01/24/85	W104 11.' 05/16/8
List 1 PAH/Heterocycles								
Benzo(a)anthracene	<0.040	<0.050	<0.025		0.046	<0.025	0.017	0.0058
Benzo(b)fluoranthene	<0.040 c	<0.050 c	<0.025 c		0.083 c	<0.025 c	0.069 c	0.019 c
Benzo(ghi)perylene	<0.040	<0.050	<0.025		0.024	<0.025	<0.010	<0.0050
Benzo(a)pyrene	<0.040	<0.050	<0.025		0.017	<0.025	0.014	<0.0050
Chrysene	<0.040 c	<0.050 c	<0.025 c		0.056 c	<0.025 c	0.029 c	0.012 c
Dibenz(ah)anthracene	<0.056	<0.070	<0.035		<0.014	<0.035	<0.014	<0.0070
Indeno(1,2,3,cd)pyrene	<0.068	<0.085	<0.043		0.023	<0.043	<0.017	<0.0085
Quinoline	<0.040	<0.050	<0.025		<0.010	0.076	<0.010	<0.0050
Sum List 1	ND	ND	ND		0.25	0.076	0.13	0.037
List 2 PAH/Heterocycles								
Acenaphthene	2.8	5.9	7.1	3.3	1.30	0.28	0.036	<0.0065
Acenaphthylene	<0.040	<0.050	0.077		0.015	0.056	<0.010	<0.0050
Acridine	<0.072	<0.090	<0.045		<0.018	<0.045	<0.018	<0.0090
Anthracene	0.055	0.13	0.10		0.078	0.09	0.011	0.0088
Benzo(k)fluoranthene	<0.040 c	<0.050 c	<0.025 c		c	<0.025 c	c	c
2,3-Benzofuran	DLND	0.033	0.052		0.040	0.15	DLND	DLND
Benzo(e)pyrene	<0.040	<0.050	<0.025		0.034	<0.025	0.043	0.0072
Benzo(b)thiophene	5.6	4.5	5.0	3.7	0.78	4.9	<0.010	0.014
Biphenyl	0.086	0.1	0.74	.3	0.25	1.1	0.036	<0.0050
Carbazole	0.13	0.022	0.11		0.030	0.073	<0.011	0.0080
Dibenzothiophene	0.062	DLND	0.35	.9	0.24	0.35	0.057	0.0045
Dibenzofuran	0.47	0.94	3.3	.5	1.0	4.0	0.046	<0.010
2,3-Dihydroindene	11	7.1	5.9	6.0	0.24	1.4	0.035	0.026
Fluoranthene	<0.040	0.062	0.097		0.30	0.24	0.064	0.025
Fluorene	0.54	0.78	4.4	.8	1.20	5.1	0.070	0.0076
Indene	6.1	2.9	2.4	1.8	0.030	0.35	<0.010	0.0086
Indole	<0.12	<0.15	<0.072		<0.029	<0.072	<0.029	<0.014
Isoquinoline	DLND	DLND	0.065		DLND	DLND	DLND	DLND
1-Methylnaphthalene	0.55	0.32	0.34	2.1 ←	2.2	16	0.39	0.027
2-Methylnaphthalene	<0.080	<0.10	0.040	2.9	3.1	16	0.61	0.030
Naphthalene	16	13	14	14	1.1	9.8	0.22	0.036
Perylene	<0.040	<0.050	<0.025		<0.010	<0.025	<0.010	<0.0050
Phenanthrene	0.25	0.082	3.3	2.2	1.2	1.6	0.16	0.022
Pyrene	<0.040	<0.050	0.033		0.23	0.14	0.081	0.024
Triphenylene	<0.040 c	<0.050 c	<0.025 c		c	<0.025 c	c	c
Sum List 2	44	36	47	39	13	62	1.8	0.25
Phenolics								
4-chloro-3-methylphenol	<5	<5	<5		<5	<5	<5	<5
2-Chlorophenol	<5	<5	<5		<5	<5	<5	<5
O-Cresol	<5	<5	<5		<5	<5	<5	<5
M-Cresol	<5 c	<5 c	<5 c		<5 c	<5 c	<5 c	<5 c
P-Cresol	<5 c	<5 c	<5 c		<5 c	<5 c	<5 c	<5 c
2,4-Dichlorophenol	<5	<5	<5		<5	<5	<5	<5
2,4-Dimethylphenol	<5	<5	<5		<5	<5	<5	<5
2,4-Dinitrophenol	<25	<25	<25		<25	<25	<25	<25
2-methyl-4,6-dinitrophenol	<25	<25	<25		<25	<25	<25	<25
2-Nitrophenol	<5	<5	<5		<5	<5	<5	<5
4-Nitrophenol	<5	<5	<5		<5	<5	<5	<5
Pentachlorophenol	<5 p	<5 p	<5 p		52	16	<5	<5 p
Phenol	<5	<5	<5		<5	<5	<5	<5
2,4,6-Trichlorophenol	<5	<5	<5		<5	<5	<5	<5
Metals	01/24/85							
Arsenic (filtered)	7	7	2		11	6	3	4
Copper (filtered)	3.4	3.4	3.0		1.4	1.0	2.2	0.8
Chromium, total (filtered)	5.5	2.0	<0.5		2.0	1.0	5.5	0.5
Chromium, hexavalent	<20	2	<1		<20	1	<20	4

---

p Small peak in chromatogram below method detection limit.

c Coeluting compound (concentrations reported with the List 1 compound). Coeluting compounds are Chrysene/Triphylene and Benzo(b)fluoranthene/Benzo(k)fluoranthene.

s Statistical analysis indicates a potential false positive value.

DLND Not detected. Detection limit not determined.

ND Not detected.

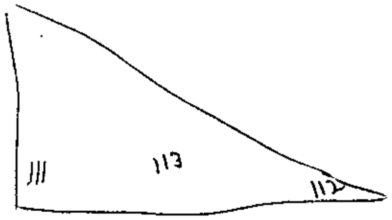


TABLE 8 (cont.)

SHALLOW GROUNDWATER QUALITY
(concentrations in ug/L)

	W111 16.4'		W112 24.5			W113 19.5	
	01/24/85	05/22/85	01/28/85	05/16/85	12/13/86	3/01/85 03/28/85	05/22/85
List 1 PAH/Heterocycles							
Benzo(a)anthracene	1.8	<5.0	<0.010	<1.0		.0012 58	2000
Benzo(b)fluoranthene	<1.0 c	<5.0 c	<0.010 c	<1.0 c		.0012 50 c	1500 c
Benzo(ghi)perylene	<1.0	<5.0	<0.010	<1.0		.0047 <10	<200
Benzo(a)pyrene	<1.0	<5.0	<0.010	<1.0		20	800
Chrysene	3.0 c	<5.0 c	<0.010 c	<1.0 c		63 c	1500 c
Dibenz(ah)anthracene	<1.4	<5.0	<0.010	<1.0		<.0011 <14	<200
Indeno(1,2,3,cd)pyrene	<1.7	<5.0	<0.010	<1.0		.0014 <17	<200
Quinoline	<1.0	<5.0	<0.010	<1.0		120	430
Sum List 1	4.8	ND	ND	ND	ND	340	6200
List 2 PAH/Heterocycles							
Acenaphthene	<1.3	39	16	7.0	20	<.001 500	6600
Acenaphthylene	<1.0	<5.0	0.25	1.2	.9	9.9 <10	<200
Acridine	<1.8	<5.0	<0.010	<1.0	<	38	790
Anthracene	7.0	<5.0	0.18	<1.0	<	.220 95	2700
Benzo(k)fluoranthene	<1.0 c	<5.0 c	<0.010 c	<1.0 c	<	.0012 c	c
2,3-Benzofuran	DLND	<5.0	1.2	12	3.8	120	250
Benzo(e)pyrene	<1.0	<5.0	<0.010	<1.0	<	21	530
Benzo(b)thiophene	140	49	14	91	45	400	1200
Biphenyl	<1.0	18	2.3	11	2.9	95	1200
Carbazole	<1.1	25	5.2	24	3.7	350	2500
Dibenzothiophene	85	33	0.26	<1.0	<	50	1200
Dibenzofuran	44	31	8.2	36	7.2	300	4500
2,3-Dihydroindene	33	40	9.2	47	12	480	1400
Fluoranthene	5.2	<5.0	0.082	<1.0	<	.0015 280	8900
Fluorene	45	27	5.0	26	5.8	2.9 330	6400
Indene	<1.0	<5.0	5.1	28	12	300	890
Indole	<2.9	<5.0	<0.010	<1.0	<	68	<200
Isoquinoline	DLND	<5.0	<0.010	<1.0	<	400	1700
1-Methylnaphthalene	1100	460	7.3	36	16	550	4500
2-Methylnaphthalene	1400	670	0.30	<1.0	.3	850	8900
Naphthalene	480	150	20	110	64	<.011 8500	38000
Perylene	<1.0	<5.0	<0.010	<1.0	<	<10	<200
Phenanthrene	130	48	2.3	9.8	1.3	<.011 650	17000
Pyrene	28	9.0	0.10	<1.0	<	<.011 200	6400
Triphenylene	c	<5.0 c	<0.010 c	<1.0 c	<	c	c
Sum List 2	3500	1600	97	440	190	15000	120000
Phenolics							
4-chloro-3-methylphenol	<50	<50	<5	<10		<50	<250
2-Chlorophenol	<50	<50	<5	<10		<50	<250
O-Cresol	<50	<10	<5	<10		<50	<250
M-Cresol	<50 c	<10 c	<5 c	<10 c		<50 pc	<250 pc
P-Cresol	<50 c	<10 c	<5 c	<10 c		<50 pc	<250 pc
2,4-Dichlorophenol	<50	<50	<5	<10		<50	<250
2,4-Dimethylphenol	<50	<50	<5	<10		<50 p	<250
2,4-Dinitrophenol	<250	<250	<25	<50		<250	<1250
2-methyl-4,6-dinitrophenol	<250	<250	<25	<50		<250	<1250
2-Nitrophenol	<50	<50	<5	<10		<50	<250
4-Nitrophenol	<50	<50	<5	<10		<50	<250
Pentachlorophenol	6100	2400	380	1100	3500	2900	12000
Phenol	<50 p	<50	<5	<10		<50	<250
2,4,6-Trichlorophenol	<50	<50	<5	<10		<50	<250
Metals							
Arsenic (filtered)	3	<1	26	4		5	4
Copper (filtered)	0.7	<0.5	5.7	0.6		4.2	1.8
Chromium total (filtered)	1.0	<0.5	2.0	<0.5		1.1	<0.5
Chromium, hexavalent	<20	<1	<20	1		9	<1

---

p Small peak in chromatogram below method detection limit.

c Coeluting compound (concentrations reported with the List 1 compound). Coeluting compounds are Chrysene/Triphylene and Benzo(b)fluoranthene/Benzo(k)fluoranthene.

s Statistical analysis indicates a potential false positive value.

DLND Not detected. Detection limit not determined.

ND Not detected.

121

TABLE 8 (cont.)

SHALLOW GROUNDWATER QUALITY

(concentrations in ug/L)

122

	split 12/12/85	W121 24' 03/28/85	W121 05/06/85	12/13/86	W122 24' 03/26/85	W122 05/06/85	12/13/86	split 12/13/86	W123 16.5' 03/26/85	W123 05/07/85
List 1 PAH/Heterocycles										
Benzo(a)anthracene	<.0011	<0.0050	<0.0010		<0.025	<0.010		<	<0.010	<0.0050
Benzo(b)fluoranthene	<.0011	<0.0050 c	<0.0010 c		<0.025 c	<0.010 c		<	<0.010 c	<0.0050 c
Benzo(ghi)perylene	<.0011	<0.0050	<0.0010		<0.025	<0.010		<	<0.010	<0.0050
Benzo(a)pyrene	<.0011	<0.0050	<0.0010		<0.025	<0.010		<	<0.010	<0.0050
Chrysene		<0.0050 c	<0.0010 c		<0.025 c	<0.010 c		<	<0.010 c	<0.0050 c
Dibenz(ah)anthracene	<.0011	<0.0070	<0.0014		<0.035	<0.014		<	<0.014	<0.0070
Indeno(1,2,3,cd)pyrene	<.0011	<0.0085	<0.0017		<0.043	<0.017		<	<0.017	<0.0085
Quinoline		<0.0050	<0.0010		<0.025	<0.010			<0.010	<0.0050
Sum List 1	ND	ND	ND	ND	ND	ND	ND		ND	ND
List 2 PAH/Heterocycles										
Acenaphthene	<.011	<0.0065	<0.0013	<	2.3	2.1	.68	<.012	<0.013	<0.0065
Acenaphthylene	.500	<0.0050	<0.0010	<	0.048	<0.010	<	<.012	<0.010	<0.0050
Acridine		<0.0090	<0.0018	<	<0.045	<0.018			<0.018	<0.0090
Anthracene	<.011	<0.0050	<0.0010	<	0.64	0.069	.022	<.01	<0.010	<0.0050
Benzo(k)fluoranthene		<0.0050 c	<0.0010 c	<	<0.025 c	<0.010 c	<	<	<0.010 c	<0.0050 c
2,3-Benzofuran		DLND	0.0041	.0040	DLND	DLND			DLND	DLND
Benzo(e)pyrene		<0.0050	<0.0010		<0.025	<0.010			<0.010	<0.0050
Benzo(b)thiophene		<0.0050	<0.0010	.0013	0.051	0.020	.016		0.86	0.69
Biphenyl		<0.0050	0.0017	.0013	<0.025	<0.010			<0.010	<0.0050
Carbazole		<0.0055	<0.0011		5.1	5.0	1.9		<0.011	<0.0072
Dibenzothiophene		DLND	DLND		DLND	0.063			DLND	DLND
Dibenzofuran		<0.010	<0.0020		4.8	<0.020	1.2		<0.020	<0.010
2,3-Dihydroindene		<0.0070	0.0072	.0070	0.90	0.77	.21		1.1	1.1
Fluoranthene	<.0011	<0.0050	0.0020	.0014	<0.025	0.23	<	<.	<0.010	0.078
Fluorene	<.011	<0.0070	<0.0014	<	<0.035	0.74		<.01	<0.014	<0.0070
Indene		<0.0050	0.0029	.0024	<0.025	0.0087	.012		0.15	0.13
Indole		<0.0145	<0.0029		<0.072	<0.029			<0.029	<0.014
Isoquinoline		DLND	DLND		DLND	DLND			DLND	DLND
1-Methylnaphthalene		0.011	0.0040	.0069	0.098	0.087	.030		0.032	0.015
2-Methylnaphthalene		<0.010	0.0058	.0098	<0.050	<0.020	.024		<0.020	0.026
Naphthalene	.230	0.014	0.012 s	.0015	<0.048	0.048	.041	<.01	0.061	0.039
Perylene		<0.0050	<0.0010		<0.025	<0.010	-		<0.010	<0.0050
Phenanthrene	<.011	0.0091	0.0021	.0016	<0.025	0.140	<	<	<0.012	0.095
Pyrene	<.011	<0.0050	0.0019	.0017	<0.025	0.071	<	<	<0.010	0.033
Triphenylene		<0.0050 c	<0.0010 c		<0.025 c	<0.010 c			<0.010 c	<0.0050 c
Sum List 2		0.034	0.044	.052	13	9.3	4.1		2.9	2.2
Phenolics										
4-chloro-3-methylphenol		<5	<5		<5	<5			<5	<5
2-Chlorophenol		<5	<5		<5	<5			<5	<5
O-Cresol		<5	<5		<5	<5			<5	<5
M-Cresol		<5 c	<5 c		<5	<5			<5 c	<5 c
P-Cresol		<5 c	<5 c		<5	<5			<5 c	<5 c
2,4-Dichlorophenol		<5	<5		<5	<5			<5	<5
2,4-Dimethylphenol		<5	<5		<5	<5			<5	<5
2,4-Dinitrophenol		<25	<25		<25	<25			<25	<25
2-methyl-4,6-dinitrophenol		<25	<25		<25	<25			<25	<25
2-Nitrophenol		<5	<5		<5	<5			<5	<5
4-Nitrophenol		<5	<5		<5	<5			<5	<5
Pentachlorophenol		<5	<5 p		<5 p	<5 p			5.8	<5 p
Phenol		<5	<5		<5	<5			<5	<5
2,4,6-Trichlorophenol		<5	<5		<5	<5			<5	<5
Metals		03/26/85								
Arsenic (filtered)		6	<1		8	10			7	3
Copper (filtered)		1.9	<0.5		2.4	<0.5			4.7	6.6
Chromium, total (filtered)		0.34	<0.5		0.37	<0.5			1.2	<0.5
Chromium, hexavalent		<1	<1		<1	<1			<1	<1

---

p Small peak in chromatogram below method detection limit.

c Coeluting compound (concentrations reported with the List 1 compound). Coeluting compounds are Chrysene/Triphylene and Benzo(b)fluoranthene/Benzo(k)fluoranthene.

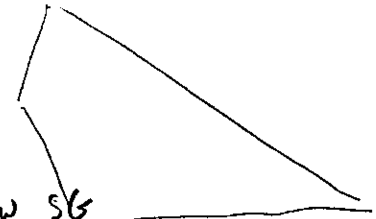
s Statistical analysis indicates a potential false positive value.

DLND Not detected. Detection limit not determined.

ND Not detected.

.124

PAH std is .028



MW 5G

H_2O 18 1

TABLE 8 (cont.)

SHALLOW GROUNDWATER QUALITY

.125

(concentrations in ug/L)

		.126 W124 27'			W125 25'			″ W126 18.5'		
		03/26/85	05/06/85	12/13/86	03/26/85	05/06/85	12/13/86	03/28/85	05/07/85	12/13/85
	List 1 PAH/Heterocycles			dff MDL						
228.29	Benzo(a)anthracene	<0.0010	<0.0010	<.0020	<0.010	<0.0010		0.012	<0.0019	
252.32	Benzo(b)fluoranthene	<0.0010 c	<0.0010 c		<0.010 c	<0.0010 c		<0.0020 c	0.0047 c	
sink	Benzo(ghi)perylene	<0.0010	<0.0010		<0.010	<0.0010		<0.0020	<0.0010	
sinker	Benzo(a)pyrene	<0.0010	<0.0010		<0.010	<0.0010		<0.0020	<0.0010	
floater	Chrysene	<0.0010 c	<0.0010 c		<0.010 c	<0.0010 c		<0.0020 c	0.0010 c	
278.35	Dibenz(ah)anthracene	<0.0014	<0.0014		<0.014	<0.0014		<0.0028	<0.0014	
gravity oil sep.	Indeno(1,2,3,cd)pyrene	<0.0017	<0.0017		<0.017	<0.0017		<0.0034	<0.0017	
	Quinoline	<0.0010	<0.0010		<0.010	<0.0010		<0.0020	<0.0010	
	Sum List 1	ND	ND	ND	ND	ND	ND	0.012	0.0057	ND
	List 2 PAH/Heterocycles									
	Acenaphthene	<0.0013	<0.0013		<0.013	<0.0013	.0037	<0.0026	<0.0013	.0014
	Acenaphthylene	<0.0010	<0.0010		<0.010	<0.0010	.0049	<0.0020	<0.0010	.0011
	Acridine	<0.0018	<0.0018		<0.018	<0.0018		<0.0036	<0.0018	
sink	Anthracene	<0.0010	0.0050		<0.010	0.0017		<0.0020	0.0013	
252.32	Benzo(k)fluoranthene	<0.0010 c	<0.0010 c		<0.010 c	<0.0010 c		<0.0020 c	c	
	2,3-Benzofuran	DLND	DLND		DLND	0.0053	.010	DLND	0.0032	
	Benzo(e)pyrene	<0.0010	<0.0010		<0.010	<0.0010		<0.0020	<0.0010	
	Benzo(b)thiophene	<0.0010	<0.0010	.0022	0.34	0.018	.156	0.0023	0.0022	.0058
	Biphenyl	0.0026	<0.0010		0.025	0.014	.0056	0.0028	0.0023	.0027
	Carbazole	<0.0011	0.011		2.0	1.2	1.070	<0.0022	<0.0011	
	Dibenzothiophene	DLND	DLND		DLND	DLND		0.0081	DLND	
	Dibenzofuran	<0.0020	<0.0020		0.17	0.12	.047	<0.0040	<0.0020	
	2,3-Dihydroindene	0.011	0.0075 s	.0075	0.037	0.018 s	.034	0.0067	0.019	.017
	Fluoranthene	0.0080	0.028		<0.010	0.0063	.0020	0.0064	<0.0067	
	Fluorene	<0.0014	<0.0014		<0.014	0.0039	.0014	0.0078	<0.0014	
	Indene	0.0056	0.0030	.0035	0.012	0.0094	.015	0.0020	0.0032 s	.0050
	Indole	<2.9	0.0029	.0058	<0.029	<0.0029		<0.0058	<0.0029	
	Isoquinoline	DLND	DLND		DLND	DLND		DLND	DLND	
	1-Methylnaphthalene	0.012	0.0047	.024	<0.012	0.014	.036	0.019	0.021	.033
	2-Methylnaphthalene	0.014	0.0081	.036	<0.020	0.017	.053	0.023	0.041	.052
	Naphthalene	0.043	0.018	.026	0.025	0.023	.082	0.022	0.037	.045
	Perylene	<0.0010	<0.0010		<0.010	<0.0010		<0.0020	<0.0010	
	Phenanthrene	0.0090	0.025		<0.010	0.015	.0010	0.030	0.0066	.0021
	Pyrene	0.0073	0.012		<0.010	0.0030	.0032	0.016	<0.0040	
	Triphenylene	<0.0010 c	<0.0010 c		<0.010 c	<0.0010 c		<0.0020 c	c	
	Sum List 2	0.11	0.13	.099	2.6	1.5	1.5	0.15	0.14	.17
	Phenolics									
	4-chloro-3-methylphenol	<5	<5		<5	<5		<5	<5	
	2-Chlorophenol	<5	<5		<5	<5		<5	<5	
	O-Cresol	<5	<5		<5	<5		<5	<5	
	M-Cresol	<5 c	<5 c		<5 c	<5 c		<5 c	<5 c	
	P-Cresol	<5 c	<5 c		<5 c	<5 c		<5 c	<5 c	
	2,4-Dichlorophenol	<5	<5		<5	<5		<5	<5	
	2,4-Dimethylphenol	<5	<5		<5	<5		<5	<5	
	2,4-Dinitrophenol	<25	<25		<25	<25		<25	<25	
	2-methyl-4,6-dinitrophenol	<25	<25		<25	<25		<25	<25	
	2-Nitrophenol	<5	<5		<5	<5		<5	<5	
	4-Nitrophenol	<5	<5		<5	<5		<5	<5	
	Pentachlorophenol	<5	<5 p	<	13	6.7	4.6p	<5	<5	<
	Phenol	<5	<5		<5	<5		<5	<5	
	2,4,6-Trichlorophenol	<5	<5		<5	<5		<5	<5	
	Metals									
	Arsenic (filtered)	7	7		5	<1		7	19	
	Copper (filtered)	3.9	1.1		3.2	2.1		5.7	<0.5	
	Chromium, total (filtered)	0.84	<0.5		0.33	<0.5		0.84	1.0	
	Chromium, hexavalent	<1	<1		<1	<1		--	<1	

---

p Small peak in chromatogram below method detection limit.

c Coeluting compound (concentrations reported with the List 1 compound). Coeluting compounds are Chrysene/Triphylene and Benzo(b)fluoranthene/Benzo(k)fluoranthene.

s Statistical analysis indicates a potential false positive value.

DLND Not detected. Detection limit not determined.

ND Not detected.

-- Not analyzed.

TABLE 8 (cont.)

SHALLOW GROUNDWATER QUALITY

(concentrations in ug/L)

HOWE Samples

	P02	P03	P23
	05/22/85	05/21/85	05/22/85
List 1 PAH/Heterocycles			
Benzo(a)anthracene	<5.0	<1.0	<0.0050
Benzo(b)fluoranthene	<5.0 c	<1.0 c	<0.0050 c
Benzo(ghi)perylene	<5.0	<1.0	<0.0050
Benzo(a)pyrene	<5.0	<1.0	<0.0050
Chrysene	<5.0 c	<1.0 c	<0.0050 c
Dibenz(ah)anthracene	<5.0	<1.0	<0.0070
Indeno(1,2,3,cd)pyrene	<5.0	<1.0	<0.0085
Quinoline	<5.0	<1.0	<0.0050
Sum List 1	ND	ND	ND
List 2 PAH/Heterocycles			
Acenaphthene	<5.0	<1.0	0.018
Acenaphthylene	<5.0	<1.0	<0.0050
Acridine	<5.0	<1.0	<0.0090
Anthracene	<5.0	<1.0	<0.0050
Benzo(k)fluoranthene	<5.0 c	<1.0 c	<0.0050 c
2,3-Benzofuran	<5.0	<1.0	0.014
Benzo(e)pyrene	<5.0	<1.0	<0.0050
Benzo(b)thiophene	<5.0	<1.0	<0.0050
Biphenyl	<5.0	<1.0	0.0053
Carbazole	<5.0	<1.0	<0.0055
Dibenzothiophene	<5.0	<1.0	0.0078
Dibenzofuran	<5.0	<1.0	<0.0010
2,3-Dihydroindene	<5.0	<1.0	0.042
Fluoranthene	<5.0	<1.0	0.0070
Fluorene	<5.0	<1.0	<0.0070
Indene	<5.0	<1.0	0.0068
Indole	<5.0	<1.0	<0.014
Isoquinoline	<5.0	<1.0	DLND
1-Methylnaphthalene	<5.0	<1.0	0.042
2-Methylnaphthalene	<5.0	<1.0	0.065
Naphthalene	<5.0	<1.0	0.094
Perylene	<5.0	<1.0	<0.0050
Phenanthrene	<5.0	<1.0	0.015
Pyrene	<5.0	<1.0	0.0055
Triphenylene	<5.0 c	<1.0 c	<0.0050 c
Sum List 2	ND	ND	0.35
Phenolics			
4-chloro-3-methylphenol	<5	<5	<5
2-Chlorophenol	<5	<5	<5
O-Cresol	<5	<5	<5
M-Cresol	<5 c	<5 c	<5 c
P-Cresol	<5 c	<5 c	<5 c
2,4-Dichlorophenol	<5	<5	<5
2,4-Dimethylphenol	<5	<5	<5
2,4-Dinitrophenol	<25	<25	<25
2-methyl-4,6-dinitrophenol	<25	<25	<25
2-Nitrophenol	<5	<5	<5
4-Nitrophenol	<5	<5	<5
Pentachlorophenol	<5	<5	<5
Phenol	<5 p	<5	7
2,4,6-Trichlorophenol	<5	<5	<5
Metals			
Arsenic (filtered)	<1	<1	<1
Copper (filtered)	0.8	0.6	<0.5
Chromium, total (filtered)	<0.5	<0.5	<0.5
Chromium, hexavalent	<1	<1	<1

---

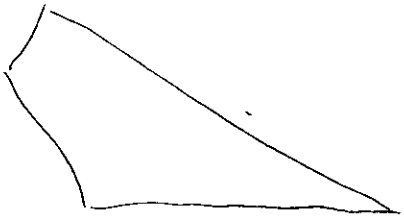
p Small peak in chromatogram below method detection limit.

c Coeluting compound (concentrations reported with the List 1 compound). Coeluting compounds are Chrysene/Triphylene and Benzo(b)fluoranthene/Benzo(k)fluoranthene.

* Statistical analysis indicates a potential false positive value.

DLND Not detected. Detection limit not determined.

ND Not detected.



W127		W128		W129	
3/86	6/86	3/86	6/86	3/86	6/86
ND	ND	ND	ND	ND	ND
1.4	8.4	.039	.009	5.	.41
17	160	ND	ND	180	8.8

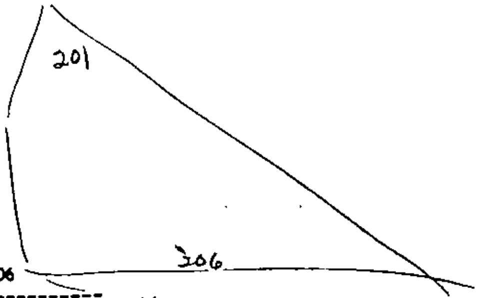


TABLE 9

MID-DEPTH GROUNDWATER QUALITY

(concentrations in ug/L)

	W201 63'			W206 52'		
	04/12/85	05/06/85	6/86	01/29/85	05/07/85	6/86
List 1 PAH/Heterocycles						
Benzo(a)anthracene	<0.0010	<0.0010		<0.025	<0.010	
Benzo(b)fluoranthene	<0.0010 c	<0.0010 c		<0.025 c	<0.010 c	
Benzo(ghi)perylene	<0.0010	<0.0010		<0.025	<0.010	
Benzo(a)pyrene	<0.0010	<0.0010		<0.025	<0.010	
Chrysene	<0.0010 c	<0.0010 c		<0.025 c	<0.010 c	
Dibenz(ah)anthracene	<0.0014	<0.0014		<0.035	<0.014	
Indeno(1,2,3,cd)pyrene	<0.0017	<0.0017		<0.043	<0.017	
Quinoline	<0.0010	<0.0010		<0.025	<0.010	
Sum List 1	ND	ND	ND	ND	ND	ND
List 2 PAH/Heterocycles						
Acenaphthene	<0.0013	<0.0013		2.5	2.900	
Acenaphthylene	<0.0010	<0.0010		0.028	<0.010	
Acridine	<0.0010	<0.0018		<0.045	<0.018	
Anthracene	<0.0010	<0.0010		<0.025	0.023	
Benzo(k)fluoranthene	<0.0010 c	<0.0010 c		<0.025 c	<0.010 c	
2,3-Benzofuran	DLND	DLND		DLND	DLND	
Benzo(e)pyrene	<0.0010	<0.0010		<0.025	<0.010	
Benzo(b)thiophene	<0.0010	<0.0010		1.2	1.1	
Biphenyl	0.0021	<0.0010		0.057	0.057	
Carbazole	<0.0014	<0.0011		0.34	0.60	
Dibenzothiophene	DLND	DLND		0.026	0.065	
Dibenzofuran	<0.0020	<0.0020		0.75	1.2	
2,3-Dihydroindene	0.0066	0.0034 s		2.2	3.1	
Fluoranthene	<0.0011	<0.0010		<0.025	0.065	
Fluorene	<0.0014	<0.0014		0.62	0.90	
Indene	0.0052	0.0016 s		0.49	0.46	
Indole	<0.0029	<0.0029		<0.072	<0.029	
Isoquinoline	DLND	DLND		DLND	DLND	
1-Methylnaphthalene	0.0040	<0.0012		0.47	0.35	
2-Methylnaphthalene	0.0084	0.0020 s		0.33	0.066	
Naphthalene	0.018	0.0090 s		0.49	0.25	
Perylene	<0.0010	<0.0010		<0.025	<0.010	
Phenanthrene	<0.0010	<0.0010		0.36	0.68	
Pyrene	<0.0010	<0.0010		<0.025	0.033	
Triphenylene	<0.0010 c	<0.001 c		<0.025 c	<0.010 c	
Sum List 2	0.044	0.016	.42	9.9	12	3.1
Pheuloics						
4-chloro-3-methylphenol	<5	<5		<5	<5	
2-Chlorophenol	<5	<5		<5	<5	
O-Cresol	<5	<5		<5	<5	
M-Cresol	<5 c	<5 c		<5 c	<5 c	
P-Cresol	<5 c	<5 c		<5 c	<5 c	
2,4-Dichlorophenol	<5	<5		<5	<5	
2,4-Dimethylphenol	<5	<5		<5	<5	
2,4-Dinitrophenol	<25	<25		<25	<25	
2-methyl-4,6-dinitrophenol	<25	<25		<25	<25	
2-Nitrophenol	<5	<5		<5	<5	
4-Nitrophenol	<5	<5		<5	<5	
Pentachlorophenol	<5	<5		14	<5 p	
Phenol	<5	<5		<5	<5	
2,4,6-Trichlorophenol	<5	<5	ND	<5	<5 p	2.0 p
Metals						
	03/28/85			01/28/85		
Arsenic (filtered)	4	<1		8	<1	
Copper (filtered)	5.3	<0.5		1.3	2.0	
Chromium, total (filtered)	1.4	<0.5		1.3	<0.5	
Chromium, hexavalent	<1	<1		<20	<1	

---

p Small peak in chromatogram below method detection limit.

c Coeluting compound (concentrations reported with the List 1 compound). Coeluting compounds are Chrysene/Triphylene and Benzo(b)fluoranthene/Benzo(k)fluoranthene.

s Statistical analysis indicates a potential false positive value.

DLND Not detected. Detection limit not determined.

ND Not detected.

.028 ug/l

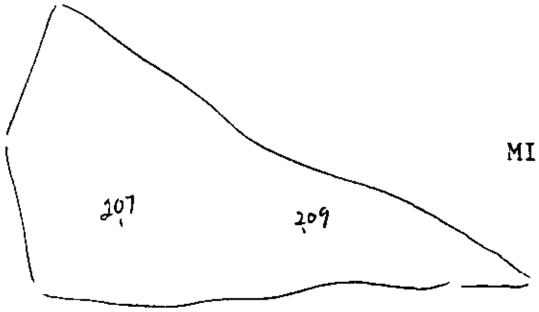


TABLE 9 (cont.)

MID-DEPTH GROUNDWATER QUALITY

(concentrations in ug/L)

W223 6/86 split Dup split		W207 51'		W209 59' "	
		03/28/85	05/16/85 6/86	01/29/85	05/07/85 6/86
	List 1 PAH/Heterocyles				
.0043 .011	Benzo(a)anthracene	<0.050	<0.50	<0.0050	0.0013
.0043 .0064	Benzo(b)fluoranthene	<0.050 c	<0.50 c	<0.0050 c	<0.0010 c
.0064 .012	Benzo(ghi)perylene	<0.050	<0.50	0.071	<0.0010
.0032 .0064	Benzo(a)pyrene	<0.050	<0.50	<0.0050	<0.0010
	Chrysene	<0.050 c	<0.50 c	<0.0050 c	0.0013 c
	Dibenz(ab)anthracene	<0.070	<0.50	<0.0070	<0.0014
.0032 .0053	Indeno(1,2,3,cd)pyrene	<0.085	<0.50	<0.0085	<0.0017
	Quinoline	<0.050	<0.50	0.0074	<0.0010
	Sum List 1	ND	ND .031	0.078	0.0026 .032
ND .0021 .0043	Benzo(K) fluoranthene				
	List 2 PAH/Heterocycles				
15 2.8	Acenaphthene	15	16.0	0.80	0.13
4.3 3.9	Acenaphthylene	<0.050	<0.50	0.42	0.049
	Acridine	<0.090	<0.50	<0.0090	<0.0018
	Anthracene	0.14	1.2	0.020	0.0051
	Benzo(k)fluoranthene	<0.050 c	<0.50 c	<0.0050 c	<0.0010 c
	2,3-Benzofuran	DLND	<0.50	0.0072	0.0045
	Benzo(e)pyrene	<0.050	<0.50	<0.0050	<0.0010
	Benzo(b)thiophene	0.24	<0.50	0.24	0.040
	Biphenyl	<0.050	<0.50	0.046	0.0054
	Carbazole	1.9	2.0	0.12	0.031
	Dibenzothiophene	2.9	1.9	0.012	0.0065
	Dibenzofuran	4.5	4.6	0.15	0.021
	2,3-Dihydroindene	6.4	6.2	0.32	0.067
.0085 .015	Fluoranthene	0.38	<0.50	0.022	0.039
.94 .16	Fluorene	0.85	7.3	0.20	0.034
	Indene	0.43	<0.50	0.072	0.013
	Indole	<0.14	<0.50	<0.014	<0.0029
	Isoquinoline	DLND	<0.50	DLND	DLND
	1-Methylnaphthalene	4.8	4.4	0.19	0.020
	2-Methylnaphthalene	1.4	2.0	0.035	0.0055
	Naphthalene	0.48	<0.50	1.3	0.17
	Perylene	<0.050	<0.50	<0.0050	<0.0010
	Phenanthrene	2.0	1.2	0.25	0.10
	Pyrene	0.29	<0.50	0.027	0.028
	Triphenylene	<0.050 c	<0.50 c	<0.0050 c	c
25	Sum List 2	42	40 16.	4.2	0.77 .28
	Phenolics				
	4-chloro-3-methylphenol	<5	<5	<5	<5
	2-Chlorophenol	<5	<5	<5	<5
	O-Cresol	<5	<5	<5	<5
	M-Cresol	<5 c	<5 c	<5 c	<5 c
	P-Cresol	<5 c	<5 c	<5 c	<5 c
	2,4-Dichlorophenol	<5	<5	<5	<5
	2,4-Dimethylphenol	<5	<5	<5	<5
	2,4-Dinitrophenol	<25	<25	<25	<25
	2-methyl-4,6-dinitrophenol	<25	<25	<25	<25
	2-Nitrophenol	<5	<5	<5	<5
	4-Nitrophenol	<5	<5	<5	<5
	Pentachlorophenol	15	15	16	<5
	Phenol	<5	<5	<5	<5
	2,4,6-Trichlorophenol	<5	<5 5.5	<5	<5 ND
	Metals			01/28/85	
	Arsenic (filtered)	5	<1	11	6
	Copper (filtered)	5.4	<0.5	1.5	<0.5
	Chromium, total (filtered)	0.98	<0.5	1.6	<0.5
	Chromium, hexavalent	<1	<1	<20	1

ND' limit 220 µg

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p Small peak in chromatogram below method detection limit.
c Coeluting compound (concentrations reported with the List 1 compound). Coeluting compounds are Chrysene/Triphylene and Benzo(b)fluoranthene/Benzo(k)fluoranthene.
s Statistical analysis indicates a potential false positive value.
DLND Not detected. Detection limit not determined.
ND Not detected.

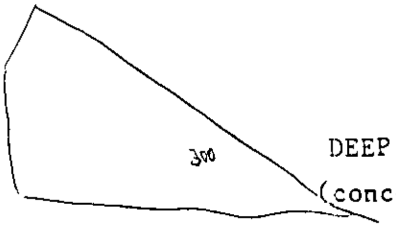

TABLE 10

W300 - plant

DEEP GROUNDWATER QUALITY

(concentrations in ug/L)

	192' deep				Prairie du Chein		
Formation	St. Peter Sandstone/ Prairie du Chien W300		Prairie du Chien 300PDC	St. Peter Sandstone 300STP			
	12/11/84	03/28/85	04/23/85	04/23/85	12/13/85	3/86	6/86
List 1 PAH & Heterocycles							
Benzo(a)anthracene	<0.0020	<0.0010	<0.0010	<0.0010	.0036		
Benzo(b)fluoranthene	<0.0020 c	<0.0010 c	<0.0010 c	<0.0010 c			
Benzo(ghi)perylene	<0.0020	<0.0010	<0.0010	<0.0010			
Benzo(a)pyrene	<0.0020	<0.0010	<0.0010	<0.0010			
Chrysene	<0.0020 c	<0.0010 c	<0.0010 c	<0.0010 c	.0033		
Dibenz(ah)anthracene	<0.0028	<0.0014	<0.0014	<0.0014			
Indeno(1,2,3,cd)pyrene	<0.0034	<0.0017	<0.0017	<0.0017			
Quinoline	<0.0020	<0.0010	<0.0010	<0.0010			
Sum List 1	ND	ND	ND	ND	.0069 ←	ND	ND
List 2 PAH & Heterocycles							
Acenaphthene	<0.0026	<0.0013	0.0051		.0014		
Acenaphthylene	<0.0020	<0.0010	<0.0010				
Acridine	<0.0036	<0.0018	<0.0018				
Anthracene	<0.0020	<0.0010	<0.0010				
Benzo(k)fluoranthene	<0.0020 c	<0.0010 c	<0.0010				
2,3-Benzofuran	0.010	0.0024	0.0023		.0034		
Benzo(e)pyrene	<0.0020	<0.0010	<0.0010				
Benzo(b)thiophene	<0.0020	<0.0010	<0.0010				
Biphenyl	<0.0020	<0.0010	0.0027		.0012		
Carbazole	<0.0022	<0.0011	<0.0011				
Dibenzothiophene	DLND	DLND	0.012				
Dibenzofuran	<0.0040	<0.0020	0.0048		.0063		
2,3-Dihydroindene	0.0099	0.0068	0.0029		.044 ←		
Fluoranthene	<0.0020	<0.0010	0.0044				
Fluorene	<0.0028	<0.0014	0.0070				
Indene	0.0050	0.0027	0.0013		.0013		
Indole	<0.0058	<0.0029	<0.0029				
Isoquinoline	DLND	DLND	DLND				
1-Methylnaphthalene	0.0060	0.0016	0.0039		.0022		
2-Methylnaphthalene	0.0076	0.0025	0.0048		.0037		
Naphthalene	0.022	0.015	0.0084		.0047		
Perylene	<0.0020	<0.0010	<0.0010				
Phenanthrene	<0.0020	0.0025	0.022		.0086		
Pyrene	<0.0020	0.0028	0.0027		.038 ←		
Triphenylene	<0.0020 c	<0.0010 c	<0.0010				
Sum List 2	0.061	0.036	0.084		.11	.02	.36
Phenolic Compounds							
4-chloro-3-methylphenol	<5	<5	<5	<5			
2-Chlorophenol	<5	<5	<5	<5			
O-Cresol	<5	<5	<5	<5			
M-Cresol	<5 c	<5 c	<5 c	<5 c			
P-Cresol	<5 c	<5 c	<5 c	<5 c			
2,4-Dichlorophenol	<5	<5	<5	<5			
2,4-Dimethylphenol	<5	<5	<5	<5			
2,4-Dinitrophenol	<25	<25	<25	<25			
2-methyl-4,6-dinitrophenol	<25	<25	<25	<25			
2-Nitrophenol	<5	<5	<5	<5			
4-Nitrophenol	<5	<5	<5	<5			
Pentachlorophenol	<5	<5	<5	<5			
Phenol	<5	<5	<5	<5			
2,4,6-Trichlorophenol	<5	<5	<5	<5			
Metals							
Arsenic (filtered)	--	4	<1	<1			
Chromium, total (filtered)	--	1.6	1.4	3.2			
Copper (filtered)	--	2.1	2.0	1.0			
Chromium, hexavalent (filtered)	--	<1	<1	<1			

Covered in St. Peter Data - not comparable to P.d.C.

composition changing

increasing?

---

p Small peak in chromatogram below method detection limit.
c Coeluting compound (concentrations reported with the List 1 compound). Coeluting compounds are Chrysene/Triphylene and Benzo(b)fluoranthene/Benzo(k)fluoranthene.
s Statistical analysis indicates a potential false positive value.
DLND Not detected. Detection limit not determined.
ND Not detected.
-- Not analyzed.

361

307

TABLE 10 (cont.)

DEEP GROUNDWATER QUALITY

(concentrations in ug/L)

137'

132'

Formation	Valley Fill Sand W301		St. Peter Sandstone W307				
	03/28/85	05/06/85 12/13/85	03/27/85	05/07/85	12/13/85	3/86	6/86
List 1 PAH/Heterocycles							
Benzo(a)anthracene	0.0045	<0.0010	<0.0020	0.0013			
Benzo(b)fluoranthene	0.014 c	<0.0010 c	<0.0020 c	<0.0010 c			
Benzo(ghi)perylene	<0.0010	<0.0010	<0.0020	<0.0010			
Benzo(a)pyrene	0.0017	<0.0010	<0.0020	<0.0010			
Chrysene	0.011 c	<0.0010 c	0.0035 c	<0.0010 c			
Dibenz(ah)anthracene	<0.0014	<0.0014	<0.0028	<0.0014			
Indeno(1,2,3,cd)pyrene	<0.0017	<0.0017	<0.0034	<0.0017			
Quinoline	<0.0010	<0.0010	<0.0020	<0.0010			
Sum List 1	0.031	ND ND 3/86 ND 6/86 ND	0.0035	0.0013	ND	ND	ND
List 2 PAH/Heterocycles							
Acenaphthene	0.0026	<0.0013	0.069	0.011	.0056		
Acenaphthylene	<0.0010	<0.0010	<0.0020	<0.0010	.0014		
Acridine	<0.0018	<0.0018	<0.0036	<0.0018			
Anthracene	0.0024	<0.0010	<0.0020	<0.0010			
Benzo(k)fluoranthene	c	<0.001 c	<0.0020 c	<0.0010 c			
2,3-Benzofuran	0.0018	DLND	0.0055	0.0066			
Benzo(e)pyrene	0.0033	<0.0010	<0.0020	<0.0010			
Benzo(b)thiophene	<0.0010	<0.0010	0.033	0.018	.020		
Biphenyl	0.0028	<0.0010	0.024	0.014	.015		
Carbazole	0.0034	<0.0011	0.086	0.037	.032		
Dibenzothiophene	0.010	DLND	0.0037	0.0030	.0047		
Dibenzofuran	<0.0020	<0.0020	0.013	0.0042	.0065		
2,3-Dihydroindene	0.0022	0.0017 .0022	0.80	0.35	.36		
Fluoranthene	0.031	0.0029 .0014	0.0083	0.013	.0078		
Fluorene	0.0048	0.0024	0.0073	0.0033	.0046		
Indene	0.0020	0.0013 s .0011	0.034	0.019	.026		
Indole	<0.0029	<0.0029	0.036	<0.0029			
Isoquinoline	DLND	DLND	DLND	DLND			
1-Methylnaphthalene	0.0073	<0.0012	0.044	0.016	.012		
2-Methylnaphthalene	0.0091	<0.0020	0.0059	0.0067	.0040		
Naphthalene	0.011	0.0063 s	0.081	0.016 s	.0078		
Perylene	<0.0010	<0.0010	<0.0020	<0.0010			
Phenanthrene	0.043	0.036 .0034	0.013	<0.024	.0087		
Pyrene	0.024	0.0039	0.0085	0.013	.0088		
Triphenylene	c	<0.001 c	c	<0.0010 c			
Sum List 2	0.16	0.055 .11 3/86 .018 6/86 .033	1.3	0.53	.52	.58	.31
Phenolics							
4-chloro-3-methylphenol	<5	<5	<5	<5			
2-Chlorophenol	<5	<5	<5	<5			
O-Cresol	<5	<5	<5	<5			
M-Cresol	<5 c	<5 c	<5 c	<5 c			
P-Cresol	<5 c	<5 c	<5 c	<5 c			
2,4-Dichlorophenol	<5	<5	<5	<5			
2,4-Dimethylphenol	<5	<5	<5	<5			
2,4-Dinitrophenol	<25	<25	<25	<25			
2-methyl-4,6-dinitrophenol	<25	<25	<25	<25			
2-Nitrophenol	<5	<5	<5	<5			
4-Nitrophenol	<5	<5	<5	<5			
Pentachlorophenol	<5	<5 <	<5	<5			
Phenol	<5	<5	<5	<5			
2,4,6-Trichlorophenol	<5	<5	<5	<5			
Metals							
Arsenic (filtered)	6	<1	5	1			
Copper (filtered)	3.5	1.1	2.0	<0.5			
Chromium, total (filtered)	1.2	<0.5	0.50	<0.5			
Chromium, hexavalent (filtered)	<1	<1	<1	<1			

---

p Small peak in chromatogram below method detection limit.
c Coeluting compound (concentrations reported with the List 1 compound). Coeluting compounds are Chrysene/Triphylene and Benzo(b)fluoranthene/Benzo(k)fluoranthene.
s Statistical analysis indicates a potential false positive value.
DLND Not detected. Detection limit not determined.
ND Not detected.

TABLE 10 (cont.)

DEEP GROUNDWATER QUALITY

(concentrations in ug/L)

North + not in plume

S of east corner of site ''

Formation	St. Peter Sandstone Well 203571		Prairie du Chien Well 203574		
	04/15/85	05/06/85	03/28/85	05/23/85	
List 1 PAH/Heterocycles					
Benzo(a)anthracene	<0.0010	0.0040	<0.0010	<0.0010	
Benzo(b)fluoranthene	<0.0010 c	0.0051 c	<0.0010 c	<0.0010 c	
Benzo(ghi)perylene	<0.0010	<0.0010	<0.0010	<0.0010	
Benzo(a)pyrene	<0.0010	0.0019	<0.0010	<0.0010	
Chrysene	<0.0010 c	<0.0049 c	<0.0010 c	<0.0010 c	
Dibenz(ah)anthracene	<0.0014	<0.0014	<0.0014	<0.0014	
Indeno(1,2,3,cd)pyrene	<0.0017	<0.0017	<0.0017	<0.0017	
Quinoline	<0.0010	<0.0010	<0.0010	<0.0010	
Sum List 1	ND	0.012	ND	ND	
List 2 PAH/Heterocycles					
Acenaphthene	0.0044	0.0027	<0.0013	0.0014	not creosote
Acenaphthylene	<0.0010	<0.0010	<0.0010	0.0013	
Acridine	<0.0018	<0.0018	<0.0018	<0.0018	
Anthracene	<0.0010	0.0047	<0.0010	<0.0010	
Benzo(k)fluoranthene	c	0.0051 c	<0.0010 c	<0.0010 c	
2,3-Benzofuran	DLND	DLND	DLND	0.011	
Benzo(e)pyrene	<0.0010	0.0018	<0.0010	<0.0010	
Benzo(b)thiophene	<0.0010	<0.0010	<0.0010	<0.0010	
Biphenyl	0.0028	0.0020	0.0037	0.0041	>
Carbazole	<0.0011	0.0061	<0.0011	<0.0011	
Dibenzothiophene	DLND	0.0057	DLND	0.0015	
Dibenzofuran	0.0051	<0.0020	<0.0020	<0.0020	
2,3-Dihydroindene	0.0060	0.027	0.0083	0.0044 s	
Fluoranthene	0.0019	0.028	0.0029	0.0062	<
Fluorene	0.0061	0.0046	<0.0014	0.0020	<
Indene	0.0047	0.0032 s	0.0031	0.0038 s	
Indole	<0.0029	0.040	<0.0029	<0.0029	
Isoquinoline	DLND	DLND	DLND	DLND	
1-Methylnaphthalene	0.0025	0.0064	0.016	0.017	>
2-Methylnaphthalene	0.0034	0.0086	0.0088	0.011	>
Naphthalene	0.012	0.018 s	0.017	0.013 s	—
Perylene	<0.0010	<0.001	<0.0010	<0.0010	
Phenanthrene	0.0012	0.036	0.0053	0.012	<
Pyrene	0.0019	0.020	0.011	0.018	< —
Triphenylene	<0.0010 c	<0.0049 c	<0.0010 c	<0.0010 c	
Sum List 2	0.052	0.021	0.076	0.11	>
Phenolics					
4-chloro-3-methylphenol	<5	<5	<5	<5	
2-Chlorophenol	<5	<5	<5	<5	
O-Cresol	<5	<5	<5	<5	
M-Cresol	<5 c	<5 c	<5 c	<5 c	
P-Cresol	<5 c	<5 c	<5 c	<5 c	
2,4-Dichlorophenol	<5	<5	<5	<5	
2,4-Dimethylphenol	<5	<5	<5	<5	
2,4-Dinitrophenol	<25	<25	<25	<25	
2-methyl-4,6-dinitrophenol	<25	<25	<25	<25	
2-Nitrophenol	<5	<5	<5	<5	
4-Nitrophenol	<5	<5	<5	<5	
Pentachlorophenol	<5	<5	<5	<5	
Phenol	<5	<5	<5	<5	
2,4,6-Trichlorophenol	<5	<5	<5	<5	
Metals					
Arsenic (filtered)	<1	<1	4	2	
Copper (filtered)	<0.5	<0.5	5.1	0.9	
Chromium, total (filtered)	3.2	<0.5	1.2	<0.5	
Chromium, hexavalent	<2	<1	2	<1	

compared with avl for Pr. du Chi. - Bob K's book

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p Small peak in chromatogram below method detection limit.

c Coeluting compound (concentrations reported with the List 1 compound). Coeluting compounds are Chrysene/Triphylene and Benzo(b)fluoranthene/Benzo(k)fluoranthene.

s Statistical analysis indicates a potential false positive value.

DLND Not detected. Detection limit not determined.

ND Not detected.

TABLE 11

TWIN LAKES QUALITY

(concentrations in ug/L)

	LS1		LS2		LS3	
	01/25/85	05/30/85	01/25/85	05/30/85	01/25/85	05/30/85
List 1 PAH/Heterocycles						
Benzo(a)anthracene	0.057	<0.0010	<0.0020	0.0050	<0.0020	<0.0010
Benzo(b)fluoranthene	<0.0050 c	<0.0010 c	<0.0020 c	0.015 c	<0.0020 c	<0.0010 c
Benzo(ghi)perylene	0.043	<0.0010	<0.0020	0.0091	<0.0020	<0.0010
Benzo(a)pyrene	0.038	<0.0010	<0.0020	0.0058	<0.0020	<0.0010
Chrysene	0.064 c	<0.0010 c	0.0024 c	0.0057 c	0.0020 c	<0.0010 c
Dibenz(ah)anthracene	<0.0070	<0.0014	<0.0028	<0.0014	<0.0028	<0.0014
Indeno(1,2,3,cd)pyrene	0.048	<0.0017	<0.0034	0.0070	<0.0034	<0.0017
Quinoline	0.0099	<0.0010	0.0061	<0.0010	0.029	0.015
Sum List 1	0.26	ND	0.0085	0.048	0.031	0.015
List 2 PAH/Heterocycles						
Acenaphthene	0.0059	<0.0013	<0.0026	<0.0013	<0.0026	<0.0013
Acenaphthylene	<0.0050	<0.0010	<0.0020	<0.0010	<0.0020	<0.0010
Acridine	<0.0090	<0.0018	<0.0036	<0.0018	<0.0036	<0.0018
Anthracene	0.0053	<0.0010	<0.0020	<0.0010	<0.0020	<0.0010
Benzo(k)fluoranthene	<0.0050 c	<0.0010 c	<0.0020 c	c	<0.0020 c	<0.0010 c
2,3-Benzofuran	DLND	0.0057	DLND	0.0085	0.0023	0.0052
Benzo(e)pyrene	0.18	<0.0010	<0.0020	0.0055	<0.0020	<0.0010
Benzo(b)thiophene	<0.0050	<0.0010	<0.0020	<0.0010	<0.0020	0.018
Biphenyl	<0.0050	0.0018	<0.0020	<0.0010	<0.0020	0.0056
Carbazole	0.0087	<0.0011	<0.0022	<0.0011	0.0062	<0.0011
Dibenzothiophene	DLND	DLND	DLND	DLND	DNLD	DLND
Dibenzofuran	0.015	<0.0020	<0.0040	<0.0020	<0.0040	<0.0020
2,3-Dihydroindene	<0.0070	0.0026 s	<0.0028	0.012	0.0043	0.0094 s
Fluoranthene	0.12	0.0019	0.0050	0.022	0.0096	0.0080
Fluorene	0.012	<0.0014	<0.0028	<0.0014	<0.0028	<0.0014
Indene	<0.0050	0.0022 s	<0.0020	0.0052	<0.0020	<0.0010
Indole	<0.014	<0.0029	<0.0058	<0.0029	<0.0058	<0.0029
Isoquinoline	0.010	DLND	0.0024	DLND	DNLD	0.012
1-Methylnaphthalene	0.017	0.0016	0.012	<0.0012	0.010	0.0027
2-Methylnaphthalene	0.019	0.0028 s	0.0065	0.0023 s	0.010	0.0032 s
Naphthalene	0.019	0.012 s	0.012	0.0020 s	0.016	0.0096 s
Perylene	0.0070	<0.0010	<0.0020	0.0011	<0.0020	<0.0010
Phenanthrene	0.073	<0.0010	0.0061	0.0052	0.010	<0.0010
Pyrene	0.12	0.0034	0.0042	0.021	0.011	0.0064
Triphenylene	c	<0.0010 c	c	c	c	<0.0010 c
Sum List 2	0.62	0.0034	0.051	0.10	0.081	0.080
Phenolics						
4-chloro-3-methylphenol	<5	<5	<5	<5	<5	<5
2-Chlorophenol	<5	<5	<5	<5	<5	<5
O-Cresol	<5	<5	<5	<5	<5	<5
M-Cresol	<5 c	<5 c	<5 c	<5 c	<5 c	<5 c
P-Cresol	<5 c	<5 c	<5 c	<5 c	<5 c	<5 c
2,4-Dichlorophenol	<5	<5	<5	<5	<5	<5
2,4-Dimethylphenol	<5	<5	<5	<5	<5	<5
2,4-Dinitrophenol	<25	<25	<25	<25	<25	<25
2-methyl-4,6-dinitrophenol	<25	<25	<25	<25	<25	<25
2-Nitrophenol	<5	<5	<5	<5	<5	<5
4-Nitrophenol	<5	<5	<5	<5	<5	<5
Pentachlorophenol	<5	<5	<5	<5	<5	<5
Phenol	<5	<5	<5	<5	<5	<5
2,4,6-Trichlorophenol	<5	<5	<5	<5	<5	<5

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p	Small peak in chromatogram below method detection limit.
c	Coeluting compound (concentrations reported with the List 1 compound). Coeluting compounds are Chrysene/Triphylene and Benzo(b)fluoranthene/Benzo(k)fluoranthene.
s	Statistical analysis indicates a potential false positive value.
DLND	Not detected. Detection limit not determined.
ND	Not detected.

TABLE 11 (cont.)

TWIN LAKES QUALITY

(concentrations in ug/L)

	LS4		LS5		LS6	
	01/25/85	05/30/85	01/25/85	05/30/85	01/25/85	05/30/85
List 1 PAH/Heterocycles						
Benzo(a)anthracene	0.21	0.0021	0.0051	<0.0010	0.0034	<0.0010
Benzo(b)fluoranthene	0.72 c	<0.0010 c	<0.0020 c	0.0022 c	0.022 c	<0.0010 c
Benzo(ghi)perylene	0.20	0.0029	<0.0020	<0.0010	0.0049	<0.0010
Benzo(a)pyrene	0.18	0.0014	<0.0020	<0.0010	0.0034	<0.0010
Chrysene	0.29 c	0.0026 c	0.0064 c	<0.0010 c	0.0077 c	<0.0010 c
Dibenz(ah)anthracene	0.031	<0.0014	<0.0028	<0.0014	<0.0028	<0.0014
Indeno(1,2,3,cd)pyrene	0.21	0.0027	<0.0034	<0.0017	0.0058	<0.0017
Quinoline	0.035	0.0027	0.015	0.0020	0.0060	<0.0010
Sum List 1	1.9	0.014	0.026	0.0042	0.053	ND
List 2 PAH/Heterocycles						
Acenaphthene	0.021	<0.0013	<0.0026	<0.0013	<0.0026	<0.0013
Acenaphthylene	0.0087	<0.0010	<0.0020	<0.0010	<0.0020	<0.0010
Acridine	0.025	<0.0018	<0.0036	<0.0018	<0.0036	<0.0018
Anthracene	0.042	<0.0010	<0.0020	<0.0010	<0.0020	<0.0010
Benzo(k)fluoranthene	c	<0.0010 c	<0.0020 c	c	c	<0.0010 c
2,3-Benzofuran	DLND	0.0051	DLND	0.0041	0.0036	0.0042
Benzo(e)pyrene	0.25	0.0014	<0.0020	0.0014	0.0049	<0.0010
Benzo(b)thiophene	<0.010	<0.0010	<0.0020	<0.0010	0.0023	<0.0010
Biphenyl	<0.010	0.017	0.0030	<0.0010	<0.0020	<0.0010
Carbazole	0.047	<0.0011	0.0042	<0.0011	0.0040	<0.0011
Dibenzothiophene	0.027	DLND	DLND	DLND	DLND	DLND
Dibenzofuran	<0.020	<0.0020	<0.0040	<0.0020	<0.0040	<0.0020
2,3-Dihydroindene	<0.014	0.0029 s	0.0029	0.0031 s	0.0053	0.0022 s
Fluoranthene	0.67	0.011	0.024	0.0047	0.025	0.0015
Fluorene	0.015	<0.0014	<0.0028	<0.0014	<0.0028	<0.0014
Indene	<0.010	0.0016 s	<0.0020	<0.0010	<0.0020	0.0013 s
Indole	<0.029	<0.0029	<0.0058	<0.0029	<0.0058	<0.0029
Isoquinoline	0.028	DLND	0.014	DLND	0.0093	0.0022
1-Methylnaphthalene	0.035	<0.0012	0.0085	<0.0012	0.0048	<0.0012
2-Methylnaphthalene	0.018	0.0020 s	0.011	<0.0020	0.0064	0.0022 s
Naphthalene	0.027	0.010 s	0.012	0.0092 s	0.013	0.0093 s
Perylene	0.031	<0.0010	<0.0020	<0.0010	<0.0020	<0.0010
Phenanthrene	0.30	0.0013	0.016	0.0018	0.019	<0.0010
Pyrene	0.69	0.0093	0.021	0.0064	0.023	0.0025
Triphenylene	c	c	c	<0.0010 c	c	<0.0010 c
Sum List 2	3.2	0.062	0.12	0.031	0.15	0.027
Phenolics						
4-chloro-3-methylphenol	<5	<5	<5	<5	<5	<5
2-Chlorophenol	<5	<5	<5	<5	<5	<5
O-Cresol	<5	<5	<5	<5	<5	<5
M-Cresol	<5 c	<5 c	<5 c	<5 c	<5 c	<5 c
P-Cresol	<5 c	<5 c	<5 c	<5 c	<5 c	<5 c
2,4-Dichlorophenol	<5	<5	<5	<5	<5	<5
2,4-Dimethylphenol	<5	<5	<5	<5	<5	<5
2,4-Dinitrophenol	<25	<25	<25	<25	<25	<25
2-methyl-4,6-dinitrophenol	<25	<25	<25	<25	<25	<25
2-Nitrophenol	<5	<5	<5	<5	<5	<5
4-Nitrophenol	<5	<5	<5	<5	<5	<5
Pentachlorophenol	<5	<5	<5	<5	<5	<5 p
Phenol	<5	<5	<5	<5	<5	<5
2,4,6-Trichlorophenol	<5	<5	<5	<5	<5	<5

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p Small peak in chromatogram below method detection limit.

c Coeluting compound (concentrations reported with the List 1 compound). Coeluting compounds are Chrysene/Triphylene and Benzo(b)fluoranthene/Benzo(k)fluoranthene.

s Statistical analysis indicates a potential false positive value.

DLND Not detected. Detection limit not determined.

ND Not detected.

TABLE 12

ESTIMATED VOLUME OF CONTAMINATED SOIL

(volumes in cubic yards)

Location	Heavily Contaminated Soil	Lightly Contaminated Soil
Pond A	12,000	--
Area West of Pond A	800	--
Pond B	2,000	--
Area 3	500	--
Area 4	5,500	--
Area 5	3,000	500
Area 6	10,000	3,500
Area 8	1,000	1,000
TOTAL	34,800 c.y.	5,000 c.y.

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TABLE 13

WATER LEVELS IN NESTED WELLS

Nest 1	Formation	Elevation of Zone Monitored (MSL)	Water Levels, (MSL) March, 1985	May, 1985
W101	Top of shallow sand	Above 842	**	852.1
W201	Mid-depth sand	787 to 797	851.4	851.9
W301	Deep sand	717 to 737	851.3	851.8
Nest 6				
W6	Top of shallow sand	Above 844	850.3	850.9
W206	Bottom of Shallow sand	812 to 817	850.3	850.9
Nest 7				
W7	Top of shallow Sand	Above 839	850.8	851.3
W207	Bottom of Shallow sand	813 to 818	850.9*	851.4*
W307	Top of bedrock	729 to 733	848.5	848.8
Nest 9				
W9	Top of shallow sand	Above 844	850.1	850.8
W209	Bottom of shallow sand	806 to 811	850.1	850.7

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* Well 207 is located 260 feet north of Well 7 and 180 feet north of Well 307.

** Ice in well.

TABLE 14

AVERAGE CONCENTRATIONS OF PAH/HETEROCYCLES AND PENTACHLOROPHENOL IN GROUNDWATER - 1984 AND 1985

(concentrations in ug/L)

WELL	PAH/HETEROCYCLES LIST 1	LIST 2	PENTACHLOROPHENOL
Shallow Wells			
2	0.023	98	2300
6	0.010	63	6100
7	ND	25	360
9	ND	550	950
10	ND	43	BDL
101	0.11	37	34
104	0.084	1.1	BDL
111	2.4	2600	4300
112	ND	270	740
113	3300	70000	7500
121	ND	0.039	BDL
122	ND	11	BDL
123	ND	6.1	5.2
124	ND	0.11	BDL
125	ND	2.0	9.9
126	0.018	0.14	BDL
Howe P23	ND	0.67	ND
Howe P02	<1	<1	ND
Howe P03	<5	<5	ND
Mid-depth Wells			
201	ND	0.030	ND
206	ND	11	8.2
207	ND	41	15
209	0.081	2.6	8.0
Deep Wells			
301	0.015	0.11	ND
307	0.0024	0.91	ND
Plant Well (300)	ND	0.064	ND
Plant Well (St. Peter)	ND	0.11	ND
Plant Well (Prairie du Chien)	ND	0.084	ND
Well 203571	ND	0.094	ND
Well 203574	0.006	0.084	ND

ND - Not Detected
BDL - Below Detection Limit

Note: Detection limits for PAH/Heterocycles at Howe P02 and P03 significantly affected by the presence of atrazine in the sample matrix.

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TABLE 15

ESTIMATED COST OF GROUNDWATER PUMP-OUT SYSTEMS

	Pump-Out System Location	
	Immediately Downgradient of Contaminated Soil	East Site Boundary
Drain Tile/Wells	$210,000	$240,000
Pumps, Controls, Appurtenances	30,000	15,000
Electric Power	10,000	10,000
Pipe/Manholes	30,000	15,000
Lift Station	60,000	60,000
Forcemain	15,000	15,000
Road/RR Crossing	25,000	25,000
Subtotal	$380,000	$380,000
Mobilization (10%)	40,000	40,000
Contingencies (20%)	75,000	75,000
Engineering, Administration, Permits (20%)	75,000	75,000
TOTAL CAPITAL COST	$570,000	$570,000
Operating and Maintenance	$ 15,000	$ 15,000
TOTAL ANNUAL COST	$ 15,000/yr	$15,000/yr

TAB1531610

TABLE 16

ESTIMATED QUALITY OF DISCHARGE FROM PUMP-OUT SYSTEMS

Pump-Out System Location	(concentrations in mg/L) Total PAH/Heterocycles	Pentachlorophenol
Immediately Downgradient of Contaminated Soil	50	8
East Site Boundary	0.08	0.25

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TABLE 17

ESTIMATED COST OF GROUNDWATER TREATMENT - SURFACE WATER DISCHARGE
100 GPM FLOW RATE

Treatment Method	Capital	Operating & Maintenance	Present Worth*
Carbon Adsorption	$ 470,000	$400,000	$5,980,000
Ozone UV/and Carbon Adsorption	870,000	280,000	4,720,000
Biological and Carbon Adsorption	1,840,000	530,000	9,140,000

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*The present worth of the annual operation and maintenance cost is computed using a 6% net annual interest rate over a 30-year period.

TABLE 18

COST ESTIMATE

ALTERNATIVE I.A. -- SITE GRADING

	Capital	Annual Operation and Maintenance	Present Worth*
Site preparation and restoration	$ 50,000		$ 50,000
Grade, place soil cover and vegetate site	$ 80,000	$ 5,000	$ 150,000
Monitor 20 wells quarterly for 30 years		96,000	1,320,000
Drain Pond A, pretreat and discharge to sanitary sewer	60,000		60,000
SUBTOTAL	$ 190,000	$101,000	$1,580,000
Mobilization (10%)	20,000		20,000
Contingencies (20%)	40,000	20,000	320,000
Engineering, Permits, Administration (20%)	40,000	20,000	320,000
TOTAL	$290,000	$141,000	$2,240,000

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*The present worth of the annual operation and maintenance cost is computed using a 6% net annual interest rate over a 30-year period.

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TABLE 19

COST ESTIMATE

ALTERNATIVE I.B. -- CAP CONTAMINATED SOIL

	Capital	Annual Operation and Maintenance	Present Worth*
Site preparation and restoration	$ 90,000		$ 90,000
Cap 3.2 acre area overlying 40,000 c.y. of contaminated soil	230,000	$ 5,000	$ 300,000
Excavate contaminated soil from outside the cap area and place in cap area			
a. 10,000 c.y. above saturated zone	70,000		70,000
b. 8,000 c.y. in saturated zone including dewatering and excavation	160,000		160,000
Backfill excavated area	130,000		130,000
Monitor 20 wells quarterly for 30 years		96,000	1,320,000
Drain Pond A, pretreat and discharge to sanitary sewer	60,000		60,000
SUBTOTAL	$740,000	$101,000	$2,130,000
Mobilization (10%)	70,000		70,000
Contingencies (20%)	150,000	20,000	430,000
Engineering, Permits, Administration (20%)	150,000	20,000	430,000
TOTAL	$1,110,000	$141,000	$3,060,000

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*The present worth of the annual operation and maintenance cost is computed using a 6% net annual interest rate over a 30-year period.

TABLE 20

COST ESTIMATE

ALTERNATIVE I.C. -- ON-SITE VAULT

	Capital	Annual Operation and Maintenance	Present Worth*
Site preparation and restoration	$ 350,000		$ 350,000
On-site vault (RCRA), 40,000 c.y.	1,000,000	$ 20,000	1,280,000
Excavate contaminated soil and place in on-site vault			
a. 25,000 c.y. above saturated zone	180,000		180,000
b. 15,000 c.y. in saturated zone including dewatering and excavation	300,000		300,000
Backfill excavated areas	280,000		280,000
Monitor 20 wells quarterly years 1-10		96,000	710,000
Monitor 20 wells semi-annually years 11-20		48,000	200,000
Monitor 20 wells annually years 21-30		24,000	60,000
Drain pond A, pretreat and discharge to sanitary sewer	60,000		60,000
SUBTOTAL	$2,170,000	$116,000**	$3,420,000
Mobilization (10%)	220,000		220,000
Contingencies (20%)	430,000	23,000	750,000
Engineering, Permits, Administration (20%)	430,000	23,000	750,000
TOTAL	$3,250,000	$162,000**	$5,140,000

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* The present worth of the annual operation and maintenance cost is computed using a 6% annual interest rate over the appropriate time period.

**The annual operation and maintenance cost decreases each decade with the change in the monitoring program. The annual cost for the first decade is shown. Contingencies and Engineering, Permits, Administration are computed on the first decade total.

TABLE 21

COST ESTIMATE

ALTERNATIVE I.D. -- ON-SITE INCINERATION

	Capital	Annual Operation and Maintenance	Present Worth*
Site preparation and restoration	$ 350,000		$ 350,000
Excavate and stockpile contaminated soil			
a. 25,000 c.y. above saturated zone	180,000		180,000
b. 15,000 c.y. in saturated zone, including dewatering and excavation	300,000		300,000
c. Contaminated soil stockpile area	100,000		100,000
Backfill excavated areas	280,000		280,000
Incinerate 40,000 c.y. of contaminated soil			
a. conduct test burn	200,000		200,000
b. incinerator	2,000,000		2,000,000
c. setup and startup	1,000,000		1,000,000
d. operate and maintain (2 years)	1,500,000		1,500,000
e. monitor (2 years)	600,000		600,000
f. dispose of ash (2 years)	300,000		300,000
g. demobilize	200,000		200,000
Monitor 20 wells as in Alternative I.C.		96,000	970,000
Drain Pond A, pretreat, and discharge to sanitary sewer	$ 60,000		$ 60,000
SUBTOTAL	$ 7,070,000	$ 96,000**	$ 8,040,000

TABLE 21 (cont'd)

Mobilization (10%)	710,000		710,000
Contingencies (20%)	1,410,000	19,000	1,670,000
Engineering, Permits, Administration (20%)	1,410,000	19,000	1,670,000
TOTAL	$10,600,000	$134,000**	$12,090,000

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* The present worth of annual operation and maintenance is computed using a 6% net annual interest rate over the appropriate time period.

** The annual operation and maintenance cost decreases each decade with the change in the monitoring program. The annual cost for the first decade is shown. Contingencies and Engineering, Permits, Administration are computed on the first decade total.

TABLE 22

COST ESTIMATE

ALTERNATIVE II.A. -- SLURRY WALL CONTAINMENT

	Capital	Annual Operation and Maintenance	Present Worth*
Site preparation and restoration	$ 90,000		$ 90,000
Slurry wall containment area and interior pump-out well	$ 610,000	$ 10,000	$ 750,000
Cap slurry wall containment (2.9 ac.)	210,000	5,000	280,000
Excavate contaminated soil located outside containment area and place within containment area			
a. 13,000 c.y. above saturated zone	90,000		90,000
b. 9,000 c.y. in saturated zone, including dewatering and excavation areas	180,000		180,000
Backfill excavation	150,000		150,000
Monitor containment area wells quarterly for 30 years		10,000	140,000
Monitor 20 wells as in Alternative I.C.		96,000	970,000
Drain Pond A, pretreat and discharge to sanitary sewer	60,000		60,000
SUBTOTAL	$1,390,000	$121,000**	$2,710,000
Mobilization (10%)	140,000		140,000
Contingencies (20%)	280,000	24,000	610,000
Engineering, Permits, Administration (20%)	280,000	24,000	610,000
TOTAL	$2,090,000	$169,000**	$4,070,000

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* The present worth of the annual operation and maintenance cost is computed using a 6% net annual interest rate over the appropriate time period.

** The annual operation and maintenance cost decreases each decade with the change in the monitoring program. The annual cost for the first decade is shown. Contingencies and Engineering, Permits, Administration are computed on the first decade total.

TABLE 23

COST ESTIMATE

ALTERNATIVE II.B. -- CAP AND SOURCE GROUNDWATER PUMP-OUT SYSTEM

	Capital	Annual Operation and Maintenance	Present Worth*
Site preparation and restoration	$ 90,000		$ 90,000
Cap 3.2 acres overlying 40,000 c.y. of contaminated soil	230,000	5,000	300,000
Excavate contaminated soil from outside the cap area and place beneath cap			
a. 10,000 c.y. above saturated zone	70,000		70,000
b. 8,000 c.y. below saturated zone, including dewatering and excavation	160,000		160,000
Backfill excavation area	130,000		130,000
Groundwater pump-out system - immediately downgradient of contaminated soil	280,000	62,000	1,130,000
Pretreat groundwater and discharge to sanitary sewer -- 30 years	270,000	150,000	2,330,000
Monitor 20 wells as in Alternative I.C.		96,000	970,000
Drain Pond A, pretreat and discharge to sanitary sewer	60,000		60,000
SUBTOTAL	$1,290,000	$313,000**	$5,240,000

TABLE 23 (cont.)

Mobilization (10%)	130,000		130,000
Contingencies (20%)	260,000	63,000	1,130,000
Engineering, Permits, Administration (20%)	260,000	63,000	1,130,000
TOTAL	$1,940,000	$439,000**	$7,630,000

* The present worth of the annual operation and maintenance cost is computed using a 6% net annual interest rate over the appropriate time period.

** The annual operation and maintenance cost decreases each decade with the change in the monitoring program. The annual cost for the first decade is shown. Contingencies and Engineering, Permits, Administration are computed on the first decade total.

TABLE 24

COST ESTIMATE
ALTERNATIVE II.C. -- ON-SITE VAULT AND SOURCE GROUNDWATER PUMP-OUT SYSTEM

	Capital	Annual Operation and Maintenance	Present Worth*
Site preparation and restoration	$ 350,000		$ 350,000
On-site vault (RCRA) 40,000 c.y.	1,000,000	$ 20,000	1,280,000
Excavate contaminated soil and place in on-site vault			
a. 25,000 c.y. above saturated zone	180,000		180,000
b. 15,000 c.y. in saturated zone, including dewatering and excavation.	300,000		300,000
Backfill excavated areas	280,000		280,000
Groundwater pump-out system -- immediately downgradient of contaminated soil	210,000	36,000	700,000
Pretreat groundwater and discharge to sanitary sewer -- 30 years	220,000	110,000	1,720,000
Monitor 20 wells as in Alternative I.C.		96,000	970,000
Drain pond A, pretreat and discharge to sanitary sewer	60,000		60,000
SUBTOTAL	$2,600,000	$262,000**	$5,840,000
Mobilization (10%)	260,000		260,000
Contingencies (20%)	520,000	54,000	1,260,000
Engineering, Permits, Administration (20%)	520,000	54,000	1,260,000
TOTAL	$3,900,000	$370,000**	$ 8,620,000

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* The present worth of the annual operation and maintenance cost is computed using a 6% net annual interest rate over the appropriate time period.

** The annual operation and maintenance cost decreases each decade with the change in the monitoring program. The annual cost for the first decade is shown. Contingencies and Engineering, Permits, Adminstration are computed on the first decade total.

TABLE 25

COST ESTIMATE

ALTERNATIVE III.A. -- GROUNDWATER PLUME PUMP-OUT

	Capital	Annual Operation and Maintenance	Present Worth*
Site preparation and restoration	50,000		50,000
Grade, place soil cover and vegetate site	80,000	5,000	150,000
Groundwater Pump-out System Immediately Downgradient of Contaminated Soil	280,000	62,000	1,130,000
Pretreat groundwater and discharge to sanitary sewer -- 30 years	270,000	150,000	2,330,000
Groundwater Pump-out System East Site Boundary	280,000	70,000	1,240,000
Monitor 20 wells as in Alternative I.C.		96,000	970,000
Drain Pond A, pretreat and discharge to sanitary sewer	60,000		60,000
SUBTOTAL	$1,020,000	$383,000**	$5,930,000
Mobilization (10%)	100,000		100,000
Contingencies (20%)	200,000	76,000	850,000
Engineering, Permits, Administration (20%)	200,000	76,000	850,000
TOTAL	$1,520,000	$535,000**	$7,730,000

---

* The present worth of the annual operation and maintenance cost is computed using a 6% net annual interest rate over the appropriate time period.

** The annual operation and maintenance cost decreases each decade with the change in the monitoring program. The annual cost for the first decade is shown. Contingencies and Engineering, Permits, Administration are computed on the first decade total.

TABLE 26

COST ESTIMATE

ALTERNATIVE III.B. -- GROUNDWATER PLUME CONTAINMENT WITH SLURRY WALL

	Capital	Annual Operation and Maintenance	Present Worth*
Site preparation and restoration	$ 150,000		$ 150,000
Grade, place soil cover and vegetate site	$ 80,000	5,000	$ 150,000
Slurry wall on site perimeter	2,180,000		2,180,000
Interior pump-out system	280,000	62,000	1,130,000
Pretreat and discharge from interior pump-out system to sanitary sewer - 30 years	270,000	150,000	2,330,000
Monitor 20 wells as in Alternative I.C.		96,000	970,000
Drain Pond A, pretreat, and discharge to sanitary sewer	60,000		60,000
SUBTOTAL	$3,020,000	$313,000**	$6,970,000
Mobilization (10%)	300,000		300,000
Contingencies (20%)	600,000	62,000	1,450,000
Engineering, Permits, Administration (20%)	600,000	62,000	1,450,000
TOTAL	$4,520,000	$437,000**	$10,170,000

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* The present worth of the annual operation and maintenance cost is computed using a 6% net annual interest rate over a 30-year period.

**The annual operation and maintenance cost decreases each decade with the change in the monitoring program. The annual cost for the first decade is shown. Contingencies and Engineering, Permits, Administration are computed on the first decade total.

TABLE 27

SUMMARY OF ALTERNATIVE REMEDIAL ACTION COSTS CAPITAL, ANNUAL, AND PRESENT WORTH

Alternative	ESTIMATED COST ($ Millions) Capital	Annual	Present Worth
I. SOURCE CONTROL - Controls Leaching From Contaminated Soil			
I.A. Site Grading	$ 0.3	0.14	2.2
I.B. Cap Contaminated Soil	1.1	0.14	3.1
I.C. On-Site Vault	3.3	0.16	5.1
I.D. On-Site Incineration	10.6	0.13	12.1
II. SOURCE AREA CONTROL - Controls Soil and Groundwater in Vicinity of Contaminated Soil Areas			
II.A. Slurry Wall Containment	2.1	0.17	4.1
II.B. Cap and Source Groundwater Pump-out System On-site	1.9	0.44	7.6
II.C. On-site Vault and Source Groundwater Pump-out System	3.9	0.37	8.6
III. SITE GROUNDWATER CONTROL - Minimizes Off-Site Migration of Contaminated Groundwater			
III.A. Groundwater Plume Control	1.5	0.54	7.7
III.B. Groundwater Plume Containment with Slurry Wall	4.5	0.44	10.2

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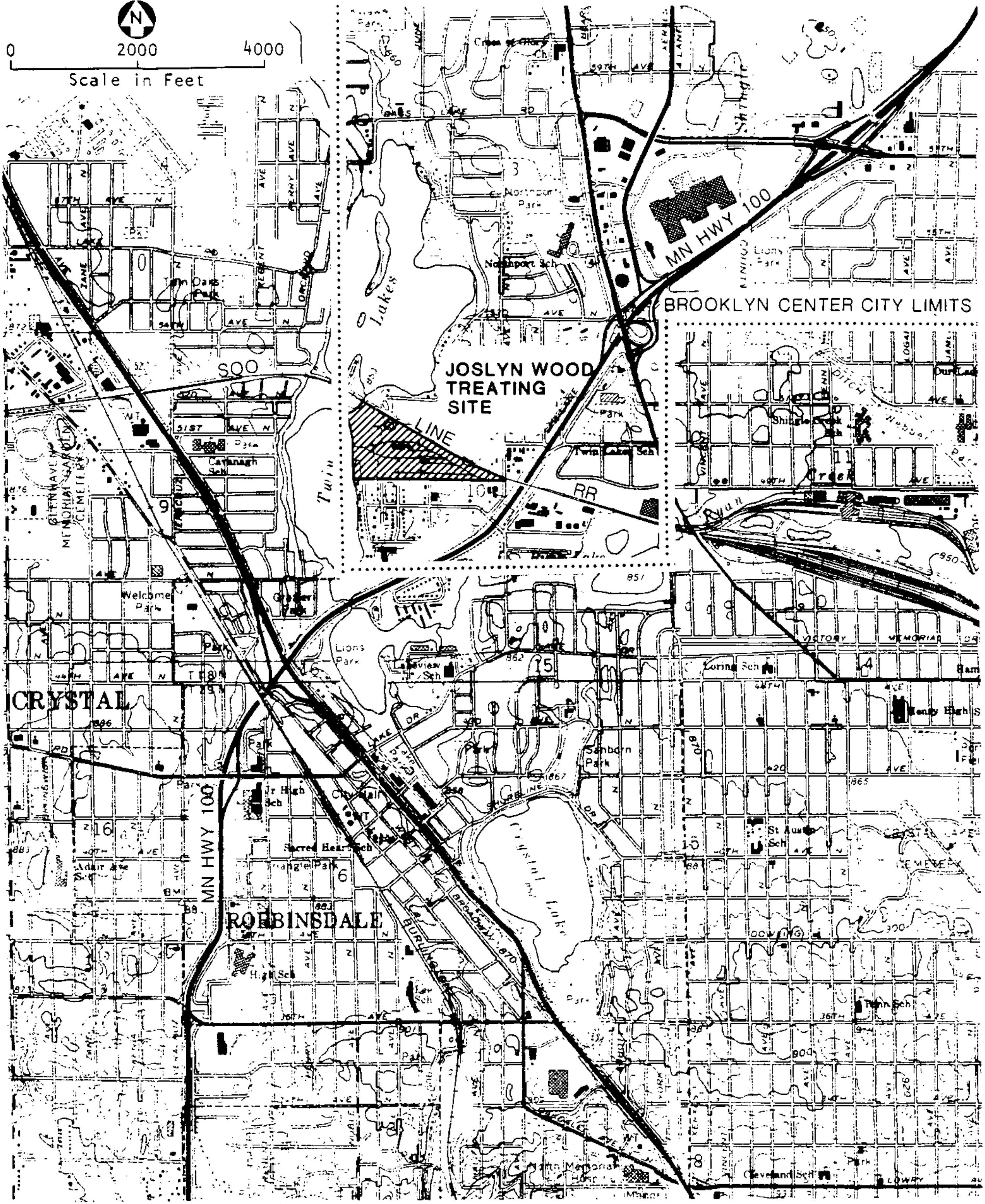
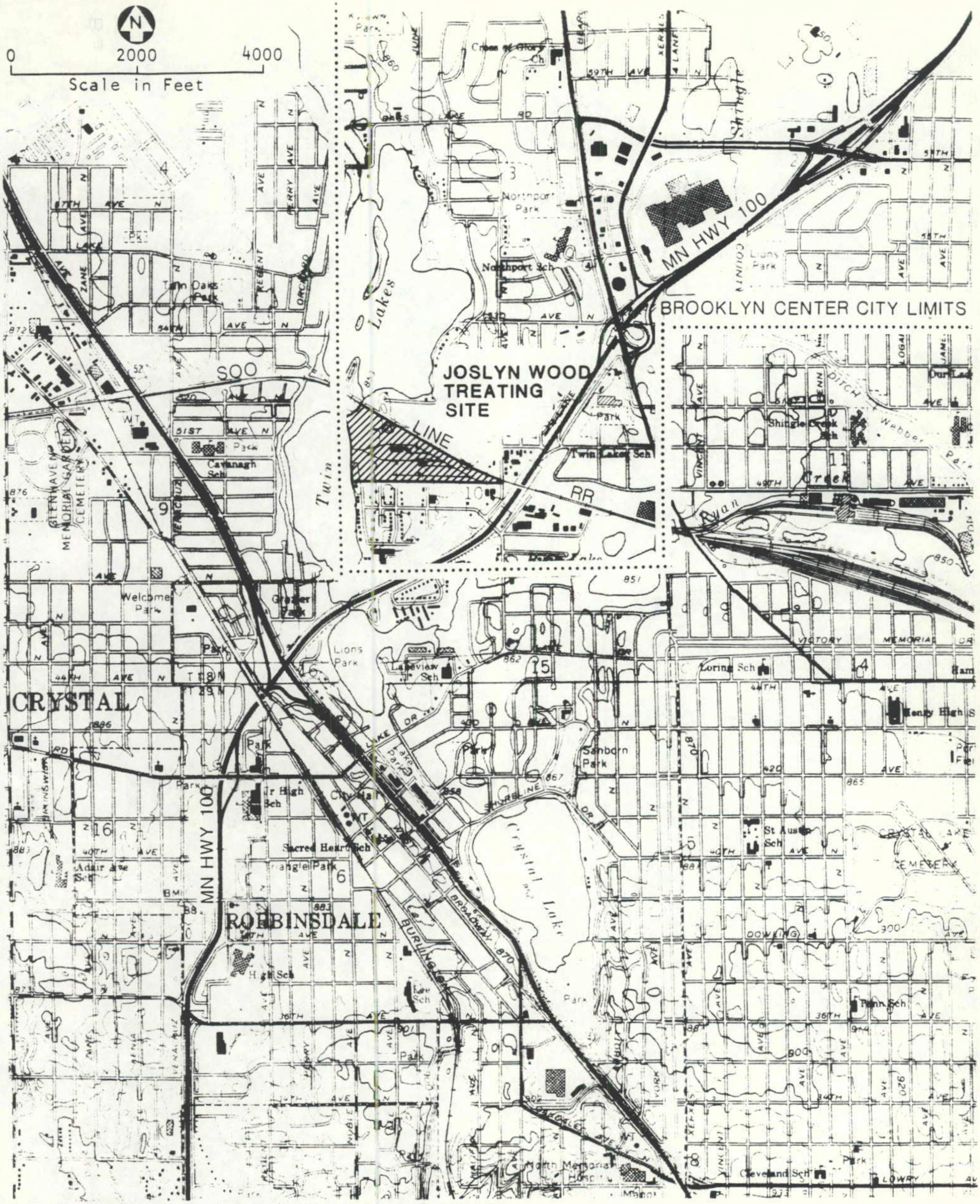
Figures



Base Map: USGS 7 1/2 Minute Minneapolis North Quadrangle

Figure 1

LOCATION OF JOSLYN SITE



Base Map: USGS 7 1/2 Minute Minneapolis North Quadrangle

Figure 1

LOCATION OF JOSLYN SITE

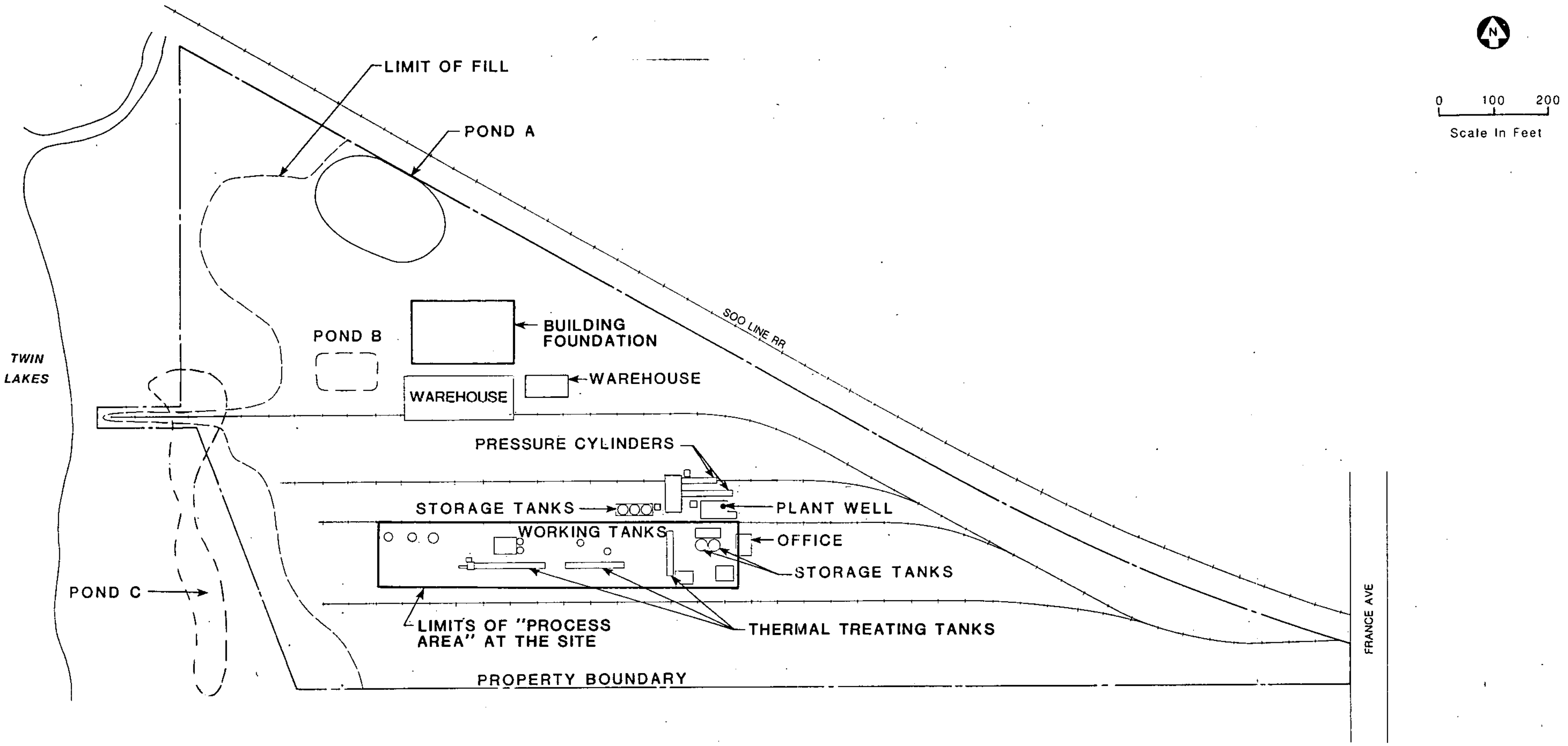
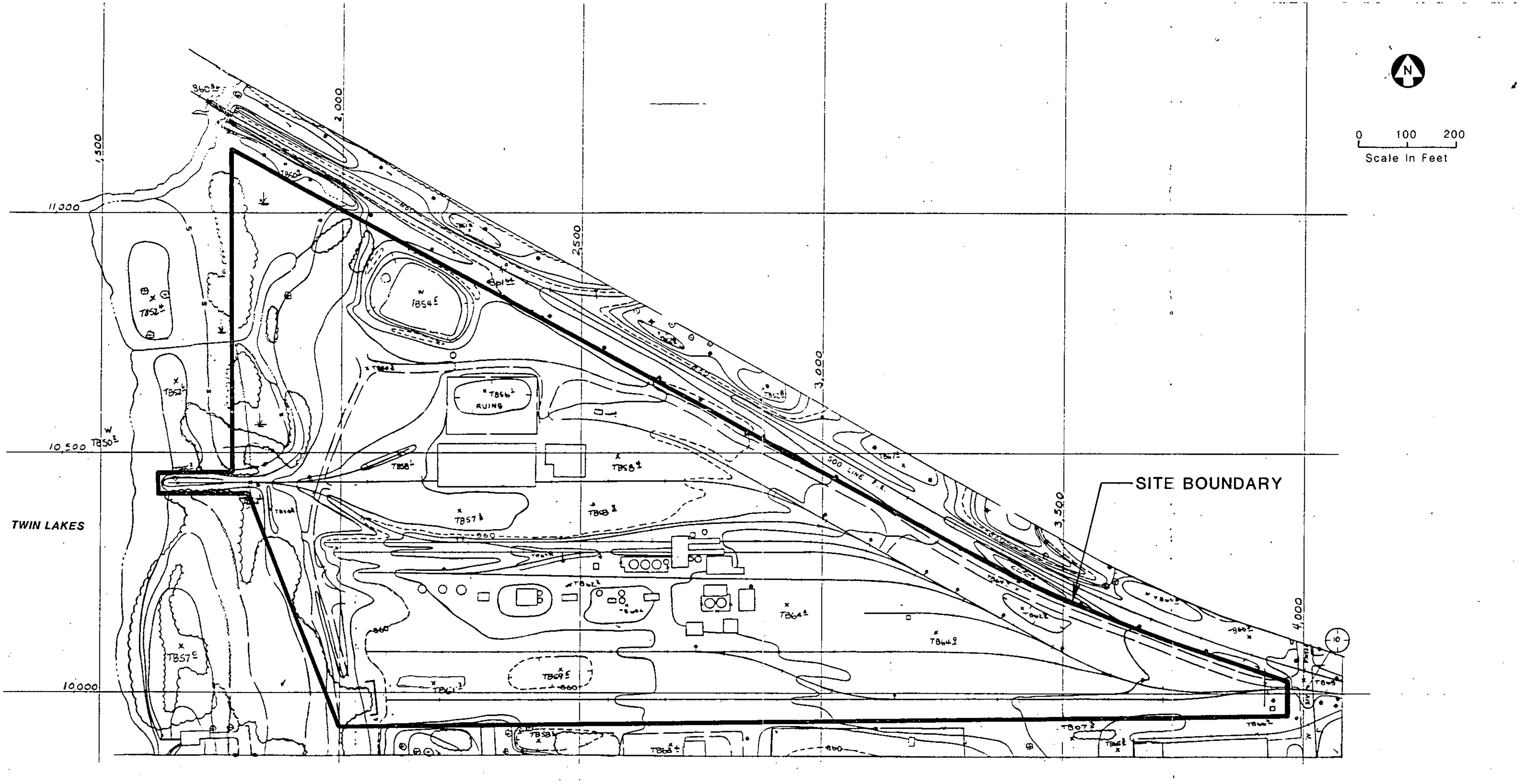


Figure 2

LAYOUT OF OPERATING AREAS
1975 AERIAL PHOTOGRAPH



2' interval ?

Figure 3

SITE TOPOGRAPHY
APRIL 1980

Vert grad 1.1 ft/yr.

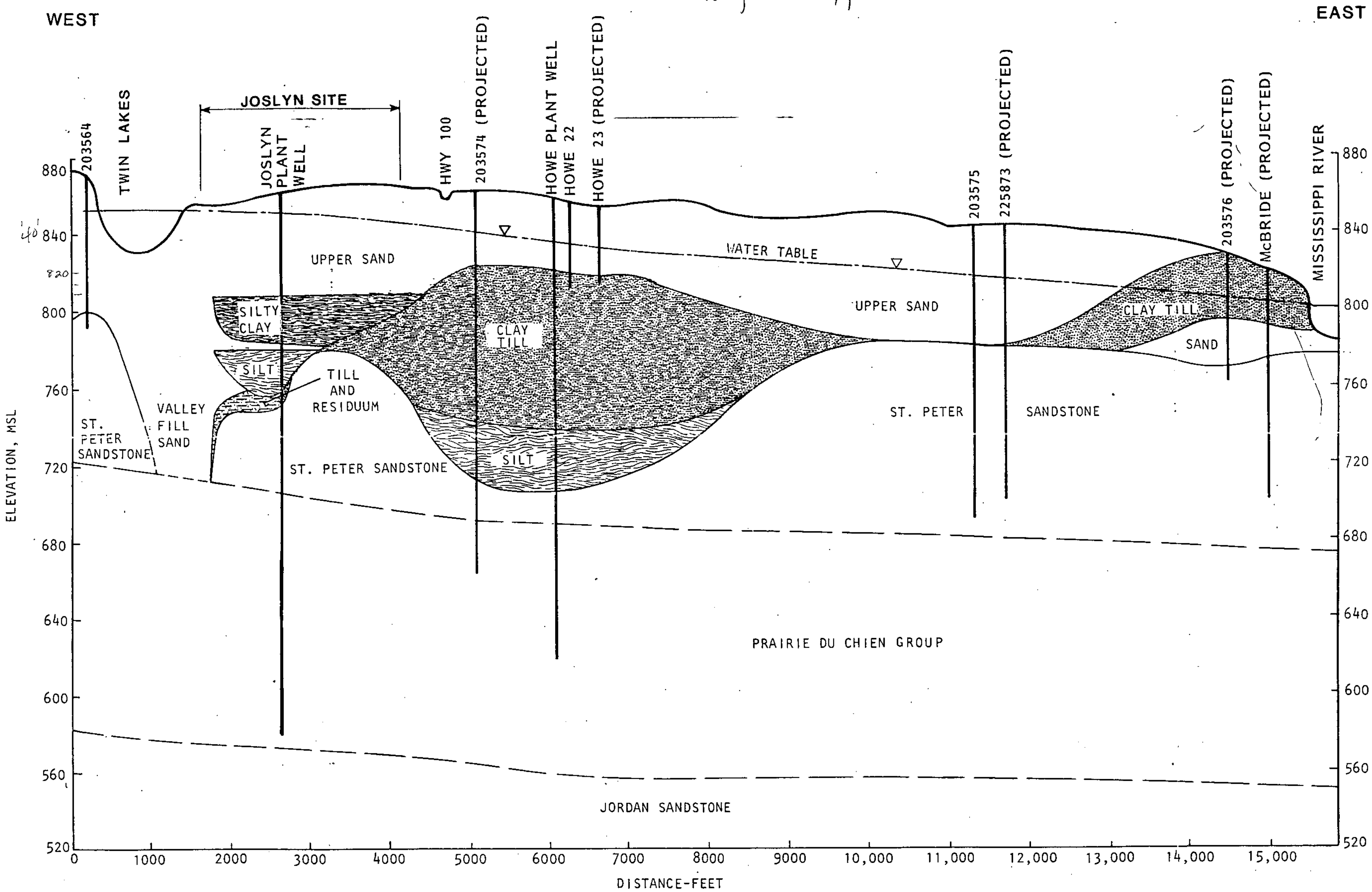


Figure 4

GENERAL WEST-EAST GEOLOGIC SECTION

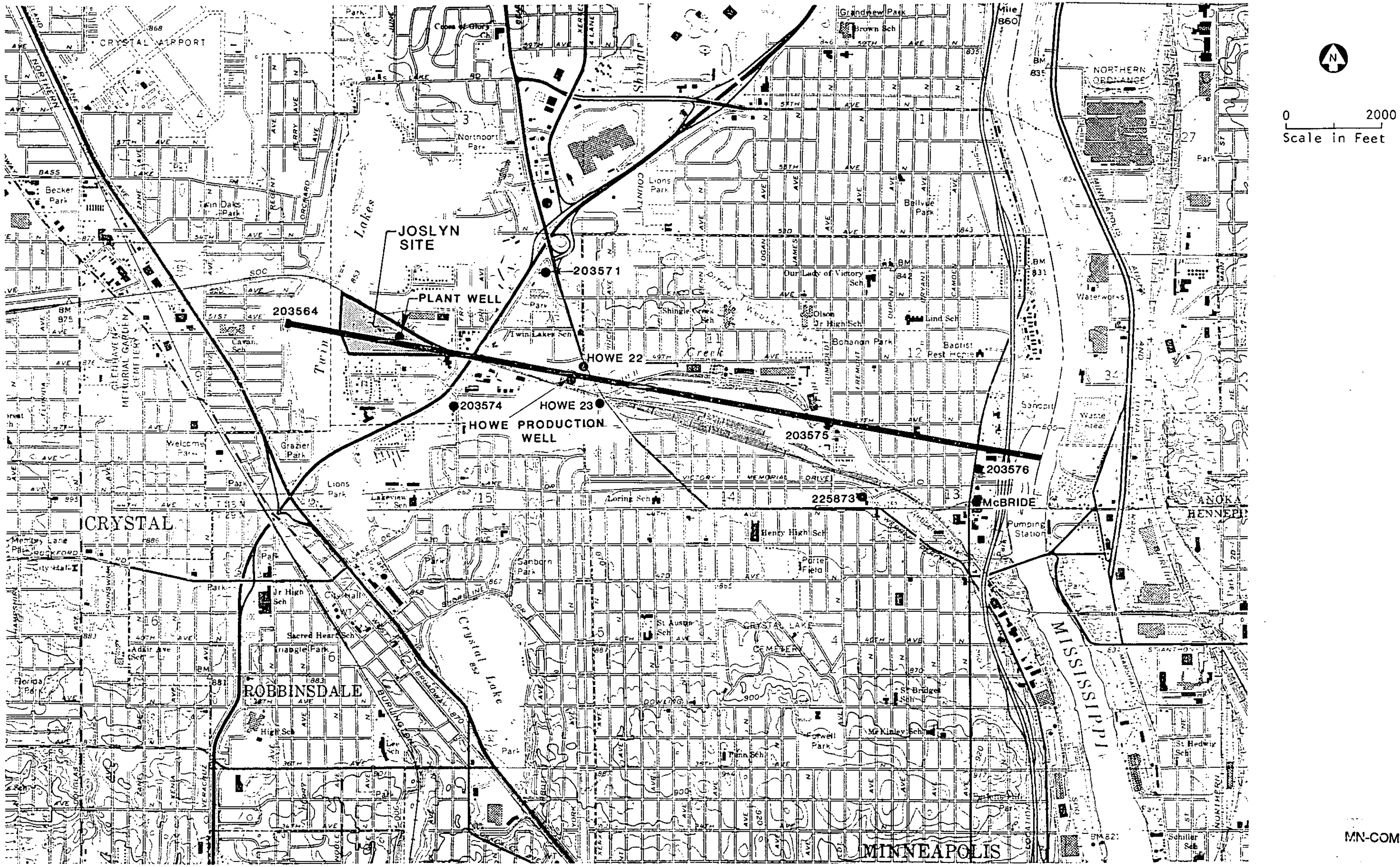


Figure 5

LOCATION OF WEST-EAST GEOLOGIC SECTION

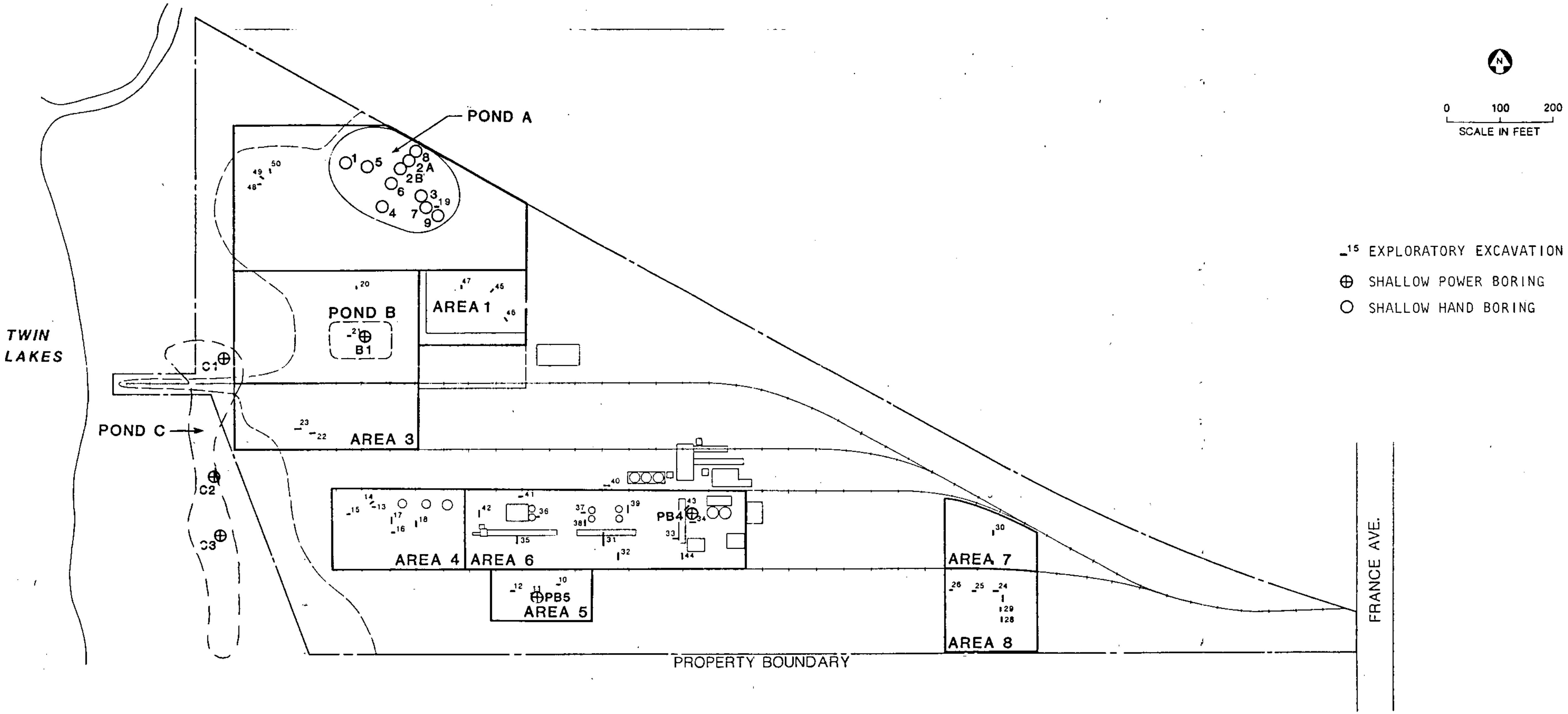


Figure 6

EXPLORATORY EXCAVATIONS AND SHALLOW BORINGS

See Appendix A-1 for wall logs.

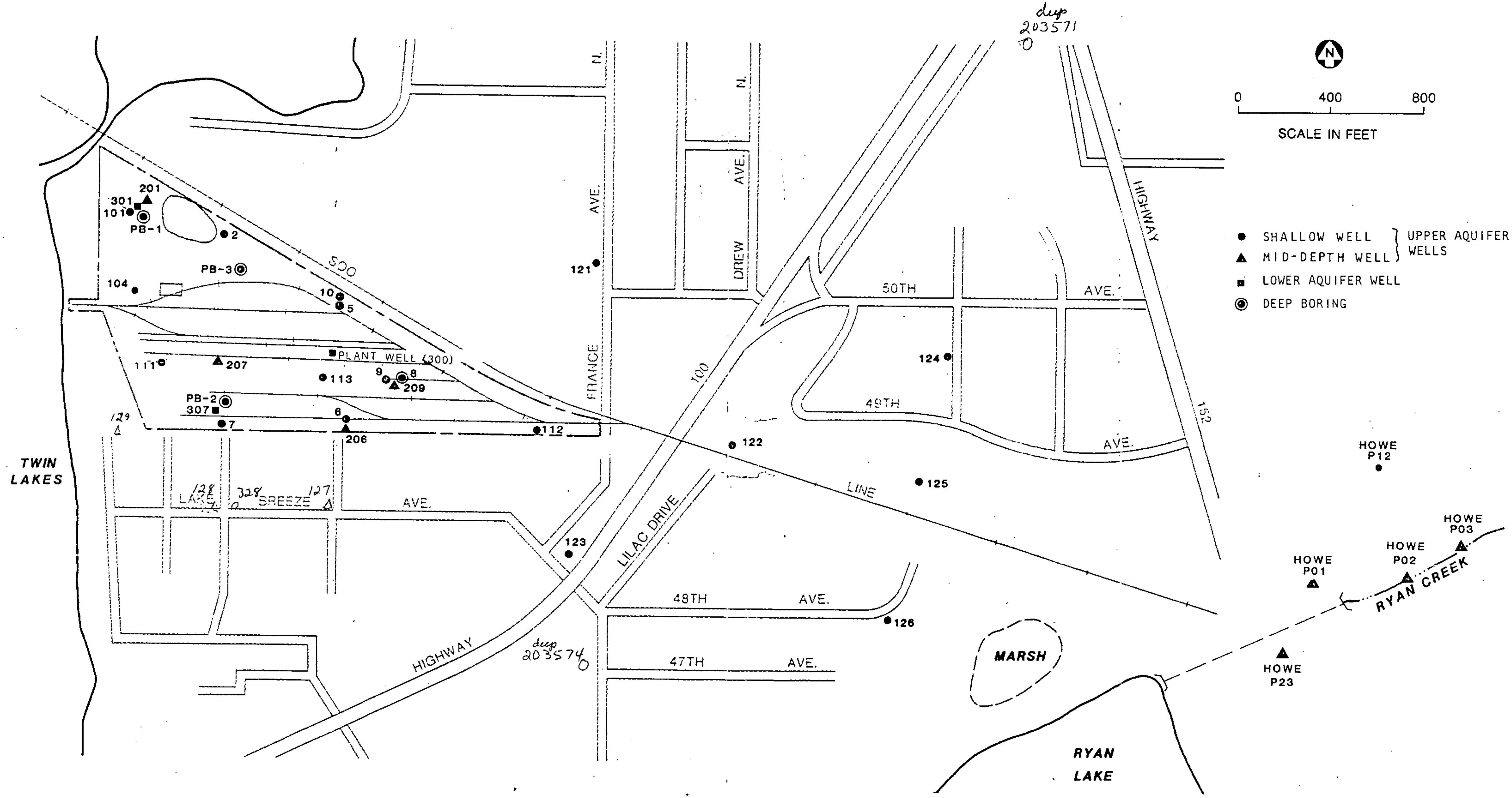


Figure 7

MONITORING WELLS
AND DEEP BORINGS

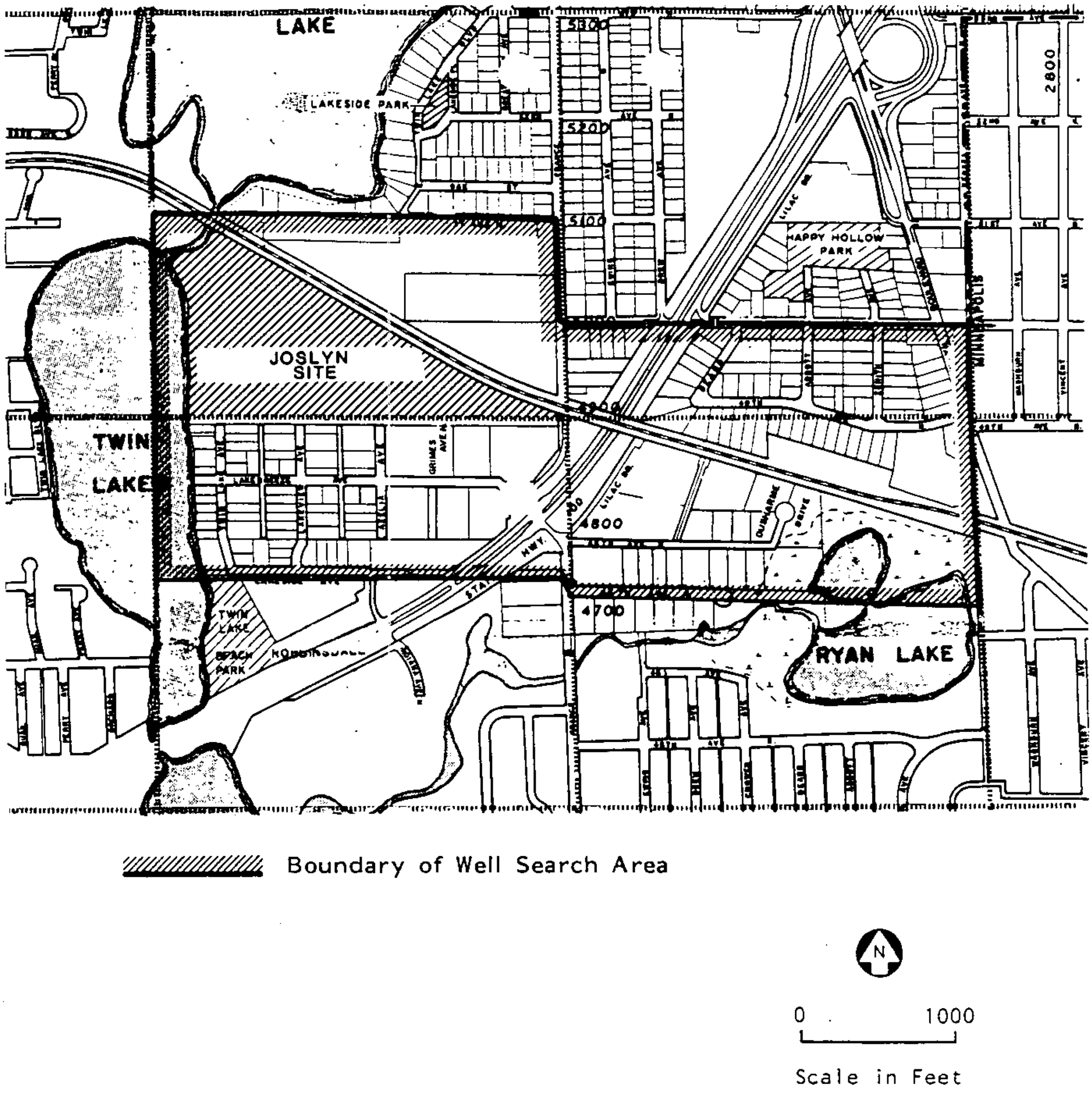
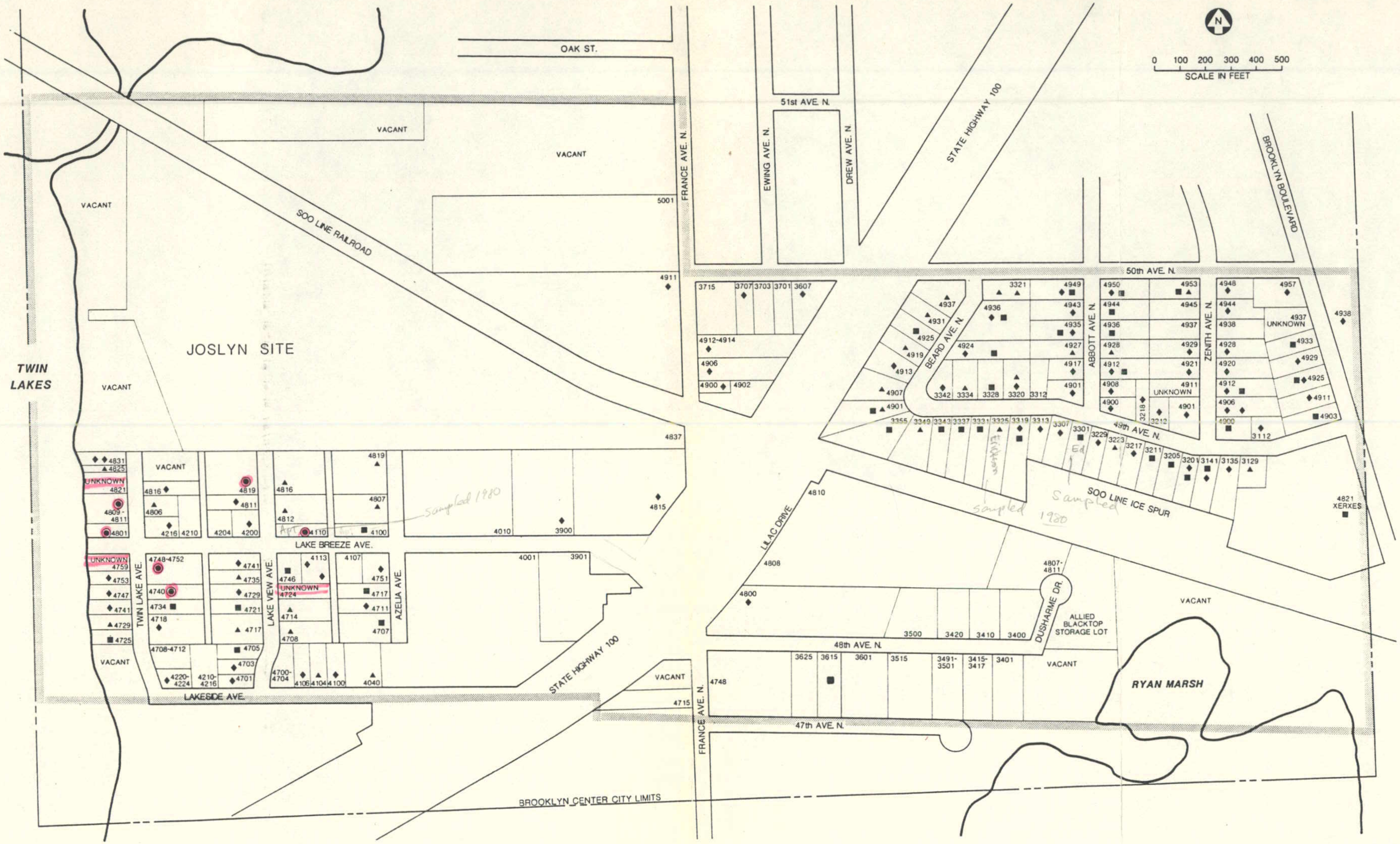


Figure 8
WELL SEARCH AREA



◉ Potable Water Supply
■ Non-Potable Water Supply
▲ Inoperable Pump
◆ Capped Or Not Accessible
UNKNOWN Owner Could Not Be Contacted
▨ Well Search Boundary

Figure 9

LOCATIONS AND STATUS OF WELLS IN SEARCH AREA

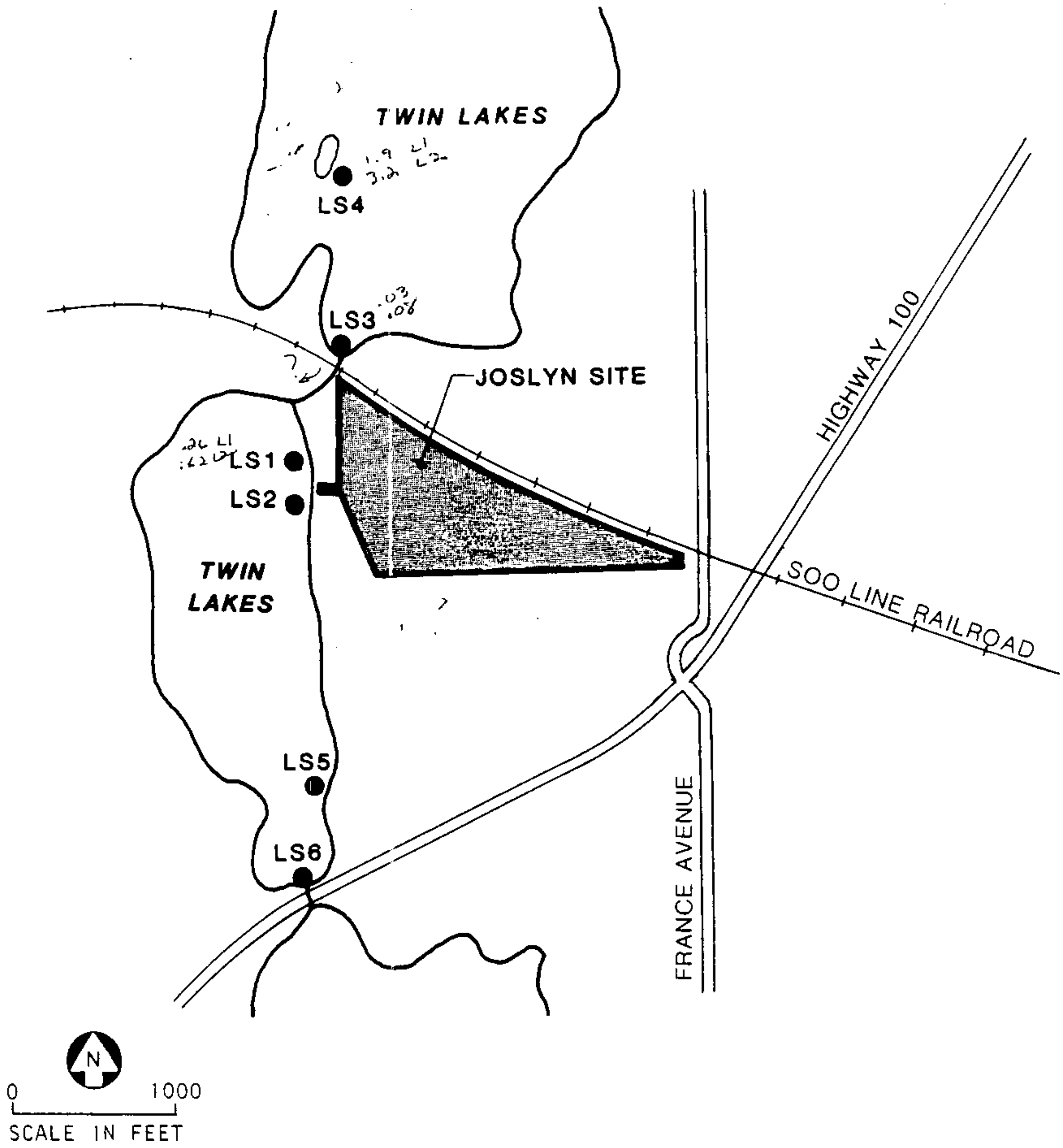


Figure 10

LAKE WATER QUALITY SAMPLING STATIONS

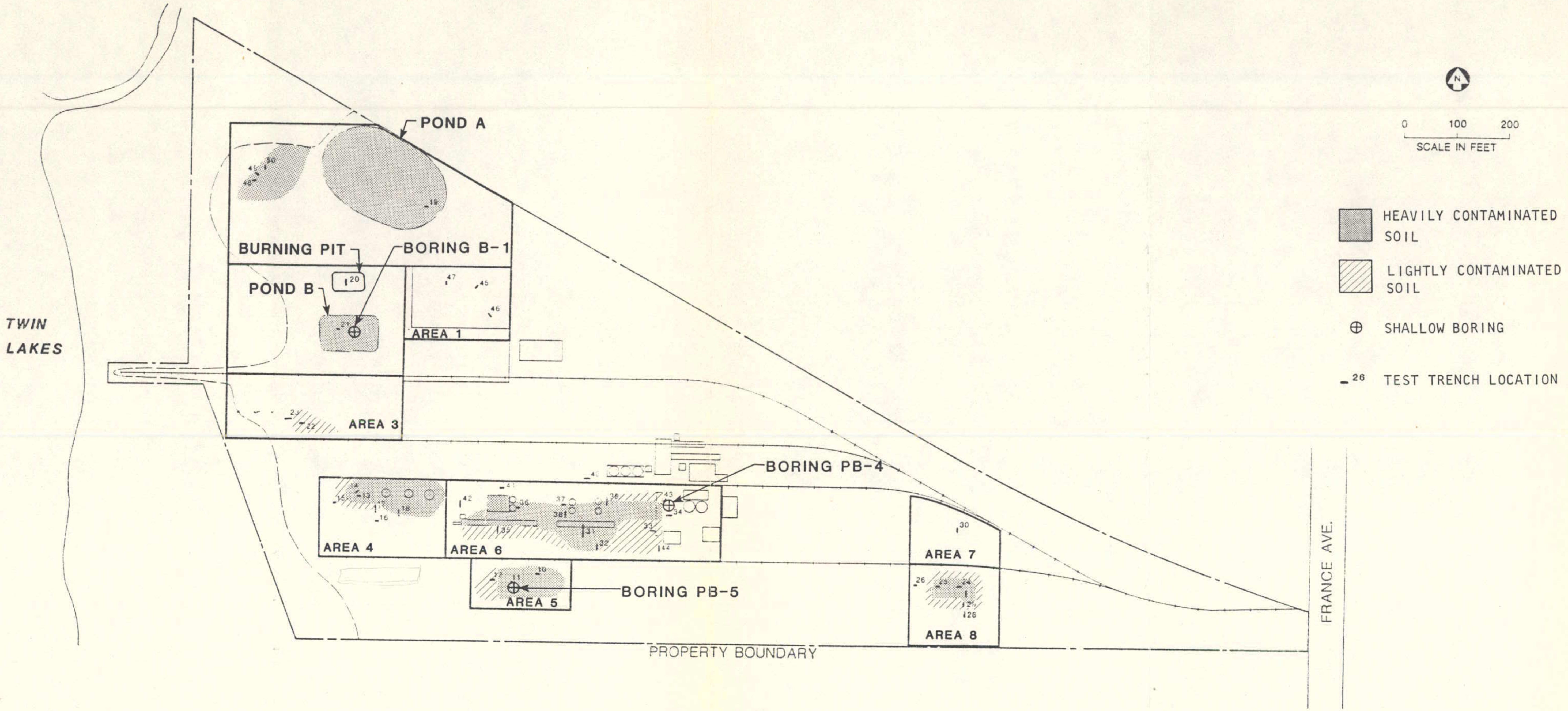


Figure 11

DISTRIBUTION OF CONTAMINATED SOIL

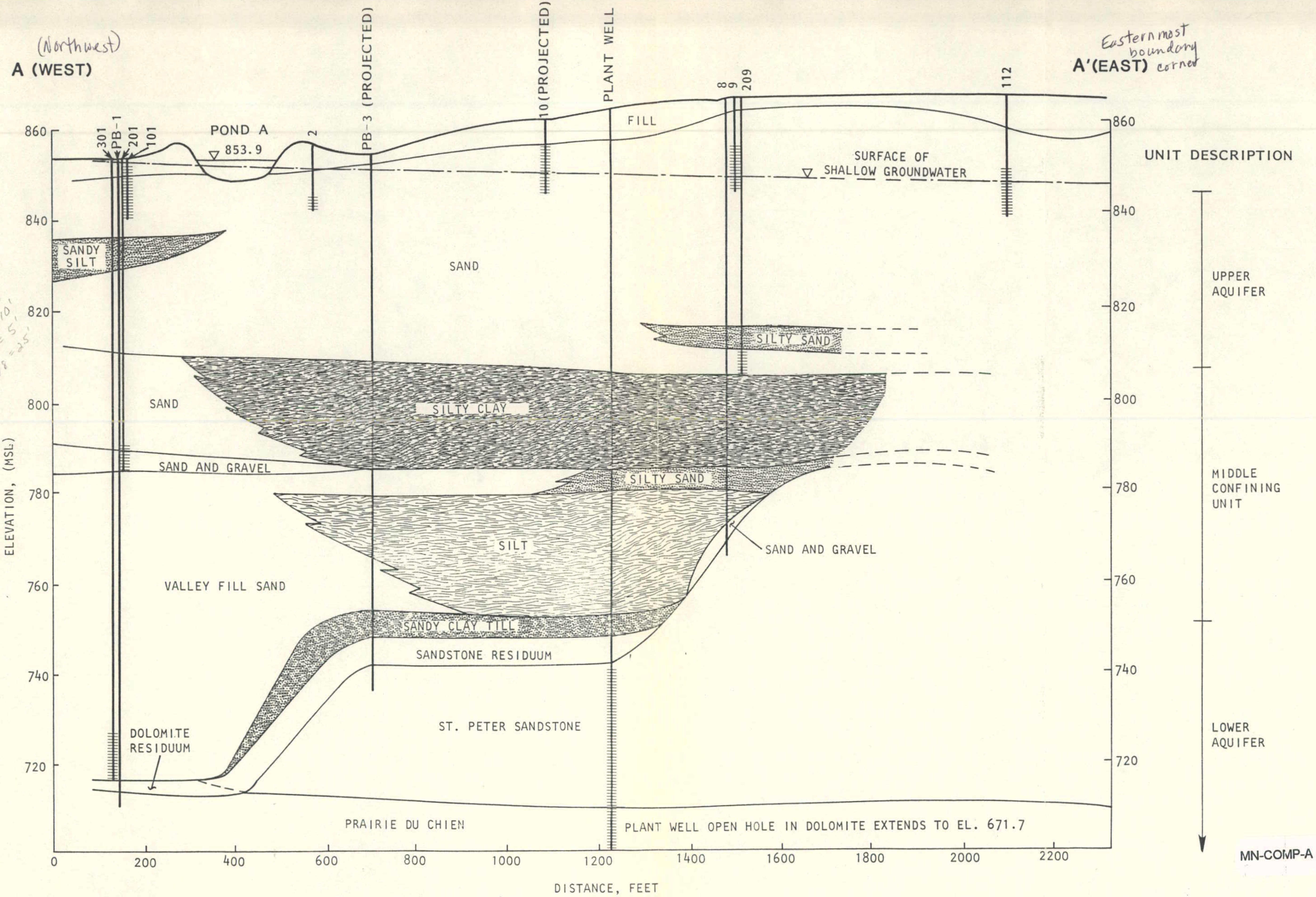


Figure 12
CROSS SECTION A-A'

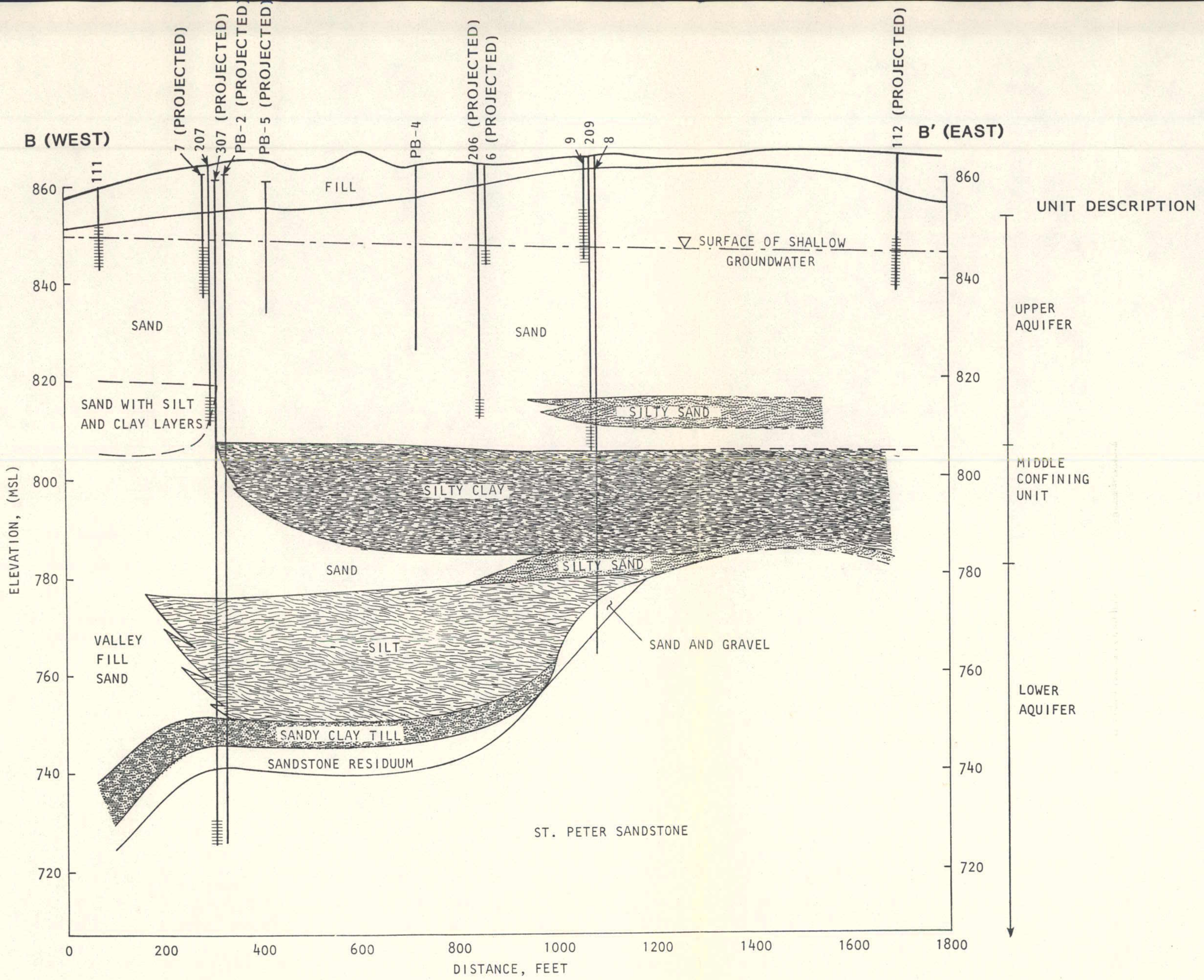


Figure 13
CROSS SECTION B-B'

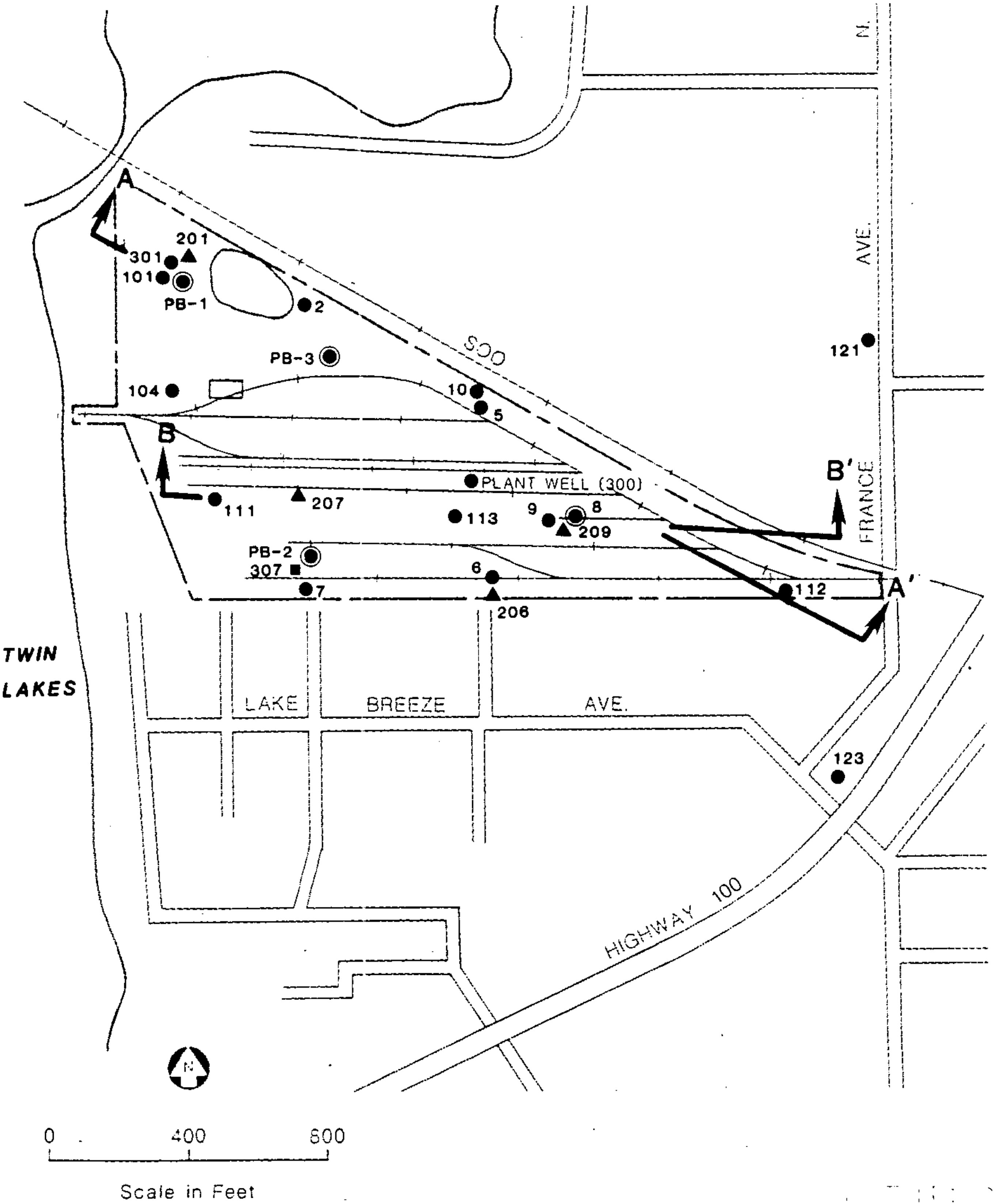


Figure 14

LOCATIONS OF CROSS
SECTIONS A-A' AND B-B'

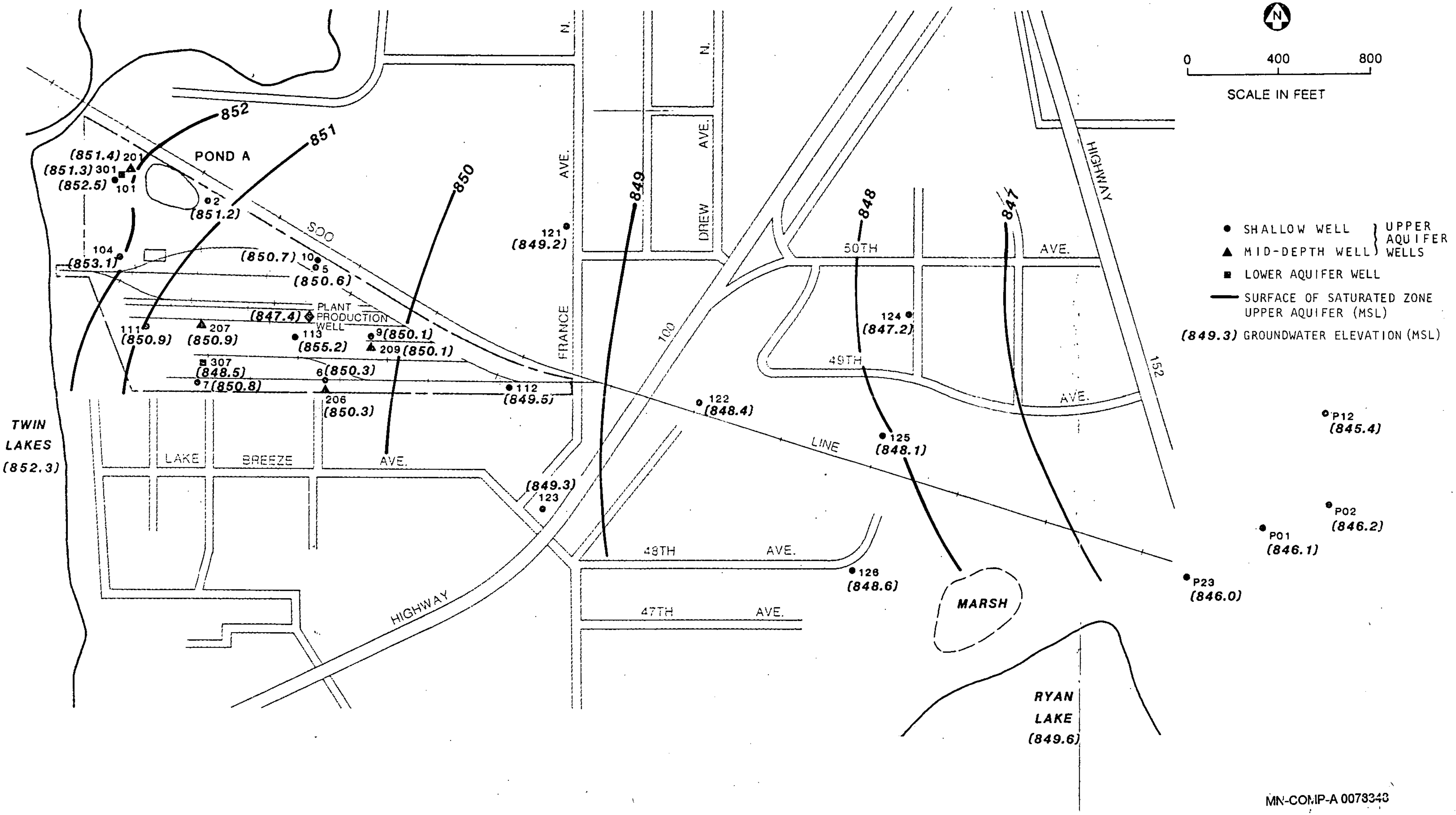


Figure 15
GROUNDWATER ELEVATIONS (MSL)
MARCH, 1985

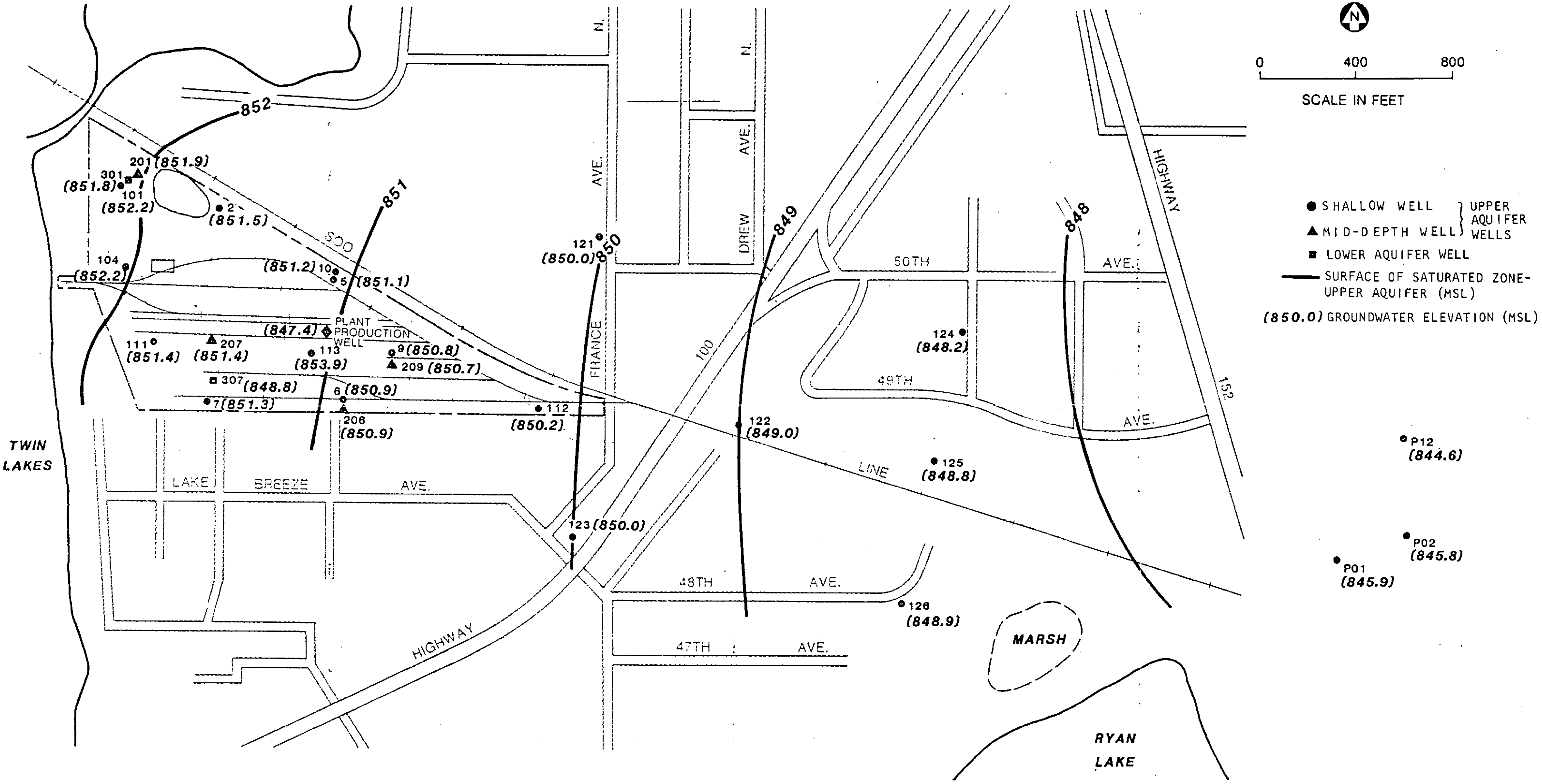
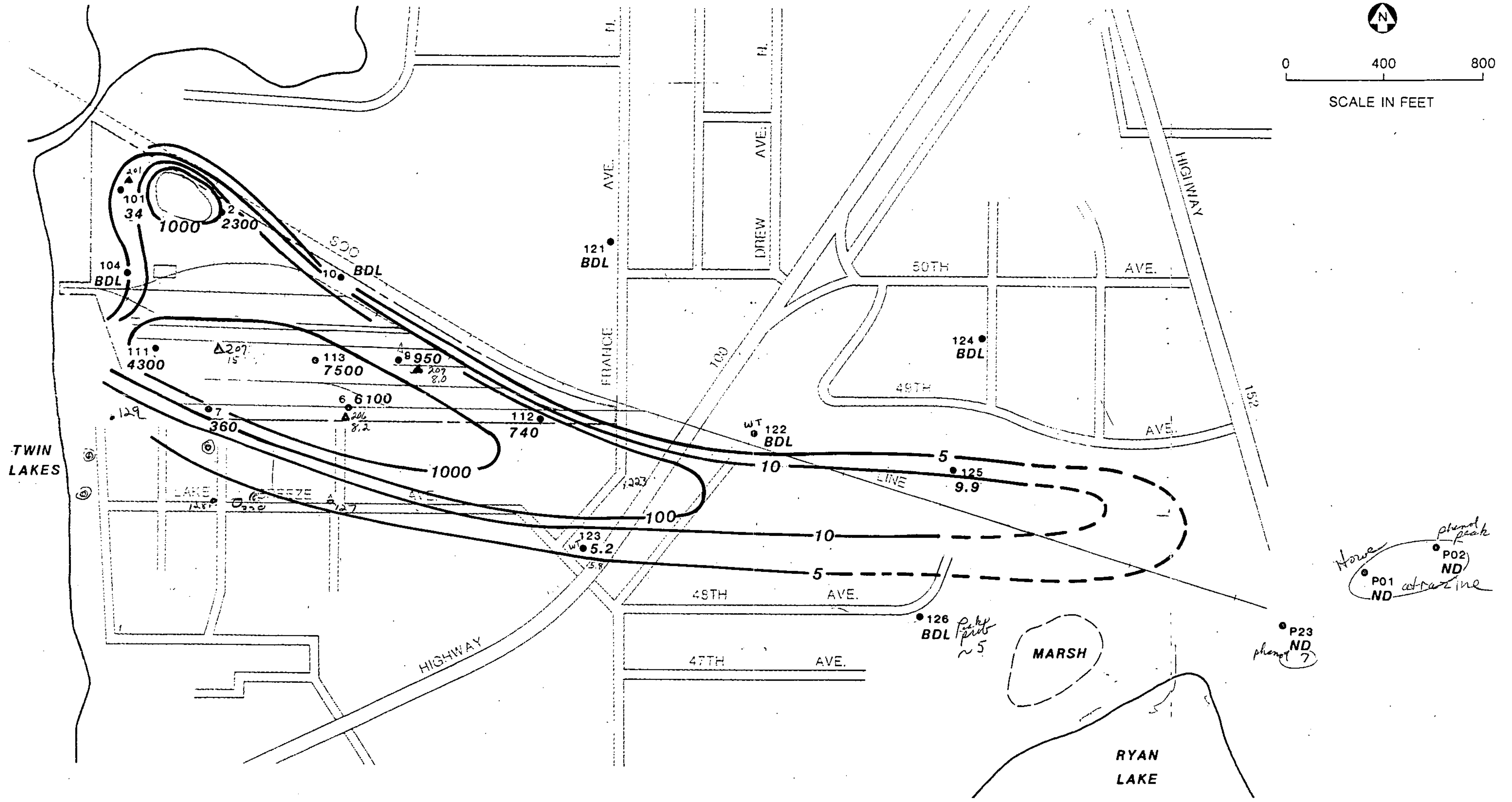


Figure 16

GROUNDWATER ELEVATIONS (MSL)
MAY, 1985



● Shallow Well

Average Pentachlorophenol Concentration Contour in Shallow Groundwater (ug/L)

ND Not Detected

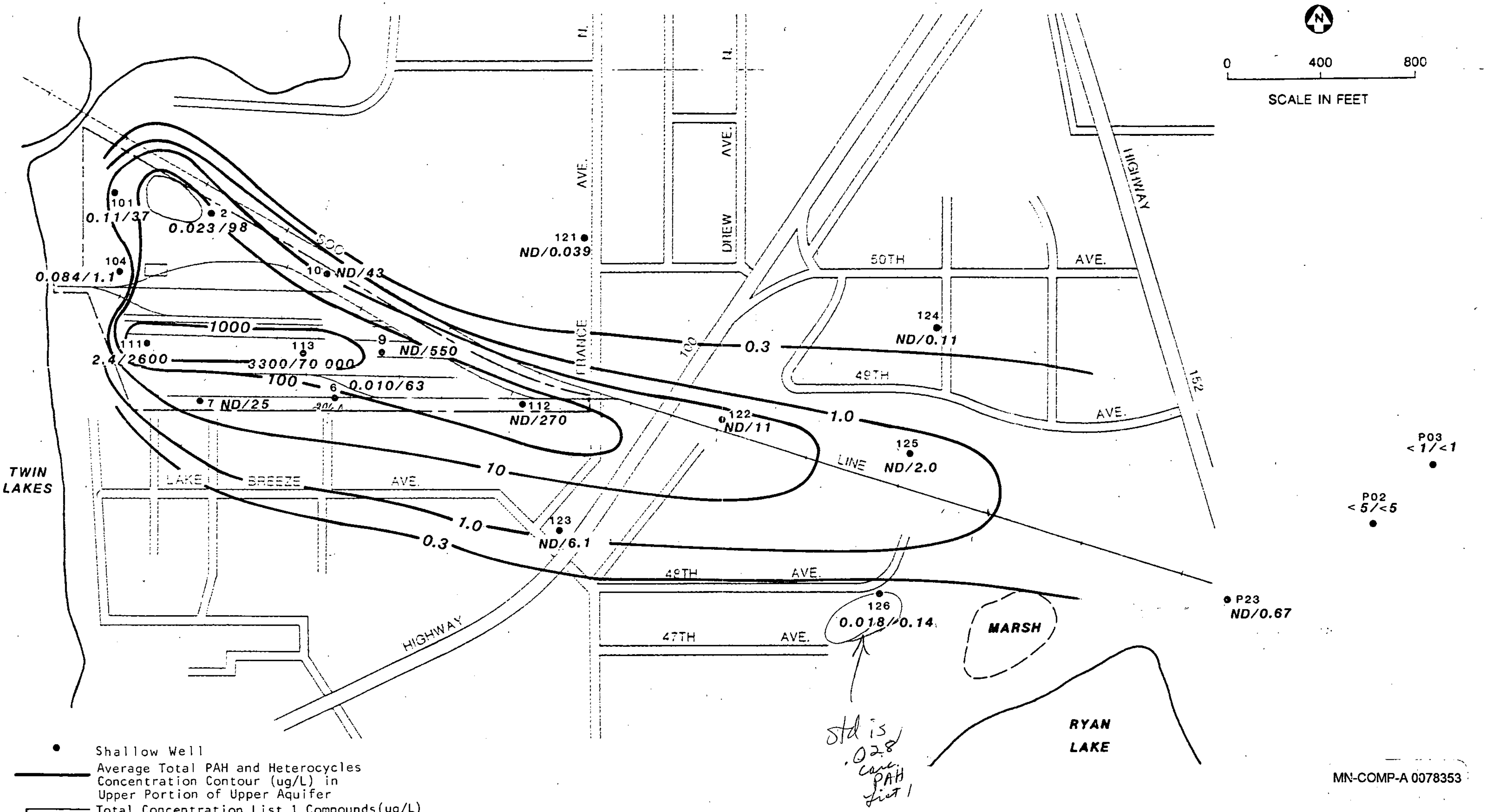
BDL Detection Below Method Detection Limit

Figure 17

AVERAGE PENTACHLOROPHENOL CONCENTRATIONS (ug/L) UPPER PORTION OF UPPER AQUIFER

MDH Limit 250 ug/l

Penta
conc.



● Shallow Well

Average Total PAH and Heterocycles Concentration Contour (ug/L) in Upper Portion of Upper Aquifer

Total Concentration List 1 Compounds (ug/L)

0.018/0.16

Total Concentration List 2 Compounds (ug/L)

ND Not Detected

Figure 18 LIST 1 / LIST 2
AVERAGE TOTAL PAH/HETEROCYCLE CONCENTRATIONS (ug/L)
UPPER PORTION OF UPPER AQUIFER

PAH
Conc.

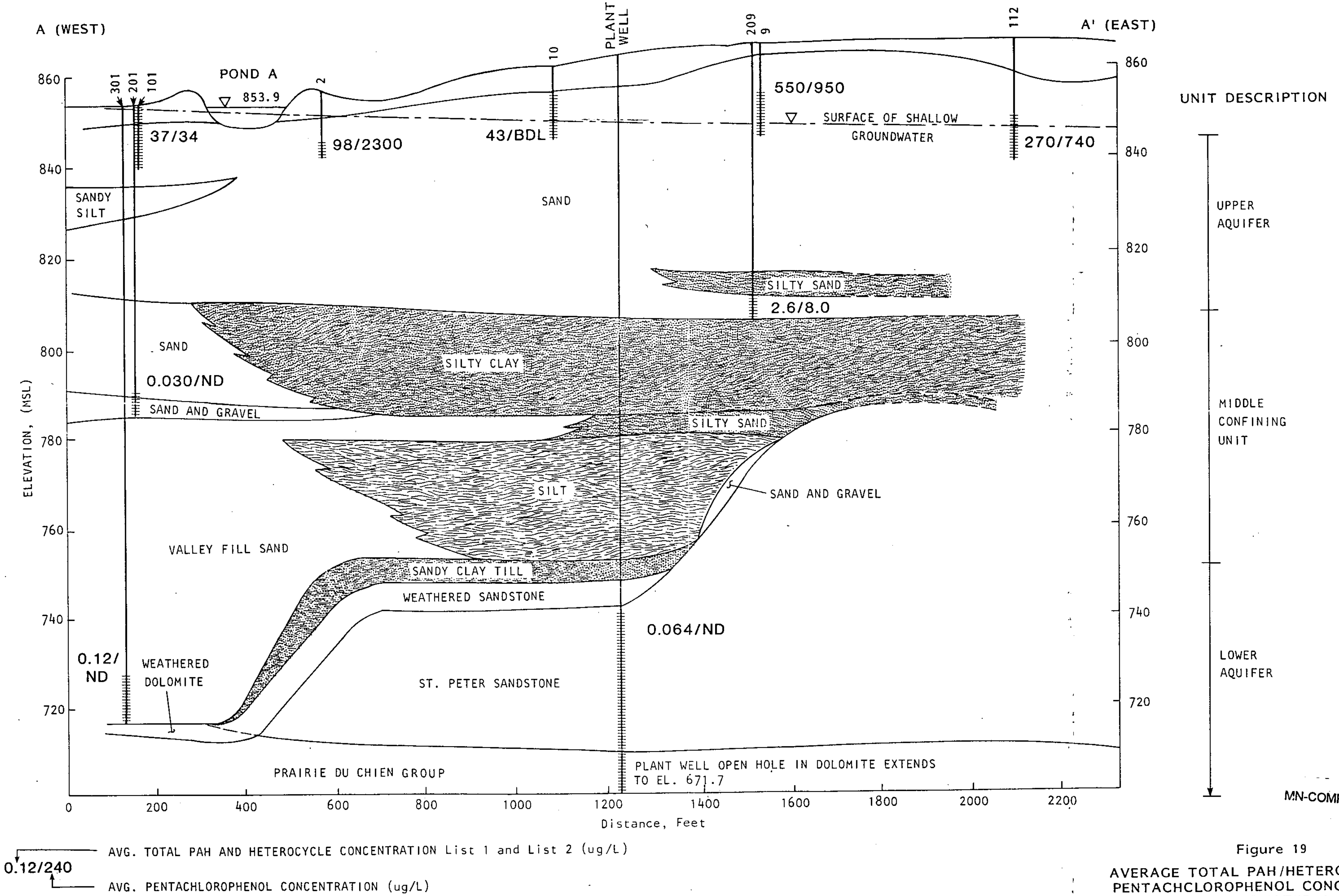


Figure 19

AVERAGE TOTAL PAH/HETEROCYCLE AND PENTACHCLOROPHENOL CONCENTATIONS IN GROUNDWATER (ug/L) CROSS SECTION A-A'

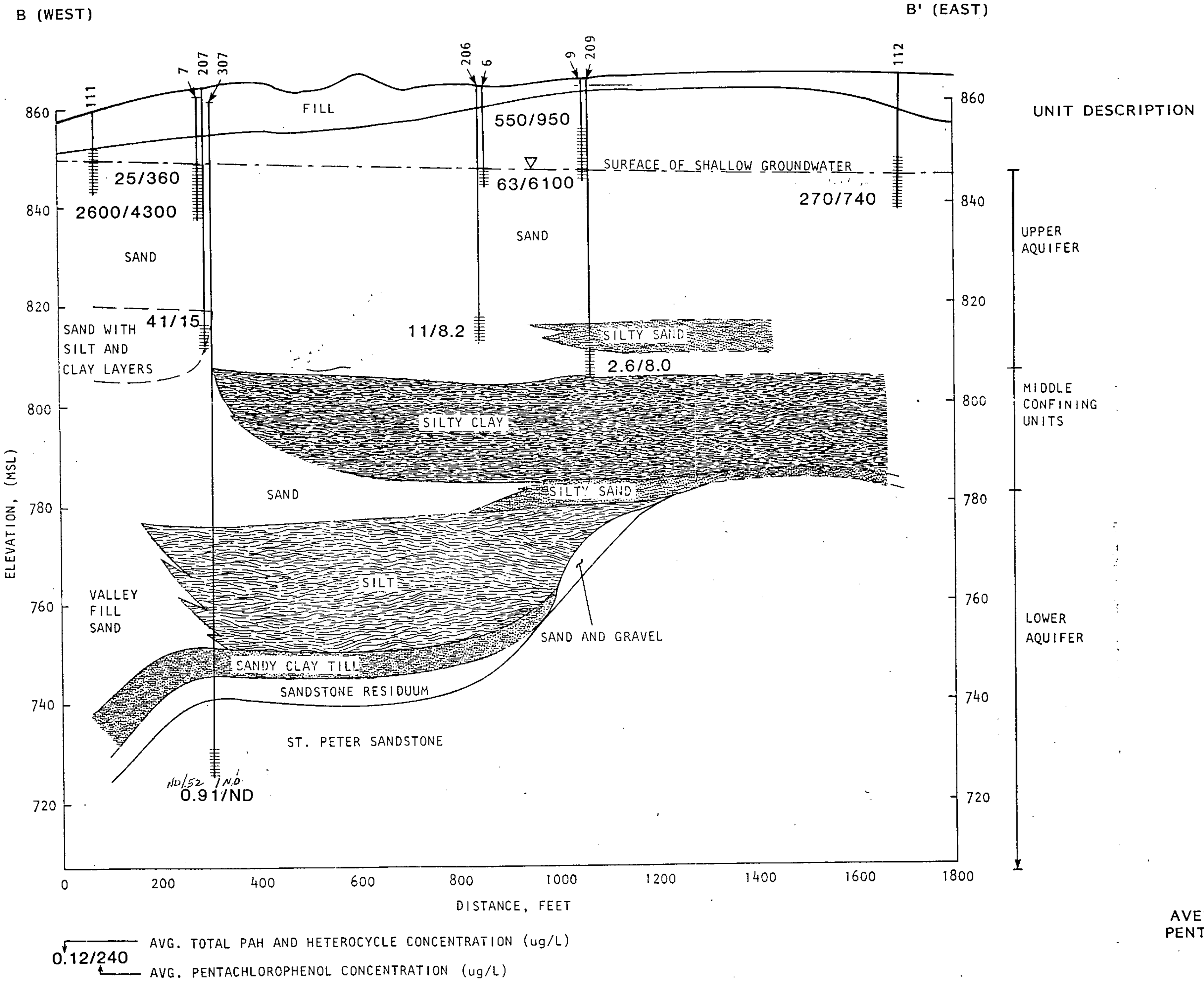


Figure 20

AVERAGE TOTAL PAH/HETEROCYCLE AND PENTACHLOROPHENOL CONCENTRATION IN GROUNDWATER (ug/L)
CROSS SECTION B-B'

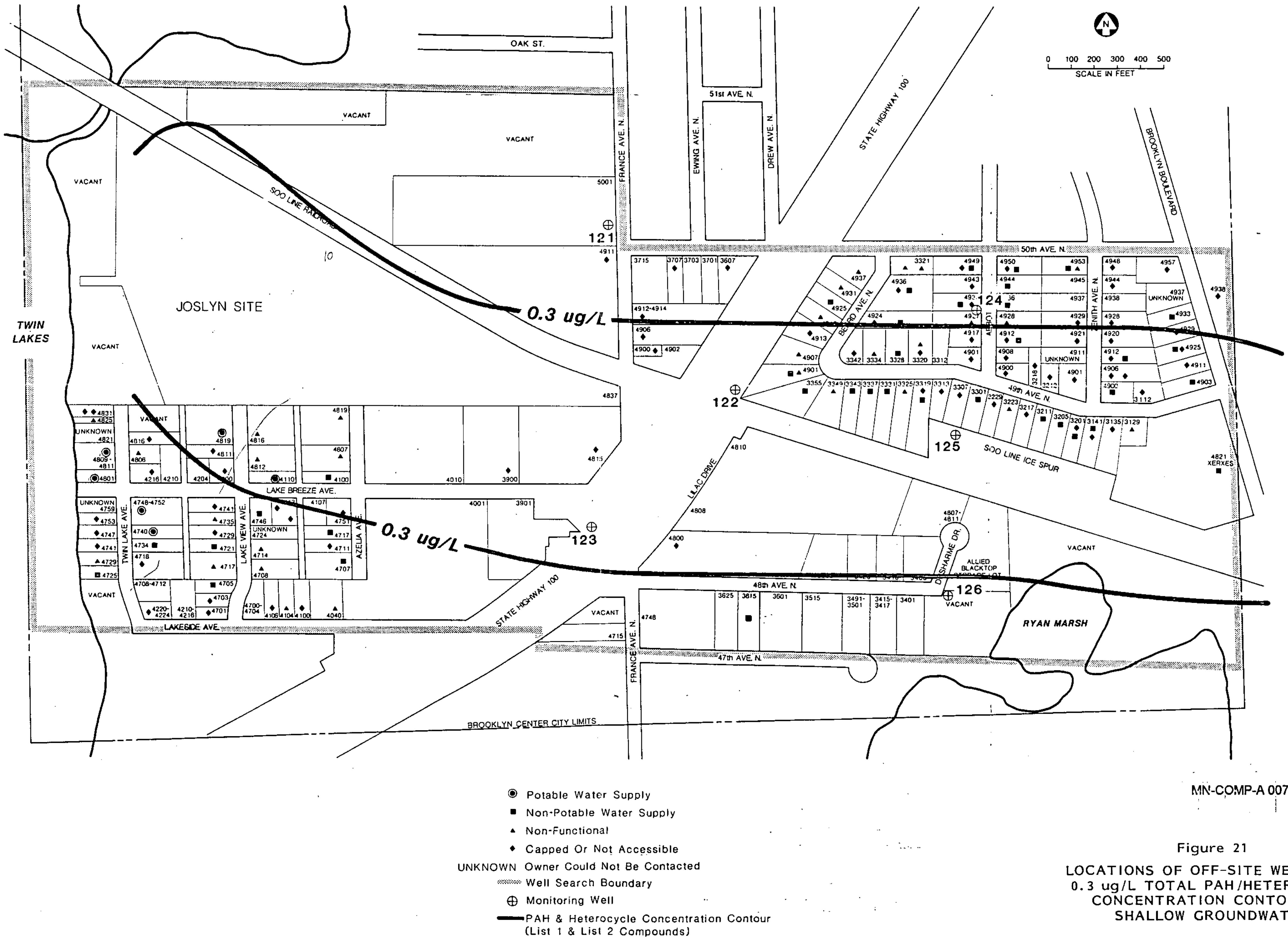


Figure 21

LOCATIONS OF OFF-SITE WELLS AND 0.3 ug/L TOTAL PAH/HETEROCYCLE CONCENTRATION CONTOUR IN SHALLOW GROUNDWATER

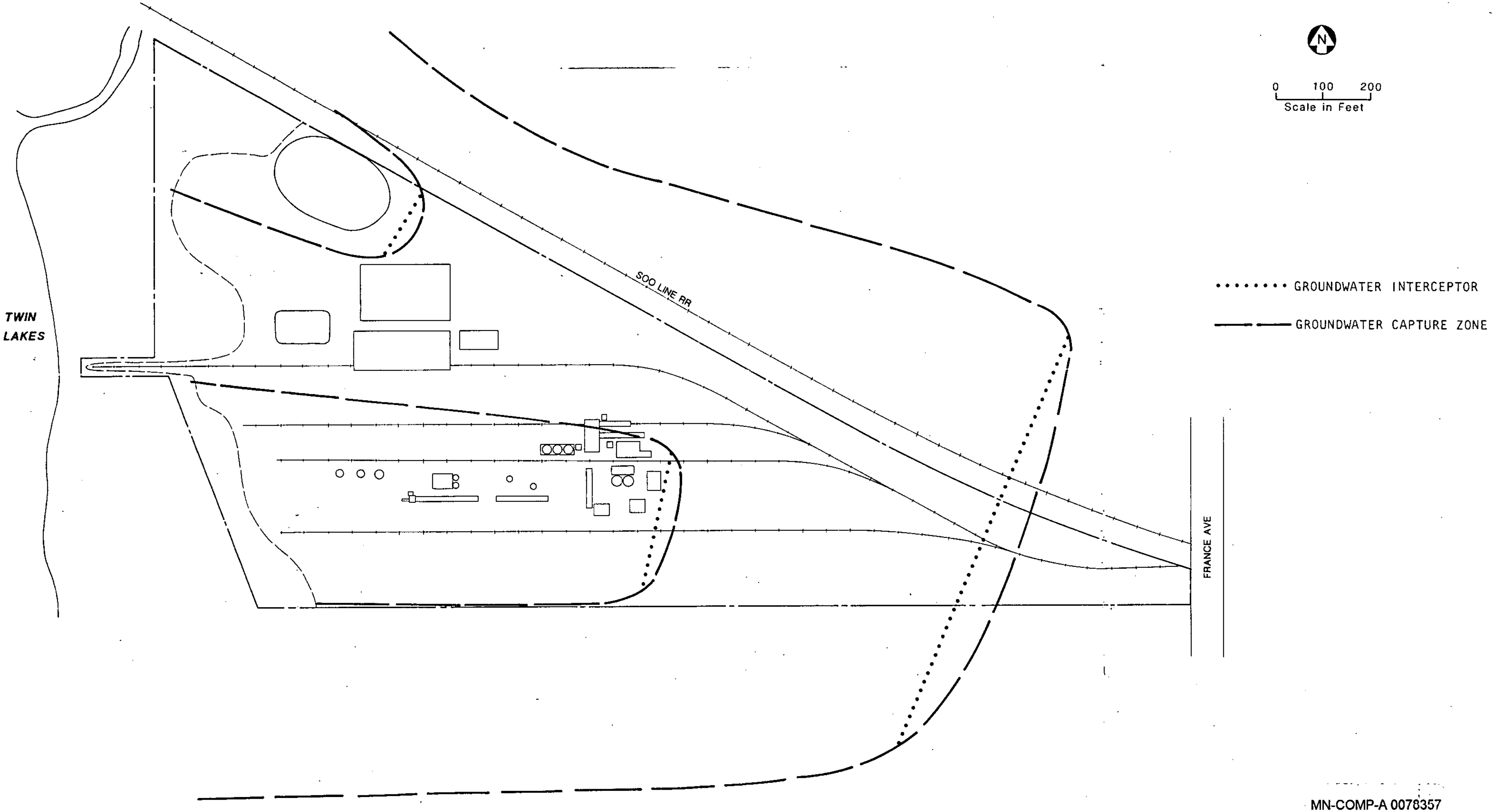


Figure 22

LOCATIONS OF GROUNDWATER PUMP-OUT SYSTEMS

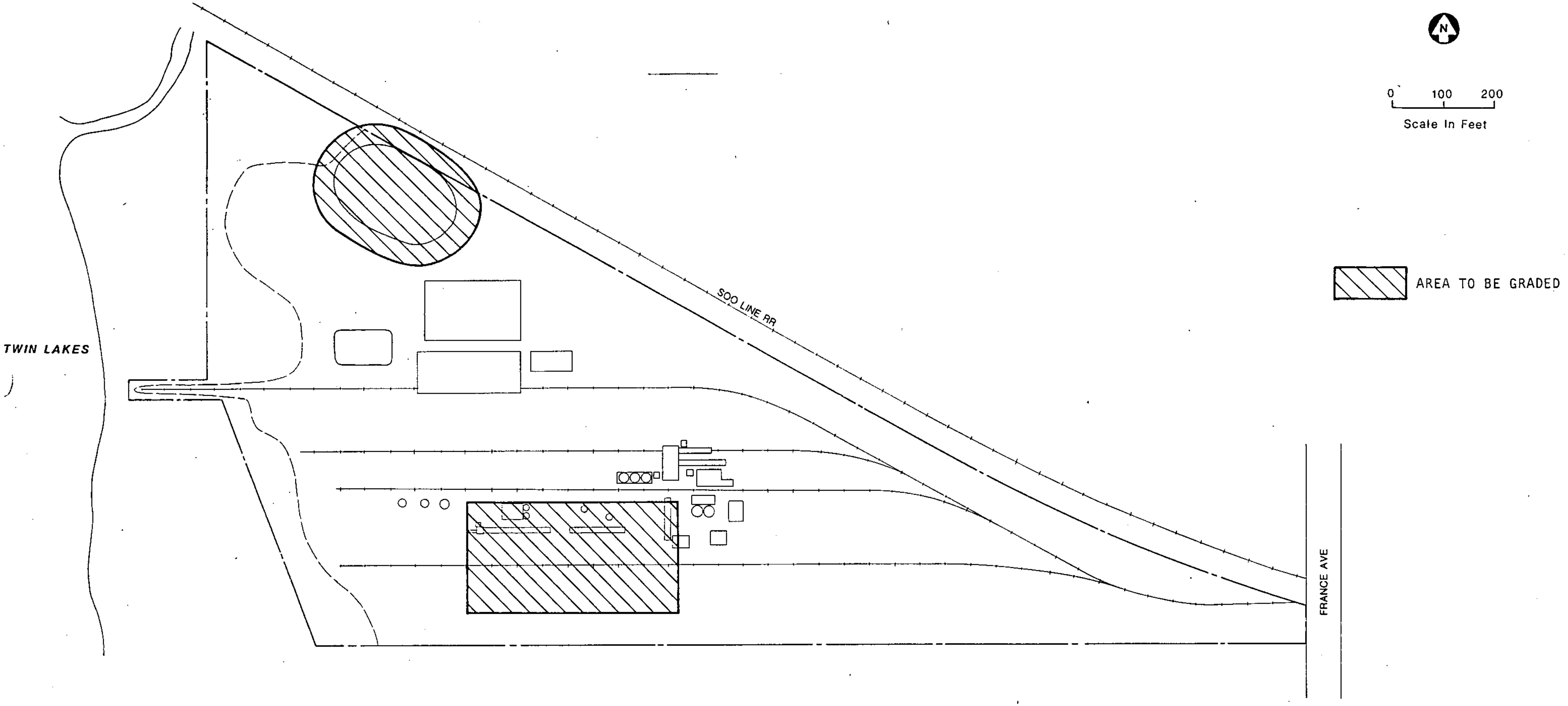


Figure 23

ALTERNATIVE I.A.
SITE GRADING

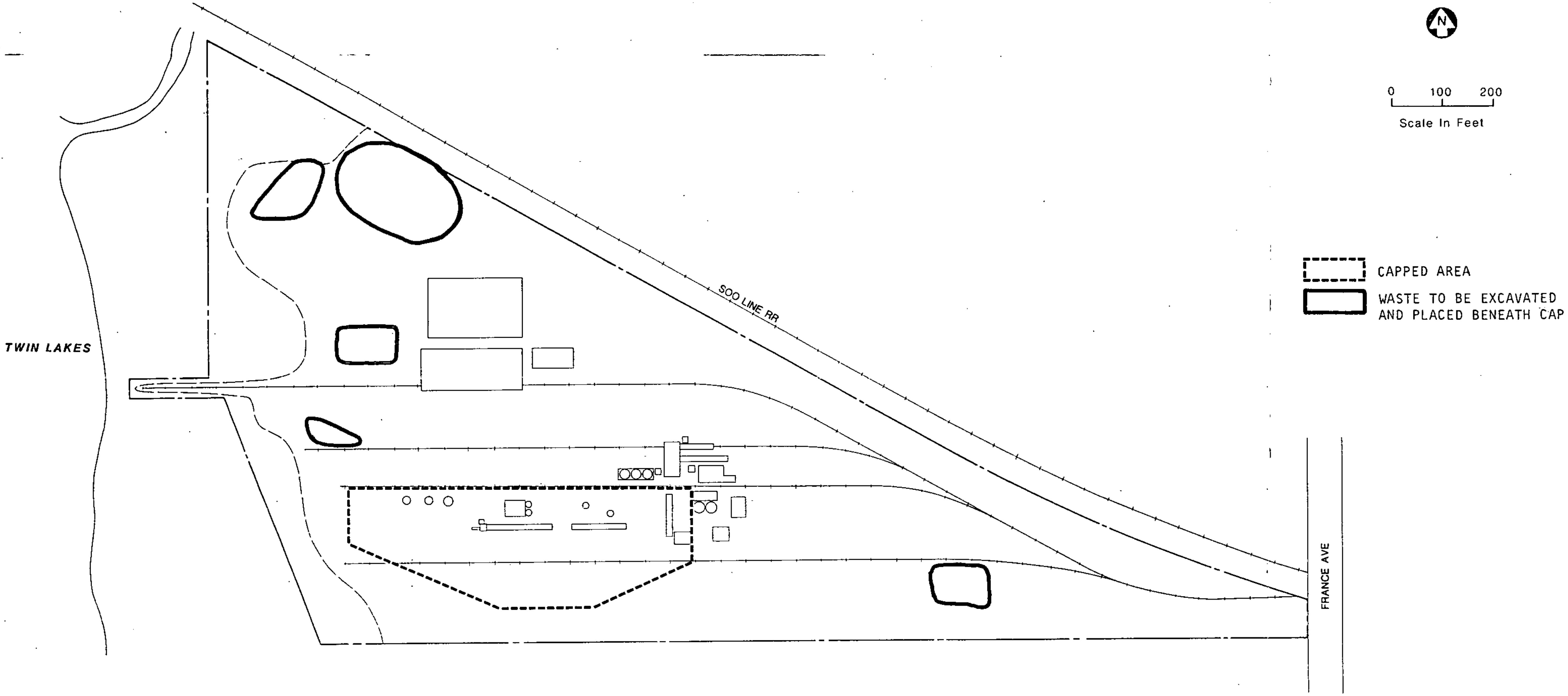


Figure 24

ALTERNATIVE I.B.
CAP CONTAMINATED SOIL

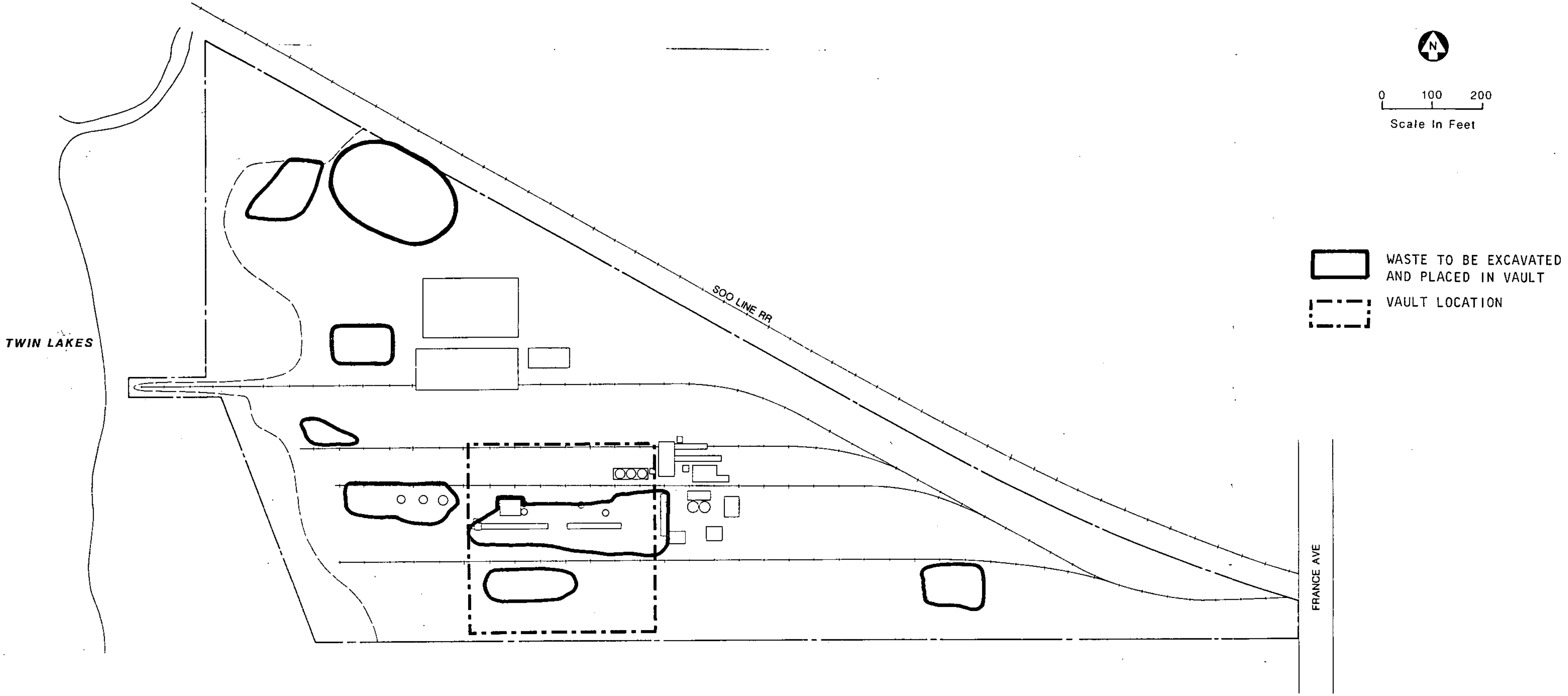


Figure 25

ALTERNATIVE I.C.
ON-SITE VAULT

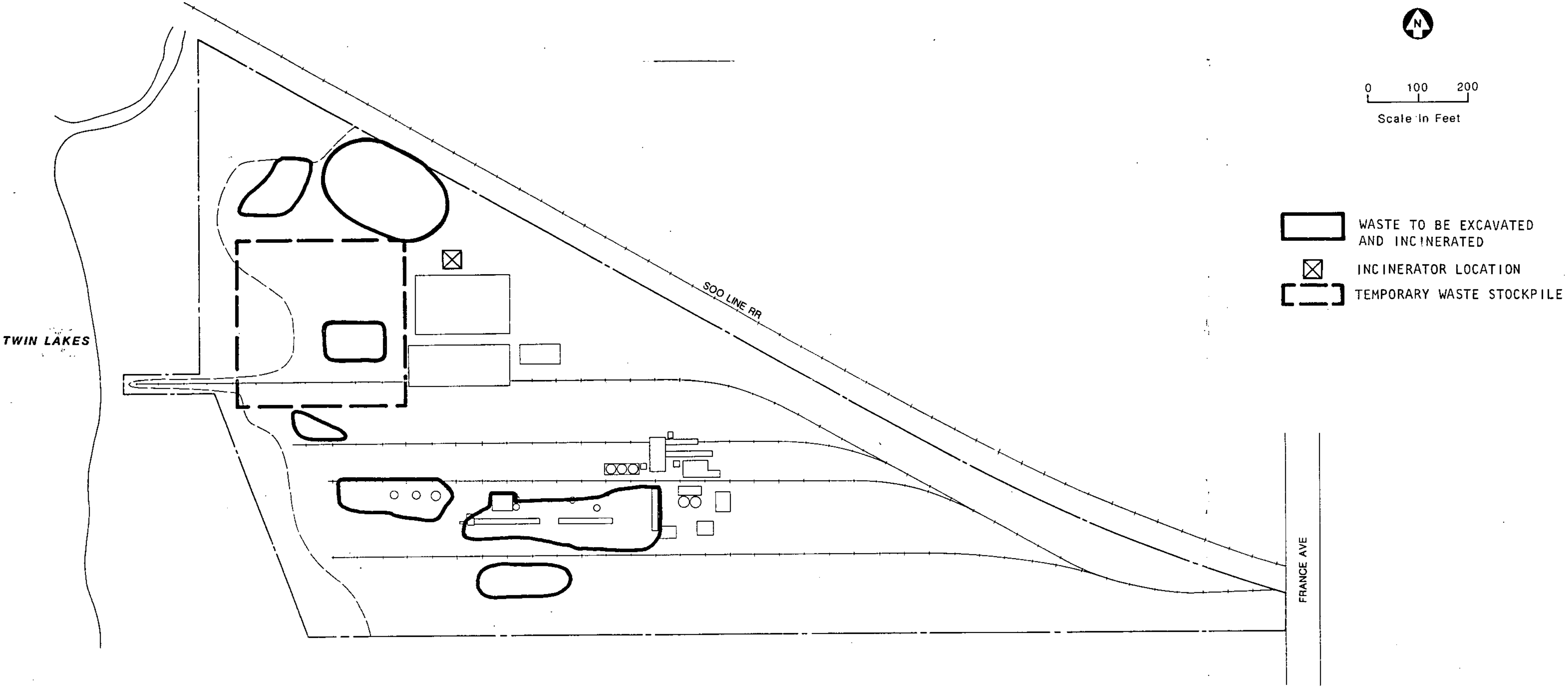


Figure 26

ALTERNATIVE I.D.
ON-SITE INCINERATION

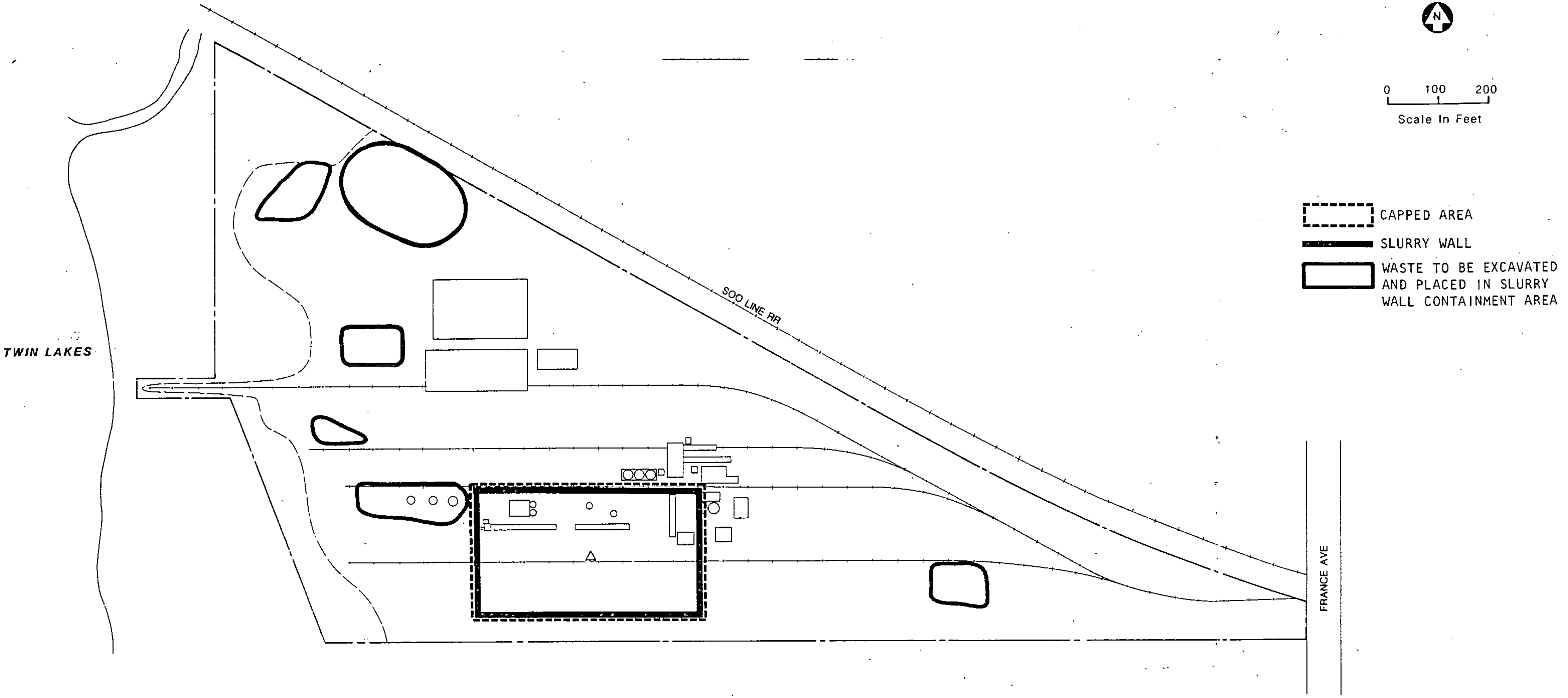


Figure 27
ALTERNATIVE II. A.
SLURRY WALL CONTAINMENT

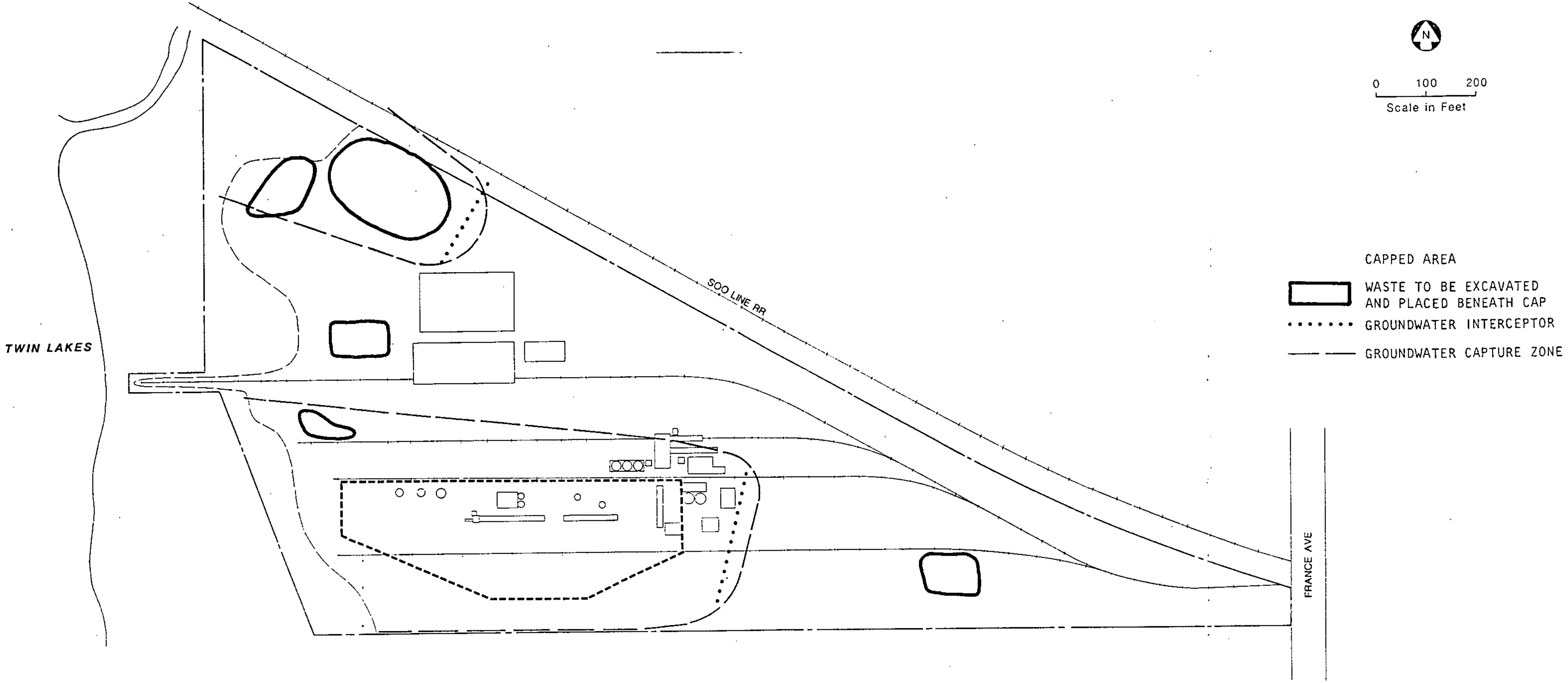


Figure 28

ALTERNATIVE II. B.
CAP AND SOURCE
GROUNDWATER PUMP-OUT

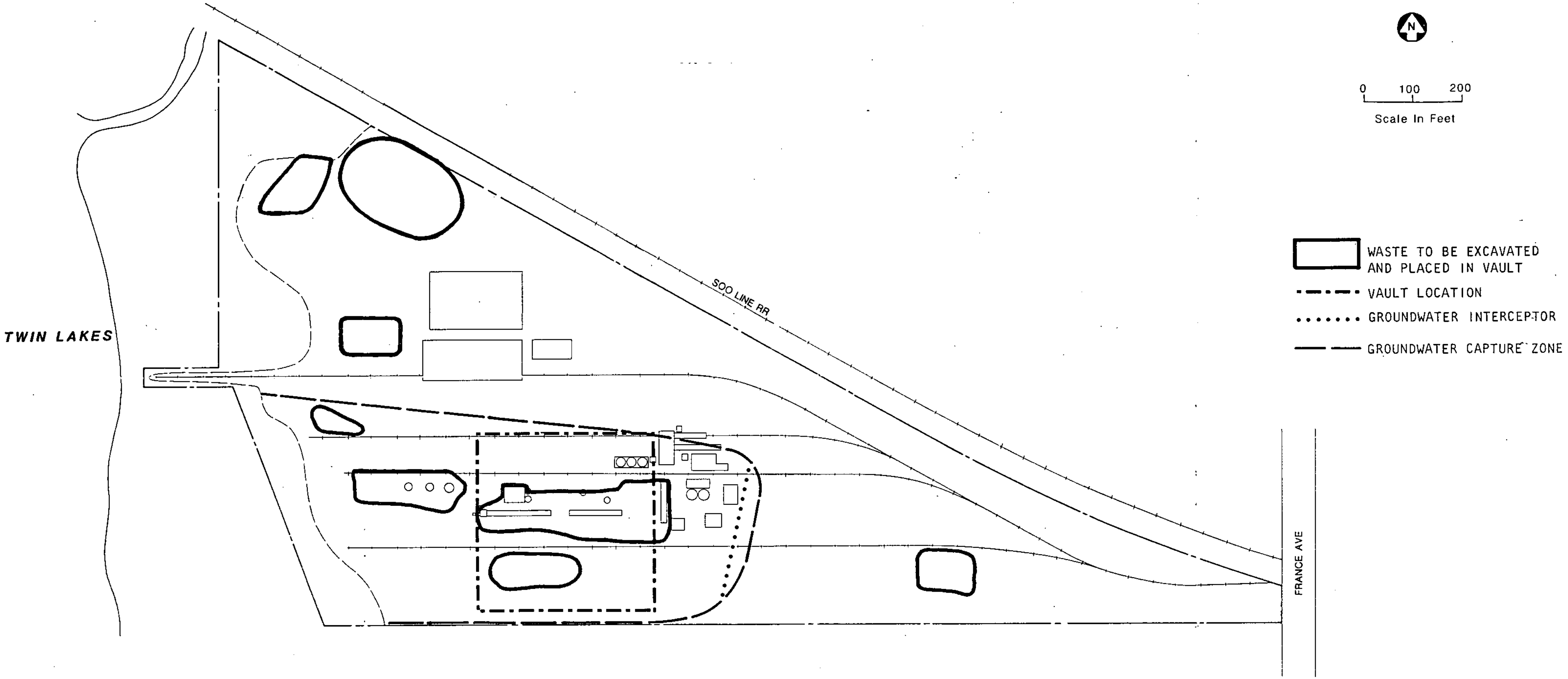


Figure 29

ALTERNATIVE II.C.
ON-SITE VAULT AND SOURCE
GROUNDWATER PUMP-OUT SYSTEM

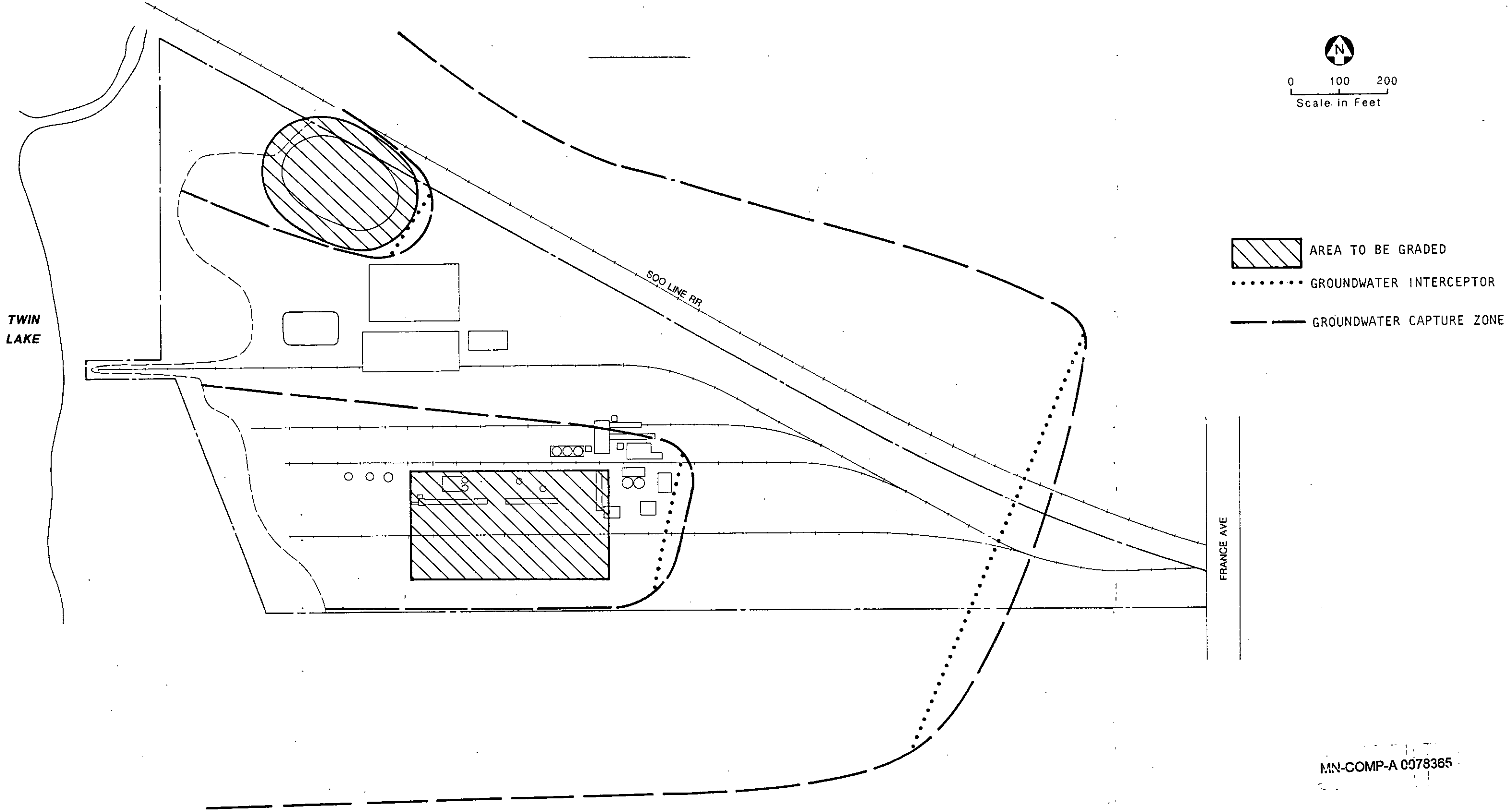


Figure 30

ALTERNATIVE III.A.
GROUNDWATER PLUME INTERCEPTION

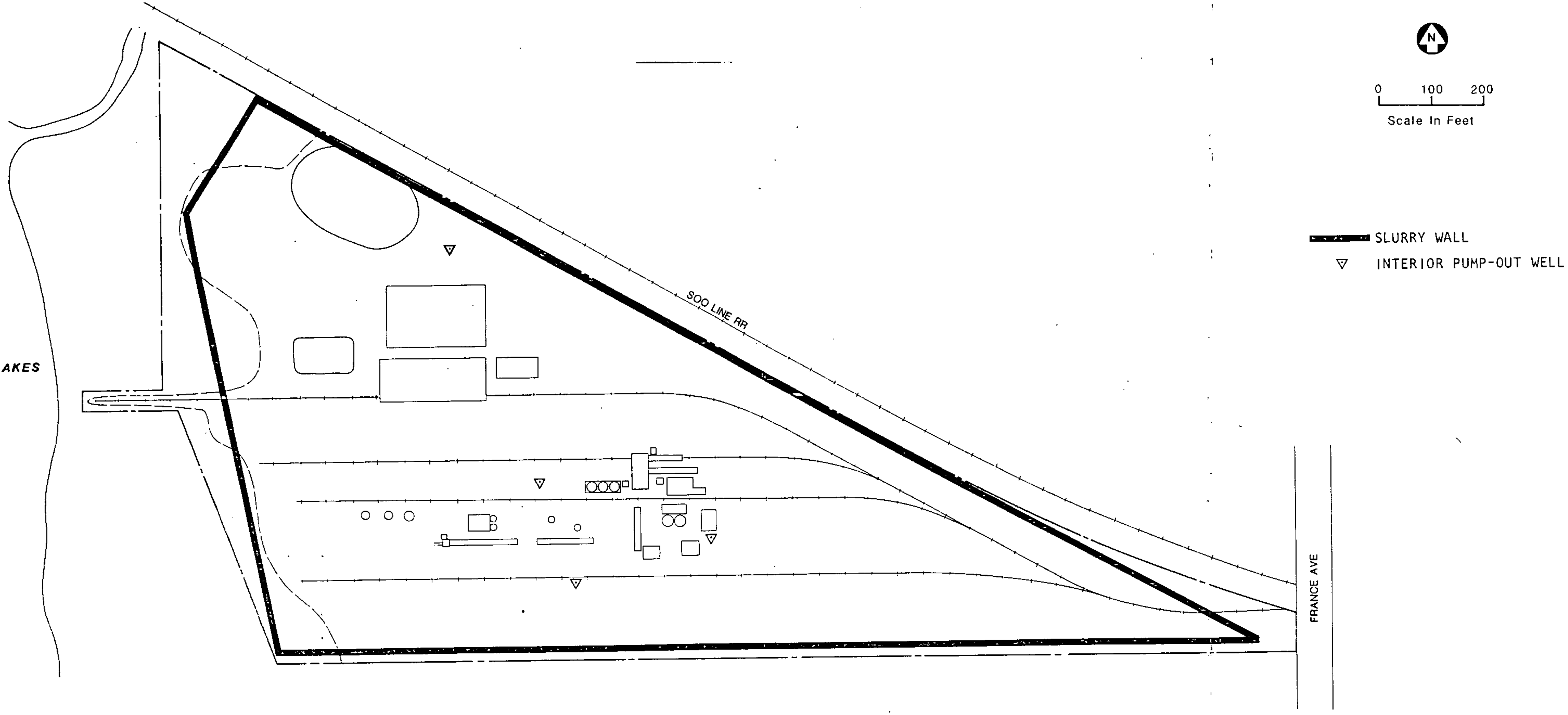
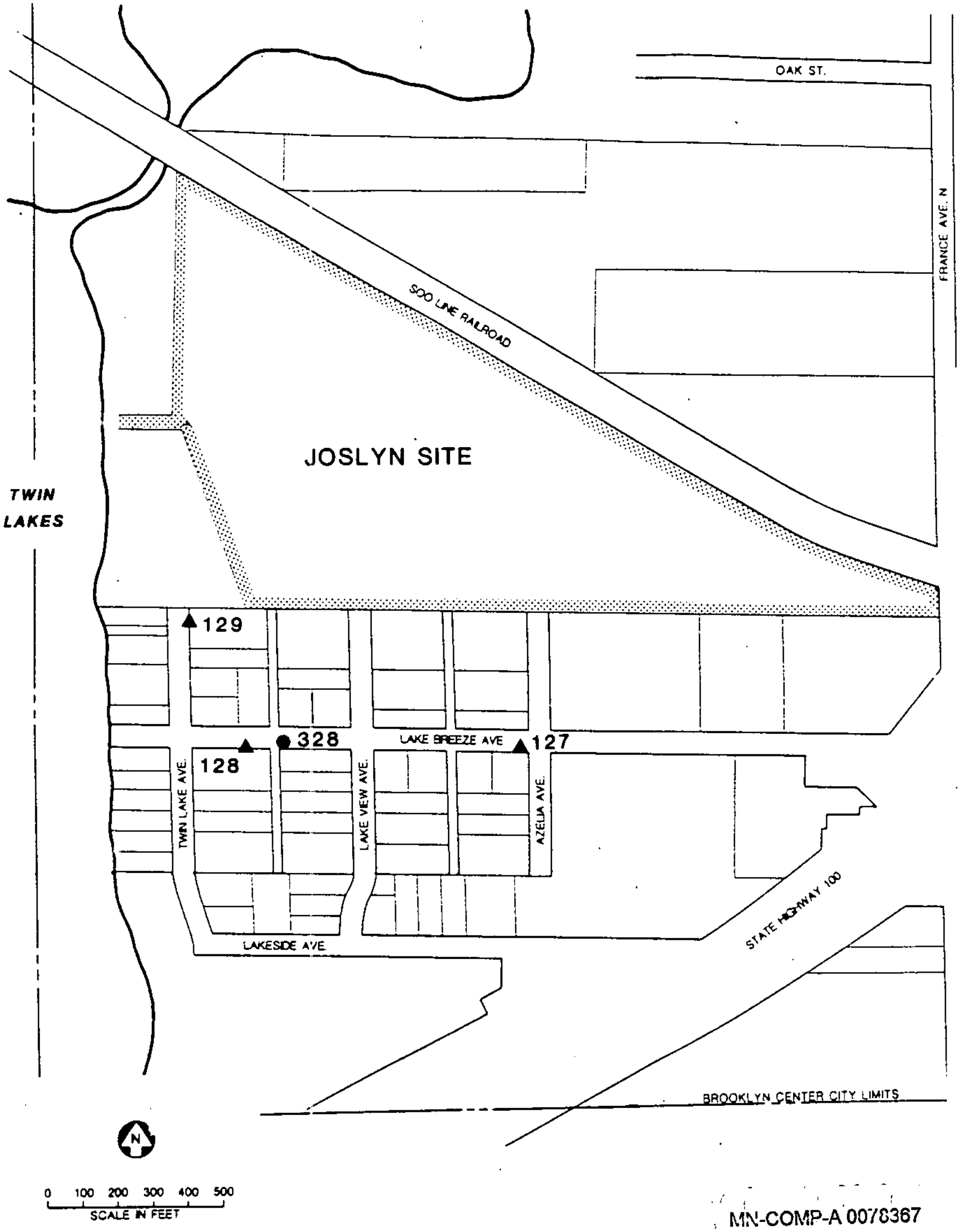


Figure 31

ALTERNATIVE III.B.
GROUNDWATER PLUME CONTAINMENT
WITH SLURRY WALL



▲ SHALLOW WELL

● LOWER AQUIFER WELL

Figure 32

RECOMMENDED ADDITIONAL MONITORING WELLS