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Site Name Sinclair Refinery

Site No. 902003

County Allegany

Town Wellsville

Foilable ____ (Yes) ____ No

File Name ____

Scanned & eDOC ____

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Basis Of Design Memorandum

For

The Sinclair Refinery
Operating Unit Two
Wellsville, New York

Prepared for:

ARCO
515 South Flower Street
Los Angeles, California 90071

Prepared by:

Remediation Technologies, Inc.
9 Pond Lane
Concord, Massachusetts 01742

Prepared by: ______________

Reviewed by: ______________

Project # 3-1077

March 1994

EXECUTIVE SUMMARY

The Sinclair Refinery Site is an 102-acre site located near Wellsville in Allegheny County, New York. The Site was named to the National Priority List (NPL) in 1983 after organic chemicals were detected in groundwater and surface water. For administrative purposes, the Site has been divided into separate areas, or operable units. Operable Unit 1 (OU1) includes a 10-acre portion of the Site where a landfilling operation for refinery wastes was conducted. Operable Unit 2 includes 90 acres where petroleum refining operations were undertaken at the Site. A Record of Decision (ROD) for the Site, signed in 1985, specified that ARCO would complete a Remedial Investigation (RI) and Feasibility Study (FS) for Operable Unit 2 (OU2).

The RI and FS were submitted in 1991, and EPA issued a proposed plan and ROD. The ROD specified remedies for surface soils, subsurface soils and groundwater at the Site. In September 1992, EPA issued an Administrative Order for Remedial Design and Remedial Action of OU2. In May 1993, ARCO submitted a Remedial Design Work Plan (RDWP) for OU2, which was approved by EPA with modifications in July 1993. The RDWP specified a series of site characterization and process evaluation activities leading to preparation of a remedial design for the Site. This Basis of Design Memorandum documents the first stage in the remedial design process.

Site Background

The Sinclair Refinery was built in 1901 for processing Pennsylvania grade crude oil. Products manufactured by the facility were made from New York and Pennsylvania crude oils, including crude from wells located several miles south of the refinery. Products manufactured included heavy oils and grease for lubrication, light oils for fuel, gasoline, lighter fluid, naphtha, and paraffin. During the early 1900's, operations at the Site were conducted by the Wellsville Refining Company. In 1919, the facility was purchased by the Sinclair Refining Company. The Sinclair Refining Company owned and operated the facility until 1958. Seven companies are currently using the Site in addition to the State University of New York, although much of the land is vacant. Ten private and government groups own parcels of land on the Site.

The RDWP identified specific chemicals of interest for impacted groundwater including the following:

- organic compounds associated with past refinery operations such as:

- benzene;
- ethylbenzene;
- toluene;
- xylenes; and
- and nitrobenzene.

- chlorinated organic compounds such as:
  - chlorobenzene;
  - 1,1-dichloroethane;
  - 1,1,2,2-tetrachloroethane;
  - trans1,2-dichloroethene;
  - 1,1,1-trichloroethane; and
  - trichloroethene.

Site characterization data gathering during the remedial design investigation was planned to update the evaluation of the distribution of these constituents in groundwater as well as in soil, a potential source of chemical impact to groundwater. The Remedial Design Investigation Report (RDIR) presents a complete discussion of the results of that investigation for both groundwater and soil.

Performance Criteria

Based on evaluations carried out in an Endangerment Assessment (Versar 1988), Feasibility Study (Ebasco 1990) and Record of Decision (USEPA 1991) chemical impacts on three media have been identified as posing potential risks to human health and the environment in OU2 at the Sinclair Refinery Site. These include surface soils, subsurface soils and groundwater. The remedial objectives for these three media provide the basis for the selection and design of remedial systems for the Site. These remedial objectives include the following:

- prevention of contact with lead and arsenic contained in surface soils;

- improvement of groundwater quality in the shallow aquifer at the Site;

- limitation of impacts to the surface water of the Genesee River caused by discharge of groundwater; and

- ensuring continued effectiveness of the remedy by evaluating changes in Site conditions and usage.

The Record of Decision (ROD) for OU2 of the Sinclair Refinery Site, signed September 30, 1991, presents the selected remedy for surface soil, subsurface soil and groundwater in the refinery portion of the site. The surface soil remedy specifies the excavation of an estimated 7700 cubic yards of surface soils with concentrations of lead or arsenic greater than cleanup goals, treatment of the excavated soils and on-site disposal. The "no-action" remedial alternative was selected for the remediation of subsurface soils at the site because no risk pathway presently exists for exposure to these soils. Although this remedy does not require any active remediation of soils at depths greater than two feet, it does require performance of specific activities.

The selected remedy for groundwater at the Site includes the extraction and treatment of groundwater from the shallow aquifer followed by discharge of the treated water. The goal of this treatment system is to achieve ARARs associated with the selected discharge alternatives. Provisions of this remedy include the following:

- extraction of impacted groundwater from the shallow aquifer;
- treatment in a system capable of meeting discharge requirements for the treated water;
- discharge of treated water directly to the Genesee River or to the local publicly owned treatment works;
- monitoring of surface water, groundwater, groundwater seeps and Genesee River biota; and
- recommendation of institutional controls in the form of local zoning ordinances.

EPA has established chemical-specific ARARs as the appropriate treatment standards for cleaning up groundwater and limiting the impact of groundwater on surface water. These include federal and state maximum contaminant levels (MCLs) for groundwater and New York State Ambient Water Quality Standards (AWQSs) for groundwater and surface water.

Current plans call for treated groundwater from the remediation to be discharged to the Genesee River. Proposed discharge criteria are presented for the remedial groundwater treatment system.

NYDEC Regulation 212 details the amount of emission control required for air emission sources. The amount of control is dependent on the toxicity of the compound. In addition to

NYDEC Regulation 212, the NYDEC Air Guide 1 establishes ambient concentrations for emitted compounds from a source. These ambient concentrations cannot be exceeded, even if the control technology meets the criteria of Regulation 212.

Design Criteria

During the air sparging component of the pilot study, the following parameters were monitored for the delineation of the Radius of Influence for individual air sparging wells: injection pressure, injection flow rate, monitoring well wellhead pressure, vapors in the treated offgas (by OVM and Dräger tubes), organic vapor concentrations in offgas prior to carbon treatment (measured by OVM, Dräger tubes, and laboratory GC analysis). Groundwater in the monitoring wells was monitored for water levels, dissolved oxygen, pH, and dissolved iron. The key principal parameters on which the ROI for the air sparging system is based in the dissolved oxygen (DO) measured in the monitoring wells.

Groundwater flow numerical modeling was conducted for the Site and adjacent areas. The purpose of the modeling is to evaluate and simulate the hydrogeologic system. The model functions as a predictive tool comparing groundwater remedial options as well as to aid in their design and to evaluate the understanding of the local and regional aquifer hydrodynamics. The flow modeling was conducted on the shallow, stratified sand and gravel deposits occurring within the valley of the Genesee River. Currently, a steady-state model has been constructed using MODFLOW, a modular, three-dimensional, finite-difference flow model to simulate groundwater flow conditions and to select the location, number, and pumping rates of wells. A separate model, MODPATH, which is a particle-tracking program is used to determine the capture zones of pumping wells.

Three sets of criteria related to the concentration and distribution of chemical constituents at the Site are relevant to the design of the groundwater treatment system at the Site including the following:

- the definition of areas at the Site where treatment will take place;
- the determination of the expected concentrations of constituents in the extracted water for design of the water treatment system; and
- the determination of vapor concentrations for design of the vapor treatment system associated with the air stripper.

Data gathered during the RI and the remedial design investigation indicate that there are two areas on-site where elevated groundwater BTEX concentrations are found at levels exceeding 1 ppm. In both of these areas, elevated soil BTEX concentrations were measured above and below the water table. These areas are designated the Northern Area, located in the area stretching from MW 73 on the National Fuels property to MW 69 near the former location of the northern oil/water separator, and the Southern Area, located in the area around MW 77 and MW 79. Treatment systems operating in these areas will be focused at the areas with the highest concentrations of dissolved (groundwater) constituents in the center of the mass, but will also provide for removal of these constituents in the source areas (soils above and below the water table). An additional area, designated the Central Area and located between the Northern and Southern Areas adjacent to the river, had groundwater BTEX concentrations in excess of 0.1 ppm. This area is also included as an area of concern. Estimates of the design concentrations of constituents of interest in discharge from groundwater and vapor extraction systems are presented.

Preliminary Design

The Record of Decision stipulates that a pump-and-treat system be used as a remedial component for the groundwater at the Site. In order to enhance the pump-and-treat and reduce the time required to remediate the Site, the preliminary design incorporates soil venting and groundwater aeration in combination with conventional pump-and-treat to enhance contaminant removal and expedite remediation focusing aggressive treatment not only on the dissolved constituents, but also treating the source of these constituents to groundwater.

The Site has been divided into three primary areas designated the Northern, Central and Southern Areas. The Northern Area is the focus for the pump-and-treat technology given the proximity of the plume of impacted groundwater to the Genesee River. In addition, enhanced recovery of organics via soil venting and groundwater aeration will be employed to remove benzene from an area with elevated concentrations in the western edge of this area. In the Southern Area, soil venting and groundwater aeration will be used to strip the volatile organics *in situ* in this area from both groundwater and soils. In the Central Area, soil venting and groundwater aeration will be used to treat groundwater.

Pumped groundwater will be pretreated as required to protect the aqueous volatile organic treatment processes. The aqueous volatile organic treatment processes include air stripping followed by granular activated carbon treatment. The vapor phase chemicals-of-interest separated by the air stripper will be combined with the vapors collected by the Northern and

Central Area soil venting systems and sent to a thermal oxidizer for final destruction. The volatile organic compounds stripped in the subsurface by the Southern Area groundwater aeration system and collected by the Southern Area soil venting system will be sent to a second independent regenerative thermal oxidizer for final destruction.

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1.0 INTRODUCTION

1.1 Site Description

The Sinclair Refinery Site is an 102-acre site located near Wellsville in Allegheny County, New York. Figure 1-1 shows a location map for the Site. The Site was named to the National Priority List (NPL) in 1983 after organic chemicals were detected in groundwater and surface water. For administrative purposes, the Site has been divided into separate areas, or operable units. Operable Unit 1 (OU1) includes a 10-acre portion of the site where a landfilling operation for refinery wastes was conducted. A Record of Decision (ROD) for the Site, signed in 1985, specified a remedy for OU1 which included channelization of the Genesee River, excavation of refinery wastes and capping of the former landfill area. A Consent Decree, signed in 1988, specified that ARCO would complete the design and construction of these remedial actions. Construction of the OU1 remedy is currently ongoing and is scheduled to be completed in 1993.

The 1985 ROD also specified that ARCO would complete a Remedial Investigation (RI) and Feasibility Study (FS) for Operable Unit 2 (OU2). Operable Unit 2 includes 90 acres where petroleum refining operations were undertaken at the Site. The RI and FS were submitted in 1991, and EPA issued a proposed plan and ROD. The ROD specified remedies for surface soils, subsurface soils and groundwater at the Site. In September 1992, EPA issued an Administrative Order for Remedial Design and Remedial Action of OU2.

In May 1993, ARCO submitted a Remedial Design Work Plan (RDWP) for OU2 (RETEC, 1993a) which was approved by EPA with modifications in July 1993. The RDWP specified a series of site characterization and process evaluation activities leading to preparation of a remedial design for the Site. Performance of the data gathering activities is documented in the Draft Remedial Design Investigation Report (RETEC, 1993c). This Basis of Design Memorandum and documents the first stage, 35% design, in the remedial design process.

1.2 Report Organization

Section 2.0 of this report presents a brief summary of conditions at the Site as determined by past investigations including site characterization activities which took place as part of the remedial design investigation. A complete report of these activities can be found in the

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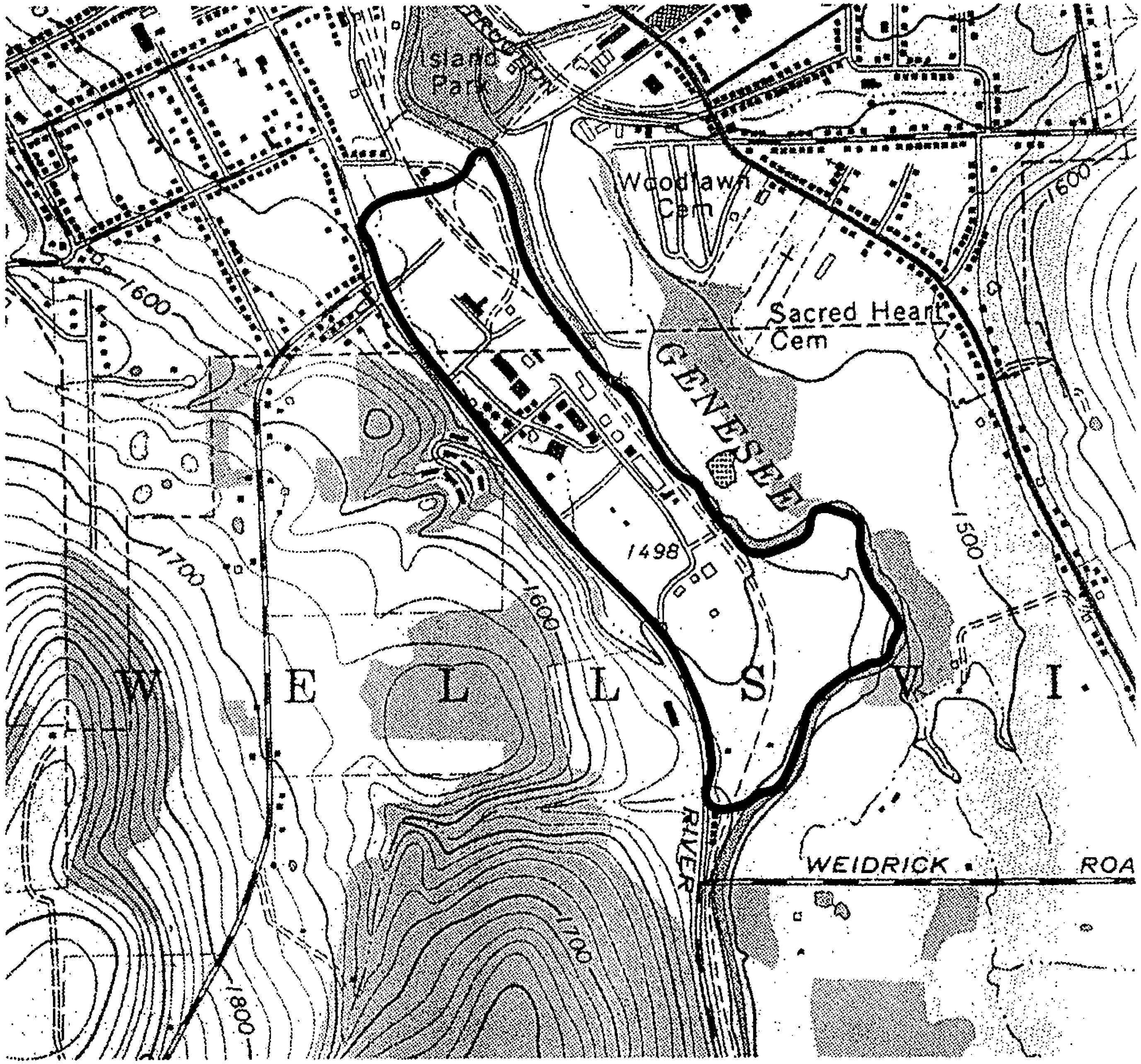

SITE LOCATION

FIGURE 1-1

RDIR. Section 3.0 presents performance criteria for the design, including regulatory and other requirements by which the success and effectiveness of the remedy will be measured. Section 4.0 presents design criteria, including physical, chemical, or engineering parameters which determine the size and configuration of design components. Section 5.0 presents a summary and component-by-component description of the remedial design for groundwater in Operable Unit 2.

2.0 SITE BACKGROUND AND HISTORY

2.1 Site History and Usage

The Sinclair Refinery was built in 1901 for processing Pennsylvania grade crude oil. Products manufactured by the facility were made from New York and Pennsylvania crude oils, including crude from wells located several miles south of the refinery. Products manufactured included heavy oils and grease for lubrication, light oils for fuel, gasoline, lighter fluid, naphtha, and paraffin. During the early 1900's, operations at the Site were conducted by the Wellsville Refining Company. In 1919, the facility was purchased by the Sinclair Refining Company. The Sinclair Refining Company owned and operated the facility until 1958. In 1939 and 1958, two large fires occurred at the refinery, causing substantial damage. The 1958 fire was a contributing factor to the decision to close the refinery. When the refinery closed, the Sinclair Refining Company transferred a majority of the property to the Village of Wellsville. The remaining property was turned over to the New York Refinery Project. Significant site features are shown in Figure 2-1.

Although most of the structures were removed by 1964, some of the original structures remain. Several refinery buildings and the storm water sewers are still in place. The remaining powerhouse is undergoing decontamination and decommissioning as part of the same action. Some of the refinery buildings were renovated by tenants of the existing industrial park and college campus, while others remain vacant. After the refinery closed, new oil and gas storage tanks were constructed by subsequent site users. This Post-Refinery Tank Farm was operated by ARCO, then the British Petroleum Company, then the United Refinery Company, and was ultimately dismantled in 1972. The Post-Refinery Tank Farm property was subsequently transferred to the State University of New York.

A portion of the Site along the Genesee River included a right-of-way for the Wellsville, Addison, and Galeton railroad line. Several railroad spurs were also present on the Site. The former railroad line is now used as a dirt road, and virtually all of the railroad ties have been removed from the site.

Seven companies are currently using the Site in addition to the State University of New York, although much of the land is vacant. Ten private and government groups own parcels of land on the Site. The businesses operating at the Site include:

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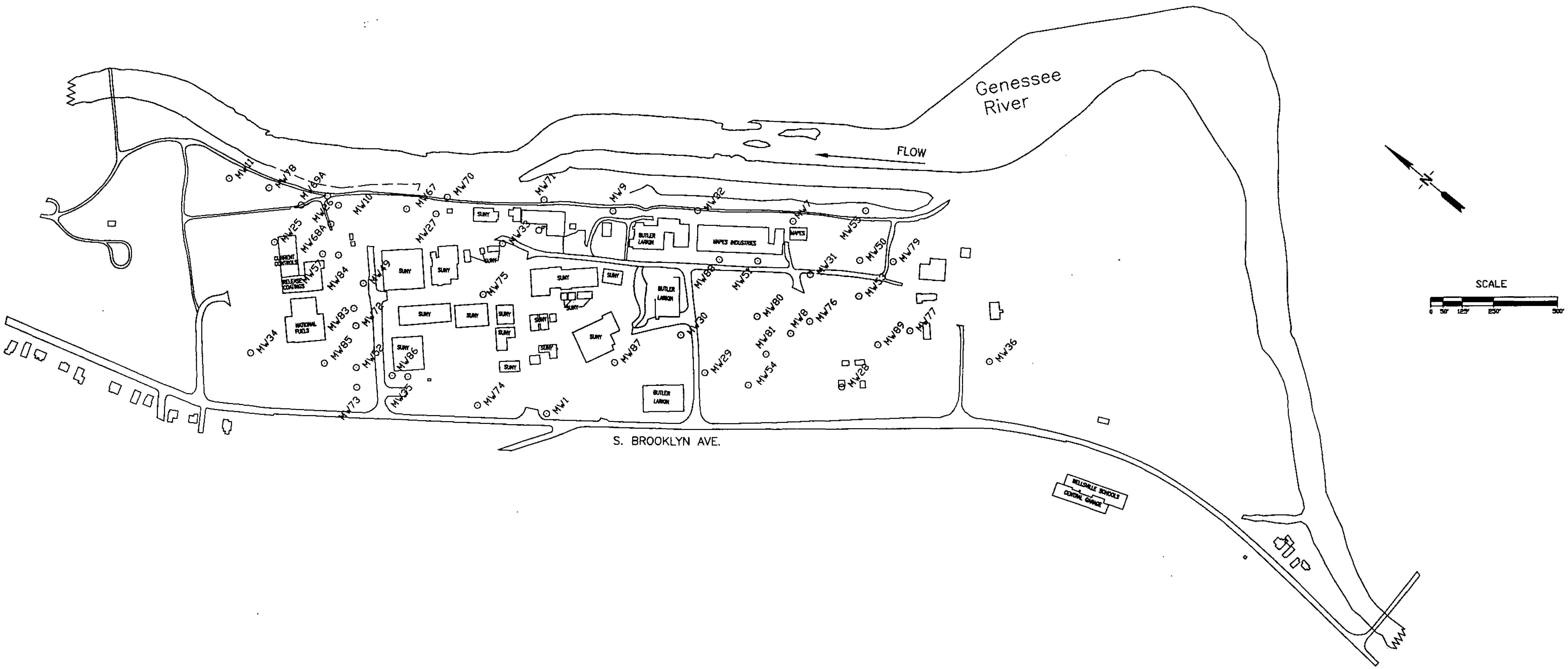

FIGURE 2-1

Site Layout

1077s002

- Butler-Larkin Company, Inc.;
- Current Controls, Inc.;
- Mapes Industries, Inc.;
- National Fuel Company, Inc.;
- Otis Eastern Service, Inc.;
- Release Coatings, Inc.; and
- Niagara Mohawk.

The former oil/water separator located on the north side of the Site near the river was decontaminated as part of an interim remedial measure completed in 1993.

Butler-Larkin Company, Inc. manufactures drilling and completion equipment for oil, gas, and water wells, and has its manufacturing facilities at the Site. They also maintain a large storage area in the central portion of the Site. Current Controls, Inc. manufactures small electrical transformers and other electronic control devices at the Site. Mapes Industries, Inc. manufactures toy chests, cribs, and other finished wood products. National Fuel Company, Inc. is the local natural gas supplier, with both its customer service and vehicular maintenance facilities located at the Site. Otis Eastern Service, Inc. is a drilling and gas pipeline construction company. Its main offices and a construction equipment storage area are located at the Site. Release Coatings, Inc. is a manufacturer of a material used to facilitate the extraction of molded products from their molds. Niagara Mohawk is an electric utility that maintains high voltage electrical transmission lines across the Site.

The State University of New York (SUNY) at Alfred campus is located in the central portion of the Site. SUNY is an agricultural and technical college that has shops for automobile repair located on site.

2.2 Site Characterization

2.2.1 Hydrogeology

The Sinclair Refinery is situated in a low terrace position along the Genesee River in western New York. The hydrogeology of the Site is controlled by the Genesee River to the northeast and an abrupt transition to an eroded upland to the southwest. The Site is relatively flat with elevation increasing steeply as the upland is encountered. Annual precipitation is approximately 37 inches evenly distributed throughout the year. Daily air temperatures dip below 32°F an average of 147 days per year.

Stratigraphy

Sediments beneath the Site reflect the heterogeneity associated with fluvial deposits. The general components of the fluvial system include a shallow upper aquifer, an aquitard, and a confined, artesian lower aquifer. The sediments comprising the shallow aquifer are fluvial in nature and range from 10 feet to greater than 50 feet in depth across the Site. The natural emplacement of different textured sediments is a reflection of the evolution of the meandering Genesee River. Channel deposits contain well-sorted sands and gravels. Lower-energy deposition areas contain deposits of sands, silts, and low-plasticity clays. The resulting sediments are generally coarse in texture, but have finer textured lenses that are horizontally continuous for hundreds of feet. Fill materials were encountered primarily in the central portion of the Site as deep as 8 feet. The fill material is predominantly borrow soil mixed with slag and construction debris placed at the Site for grading purposes,

The base of the shallow aquifer is defined by a low-permeability glaciolacustrine clay layer. The surface of the glaciolacustrine clay layer reflects the erosional forces of the Genesee River. Channels cut into the clay layer appear to be deepest in the northwestern portion of the Site. The clay layer appears to be continuous and of low permeability, based on the artesian nature of the underlying aquifer. Figure 2-2 shows the locations of representative cross sections and the monitoring wells and borings used to draw them. The cross sections are presented in Figures 2-3, 2-4, 2-5 and 2-6.

The lower aquifer occurs at depths greater than 70 to 100 feet beneath the ground surface and was reached by only a few borings during past investigations. The lower aquifer materials are glacial sands and gravels that appear to be inter-bedded with glacial clays. The artesian nature of the lower aquifer indicates communication between the uplands and the aquifer. Constituents from the Site have not penetrated into the lower aquifer based on groundwater analytical data.

Hydraulic Gradients

Potentiometric surface maps of the water table in the upper aquifer based on data collected in July and September 1993 are presented in Figures 2-7 and 2-8. Equipotential lines run roughly parallel to the Genesee River. Groundwater flow in the upper aquifer is towards the river from southwest to northeast. Based on the potentiometric surface map, horizontal flow gradients range from 0.016 ft/ft in the northern portion of the Site to 0.0006 ft/ft in the central

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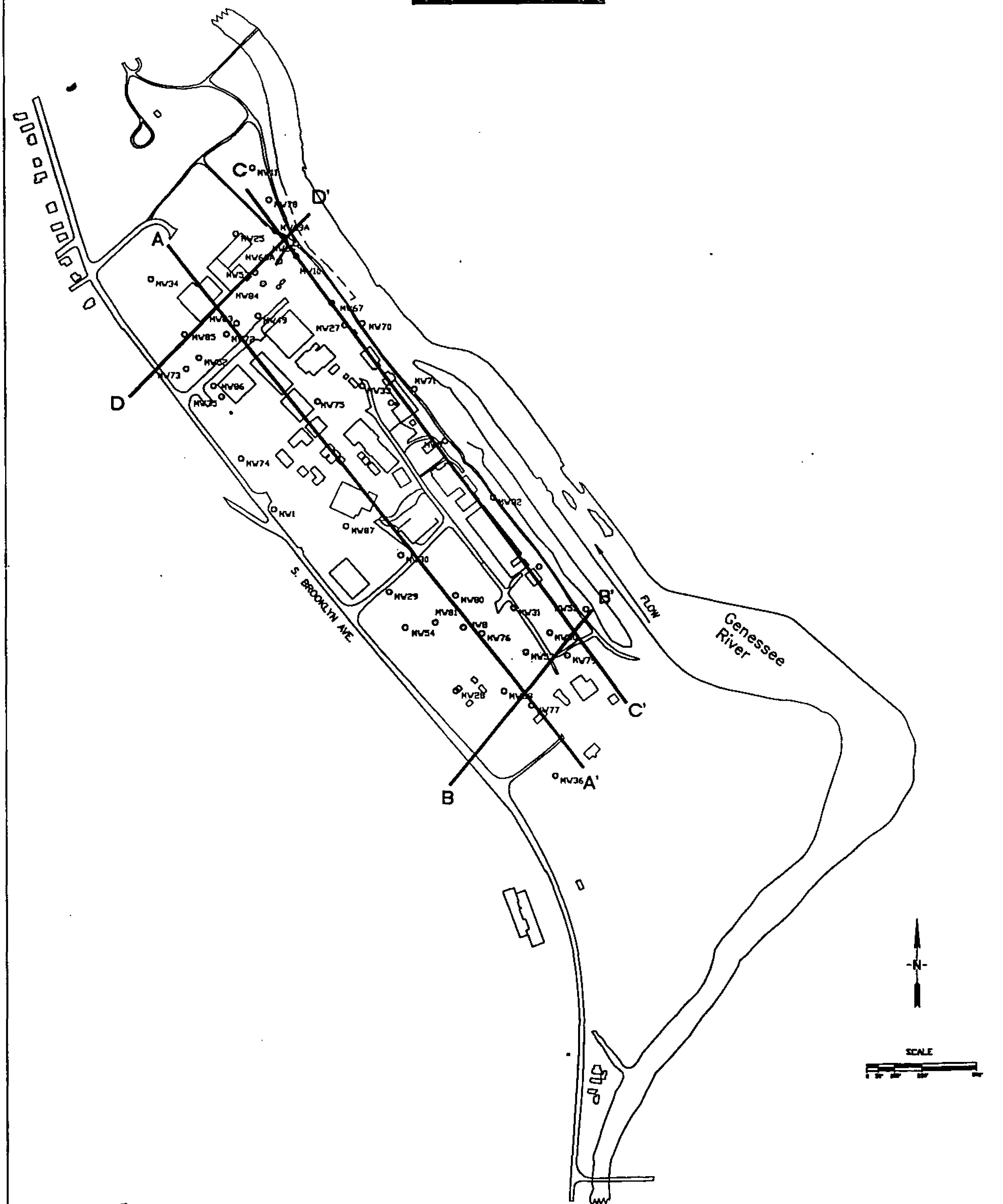

Site Cross-Section Locations

FIGURE 2-2

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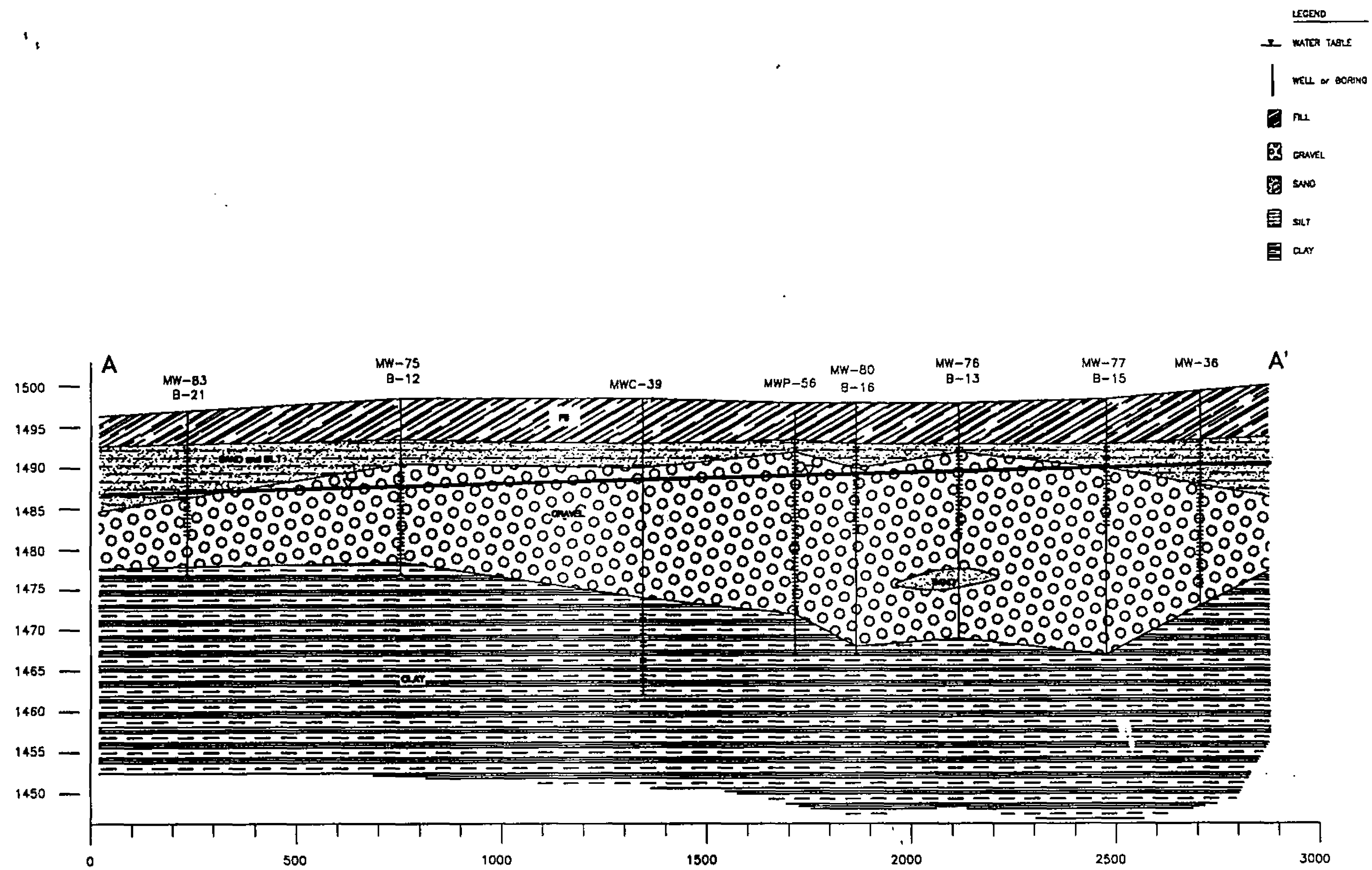

Cross Section A - A'

FIGURE
2-3
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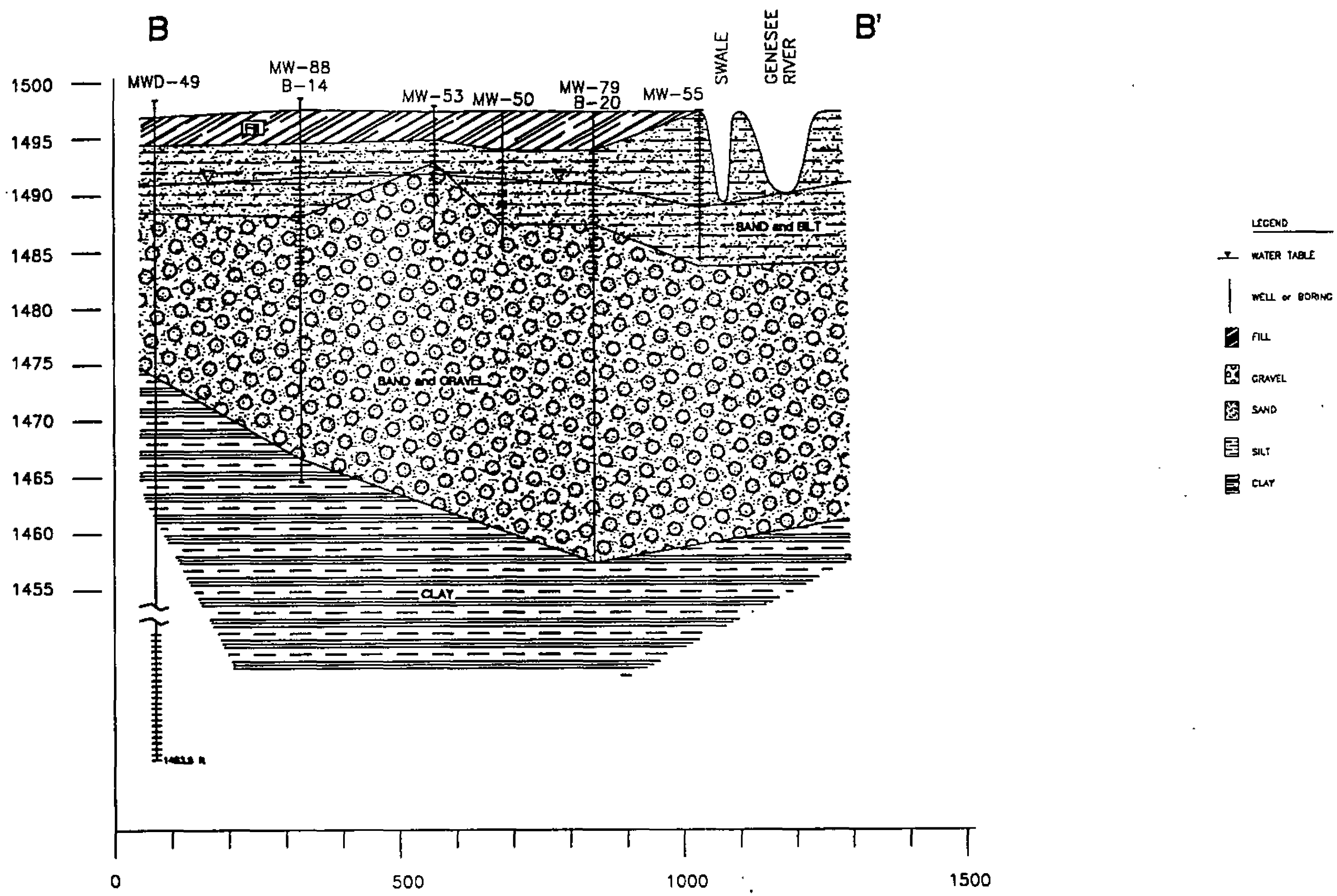

Cross Section B - B'

FIGURE 2-4

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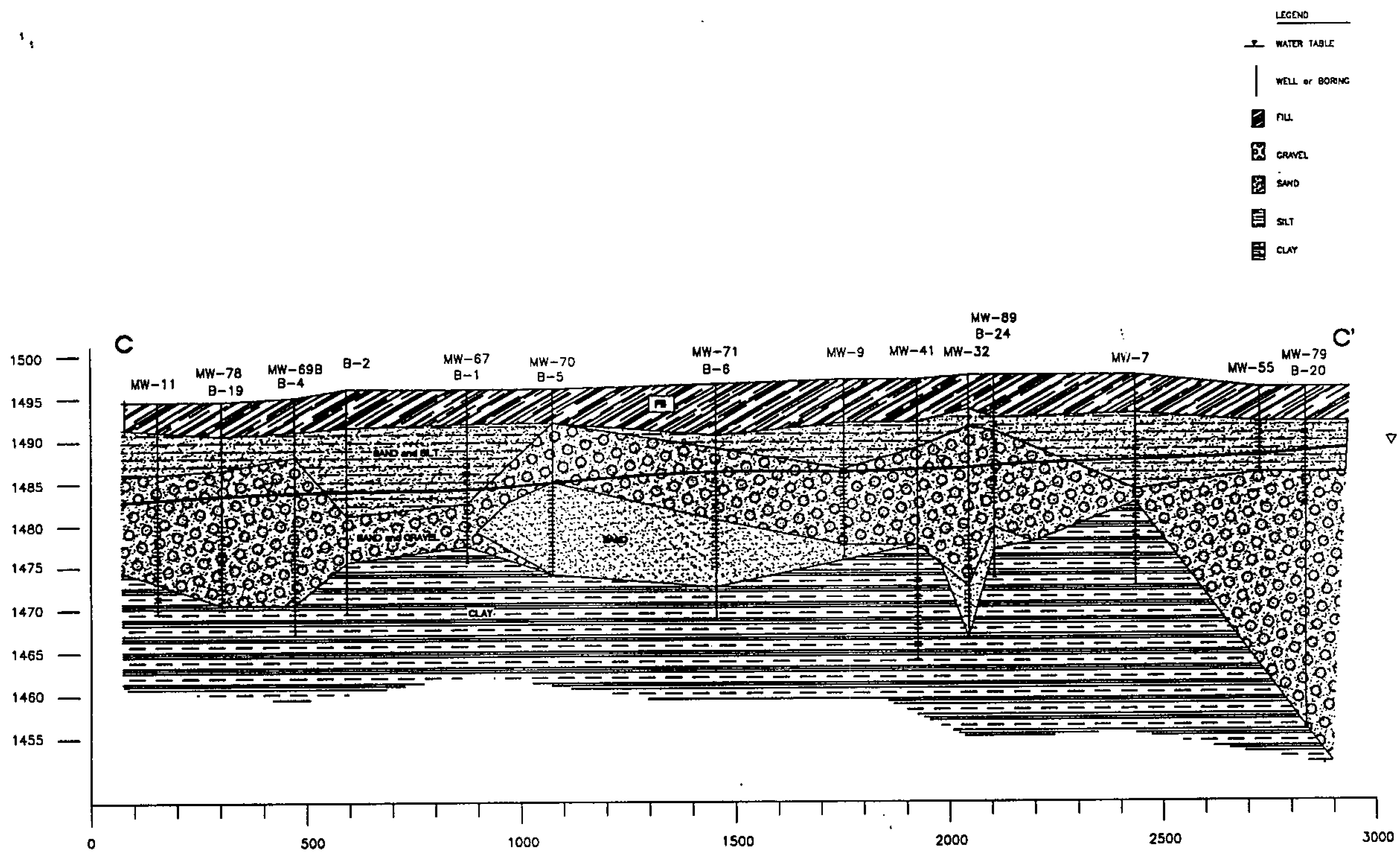

Cross Section C - C'

FIGURE 2-5

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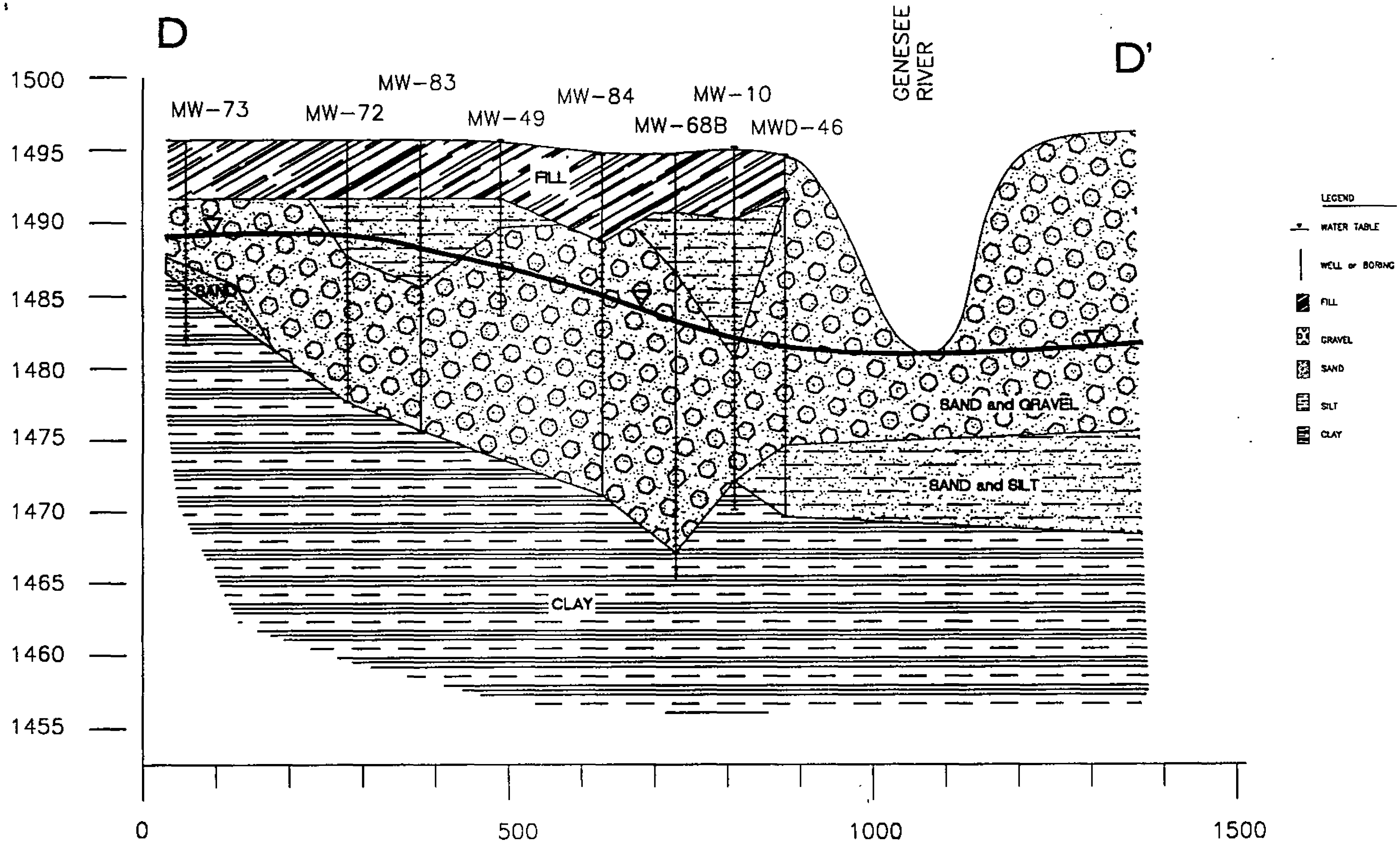

Cross Section D - D'

FIGURE 2-6

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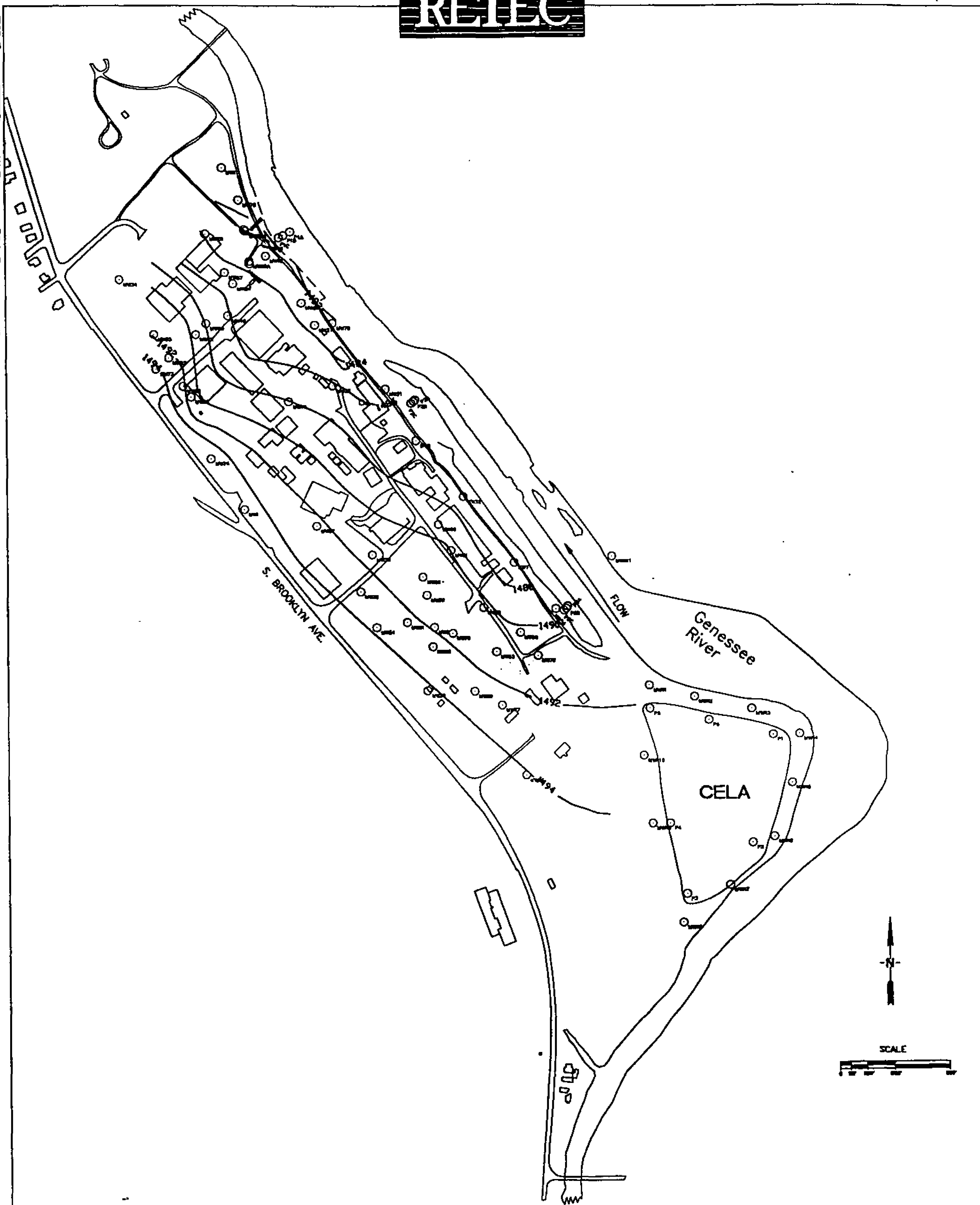

July 1993 Groundwater Contours

FIGURE
2-7
1077s002

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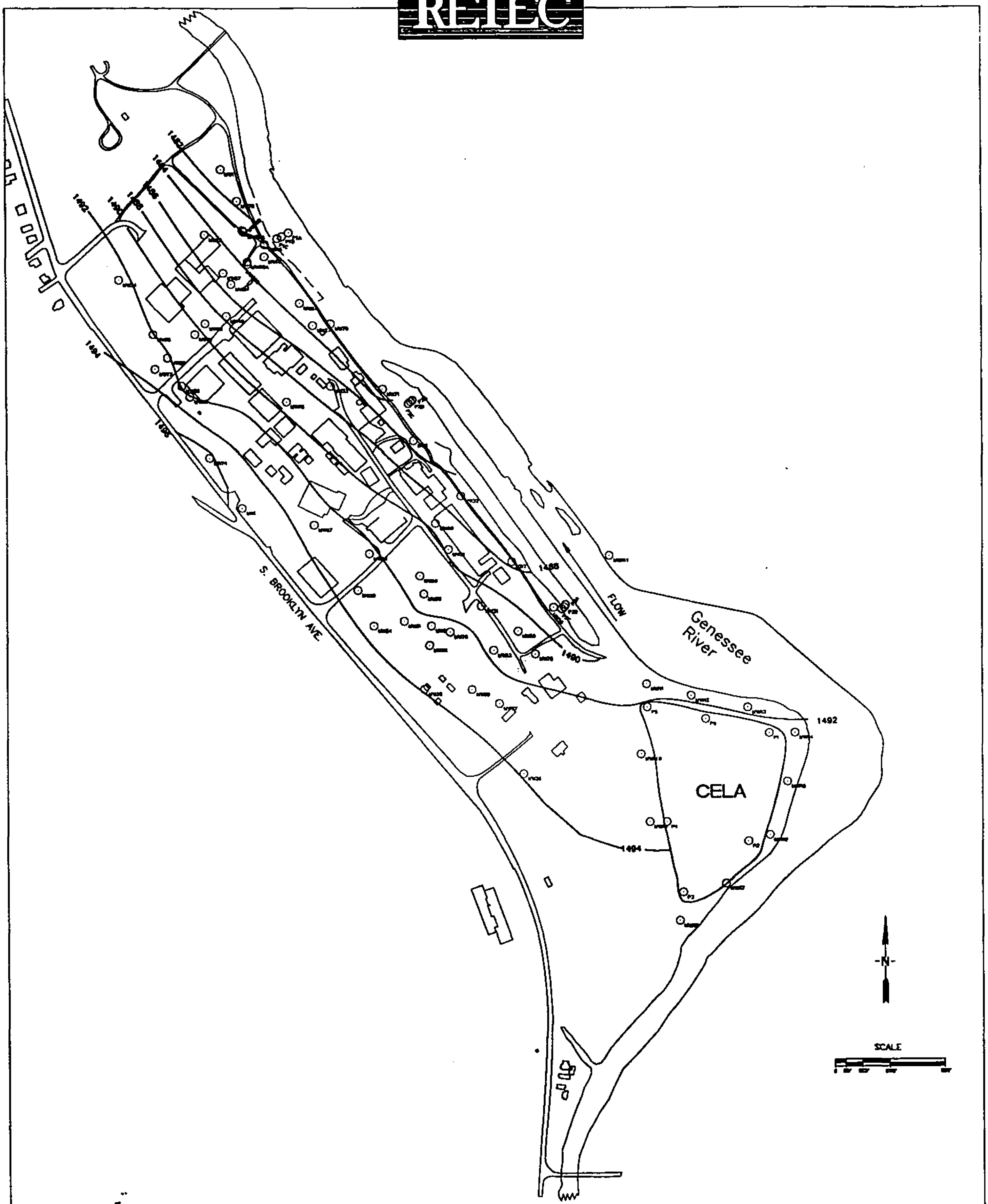

September 1993 Groundwater Contours

FIGURE
2-8
1077s002

area. Based on water levels measured in deep monitoring wells, it appears that flow in the deep aquifer is also towards the river.

Vertical flow gradients were determined by comparing hydraulic head in deep monitoring wells with hydraulic head in nearby shallow monitoring wells. The difference between lower and upper aquifer heads ranged from 9.1 to 14.0 feet. In all cases, the lower aquifer wells had higher water level elevations, indicating an upward, vertical hydraulic gradient. Estimated vertical hydraulic gradients ranged from 0.017 to 1.4 ft/ft.

<u>Hydraulic Conductivities</u>

During the RI, two pumping tests and 20 slug tests were conducted in the upper aquifer at the Site. Calculated hydraulic conductivities ranged from 5 to 245 ft/day. Based on the results of the pumping tests, the soils in the central area of the Site are generally more permeable than those to the north. Pumping tests in the central area yielded a range of calculated hydraulic conductivities from 56 to 245 ft/day. A pumping test was also conducted in the northern area of the Site as part of the RI. Calculated hydraulic conductivities ranged from 5 to 62 ft/day, with an average of 26 ft/day. Calculated hydraulic conductivities from slug tests performed during the RI ranged from 6.7 to 69 ft/day.

<u>Groundwater Flow Rate and Velocity</u>

Groundwater flow rates in the upper aquifer ranging from 8,800 to 388,000 gal/day were estimated during the RI across the central portion of the Site. The best estimate of discharge to the Genesee River was 186,000 gal/day. A value of 0.25 for effective porosity was estimated for the upper aquifer. The average calculated velocity across the Site was 1.5 ft/day in the north, and 2.8 ft/day in the central area. The calculated time for groundwater to travel the width of the Site ranged from two years in the northern portion to one year in the central and southern portions of the Site.

2.2.2 Site Chemical Constituents

The RDWP identified specific chemicals of interest for impacted groundwater including the following:

- organic compounds associated with past refinery operations such as:

- benzene;
- ethylbenzene;
- toluene;
- xylenes; and
- and nitrobenzene.

- chlorinated organic compounds such as:
  - chlorobenzene;
  - 1,1-dichloroethane;
  - 1,1,2,2-tetrachloroethane;
  - trans 1,2-dichloroethene;
  - 1,1,1-trichloroethane; and
  - trichloroethene.

Data gathered during the RI and summarized in the RDWP indicated that the highest groundwater concentrations of non-chlorinated organic compounds are found in three relatively limited areas on the site. These areas characterized by elevated concentrations of total benzene, toluene, ethylbenzene, and xylenes (BTEX) are located near the northern oil/water separator and monitoring well MW-52 in the northern part of the site, and around monitoring well MW-53 in the central area of the site.

Data from RI also indicated that chlorinated volatile organic compounds are found in two isolated areas at the Site centered on the Northern oil-water separator and wells MW-50/MW-53. Nitrobenzene was encountered in groundwater in a single small area near MW-27. Areas of elevated arsenic concentrations correspond generally to those areas where BTEX concentrations are also elevated.

Site characterization data gathering during the remedial design investigation was planned to update the evaluation of the distribution of these constituents in groundwater as well as in soil, a potential source of chemical impact to groundwater. The RDIR presents a complete discussion of the results of that investigation for both groundwater and soil. Table 2-1 presents a statistical summary of groundwater analytical results for COI based on data from the July 1993 sampling event. This summary shows that benzene, toluene, ethylbenzene, and xylenes are the most commonly found and widely distributed organic compounds in groundwater. Other constituents are less widely distributed and less common.

Figures 2-9, and 2-10 are site maps showing groundwater concentration contours for benzene, and the sum of benzene, toluene, ethylbenzene and xylenes (BTEX) based on data gathered during the July 1993 groundwater sampling event at the Site. Figures 2-11 and 2-12

Table 2-1
July 1993 Groundwater Analytical Statistical Summary
Concentrations in μg/L

	Total No. of Samples	No. Samples Above Det. Limit	Max. Value	Min. Value	Arith. Mean	Geom. Mean	Median Value
Benzene	46	35	1500	ND	168	50	88
Toluene	46	35	730	1	55	18	21
Ethylbenzene	46	34	580	1	99	31	36
Xylene	46	37	3200	8	436	111	170
Nitrobenzene	10	4	5300	6	531	21	ND
Chlorobenzene	44	0	ND	ND	ND	ND	ND
1,1-Dichloroethane	44	12	38	ND	22	8	ND
1,1,2,2-Tetrachloroethane	44	0	ND	ND	ND	ND	ND
1,2-Dichloroethene	44	7	6900	ND	417	11	ND
1,1,1-Trichloroethane	44	5	1000	ND	54	9	ND
Trichloroethene	44	0	ND	ND	ND	ND	ND
Arsenic (Total)	52	49	253	ND	70	62	72

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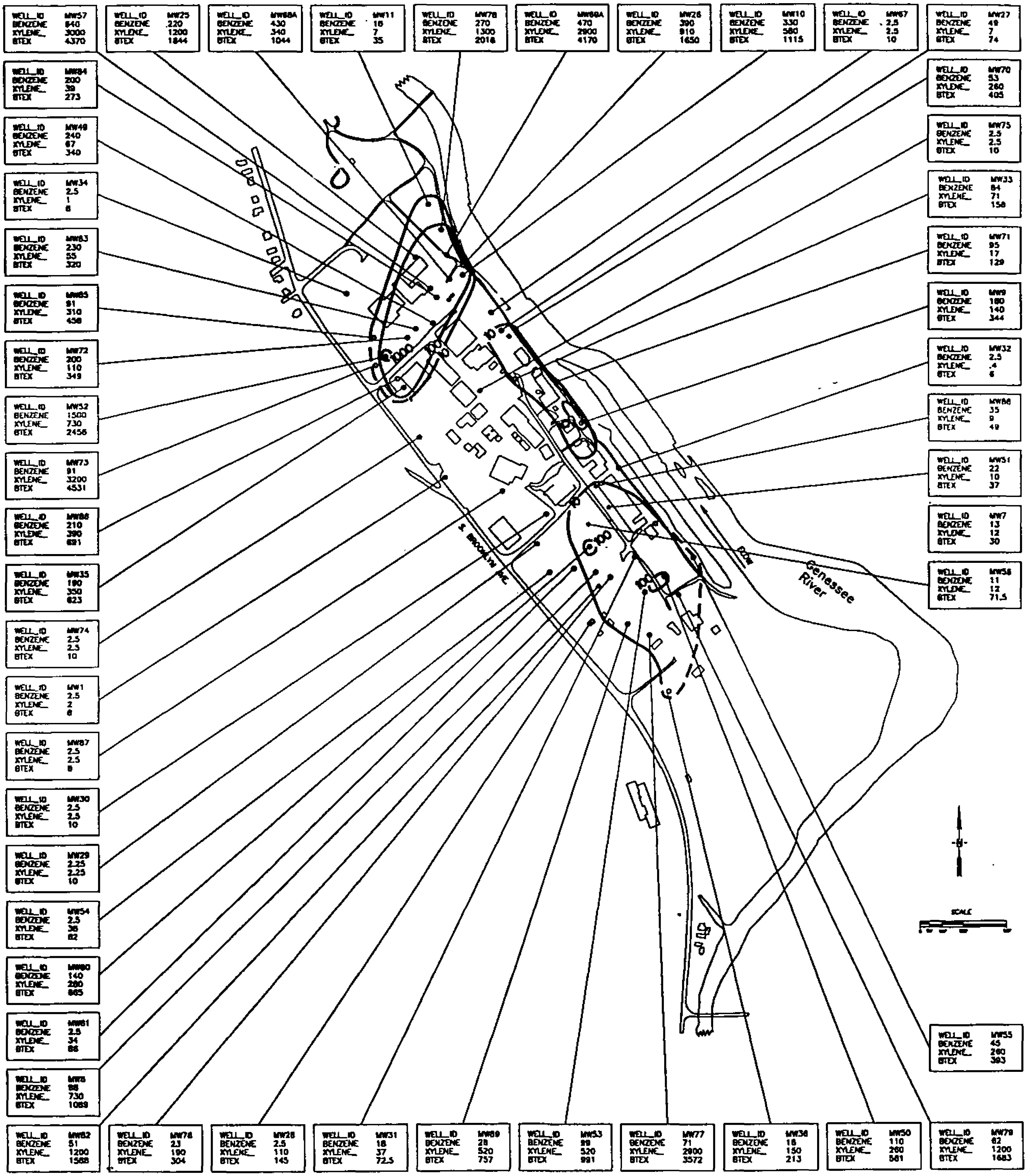

Benzene Contours in Groundwater (ug/L)

FIGURE 2-9

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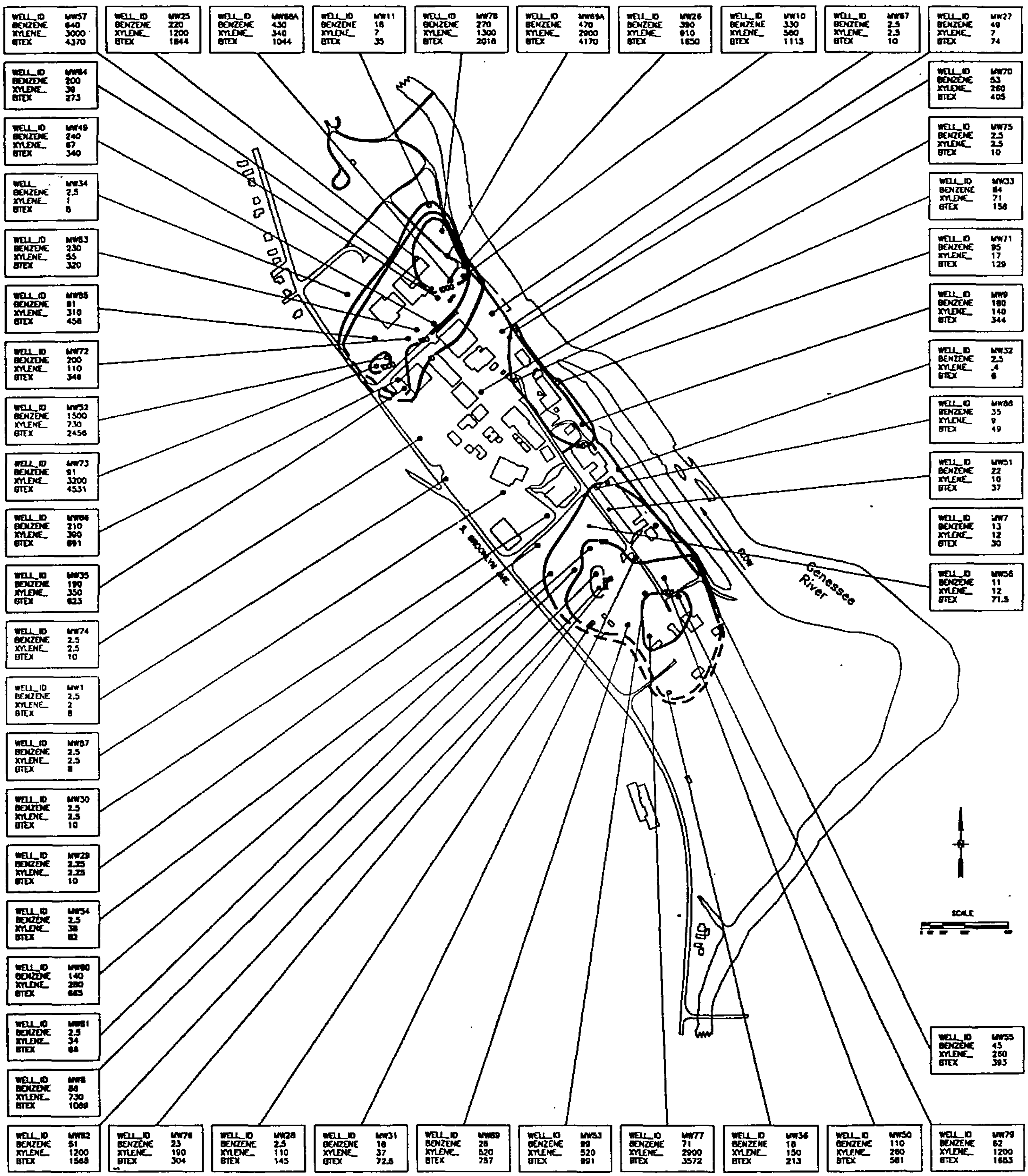

BTEX Contours in Groundwater (ug/L)

FIGURE 2-10

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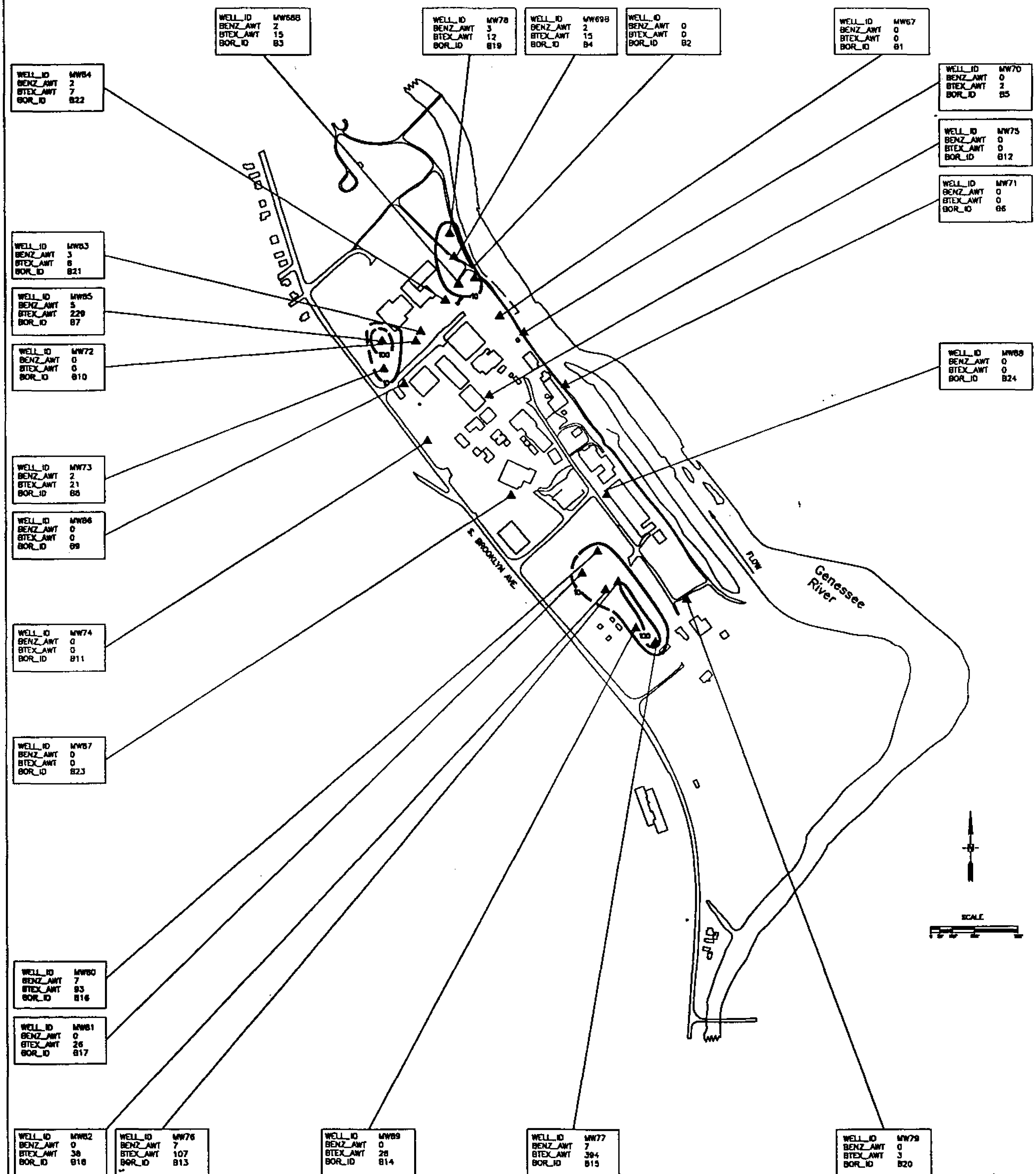

BTEX Contours in Soil
Above the Water Table (mg/Kg)

FIGURE
2-11
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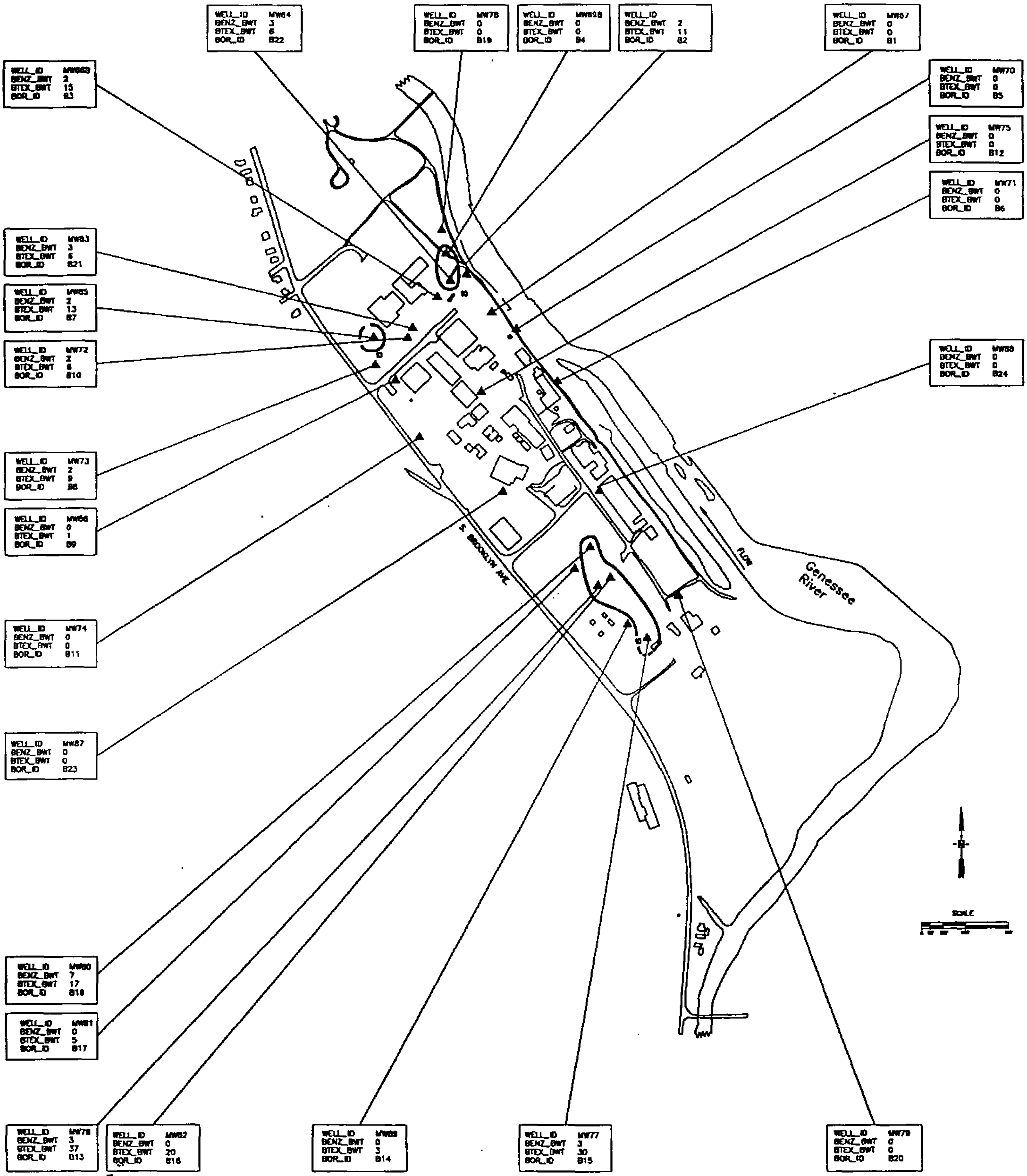


BTEX Contours in Soil
Below the Water Table (mg/Kg)

FIGURE
2-12

1077s002

present BTEX concentration contours for soils located above and below the water table based on analysis of samples collected during soil borings which took place in July 1993. These figures, taken together, present a picture of the distribution of chemical constituents at the Site which is generally consistent with the site conceptual model presented in the RDWP.

3.0 PERFORMANCE CRITERIA

3.1 Operable Unit 2 Groundwater Remedial Objectives

Based on evaluations carried out in an Endangerment Assessment (Versar 1988), Feasibility Study (Ebasco 1990) and Record of Decision (USEPA 1991) chemical impacts on three media have been identified as posing potential risks to human health and the environment in OU2 at the Sinclair Refinery Site. These include surface soils, subsurface soils and groundwater. The remedial objectives for these three media provide the basis for the selection and design of remedial systems for the Site. These remedial objectives include the following:

- prevention of contact with lead and arsenic contained in surface soils;
- improvement of groundwater quality in the shallow aquifer at the Site;
- limitation of impacts to the surface water of the Genesee River caused by discharge of groundwater; and
- ensuring continued effectiveness of the remedy by evaluating changes in Site conditions and usage.

3.2 Selected Remedy

The Record of Decision (ROD) for OU2 of the Sinclair Refinery Site, signed September 30, 1991, presents the selected remedy for surface soil, subsurface soil and groundwater in the refinery portion of the site. The surface soil remedy specifies the excavation of an estimated 7700 cubic yards of surface soils with concentrations of lead or arsenic greater than cleanup goals, treatment of the excavated soils and on-site disposal. Surface soils are defined as soils located between the ground surface and a depth of two feet. Specific provisions of this remedy include the following:

- excavation of surface soils with concentrations of lead greater than 1000 mg/kg or arsenic greater than 25 mg/kg;
- treatment of excavated soils by solidification or other methods so that the soil meets RCRA land disposal restriction regulatory levels for lead and arsenic;

- disposal of treated soils in the on-site Central Elevated Landfill Area undergoing closure as part of the remedial action for Operable Unit One at the Site; and

- reevaluation of the remedy after five years to determine whether or not it is still protective.

The selected remedy for surface soils is currently being implemented. The design of this remedy has been presented in the final CELA design (Ebasco, 1992), and its implementation will be presented in a Remedial Action Report when the work is complete. In addition to these requirements, the ROD recommended the implementation of a local zoning ordinance to require notification of the New York State Department of Health in the event of construction activities which will alter site use.

The "no-action" remedial alternative was selected for the remediation of subsurface soils at the site because no risk pathway presently exists for exposure to these soils. Although this remedy does not require any active remediation of soils at depths greater than two feet, it does require performance of specific activities including the following:

- implementation of a public awareness program;

- long-term monitoring of surface water, groundwater and soil-gas;

- recommendation of institutional controls in the form of local zoning ordinances restricting changes in site use; and

- reevaluation of the remedy after five years to determine whether or not it is still protective.

The selected remedy for groundwater at the Site includes the extraction and treatment of groundwater from the shallow aquifer followed by discharge of the treated water. The goal of this treatment system is to improve the quality of groundwater in the shallow aquifer so that it may be used as a source of drinking water in the future. The basis of EPA's evaluation of this technology is the conceptual design for a site-wide extraction system developed during the Feasibility Study. The ROD indicates that specific details and design options for the treatment system are to be determined during the remedial design stage. Provisions of this remedy include the following:

- extraction of impacted groundwater from the shallow aquifer;

- treatment in a system capable of meeting discharge requirements for the treated water;
- discharge of treated water directly to the Genesee River or to the local publicly owned treatment works;
- monitoring of surface water, groundwater, groundwater seeps and Genesee River biota; and
- reccommendation of institutional controls in the form of local zoning ordinances.

The ROD specifies potential contingency measures to be implemented if it is determined during operation that the pump and treat remedy will not be able to meet ARAR groundwater cleanup levels in a reasonable period of time. These measures may include the following:

- discontinuation of pumping at selected wells;
- alternation of pumping at different wells;
- pulse pumping; and
- installation of additional wells.

If it is determined that cleanup standards cannot be met in all or part of the aquifer, the ROD specifies that long-term management will be implemented including some or all of the following:

- engineering controls such as source control or containment;
- waiver of chemical-specific ARARs based on the technical impracticability of reaching these standards;
- institutional controls;
- monitoring; and
- evaluation of alternative technologies.

3.3 Clean-Up Standards

EPA has established chemical-specific ARARs as the appropriate treatment standards for cleaning up groundwater and limiting the impact of groundwater on surface water. These include federal and state maximum contaminant levels (MCLs) for groundwater and New York State Ambient Water Quality Standards (AWQSs) for groundwater and surface water. Tables 3-1 and 3-2 present these chemical-specific ARARs along with the maximum concentration of each relevant constituent detected at the Site.

3.4 Discharge Criteria

Treatment systems planned as part of the remedial action will require discharges of treated water and air. These discharges must meet regulatory standards or standards set by off-site treatment facilities. These discharge criteria are discussed below.

3.4.1 Water Discharge

Current plans call for treated groundwater from the remediation to be discharged to the Genesee River. Table 3-3, which presents surface water discharge criteria and proposed site-specific discharge criteria, was developed using the published Ambient Water Quality Standards and Guidance Values for the State of New York (rev. September 25, 1990). An application for a SPDES permit for the site has been submitted and is included in Appendix A.

The proposed discharge limitations shown in Table 3-3 are based on the assimilative capacity of the Genesee River at the proposed point of discharge. As a conservative, worst case scenario, the lowest reported flowrate for the river was used to determine an attenuation factor for the proposed discharge. The lowest reported monthly mean (for the period of 1955 through 1992) for the Genesee River at gauging station 15 (approximately four miles northwest of the Site) is 22.1 cfs (9918 gpm) (N.Y. U.S.G.S., 1992). The maximum design discharge flowrate from the water treatment plant is 50 gpm. Therefore, the appropriate attenuation factor is 9918 divided by 50, or 198. A stream of water at this flowrate meeting these proposed detection values discharging into a river with the minimum flowrate of 22.1 cfs will result in water quality standards which meet or exceed the New York State Ambient Water Quality Standards.

TABLE 3-1

Treatment Performance Standards
Sinclair Refinery Site, OU2
Inorganic Constituents
(Concentrations in mg/l)

Constituent	GROUNDWATER					GENESEE RIVER SURFACE WATER		
	Federal MCL	NY MCL	NY AWQS	Maximum Background Concentration	Maximum Concentration	NY AWQS	Maximum Background Concentration	Maximum Concentration
Aluminum	0.05	0.05	--	1.9	113.0	0.1	0.049	0.556
Antimony	0.006	--	--	0.06	ND	--	ND	ND
Arsenic	0.05	--	0.025	0.04	0.884	0.05	ND	0.089
Barium	2.0	1.0	1.0	0.25	2.36	1.0	0.065	0.268
Beryllium	0.004	--	--	ND	0.008	--	ND	0.004
Cadmium	0.005	0.01	0.01	0.007	0.010	0.01	0.009	ND
Chromium	0.1	0.05	0.05	0.061	0.3	0.05	ND	ND
Cobalt	--	--	--	0.006	0.042	0.005	ND	0.006
Copper	--	--	0.2	0.064	1.04	0.2	0.007	0.033
Cyanide	0.2	--	--	ND	ND	--	ND	0.013
Iron	--	--	0.3	17.0	280.0	0.3	0.210	20.3
Lead	0.05	0.05	0.025	0.688	0.249	0.05	0.014	0.155
Magnesium	--	--	--	2.86	30.6	35.0	5.05	5.19
Manganese	--	--	0.3	2.93	31.5	0.3	0.029	8.97
Mercury	0.002	0.002	0.002	ND	0.0002	0.002	0.002	0.002
Nickel	0.1	--	--	0.037	0.386	--	0.46	1.62
Selenium	0.05	0.01	--	ND	0.043	--	ND	ND
Silver	0.05	0.05	0.05	ND	0.026	0.05	0.009	ND
Sodium	--	--	20.0	6.92	70.0	--	10.8	10.9
Thallium	0.002	--	--	ND	NF	--	ND	ND
Vanadium	--	--	--	0.003	0.149	0.014	ND	ND
Zinc	--	--	0.3	86.3	21.5	0.3	0.086	0.33

Notes: Concentrations measured on unfiltered samples.
New York State AWQSs listed are human health based.

TABLE 3-2
Treatment Performance Standards
Sinclair Refinery Site, OU2
Organic Constituents
(Concentrations in mg/l)

Constituent	GROUNDWATER				GENESEE RIVER SURFACE WATER	
	Federal MCL	NY MCL	NY AWQS	Maximum Concentration	NY AWQS	Maximum Concentration
Benzene	0.005	0.005	0.0007	1.5	--	3.3
Bromobenzene	--	0.005	--		--	
Bromochloromethane	--	0.005	--		--	
Bromomethane	--	0.005	--		--	
n-Butylbenzene	--	0.005	--		--	
sec-Butylbenzene	--	0.005	--		--	
tert-Butylbenzene	--	0.005	--		--	
Carbon tetrachloride	0.005	0.005	--		--	
Chlorobenzene	--	0.005	0.005	0.125	--	0.010
Chloroethane	--	0.005	--		--	
Chloromethane	--	0.005	--		--	
2-Chlortoluene	--	0.005	--		--	
4-Chlortoluene	--	0.005	--		--	
Dibromomethane	--	0.005	--		--	
o-Dichlorobenzene	0.60	0.005	--		--	
m-Dichlorobenzene	--	0.005	--		--	
p-Dichlorobenzene	0.075	0.005	--	--	--	0.029
Dichlorodifluoromethane	--	0.005	--		--	
1,2-Dichloroethane	0.085	0.005	--	9.70	--	
1,1-Dichloroethane	--	0.005	0.005	0.690	--	
1,1-Dichloroethylene	0.007	0.005	--		--	
	0.07	0.005	--	6.9	--	
trans-1,2-Dichloroethylene	0.1	0.005	0.005	2.6	--	3.3

TABLE 3-2 (continued)

Treatment Performance Standards
Sinclair Refinery Site, OU2
Organic Constituents
(Concentrations in mg/l)

Constituent	GROUNDWATER				GENESEE RIVER SURFACE WATER	
	Federal MCL	NY MCL	NY AWQS	Maximum Concentration	NY AWQS	Maximum Concentration
1,2-Dichloropropane	0.005	0.005	--		--	
1,3-Dichloropropane	--	0.005	--		--	
2,2-Dichloropropane	--	0.005	--		--	
1,1-Dichloropropene	--	0.005	--		--	
cis-1,3-Dichloropropene	--	0.005	--		--	
trans-1,3-Dichloropropene	--	0.005	--		--	
Ethylbenzene	0.7	0.005	0.005	1.10	--	3.8
Ethylene dibromide	--	--	--		--	
Hexachlorobenzene	0.001	--	--		--	
Hexachlorobutadiene	--	0.005	--		--	
Isopropylbenzene	--	0.005	--		--	
p-Isopropyltoluene	--	0.005	--		--	
Methylene chloride	0.005	0.005	--	0.005	--	9.7
Monochlorobenzene	0.1	0.005	--		--	
Naphthalene	--	--	--		0.010	
Nitrobenzene	--	--	0.005	5.30	0.030	
PAHs	0.0002	--	--		--	
Pentachlorophenol	0.001	--	--		--	
PCBs	0.0005	0.005	--		--	
n-Propylbenzene	--	0.005	--		--	
Styrene	0.1	0.005	--		--	
1,1,1,2-Tetrachloroethane	--	0.005	--		--	

TABLE 3-2 (continued)

Treatment Performance Standards
Sinclair Refinery Site, OU2
Organic Constituents
(Concentrations in mg/l)

Constituent	GROUNDWATER				GENESEE RIVER SURFACE WATER	
	Federal MCL	NY MCL	NY AWQS	Maximum Concentration	NY AWQS	Maximum Concentration
1,1,2,2-Tetrachloroethane	--	0.005	0.005	0.125	--	--
Tetrachloroethylene	0.005	0.005	--	0.002	--	
Toluene	1.0	0.005	--	0.730	--	0.054
1,2,3-Trichlorobenzene	--	0.005	--		--	
1,2,4-Trichlorobenzene	--	0.005	--		--	
1,1,1-Trichloroethane	--	0.005	0.005	2.0	--	0.016
1,1,2-Trichloroethane	--	0.005	--	0.005	--	
Trichloroethylene	0.005	0.005	0.005	3.10	--	5.0
Trichlorofluoromethane	--	0.005	--		--	
1,2,3-Trichloropropane	--	0.005	--		--	
1,2,4-Trimethylbenzene	--	0.005	--	1.50	--	
1,3,5-Trimethylbenzene	--	0.005	--	0.035	--	
Vinyl chloride	0.002	0.002	--	3.30	--	
Xylenes (total)	10.0	0.002	0.005	3.20	--	2.7
Trihalomethanes (total)	0.1	0.1	--		--	
Unspecified organic contaminant (UOC)	--	0.05	--	NA	--	NA
Total principal organic contaminant (POC)+ and UOCs++	--	0.1	--	NA	--	NA

Notes: NA - Not analyzed.
New York State AWQSs listed are human health based.

Table 3-3

Proposed Discharge Limitations, Sinclair Refinery Superfund Site

Constituent	NYAWQS - Class AA Surface Water (µg/L)[1]	Proposed SPDES Limitation (µg/L)	Proposed SPDES Limitation (lbs/day)	Proposed POTW Limitation (µg/L)[2]
Arsenic	50	9,900	5.9	1,000
Cyanide	100	19,800	11.9	--
Chromium (Total)	50	9,900	5.9	1,000
Iron	300	59,500	35.8	--
Lead	50	9,900	5.9	1,000
Zinc	300	59,500	35.8	--
Benzene	0.7	138.9	0.08	--
Ethylbenzene	50	9,900	5.9	--
Toluene	50	9,900	5.9	--
Xylenes (Total)	50	9,900	5.9	--
1,1-Dichloroethane	50	9,900	5.9	--
1,2-Dichloroethylene	50	9,900	5.9	--
1,1,1-Trichloroethane	50	9,900	5.9	--
Vinyl Chloride	2	390	0.23	--

1 Water Quality Regulations, Surface and Groundwater Classificaions and Standards, New York State Department of Environmental Conservation, effective September 1, 1991.

2 As identified in the Ebasco Final Design for the CELA

3.4.2 POTW Discharge

Discussions with Wellsville's local publicly owned treatment works (POTW) indicate that the facility will not be able to accept flows of water from the Site at the rates planned for the full capacity of OU2 remedial design. Even so, it may be possible to discharge water at lower flow rates or on a short term basis if this becomes necessary during the course of site remediation. ARCO is currently engaged in discussions with the POTW to allow discharge of water associated with continuous backflow from the sand filter included in the Northern Area water treatment system.

3.4.3 Air Discharge

NYDEC Regulation 212 details the amount of emission control required for air emission sources. The amount of control is dependent on the toxicity of the compound. NYDEC rates the toxicity of compounds by letter: A being highly toxic; B being moderately toxic; C being low toxic; and D being water vapor or simple asphyxiants. Compounds rated A toxicity must use the Best Available Emission Control Technology (BACT) that is 99% efficient, if the emission rate is above one pound per hour. Compounds rated B or C toxicity must use a Reasonably Available Emission Control Technology (RACT) that is 90% and 70% efficient, respectively if the emission rates are above ten pounds per hour. Compounds rated D need no control.

In addition to NYDEC Regulation 212, the NYDEC Air Guide 1 (NYSDEC, 1991) establishes ambient concentrations for emitted compounds from a source. These ambient concentrations cannot be exceeded, even if the control technology meets the criteria of Regulation 212. If an emission source meets the 90% removal efficiency for compounds rated B, but fails to meet the ambient standards in Air Guide 1, the source must increase its efficiency to meet the ambient standard. If the source maintains a 99% removal efficiency, but still can not meet the ambient air standard, NYDEC will allow the emissions, if the ambient concentration is less than 10 times the ambient standard. Table 3-4 presents a summary of air discharge limits and control technology requirements.

Table 3–4

Air Discharge Requirement Summary
Wellsville, New York

Compounds	NYDEC Emission Limits[1]			AGC[3] (ug/m³)	SGC[3] (ug/m³)
	BACT	RACT	No Control[2]		
Benzene	>1.0	0.1<C<1.0	<0.1	0.12	30
Toluene	NA[2]	>10	<10	2,000	89,000
Ethlybenzene	NA[2]	>10	<10	1,000	100,000
Xylene	NA[2]	>10	<10	300	100,000
Vinyl Chloride	>1.0	0.1<C<1.0	<0.1	0.02	1,300
1,1–Dichloroethane	NA[2]	>10	<10	500	190,000
1,2–Dichloroethane (total)	NA[2]	>10	<10	1,900	190,000
1,1,1–Trichloroethane	NA[2]	>10	<10	1,000	450,000

Notes:

[1]NYDEC Air Regulation 212, Table 2.0
[2]NYDEC Air Guide–1, Section IV.B.1.a. "Degree of control may be specified by the Commissioner".
[3]NYDEC Air Guide–1, Appendix C
AGC: Annual Guideline Concentration
SGC: Short–Term Guideline Concentration
BACT: Best Available Control Technology
RACT: Reasonable Available Control Technology

4.0 DESIGN CRITERIA

Design criteria include the physical, chemical and engineering parameters needed to design each component of the remedial design. These values are selected based on engineering evaluations of data collected during the RI and remedial design investigatory and process evaluation activities. Those evaluations focus on reducing the large amount of available data to specific values for each characteristic required. Discussions of these design criteria are presented below.

4.1 Civil Criteria

Civil criteria relate to the physical layout of the Site and design issues related to the design of physical structures and facilities. Civil design issues which will require attention include the following:

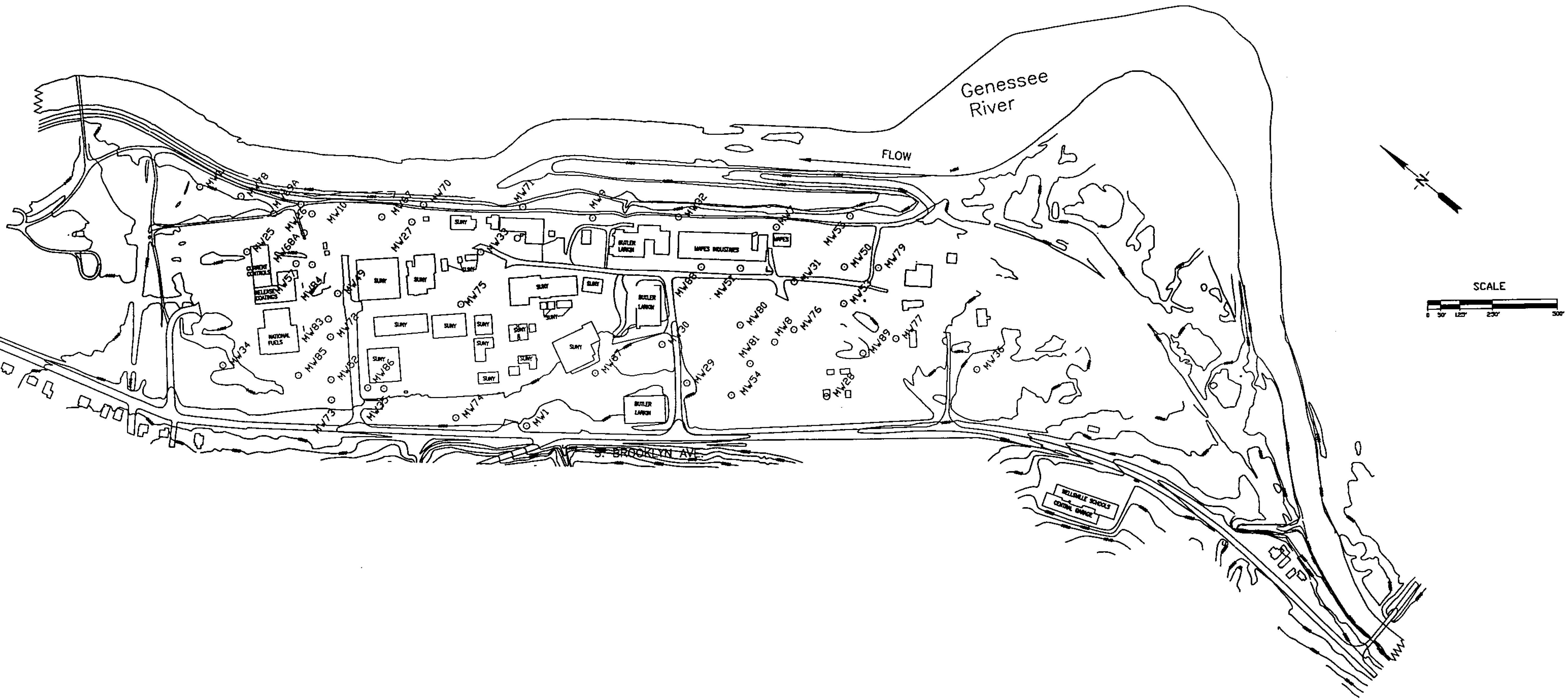
- topography;
- access and ownership;
- existing Site buildings;
- utilities locations; and
- building requirements.

The topography of the Site slopes gently from South Brooklyn Avenue to the river. The locations where facilities are likely to be constructed are relatively flat and easily accessible. Roads at the Site are in generally good shape and are capable of handling vehicles likely to be associated with implementation of the remedial design. Site features related to civil design criteria are presented in Figure 4-1.

As discussed in Section 2, parts of the Site are owned by a number of different private companies and institutions. During site activities performed as part of the remedial design investigation, obtaining permission for site access required significant efforts to coordinate the activities and the requirements of property owners and occupants. Maintaining the schedule of construction work will require planning and coordination to maintain the work on schedule.

As shown on site maps, existing site buildings are found in a number of locations on-site. In the northern part of the Site, a number of buildings are found near areas previously identified

RETEC



Site Civil Layout

FIGURE
4-1
1077s002

as areas where constituents-of-interest have been measured at elevated levels and which are likely to be areas where treatment systems are required. For that reason, the layout of individual components must accommodate existing buildings and infrastructure.

Issues related to utilities will have an impact on the design. Past investigations have shown that the Site has a large number of above and below ground utility lines, including major electric power lines, natural gas pipelines, water lines and sewers. Although this means that access to utilities required for construction and operation of remedial systems will not be difficult, past activities on site have been delayed because of uncertainties about the locations of underground utilities. In the past, this has led to significant extra work and delay associated with locating the utilities before work proceeds. In addition, there is the potential that underground pipelines may affect the hydraulic characteristics of the Site which will affect the performance of design components.

Several small buildings will be constructed during implementation of the remedial design. In addition to any structural or foundation requirements for these buildings, they will be constructed to meet the requirements of the local building and fire code. Provisions of the New York Building Code related to structural requirements for these buildings are presented in Appendix E.

4.2 Site Criteria

Site criteria include those physical and chemical characteristics of the Site which will determine the required performance of each of the elements of the various design components.

4.2.1 Physical Characteristics

Stratigraphy

Past investigations including the RI and remedial design investigation of the Site have indicated that the soil stratigraphy is somewhat heterogeneous. For the purposes of groundwater remedial design, it is necessary to simplify that understanding based on measured and inferred aquifer characteristics. More complete discussions of site stratigraphy can be found in Section 2, the RDWP and the RDIR.

The stratigraphic unit of principle concern is the upper aquifer. This unit is a stratified sand and gravel alluvial deposit. The sediments comprising the shallow aquifer are alluvial in nature and range from 10 feet to greater than 50 feet in depth across the Site. The natural emplacement of different textured sediments is a reflection of the evolution of the meandering Genesee River. Channel deposits contain well-sorted sands and gravels. Lower-energy deposition areas contain deposits of sands, silts, and low-plasticity clays. The resulting sediments are generally coarse in texture, but have finer textured lenses that are horizontally discontinuous.

Four distinct units of sub-surface soils were identified during the drilling program which are found in or above the shallow aquifer. The upper four feet of soil was a well graded fill ranging from coarse gravel to silt. Brick ash, metal and wood debris were found throughout this layer. Below the fill was one to six feet of fine sand and silt with little gravel. This strata is alluvial in origin. The fine sand and silt layer was underlain with ten to twenty feet of well graded soil with particle sizes ranging from coarse gravel to silt. This deposit was well stratified with discontinuous units of sand, gravel and silt. For design purposes, this layer can be viewed as one unit. The fourth unit is a glaciocalustrine clay which underlies the alluvial deposits and separated the upper aquifer from the lower artesian aquifer. The four units described will comprise the conceptual model on which the groundwater flow and transport of COI are based.

Design Parameters

Soil Venting System Design Parameters

During the operation of the soil venting and aquifer aeration pilot study described in detail in the RDIR, personnel monitored site conditions and equipment operations. Soil vapor in the unsaturated zone was monitored for the following indicator parameters to evaluate the soil vapor extraction process for design: wellhead vacuum, blower intake vacuum, blower discharge pressure, flow (wellhead flow, bleed-in of ambient air, and total flow at the carbon unit discharge), temperature after blower discharge, and organic vapor concentrations in off-gas prior to carbon treatment (measured by OVM, Dräger tubes, and laboratory GC analysis)

The principal measurements recorded during the venting pilot study for determination of the Radius of Influence (ROI) were the air flow rate, vacuum in the unsaturated zone, and organic vapor concentrations in both the unsaturated zone and the venting system off-gas. The analysis of the soil venting data was performed by plotting the distance verses the log of the induced vacuum for both the north and south areas. The regression lines for the Southern Area calculated for the two wellhead vacuum levels have similar slopes, indicating that the change in the logarithms of the induced vacuum was the same at various measuring distances as the wellhead vacuum varied. The results in the Northern Area also show a good correlation between the logarithm of the induced vacuum and the distance from the venting well to the measuring point. This data suggests that predicted ROI's will not be significantly impacted by anisotropic conditions.

The unsaturated zone permeability was calculated from pilot test data. The site-specific physical characteristics, calculated vadose zone permeability, and wellhead vacuum were input into a flow model to predict the ROI in terms of flushout time. A discussion of the flow model is presented in Appendix C and the RDIR. (Flushout time is the time to remove and replenish one pore volume of air in the vadose zone.) The ROI is defined as that area around the extraction well which has one pore volume exchanged in an 8 hour period. The flow model, calibrated to match performance data collected during both pilot system operations, will be used to predict the performance of a full-scale system.

The simulation of the soil venting pilot system performance consisted of estimating the treatment zone permeability from two vacuum drawdown tests and one vacuum build-up test. The average estimated permeability from these tests then became the input parameter for RETEC's flow model. Other site-specific inputs for the model included:

- depth to water table;
- depth of soil venting well;
- length of well screen;
- wellhead vacuum;
- radius of well;
- thickness and permeability of cap if any; and
- vacuum at wellhead.

The flow model predicts flow rate and flushout time after several iterations. The first iteration was based on site characteristics, wellhead vacuum and the calculated permeability. In subsequent iterations, the permeability of the treatment zone was adjusted until the computer simulated flow rate matched the pilot system flow rate for the given wellhead vacuum.

The permeability of the vadose zone in the Southern Area was estimated from two drawdown tests and one build-up test. The drawdown and build-up tests were conducted using a soil gas monitoring point (VP-5) located at a 30 foot radial distance from the soil venting well and screened in the unsaturated zone to measure the change in subsurface vacuum with time.

The field data and the permeability calculations are presented in the RDIR. Table 4-1 is a summary of the input data and the calculated permeability. The calculated permeability from the slope and y-intercept of the vacuum versus natural log of time ranged from 1.16 x 10^{-7} cm^2 to 2.79 x 10^{-6} cm^2.

The pilot system in the Southern Area was operated at 80 cfm at 80 iwc and 49 cfm at 40 iwc. The flow model was used to simulate both situations. The model simulation was performed three times with the input value for the permeability adjusted each time until the field-measured flow rates and simulated flow rate of 80 cfm at a wellhead vacuum of 80 iwc was matched. Table 4-2 presents a summary of the input parameters and final permeability for the 80 cfm and 49 cfm cases. Figure 4-2 shows the flushout time in days versus radial distance from the vapor extraction well for both the 80 cfm/80 iwc case and the 49 cfm/40 iwc case. As shown on Figure 4-2, the estimated ROI is approximately 90 feet for 40 iwc and 115 for 80 iwc for a flushing rate of one pore volume per eight hours.

The simulation of the soil venting pilot system performance in the Northern Area consisted of estimating the treatment zone permeability from three vacuum drawdown tests. The estimated permeability from these tests was then used as an input parameter for the flow model along with other information which was needed to simulate the soil venting system.

The permeability of the treatment zone was estimated from three drawdown tests which were conducted using a soil gas monitor point (VP-10) which is located at a 30 foot radial distance from the soil venting well and screened in the unsaturated zone to measure the change in subsurface vacuum with time. The field data and the permeability calculations are presented in the RDIR. Table 4-3 is a summary of the input data and the calculated permeability. The calculated permeability using the slope and y-intercept method ranged from 5.00 x 10^{-7} cm^2 to 4.31 x 10^{-4} cm^2.

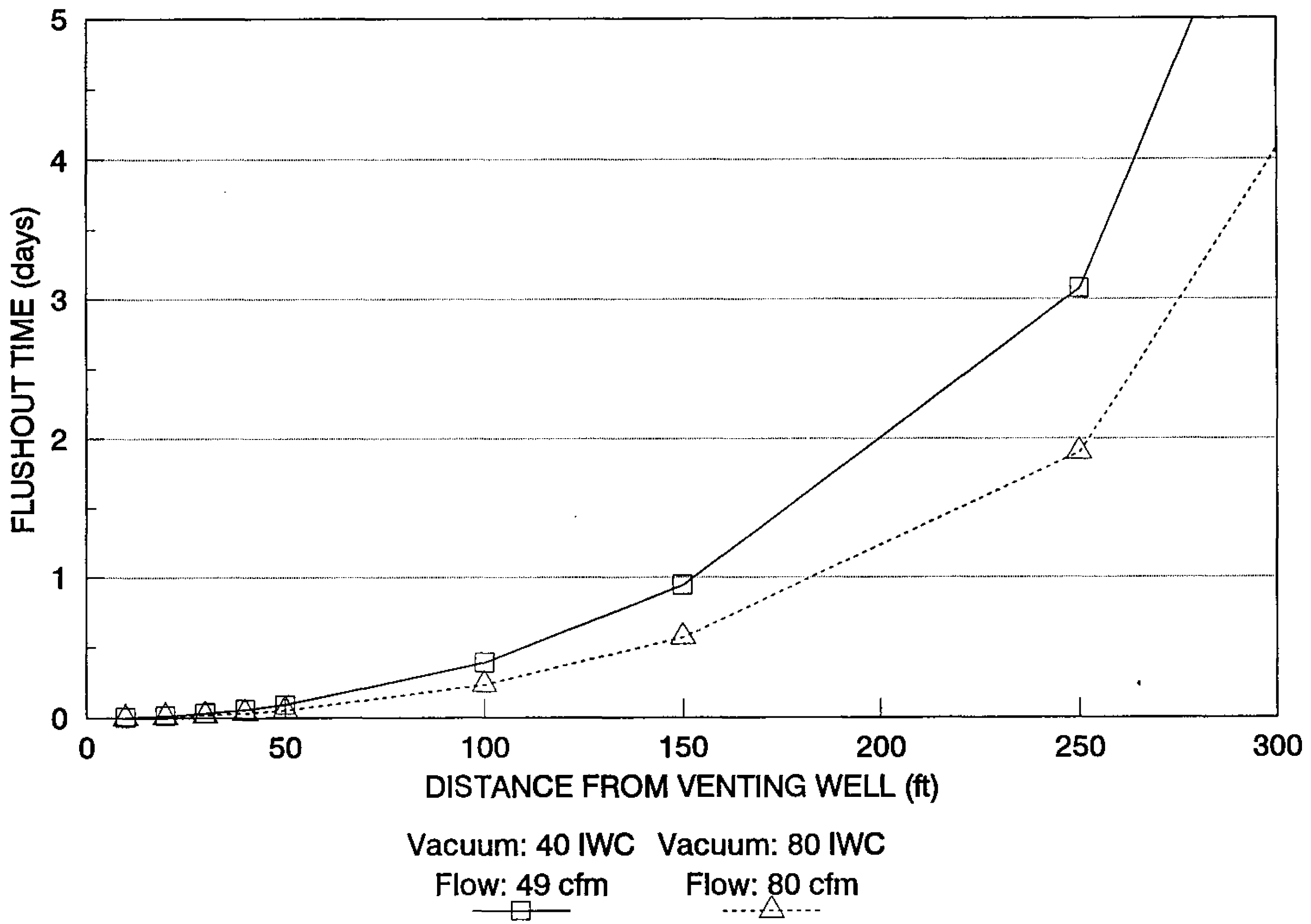
The pilot system was operated at 160 cfm and 30 iwc. The flow model was run three times to simulate the soil venting system flow by adjusting the permeability until the simulated flow rate matched the field-measured flow rate of 160 cfm at a wellhead vacuum of 30 iwc. Table 4-4 presents a summary of the input parameters and final permeabilities. Figure 4-3 shows the flushout time in days versus radial distance from the well for 160 cfm at a wellhead vacuum of 30 iwc. As shown on Figure 4-3, the estimated ROI is approximately 115 feet at 30 iwc. Table 4-5 presents a summary of soil venting performance data for both areas.

TABLE 4-1
Summary of Permeability Calculation
Southern Area (NEAR MW-8)

TEST:	DRAWDOWN		DRAWDOWN		DRAWDOWN	
DATE:	7/21/93		7/21/93		7/21/93	
TIME:	1:20 p.m.		1:45 p.m.		6:30 p.m.	
Vacuum at Wellhead (IWC)	80	Field Measured	80	Field Measured	40	Field Measured
Vacuum at Blower (IWC)	90	Field Measured	90	Field Measured	68	Field Measured
Flow Rate (SCFM)	80	Gast Blower Performance	80	Gast Blower Performance	49	Calculated
Treatment Zone Thickness (feet)	3	As-Built Drawing	3	As-Built Drawing	3	As-Built Drawing
Distance from Soil Venting Well (ft)	30	Field Measured	30	Field Measured	30	Field Measured
Calculated Permeability from Slope (cm^2)	5.6×10^{-6}	Calculated	6.04×10^{-6}	Calculated	4.9×10^{-6}	Calculated
Calculated Permeability from Slope and Y-Intercept (cm^2)	2.41×10^{-6}	Calculated	2.79×10^{-6}	Calculated	1.16×10^{-7}	Calculated

TABLE 4-2
Simulation Input and Output Parameters
Southern Area (NEAR MW-8)

	Input/Output	Source	Input/Output	Source
Depth to Water Table (feet)	3	Field Measured	3	Field Measured
Height Above Water Table Where Screen is Placed (feet)	1	Field Measured	1	Field Measured
Length of Screen (feet)	2	Field Measured	2	Field Measured
Radius of Well (inches)	2	Field Measured	2	Field Measured
Soil Porosity (fraction)	30%	Estimated	30%	Estimated
Soil Permeability (cm^2)	6.04×10^{-7}	Model	6.96×10^{-7}	Model
Impermeable Cover Thickness (feet)	3	Site Cross-Section A-A' (Figure 2-1)	3	Site Cross-Section A-A' (Figure 2-1)
Impermeable Cover Permeability (cm^2)	1×10^{-10}	Freeze & Cherry	1×10^{-10}	Freeze & Cherry
Flow (SCFM)	81	Model	48.6	Model
Pilot System Flow Rate (SCFM)	80	Field Measured	49	Field Measured
Pilot System Vacuum (IWC)	80	Field Measured	40	Field Measured



Predicted Flushout Times – Southern Area

FIGURE 4–2

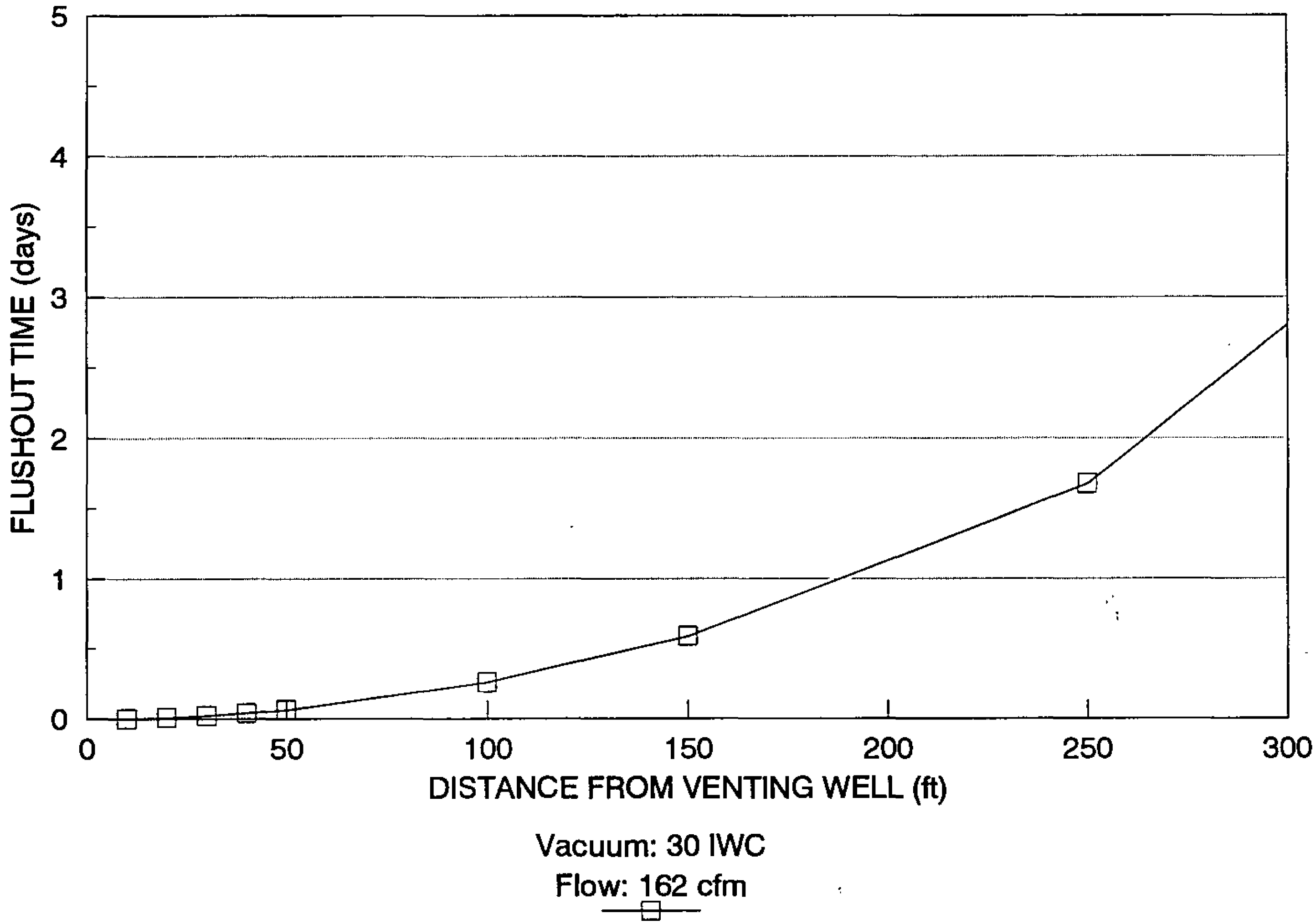
TABLE 4-3
Summary of Permeability Calculation
Northern Area (NEAR MW-10)

TEST:	DRAWDOWN		DRAWDOWN		BUILDUP	
DATE:	7/24/93		7/24/93		7/25/93	
TIME:	7:56 a.m.		1:30 p.m.		8:53 a.m.	
Vacuum at Wellhead (IWC)	30	Field Measured	30	Field Measured	30	Field Measured
Vacuum at Blower (IWC)	62	Field Measured	62	Field Measured	62	Field Measured
Flow Rate (SCFM)	160	Gast Blower Performance	160	Gast Blower Performance	160	Calculated
Treatment Zone Thickness (feet)	7	As-Built Drawing	7	As-Built Drawing	7	As-Built Drawing
Distance from Soil Venting Well (feet)	30	Field Measured	30	Field Measured	30	Field Measured
Calculated Permeability from Slope (cm^2)	1.03×10^{-5}	Calculated	3.07×10^{-6}	Calculated	4.46×10^{-6}	Calculated
Calculated Permeability from Slope and Y-Intercept (cm^2)	4.31×10^{-4}	Calculated	5.00×10^{-7}	Calculated	1.08×10^{-5}	Calculated

TABLE 4-4
Simulation Input and Output Parameters
Northern Area (NEAR MW-10)

	Input/Output	Source
Depth to Water Table (feet)	7	Field Measured
Height Above Water Table Where Screen is Placed (feet)	1	Field Measured
Length of Screen (feet)	2	Field Measured
Radius of Well (inches)	2	Field Measured
Soil Porosity (fraction)	30%	Estimated
Soil Permeability (cm^2)	1.03×10^{-5}	Model
Impermeable Cover Thickness (feet)	5	Site Cross-Section D-D' (Figure 2-4)
Impermeable Cover Permeability (cm^2)	1×10^{-10}	Freeze & Cherry
Flow (SCFM)	160	Model
Pilot System Flow Rate (SCFM)	160	Field Measured
Pilot System Vacuum (IWC)	30	Field Measured

RETEC



Predicted Flushout Times – Northern Area

FIGURE 4–3

TABLE 4-5

Summary of Soil Venting Performance Data

	Southern Area	Northern Area
Intrinsic Permeability[a]		
cm^2	5.62×10^{-6}	2.56×10^{-6}
Darcys	568	259
Hydraulic Conductivity[b]		
cm/s	5.49×10^{-1}	2.50×10^{-1}
ft/day	1,557	709
Radius of Influence (ft)[c]		
V = 40 iwc , Q = 49 cfm	88	
V = 80 iwc , Q = 80 cfm	115	
V = 30 iwc , Q = 162 cfm		112

NOTES:

[a]Intrinsic permeability calculated from vacuum build-up and recovery tests.

[b]Hydraulic conductivity calculated from intrinsic permeability.

[c]Radius of influence from RETEC flow model based on flushing of 3 pore volumes per day.

Table 4-5 presents a summary of venting system performance data . Based on this data, the design radius of influence for design of the soil vapor extraction system will be 100 feet for both areas operating at approximately 40 iwc and a flow rate of 50 cfm. Although no pilot study was performed in the Central Area, the same venting design parameters will be used for this area as for the other two.

Aeration System Design Parameters

The key measurements during the aeration studies in the Northern and Southern Areas were dissolved oxygen (DO) measurements in the monitoring wells. Complete results of the aeration studies are presented in the RDIR. Table 4-6 lists the DO readings for the sparging pilot study in the Southern Area. Increases in DO above background were observed in the aeration well (AR-1) and in two monitoring wells (OB-2 and MW-8) at distances of 12 and 20 feet. These results indicate that oxygen was effectively introduced to the aquifer and the radius of influence of the aeration well was approximately 20 feet. Table 4-7 lists DO measurements from the study in the Northern Area. Increases above background levels were observed in the aeration well (AR-2) and in MW-10 at a distance of 12 feet. No increases were observed in OB-3 and OB-4. The radius of influence of the aeration well was between 12 -15 feet. However, the increases in DO concentration in the aeration well were quite significant (from background of 1 mg/L to 11 mg/L during aeration). No aeration studies were prepared in the Central Area.

A single design value of 15 feet for ROI was selected for the air sparging systems in the Northern, Central and Southern Areas. This value was selected based on dissolved oxygen concentrations at monitoring points.

Groundwater Modeling

A two-dimensional groundwater flow numerical model has been setup and calibrated for the former Sinclair Refinery site and adjacent areas. The purpose of this effort is to create a model as a tool to evaluate and compare alternative groundwater remedial options. The model can also be used to aid in the design of the selected options and to evaluate the understanding of the local and regional aquifer hydrodynamics.

Appendix D contains a report detailing the results of the groundwater modeling effort. This appendix contains information on the conceptual model, model grid, boundary conditions, input parameters, calibration, and results.

TABLE 4-6
DISSOLVED OXYGEN MEASUREMENTS (mg/L)
SOUTHERN AREA

Date	Time	Conditions	AR-1	OB-1	OB-2	MW-8
Distance from Sparging Well			0'	10'	20'	12'
7/21/93	0800	Background	0.6	0.7		
7/22/93	1320	After 4 hours of aeration	1.8	0.5	0.5	6.5
	1630	During recovery				1.35
7/23/93	1345	After 8.5 hours of aeration/ venting		0.65	2.78	1.55
	1734	During recovery	4.5	0.7	0.5	

TABLE 4-7
DISSOLVED OXYGEN MEASUREMENTS (mg/L)
NORTHERN AREA

Date	Time	Conditions	AR-2	OB-3	OB-4	MW-10
Distance from Sparging Well			0'	10'	20'	12'
7/24/93	1000	Venting Only	1.0	1.0	1.0	1.5
	1540	After 1 hour aeration		1.0	0.8	1.2
7/25/93	0800	Background		1.0	1.3	1.35
	1020	After 1 hour aeration/venti ng		0.95	0.8	0.5
	1210	After 3 hours aeration/venti ng		0.3		0.5
	1510	Just after shutdown	11			2.25
	1545	30 minutes after shutdown		0.2	0.5	0.6
	1718	During recovery	10.2			
	1731	During recovery	10.0			
	1746	During recovery	10.6			
	1800	During recovery	10.4			
	1850	During recovery	10.1			
7/26/93	0730	14 hours after shutdown	7.5	0.9		0.7

The flow modeling was conducted on the shallow, stratified, sand and gravel deposits occurring within the valley of the Genesee River. These deposits are Holocene in age and alluvial in origin. Groundwater in the sand and gravel is under unconfined conditions.

The groundwater model was used as the basis for evaluating and comparing a number of different hydraulic containment options in the immediate vicinity of the northern oil/water separator. The primary objective of the modeled alternatives was to contain groundwater from migrating into the Genesee River in this area. All simulated runs employed a series of pumping wells in the vicinity of the northern oil-water separator which are placed perpendicular to groundwater flow, paralleling the Genesee River.

The placement of the pumping wells was chosen so as to minimize potential induced infiltration from the river. A number of simulations were run varying the number, placement, and pumping rate of wells. A series of simulations were conducted and consisted of between one to four wells pumping a total discharge ranging between 10 to 50 gpm.

Complete capture of the soluble plume in the northern oil-water separator area is attained in a scenario involving three wells pumping at 10 gpm each. The wells are aligned in a southeast to northwest direction spaced approximately 150 feet apart with the central well located at MWP-57. Maximum predicted drawdown is approximately 5 feet in the center of the three well system. This scenario did not induce any infiltration from the river.

4.2.2 Chemical Characterization

Three sets of criteria related to the concentration and distribution of chemical constituents at the Site are relevant to the design of the groundwater treatment system at the Site including the following:

- the definition of areas at the Site where treatment will take place;
- the determination of the expected concentrations of constituents in the extracted water for design of the water treatment system; and
- the determination of vapor concentrations for design of the vapor treatment system associated with the air stripper.

These issues are discussed in more detail below.

Areas of Concern

Figures 2-10 through 2-12, which show groundwater and soil BTEX concentrations, are the basis for the selection of areas at the Site where aggressive remediation will take place. Data gathered during the RI and the remedial design investigation indicate that there are two areas on site where elevated groundwater BTEX concentrations are found at levels exceeding 1000 ug/l . In both of these areas, elevated soil BTEX concentrations were measured above and below the water table. These areas are designated the Northern Area, located in the area stretching from MW 73 on the National Fuels property to MW 69 near the former location of the Northern oil/water separator, and the Southern Area, located in the area around MW 77 and MW 79. Treatment systems operating in these areas will be focused at the areas with the highest concentrations of dissolved (groundwater) constituents in the center of the mass, but will also provide for removal of these constituents in the source areas (soils above and below the water table). In addition to these two areas, Figure 2-10 shows an area adjacent to the river between the Northern and Southern Areas where groundwater BTEX concentrations exceeding 100 ug/l were measured. This area is designated the Central Area. The treatment system in the Central Area is focused on treating volatile constituents in groundwater.

Design Water Concentrations

As discussed above, three areas of concern which will require aggressive groundwater remediation have been identified at the Site. The technical approach for groundwater remedial action for the Southern and Central Areas involves treatment of organic constituents using a soil venting/groundwater aeration system. In the Northern Area, a combination of soil venting/groundwater aeration and groundwater pump-and-treat systems will be used.

Table 4-8 presents a statistical summary of groundwater concentrations of compounds-of-concern in groundwater to be extracted from the Northern Area based on analysis of samples collected during the July 1993 sampling event. Maximum, minimum, arithmetic mean, median, geometric mean, and distance weighted mean values have been determined for the chemicals listed. Figure 4-4 shows the locations of the wells which were included in the determination of statistical values as well as the location of the proposed extraction wells which are the basis of the distance weighted mean.

The distance weighted mean concentration values have been selected as the design concentration values for the groundwater extraction system. This type of mean puts extra weight on concentration values for samples collected close to the expected extraction location and less

Table 4-8
Groundwater Extraction System
Constituent Concentrations in ug/L

Monitoring Parameter	Max.	Min.	Arith. Mean	Median	Geo. Mean	Dist. Weight. Mean
Benzene	1,500	<3	368	290	227	459
1,1-Dichloroethane	380	<3	58	<50	60	142
1,2-Dichloroethene (total)	6,900	<3	1,207	<50	494	5,019
1,1,1-trichloroethane	1,000	<3	156	<50	296	529
Vinyl Chloride	550	<5	104	<100	385	228
Arsenic	238	<25	127	136	107	180
Iron	75,300	14,300	41,470	40,950	37,110	51,670
Lead	9	<2	3	<3	2	2
Total BTEX	4,531	<8	1,793	1,382	922	3,582

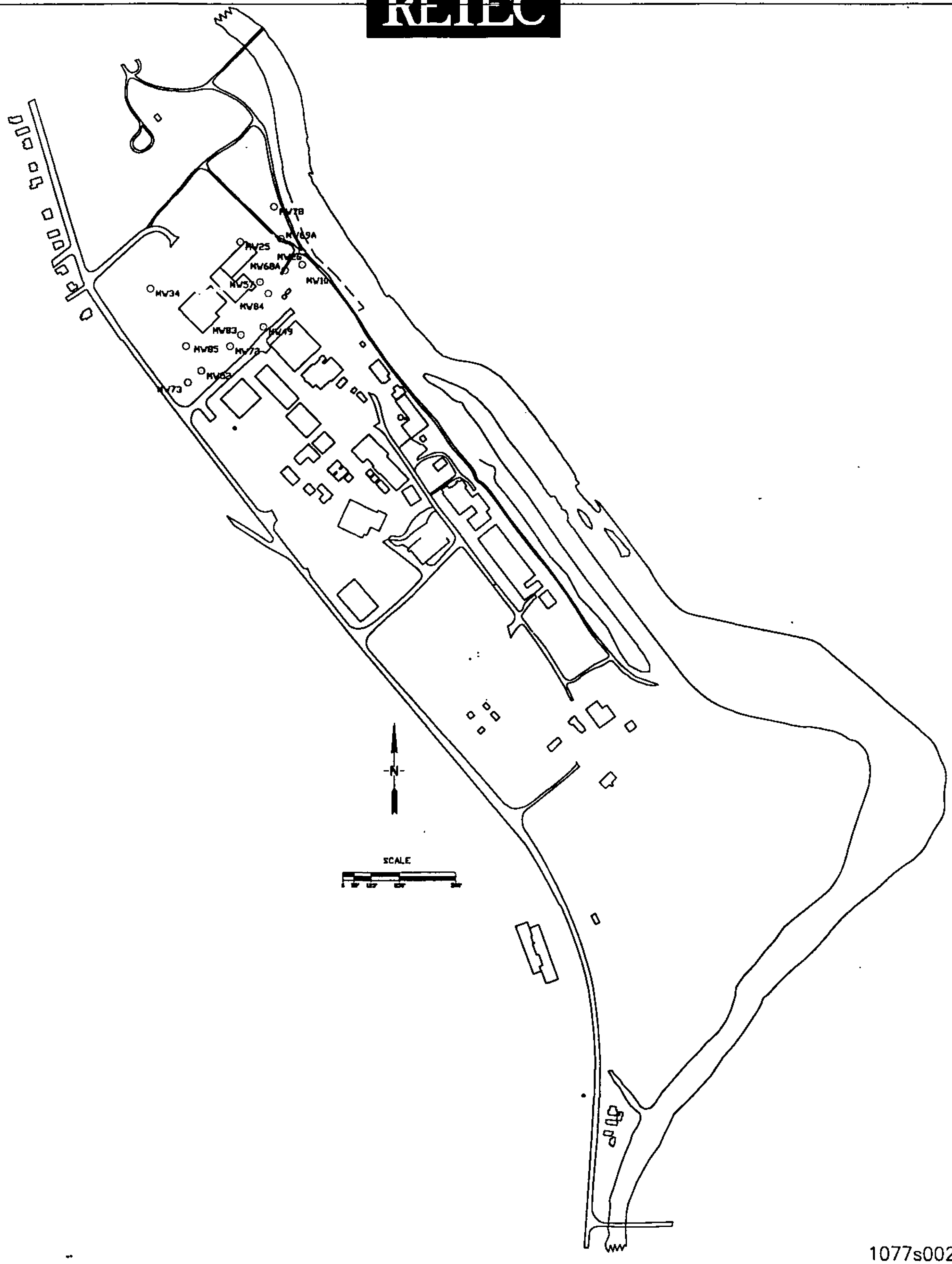


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FIGURE 4-4

Wells Included in Water Concentration Calculations weight the farther the sample location is away. This is consistent with the physical effect of the groundwater concentrations during pumping.

Design Vapor Concentrations

Table 4-9 presents concentrations of organics for vapor samples collected from the soil venting/groundwater aeration pilot system operated during the pilot studies during the remedial design investigation at the Site in July 1993. One sample was collected for laboratory analysis from the Northern and Southern Areas. Measured values in the Southern Area are those reported by the laboratory. Actual values are those calculated when the effects of adding additional air to the vapor stream to reduce the total vapor concentration are considered. A complete description of the study and analytical results is presented in the RDIR. Design values for extraction system vapor concentrations are the reported values in the Northern Area and the actual values in the Southern Area. Design values for the central treatment area and soil vapor concentrations obtained in the Northern Area.

Constituent emission rates for the soil vapor systems in the Southern, Northern and Central Areas are presented in Table 4-10. The benzene emission rate from the Southern Area was calculated to be 0.028 pounds per hour . Toluene and ethylbenzene levels were 0.011 and 0.012 lbs/hr , respectively. The Northern Area has a calculated hourly benzene emission rate of 0.105 pounds. Toluene and ethylbenzene were 0.027 and 0.022 lbs/hr , respectively. Total xylenes were calculated to be 0.027 lbs/hr . Constituents emission rates from the Central Area were calculated to be 0.131 lbs/hr for benzene, 0.033 lbs/hr for toluene, 0.027 lbs/hr for ethylbenzene and 0.034 lbs/hr for total xylenes.

Emission rates for the constituents of interest from the groundwater treatment system air stripper are presented in Table 4-11 . The groundwater pumping rate of 50 gpm represents the predicted treatment flow rate. An estimated hourly emission rate for benzene, at 50 gpm, from the stripper is 0.012 lbs/hr . Vinyl chloride and 1,1-dichloroethane emission rates were calculated to be 0.006 and 0.003 lbs/hr , respectively. The emission rate of 0.125 lbs/hr was estimated for 1,2-dichloroethene (total) and 0.013 lbs/hr for 1,1,1-trichloroethane. Calculations used to quantify compound emission rates, in units of pounds per hour (lbs/hr) from the vapor and groundwater were contained in NYDEC regulation 212 and the Air Guide 1.

The Standard Point Source Method, presented in the Air Guide 1, was used to determine the ambient downwind concentration from each individual remedial treatment system and again

Table 4-9
Summary of Vapor Analytical Results
Soil Vapor Extraction/Aeration Process Evaluation Study

Units (µg/L)	7/23/93 Southern Area		7/23/93 Southern Area (Duplicate)		7/25/93 Northern Area	
	Measured[a]	Actual[b]	Measured[a]	Actual[b]		
Benzene	4.3	12.6	3.6	10.5	140	
Toluene	1.7	5.0	1.9	5.5	36	(1.8)[c]
Ethylbenzene	1.9	5.5	1.6	4.7	29	
Total Xylenes	<1		<1		37	(0.4)[c]
	7.9	23.1	7.1	20.7	242	
TVPH (Total Volatile Petroleum Hydrocarbons)	570	1,664	730	2,132	10,000	
Chlorinated Hydrocarbons	None Detected		None Detected		None Detected	
OVM Reading (ppm)	135		135		148	

NOTES:

[a]Concentrations measured by laboratory analyses.
[b]Conversion based on dilution of soil gas with fresh air at venting well.
[c]Blank concentrations.

Table 4-10

Estimated VOC Emission Rates from Soil Vapor Extraction Systems - North and South Wellsville, New York

Area	Southern Area			Northern Area			Central Area		
Compounds	Vapor Conc. (ug/L)	Vapor Conc. (ug/m³)	Emission Rate (lbs/hr)	Vapor Conc. (ug/L)	Vapor Conc. (ug/m³)	Emission Rate (lbs/hr)	Vapor Conc. (ug/L)	Vapor Conc. (ug/m³)	Emission Rate (lbs/hr)
Benzene	12.6	12,600	0.0283	140	140,000	0.1047	140	140,000	0.1310
Toluene	5.0	5,000	0.0112	36	36,000	0.0269	36	36,000	0.0337
Ethylbenzene	5.5	5,500	0.0124	29	29,000	0.0217	29	29,000	0.0271
Xylene	ND			37	37,000	0.0277	37	37,000	0.0346

Permit Assumptions:

Southern area design flow = 600 cfm

Northern area design flow = 200 cfm

Central area design flow = 250 cfm

Vapor concentrations from Table 3-2

Table 4–11

Estimated VOC Emission Rates from Northern Groundwater Air Stripper Wellsville, New York

Compounds	Groundwater Concentration (ug/l)	Emission Rate @ 50 gpm (lbs/hr)
Benzene	500	0.0125
Toluene	400	0.0100
Ethlybenzene	500	0.0125
Xylene	2,200	0.0550
Vinyl Chloride	230	0.0057
1,1–Dichloroethane	140	0.0035
1,2–Dichloroethane (total)	5,000	0.1249
1,1,1–Trichloroethane	530	0.0132

for total emissions. The Standard Point Source Method is a conservative dispersion equation that details a simple approximation of the ambient impact of a constituent of concern. The method calculates the maximum annual impact (C_a), the maximum potential annual impact (C_p) and the short-term ambient impact (C_{st}). Results from the potential annual impact equation are compared to the ambient standards to determine if special permit conditions are to be added to restrict the hours per year of operation. Short-term impacts represent one hour exposure limits, the maximum annual impact represents a 70 year exposure limit.

The maximum annual impact equation (equation 4.1) is as follows:

$$C_a = \frac{0.482 \times Q_a}{h_e^{2.16}} \qquad 4.1$$

where:

C_a = ambient air concentration (ug/m^3)
Q_a = constituent emission rate (lbs/yr)
h_e = stack height (ft)

The maximum potential annual impact equation (equation 4.2) is as follows:

$$C_p = \frac{4{,}218 \times Q}{h_e^{2.16}} \qquad 4.2$$

where:

C_p = ambient air concentration (ug/m^3)
Q = constituent emission rate (lbs/hr)
h_e = stack height (ft)

Permit conditions may restrict the hours per year of operation if $C_p >$ air standard, but $C_a <$ air standard.

The short-term impact equation (equation 4.3) is:

$$C_{st} = C_p \times 420 \qquad 4.3$$

An example of the equations used for the SPS method are presented here for benzene concentration. Total height of the stack is estimated to be 15 feet from the ground surface.

Plume rise was not considered (Section III.A.1.a) for the effective stack height. So the effective stack height (h_e) is equal to the physical stack height (h_s). The maximum Actual Annual Impact, C_a (Section III.A.2.), of benzene was calculated to be 0.03 ug/m^3 using equation 4.1.

where:

Q_a	=	treated emission rate in lbs/yr (24.53 lbs/yr)
h_e	=	the physical stack height in feet (15 ft)

The maximum Potential Annual Impact, C_p (Section III.A.3.), from the stack was calculated using equation 4.2.

where:

Q	=	treated emission rate in lbs/hr (0.0028 lbs/hr)
h_e	=	the physical stack height in feet (15 ft)

Potential Annual Impact for benzene was calculated to be 0.03 ug/m^3.

The maximum Short-Term Impact, C_{st} (Section III.A.4), for benzene was calculated to be 14.1 ug/m^3, using equation 4.3. Results from the Actual Annual method represent concentrations associated with long-term exposure levels. Results are compared to the Annual-average-based Guideline Concentrations (AGCs) presented in Air Guide-1. AGCs are ambient constituent concentration limits developed to protect the environment and public health from the effects which may be associated with long-term exposure. The Potential Annual Impact method predicts hourly ambient concentrations that may be influenced by process conditions. Restriction in operation may be required if C_p >AGC but, C_a <AGC.

The Short-Term Impact equation predicts ambient constituent concentrations which might be associated with acute exposures effects. Short-term ambient Guideline Concentrations (SGCs) are also presented in Air Guide-1 and are analogous to < 1 hour exposure impact levels.

The production of HCL is expected to be 0.15 lbs/hr, using the assumption of 1 lb of HCL per 1 lb of chlorinated VOCs oxidized. This level is below the EPA/NYSDEC guidelines (EPA 40 CFR part 264.343) of 4 lbs/hr.

As indicated in Table 4-10 all of the parameters are in compliance with the acceptable ambient concentrations established by NYSDEC. Air Guide - 1

According to NYDEC, when there are multiple sources of a contaminant, the individual source impacts should be summed to determine a worst case total ambient impact. Alternatively, an impact may be estimated by summing the emissions and assuming a single point source. Table 4-12 presents the results from the air permitting program, as the sum of emission rates out of one point source, at the Site.

Results indicate that predicted emission rates concerning compounds of interest from the remedial treatment systems are in compliance with NYDEC part 212 air regulation. Regulation 212 states that emission rates of highly toxic compounds (benzene and vinyl chloride) above one lb/hr must control emissions using BACT. The emission rates for benzene and vinyl chloride were predicted at 0.27 and 0.006 lbs/hr, respectively and are below regulation 212 standard for use of BACT; however, predicted emission rates for benzene would necessitate use of RACT. The remaining organic compounds of concern, rated moderate to low in toxicity, had predicted emission rates far below Regulation 212 of 10 lbs/hr.

During the course of the remedial treatment program, off-gas streams will be monitored on a periodic basis to determine compound emission rates. If during the course of operations, influent monitoring data indicates that air meets permit requirements without treatment, ARCO may seek EPA/NYSDEC permission to discharge the air directly without treatment. Subsequently, the off-gas treatment system would be re-activated if the measured emission rate indicated non-compliance with the appropriate ambient air standard (Air Guide 1).

Table 4-12

Modeled Ambient Air Concentrations
From Remedial Treatment Systems
Northern and Southern Areas
Wellsville, New York

Area Emission Rates (lbs/hr)	Northern		Southern	Central	Total	99% Contolled	Modeled Concentrations (ug/m^3)			NYDEC Limits (ug/m^3)	
Compounds	Groundwater Stripper	Soil Vapor Extraction	Soil Vapor Extraction	Soil Vapor Extraction	Emissions	Emissions	Annual C_a	Potential C_p	Short-Term C_{st}	AGC	SGC
Benzene	0.0125	0.1047	0.0283	0.1310	0.2765	0.0028	0.033	0.034	14.1	0.12	30
Toluene	0.0100	0.0269	0.0112	0.0337	0.0818	0.0008	0.010	0.010	4.2	2,000	89,000
Ethlybenzene	0.0125	0.0217	0.0124	0.0271	0.0737	0.0007	0.009	0.009	3.8	1,000	100,000
Xylene	0.0550	0.0277	ND	0.0346	0.1172	0.0012	0.014	0.014	6.0	300	100,000
Vinyl Chloride	0.0057	ND	ND	ND	0.0057	0.0001	0.001	0.001	0.3	0.02	1,300
1,1-Dichloroethane	0.0035	ND	ND	ND	0.0035	0.0000	0.0004	0.0004	0.2	500	190,000
1,2-Dichloroethane (total)	0.1249	ND	ND	ND	0.1249	0.0012	0.015	0.015	6.4	1,900	190,000
1,1,1-Trichloroethane	0.0132	ND	ND	ND	0.0132	0.0001	0.002	0.002	0.7	1,000	450,000
Total	0.2373	0.1810	0.0519	0.2264	0.6966	0.0070					

Permit Assumptions:
Stack height = 15 ft
ND = Not Detected

5.0 PRELIMINARY DESIGN

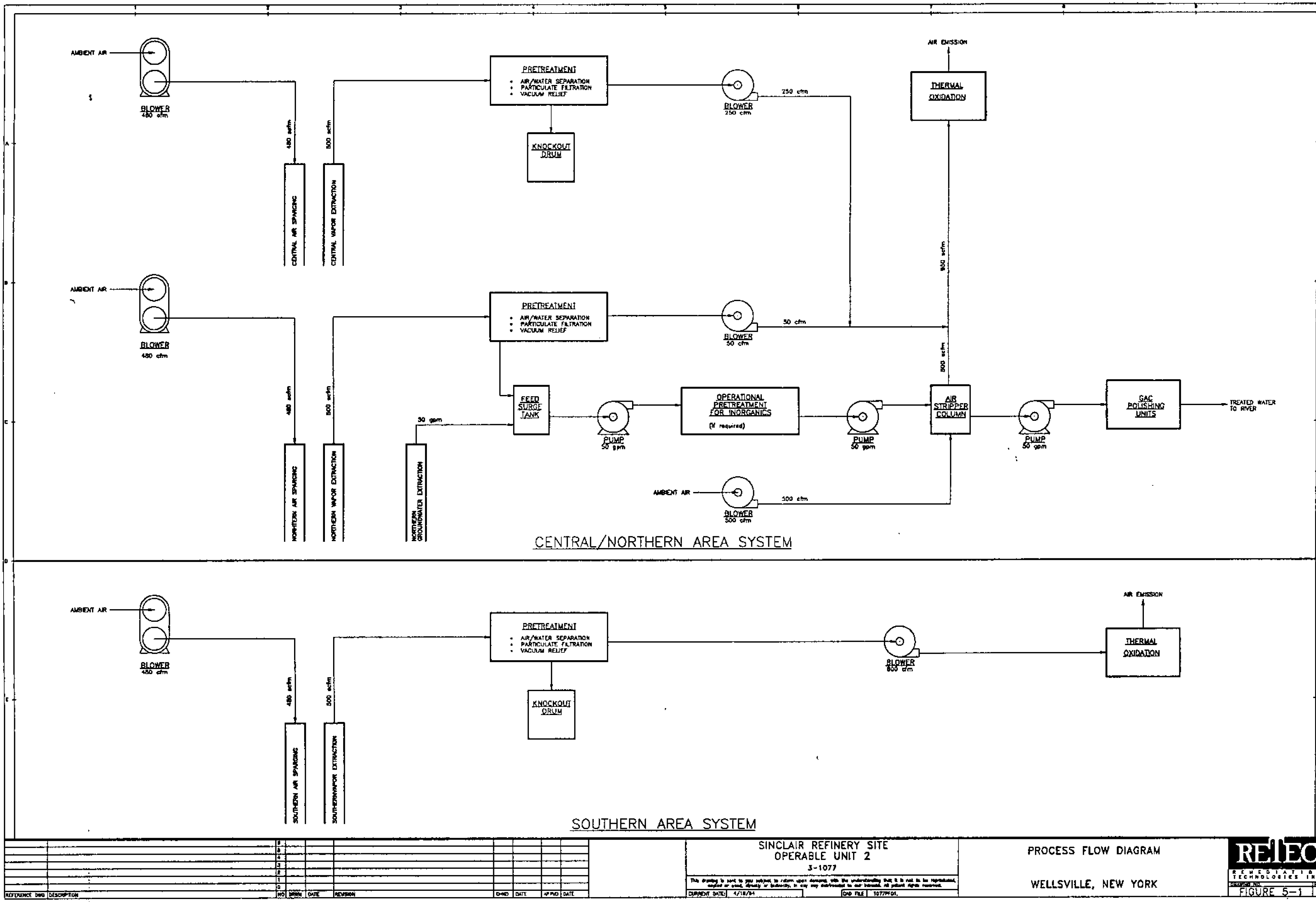
This section presents the preliminary design for the groundwater remediation system at Operable Unit 2 of the Sinclair Refinery Site. Section 5.1 provides an overview of the complete system for remediating the site. It describes the major treatment components including groundwater aeration, vapor extraction, groundwater extraction, aboveground groundwater treatment and offgas treatment and how they will be integrated to accomplish the remediation objectives. More detailed design information on the subsystems and their components is presented in Section 5.2. This includes the process description, the process parameters and the configuration and layout of the equipment as well as the methods to be used to monitor the operation and performance of these systems.

5.1 Preliminary Design

The Record of Decision stipulates that a pump-and-treat system be used as a remedial component for the groundwater at the Site. The primary chemicals of interest are detailed in Section 4.0. In order to enhance the pump-and-treat and reduce the time required to remediate the Site, the preliminary design incorporates soil venting and groundwater aeration in combination with conventional pump-and-treat to enhance contaminant removal and expedite remediation focusing aggressive treatment not only on the dissolved constituents, but also treating the source of these constituents to groundwater.

The site has been divided into three primary areas designated the Northern, Central and Southern Areas. The Northern Area is the focus for the pump-and-treat technology given the proximity of the plume of impacted groundwater to the Genesee River. In addition, enhanced recovery of organics via soil venting and groundwater aeration will be employed to remove benzene from an area with elevated concentrations in the western edge of this area. In the Southern Area, soil venting and groundwater aeration will be used to strip the volatile organics *in situ* in this area from both groundwater and soils. In the Central Area, no source of organic constituents has been identified in soils. Venting and aeration will be used in the Central Area to treat groundwater.

The process flow diagram, Figure 5-1, which presents the major unit operations of the Northern/Central and Southern treatment systems can be referred to for the following discussion of the preliminary design. The pumped groundwater will be pretreated as required to protect the aqueous volatile organic treatment processes. The aqueous volatile organic treatment


AMBIENT AIR
BLOWER
480 cfm
PRETREATMENT
• AIR/WATER SEPARATION
• PARTICULATE FILTRATION
• VACUUM RELIEF
KNOCKOUT DRUM
480 scfm
500 scfm
CENTRAL AIR SPARGING
CENTRAL VAPOR EXTRACTION
BLOWER
250 cfm
250 cfm
AIR EMISSION
THERMAL OXIDATION
500 scfm
AMBIENT AIR
BLOWER
480 cfm
PRETREATMENT
• AIR/WATER SEPARATION
• PARTICULATE FILTRATION
• VACUUM RELIEF
BLOWER
50 cfm
50 cfm
500 scfm
480 scfm
500 scfm
50 gpm
FEED SURGE TANK
PUMP
50 gpm
OPERATIONAL PRETREATMENT FOR INORGANICS
(if required)
PUMP
50 gpm
AIR STRIPPER COLUMN
PUMP
50 gpm
GAC POLISHING UNITS
TREATED WATER TO RIVER
AMBIENT AIR
BLOWER
500 cfm
500 cfm
NORTHERN AIR SPARGING
NORTHERN VAPOR EXTRACTION
NORTHERN GROUNDWATER EXTRACTION
CENTRAL/NORTHERN AREA SYSTEM
AMBIENT AIR
BLOWER
480 cfm
PRETREATMENT
• AIR/WATER SEPARATION
• PARTICULATE FILTRATION
• VACUUM RELIEF
KNOCKOUT DRUM
480 scfm
500 scfm
SOUTHERN AIR SPARGING
SOUTHERN VAPOR EXTRACTION
BLOWER
800 cfm
AIR EMISSION
THERMAL OXIDATION
SOUTHERN AREA SYSTEM
REFERENCE DWG DESCRIPTION
NO DRWN DATE REVISION CHKD DATE APPVD DATE
SINCLAIR REFINERY SITE
OPERABLE UNIT 2
3-1077
CURRENT DATE: 4/18/94
CAD FILE 1077PF01.
PROCESS FLOW DIAGRAM
WELLSVILLE, NEW YORK
RETEC
REMEDIATION TECHNOLOGIES INC
FIGURE 5-1
0

processes include air stripping followed by granular activated carbon treatment. During the 65% design phase, the pretreatment process for protecting the air stripper and carbon from fouling will be refined and incorporated into the system design. The vapor phase chemicals-of-interest separated by the air stripper will be combined with the vapors collected by the Northern and Central Area soil venting systems and sent to a thermal oxidizer for final destruction. The volatile organic compounds stripped in the subsurface by the Southern Area groundwater aeration system and collected by the Southern Area soil venting system will be sent to a second independent regenerative thermal oxidizer for final destruction. A more detailed description of the Northern, Central and Southern Area treatment systems is presented below.

5.2 Design Components

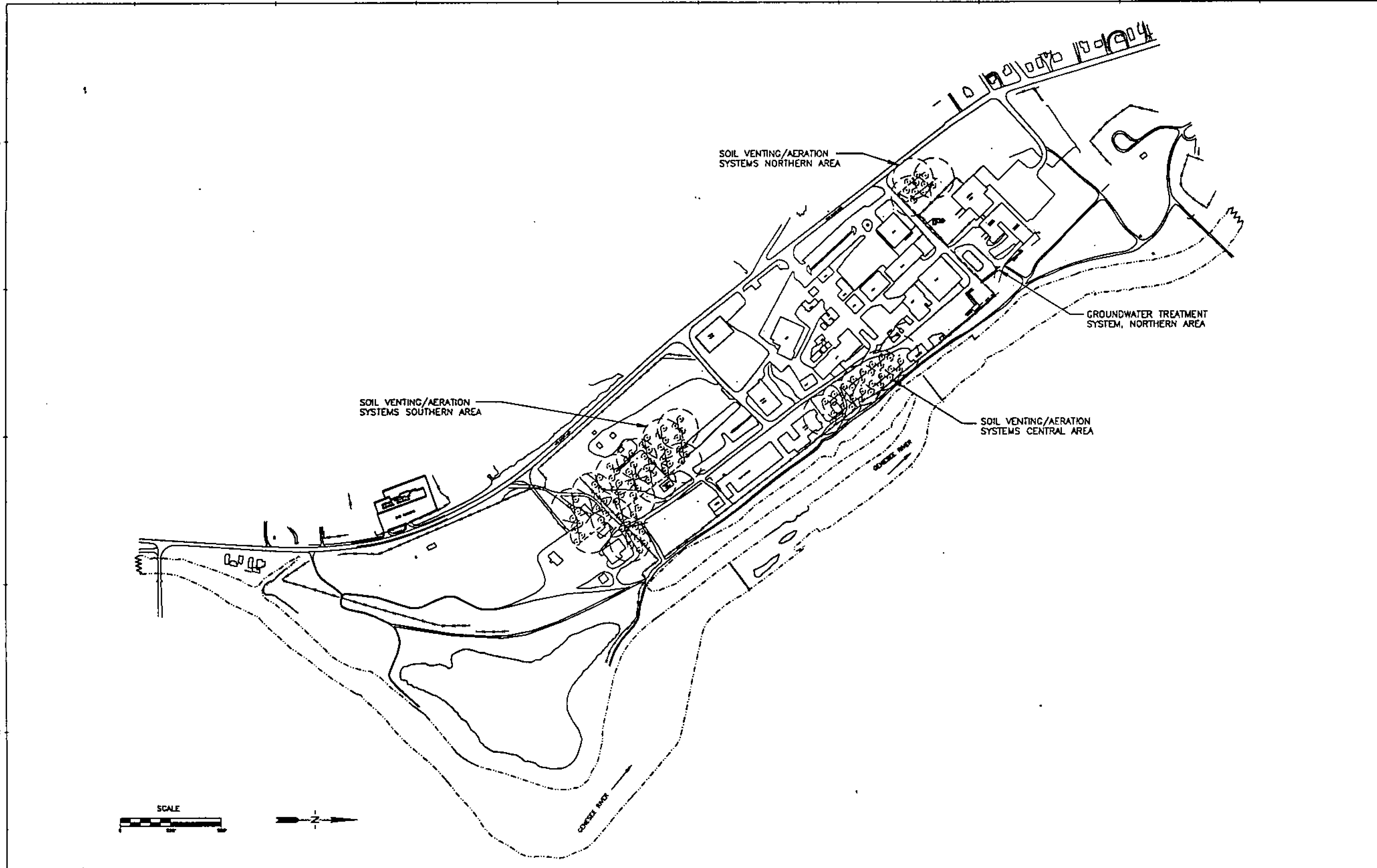
Implementation of the groundwater treatment system described above will require the design of seven specific component systems including the following:

- civil design;
- groundwater extraction system;
- air sparging system;
- vapor extraction system;
- water treatment system;
- vapor treatment system; and
- monitoring.

A description of the details of each of these components is presented below.

5.2.1 Civil Design

The civil components of the design include a shelter which will be constructed as part of the groundwater remedy and associated infrastructure improvements. Figure 5-2 shows the site layout including the treatment system locations. In the Northern Area, the shelter shown will enclose the groundwater and vapor treatment systems. The shelter will be a steel frame building, 40 feet by 60 feet with insulated steel roof and walls. The building foundation will be a reinforced concrete with a slab-on-grade which will include a concrete curb to act as containment for the largest tank included in the system. In the Southern Area, the treatment system will be installed on a 20 foot by 40 foot reinforced concrete slab surrounded by a chain



ARCO	SINCLAIR REFINERY SITE OPERABLE UNIT 2 3-1077	SYSTEM LAYOUT PLAN WELLSVILLE, NY	RETEC REMEDIATION TECHNOLOGIES INC FIGURE 5-2 A

A | PROPOSED DESIGN LAYOUT

link fence to prevent unauthorized access. All installations which are part of the treatment system will be constructed in accordance with the National Electrical Code which includes provisions for preliminary fires and explosions. Appropriate provisions for ventilation will be incorporated into the design to satisfy code.

Other required civil design elements will be the temporary construction facilities and structures which will include access roads, storage areas, utility installations, office trailers and decontamination facilities. The details and locations of these facilities will be determined during later phases of the design.

5.2.2 Groundwater Extraction

Process Description

The groundwater extraction system consists of a number of wells which are used to capture COI migrating into the Genesee River in the area of the Northern oil/water separator. The design of the groundwater extraction system has been refined to include the results of groundwater simulation of the flow system at the site and the integration of the vapor extraction and air sparging systems in the area of monitoring well MW-52, on National Fuels property.

A steady-state model has been constructed using MODFLOW, a modular, three-dimensional, finite-difference flow model to simulate groundwater flow conditions and to select the location, number, and pumping rates of wells. A particle tracking model, MODPATH, was used to determine the area of contribution to the pumping wells. Both MODFLOW and MODPATH are widely used models which were developed by McDonald and Harbaugh (1984) and Pollock (1989) for the U.S. Geological Survey. Documentation for the modeling is presented in Appendix D.

Containment of the soluble plume will be achieved in the area of the Northern oil/water separator with three strategically placed extraction wells, each pumping at a rate of 10 gpm. The maximum predicted drawdown is approximately 5.5 feet in the center of the three wells. Recovered ground water will be pumped to an above ground treatment system prior to discharge to the river.

System Layout

The groundwater extraction system for the site will consist of three wells located within the area of the Northern oil/water separator adjacent to the Genesee river. These wells will operate at rates ranging from 10 to 17 gpm each to maximize contaminant mass removal and containment. The three wells will provide a combined pumping rate ranging from 30 to 50 gpm. The wells will be aligned in a southeast to northwest direction spaced approximately 150 feet apart with the central well located at MWP-57. The recovery wells will be eight-inch to ten-inch gravel packed wells approximately twenty feet deep. Well screens will be five to ten feet in length and will be of wire-wrapped construction to maximize well efficiencies. The Remedial Investigation concluded concentrations of chlorinated solvents decrease with depth. Therefore, no heavier-than-water constituents are anticipated and screening the bottom of the aquifer should not be necessary. Figure 5-3 shows the location of the extraction system wells.

5.2.3 Air Sparging System

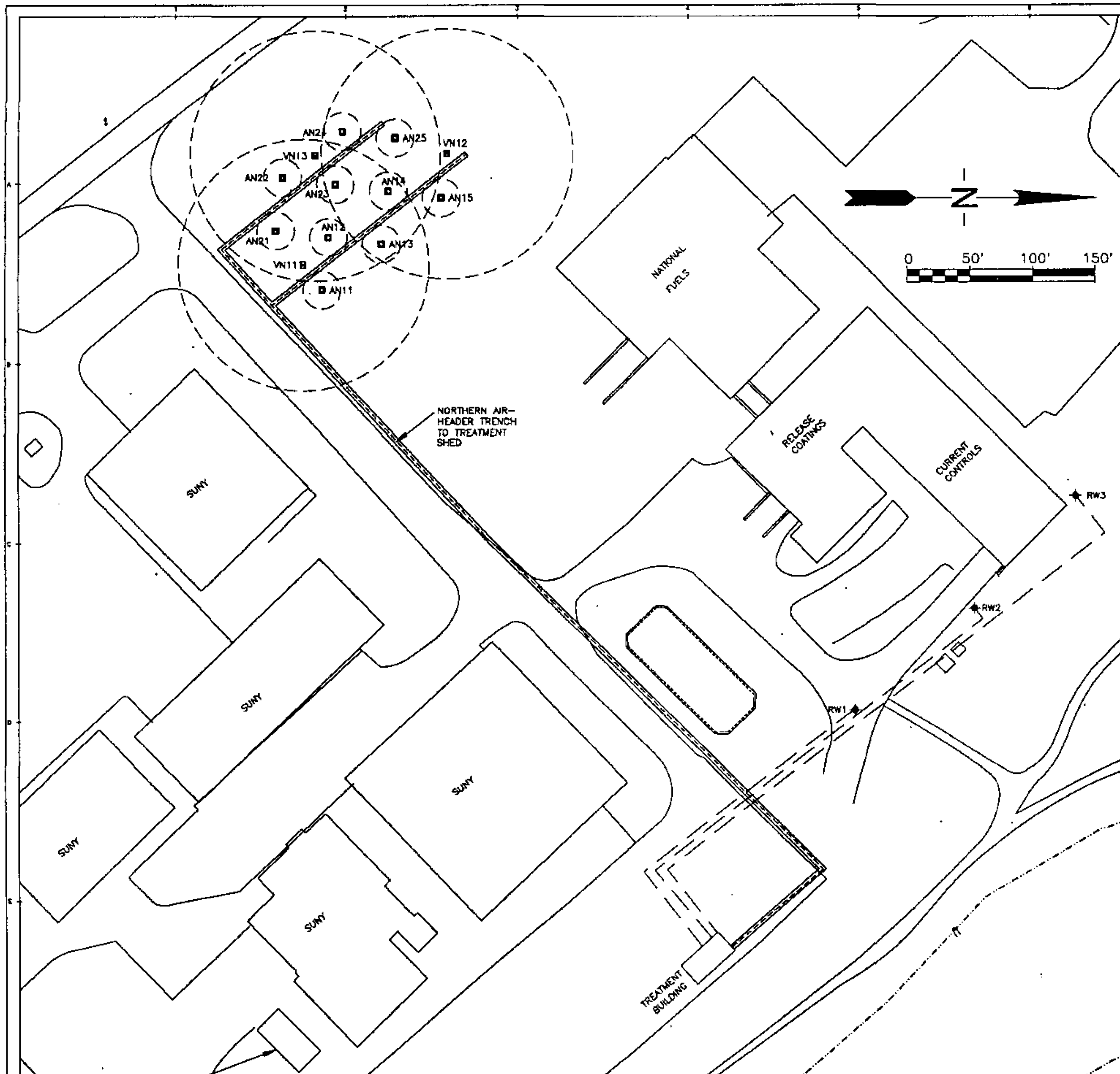
Process Description

In an air sparging or groundwater aeration system, air is injected into a permeable aquifer. The injected air moves outward and upward from the point of injection through the pores of the saturated zone. As it permeates, the injected air competes with the water present in the soil pore space, driving the water out temporarily and replacing it with air. This causes significant turbulence and mixing at the soil/water/air interface. The use of air sparging, coupled with vapor extraction, is a highly effective means of effecting the volatilization and removal of VOCs from the saturated zone. As the air moves through the saturated zone, VOCs will partition into the vapor phase from the water and soil phase. Additionally, the increase in dissolved oxygen in the aquifer will increase *in situ* biodegradation resulting in additional mass removal. The VOCs travel with the air upward to the unsaturated zone where they are captured by a soil venting system which removes the air. The exhaust air from the blower is discharged after treatment.

Process Parameters

The parameters upon which the air sparging system will be based are:

- air injection rate and pressure;



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CURRENT DATE: 03/16/94 CAD FILE: 1077..01.DWG

AIR INJECTION AND EXTRACTION SYSTEMS
AND GROUND WATER RECOVERY SYSTEM
NORTHERN AREA
WELLSVILLE, NY

RETEC
REMEDIATION TECHNOLOGIES INC

DRAWING NO. FIGURE 5-3 REV. A

- number of wells; and
- radius-of-influence (ROI) as defined by well design, depth of screen, air pressure, and depth of water.

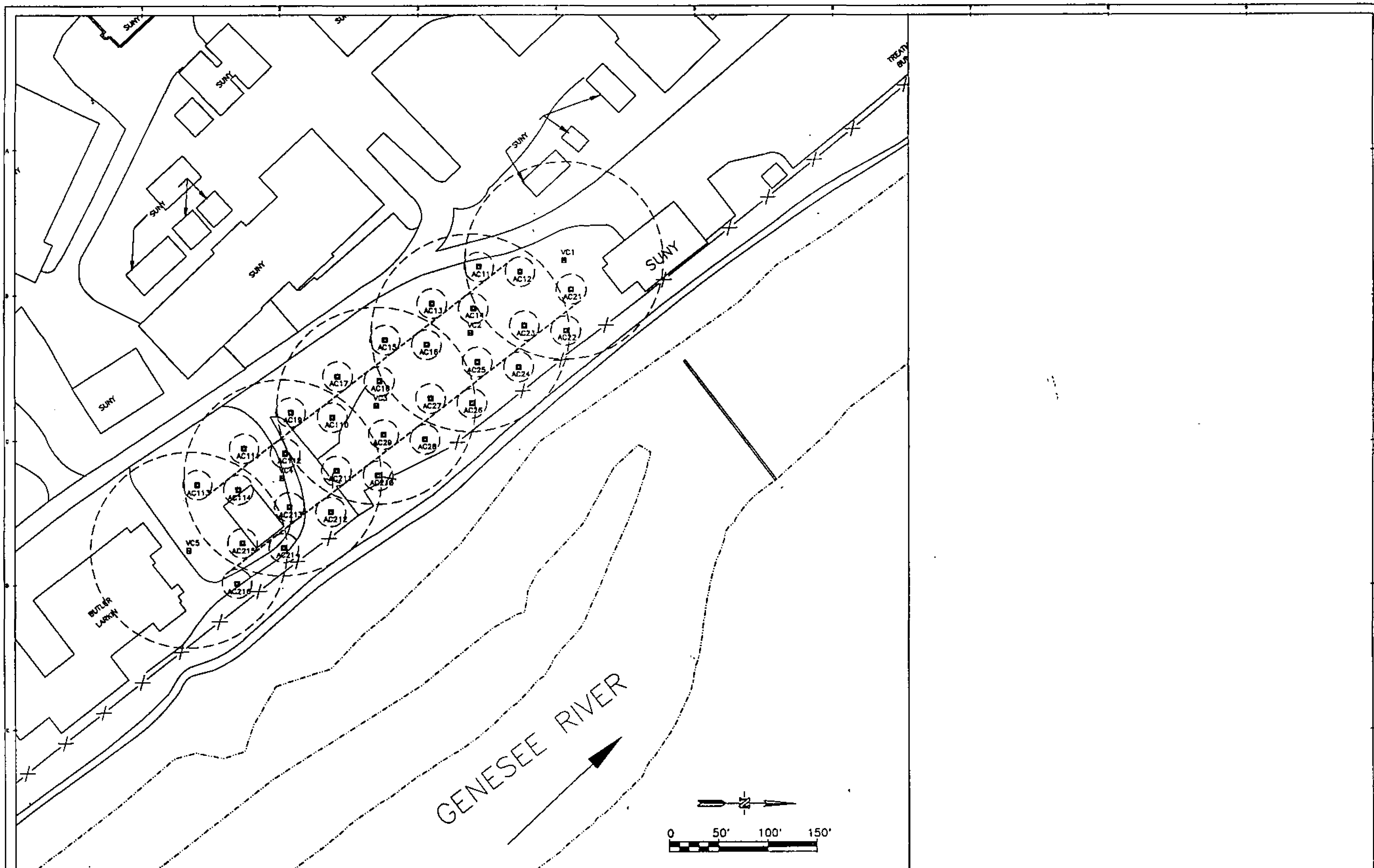
The basic design parameters for an air sparging system are the pressure and rate at which compressed air is injected into the aquifer and the resulting radius of influence (ROI). This pressure is dependent on the depth of the injection point below the water table. However, the achievable radius of influence is limited by the operating pressure which produces fracturing or short circuiting of the air flow through the formation and/or an excessively turbulent air flow regime. Past experience shows that the estimated ROI of each injection point is conservatively equal to the saturated thickness above the injection point.

Given a preliminary depth of the screen 30 feet below the water table, the radius of influence for a sparging well set immediately above the aquitard is estimated to be 30 feet. This general rule was a fair approximation for this site where the ROI for the southern area was measured at twenty feet and the ROI of the northern area was noted at 15 feet. The injection points of the two pilot areas were 26 to 24 ft below ground surface (bgs) for the southern system and 25 to 23 ft bgs for the northern system. The ROI in this case was measured by the increase in DO in the surrounding monitoring wells.

Another key parameter is the ratio of the air withdrawal rate to air injection rate. To insure that all injected air is extracted by the vapor extraction system, a ratio of two or greater is maintained or the air injection flow rate is kept at approximately 50% of the extracted flow rate. Past studies have shown that operating sparging systems in a pulsed manner can help make system operations more effective by minimizing channelling of air in the saturated zone. Channeling occurs when air travels in preferential channels through the soil. This effect creates areas within the saturated zone soils where air does not penetrate and where the dissolved oxygen concentration is low. Pulsed operation of the system is achieved by operating only half of the sparging wells in each treatment area at any one time. Turning the wells on and off has been found to be an effective procedure for closing old flow paths and creating new ones. For this reason, the design air sparging flow rates in each area of the site are one half of the maximum possible flow rate from that area.

System Layout

The system layouts for the Northern, Central and Southern Areas are presented in Figures 5-3, 5-4 and 5-5 . The system layout for National Fuels consists of 10 sparging wells



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AIR INJECTION AND
EXTRACTION SYSTEMS
CENTRAL AREA
WELLSVILLE, NY

REMEDIATION TECHNOLOGIES INC

FIGURE 5-4 | A

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AIR INJECTION AND
EXTRACTION SYSTEMS
SOUTHERN AREA
WELLSVILLE, NY

RETEC
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DRAWING NO. FIGURE 5-5
REV. A

arranged in an array of four lines with alternating spacing. The lines are located perpendicular to the direction of groundwater flow with a diagonal spacing of 30 feet and 60 foot-on-center for each header. The diffusion of air, pressure differences, and groundwater flow will increase the zone of influence to help insure the entire source area is treated. Each header supplies air to five sparging wells at a rate of 6 to 10 scfm at 8 to 10 psi.

The Central Area aeration system consists of 30 wells on two headers. Layout for the system is similar to that of the Northern Area. The wells are oriented perpendicular to the groundwater flow. The wells are layed out with a ROI of 15 feet and are designed for a flow of 6 to 10 scfm at 8 to 10 psi.

The southern system consists of 67 air sparging wells situated on eight headers. The lines of these wells are positioned perpendicular to the direction of flow identified in this area. The well spacing is 30 feet diagonal and 60 feet-on-center on each header pipe. Each header pipe supplies air to up to eight sparging wells at a rate of 6 to 10 scfm at 8 to 10 psi. The air sparging wells are spaced such that the ROI of the air sparging wells are contained within the ROI of the vapor extraction wells to insure that all injected air is captured by the vapor extraction system. Headers are designed with five to eight wells each. A manifold system including valves and meters will allow individual adjustment of the pressure and flow rate at each sparging well.

5.2.4 Vapor Extraction System

Process Description

Vapor extraction, or soil venting, is the process by which soil gas containing VOCs is flushed from the unsaturated soil (vadose zone) for the purpose of reducing VOC concentrations in the soil gas, thus reducing soil VOC concentrations. Vapor extraction is achieved by installing a slotted pipe into the vadose zone in the area of contamination. Air is then flushed through the soil by applying low vacuum pressure to the pipe. The VOCs are flushed from the soil in the soil gas along with the flushing air.

Typically for an extraction system, the concentration of VOC's declines and levels off at lower concentrations. As the soil vapor extraction replaces the saturated air with cleaner air, there is an exponential decline in soil vapor concentration. Initially, the system is exhausting vapors laden with VOCs. After the first few weeks, the concentrations typically decrease rapidly. At this point the VOCs, which are adsorbed to the soil, partition to the air phase and are flushed out through the venting system.

Process Parameters

The parameters upon which the vapor extraction system will be based are:

- soil permeability;
- depth to water table;
- area-of-influence of wells and trenches; and
- flush rate.

The basic design parameters for a vapor extraction system are the ROI of the well, and the air flow induced into the blower. The ROI is the radial distance from a well over which the air flow is induced in the vadose zone; it corresponds to the distance over which soil remediation can be expected. The ROI is defined in terms of the air flush rate induced by the well, or the number of pore volumes flushed out of the vadose zone per day.

Based on preliminary modeling, it is estimated that for a flush rate of 3 pore volumes per day, the ROI of each soil vapor extraction well is at least 100 feet. The flow rate of air extracted from the soil depends on the applied vacuum, and on site specific parameters such as the soil permeability. The model predicts that with 40 inches-of-water column vacuum at the collection header, a flow of 50 scfm will be induced in each vapor extraction well.

System Layout

Three vapor extractions wells will be installed in the National Fuels area. Each well will be installed 150 feet-on-center and operated at 50 scfm at approximately 40-inches of water. This array results in a operational ratio of approximately 0.5, volume of sparging air injected versus the volume of air extracted, taking into account the pulsed approach to air sparging discussed above resulting in a total flow from this area of approximately 150 scfm . The Central Area treatment system consists of five extraction wells installed about 150 feet apart as shown on Figure 5-4. The system will be operated at a rate of 50 scfm per well at a vacuum of an estimated 40 inches of water for a total flow of 250 scfm..

The southern system is composed of 12 vapor extraction wells located approximately 150 feet-on-center operating at 50 scfm at approximately 40-inches of water. This system will have an approximate operational ratio of 0.5 depending on localized variations in vadose zone permeability. This array will result in a total flow of 600 scfm for the southern area.

5.2.5 Water Treatment System

Design Parameters

The groundwater treatment system is designed is remove volatile organics on a continuous basis from the water generated by the groundwater extraction system described in Section 5.2.2. The primary treatment for removing the majority of the organics is air stripping. It is followed by liquid phase carbon adsorption which removes the residual trace quantities of organics. A SPDES permit application submitted to EPA and NYSDEC which includes criteria for iron and the constituents of concern. The final treatment will meet those discharge criteria. A copy of the application is included in Appendix A. The design conditions, expected influent concentrations and the required discharge levels are summarized in Table 5-1.

The design of the system will be controlled by the compound vinyl chloride. The design objective will be to maximize the removal of the vinyl chloride in the air stripper. This will be done because of vinyl chloride's poor loading capacity on the liquid phase carbon. Even though the air stripper does not have to meet the discharge requirements by itself, if any significant amount of vinyl chloride is left in the groundwater then the utilization rates for the liquid phase carbon will be very high.

The design of the stripper, i.e. the number of stages for contacting the air and the water and the air to water volumetric ratio, will be determined by comparing results from modelling with vendor recommendations and historical data.

Process Flow Description

The groundwater treatment system is shown schematically in the process flow diagram, Figure 5-1. The groundwater is pumped from the individual wells by the submersible pumps via a manifold to the Northern groundwater treatment system. The system is designed to handle a total of 50 gpm from the groundwater extraction system.

TABLE 5-1
Groundwater Treatment System Design Basis

Parameter	Nominal/Average	Design
Groundwater Flowrate	30 gpm	50 gpm
Air Temperature	50 F	10 F
Groundwater Temperature	55 F	45 F

Compound	Design Influent (ug/L)	Proposed Permit Discharge Limit (ug/L)
Benzene	500	139
Ethyl Benzene	500	9,900
Toluene	400	9,900
Xylenes	2200	9,900
1,1-Dichloroethane	140	9,900
1,2-Dichloroethylene	5000	9,900
1,1,1-Trichloroethane	530	9,900
Vinyl Chloride	230	390
Arsenic	180	9,900

The groundwater is collected in the feed surge tank. The surge tank will be sized to handle any flow surges which will be primarily due to water generated from backwashing the carbon filters. The surge tank will also serve to equalize the flow and concentration of contaminants to the treatment system which will improve process control.

The groundwater is then pretreated, if necessary, to remove iron and manganese which can decrease the efficiency of the organics treatment system by fouling or plugging the air stripper and carbon adsorption beds. The fouling will be caused by the deposition of precipitated iron and bacteria on the surfaces of the stripper, the carbon and interconnecting piping. If the metals are removed, the pretreatment system will include operations to add chemicals to minimize iron solubility, to oxidize the metals and to flocculate the precipitates to form a sludge which can be dewatered and disposed of off site.

The groundwater is then pumped to an air stripper which is designed to remove the volatile organics. A blower forces ambient air into the stripper which is brought into intimate counter current contact with the groundwater. The mass transfer area will be provided for by random packing in a tower stripper or by a series of perforated contacting plates in a low profile stripper. The stripper offgas is then passed through an internal demister to remove entrained water and is sent to the Northern area vapor treatment system. The treated groundwater is then pumped either from the internal or external sump of the stripper through the liquid phase carbon beds.

The liquid phase granular activated carbon beds are designed to remove the trace amounts of volatile organics remaining in the stripped groundwater. Two carbon beds operating in series will be used. When breakthrough occurs in the primary bed, the carbon will be replaced in that bed and the order of the series will be reversed. With proper monitoring of the first carbon vessels discharge, meeting the discharge criteria will be ensured, see section 5.2.7. The treated groundwater will then be directly discharged to the Genesee River.

5.2.6 Vapor Treatment System

Northern/Central Vapor Treatment System Design Parameters

The vapor treatment system for the Northern/Central area is designed to treat the combined offgas from the soil venting systems in the Northern and Central Areas and the air stripping system in the Northern Area. The concentrations of volatile organics from the soil venting stream were taken from actual field soil venting tests performed in the Northern area. Although no field pilot test was performed in the Central Area, use of the design values from the Northern Area should be conservative because soil and groundwater BTEX concentrations are significantly greater in the area around National Fuels. The concentrations for the emissions from the air stripper were calculated on the conservative assumption that all of the organics present in the groundwater are stripped. The design basis assumes based upon preliminary modeling that 50 gpm of groundwater is stripped with 500 cfm of air which represents an air to water volumetric ratio of 75 to 1. It also assumes that up to nine vapor extraction wells drawing at 50 cfm of air each is also sent to the Northern vapor treatment system. The design conditions, expected influent and discharge rates are summarized in Table 5-2.

The design of the system was determined by the presence of chlorinated organics, particularly vinyl chloride. The design objective will be to maximize the removal of the organics from the offgas. This would be difficult and expensive to accomplish with vapor phase carbon due to the extremely low loading capacity of vinyl chloride on vapor phase carbon. A catalytic oxidizer will not be used due to the uncertainty of the destruction removal efficiency and operation and maintenance issues associated with the chlorinated organics. For preliminary purposes, a thermal oxidizer is planned to control the offgas. Destruction removal efficiencies greater than or equal to 99% are easily attained for the compounds present with a thermal oxidizer. A regenerative style thermal oxidizer will be used to increase thermal efficiency, i.e. heat recovery.

Northern Vapor Treatment System Process Flow Description

The Northern vapor treatment system is shown in the process flow diagram, Figure 5-1. The soil venting gas is drawn under vacuum from the vapor extraction wells by the soil venting blower. The collected vent gas is sent through a knockout drum to remove any entrained moisture before the gas is sent by the blower to the combined offgas treatment train. The knockout condensates are drained to the groundwater treatment system's surge tank. The airstripper offgas, after passing through an internal demister to knockout its entrained water, combines with the vent system off gas before entering the thermal oxidizer.

Internal to the regenerative thermal oxidizer, the incoming, untreated gas passes over a hot bed of silica. The initial heating of the bed is provided for by an electrical coil. As the combustion of the offgas takes place, the heating of the bed material is supplemented or replaced by the heat of combustion provided by the organics in the offgas. The direction by which the feed gas and combusted gas pass through the bed is alternated to keep the surface temperature

TABLE 5-2

Northern Area Vapor Treatment System Design Basis

Parameter	Design Value
Vapor Flowrate	950 cfm
Process Air Temperature	45 F
Ambient Air Temperature	10 F

Compound	Design Influent Flows (lb/hr)	Estimated Discharge @ 99% DRE (lb/hr)
Benzene	0.2432	0.0025
Ethyl Benzene	0.0613	0.0006
Toluene	0.0706	0.0007
Xylenes	0.1173	0.0012
1,1-Dichloroethane	0.0004	0.0000
1,2-Dichloroethylene	0.1250	0.0013
1,1,1-Trichloroethane	0.0130	0.0001
Vinyl Chloride	0.0060	0.0001

of the bed material constant. The heat recovery for these units is on the order of 95-99%. Thus the thermal oxidizer offgas is not significantly above ambient temperature. The offgas is then discharged to the atmosphere through a stack.

Southern Vapor Treatment System Design Parameters

The vapor treatment system for the Southern area is designed to treat the offgas from the Southern soil venting system. The concentrations of volatile organics from the soil venting stream were taken from actual field soil venting tests performed in the Southern Area. The design basis assumes up to 12 vapor extraction wells drawing 50 cfm of air each which are collectively sent to the Southern vapor treatment system. The design conditions, expected influent and discharge rates are summarized in Table 5-3.

Southern Vapor Treatment System Process Flow Description

The Southern vapor treatment system is also shown in the process flow diagram, Figure 5-1. The Southern system will handle only offgas from a soil venting system. The soil venting gas is drawn under vacuum from the vapor extraction wells by the soil venting blower. The collected vent gas is sent through a knockout drum to remove any entrained moisture before the gas is sent by the blower to the final offgas treatment system. The knockout condensates are drained to a collection vessel, a 55-gallon drum whose contents can be manually transferred to the Northern groundwater treatment system's surge tank. The vent gas discharged from the blower is sent to the Southern area regenerative thermal oxidizer. The process description for this unit operation is supplied in the description of the Northern vapor treatment system.

5.2.7 Preliminary Design

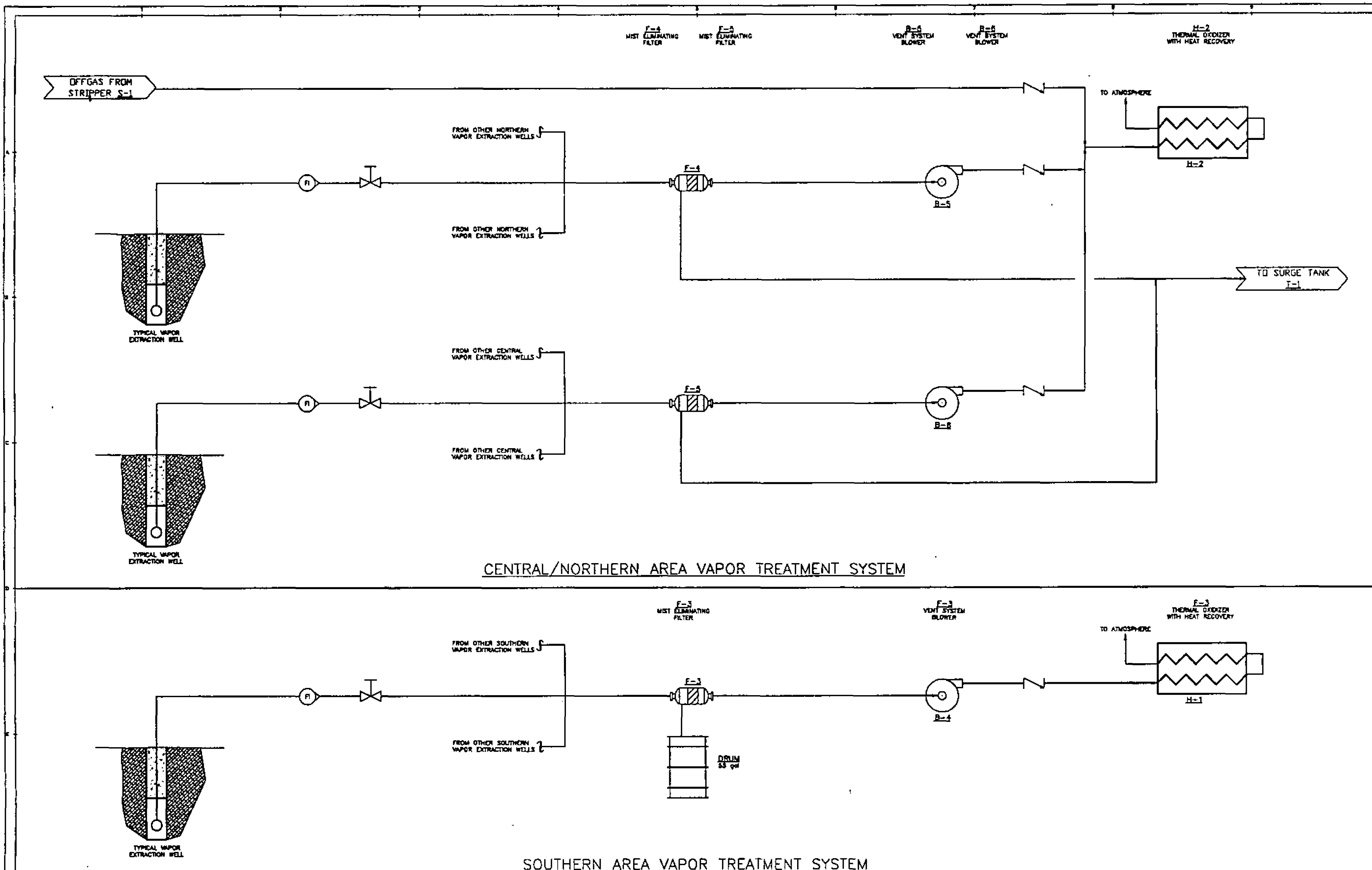
A preliminary set of piping and instrumentation diagrams and the associated equipment list are shown in Figures 5-6 and 5-7 and Table 5-4. These preliminary documents show the southern vapor treatment system and the northern treatment system. The northern treatment system includes the vapor treatment system and the groundwater treatment system which includes for completeness the operational pretreatment equipment for removing metals. If these pretreatment unit operations are found to be unnecessary, they will be removed from the final design.

TABLE 5-3

Southern Area Vapor Treatment System Design Basis

Parameter	Design Value
Vapor Flowrate	600 cfm
Process Air Temperature	45 F
Ambient Air Temperature	10 F

Compound	Design Influent Flows (lb/hr)	Estimated Discharge @ 99% DRE (lb/hr)
Benzene	0.0283	0.0003
Ethyl Benzene	0.0124	0.0001
Toluene	0.0112	0.0001



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3-1077

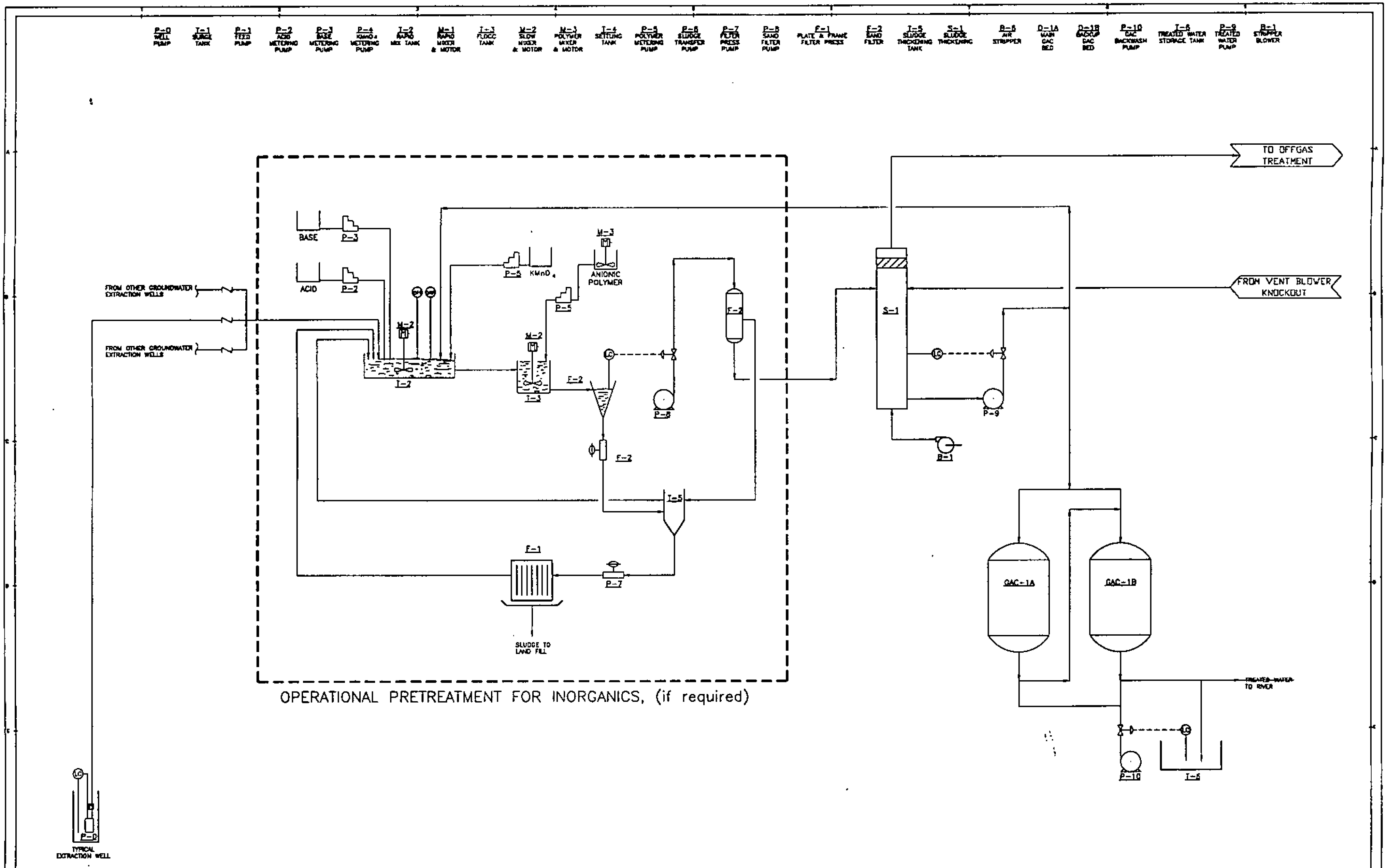
CURRENT DATE: 4/18/94 CAD FILE: 1077PF02

PRELIMINARY
PIPING & INSTRUMENT DIAGRAM OF
VAPOR TREATMENT SYSTEMS
WELLSVILLE, NEW YORK

RETEC
REMEDIATION TECHNOLOGIES INC

FIGURE 5-6 REV. 0

REFERENCE DWG	DESCRIPTION	NO	DRAWN	DATE	REVISION	CHKD	DATE	APPVD	DATE



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PRELIMINARY PIPING & INSTRUMENT DIAGRAM OF NORTHERN AREA GROUNDWATER TREATMENT SYSTEMS WELLSVILLE, NEW YORK

REMEDIATION TECHNOLOGIES INC

FIGURE 5-7 | REV. 0

TABLE 5-4
Major Equipment List

Tag	Description	Capacity/Size	Motor
P-0A/B/C	Groundwater Pump	10 gpm	3/4 HP
T-1	Surge Tank	5000 gallons	
P-1	Feed Pump	50 gpm	1.5 HP
T-2	Rapid Mix Tank	500 gallons	
M-1	Rapid Mixer	High RPM	1 HP
P-2	Acid Metering Pump	0.1 gpm	1/4 HP
P-3	Base Metering Pump	0.1 gpm	1/4 HP
P-4	KMnO4 Metering Pump	0.1 gpm	1/4 HP
T-3	Flocc Tank	750 gallons	
M-2	Slow Mixer	Low RPM	1/2 HP
P-5	Polymer Metering Pump	0.1 gpm	1/4 HP
T-4	Settling Tank	750 gallons	
P-6	Sludge Transfer Pump	10 gpm	Air
T-5	Sludge Thickening Tank	1500 gallons	
P-7	Filter Press Pump	10 gpm	Air
F-1	Filter Press	20 ft3	
P-8	Sand Filter Pump	50 gpm	2 HP
F-2	Sand Filter	5 gpm/ft2	
S-1	Air Stripper	50 gpm/500 cfm	
B-1	Air Stripper Blower	500 cfm	3 HP
P-9	Treated Water Pump	50 gpm	2 HP
D-1A/B	Liquid GAC Vessels	4 ft, 2000 lbs	

TABLE 5-4 (Continued)
Major Equipment List

Tag	Description	Capacity/Size	Motor
T-6	Treated Water Tank	3000 gallons	
B-2	South Sparging Blower	480 cfm, 15 psi	10 HP
B-3	North Sparging Blower	90 cfm, 15 psi	5 HP
F-3	Blower, B-4 Demister	1 micron	
B-4	South Venting Blower	600 cfm	30 HP
F-4	Blower, B-5 Demister	1 micron	
B-5	North Venting Blower	200 cfm	10 HP
H-1	South Thermal Oxidizer	600 cfm	5 HP
H-2	North Thermal Oxidizer	700 cfm	5 HP

5.2.8 Monitoring

Visual observations, instrument readings, real time analyzers, qualitative indicators such as pH tape and sampling and laboratory analysis of the samples will be used to monitor for regulatory discharge compliance, to evaluate the progress of remediation at the site and control the treatment system.

Process Monitoring

Temperatures in the thermal oxidizers, levels in tanks, pressure drops across the filters, the stripper and the carbon vessels and the discharge pressures from the pumps and blowers will be monitored to ensure that the process equipment is operating properly and not excessively fouled or plugged. A schedule for monitoring the process parameters and the levels of chemicals in any chemical addition systems will be set forth in a operations and maintenance plan.

High pressure drops through the air stripper and the carbon vessels will indicate when washing the stripper and backwashing the carbon vessels are required. If a metals removal system is employed, dipsticks will be used to qualitatively monitor the performance on a real time basis. The performance of the thermal oxidizer will be checked on a real time basis by monitoring the THC level in the offgas.

Progress Monitoring

The progress of the remediation will be monitored by taking samples of the groundwater and the soils. The groundwater samples will be taken at monitoring wells. The soil quality will be monitored by taking core samples. The samples will be analyzed for the chemicals of interest including organic and inorganic constituents. The frequency of monitoring and specific sampling and analytical protocols will be detailed in addenda to this document which will specify monitoring requirements for the site during system operation. These addenda will be submitted separately at a later date.

Compliance Monitoring

Compliance monitoring for the groundwater discharged to the river and the offgas discharged to the atmosphere will be performed on a regular basis. The groundwater samples will be taken as grab samples at the discharge from the liquid phase carbon vessels and will be analyzed for the metals, BTEX, semi-volatile organics, pH, and oil and grease in accordance with permit regulations for the State of New York SPDES. Compliance for offgas discharge will be conducted via stack testing during startup. Three consecutive simultaneous runs collecting data and sample of inlet and outlet gas from the control technology i.e. the thermal oxidizer, will be conducted. The samples will be taken in carbon tubes and analyzed for the chemicals of interest at frequency and by protocols in substantative conformance with permit requirements.

A Sampling, Analysis and Monitoring Plan for system operations will be prepared. This plan will specify the locations, frequency, procedures and analyses of sampling required to verify system effectiveness in meeting remedial objectives.

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Remediation Technologies, Inc. (RETEC), *"Sampling, Analysis and Monitoring Plan, Wellsville Operating Unit Two, Groundwater Remedial Design, Wellsville, New York,"* May 1993, prepared for ARCO Corporation, Los Angeles, California.

Remediation Technologies, Inc. (RETEC), *"Quality Assurance Project Plan, Wellsville Operating Unit Two (OU2), Groundwater Remedial Design, Wellsville, New York,"* May 1993, prepared for ARCO Corporation, Los Angeles, California.

SMC Martin, Inc., *"Draft Phase I Remedial Investigation, Sinclair Refinery Site, Wellsville, New York,"* March 1985, prepared for New York State Department of Environmental Conservation, Bureau of Remedial Action, Division of Solid and Hazardous Waste, Albany, New York.

U.S. Environmental Protection Agency, Region II, *"Record of Decision, Sinclair Refinery Site Landfill,"* October 7, 1991.

Versar, Inc., *"Revised Final Endangerment Assessment, Sinclair Refinery Site,"* June 1990, for CDM Federal Programs Corporation for the U.S. EPA Contract No. 68-W9-0002, Document No. 01006.

Appendix A

SPDES Permit Application

Please print or type in the unshaded areas only
(fill–in areas are spaced for elite type, i.e., 12 characters/inch).

Form Approved. OMB No. 2040-0086. Approval expires 5-31-92.

FORM 1 GENERAL — EPA — U.S. ENVIRONMENTAL PROTECTION AGENCY

GENERAL INFORMATION

Consolidated Permits Program
(Read the "General Instructions" before starting.)

I. EPA I.D. NUMBER: F — D

LABEL ITEMS

I. EPA I.D. NUMBER

III. FACILITY NAME

V. FACILITY MAILING ADDRESS

VI. FACILITY LOCATION

PLEASE PLACE LABEL IN THIS SPACE

GENERAL INSTRUCTIONS

If a preprinted label has been provided, affix it in the designated space. Review the information carefully; if any of it is incorrect, cross through it and enter the correct data in the appropriate fill–in area below. Also, if any of the preprinted data is absent *(the area to the left of the label space lists the information that should appear)*, please provide it in the proper fill–in area(s) below. If the label is complete and correct, you need not complete Items I, III, V, and VI *(except VI-B which must be completed regardless)*. Complete all items if no label has been provided. Refer to the instructions for detailed item descriptions and for the legal authorizations under which this data is collected.

II. POLLUTANT CHARACTERISTICS

INSTRUCTIONS: Complete A through J to determine whether you need to submit any permit application forms to the EPA. If you answer "yes" to any questions, you must submit this form and the supplemental form listed in the parenthesis following the question. Mark "X" in the box in the third column if the supplemental form is attached. If you answer "no" to each question, you need not submit any of these forms. You may answer "no" if your activity is excluded from permit requirements; see Section C of the instructions. See also, Section D of the instructions for definitions of bold–faced terms.

SPECIFIC QUESTIONS	YES	NO	FORM ATTACHED	SPECIFIC QUESTIONS	YES	NO	FORM ATTACHED
A. Is this facility a **publicly owned treatment works** which results in a discharge to **waters of the U.S.**? (FORM 2A)		X		B. Does or will this facility *(either existing or proposed)* include a **concentrated animal feeding operation** or **aquatic animal production facility** which results in a discharge to **waters of the U.S.**? (FORM 2B)		X	
	16	17	18		19	20	21
C. Is this a facility which currently results in discharges to waters of the U.S. other than those described in A or B above? (FORM 2C)		X		D. Is this a proposed facility *(other than those described in A or B above)* which will result in a discharge to **waters of the U.S.**? (FORM 2D)	X		X
	22	23	24		25	26	27
E. Does or will this facility treat, store, or dispose of **hazardous wastes**? (FORM 3)		X		F. Do you or will you inject at this facility industrial or municipal effluent below the lowermost stratum containing, within one quarter mile of the well bore, underground sources of drinking water? (FORM 4)		X	
	28	29	30		31	32	33
G. Do you or will you inject at this facility any produced water or other fluids which are brought to the surface in connection with conventional oil or natural gas production, inject fluids used for enhanced recovery of oil or natural gas, or inject fluids for storage of liquid hydrocarbons? (FORM 4)		X		H. Do you or will you inject at this facility fluids for special processes such as mining of sulfur by the Frasch process, solution mining of minerals, in situ combustion of fossil fuel, or recovery of geothermal energy? (FORM 4)		X	
	34	35	36		37	38	39
I. Is this facility a proposed **stationary source** which is one of the 28 industrial categories listed in the instructions and which will potentially emit 100 tons per year of any air pollutant regulated under the Clean Air Act and may affect or be located in an **attainment area**? (FORM 5)		X		J. Is this facility a proposed **stationary source** which is NOT one of the 28 industrial categories listed in the instructions and which will potentially emit 250 tons per year of any air pollutant regulated under the Clean Air Act and may affect or be located in an **attainment area**? (FORM 5)		X	
	40	41	42		43	44	45

III. NAME OF FACILITY

1 SKIP SINCLAIR REFINERY SUPERFUND SITE

IV. FACILITY CONTACT

A. NAME & TITLE *(last, first, & title)*	B. PHONE *(area code & no.)*
2 DAVID CHRISTENSEN PROJECT MGR	213 486 3622

V. FACILITY MAILING ADDRESS

A. STREET OR P.O. BOX

3 515 SOUTH FLOWER ST

B. CITY OR TOWN	C. STATE	D. ZIP CODE
4 LOS ANGELES	CA	90071

VI. FACILITY LOCATION

A. STREET, ROUTE NO. OR OTHER SPECIFIC IDENTIFIER

5 2448 SOUTH BROOKLYN AVENUE

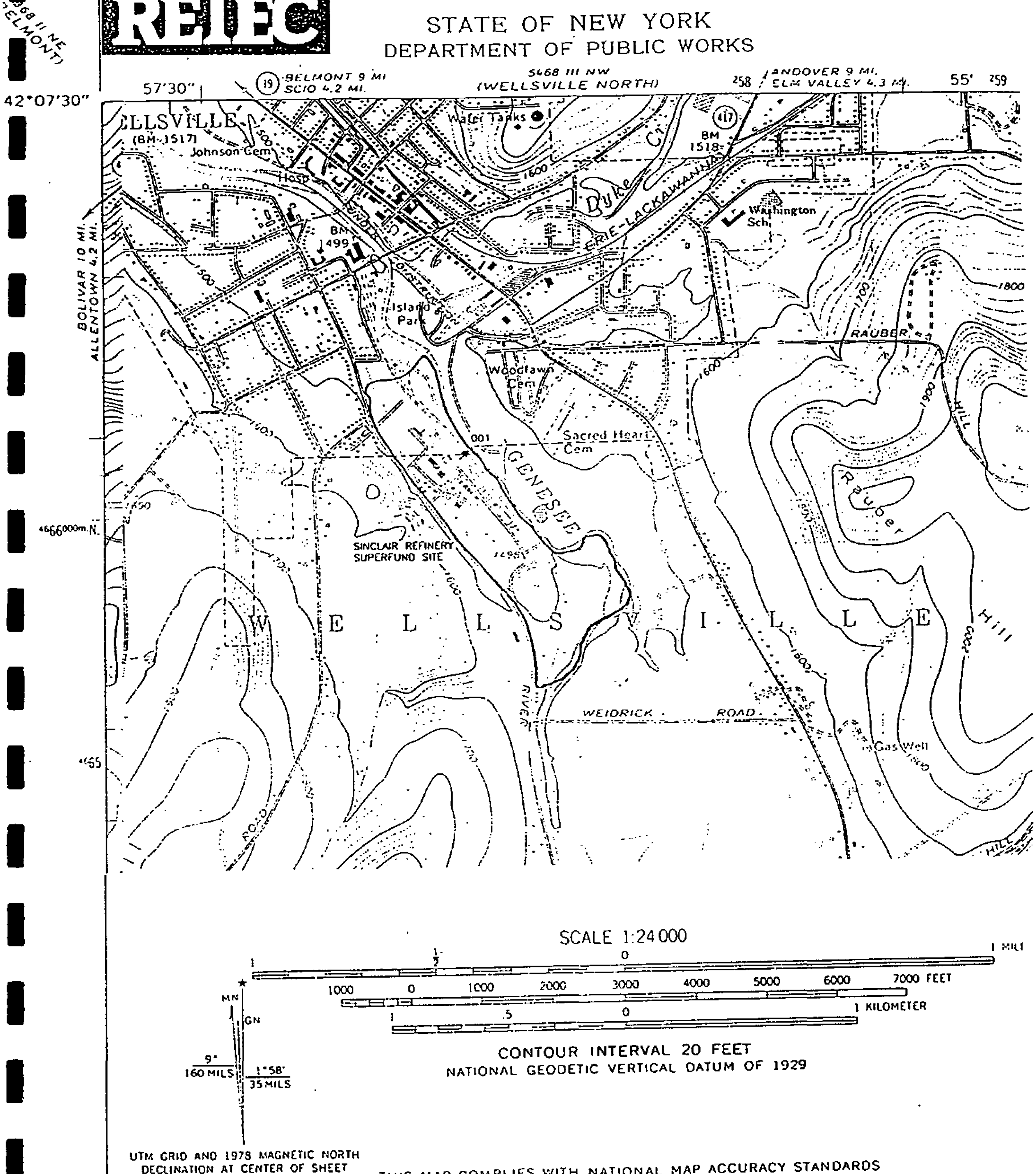
B. COUNTY NAME

ALLEGANY

C. CITY OR TOWN	D. STATE	E. ZIP CODE	F. COUNTY CODE *(if known)*
6 WELLSVILLE	NY	14895	

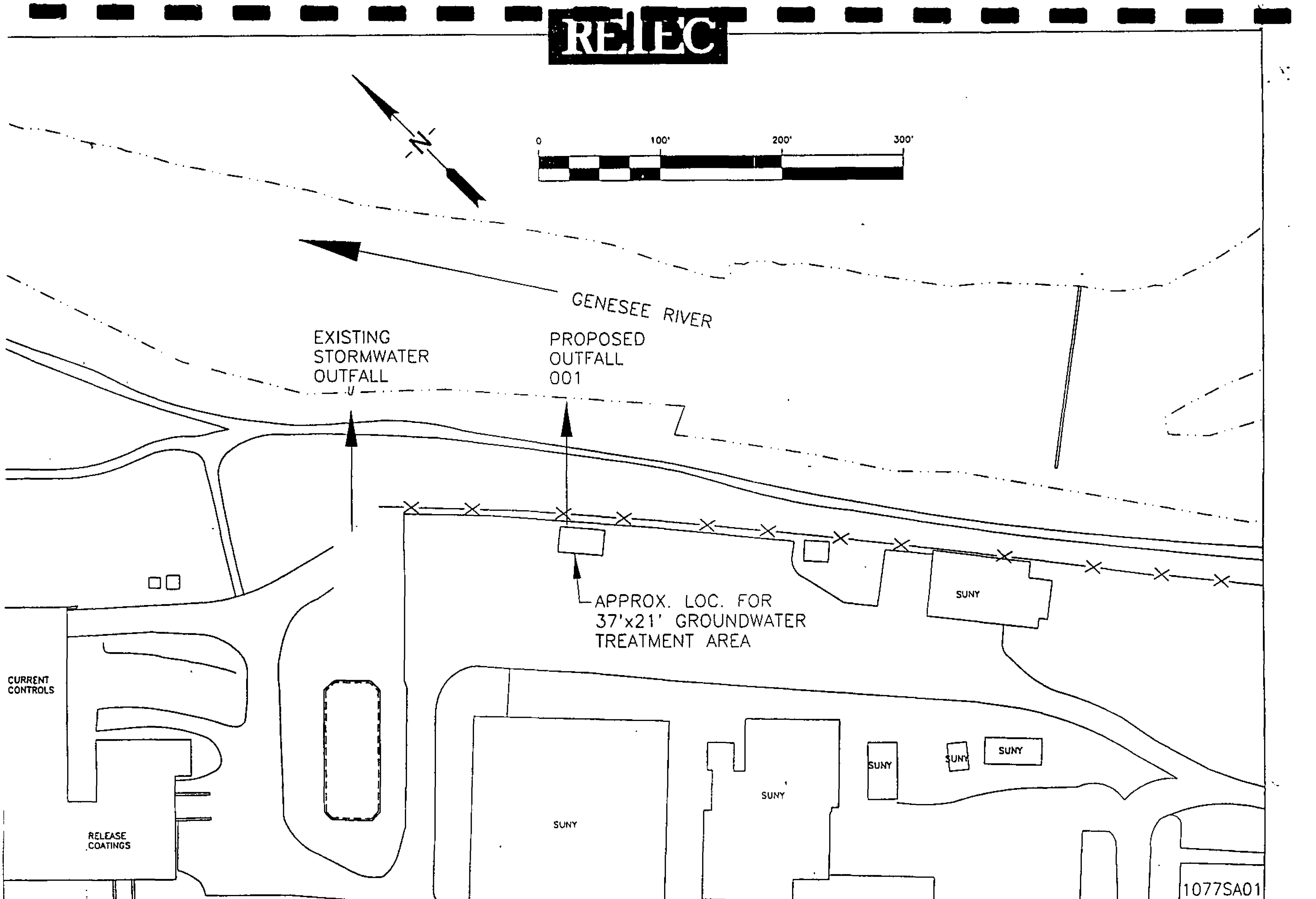
EPA Form 3510-1 (8-90)

CONTINUE ON REVERSE



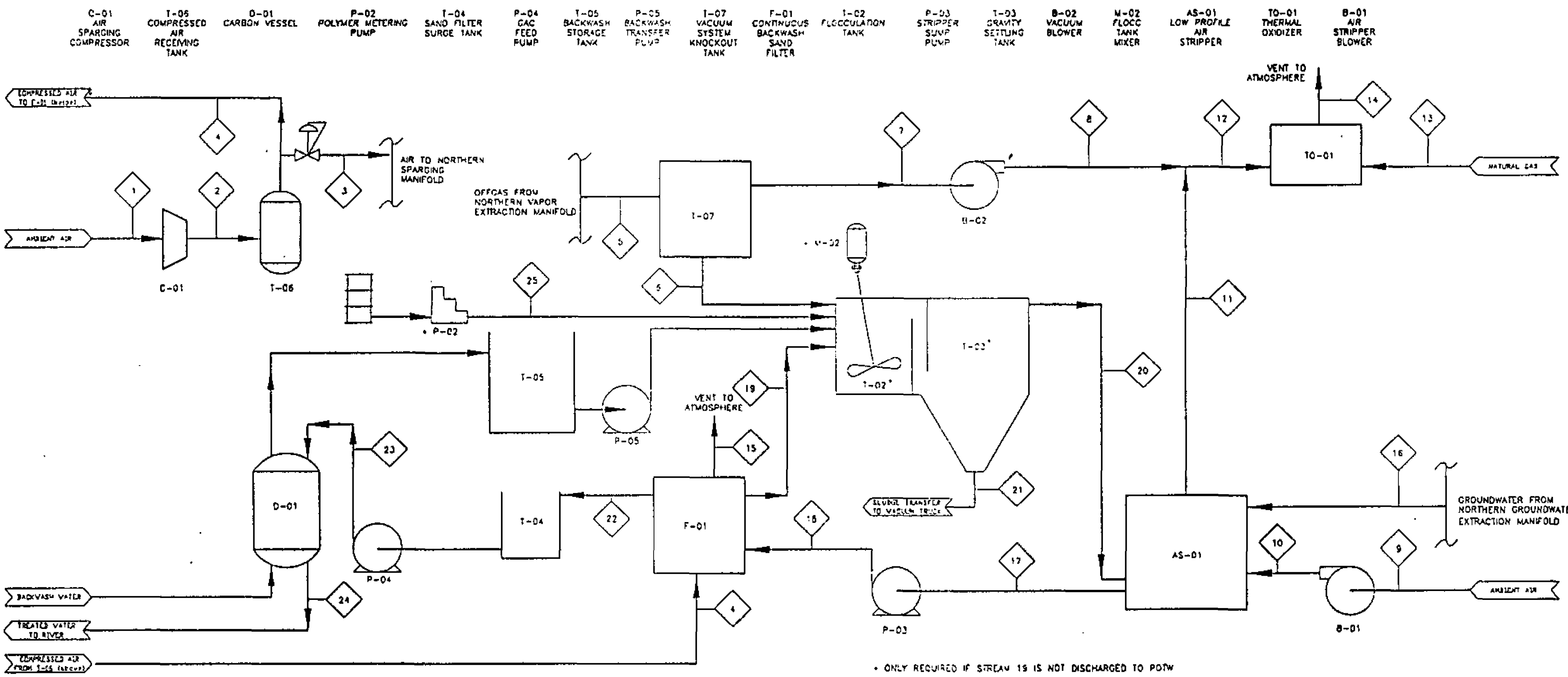
TOPOGRAPHIC MAP OF THE SINCLAIR REFINERY SUPERFUND SITE

FIGURE 1



SITE MAP
SINCLAIR REFINERY WELLSVILLE, N.Y.

FIGURE
2



[illegible]

[illegible]

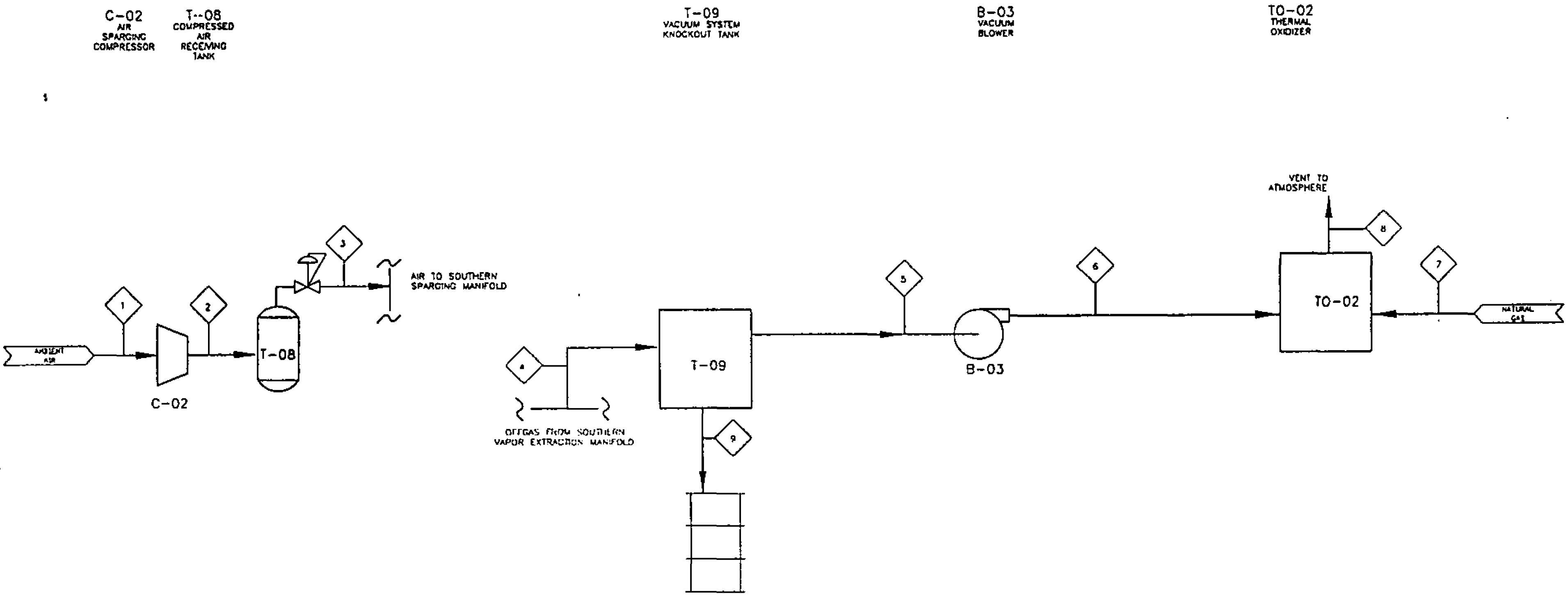
ARCO

SINCLAIR REFINERY SITE
OPERABLE UNIT 2
3-1077

PROCESS FLOW DIAGRAM
NORTHERN GROUNDWATER TREATMENT SYSTEM
ARCO
WELLSVILLE, NEW YORK

RETEC REMEDIATION TECHNOLOGIES INC

P-1 A



	Ambient Air	Compress Air	Sparging Air	Vent Gas @ Wells	Demisted Vent Gas	Blower Discharge	Natural Gas	Oxidizer Discharge	Mist Knockout
Stream #	1	2	3	4	5	6	7	8	9
Temperature (F)	45	448	100	45	50	113	70	1500	50
Pressure (psia)	14.7	114.7	64.7	13.3	11.5	15.8	14.7	15.8	11.5
Water (lb/hr)	7.5	7.5	7.5	27.6	24.6	24.6		24.6	3.0
Air (lb/hr)	1247.5	1247.5	1247.5	2483.3	2483.3	2483.3		2483.3	0.0
Benzene (ug/L)				15	13	15		0	46
Ethyl benzene (ug/L)				7	6	7		0	17
Toluene (ug/L)				7	6	7		0	18
Xylenes (ug/L)									
Natural Gas (lb/hr)							1.8		
TOTAL (LB/HR)	1255.0	1255.0	1255.0	2511.0	2508.0	2508.0	1.8	2507.9	3.0
GAS FLOW (ACFM)	257.1	61.6	92.7	594.8	690.8	564.6	0.7	1933.11	
LIQUID FLOW (GPM)									0.01

A	BW	12/28/93	ISS DESIGN - ISSUE TO AGENCY		
NO	DRWN	DATE	REVISION	CHKD / DATE	APPVD / DATE

REFERENCE DWG | DESCRIPTION

ARCO

SINCLAIR REFINERY SITE
OPERABLE UNIT 2
3-1077

CURRENT DATE 12/28/93 | CAD FILE 1077P002

PROCESS FLOW DIAGRAM
SOUTHERN GROUNDWATER TREATMENT SYSTEM
ARCO
WELLSVILLE, NEW YORK

REMEDIATION TECHNOLOGIES INC

P-2 | A

Please type or print in the unshaded areas only	EPA ID Number *(copy from Item 1 of Form 1)*	*Form Approved OMB No. 2040-0086 Approval expires 7-31-88*

Form 2D NPDES

EPA New Sources and New Dischargers Application for Permit to Discharge Process Wastewater

I. Outfall Location

For each outfall, list the latitude and longitude, and the name of the receiving water.

Outfall Number *(list)*	Latitude Deg	Latitude Min	Latitude Sec	Longitude Deg	Longitude Min	Longitude Sec	Receiving Water *(name)*
001	42	6	38	77	56	32	Genesee River

II. Discharge Date *(When do you expect to begin discharging?)*

January 1995

III. Flows, Sources of Pollution, and Treatment Technologies

A. For each outfall, provide a description of (1) All operations contributing wastewater to the effluent, including process wastewater, sanitary wastewater, cooling water, and stormwater runoff; (2) The average flow contributed by each operation; and (3) The treatment received by the wastewater. Continue on additional sheets if necessary.

Outfall Number	1. Operations Contributing Flow *(list)*	2. Average Flow *(include units)*	3. Treatment *(Description or List Codes from Table 2D-1)*
001	Water Treatment Plant	30 gpm	1-G, 1-O, 1-R, 2-A, 5-L

CONTINUED FROM THE FRONT	EPA ID Number *(copy from Item 1 of Form 1)*	Outfall Number 001

V. Effluent Characteristics

A, and B: These items require you to report estimated amounts *(both concentration and mass)* of the pollutants to be discharged from each of your outfalls. Each part of this item addresses a different set of pollutants and should be completed in accordance with the specific instructions for that part. Data for each outfall should be on a separate page. Attach additional sheets of paper if necessary.

General Instructions *(See table 2D-2 for Pollutants)*

Each part of this item requests you to provide an estimated daily maximum and average for certain pollutants and the source of information. Data for all pollutants in Group A, for all outfalls, must be submitted unless waived by the permitting authority. For all outfalls, data for pollutants in Group B should be reported only for pollutants which you believe will be present or are limited directly by an effluent limitations guideline or NSPS or indirectly through limitations on an indicator pollutant.

1. Pollutant	2. Maximum Daily Value *(include units)*	3. Average Daily Value *(include units)*	4. Source *(see instructions)*
BOD	NA	NA	Present in extracted groundwater
COD	NA	NA -	" " " "
TOC	200,000ug/L	<200,000ug/L	" " " "
TSS	45,000 ug/L	30,000 ug/L	" " " "
Flow	72,000 ug/L	43,200 ug/L	" " " "
Ammonia (as N)	NA	NA	" " " "
Temperature (winter)	65° F	45° F	" " " "
Temperature (summer)	85° F	65° F	" " " "
pH	8.5 S.U.	6.5-8.5 S.U.	" " " "
Arsenic, Total	9,900 ug/L	9,900 ug/L	" " " "
Cyanide, Total	19,800 ug/L	19,800 ug/L	" " " "
Chromium, Total	9,900 ug/L	9,900 ug/L	" " " "
Iron, Total	59,500 ug/L	59,500 ug/L	" " " "
Lead, Total	9,900 ug/L	9,900 ug/L	" " " "
Zinc, Total	59,500 ug/L	59,500 ug/L	" " " "
Benzene	138.9 ug/L	138.9 ug/L	" " " "
Ethylbenzene	9,900 ug/L	9,900 ug/L	" " " "
Toluene	9,900 ug/L	9,900 ug/L	" " " "
1,1-Dichloroethane	9,900 ug/L	9,900 ug/L	" " " "
1,2-Dichloroethylene	9,900 ug/L	9,900 ug/L	" " " "
1,1,1-Trichloroethane	9,900 ug/L	9,900 ug/L	" " " "
Vinyl Chloride	390 ug/L	390 ug/L	" " " "

CONTINUE ON REVERSE

EPA ID Number *(copy from item one of Form 1)*

VII. Other Information *(Optional)*

Use the space below to expand upon any of the above questions or to bring to the attention of the reviewer any other information you feel should be considered in establishing permit limitations for the proposed facility. Attach additional sheets if necessary.

See Attached

VIII. Certification

I certify under penalty of law that this document and all attachments were prepared under my direction or supervision in accordance with a system designed to assure that qualified personnel properly gather and evaluate the information submitted. Based on my inquiry of the person or persons who manage the system, or those persons directly responsible for gathering the information, the information submitted is, to the best of my knowledge and belief, true, accurate, and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment for knowing violations.

A. Name and Official Title *(type or print)*	B. Phone No.
Mr. David A. Christensen, Project Manager	(213) 486-3622
C. Signature	D. Date Signed

Item VII. Other Information

The Sinclair Refinery Superfund Site is a former refinery operated from the late 1800's until 1958. During operation, the refinery manufactured various petroleum derivatives including heavy oils and grease used for lubricants, light oil for fuel, naphtha, gasoline, lighter fluid, kerosene, and paraffin. The Site was named to the National Priority list (NPL) in 1983 after organic chemicals were detected in groundwater and surface water. The selected remedy for groundwater at the site includes the extraction and treatment of groundwater from the shallow aquifer followed by discharge of the treated water. This permit application is being submitted to form the basis for selection of the appropriate discharge limitations for the treated extracted groundwater.

The constituents identified in Item V may be present in the influent to the water treatment plant to be constructed at the Site. The treatment system described in the enclosed process flow diagrams will be operated 24 hours a day to treat the extracted groundwater prior to discharge. All flow to the plant will be discontinued should there be any upset conditions at the plant. Therefore, no discharge of untreated, or partially untreated water will occur.

The proposed discharge limitations shown in Table 1 are based on the assimilative capacity of the Genesee River at the proposed point of discharge. As a conservative, worst case scenario, the lowest reported flowrate for the river was used to determine an attenuation factor for the proposed discharge. The lowest reported monthly mean (for the period of 1955 through 1992) for the Genesee River at gauging station 15 (approximately four miles northwest of the Site) is 22.1 cfs (9918 gpm) (N.Y. U.S.G.S., 1992). The maximum design discharge flowrate from the water treatment plant is 50 gpm. Therefore, the appropriate attenuation factor is 9918 divided by 50, or 198. A stream of water at this flowrate meeting these proposed detection values discharging into a river with the minimum flowrate of 22.1 cfs will result in water quality standards which meet or exceed the New York State Ambient Water Quality Standards.

N.Y. U.S.G.S., 1972. Water Resouces Data, New York, Water Year 1992, Volume 3, Western New York. U.S. Geological Survey, Washington, D.C.

TABLE 1

Proposed Discharge Limitations, Sinclair Refinery Superfund Site

CONSTITUENT	NYAWQS - Class AA Surface Water (μg/L)[1]	Proposed SPDES Limitation (μg/L)	Proposed SPDES Limitation (lbs/day)
Arsenic	50	9,900	5.9
Cyanide	100	19,800	11.9
Chromium (Total)	50	9,900	5.9
Iron	300	59,500	35.8
Lead	50	9,900	5.9
Zinc	300	59,500	35.8
Benzene	0.7	138.9	0.08
Ethylbenzene	50	9,900	5.9
Toluene	50	9,900	5.9
Xylenes (Total)	50	9,900	5.9
1,1-Dichloroethane	50	9,900	5.9
1,2-Dichloroethylene	50	9,900	5.9
1,1,1-Trichloroethane	50	9,900	5.9
Vinyl Chloride	2	390	0.23

[1] Water Quality Regulations, Surface Water and Groundwater Classifications and Standards, New York State Department of Environmental Conservation, effective September 1, 1991.

NYSDEC SUPPLEMENTAL INSTRUCTIONS - ATTACHMENT

Your SPDES permit, when issued, may require you to periodically submit a Discharge Monitoring Report (DMR). The reports must be signed as follows:

1. for a corporation: by a responsible corporate officer. For the purposes of this section, a responsible corporate officer means:

(i) a president, secretary, treasurer, or a vice president of the corporation in charge of a principal business function, or any other person who performs similar policy or decision-making function for the corporation, or

(ii) the manager of one or more manufacturing, production, or operating facilities employing more than 250 persons or having annual sales or expenditures exceeding $25 million (in second quarter 1980 dollars), if authority to sign documents has been assigned or delegated to the manager in accordance with corporate procedures; or

2. for a partnership or sole proprietorship: by a general partner or the proprietor, respectively; or

3. for a municipality, state, federal, or other public agency: by either a principal or executive officer or ranking elected official. A principal executive officer of a federal agency includes: (i) the chief executive officer of the agency, or (ii) a senior executive officer having responsibility for the overall operations of a principal geographic unit of the agency; or

4. a duly authorized representative of the person described in items (1), (2) or (3). A person is a duly authorized representative only if:

(i) the authorization is made in writing by a person described in paragraph (1), (2) or (3);

(ii) the authorization specifies either an individual or a position having responsibility for the overall operation of the regulated facility or activity such as the position of plant manager, operator of a well or well field, superintendent, position of equivalent responsibility, or an individual or position having overall responsibility for environmental matters for the company. (A duly authorized representative may thus be either a named individual or any individual occupying a named position).

(iii) the written authorization is submitted to the Department.

Changes to authorization: If an authorization under paragraph (4) is no longer accurate because a different individual or position has responsibility for the overall operation of the facility, a new authorization satisfying the requirements of paragraph (4) must be submitted to the Department prior to or together with any reports to be signed by an authorized representative.

THE TABLE BELOW MUST BE COMPLETED AND FILED WITH YOUR APPLICATION. The person identified on the first line will be listed in Part I of the issued permit under the DMR MAILING ADDRESS section and must be a person described in paragraph (1), (2), (3) or (4). The table may be used to designate an authorized representative as described in paragraph (4).

THE APPLICANT MUST NOTIFY THE DEPARTMENT OF ANY CHANGE IN THIS INFORMATION DURING THE LIFE OF THE PERMIT.

Name and/or Title of person responsible for signing and submitting DMR's:			Phone: ( )
Mailing Name:			
Mailing Address:	City:	State:	Zip Code:
Name of person described in paragraph (1), (2) or (3):		Title:	
Signature of person described in paragraph (1), (2), or (3):			Date:

Failure to submit this completed page with your application will result in your application being declared incomplete. This will delay issuance of your permit and authorization to discharge.

Appendix B

Air Permit Application

DRAFT APPLICATION
FOR A PERMIT TO CONSTRUCT

SOIL VENTING/GROUNDWATER
REMEDIAL SYSTEM
SINCLAIR REFINERY
WELLSVILLE, NEW YORK

Prepared For:

The State of New York
Department of Environmental Conservation
Division of Air Quality
270 Michigan Avenue
Buffalo, New York 14203

Prepared on Behalf of:

ARCO
515 South Flower Street
Los Angeles, CA 90071

Prepared By:

Remediation Technologies, Inc.
9 Pond Lane
Concord, MA 01742

Project # 3-1077

March 1994

DRAFT APPLICATION
FOR A PERMIT TO CONSTRUCT

SOIL VENTING/GROUNDWATER
REMEDIAL SYSTEM
SINCLAIR REFINERY
WELLSVILLE, NEW YORK

Prepared For:

The State of New York
Department of Environmental Conservation
Division of Air Quality
270 Michigan Avenue
Buffalo, New York 14203

Prepared on Behalf of:

ARCO
515 South Flower Street
Los Angeles, CA 90071

Prepared By:

Remediation Technologies, Inc.
9 Pond Lane
Concord, MA 01742

Prepared by: ____________________

Reviewed by: ____________________

DRAFT

Project # 3-1077

March 1994

TABLE OF CONTENTS

NO. SECTION **PAGE NO.**

LIST OF FIGURES

LIST OF TABLES

1.0 INTRODUCTION

ARCO, is submitting this document to obtain a permit to construct and operate two air emission sources at the Sinclair Refinery Superfund Site located in Wellsville, New York. This report presents the design criteria, assumptions, and performance criteria from which the remedial design and subsequent off-gas treatment controls have been developed.

1.1 Site Description and History

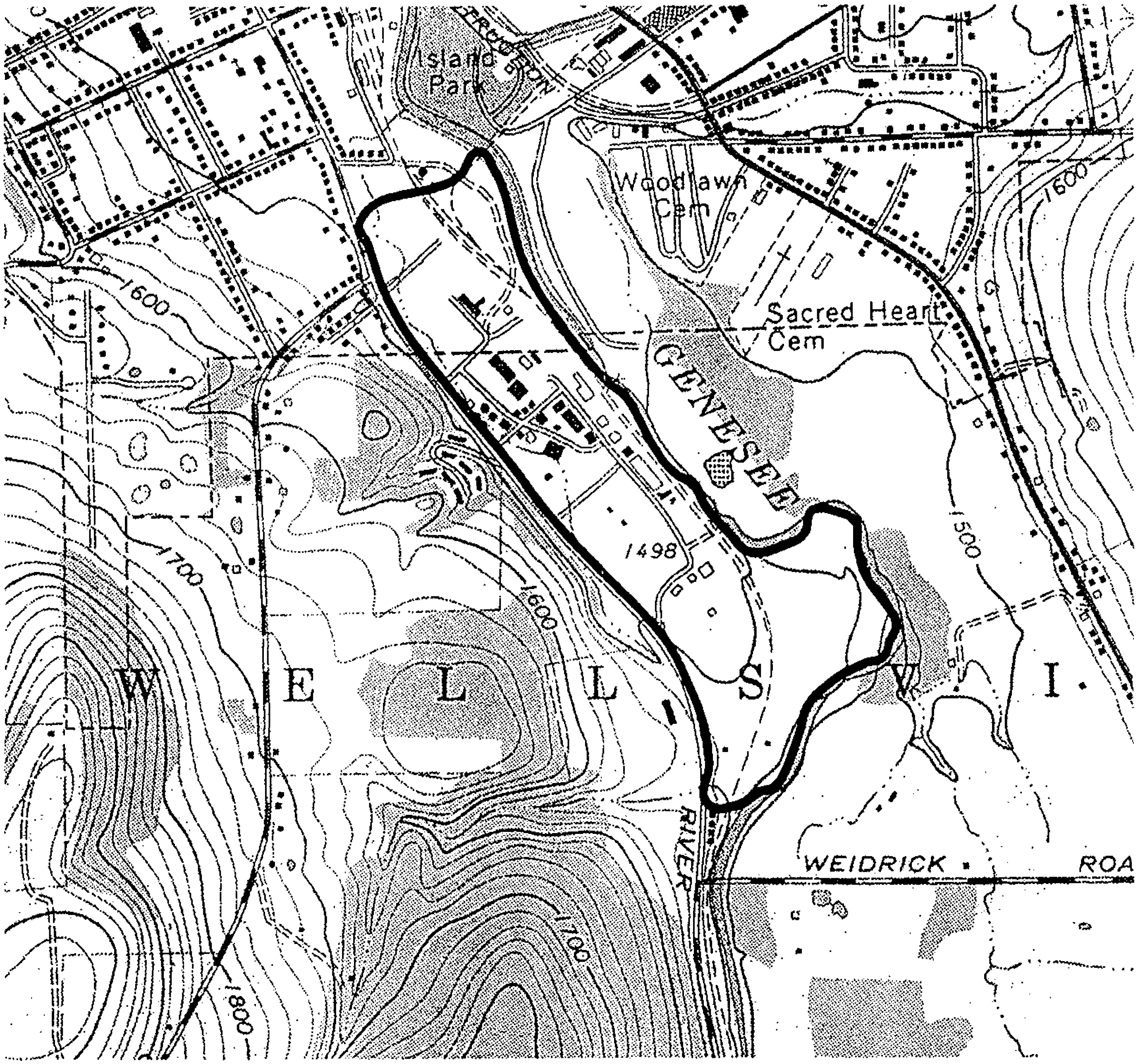
The Sinclair Refinery Superfund Site (the Site) was built in 1901 for processing Pennsylvania grade crude oil. The location of the Site is provided in Figure 1-1. Products manufactured included heavy oils and grease for lubrication, light oils for fuel, gasoline, lighter fluid, naphtha, and paraffin. During the early 1900's, operations at the Site were conducted by the Wellsville Refining Company. In 1919, the facility was purchased by the Sinclair Refining Company. The Sinclair Refining Company owned and operated the facility until 1958. In 1939 and 1958, two large fires occurred at the refinery, causing substantial damage. The 1958 fire was a contributing factor to the decision to close the refinery. When the refinery closed, the Sinclair Refining Company transferred a majority of the property to the Village of Wellsville.

After the refinery closed, new oil and gas storage tanks were constructed by subsequent site users. This Post-Refinery Tank Farm was operated by ARCO, then the British Petroleum Company, then the United Refinery Company, and was ultimately dismantled in 1972. The Post-Refinery Tank Farm property was subsequently transferred to the State University of New York.

Seven companies are currently using the Site in addition to the State University of New York, although much of the land at the Site is vacant. Ten private and government groups own parcels of land on the Site. The businesses operating at the Site include:

- Butler-Larkin Company, Inc.;
- Current Controls, Inc.;
- Mapes Industries, Inc.;
- National Fuel Company, Inc.;
- Otis Eastern Service, Inc.;

RETEC



SITE LOCATION

FIGURE 1-1

- Release Coatings, Inc.; and
- Niagara Mohawk.

Butler-Larkin Company, Inc. manufactures drilling and completion equipment for oil, gas, and water wells, and has its manufacturing facilities at the Site. They also maintain a large storage area in the central portion of the Site. Current Controls, Inc. manufactures small electrical transformers and other electronic control devices at the Site. Mapes Industries, Inc. manufactures toy chests, cribs, and other finished wood products. National Fuel Company, Inc. is the local natural gas supplier, with both its customer service and vehicular maintenance facilities located at the Site. Otis Eastern Service, Inc. is a drilling and gas pipeline construction company. Its main offices and a construction equipment storage area are located at the Site. Release Coatings, Inc. is a manufacturer of a material used to facilitate the extraction of molded products from their molds. Niagara Mohawk is an electric utility that maintains high power voltage poles and transmission lines on the Site.

The State University of New York (SUNY) at Alfred campus is located in the central portion of the Site. SUNY is an agricultural and technical college that has shops for automobile repair located on site.

2.0 CONSTITUENTS OF INTEREST

Past investigations at the Site have identified soil, groundwater, and surface water impacted by organic and inorganic chemicals. This section specifically addresses the extent of volatile organic compounds (VOCs) in soil and groundwater, since they are the critical parameters in the analysis of off-gas emissions that result from the Site remediation. Specific chemicals of interest (COI) include:

- organic compounds associated with past refinery operations such as
  - benzene,
  - ethylbenzene,
  - toluene, and
  - xylenes;

- chlorinated organic compounds such as
  - 1,1-dichloroethane,
  - trans-1,2-dichloroethene,
  - 1,1,1-trichloroethane, and
  - vinyl chloride

The chlorinated compounds listed are not commonly associated with refinery operations, and were not in common use when the refinery was in operation. These compounds are typically used as solvents, and may be associated with more recent manufacturing activities at the Site.

3.0 SOIL VENTING AND GROUNDWATER AERATION DESIGN

Design criteria include the physical, chemical and engineering parameters needed to design each component of the remedial treatment system. These values were selected based on engineering evaluations of data collected during the Remedial Investigation (RI), remedial design investigatory and process evaluation activities. Those evaluations focus on reducing the large amount of available data to specific values for each characteristic required. Discussions of these design criteria are presented below.

3.1 Conceptual Treatment Description of Soil Venting and Aeration Design

The Record of Decision (ROD) stipulates that a pump-and-treat system be used as a remedial component for the groundwater treatment at the Site. The primary chemicals of interest were detailed in Section 2.0. In order to enhance the pump-and-treat and reduce the time required to remediate the Site, the preliminary design incorporates soil venting and groundwater aeration (air sparging), in combination with conventional pump-and-treat, to enhance contaminant removal and expedite remediation focusing aggressive treatment not only on the dissolved constituents, but also treating the source of these constituents to groundwater.

The site has been divided into three primary areas designated the Northern, Southern, and Central Areas. The Northern Area is the focus for the groundwater pump-and-treat technology given the proximity of the plume of impacted groundwater to the Genesee River. In addition, enhanced recovery of organics via soil venting and groundwater aeration will be employed to remove benzene from an area with elevated concentrations in the western edge of this area. In the Southern Area, soil venting and groundwater aeration will be used to strip the volatile organics *in situ* in this area from both groundwater and soils. In the Central Area, no source of organic constituents has been identified in soils. Venting and aeration will be used in the Central Area to treat groundwater.

Figure 3-1, which presents the major unit operations of the Northern, Southern, and Central treatment systems, can be referred to for the following discussion. The pumped groundwater from the Northern Area will be pretreated as required to protect the aqueous volatile organic treatment processes. The aqueous volatile organic treatment processes include groundwater stripping followed by granular activated carbon water treatment.

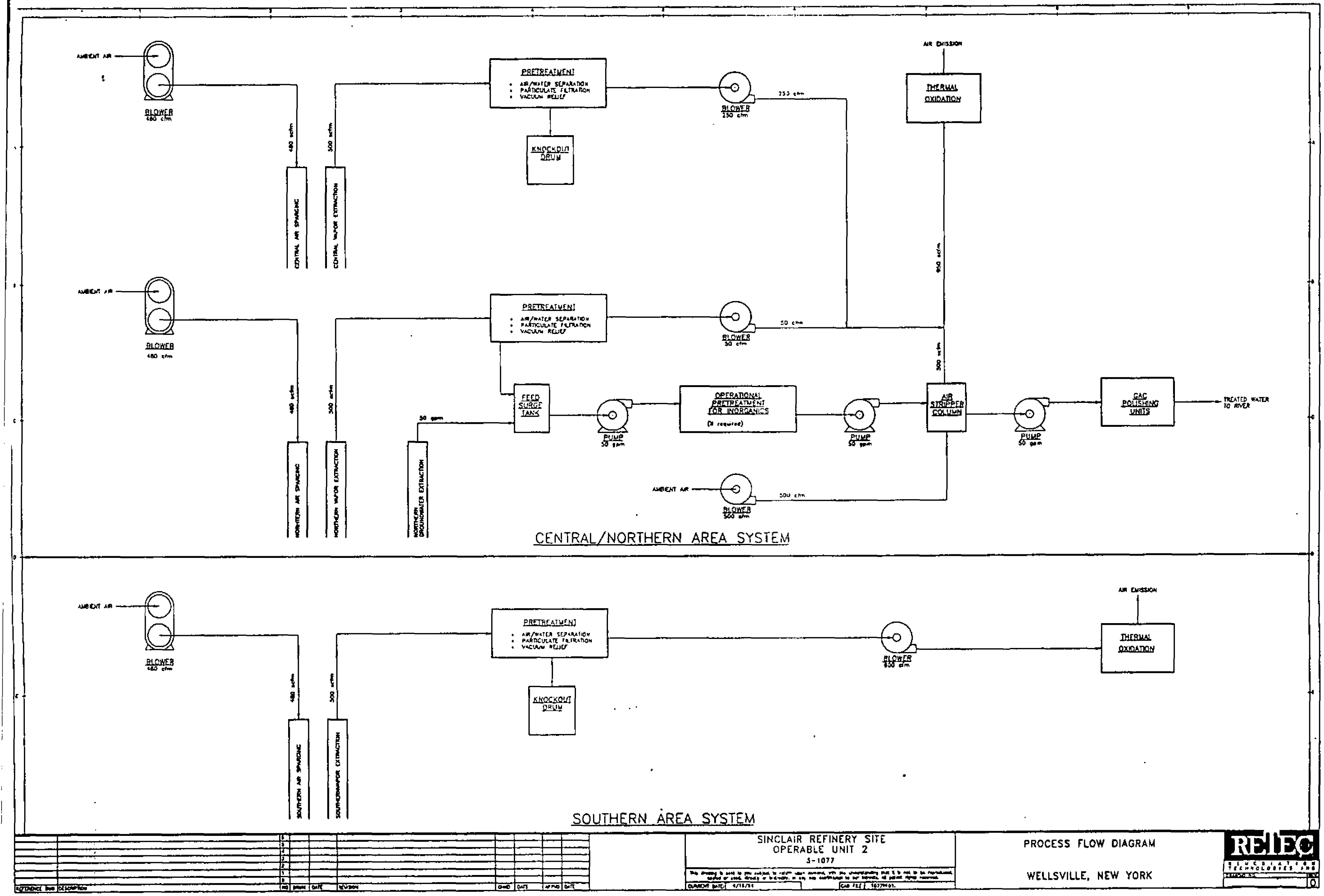

AMBIENT AIR
BLOWER
480 cfm
480 scfm
500 scfm
CENTRAL AIR SPARGING
CENTRAL VAPOR EXTRACTION
PRETREATMENT
AIR/WATER SEPARATION
PARTICULATE FILTRATION
VACUUM RELIEF
KNOCKOUT DRUM
BLOWER
250 cfm
250 cfm
AIR EMISSION
THERMAL OXIDATION
950 scfm
NORTHERN AIR SPARGING
NORTHERN VAPOR EXTRACTION
NORTHERN GROUNDWATER EXTRACTION
50 gpm
FEED SURGE TANK
PUMP
50 gpm
OPERATIONAL PRETREATMENT FOR INORGANICS
(if required)
BLOWER
50 cfm
500 scfm
AIR STRIPPER COLUMN
GAC POLISHING UNITS
TREATED WATER TO RIVER
BLOWER
500 cfm
CENTRAL/NORTHERN AREA SYSTEM
SOUTHERN AIR SPARGING
SOUTHERN VAPOR EXTRACTION
BLOWER
850 cfm
SOUTHERN AREA SYSTEM
SINCLAIR REFINERY SITE
OPERABLE UNIT 2
3-1077
PROCESS FLOW DIAGRAM
WELLSVILLE, NEW YORK
REMEDIATION TECHNOLOGIES INC
RETEC

Figure 3-1

The vapor phase chemicals-of-interest separated by the stripper will be combined with the vapors collected by the Northern and Central Area soil venting systems and sent to a thermal oxidizer for final destruction. The volatile organic compounds stripped in the subsurface by the Southern Area groundwater aeration system and collected by the Southern Area soil venting system will be sent to a second independent regenerative thermal oxidizer for final destruction. A more detailed description of the treatment systems is presented in subsequent sections.

3.2 Northern Area Treatment System

3.2.1 Design Groundwater Concentrations

Table 3-1 presents a statistical summary of groundwater concentrations of COI to be extracted from the Northern Area based on analysis of samples collected during the July 1993 sampling event. Maximum, minimum, arithmetic mean, median, geometric mean, and distance weighted mean values have been determined for the chemicals listed. Figure 3-2 shows the locations of the wells which were included in the determination of statistical values, as well as the location of the proposed extraction wells, which are the basis of the distance weighted mean.

The distance weighted mean concentration values have been selected as the design concentration values for the groundwater extraction system. This type of mean puts extra weight on concentration values for samples collected close to the expected extraction location and less weight the farther the sample location is away. This is consistent with the physical effect of the groundwater concentrations during pumping.

3.2.2 Groundwater Treatment System

The groundwater treatment system will be designed to remove volatile organics on a continuous basis from the water generated by the groundwater extraction system. The primary treatment for removing the majority of the organics is air stripping.

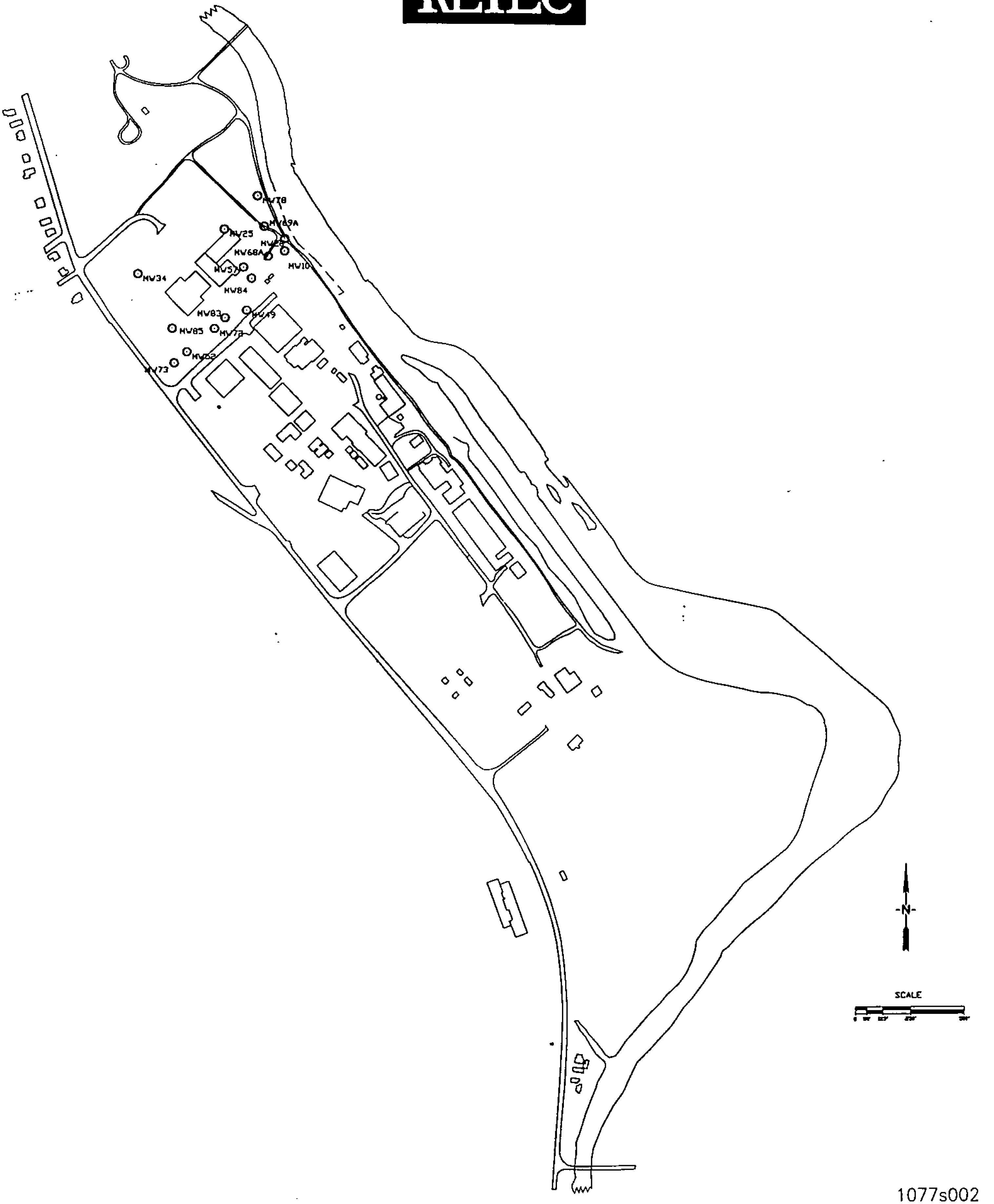
The groundwater will be pumped to an air stripper which is designed to remove the volatile organics. A blower forces ambient air into the stripper which is brought into intimate counter current contact with the groundwater. The mass transfer area will be provided for by random packing in a tower stripper or by a series of perforated contacting plates in a low profile stripper. The stripper offgas is then passed through an internal demister to remove entrained

Table 3-1

Northern Groundwater Statistical
Constituent Concentrations (ug/l)
Wellsville, New York

Constituents	Max. Conc.	Min. Conc.	Arith. Mean	Median	Geo Mean	Weight Dist. Mean
Benzene	1,500	<3	368	290	227	459
1,1-Dichloroethane	380	<3	58	<50	60	142
1,2-Dichloroethene	6,900	<3	1,207	<50	494	5019
1,1,1-Trichloroethane	1,000	<3	156	<50	296	529
Vinyl Chloride	550	<5	104	<100	385	228
Total BTEX	4,531	<8	1,793	1,382	922	3582

RE|EC



1077s002

Wells Included in Water Concentration Calculations

FIGURE
3-2

water and is sent to the Northern Area vapor treatment system. The treated groundwater is then pumped, either from the internal or external sump of the stripper, through the liquid phase carbon beds.

The design basis assumes, based upon preliminary modeling, that 50 gpm (6.7 cfm) of groundwater is stripped with 500 cfm of air, which represents an air to water volumetric ratio of 75 to 1. Calculated emission rates (lbs/hr) for the volatile organic compounds of concern have been performed for the groundwater stripper at the Northern Area. Table 3-2 presents the results.

3.2.3 Soil Vapor Extraction and Groundwater Aeration System

Vapor extraction, or soil venting, is the process by which soil gas containing VOCs is flushed from the unsaturated soil (vadose zone) for the purpose of reducing VOC concentrations in the soil gas, thus reducing soil VOC concentrations. Vapor extraction is achieved by installing a slotted pipe into the vadose zone in the area of contamination. Air is then flushed through the soil by applying low vacuum pressure to the pipe. The VOCs are flushed from the soil in the soil gas along with the flushing air.

Typically for an extraction system, the concentration of VOC's in soil decline and level off at lower concentrations. As the soil vapor extraction replaces the saturated air with cleaner air, there is an exponential decline in soil vapor concentration. Initially, the system is exhausting vapors laden with VOCs. After the first few weeks, the concentrations typically decrease rapidly. At this point the VOCs, which are adsorbed to the soil, partition to the air phase and are flushed out through the venting system.

In addition to the extraction system, a groundwater aeration, or air sparging system will be installed in the Northern Area. This system will consist of wells which will be used to inject air into groundwater and soils below the water table. This system increases the effectiveness of the venting system by volatilizing organic constituents in the groundwater and saturated soils. In addition, injection of air provides a source of oxygen which enhances natural bioremediation of organic constituents.

Three vapor extractions wells will be installed in the Northern Area. Each well will be installed 150 feet-on-center and operated at 50 scfm at approximately 40-inches of water. The system will also include approximately 10 air sparging wells spaced 60 feet on center with an

Table 3-2

Estimated VOC Emission Rates from Northern Groundwater Air Stripper Wellsville, New York

Compounds	Groundwater Concentration (ug/l)	Emission Rate @ 50 gpm (lbs/hr)
Benzene	500	0.0125
Toluene	400	0.0100
Ethlybenzene	500	0.0125
Xylene	2,200	0.0550
Vinyl Chloride	230	0.0057
1,1-Dichloroethane	140	0.0035
1,2-Dichloroethane (total)	5,000	0.1249
1,1,1-Trichloroethane	530	0.0132

injection rate of 6 to 10 scfm per well at a pressure of 8 to 10 psi. During system operations, it is planned that air injection will be pulsed so that only half of the sparging wells will be operated at one time. This procedure will result in a operational ratio of approximately 2 to 1, volume of air extracted versus the volume of air injected, resulting in a total flow from this area of approximately 150 scfm.

3.3 Central Area Treatment System

The treatment system in the Central Area consists of a soil venting and groundwater aeration system identical in concept to that used in the Northern Area. The system will include five venting wells and approximately 30 sparging wells. Venting wells are placed 150 feet on center and sparging wells are 30 feet on center oriented perpendicular to groundwater flow. The venting system is designed to remove 50 scfm of air per well for a total of 250 scfm for treatment. Vapors will be routed to the treatment system located in the Northern Area. Air sparging will be operated in a pulsed manner at a rate of 6 to 10 scfm per well to maintain approximately a two to one extraction to injection rate ratio.

3.4 Southern Area Treatment System

The southern treatment system will consist of a soil venting and groundwater aeration layout similar to those found in the Northern and Central Areas. The system will be composed of 12 vapor extraction wells and approximately 67 sparging wells. Spacing and operational parameters for the injection and extraction wells is the same as for the Northern and Central Areas. This system will maintain approximately the same 2 to 1 venting rate to sparging rate ratio as the other areas. This array will result in a total flow of 600 scfm for the Southern Area.

3.5 Design Concentrations for Soil Venting Systems

Table 3-3 presents concentrations of organics for vapor samples collected from the soil venting/groundwater aeration pilot system operated as part of the remedial design investigation at the Site in July 1993. One sample each was collected for laboratory analysis from the Northern and Southern Areas. Soil vapor concentrations used to estimate emissions from the Central Area used levels obtained from the Northern Area. Measured values in the Southern Area are those reported by the laboratory. Actual values are those calculated when the effects

Table 3-3

Summary of Vapor Analytical Results
Soil Vapor Extraction/Aeration Process Evaluation Study

Units (µg/L)	7/23/93 Southern Area		7/23/93 Southern Area (Duplicate)		7/25/93 Northern Area	
	Measured[a]	Actual[b]	Measured[a]	Actual[b]		
Benzene	4.3	12.6	3.6	10.5	140	
Toluene	1.7	5.0	1.9	5.5	36	(1.8)[c]
Ethylbenzene	1.9	5.5	1.6	4.7	29	
Total Xylenes	<1		<1		37	(0.4)[c]
Total BTEX	**7.9**	**23.1**	**7.1**	**20.7**	**242**	
TVPH (Total Volatile Petroleum Hydrocarbons)	570	1,664	730	2,132	10,000	
Chlorinated Hydrocarbons	None Detected		None Detected		None Detected	
OVM Reading (ppm)	135		135		148	

NOTES:

a Concentrations measured by laboratory analyses.
b Conversion based on dilution of soil gas with fresh air at venting well.
c Blank concentrations.

of adding additional air to the vapor stream to reduce the total vapor concentration are considered. Design values for extraction system vapor concentrations are the reported values in the Northern Area and the actual values in the Southern Area.

These vapor levels were used to estimate the emission rates (lbs/hr) of volatile compounds from the Northern, Southern, and Central Area soil vapor extraction systems. Table 3-4 presents the results.

3.6 Vapor Treatment System

Northern Vapor Treatment System Design Parameters

The vapor treatment system for the Northern Area is designed to treat the combined offgas from the soil venting and groundwater stripping systems as well as the soil venting off gas from the Central Area. The concentrations of volatile organics from the soil venting stream were taken from actual field soil venting tests performed in the Northern Area. The concentrations for the emissions from the groundwater stripper were calculated on the conservative assumption that all of the organics present in the groundwater are stripped. The design conditions, expected influent and discharge rates are summarized in Table 3-5.

The soil venting gas is drawn under vacuum from the vapor extraction wells by the soil venting blower. The collected vent gas is sent through a knockout drum to remove any entrained moisture before the gas is sent by the blower to the combined offgas treatment train. The knockout condensates are drained to the groundwater treatment system's surge tank. The airstripper offgas, after passing through an internal demister to knockout its entrained water, combines with the vent system offgas before entering the thermal oxidizer.

The design of the system was determined by the presence of chlorinated organics, particularly vinyl chloride. The design objective will be to maximize the removal of the organics from the offgas. This would be difficult and expensive to accomplish with vapor phase carbon due to the extremely low loading capacity of vinyl chloride on vapor phase carbon. A catalytic oxidizer will not be used due to the uncertainty of the destruction removal efficiency and operation and maintenance issues associated with the chlorinated organics. For preliminary purposes, a thermal oxidizer is planned to control the offgas. Destruction removal efficiencies greater than or equal to 99% are easily attained for the compounds present with a thermal

Table 3-4

Estimated VOC Emission Rates from Soil Vapor Extraction Systems Wellsville, New York

Area	Southern Area			Northern Area			Central Area		
Compounds	Vapor Conc. (ug/L)	Vapor Conc. (ug/m^3)	Emission Rate (lbs/hr)	Vapor Conc. (ug/L)	Vapor Conc. (ug/m^3)	Emission Rate (lbs/hr)	Vapor Conc. (ug/L)	Vapor Conc. (ug/m^3)	Emission Rate (lbs/hr)
Benzene	12.6	12,600	0.0283	140	140,000	0.1047	140	140,000	0.1310
Toluene	5.0	5,000	0.0112	36	36,000	0.0269	36	36,000	0.0337
Ethylbenzene	5.5	5,500	0.0124	29	29,000	0.0217	29	29,000	0.0271
Xylene	ND			37	37,000	0.0277	37	37,000	0.0346

Permit Assumptions:
Southern area design flow = 600 cfm
Northern area design flow = 200 cfm
Central area design flow = 250 cfm
Vapor concentrations from Table 3-2

TABLE 3-5
Northern Area Vapor Treatment System Design Basis

Parameter	Design Value
Vapor Flowrate	950 cfm
Process Air Temperature	45 F
Ambient Air Temperature	10 F

Compound	Design Influent Flows (lb/hr)	Estimated Discharge @ 99% DRE (lb/hr)
Benzene	0.2432	0.0025
Ethyl Benzene	0.0613	0.0006
Toluene	0.0706	0.0007
Xylenes	0.1173	0.0012
1,1-Dichloroethane	.004	0.0000
1,2-Dichloroethylene	0.1250	0.0013
1,1,1-Trichloroethane	0.0130	0.0001
Vinyl Chloride	0.0060	0.0001

oxidizer. A regenerative style thermal oxidizer will be used to increase thermal efficiency, i.e. heat recovery.

Internal to the regenerative thermal oxidizer, the incoming, untreated gas passes over a hot bed of silica. The initial heating of the bed is provided for by an electrical coil. As the combustion of the offgas takes place, the heating of the bed material is supplemented or replaced by the heat of combustion provided by the organics in the offgas. The direction by which the feed gas and combusted gas pass through the bed is alternated to keep the surface temperature of the bed material constant. The heat recovery for these units is on the order of 95-99%. Thus the thermal oxidizer offgas is not significantly above ambient temperature. The offgas is then discharged to the atmosphere through a stack.

Southern Vapor Treatment System Design Parameters

The vapor treatment system for the Southern Area is designed to treat the offgas from the Southern soil venting system. The concentrations of volatile organics from the soil venting stream were taken from actual field soil venting tests performed in the Southern Area. The design basis assumes that there are up to 12 vapor extraction wells drawing 50 cfm of air each which are collectively sent to the Southern vapor treatment system. The design conditions, expected influent and discharge rates are summarized in Table 3-6.

The soil venting gas is drawn under vacuum from the vapor extraction wells by the soil venting blower. The collected vent gas is sent through a knockout drum to remove any entrained moisture before the gas is sent by the blower to the final offgas treatment system. The knockout condensates are drained to a collection vessel, a 55-gallon drum whose contents can be manually transferred to the Northern groundwater treatment system's surge tank. The vent gas discharged from the blower is sent to the Southern Area regenerative thermal oxidizer. The process description for this unit operation is supplied in the description of the Northern vapor treatment system.

3.7 Organic Vapor Discharge Estimates

NYDEC Regulation 212 details the amount of emission control required for air emission sources. The amount of control is dependent on the toxicity of the compound. NYDEC rates the toxicity of compounds by letter: A being highly toxic; B being moderately toxic; C being low toxic; and D being water vapor or simple asphyxiants. Compounds rated A toxicity must

TABLE 3-6

Southern Area Vapor Treatment System Design Basis

Parameter	Design Value
Vapor Flowrate	600 cfm
Process Air Temperature	45 F
Ambient Air Temperature	10 F

Compound	Design Influent Flows (lb/hr)	Estimated Discharge @ 99% DRE (lb/hr)
Benzene	0.0283	0.0003
Ethyl Benzene	0.0124	0.0001
Toluene	0.0112	0.0001

use the Best Available Emission Control Technology (BACT) that is 99% efficient, if the emission rate is above one pound per hour. Compounds rated B or C toxicity must use a Reasonably Available Emission Control Technology (RACT) that is 90% and 70% efficient, respectively if the emission rates are above ten pounds per hour. Compounds rated D need no control.

In addition to NYDEC Regulation 212, the NYDEC Air Guide 1 establishes ambient concentrations for emitted compounds from a source. These ambient concentrations cannot be exceeded, even if the control technology meets the criteria of Regulation 212. If an emission source meets the 90% removal efficiency for compounds rated B, but fails to meet the ambient standards in Air Guide 1, the source must increase its efficiency to meet the ambient standard. If the source maintains a 99% removal efficiency, but still can not meet the ambient air standard, NYDEC will allow the emissions, if the ambient concentration is less than 10 times the ambient standard (Air Guide - 1, appendix A, Section III.C.3.a). Table 3-7 presents a summary of air discharge limits and control technology requirements for the specific compounds of interest.

3.7.1 Emissions Calculations

The Standard Point Source Method, presented in the Air Guide 1 (Appendix B, Section III.A), was used to determine the ambient downwind concentration from each individual remedial treatment system and again for total emissions from the site. The Standard Point Source Method is a conservative dispersion equation that details a simple approximation of the ambient impact of a constituent of concern. The method calculates the maximum annual impact (C_a), the maximum potential annual impact (C_p) and the short-term ambient impact (C_{st}). Results from the potential annual impact equation are compared to the ambient standards to determine if special permit conditions are to be added to restrict the hours per year of operation. Short-term impacts represent one hour exposure limits, the maximum annual impact represents a 70 year exposure limit.

Table 3-7

Air Discharge Requirement Summary
Wellsville, New York

Compounds	NYDEC Emission Limits[1]			AGC[3] (ug/m^3)	SGC[3] (ug/m^3)
	BACT	RACT	No Control[2]		
Benzene	>1.0	0.1<C<1.0	<0.1	0.12	30
Toluene	NA[2]	>10	<10	2,000	89,000
Ethlybenzene	NA[2]	>10	<10	1,000	100,000
Xylene	NA[2]	>10	<10	300	100,000
Vinyl Chloride	>1.0	0.1<C<1.0	<0.1	0.02	1,300
1,1-Dichloroethane	NA[2]	>10	<10	500	190,000
1,2-Dichloroethane (total)	NA[2]	>10	<10	1,900	190,000
1,1,1-Trichloroethane	NA[2]	>10	<10	1,000	450,000

Notes:

[1]NYDEC Air Regulation 212, Table 2.0
[2]NYDEC Air Guide-1, Section IV.B.1.a. "Degree of control may be specified by the Commissioner".
[3]NYDEC Air Guide-1, Appendix C
AGC: Annual Guideline Concentration
SGC: Short-Term Guideline Concentration
BACT: Best Available Control Technology
RACT: Reasonable Available Control Technology

The maximum annual impact equation is as follows:

$$C_a = \frac{0.482 \times Q_a}{h_e^{2.16}}$$

where:

C_a = ambient air concentration (ug/m^3)
Q_a = constituent emission rate (lbs/yr)
h_e = stack height (ft)

The maximum potential annual impact equation is as follows:

$$C_p = \frac{4218 \times Q}{h_e^{2.16}}$$

where:

C_p = ambient air concentration (ug/m^3)
Q = constituent emission rate (lbs/hr)
h_e = stack height (ft)

Permit conditions may restrict the hours per year of operation if $C_p >$ air standard, but $C_a <$ air standard.

The short-term impact equation is:

$$C_{st} = C_p \times 420$$

According to NYDEC, when there are multiple sources of a contaminant, the individual source impacts should be summed to determine a worst case total ambient impact. Alternatively, an impact may be estimated by summing the emissions and assuming a single point source (appendix B, Section III). Table 3-8 presents the results from the air permitting program as the sum of emission rates out of one point source at the Site.

Table 3-8

Modeled Ambient Air Concentrations
From Remedial Treatment Systems
Northern and Southern Areas
Wellsville, New York

Area Emission Rates (lbs/hr)	Northern		Southern	Central	Total	99% Contolled	Modeled Concentrations (ug/m^3)			NYDEC Limits (ug/m^3)	
Compounds	Groundwater Stripper	Soil Vapor Extraction	Soil Vapor Extraction	Soil Vapor Extraction	Emissions	Emissions	Annual C_a	Potential C_p	Short-Term C_{st}	AGC	SGC
Benzene	0.0125	0.1047	0.0283	0.1310	0.2765	0.0028	0.033	0.034	14.1	0.12	30
Toluene	0.0100	0.0269	0.0112	0.0337	0.0818	0.0008	0.010	0.010	4.2	2,000	89,000
Ethlybenzene	0.0125	0.0217	0.0124	0.0271	0.0737	0.0007	0.009	0.009	3.8	1,000	100,000
Xylene	0.0550	0.0277	ND	0.0346	0.1172	0.0012	0.014	0.014	6.0	300	100,000
Vinyl Chloride	0.0057	ND	ND	ND	0.0057	0.0001	0.001	0.001	0.3	0.02	1,300
1,1-Dichloroethane	0.0035	ND	ND	ND	0.0035	0.0000	0.0004	0.0004	0.2	500	190,000
1,2-Dichloroethane (total)	0.1249	ND	ND	ND	0.1249	0.0012	0.015	0.015	6.4	1,900	190,000
1,1,1-Trichloroethane	0.0132	ND	ND	ND	0.0132	0.0001	0.002	0.002	0.7	1,000	450,000
Total	0.2373	0.1810	0.0519	0.2264	0.6966	0.0070					

Permit Assumptions:
Stack height = 15 ft
ND = Not Detected

Results indicate that predicted emission rates concerning compounds of interest from the remedial treatment systems are in compliance with NYDEC part 212 air regulations. Regulation 212 states that emission rates of highly toxic compounds (benzene and vinyl chloride) above one lb/hr must control emissions using BACT. The emission rates for benzene and vinyl chloride were predicted at 0.03 and 0.006 lbs/hr, respectively and are below regulation 212 standard for the use of BACT; however, predicted ambient dispersion concentration for benzene would necessitate the use of Reasonable Available Control Technology (RACT). The remaining organic compounds of concern, rated moderate to low in toxicity, had predicted emission rates far below Regulation 212 of 10 lbs/hr.

The uncontrolled emission rates were then entered into the maximum annual impact (C_a), the maximum potential annual impact (C_p) and the short-term ambient impact (C_{st}) equations. All toxic, A rated compounds failed to meet the annual and short-term ambient concentration limits, presented in NYDEC Air Guide 1, justifying the need for off-gas treatment. The remaining organic compounds of concern, rated moderate to low in toxicity, had predicted ambient concentrations below the regulated standards. Table 3-8 also presents the results of the point source method using 99% control emission rates.

If RACT is used to control emissions from the remedial treatment system, the predicted ambient air concentrations for benzene and vinyl chloride would be below the Air Guide 1 regulation concentration and, subsequently, be in compliance. Alternatively, no emission controls would be considered if results from on-site quantitative gas monitoring indicate lower emission rates, contributing to lower ambient concentrations that are below the Air Guide 1 standards.

During the course of the remedial treatment program, off-gas stream will be monitored on a periodic basis to determine compound emission rates. The proposed off-gas treatment system would be shut down if the measured emission rate indicated compliance with the appropriate ambient air standard (Air Guide 1). Subsequently, the off-gas treatment system would be re-activated if the measured emission rate corresponds to an unacceptable ambient dispersion concentration (C_a).

3.8 Compliance Monitoring

Compliance monitoring for the groundwater discharged to the river and the offgas discharged to the atmosphere will be performed on a regular basis. Compliance for offgas discharge will be conducted via stack testing during startup. Three consecutive simultaneous runs collecting data and sample of inlet and outlet gas from the control technology i.e. the thermal oxidizer, will be conducted. The samples will be taken in carbon tubes and analyzed for the chemicals of interest at frequency and by protocols in substantive conformance with permit requirements.

3.9 Permit Form 76-19-3

Permit to construct, form 76-19-3, has been completed for the Northern and Southern off-gas treatment systems and is included as Attachment 1 of this report.

ATTACHMENT 1

Permit to Construct

NYDEC Form 76-19-3

OP | LOCATION | FACILITY | EMISSION POINT | I

A ADD
C CHANGE
D DELETE

READ INSTRUCTIONS CONTAINED IN FORM 76-11-12 BEFORE ANSWERING ANY QUESTION

NEW YORK STATE
DEPARTMENT OF ENVIRONMENTAL CONSERVATION

COPIES
WHITE - ORIGINAL
GREEN - DIVISION OF AIR
WHITE - REGIONAL OFFICE
PINK - FIELD REP
YELLOW - APPLICANT

PROCESS, EXHAUST OR VENTILATION SYSTEM

APPLICATION FOR PERMIT TO CONSTRUCT OR CERTIFICATE TO OPERATE

SECTION A

1. NAME OF OWNER/FIRM: ARCO
2. NUMBER AND STREET ADDRESS: 515 South Flower Street
3. CITY - TOWN - VILLAGE: Los Angeles
4. STATE: CA
5. ZIP: 90071
6. OWNER CLASSIFICATION: A. ☐ COMMERCIAL B. ☐ INDUSTRIAL C. ☐ UTILITY D. ☐ FEDERAL E. ☐ STATE F. ☐ MUNICIPAL G. ☐ EDUC. INST. H. ☐ HOSPITAL I. ☐ RESIDENTIAL J. ☒ OTHER
7. NAME & TITLE OF OWNERS REPRESENTATIVE:
8. TELEPHONE:
9. NAME OF AUTHORIZED AGENT: Remediation Technologies
10. TELEPHONE: 508 371-1422
11. NUMBER AND STREET ADDRESS: 9 Pond Lane
12. CITY - TOWN - VILLAGE: Concord
13. STATE: MA
14. ZIP: 01742
15. NAME OF P.E. OR ARCHITECT PREPARING APPLICATION: Rob Block
16. N.Y.S. P.E. OR ARCHITECT LICENSE NO.:
17. TELEPHONE: 508 371-1422
18. SIGNATURE OF OWNERS REPRESENTATIVE OR AGENT WHEN APPLYING FOR A PERMIT TO CONSTRUCT:
19. FACILITY NAME (IF DIFFERENT FROM OWNER/FIRM): Sinclair Refinery
20. FACILITY LOCATION (NUMBER AND STREET ADDRESS):
21. CITY-TOWN-VILLAGE: Wellsville
22. ZIP:
23. BUILDING NAME OR NUMBER: Northern Area
24. FLOOR NAME OR NUMBER:
25. START UP DATE: MO / YR
26. DRAWING NUMBERS OF PLANS SUBMITTED:
27. PERMIT TO CONSTRUCT: A. ☒ NEW SOURCE B. ☐ MODIFICATION
28. CERTIFICATE TO OPERATE: A. ☐ NEW SOURCE B. ☐ MODIFICATION C. ☐ EXISTING SOURCE

SEC. B

29. EMISSION POINT ID.	30. GROUND ELEVATION (FT.)	31. HEIGHT ABOVE STRUCTURES (FT)	32. STACK HEIGHT (FT)	33. INSIDE DIMENSIONS (IN.)	34. EXIT TEMP (°F)	35. EXIT VELOCITY (FT/SEC)	36. EXIT FLOW RATE (ACFM)	37. SOURCE CODE	38. HRS/DAY	39. DAYS/YR	40. % OPERATION BY SEASON Winter	Spring	Summer	Fall
00001	1500	5	15	10	400	1,760	950		24	365	25	25	25	25

SEC. C

41. DESCRIBE PROCESS OR UNIT
1. Soil venting/groundwater air stripper
2.
3.
4.
5.
6.
7.
8.

SEC. D

EMISSION CONTROL EQUIPMENT I.D.	CONTROL TYPE	MANUFACTURER'S NAME AND MODEL NUMBER	DISPOSAL METHOD	DATE INSTALLED MONTH / YEAR	USEFUL LIFE
42. 01A	43. 99	44. To be provided	45. 4	46. /	47. 10
48.	49.	50.	51.	52. /	53.

SECTION E

CALCULATIONS

Presented in Permit to Construct Application

SECTION F

CONTAMINANT NAME	CAS NUMBER	INPUT OR PRODUCTION	UNIT	ENV. RATING	EMISSIONS ACTUAL	UNIT	HOW DET	PERMISSIBLE	% CONTROL EFFIC'CY	HOURLY EMISSIONS (LBS/HR) ERP	HOURLY ACTUAL	ANNUAL EMISSIONS (LBS/YR) ACTUAL	10^x	PERMISSIBLE
54. Benzene	55. -	56. lb/hr	57. 1	58. A	59. 0.25	60. 1	61. 5	62.	63. 99	64.	65. .0025	66. 22	67.	68.
69. Vinyl Chloride	70. -	71. lb/hr	72. 1	73. A	74. 0.006	75. 1	76. 5	77.	78. 99	79.	80. .00006	81. .52	82.	83.
84. Xylene	85. -	86. lb/hr	87. 1	88. B	89. 0.12	90. 1	91. 5	92.	93. 99	94.	95. 0.001	96. 10.5	97.	98.
99. Toluene	100. -	101. lb/hr	102. 1	103. C	104. 0.07	105. 1	106. 5	107.	108. 99	109.	110. .0007	111. 6.2	112.	113.
114. 1,2-dichloroethane	115. -	116. lb/hr	117. 1	118. B	119. 0.12	120. 1	121. 5	122.	123. 99	124.	125. .0012	126. 10.5	127.	128.
129. 1,1,1-trichloroethane	130. -	131. lb/hr	132. 1	133. B	134. 0.01	135. 1	136. 5	137.	138. 99	139.	140. .0001	141. 0.9	142.	143.

SEC. G

SOLID FUEL TYPE	TONS/YR	% S	OIL TYPE	THOUSANDS OF GALLONS / YR	% S	GAS TYPE	THOUSANDS OF CF/YR	BTU/CF	APPLICABLE RULE	APPLICABLE RULE
144.	145.	146.	147.	148.	149.	150.	151.	152.	153.	154.

Upon completion of construction sign the statement listed below and forward to the appropriate field representative
THE PROCESS, EXHAUST OR VENTILATION SYSTEM HAS BEEN CONSTRUCTED AND WILL BE OPERATED IN ACCORDANCE WITH STATED SPECIFICATIONS AND IN CONFORMANCE WITH ALL PROVISIONS OF EXISTING REGULATIONS.

155. SIGNATURE OF AUTHORIZED REPRESENTATIVE OR AGENT | DATE

AGENCY USE ONLY

156. LOCATION CODE | 157. FACILITY ID. NO. | 158. U.T.M. (E) | 159. U.T.M. (N) | 160. SIC NUMBER | 161. DATE APPL. RECEIVED / / | 162. DATE APPL. REVIEWED / / | 163. REVIEWED BY:

PERMIT TO CONSTRUCT

164. DATE ISSUED / / | 165. EXPIRATION DATE / / | 166. SIGNATURE OF APPROVAL | 167. FEE

168.
1. DEVIATION FROM APPROVED APPLICATION SHALL VOID THIS PERMIT
2. THIS IS NOT A CERTIFICATE TO OPERATE
3. TESTS AND/OR ADDITIONAL EMISSION CONTROL EQUIPMENT MAY BE REQUIRED PRIOR TO THE ISSUANCE OF A CERTIFICATE TO OPERATE

RECOMMENDED ACTION RE: C.O.

169. DATE ISSUED / / | 170. EXPIRATION DATE / / | 171. SIGNATURE OF APPROVAL | 172. FEE

173.
1. ☐ INSPECTED BY ________ DATE ____
2. ☐ INSPECTION DISCLOSED DIFFERENCES AS BUILT VS. PERMIT, CHANGES INDICATED ON FORM
3. ☐ ISSUE CERTIFICATE TO OPERATE FOR SOURCE AS BUILT
4. ☐ APPLICATION FOR C.O. DENIED ________ DATE ________ INITIALED

174. SPECIAL CONDITIONS:
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76-19-3 (10-79)

NEW YORK STATE
DEPARTMENT OF ENVIRONMENTAL CONSERVATION

COPIES: WHITE - ORIGINAL; GREY - DIVISION OF AIR; WHITE - REGIONAL OFFICE; PINK - FIELD REP; YELLOW - APPLICANT

OP | LOCATION | FACILITY | EMISSION POINT | I

A ADD / C CHANGE / D DELETE

READ INSTRUCTIONS CONTAINED IN FORM 76-11-12 BEFORE ANSWERING ANY QUESTION

PROCESS, EXHAUST OR VENTILATION SYSTEM

APPLICATION FOR PERMIT TO CONSTRUCT OR CERTIFICATE TO OPERATE

SECTION A

1. NAME OF OWNER/FIRM: ARCO
2. NUMBER AND STREET ADDRESS: 515 South Flower Street
3. CITY - TOWN - VILLAGE: Los Angeles
4. STATE: CA
5. ZIP: 90071
6. OWNER CLASSIFICATION: A. ☐ COMMERCIAL B. ☐ INDUSTRIAL C. ☐ UTILITY D. ☐ FEDERAL E. ☐ STATE F. ☐ MUNICIPAL G. ☐ EDUC. INST. H. ☐ HOSPITAL I. ☐ RESIDENTIAL J. ☒ OTHER
7. NAME & TITLE OF OWNERS REPRESENTATIVE:
8. TELEPHONE:
9. NAME OF AUTHORIZED AGENT: Remdiation Technologies
10. TELEPHONE: 508 371-1422
11. NUMBER AND STREET ADDRESS: 9 Pond Lane
12. CITY - TOWN - VILLAGE: Concord
13. STATE: MA
14. ZIP: 01742
15. NAME OF P.E. OR ARCHITECT PREPARING APPLICATION: Robert Block
16. N.Y.S. P.E. OR ARCHITECT LICENSE NO.:
17. TELEPHONE: 508 371-1422
18. SIGNATURE OF OWNERS REPRESENTATIVE OR AGENT WHEN APPLYING FOR A PERMIT TO CONSTRUCT:
19. FACILITY NAME (IF DIFFERENT FROM OWNER/FIRM): Sinclair Refinery
20. FACILITY LOCATION (NUMBER AND STREET ADDRESS):
21. CITY - TOWN - VILLAGE: Wellsville
22. ZIP:
23. BUILDING NAME OR NUMBER: Southern Area
24. FLOOR NAME OR NUMBER:
25. START UP DATE: MO / YR
26. DRAWING NUMBERS OF PLANS SUBMITTED:
27. PERMIT TO CONSTRUCT: A. ☒ NEW SOURCE B. ☐ MODIFICATION
28. CERTIFICATE TO OPERATE: A. ☐ NEW SOURCE B. ☐ MODIFICATION C. ☐ EXISTING SOURCE

SEC. B

29. EMISSION POINT ID.	30. GROUND ELEVATION (FT.)	31. HEIGHT ABOVE STRUCTURES (FT.)	32. STACK HEIGHT (FT)	33. INSIDE DIMENSIONS (IN.)	34. EXIT TEMP (°F)	35. EXIT VELOCITY (FT/SEC)	36. EXIT FLOW RATE (ACFM)	SOURCE CODE	38. HRS/DAY	39. DAYS/YR	40. % OPERATION BY SEASON Winter	Spring	Summer	Fall
00002	1,500	5	15	10	400	1,110	600		24	365	25	25	25	25

SEC. C

41. DESCRIBE PROCESS OR UNIT
1. Soil venting system
2.
3.
4.
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SEC. D

EMISSION CONTROL EQUIPMENT I.D.	CONTROL TYPE	MANUFACTURER'S NAME AND MODEL NUMBER	DISPOSAL METHOD	DATE INSTALLED MONTH / YEAR	USEFUL LIFE
42. 02A	43. 99	44. To be provided	45. 4	46. /	47. 10
48.	49.	50.	51	52. /	53.

SECTION E

CALCULATIONS

Presented in Permit to Construct Application

SECTION F

CONTAMINANT NAME	CAS NUMBER	INPUT OR PRODUCTION	UNIT	ENV. RATING	EMISSIONS ACTUAL	UNIT	HOW DET	PERMISSIBLE	% CONTROL EFFIC'CY	HOURLY EMISSIONS (LBS/HR) ERP	HOURLY ACTUAL	ANNUAL EMISSIONS (LBS/YR) ACTUAL	10ˣ	PERMISSIBLE
54. Benzene	55.	56. lb/hr	57. 1	58. A	59. 0.03	60. 1	61. 5	62.	63. 99	64.	65. .0003	66. 2.6	67.	68.
69. Toluene	70.	71. lb/hr	72. 1	73. C	74. 0.01	75. 1	76. 5	77.	78. 99	79.	80. .0001	81. 0.9	82.	83.
84. Ethylbenzene	85.	86. lb/hr	87. 1	88. B	89. 0.01	90. 1	91. 5	92.	93. 99	94.	95. .0001	96. 0.9	97.	98.
99.	100.	101.	102.	103.	104.	105.	106.	107.	108.	109.	110.	111.	112.	113.
114.	115.	116.	117.	118.	119.	120.	121.	122.	123.	124.	125.	126.	127.	128.
129.	130.	131.	132.	133.	134.	135.	136.	137.	138.	139.	140.	141.	142.	143.

SEC. G

SOLID FUEL TYPE	TONS/YR	% S	OIL TYPE	THOUSANDS OF GALLONS / YR	% S	GAS TYPE	THOUSANDS OF CF/YR	BTU/CF	APPLICABLE RULES	APPLICABLE RULES
144	145	146.	147.	148	149	150	151.	152	153.	154.

Upon completion of construction sign the statement listed below and forward to the appropriate field representative

THE PROCESS, EXHAUST OR VENTILATION SYSTEM HAS BEEN CONSTRUCTED AND WILL BE OPERATED IN ACCORDANCE WITH STATED SPECIFICATIONS AND IN CONFORMANCE WITH ALL PROVISIONS OF EXISTING REGULATIONS.

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PERMIT TO CONSTRUCT

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RECOMMENDED ACTION RE: C.O.

169 DATE ISSUED / / | 170 EXPIRATION DATE / / | 171 SIGNATURE OF APPROVAL | 172 FEE

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Appendix C

Soil Venting Flow Model Documentation

DESCRIPTION OF RETEC'S SOIL VENTING MODEL

RETEC has developed a computer program to calculate the air pressure and velocity fields in the subsurface induced by a vertical soil venting well. The program, V_VENT3.E, was written in the programming language GAUSS, and can be run on any personal computer equipped with the GAUSS software. A printout of the program is attached as Attachment 1.

V_VENT3 is based on the analytical solutions for compressible air flow equations in a homogeneous, anisotropic porous medium presented in the paper *Evaluation of Unsaturated Zone Air Permeability Through Pneumatic Tests*, by A.L. Baehr and M.F. Hult, Water Resources Research, Vol. 27, No. 10, pages 2606-2617, October 1991 (attached as Attachment 2). The relevant equations are equations 49 and 56 in the above quoted paper.

V_VENT3 can calculate the air pressure and velocity fields subject to two different types boundary conditions. In the first type, the water table is assumed to be an impermeable boundary to air flow, and the soil surface is assumed to be at a constant atmospheric pressure. In the second type, the water table is assumed to be an impermeable boundary to air flow, and a low permeability layer is assumed to cover the soil surface. This layer can represent a stratigraphic layer, such as a clay layer, or an asphalt layer, or a plastic layer.

The somewhat idealized situation depicted in Figure 3 of the Baehr and Hult paper is considered, in which the horizontal extent of the layer to be vented is infinite, the ground surface is flat, and the porous medium is homogeneous, but anisotropic. This means that vertical and horizontal permeabilities are not constrained to be equal, but can be set independently.

Two types of parameters need to be specified in order to run a simulation: site specific parameters and constant parameters (see program printout). The site specific parameters include the geometry of the soil venting system, and soil characteristics. The constant parameters refer to physical and chemical constants relevant to the problem.

A typical output of a V_VENT3 run is attached as Attachment 3. As the output shows, the air flow induced into the air extraction well is calculated, as well as the air pressure in the subsurface (in inches of water column), and the radial and vertical components of the air velocity (in ft/day). Given the geometry of the system, the problem is axially symmetric about the vertical well's axis, so that only radial and vertical velocities are relevant. The radial and vertical distances at which the fields are required are specified by the user.

The final output item of V_VENT3 is the "flushout time" as a function of the distance from the well. The flushout time represents the time necessary to extract from the subsurface a volume of air contained in a cylinder of radius r (variable), and height equal to the height of the vadose zone. This time is estimated by the program by numerically integrating the velocity field.

The radius of influence of the well is established as the radius corresponding to a prescribed value of the flushout time. For typical soil venting applications, the prescribed flushout time is 1/3 of a day, meaning that the system is designed to exchange three pore volumes of air per day within its radius of influence. In the output example presented in Attachment 3, based on the flushout time calculation, the radius of influence of the well would be estimated to be approximately 60 ft.

ATTACHMENT 1

V_VENT3 PRINTOUT

```
/* Program V_VENT3.E

Calculates the pressure and air velocity fields for a vertical well.
It also calculates the air flow into the well.
The bottom boundary condition is an impermeable one (the water table).
The pressure is set to required pressure (Pw) at the top of the well.

The user can choose the boundary condition at the top surface:

    if BC=1 -> Lower permeability unit at the top;

    if BC=0 -> Top surface is at atmospheric pressure;

The calculation is based on the paper "Evaluation of Unsaturated zone
air permeability through pneumatic tests" by Baher and Hult,
WRR 27 (10), 2605-2617, 1991.

  *****************  SITE SPECIFIC INPUTS  ******************

BC= boundary conditions identifier

B = depth to water table (ft)
Lw = length of well (ft)
Dw = height above impervious surface at which bottom of well is placed (ft)
Pw = negative air pressure at the well (atm)
Rw = radius of the well (inches)
eps= soil porosity (m^3 void/m^3 soil)
T = soil temperature (½F)
kr = soil permeability in radial direction (cm^2)
kz = soil permeability in vertical direction (cm^2)
kprime=permeability of upper confining unit (cm^2)
bprime=thickness of upper confining unit (ft)

  *****************  CONSTANT INPUTS  ******************

g = acceleration of gravity (m/sec^2)
omg= air molecular weight (Kg/mole)
Pa=atmospheric pressure, taken as 1 atm
Mu = air viscosity (kg/m sec)
R = universal gas constant (kg*m^2/sec^2*mole*½K)

  ****************** PROGRAM OUTPUT  *******************

    P(r) = air pressure field (in atmospheres)
    vr   = radial velocity component
    vz   = vertical velocity component
    Q    = air flow into the well (in scfm)
*/

output file=v_vent3.out reset;
tsbeg=hsec/(100*60);
format /rz 10,3;
/* **************** VALUES OF SITE SPECIFIC PARAMETERS ******************* */

BC=0;  /* specify boundary conditions
        BC=1 -> low permeability unit as top BC
        BC=0 -> top surface at atmospheric pressure */


B=25;  /*  ft  */
Lw=10;  /*  ft  */
Dw=1;  /*  ft  */
Pw=40/406.8;  /*  atm  */
Rw=2;  /*  inches  */
eps=0.3; /* m^3 void/m^3 soil */
T= 70; /* ½F */
```

```
kr=2.6e-7; /* cm^2 */
kz=0.1*kr; /* cm^2 */

/*  **** The following two parameters need not be specified if BC=0 ***** */
kprime=1e-12; /*cm^2 */
bprime=.333;  /* ft */

/* **************** VALUES OF CONSTANT PARAMETERS ******************** */

Mu=1.8E-5;  /*  kg/m sec  */
g=9.8;  /*  m/sec^2  */
pmg=28.8E-3; /* kg/mole of air*/
Pa=1.013e5; /*kg/m*sec^2 = 1 atmosphere */
R=8.414510; /* kg*m^2/sec^2*mole*½K */

/* Write out the problem's parameters */

"Program V_VENT3.OUT";"Output from V_VENT3.E";
"Calculates pressure and air velocity fields due to a vertical well";
"It also calculates the air flow into the well.";"";
"THE BOUNDARY CONDITIONS ARE:";"";
        if BC == 1;
        "Water table (impermeable surface) at the bottom,";
        "Lower permeability unit at the top,";
        "P=Pw at screen.";
        else;
        "Water table (impermeable surface) at the bottom,";
        "Top surface at atmospheric pressure";
        "P=Pw at screen.";
        endif;
"";"";
"******************* SITE SPECIFIC INPUT PARAMETERS ***************";"";
"Depth to G.W Table B=" B "ft";
"Height above G.W. table at which bottom of well is placed Dw=" Dw "ft";
"Length of well Lw=" Lw "ft";
"Radius of the well Rw=" Rw "inches";
"Negative Pressure at the Well Pw=" Pw "atm = ";;Pw*406.8 "iwc";
"Soil Temperature T=" T "½F";
"Soil Permeability in Radial Direction kr=" kr "cm^2";
"Soil Permeability in Vertical Direction kz=" kz "cm^2";
"Soil Porosity eps=" eps;

  if BC == 1;
  "Permeability of upper confining unit kprime=" kprime "cm^2";
  "Thickness of upper confining unit bprime=" bprime "ft";
  endif;

"";"";

/*  SPECIFY PTS AT WHICH PRESSURE AND VELOCITY FIELDS ARE REQUIRED   */

/* rpoint and zpoint are the array containing the distances (in ft) at
which the velocity is required  REMEMBER: if you wan to plot the
contour levels, nr and nz must be odd */
rpoint = { 1, 3, 5, 10, 20, 50 };
zpoint = { 0, 1, 3, 5, 7, 10, 11 };

/*If you want equally spaced r and z points between, respectively,
rmin and rmax and 0 and B, use the following segment of program */

nr=11;      /* number of points in radial direction */
nz=3;     /* number of points in vertical direction */
rmax=101;   /* ft */
rmin=1;   /* ft */
rpoint=seqa(rmin,(rmax-rmin)/(nr-1),nr);
zpoint=seqa(0,B/(nz-1),nz);
```

```
/* ******************* CONVERT TO MKS UNIT ***************** */

Pw=Pw*1.013e5 /* kg/m*sec^2 */;
kr=kr/1e4; /* m^2 */
kz=kz/1e4; /* m^2 */
kprime=kprime/1e4; /* m^2 */
B=B*.3048; /* m */
Dw=Dw*.3048; /* m */
Lw=Lw*.3048; /* m */
Rw=Rw*.0254; /* m */
bprime=bprime*.3048; /* m */
T=273 + (T-32)/1.8; /* ½K */
rpoint=rpoint*.3048;
zpoint=zpoint*.3048;

/****** create parameters used in the paper (fig 4) ********** */
l=B-Dw;
d=B-Dw-Lw;
a=sqrt(kr/kz);
/* determine Qstar by setting pressure at the well
   equal to assumed imposed pressure */
Qstar=( (Pa-Pw)^2-Pa^2 )*(pi*kr*Rw)/(a*bc_funct(Rw,d+(l-d)/2,l,d));
/* Qstar=( (Pa-Pw)^2-Pa^2 )*(pi*kr*Rw)/(a*bc_funct(Rw,d,l,d));*/

Qm=Qstar*omg/(mu*R*T);
Q=(Qm/omg)*22.4;  /* convert from kg/sec to liters at STP */

"NOTE:";
"z=0 -> top of vented layer ; z=B -> water table";
"Negative flow corresponds to air being extracted from the soil";
"Positive flow corresponds to air being injected into the soil";
"";"";
"Induced air mass flow, Qm =" Qm "Kg/sec";
"Induced volume flow of air, Q =" Q "L/sec=" (Q/28.32)*60 "scfm";


/* initialize fields */
nr=rows(rpoint);
nz=rows(zpoint);
vr=zeros(nr,nz);
vz=zeros(nr,nz);
P=zeros(nr,nz);

/* calculate quantities at (rpoint,zpoint)  */

i=1;
do while i <= nr;
format /rd 10,3;
"";"";"r= " rpoint[i,1]/.3048 " ft";
"***************";"";
"      z";;"        P(r,z)";;"     Vr(r,z)";;"     Vz(r,z)";
"    (ft)";;"       (iwc)";;"     (ft/day)";;"    (ft/day)";

   j=1;
   do while j<= nz;
   temp_z=zpoint[j,1];
   temp_r=rpoint[i,1];

     P[i,j]=press(rpoint[i,1],zpoint[j,1]);  /* pressure in MKS units */
     P[i,j]=Pa-P[i,j];                /* convert to gage pressure */
     P[i,j]=P[i,j]/1.013e5;           /*convert to atm */

/* Calculate radial and vertical velocities */
     vr[i,j]=rad_vel(rpoint[i,1]);  /* flow/area m/sec */
     vr[i,j]=vr[i,j]*60*60*24/(.3048*eps);  /* convert to ft/day air vel*/
```

```
    vz[i,j]=z_vel(zpoint[j,1]);  /* flow/area in m/sec */
    vz[i,j]=vz[i,j]*60*60*24/(.3048*eps);  /* convert to ft/day air vel*/

/* print values of all quantities */
zpoint[j,1]/.3048;;P[i,j]*406.8;;vr[i,j];;vz[i,j];

   j=j+1;
   endo;  /* of loop over nr */
i=i+1;
endo;  /* of loop over nz */


/* section to calculate the "flushout time" */

t_flush=zeros(nr,1);
temp_z=d+(l-d)/2;
  dr=rpoint[1,1]-Rw;
  t_flush[1,1]=dr*vr1(Rw+dr/2);
  i=2;
  do while i <= nr;
  dr=rpoint[i,1]-rpoint[i-1,1];
  t_flush[i,1]=t_flush[i-1,1] + dr*vr1(rpoint[i-1]+dr/2);
  i=i+1;
  endo;

/* write out flushout time vs r */

"";"";"Calculation of 'flushout time' vs distance from the well";"";
"       r";;"      t_flush(r)";
"      (ft)";;"      (days)";

i=1;
do while i <= nr;
rpoint[i,1]/.3048;; t_flush[i,1]/(60*60*24);
i=i+1;
endo;

/* *********** SECTION FOR DEFINITION OF PROCEDURES **************** */

#include c:\ab\venting\bessel.e;
#include c:\ab\venting\baher1.e;
#include c:\ab\venting\baher2.e;

proc(1)=press(r,z);
local p;
p=sqrt( Pa^2 + ((a*Qstar)/(pi*kr*Rw))*
        bc_funct(r,z,l,d) );  /* Units are MKS */
retp(p);
endp;

proc(1)=bc_funct(r,z,l,d);
local f;
  if BC == 1;
  f=baher1(r,z,l,d);
  else;
  f=baher2(r,z,l,d);
  endif;
retp(f);
endp;


proc(1)=dummy_r(r);
retp( press(r,temp_z) );
endp;
```

```
proc(1)=rad_vel(r);
retp( -(kr/mu)*gradp(&dummy_r,r) );
endp;

proc(1)=dummy_z(z);
retp( press(temp_r,z) );
endp;

proc(1)=z_vel(z);
retp( -(kz/mu)*gradp(&dummy_z,z) );
endp;

proc(1)=vr1(r);    /* 1/vr, in sec/m */
retp( -eps/rad_vel(r) );
endp;


tsend=hsec/(100*60);
telaps=tsend-tsbeg;
"";"";
"Time for run in minutes = " telaps;

end;
```

ATTACHMENT 2

EVALUATION OF UNSATURATED ZONE AIR PERMEABILITY THROUGH PNEUMATIC TESTS

BY BAEHR AND HULT

WATER RESOURCES RESEARCH, VOL. 27, NO. 10, PAGES 2605–2617, OCTOBER 1991

Evaluation of Unsaturated Zone Air Permeability Through Pneumatic Tests

ARTHUR L. BAEHR

U.S. Geological Survey, West Trenton, New Jersey

MARC F. HULT

U.S. Geological Survey, Saint Paul, Minnesota

Predicting the steady state distribution of air pressure in the unsaturated zone resulting from a pneumatic test provides a method for determining air-phase permeability. This technique is analogous to the inverse problem of well hydraulics; however, air flow is more complicated than ground water flow because of air compressibility, the Klinkenberg effect, variations in air density and viscosity that result from temperature fluctuations in the unsaturated zone and the possibility of inducing water movement during the pneumatic test. An analysis of these complicating factors reveals that, when induced water movement can be neglected, a linear version of the airflow equation can provide an appropriate approximation for the purpose of determining air-phase permeability. Two analytical solutions for steady state, two-dimensional, axisymmetric airflow to a single well partially screened in the unsaturated zone are developed. One solution applies where there is a stratum of relatively low air permeability, separating the stratum in which the well is completed, from the atmosphere. The other solution applies where there is no separating stratum between the domain and atmosphere. In both situations the water table forms the lower horizontal boundary. Applications of both solutions to determine air permeability from data collected during pneumatic tests are presented.

Introduction

Mathematical models of contaminant transport in the unsaturated zone have, until recently, neglected the advection of vapors through the air-filled fraction of pores. Therefore the air permeability of the unsaturated zone has been a parameter of limited practical interest. Recently, researchers have incorporated advective vapor transport in model equations to describe the natural movement of dense organic vapors in the unsaturated zone [*Sleep and Sykes*, 1989; *Falta et al.*, 1989; *Thorstenson and Pollock*, 1989; *Baehr and Bruell*, 1990; *Mendoza and Frind*, 1990]. *Baehr et al.* [1989] present an analysis of volatile organic contaminant removal from the unsaturated zone through induced advection. The model equations given in the works cited above require values of air permeability of the unsaturated zone for site-specific applications.

The evaluation of gas reservoir permeability using flow models is a long standing technique [*Muskat and Botset*, 1931]. Soil scientists also have injected air and measured soil air pressure to evaluate soil permeability (e.g., *Krikham*, 1946].

More recently, hydrologists have applied similar techniques to evaluate the air permeability of the unsaturated zone. *Weeks* [1977] describes the use of depth-dependent air pressure variations caused by natural fluctuation in atmospheric pressure to calibrate a one-dimensional air flow model to obtain air permeability. This method was developed primarily as a way to approximate the vertical component of hydraulic conductivity. *Massmann* [1989] adapted the Theis solution for one-dimensional radial groundwater flow to predict pressure drawdowns within a vapor extraction well as a function of extraction rate. *Baehr and Hult* [1988] adapted Hantush's solution for two-dimensional axisymmetric ground water flow to a partially penetrating well in a confined aquifer to evaluate air flow in the unsaturated zone induced by a vapor extraction well. Their solution to the air flow equation requires the extraction well to be modeled as an infintesimal line source and the domain to be bounded above by a confining unit (such as a silty lens or asphalt-covered land).

In this paper, two new analytical solutions are presented for the equations describing steady state two-dimensional axisymmetric flow in the unsaturated zone induced during pneumatic tests designed to evaluate air permeability and to examine two-dimensional flow patterns. The two solutions allow for analysis of airflow for confined and unconfined domains, and both solutions allow for modeling an extraction well of finite radius. The paper also provides a general method of analysis for the induced movement of air to determine conditions under which the linearized flow equation is appropriate. The solutions are applied to pneumatic tests conducted near Bemidji, Minnesota, to calculate the air permeability of the unsaturated zone.

General Airflow Equation

The equation for airflow in an unsaturated, unconsolidated porous medium is derived from the conservation-of-mass principle as follows:

$$\frac{\partial}{\partial t}(\rho\theta) + \nabla \cdot (\rho \mathbf{q}) = 0 \qquad (1)$$

where ρ is the density of air, in grams per cubic centimeter, θ is air-filled porosity, dimensionless, $\mathbf{q}$ is the specific discharge vector for air, in centimeters per second, and t is time, in seconds.

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Paper number 91WR01655.

Dr. ALESSANDRO BATTAGLIA
P. IVA 09337810585
C. F. BTT LSN 58P14 M082X

Darcy's law is assumed as follows for a compressible fluid [*Hubbert*, 1940]:

$$q = \frac{-\rho g}{\mu} \mathrm{k}\nabla\left[z + \frac{1}{g}\int_{P_0}^{P} \frac{1}{\rho}\, dP\right] \tag{2}$$

where μ is the dynamic viscosity of air, in grams per centimeter per second, g is the acceleration due to gravity, k is the air-phase permeability tensor, the components of which are in centimeters squared, z is elevation in centimeters, P is air-phase pressure, and P_0 is a reference air-phase pressure, in grams per centimeter per second squared.

Darcy's law is widely accepted as a valid approximation to the conservation of momentum principle for airflow in porous media at low Reynolds Number Re defined as follows:

$$Re = \frac{dq_m}{\mu\theta} \tag{3}$$

where d is a representative pore-space diameter and q_m is specific mass flux for air, in grams per centimeter squared per second. Column experiments by *Yu* [1985] to test the validity of Darcy's law for air flow through various-sized sands showed that Darcy's law was valid for $Re < 6$.

The ideal gas law is assumed to relate pressure and density and thus represents air compressibility as follows:

$$\rho = \frac{\omega P}{RT} \tag{4}$$

where ω is the average molecular weight of the air phase, in grams per mole, T is temperature, in Kelvin, and R is the universal gas constant, 8.314×10^7 grams per centimeters squared per seconds squared per mole per degrees Kelvin. Substituting (4) into (2) yields the following form of Darcy's law in terms of elevation, pressure, and temperature:

$$\vec{q} = \frac{-\rho g}{\mu} \mathrm{k}\vec{\nabla}\left[z + \frac{RT}{\omega g}\ln\frac{P}{P_{\mathrm{atm}}}\right] \tag{5}$$

where the reference pressure is prevailing atmospheric pressure P_{atm}.

Substituting (4) into (1) and further assuming ω is constant (28.8 grams per mole for humid air) and that $\partial T/\partial t = 0$ (steady temperature distribution) yields the following equation:

$$\frac{\partial}{\partial t}(P\theta) + P(\nabla \cdot \mathbf{q}) + T\nabla\left(\frac{P}{T}\right) \cdot \mathbf{q} = 0 \tag{6}$$

Substituting (5) into (6) and applying the following change of variable:

$$\phi = P^2 \tag{7}$$

yields the basic air flow equation for any coordinate system. The resultant equation in terms of ϕ is simpler than the equation that would result in terms of P without use of the transformation given by (7). This is due to the algebraic simplification of nonlinear terms that are attributed to air compressibility. This transformation was used by *Muskat and Botset* [1931] in their analysis of natural gas reservoirs to linearize flow equations.

For a cylindrical coordinate system the basic airflow equation is

$$\begin{aligned}\mu\theta \frac{1}{\sqrt{\phi}}\frac{\partial\phi}{\partial t} &= k_r \frac{\partial^2\phi}{\partial r^2} + k_z \frac{\partial^2\phi}{\partial z^2} + \left(\frac{\partial k_r}{\partial r} + \frac{1}{r}k_r\right)\frac{\partial\phi}{\partial r}\\ &+ \left[2k_z\frac{\omega g}{RT} + \frac{\partial k_z}{\partial z} - k_z\left(\frac{1}{T}\frac{\partial T}{\partial z} + \frac{1}{\mu}\frac{\partial u}{\partial z}\right)\right]\frac{\partial\phi}{\partial z}\\ &+ 2\left[\frac{\omega g}{RT}\left(\frac{\partial k_z}{\partial z} - k_z\frac{1}{\mu}\frac{\partial u}{\partial z}\right) - 2k_z\frac{\omega g}{RT}\frac{1}{T}\frac{\partial T}{\partial z}\right]\phi\end{aligned} \tag{8}$$

In obtaining (8) the further assumption was made that $\partial\theta/\partial t = 0$ (steady state air-water distribution) and that $\partial T/\partial r = 0$ (only vertical soil temperature variation). The latter assumption is valid because natural areal temperature variations can be neglected over the scale of a pneumatic test and because temperature variations due to energy transport associated with induced air movement will be negligible as a result of the high thermal capacity of natural sediments and low-energy content of air. Further, the principal components of the air permeability tensor are assumed to be aligned with coordinate axes.

Injecting or withdrawing air through a well screened in the unsaturated zone can cause water movement. The corresponding redistribution of air and water in the pores surrounding the well will interfere with measurement of air permeability because, in multiphase systems, phase-specific or relative permeabilities are dependent on fluid distribution. Thus the soil properties and operating conditions for pneumatic tests under which induced water movement can be neglected are of interest to justify an analysis based on single phase flow. Another consideration is that pumping may induce inflow of dry atmospheric air that could decrease water saturation in the unsaturated zone around the well.

An analysis of the simultaneous radial flow of air and water to a well revealed that the effect of water redistribution on air permeability determination was dependent on capillary pressure and relative permeability functions as well as on prevailing moisture conditions. The transfer value of this analysis is minimal because these factors vary widely from site to site. Practical methods for evaluating the single phase flow analysis of pneumatic tests are therefore recommended. For example, pneumatic tests conducted by both withdrawing and injecting air at different flow rates, might allow detection of whether redistribution was occurring. Another approach would be to monitor the mass withdrawal rate and pressure at the well over a sufficient period of time to allow water redistribution. If the rate and/or pressure changed significantly during this period, then redistribution might be occurring near the well. In this paper, water redistribution that results from the pneumatic test is assumed negligible, as was the case for the field application near Bemidji, Minnesota.

SIMPLIFICATIONS TO THE GENERAL AIRFLOW EQUATION TO OBTAIN ANALYTICAL SOLUTIONS

The Klinkenberg Effect

The Klinkenberg effect is an enhancement of air-phase permeability through slippage of air molecules along the boundaries of air-filled pores. This occurs when the mean free path of air molecules approaches the dimensions of the pores. The Klinkenberg effect then is greatest in fine-grained porous media and increases with decreasing air-phase pressure. This effect [*Klinkenberg*, 1941] is expressed as follows:

$$k = k_\infty\left(1 + \frac{b}{P}\right) \tag{9}$$

where k_∞ is the air-phase permeability at high air-phase pressure and b is a parameter of the porous medium. The following empirical relation between k_∞ and b is a based on data presented by *Heid et al.* [1950]:

$$b = (3.98 \times 10^{-5})k_\infty^{-0.39} \tag{10}$$

where b is in atmospheres and k_∞ is in units of centimeters squared. Equation (10) is The American Petroleum Institute (API) standard correction for the Klinkenberg effect and is based on air-dry consolidated media and therefore may not be applicable to certain soils and unconsolidated media. For example, *Stonestrom and Rubin* [1989] report the following values, $k_\infty = 1.2 \times 10^{-7}$ cm^2 and $b = 0.059$ atmospheres for dry Oakley sand. This value for b is 2.94 times larger than the value given by (10). Unpublished data (D. A. Stonestrom, personal communication, 1991) show that (10) systematically underestimates b for soils; however, the Oakley sand deviation is most severe, and (10) can be used to approximate the magnitude of the Klinkenberg effect over a range of soil permeability.

Incorporation of the Klinkenberg effect, as expressed in (9), into the airflow model given by (8), introduces nonlinear terms that preclude the development of analytical solutions. Thus the conditions under which the Klinkenberg effect can be neglected must be indentified. For a hypothetical homogeneous and isotropic porous media the maximum percent error possible in obtaining an air permeability estimate through omission of the Klinkenberg effect is as follows:

$$e_{\max} = 100\left[\frac{k(P_w) - k(P_{\text{atm}})}{k(P_{\text{atm}})}\right] \tag{11}$$

where P_w is air pressure at the well and P_{atm} is atmospheric air pressure. Equation (9) and (11) imply the following:

$$e_{\max} = \frac{100\left[\dfrac{P_{\text{atm}}}{P_w} - 1\right]}{\left[\dfrac{P_{\text{atm}}}{b} + 1\right]} \tag{12}$$

Contours of $e_{\max}$ as a function of P_w/P_{atm} and Klinkenberg parameter b (or k_∞ according to (10)) for air withdrawal are shown in Figure 1*a*; those for the case of air injection in Figure 1*b*. These graphs illustrate how omission of Klinkenberg effect in estimating air permeability from pneumatic tests can be of practical significance (>10%) for porous media with an intrinsic permeability of 10^{-9} cm^2 of less (silty sand range).

The actual error incurred through omission of the Klinkenberg effect would be less than that indicated by Figures 1*a* and 1*b* and would be dependent on unsaturated zone geometry and the location of the air pressure data. For steady one-dimensional radial flow, substituting (9) into (8) and applying the chain rule, $dk/dr = (dk/d\phi)(d\phi/dr)$, yields the following airflow equation:

$$\frac{d^2\phi}{dr^2} + \frac{1}{r}\frac{d\phi}{dr} = \frac{b}{2\phi(\phi^{1/2} + b)}\left(\frac{d\phi}{dr}\right)^2 \tag{13}$$

The appropriate boundary conditions are as follows:

$$\phi = P_{\text{atm}}^2 \qquad r = r_f \tag{14}$$

$$\frac{d\phi}{dr} = \frac{-Q\,RT\mu}{\pi H\omega r_f k_\infty\left(1 + \dfrac{b}{P_{\text{atm}}}\right)} \quad r = r_f \tag{15}$$

where r_f (in centimeters) defines the far boundary, Q is mass flux of air in grams per second (negative for withdrawal, positive for injection), and H is well-screen length in centimeters. The Klinkenberg effect is represented by the nonlinear term on the right-hand side of (13).

Predictions obtained from the numerical solution to (13) through (15) are used as data to obtain an estimate of air permeability through the following linearized equation:

$$\frac{d^2\phi}{dr^2} + \frac{1}{r}\frac{d\phi}{dr} = 0 \tag{16}$$

$$\phi = P_{\text{atm}}^2 \quad r = r_f \tag{17}$$

$$\frac{d\phi}{dr} = \frac{-QRT\mu}{\pi H\omega r_f\, k^*} \quad r = r_f \tag{18}$$

where k^* is an air permeability estimate that considers the Klinkenberg effect in a composite sense. The analytical solution to (16) through (18) is as follows:

$$\phi = P_{\text{atm}}^2 + \left[\frac{QRT\mu}{\pi H\omega k^*}\right]\ln\frac{r_f}{r} \tag{19}$$

Values for model parameters assumed for this one-dimensional reference case are listed in Table 1. Predictions at $r = 6$, 100, and 500 cm obtained from the numerical solution to (13) through (15) are used as data to obtain the least squares composite air permeability estimate k^* defined by (19). The percent error e_{ref} is for this reference example and is defined as follows:

$$e_{\text{ref}} = 100\left[\frac{k^* - k_\infty\left(1 + \dfrac{b}{P_{\text{atm}}}\right)}{k_\infty\left(1 + \dfrac{b}{P_{\text{atm}}}\right)}\right] \tag{20}$$

A plot of the reference error (e_{ref}) as a function of P_w/P_{atm} for a porous medium corresponding to silt ($k_\infty = 10^{-11}$ cm^2, $b = 0.766$ atmospheres) for air withdrawal and air injection are given in Figures 2*a* and 2*b*, respectively. Volumetric flow, in standard liters of air per minute, that corresponds to this one-dimensional reference example is included in Figures 2*a* and 2*b* and is defined as follows:

$$V_s = \frac{Q}{\rho_s} \tag{21}$$

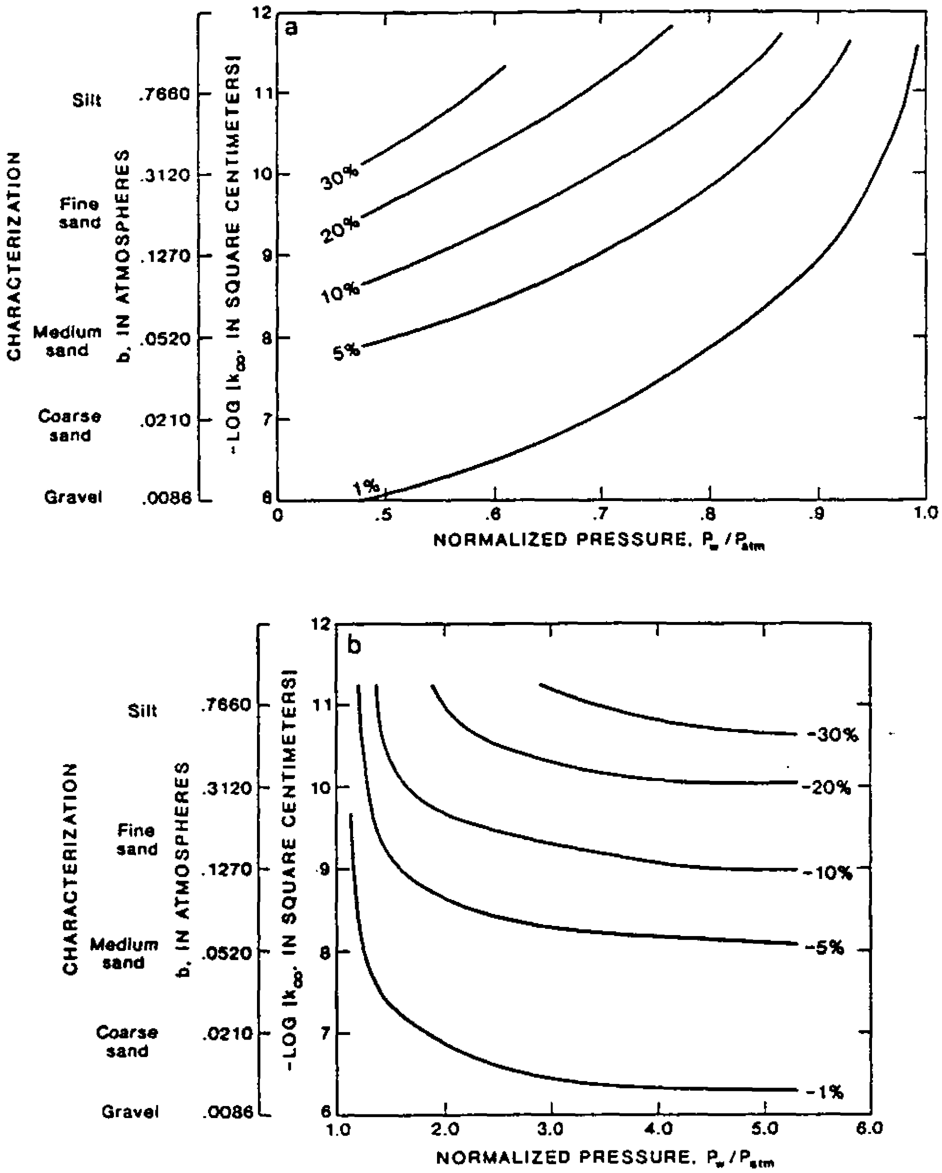

Fig. 1. Maximum possible percent error in obtaining air permeability estimate due to neglecting the Klinkenberg Effect. (*a*) Case of air withdrawal and (*b*) case of air injection.

where V_s is the equivalent volumetric flow of air at standard conditions, Q is the mass flux for the pneumatic test, and ρ_s is density of air at standard conditions ($\rho_s = \omega P_{atm}/RT = 1.24 \times 10^{-3}$ g/cm^3).

Comparing Figures 2*a* and 2*b* with Figures 1*a* and 1*b* reveals that the error incurred in neglecting the Klinkenberg effect is dependent on pneumatic test geometry and observation location. Further, this error can be considerably less than the maximum possible error; for example, the maximum percent error incurred at $P_w/P_{atm} = 0.56$ is 30% (Figure 1*a*, $k_\infty = 10^{-11}$ cm^2), whereas the error in the one-dimensional reference case at $P_w/P_{atm} = 0.56$ is about 11% (Figure 2*a*).

Temperature Gradients and Elevation Head

The derivation of two-dimensional analytical solutions for steady state, radially symmetric flow (presented in the next section) requires that terms in (8) that result from temperature gradients and the elevation component of head be negligible. These terms are identified in this section to provide a point of departure between the analyses of natural and induced unsaturated zone gas movement.

The viscosity of an ideal gas is independent of its pressure and dependent on temperature as follows [*Noggle*, 1985]:

$$\mu = \mu_R \left(\frac{T}{T_R}\right)^{1/2} \tag{22}$$

where μ_R is the air-phase viscosity at a reference temperature T_R.

Equation (22) implies the following:

$$\frac{1}{\mu}\frac{\partial \mu}{\partial z} = \frac{1}{2T}\frac{\partial T}{\partial z} \tag{23}$$

Therefore all terms in the general air-flow equation (8) that result from temperature gradients have the normalized gradient, $1/T\ (\partial T/\partial z)$, as a common coefficient. Substituting (23) into (8) and assuming homogeneity ($\partial k_r/\partial r = 0$, $\partial k_z/\partial z = 0$) yields the following equation for axisymmetric air flow:

$$\mu\theta \frac{1}{\sqrt{\phi}} \frac{\partial \phi}{\partial t} = k_r \frac{\partial^2 \phi}{\partial r^2} + k_r \frac{1}{r}\frac{\partial \phi}{\partial r} + k_z \frac{\partial^2 \phi}{\partial z^2} - \left[\left(3/2\ k_z \frac{1}{T}\frac{\partial T}{\partial z}\right)\frac{\partial \phi}{\partial z} + \left(5 \frac{\omega g}{RT} k_z \frac{1}{T}\frac{\partial T}{\partial z}\right)\phi\right] + \left(2k_z \frac{\omega g}{RT}\right)\frac{\partial \phi}{\partial z} \qquad (24)$$

The terms in square brackets depend on normalized temperature gradient, and the last term of (24) is due to the elevation component of head. It is assumed that these terms are negligible for induced flow associated with a pneumatic test. The terms may, however, be required to model natural flows.

ANALYTICAL SOLUTIONS FOR STEADY STATE AXISYMMETRIC FLOW

To determine air permeability with pneumatic tests, the Klinkenberg effect as well as temperature gradients and the elevation component of head are neglected. If lateral heterogeneity in air permeability, including the effect of water redistribution caused by induced air movement, also can be neglected, then $\partial k_r/\partial r = 0$, and the airflow equation simplifies accordingly. Vertical heterogeneity in air permeability, as represented by $\partial k_z/\partial z$ in (8), can arise through variation in moisture content and the presence of layered strata over the scale of the pneumatic test. However, these vertical variations preclude the development of analytical solutions; therefore the analytical solutions presented below represent vertical heterogeneity in air permeability as an apparent anisotropy.

Application 1: Domain Separated From Atmosphere by a Confining Unit

The domain simulated is sketched in Figure 3. The upper confining unit is leaky and can be, for example, a stratum less permeable to air than the domain or perhaps a slightly permeable paved surface. The bottom boundary is formed by the water table (impervious to air). Emulating the leaky

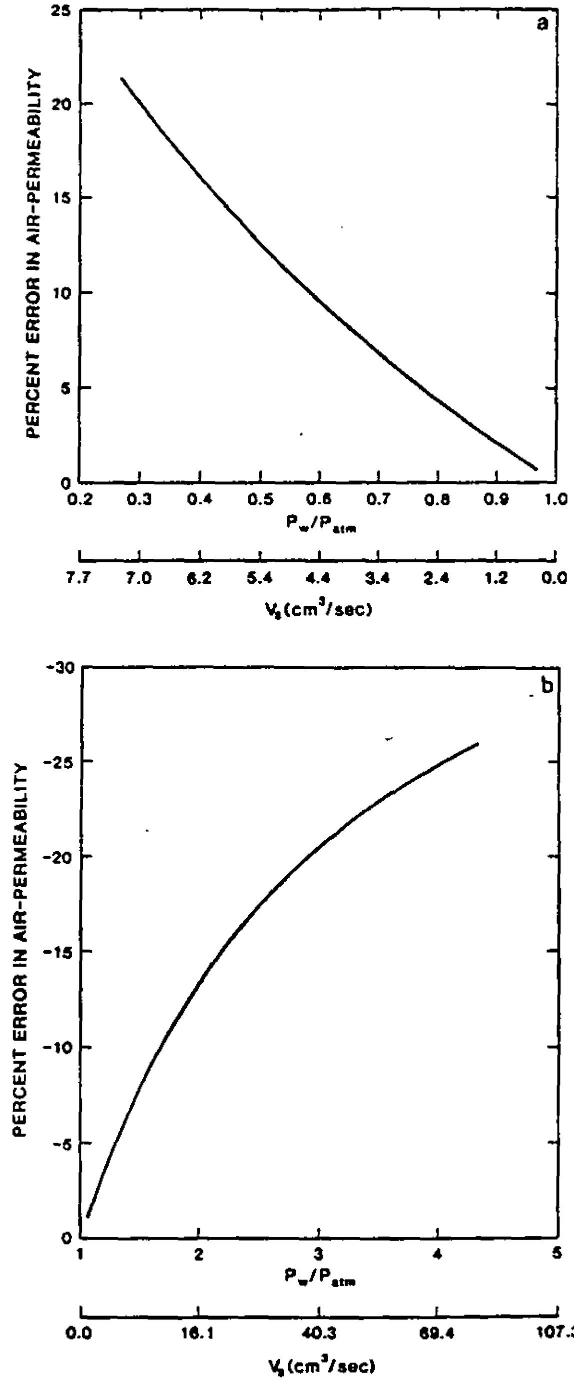

Fig. 2. Percent error in obtaining air permeability estimate due to neglecting the Klinkenberg Effect for one dimensional reference case. (*a*) Case of air withdrawal and (*b*) case of air injection.

TABLE 1. Assumed Values for Parameters for One-Dimensional Reference Case

Parameters	Values
Radius of well	$r_0 = 5$ cm
Far radius	$r_f = 1000$ cm
Screen height	$H = 100$ cm
Atmospheric pressure	$P_{atm} = 1013200.0$ g/cm s² (1 atmosphere)
Temperature	$T = 283$ K
Air molecular weight	$\omega = 28.8$ g/mole
Air viscosity	$\mu = 1.76 \times 10^{-4}$ g/cm-s
Gas constant	$R = 8.3143 \times 10^7$ g cm²/s² mole K
Acceleration due to gravity	$g = 981.0$ cm/s²
Klinkenberg parameters	see equation (10)

aquifer theory of *Hantush* [1964], leakage through the confining unit is assumed to be distributed across the domain and is accounted for by adding the term:

$$\frac{-1}{b}\left(\frac{k'}{b'}\right)(\phi - P_{atm}^2)$$

to the first three terms of (24), where k'/b' is the ratio of air permeability to thickness of the confining unit in centimeters and b is the thickness of the domain (Figure 3). The resulting equation is

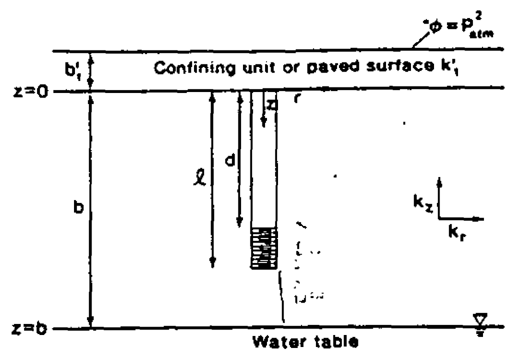

Fig. 3. Domain separated from atmosphere by a confining unit.

$$k_r \frac{\partial^2 \phi}{\partial r^2} + k_r \frac{1}{r}\frac{\partial \phi}{\partial r} + k_z \frac{\partial^2 \phi}{\partial z^2} - \frac{k'}{bb'}(\phi - P_{\text{atm}}^2) = 0 \qquad (25)$$

The boundary conditions are as follows:

$$\frac{\partial \phi}{\partial z}(r, 0) = \frac{\partial \phi}{\partial z}(r, b) = 0 \qquad (26)$$

$$\lim_{r\to\infty} \phi(r, z) = P_{\text{atm}}^2 \qquad (27)$$

at $r = r_w$,

$$\frac{\partial \phi}{\partial r} = 0 \qquad 0 < z < d \qquad (28a)$$

$$\frac{\partial \phi}{\partial r} = \frac{-Q^*}{\pi k_r(1-d)r_w} \qquad d < z < 1 \qquad (28b)$$

$$\frac{\partial \phi}{\partial r} = 0 \qquad 1 < z < b \qquad (28c)$$

where r_w is the radius of the well and $Q^* = (Q\mu RT)/\omega$. The distances 1, d, and b are defined in Figure 3. *Baehr and Hult* [1988] present an application of an analytical solution to the transient airflow equation based on Hantush's analysis of drawdown caused by a partially penetrating well in a confined aquifer. This solution requires the well to be modeled as an infinitesimal line source. This restriction, is not needed to solve the steady state problem, however. Thus the following solution allows for a specified well radius r_w. This feature can be of significance for pneumatic tests where the injection or withdrawal well is the only location for obtaining air pressure data.

The transformations:

$$s = \phi - P_{\text{atm}}^2 \qquad (29)$$

$$x = \frac{r}{a} \qquad (30)$$

where

$$a^2 = \frac{k_r}{k_z}$$

$$y = \frac{\pi}{b} z \qquad (31)$$

are used to state the problem in standard form as follows:

$$\frac{\partial^2 s}{\partial x^2} + \frac{1}{x}\frac{\partial s}{\partial x} + \left(\frac{\pi}{b}\right)^2 \frac{\partial^2 s}{\partial y^2} - \frac{k'}{bb'k_z} s = 0 \qquad (32)$$

$$\frac{\partial s}{\partial y}(x, 0) = \frac{\partial s}{\partial y}(x, \pi) = 0 \qquad (33)$$

$$\lim_{x\to\infty} s(x, y) = 0 \qquad (34)$$

at $x = r_w/a$

$$\frac{\partial s}{\partial x} = 0 \qquad 0 < y < \frac{d}{b}\pi$$

$$\frac{\partial s}{\partial x} = \frac{-aQ^*}{\pi k_r(1-d)r_w} \qquad \frac{d}{b}\pi < y < \frac{1}{b}\pi \qquad (35)$$

$$\frac{\partial s}{\partial x} = 0 \qquad \frac{1}{b}\pi < y < \pi$$

The finite cosine transform applied by *Hantush* [1964] to solve the partially penetrating well hydraulics problem is defined as follows:

$$C_n\{f(y)\} \equiv f_c(n) = \int_0^{\pi} f(y) \cos(ny)\, dy \qquad (36)$$

$$n = 0, 1, 2, \cdots$$

The inversion formula is as follows:

$$f(y) = \frac{1}{\pi} f_c(0) + \frac{2}{\pi}\sum_{n=1}^{\infty} f_c(n)\cos(ny) \qquad (37)$$

The finite cosine transform has the following operational property:

$$C_n\{f''\} = -n^2 f_c(n) + (-1)^n f'(\pi) - f'(0) \qquad (38)$$

Applying the finite cosine transform to (32) and employing boundary conditions of (33) yields the following ordinary differential equation:

$$\frac{d^2 s_c}{dx^2} + \frac{1}{x}\frac{ds_c}{dx} - \left[\left(\frac{n\pi}{b}\right)^2 + \frac{k'}{bb'k_z}\right] s_c = 0 \qquad (39)$$

Applying the finite cosine transform to (34) and (35) provides the following boundary conditions corresponding to (39):

$$\lim_{x\to\infty} s_c = 0 \qquad (40)$$

$$\frac{ds_c}{dx} = \left(\frac{aQ^*}{\pi k_r(1-d)r_w}\right)\frac{1}{n}\left[\sin\left(\frac{n\pi d}{b}\right) - \sin\left(\frac{n\pi 1}{d}\right)\right] \qquad (41)$$

The general solution to the zero order modified Bessel equation (39) is as follows:

$$s_c = c_n K_0(M_n x) + d_n I_0(M_n x) \qquad (42)$$

where

$$M_n = \left[\left(\frac{n\pi}{b}\right)^2 + \frac{k'}{bb'k_z}\right]^{1/2} \qquad (43)$$

I_0 and K_0 are the zero-order modified Bessel functions of the first and second kind, respectively. The following properties of the Bessel functions are used to evaluate the constants c_n and d_n:

$$\lim_{x \to \infty} I_0(M_n x) = \infty \tag{44}$$

$$\frac{dK_0(M_n x)}{dx} = -M_n K_1(M_n x) \tag{45}$$

where K_1 is the first-order modified Bessel function of the second kind. Equations (42), (44), and (45) imply the following:

$$d_n = 0 \tag{46}$$

$$c_n = \left[\frac{aQ^*}{\pi k_r(1-d)r_w M_n K_1\left(M_n \frac{r_w}{a}\right)}\right] \cdot \frac{1}{n}\left[\sin\left(\frac{n\pi 1}{b}\right) - \sin\left(\frac{n\pi d}{b}\right)\right] \tag{47}$$

For the special case of $n = 0$, l'Hôpital's rule is used to evaluate c_0 as follows:

$$\lim_{n \to 0}\left[\frac{\sin\left(\frac{n\pi 1}{b}\right) - \sin\left(\frac{n\pi d}{b}\right)}{n}\right] = \frac{\pi}{b}(1-d) \tag{48}$$

The analytical solution to the problem given by (25) through (28) is obtained by combining (29), (30), (31), (37), (42), (43), (46), (47), and (48) and is given by the following equation:

LOWER PERMEABILITY UPPER CONFINING UNIT

$$\phi = P_{\text{atm}}^2 + \frac{aQ^*}{\pi k_r r_w}\left\{\frac{K_0\left(M_0 \frac{r}{a}\right)}{bM_0 K_1\left(M_0 \frac{r_w}{a}\right)} + \frac{2}{\pi(1-d)}\sum_{n=1}^{\infty}\frac{1}{n}\left[\frac{\sin\left(\frac{n\pi 1}{b}\right) - \sin\left(\frac{n\pi d}{b}\right)}{M_n K_1\left(M_n \frac{r_w}{a}\right)}\right] \cdot K_0\left(M_n \frac{r}{a}\right)\cos\left(\frac{n\pi z}{b}\right)\right\} \tag{49}$$

Equation (49) satisfies (25) through (28).

Application 2: Domain With Land Surface as an Upper Boundary

The domain for application 2 is illustrated in Figure 4. In this example the top of the unsaturated zone is assumed to be in direct connection with land surface. The bottom boundary is formed by the water table or an impervious unit. For this unconfined domain it is inappropriate to model a lower leaky confining unit with an underlying constant pressure source bed. Thus, if a unit of lower permeability separates the domain from the water table, it must be approximated as an impermeable boundary to use the analytical solution presented below.

The governing equation is as follows:

$$k_r \frac{\partial^2 \phi}{\partial r^2} + k_r \frac{1}{r}\frac{\partial \phi}{\partial r} + k_z \frac{\partial^2 \phi}{\partial z^2} = 0 \tag{50}$$

The boundary conditions are as follows:

$$\phi(r, 0) = p_{\text{atm}}^2 \tag{51}$$

$$\frac{\partial \phi}{\partial z}(r, b) = 0 \tag{52}$$

The remaining boundary conditions are given by (27) through (28). The problem is transformed to standard form through (29) through (31).

The modified finite sine transform [*Churchill*, 1972] is defined as follows:

$$S_m\{f(y)\} \equiv f_s(m) = \int_0^{\pi} f(y)\sin(my)\,dy \tag{53}$$

where $m = n - 1/2$, $n = 1, 2, \cdots,$. The inversion formula is as follows:

$$f(y) = \frac{2}{\pi}\sum_{n=1}^{\infty} f_s(m)\sin(my) \tag{54}$$

where $m = n - 1/2$, $n = 1, 2, \cdots,$. The modified finite sine transform has the following operational property:

$$S_m\{f''\} = -m^2 f_s(m) + mf(0) - (-1)^n f'(\pi) \tag{55}$$

Applying the modified finite sine transform to the standard form of the problem stated by (50), (51), (52), (27), and (28) yields the following solution for the example with land surface as an upper boundary:

UPPER SURFACE AT ATMOSPHERIC PRESSURE

$$\phi = P_{\text{atm}}^2 + \frac{2aQ^*}{\pi^2 k_r(1-d)r_w}\cdot\left\{\sum_{n=1}^{\infty}\frac{1}{m}\left[\frac{\cos\left(\frac{m\pi d}{b}\right) - \cos\left(\frac{m\pi 1}{b}\right)}{M_m K_1\left(M_m \frac{r_w}{a}\right)}\right] \cdot K_0\left(M_m \frac{r}{a}\right)\sin\left(\frac{m\pi z}{b}\right)\right\} \tag{56}$$

where $m = n - 1/2$ and $M_m = [m\pi/b]$.

APPLICATION AT A FIELD SITE

The U.S. Geological Survey is conducting research at a site where crude oil spilled from a pipeline break near Bemidji, Minnesota, in August 1979. Studies at the site, beginning in 1983, indicate that significant amounts of volatile petroleum hydrocarbons are transported through the unsaturated zone as vapors and either dissipate to the atmosphere or biodegrade [*Hult and Grabbe*, 1986; *Hult*,

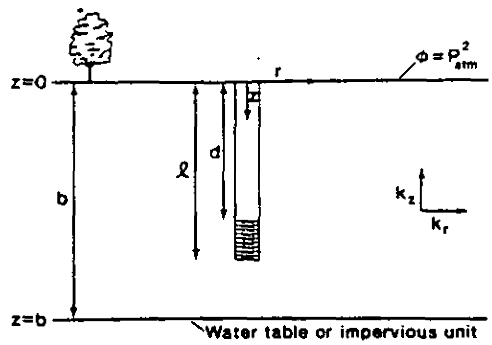

Fig. 4. Domain with land surface as an upper boundary.

1987]. The rates at which these processes occur need to be quantified to predict the distribution of contaminants over time. Mathematical models of vapor movement in the unsaturated zone require estimates of air-phase permeability and other parameters such as air-filled porosity and diffusion constants. Thus a program to estimate these parameters was initiated.

Pneumatic tests were conducted in August 1987 [*Baehr and Hult*, 1988]. A well was installed with a 60-cm screened interval in the middle of the unsaturated zone (see Figure 5). At that time the existence of the thin silt and fine-grained sand lens just above the well screen was unknown. Thus a single well was expected to be adequate for estimating air permeability over the entire unsaturated thickness. Only probes located below the lens demonstrated measurable responses to pumping, however, which suggested the presence of a thin layer of lower permeability and a situation analogous to a confined aquifer. In June 1988 a second well was installed above the confining lens to allow evaluation of the upper unsaturated zone, and in August 1988 the pneumatic tests of both the upper and lower unsaturated zones were conducted.

A 23-cm-diameter hollow-stem auger was used to drill the holes for the wells. The well casings have an inside diameter of 10.2 cm and a wall thickness of 0.64 cm. The 60-cm screened intervals were placed as illustrated in Figure 5. The annulus between the casing and borehole wall was filled with pea gravel adjacent to the screened intervals. To prevent airflow through the borehole, a cement and bentonite grout was placed in the borehole interval just above the screen to land surface. Pressure probes and thermistors were installed adjacent to the well screens. Pressure probes were constructed from flexible copper tubing that has a 0.159-cm inside diameter and 0.159-cm wall thickness. The tubing was slotted over a length of 10 cm at the lower end to form the probe. The copper tubing extended to land surface and was attached to a ±5 psi (pounds per square inch) pressure transducer. The probes were nested, as shown in Figure 5, in holes drilled with a 10-cm-diameter auger at radial distances of 100, 300, and 1000 cm from the center of the well. The holes were filled with native sand, and granulated bentonite was used to provide a 10-cm-thick layer equidistant between vertically adjacent probes to prevent air flow in the annulus.

Each test consisted of injecting or withdrawing air at one of the two wells and measuring the pressure response throughout the monitoring network and the mass flux through the screen. A temperature-compensated flow meter, thermistor, and pressure probe were installed in the piping system to enable the calculation of mass flux. Air pressure measurements were made with a Setra Systems, model 239 differential transducer (Use of brand name is for identification purpose only and does not constitute an endorsement by USGS). A temperature profile in the unsaturated zone at the test site during the week of the pneumatic tests is given in Figure 6. Measurements were made with thermistors placed 50 cm apart. The hump bounded by the two inflection points of the curve corresponds to the level of the silt lens, and the lower unsaturated zone is essentially isothermal.

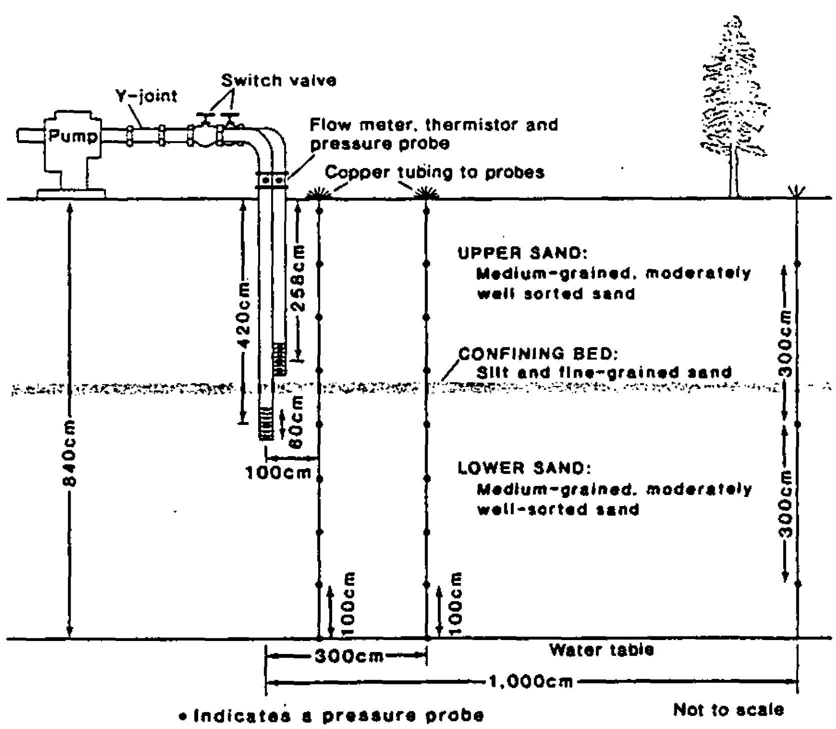

Fig. 5. Schematic of site instrumentation for conducting pneumatic tests of the unsaturated zone near Bemidji, Minnesota.

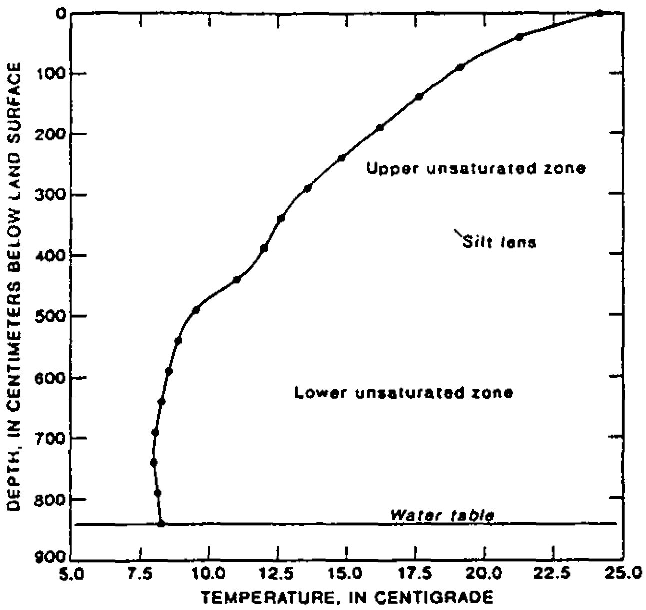

Fig. 6. Temperature profile in the unsaturated zone at the Bemidji, Minnesota, site, August 1988.

TABLE 3. Probe Locations and Coordinates (r, z)

Probe Label	r, cm	z, cm
	*Lower Unsaturated Zone**	
T1-2	(pumping well)	80.0
T2-1	100.0	480.0
T2-2	100.0	380.0
T2-3	100.0	280.0
T2-4	100.0	180.0
T2-5	100.0	80.0
T3-1	300.0	480.0
T3-2	300.0	380.0
T3-3	300.0	280.0
T3-4	300.0	180.0
T3-5	300.0	80.0
T4-1	1,000.0	380.0
T4-2	1,000.0	80.0
	Upper Unsaturated Zone†	
T6-2	(pumping well)	258.0
T2-6	100.0	317.0
T2-7	100.0	217.0
T2-8	100.0	117.0
T2-9	100.0	17.0
T3-6	300.0	317.0
T3-7	300.0	217.0
T3-8	300.0	117.0
T3-9	300.0	17.0
T4-3	1,000.0	117.0

*Refer to Figure 3 for coordinate definition.
†Refer to Figure 4 for coordinate definition.

Parameter values assumed in the simulation of pneumatic tests of the lower and upper unsaturated zones are listed in Table 2, and a labeling scheme for the probe locations and the corresponding coordinates for observations is given in Table 3. Pneumatic pump tests were conducted at several withdrawal and injection rates in both the lower and upper unsaturated zones; results are presented in Table 4 (lower) and Table 5 (upper). The Reynolds numbers reported in Table 4 and Table 5 were computed for flow adjacent to the well. These values indicate that non-Darcy flow may occur only in the immediate vicinity of the well, even during the highest flow tests.

To obtain permeability estimates from air pressure data the inverse problem is solved as follows: Let

$$u = \phi/P_{\rm atm}^2 \qquad u_i = P_i^2/P_{\rm atm}^2, \qquad i = 1, \cdots, N;$$

where N is the number of observations. For the lower unsaturated zone, all data listed on Table 4 except for the pressure measured at the well (Probe T1-2) was used to obtain air permeability; therefore $N = 10$ for each of the five pneumatic tests. Likewise, for the upper unsaturated zone, all data listed on Table 5, except for Probe T6-2 was used; therefore $N = 9$ for each of the five upper zone pneumatic tests. Well pressures were not used because of the possibility of pressure losses not attributed to the porous media, as well as disturbances around the well created during installation. Find $(k_r, k_z, k'/b')$ if (49) applies (lower unsaturated zone) or (k_r, k_z) if (56) applies (upper unsaturated zone) that minimizes the sum of squared errors defined as follows:

$$\chi = \sum_{i=1}^{N} (u - u_i)^2 \tag{57}$$

An algorithm was developed to minimize χ that uses numerical evaluations of the partial derivatives

$$\frac{\partial \chi}{\partial k_r}, \quad \frac{\partial \chi}{\partial k_z}, \quad \frac{\partial \chi}{\partial (k'/b')}$$

to follow a path of descent defined by line searches.

The least squares fit of air permeability parameters for the

TABLE 2. Parameter Values Assumed in the Simulation of Pneumatic Pump Tests

Parameter	Lower Unsaturated Zone*	Upper Unsaturated Zone†
Vertical distances in centimeters (Figure 4)		
(d) top boundary to top of well screen	50	228
(l) top boundary to bottom of well screen	110	288
(b) thickness of unit	547	337
Average temperature T in degrees centigrade	9.1	16.5
Dynamic viscosity of air $\mu(T)$ in grams per centimeter per second	1.73×10^{-4}	1.75×10^{-4}

Average molecular weight of air ω = 28.8 grams per mole well radius, r_w = 11.5 cm.
*Refer to Figure 3 for coordinate definition.
†Refer to Figure 4 for coordinate definition.

TABLE 4. Normalized Pressures (P/P_{atm}) for Pneumatic Tests of the Lower Unsaturated Zone as a Function of Air Withdrawal or Injection Rate (Q)

Probe	Q = −8.2 g/s P_{atm} = 757 torr	Q = −20.6 g/s P_{atm} = 757 torr	Q = −41.2 g/s P_{atm} = 757 torr	Q = 8.0 g/s P_{atm} = 760 torr	Q = −52.9 g/s P_{atm} = 760 torr
T1-2	0.9883	0.9649	0.9205	1.016	1.106
T2-1	*	*	*	*	*
T2-2	0.9998	0.9980	0.9942	1.003	1.010
T2-3	0.9994	0.9970	0.9924	1.003	1.012
T2-4	0.9983	0.9938	0.9863	1.004	1.020
T2-5	0.9958	0.9875	0.9842	1.006	1.037
T3-1	*	*	*	*	*
T3-2	1.0	0.9982	0.9951	1.002	1.009
T3-3	0.9998	0.9977	0.9941	1.002	1.010
T3-4	0.9994	0.9971	0.9927	1.002	1.011
T3-5	0.9989	0.9961	0.9902	1.003	1.014
T4-1	1.0	0.9994	0.9974	1.002	1.006
T4-2	1.0	0.9995	0.9979	1.001	1.004
Re†	0.7	1.8	3.7	0.7	4.7

Q negative → air withdrawal; Q positive → air injection. Re = $(dq_m/\mu\theta) = (dQ/2\pi r_w h\mu\theta)$; d = 0.02 cm representative of sand at $k = 10^{-7}$ cm^2; r_w = 11.5 cm; h = 60 cm; $\mu = 1.73 \times 10^{-4}$ g/cm s; θ = 0.3.
*Probe clogged.
†Reynolds number Re computed at well radius.

lower and upper unsaturated zone as a function of mass flow, Q are summarized in Table 6. The apparent anisotropy estimates k_r/k_z, obtained from the lower unsaturated zone analysis, vary widely as a function of Q, indicating that the assumption of homogeneity is not strictly valid. The estimates for the air permeability of the silt lens are within an order or magnitude ($\sim 10^{-9}$ cm^2), except for the lowest withdrawal rate. The best estimate of this parameter is obtained at the highest flows ($k' = 1.9 \times 10^{-9}$ cm^2). The estimates for k_r are consistent. Despite the dependence of estimates on the mass flow rate (Q) and its direction the analysis of the lower unsaturated zone pneumatic tests by the analytical solution provides an order-of-magnitude estimate of the air permeability of that zone and of the confining silt lens. Figure 7 shows plots of normalized pressure P/P_{atm} as a function of radial distance from the pumped well, r, at probe levels z = 80, 180, 280, and 380 cm below the confining silt lens and corresponding to the pneumatic test with Q = 52.9 g/s (injection). The solid-line predictions were generated by substituting the least squares parameter estimates

$$k_r = 3.2 \times 10^{-7}\ \text{cm}^2, \qquad \frac{k_r}{k_z} = 2.6, \qquad k' = 1.9 \times 10^{-9}$$

into (49). The corresponding data points are also plotted.

The air permeability estimates k_r obtained for the upper unsaturated zone are very consistent, although the apparent anisotropy, k_r/k_z vary widely as a function of Q. The upper unsaturated zone is approximately 4 times more permeable to air than the lower unsaturated zone. This difference in air permeability is consistent with the physical description of sediments at the test site (Table 7), as the upper unsaturated zone consists mainly of coarse to medium sands and the lower unsaturated zone consists mainly of medium sand. Figure 8 shows plots of normalized pressure, P/P_{atm}, as a function of radial distance from the pumped well, r, at probe levels z = 317, 258, 217, and 117 cm below land surface and corresponding to the pneumatic test with Q = 70.5 g/s

TABLE 5. Normalized Pressures (P/P_{atm}) for Pneumatic Tests of the Upper Unsaturated Zone as a Function of Air Withdrawal or Injection Rate (Q)

Probe	Q = −23.5 g/s P_{atm} = 761 torr	Q = −45.1 g/s P_{atm} = 761 torr	Q = −64.6 g/s P_{atm} = 761 torr	Q = −39.2 g/s P_{atm} = 761 torr	Q = −70.5 g/s P_{atm} = 761 torr
T6-2	0.9877	0.9717	0.9560	1.022	1.043
T2-6	0.9975	0.9939	0.9901	1.006	1.011
T2-7	0.9987	0.9968	0.9948	1.004	1.006
T2-8	0.9993	0.9983	0.9972	1.002	1.004
T2-9	1.0	0.9998	0.9996	1.001	1.001
T3-6	0.9991	0.9972	0.9954	1.004	1.006
T3-7	0.9999	0.9994	0.9987	1.002	1.002
T3-8	1.0	0.9996	0.9991	1.001	1.002
T3-9	1.0	1.0	1.0	1.0	1.001
T4-3	1.0	1.0	1.0	1.0	1.001
Re*	2.1	4.0	5.7	3.5	6.2

Q negative → air withdrawal; Q positive → air injection. Re = $(dq_m/\mu\theta) = (dQ/2\pi r_w h\mu\theta)$; d = 0.02 cm representative of sand at $k = 10^{-7}$ cm^2; r_w = 11.5 cm; h = 60 cm; $\mu = 1.73 \times 10^{-4}$ g/cm s; θ = 0.3.
*Reynolds number Re computed at well radius.

TABLE 6. Least Squares Fit of Air Permeability Parameters

Q,* g/s	k_r, cm^2	k_r/k_z	k',† cm
Lower Unsaturated Zone			
−8.2	3.0×10^{-7}	3.0	3.6×10^{-8}
−20.6	3.1×10^{-7}	2.3	9.5×10^{-9}
−41.2	4.8×10^{-7}	1.3	1.9×10^{-9}
8.0	3.0×10^{-7}	1.4	4.9×10^{-9}
52.9	3.2×10^{-7}	2.6	1.9×10^{-9}
Upper Unsaturated Zone			
−23.5	1.5×10^{-6}	1.0	
−45.1	1.4×10^{-6}	1.7	
−64.6	1.3×10^{-6}	2.0	
39.2	1.6×10^{-6}	6.5	
70.5	1.4×10^{-6}	3.2	

*$Q < 0$ implies withdrawal; $Q > 0$ implies injection.
†Assuming $b' = 20$ cm (thickness of silt lens).

(injection). The solid-line predictions were generated by substituting the least squares parameter estimates

$$k_r = 1.4 \times 10^{-6} \text{ cm}^2, \qquad k_z = 4.4 \times 10^{-7} \text{ cm}^2$$

into (56). The corresponding data points are also plotted.

The silt lens was discovered after conducting the first

TABLE 7. Physical Description of Sediments at the Test Site From Split-Spoon Sampling Near Probe Location T4

Interval Below Land Surface, cm	Description
Upper Unsaturated Zone	
0–40	sandy soil
40–90	medium sand
90–110	coarse sand
110–140	medium sand
140–160	coarse sand
160–190	medium-coarse sand
190–300	very coarse sand
300–340	medium sand
Confining Unit	
340–360	silt and fine sand
Lower Unsaturated Zone	
360–380	fine sand
380–400	medium sand
400–490	fine-medium sand
490–510	medium sand
510–550	medium-coarse sand
550–905	medium sand
905	water table

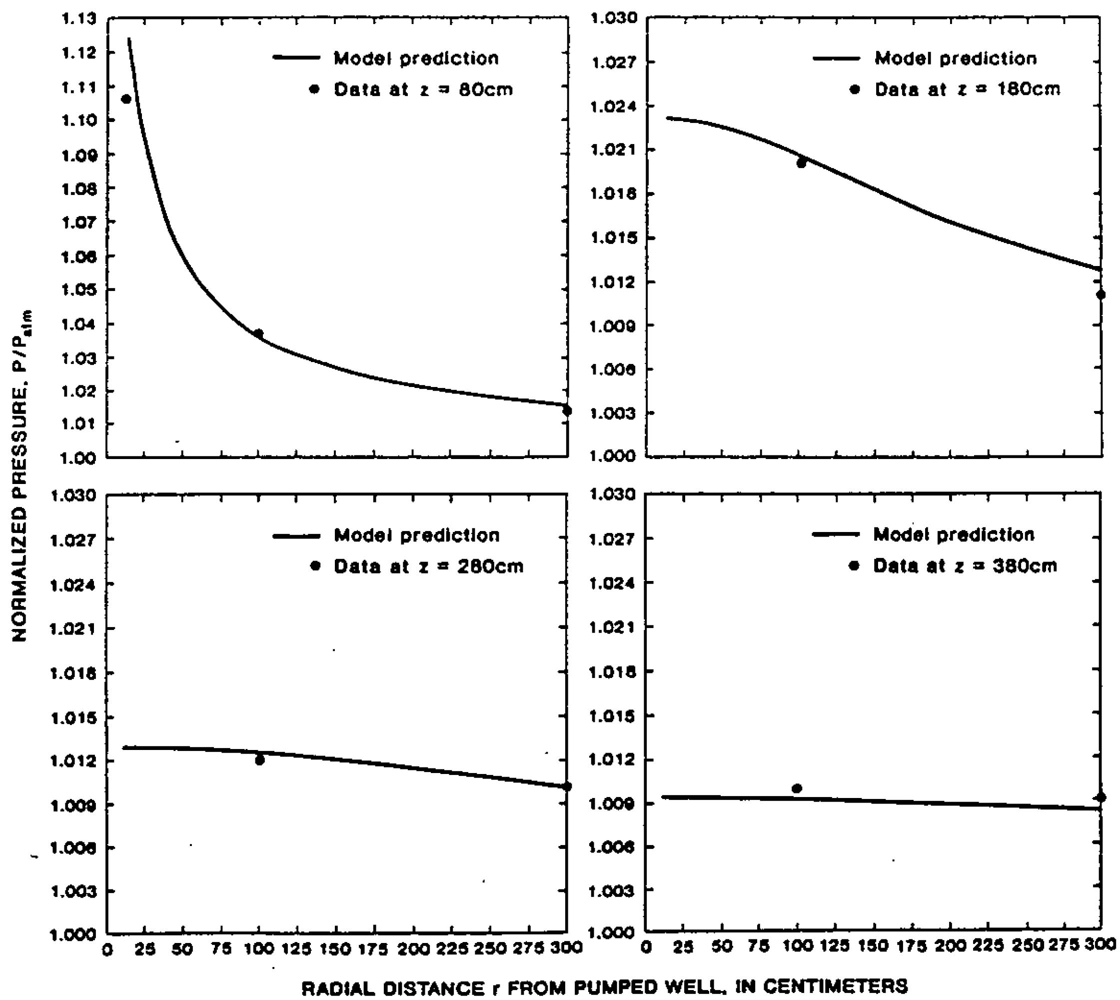

Fig. 7. Normalized pressure P/P_{atm} as a function of cylindrical coordinates (r, z) in the lower unsaturated zone for $Q = 52.9$ g/s.

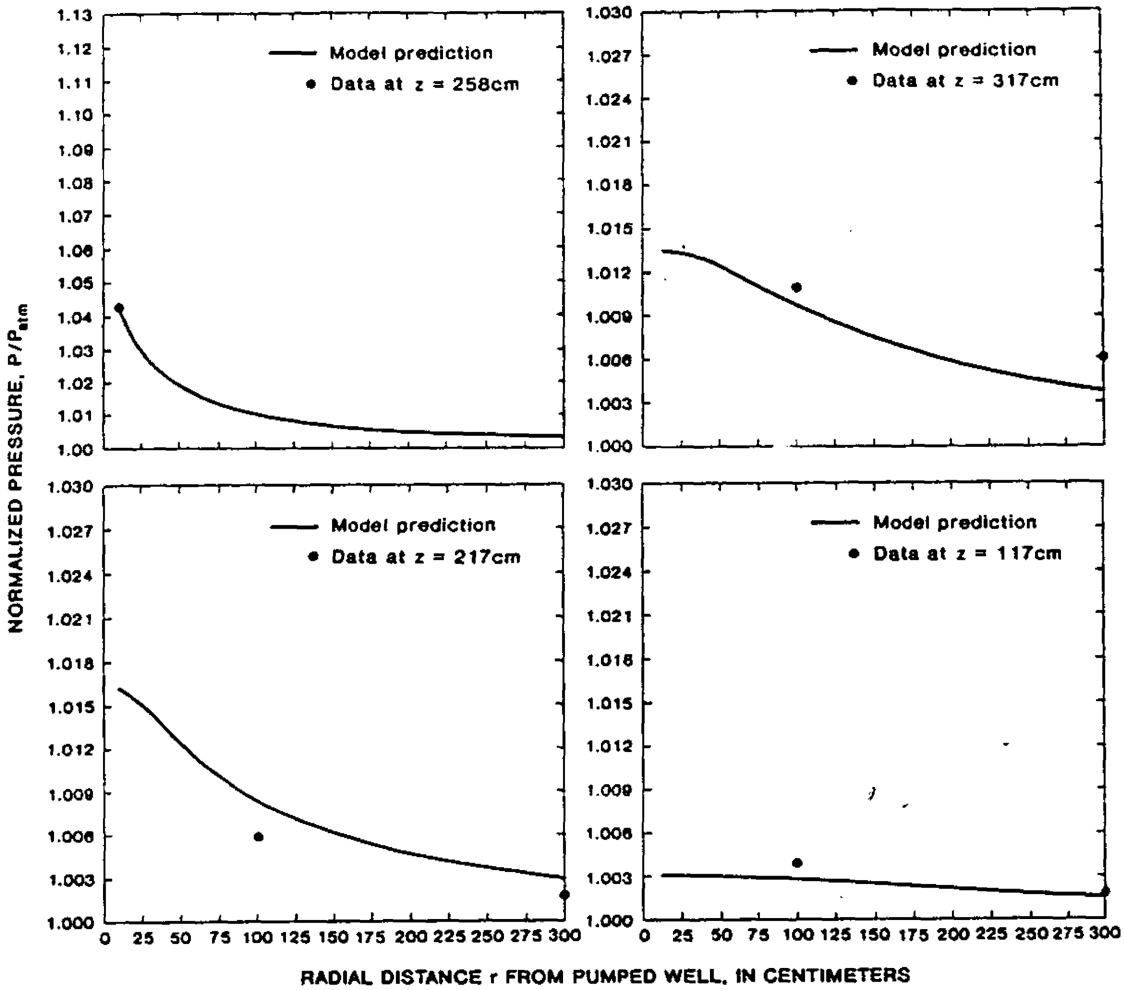

Fig. 8. Normalized pressure P/P_{atm} as a function of cylindrical coordinates (r, z) in the upper unsaturated zone for $Q = 70.5$ g/s.

pneumatic test in 1987. In August 1988 just before the pneumatic tests reported here were conducted, core samples of unsaturated zone sediments were collected near probe nest T4. The samples were collected by alternatively driving a 61-cm long nominal 5-cm outside diameter split-spoon sampler through the bottom of a nominal 15 cm outside diameter hollow-stem auger and augering to the bottom of the cored hole. The split-spoon sampler had a 3.81-cm inner diameter stainless steel liner that was sectioned into seven pieces of equal length. Sections of the split spoon sample were removed at closely spaced intervals to determine porosity, water and air-filled porosity, and bulk density. Table 7 summarizes the physical description of the sediments. The percent saturation (volumetric moisture content divided by porosity) is plotted in relation to depth below land surface in Figure 9. A sharp peak in water content that corresponds to the silt lens is observed at about 410 cm below land surface. This reflects the finer grained silt lens, which retains more water at a given capillary pressure than the sands. This increased moisture content contributes to the 2 to 3 orders of magnitude difference between air permeability of the silt lens and that of the adjacent lower and upper sand units reported in Table 6.

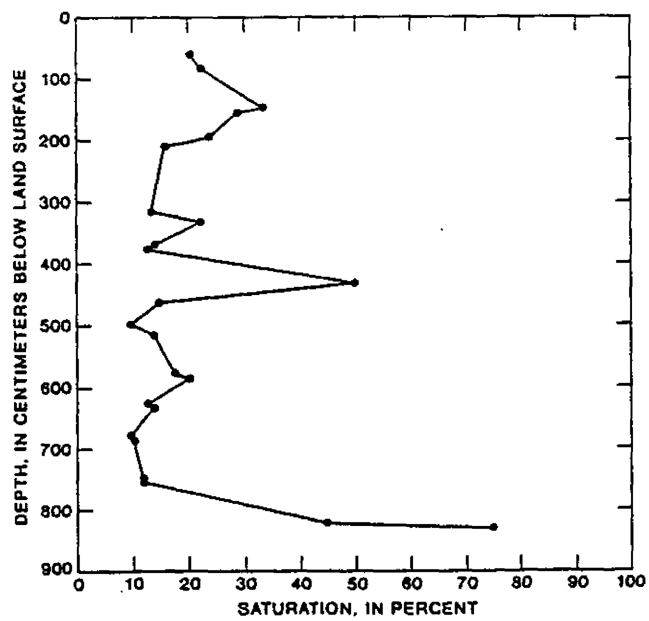

Fig. 9. Percent saturation as a function of depth below land surface at the pneumatic test site near probe test T4.

SUMMARY

A method for determining air permeability of an unsaturated zone entails analysis of pneumatic tests based on an equation of air flow. Air movement is more complicated than water movement, however, under conditions anticipated with pneumatic tests, compressibility does not introduce nonlinearities to the airflow equation when the equation is expressed in terms of air pressure squared. Furthermore, the Klinkenberg effect can be neglected under most anticipated applications.

Two analytical solutions were developed that assume a homogeneous, anisotropic porous medium and uniform mass flow across the well screen. One solution is appropriate for an unconfined domain bounded above by land surface (open to the atmosphere) and below by an impervious unit (or the water table). The other approximates airflow in a confined domain (separated from the atmosphere by a unit of lower permeability). The confined-domain solution required use of a Hantush-type leakage term. Both solutions incorporate a specified well radius and do not require that the well be approximated as a line source as would be the case for an analytical solution to the transient flow equation. This feature should provide better simulation of flow near the well which would lead to a better air permeability estimate when data at or close to the well is used.

Pneumatic tests conducted at a research site near Bemidji, Minnesota, allowed for the characterization of a thin, but significant silt lens that separates the unsaturated zone into two parts. The silt lens represents a sharp heterogeneity with respect to air permeability and moisture content. Anisotropy of air permeability estimated through the analytic solutions varied significantly as a function of mass injection or withdrawal rate. Thus the assumption of homogeneity was not entirely valid. Analysis of the pneumatic tests of the lower and upper unsaturated zones provided approximations of the air permeability of both zones and the silt lens.

A numerical solution to the governing airflow equation would allow incorporation of heterogeneity within the simulated domain and an improved simulation of leakage through the confining unit and flow near the well screen. The scale over which the pneumatic test was conducted did not allow determination of small-scale vertical variations in the air permeability of the unsaturated zone. Such a determination would be useful in predicting flow paths for contaminant vapor recovery. The development of smaller-scale pneumatic tests and the application of analytical solutions to determine vertical variations in air permeability is suggested as a topic for further research. For this anticipated application the finite well radius feature of the solutions presented in this paper will allow for better simulation of steady state airflow than solutions assuming an infinitesimal well.

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A. L. Baehr, U.S. Department of the Interior, U.S. Geological Survey, Water Resources Division, 810 Bear Tavern Road, Suite 206, West Trenton, NJ 08628.

M. F. Hult, U.S. Department of Geological Survey, Saint Paul, MN 55101.

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ATTACHMENT 3

TYPICAL V_VENT3 OUTPUT

Program V_VENT3.OUT
Output from V_VENT3.E
Calculates pressure and air velocity fields due to a vertical well
It also calculates the air flow into the well.

THE BOUNDARY CONDITIONS ARE:

Water table (impermeable surface) at the bottom,
Top surface at atmospheric pressure
P=Pw at screen.

******************* SITE SPECIFIC INPUT PARAMETERS ***************

Depth to G.W Table B= 25 ft
Height above G.W. table at which bottom of well is placed Dw= 1 ft
Length of well Lw= 10 ft
Radius of the well Rw= 2 inches
Negative Pressure at the Well Pw= 0.0983 atm = 40 iwc
Soil Temperature T= 70 ½F
Soil Permeability in Radial Direction kr= 2.6e-07 cm^2
Soil Permeability in Vertical Direction kz= 2.6e-08 cm^2
Soil Porosity eps= 0.3

NOTE:
z=0 -> top of vented layer ; z=B -> water table
Negative flow corresponds to air being extracted from the soil
Positive flow corresponds to air being injected into the soil

Induced air mass flow, Qm = -0.0478 Kg/sec
Induced volume flow of air, Q = -37.2 L/sec= -78.8 scfm

r= 1.000 ft
****

z (ft)	P(r,z) (iwc)	Vr(r,z) (ft/day)	Vz(r,z) (ft/day)
0.000	0.000	0.000	30.407
12.500	6.028	-197.521	111.157
25.000	11.694	767.100	0.000

r= 11.000 ft
****

z (ft)	P(r,z) (iwc)	Vr(r,z) (ft/day)	Vz(r,z) (ft/day)
0.000	0.000	0.000	24.667
12.500	5.503	-57.803	162.810
25.000	11.334	-195.225	0.000

r= 21.000 ft
****

z (ft)	P(r,z) (iwc)	Vr(r,z) (ft/day)	Vz(r,z) (ft/day)
0.000	0.000	0.000	24.270
12.500	4.935	-64.571	113.724
25.000	9.622	-176.588	0.000

r= 31.000 ft

****

z (ft)	P(r,z) (iwc)	Vr(r,z) (ft/day)	Vz(r,z) (ft/day)
0.000	0.000	0.000	23.754
12.500	4.382	-58.005	81.576
25.000	8.201	-141.349	0.000

r= 41.000 ft
****

z (ft)	P(r,z) (iwc)	Vr(r,z) (ft/day)	Vz(r,z) (ft/day)
0.000	0.000	0.000	23.058
12.500	3.899	-49.976	61.442
25.000	7.063	-113.651	0.000

r= 51.000 ft
****

z (ft)	P(r,z) (iwc)	Vr(r,z) (ft/day)	Vz(r,z) (ft/day)
0.000	0.000	0.000	22.224
12.500	3.483	-42.907	48.154
25.000	6.141	-92.897	0.000

r= 61.000 ft
****

z (ft)	P(r,z) (iwc)	Vr(r,z) (ft/day)	Vz(r,z) (ft/day)
0.000	0.000	0.000	21.291
12.500	3.125	-37.046	38.903
25.000	5.382	-77.108	0.000

r= 71.000 ft
****

z (ft)	P(r,z) (iwc)	Vr(r,z) (ft/day)	Vz(r,z) (ft/day)
0.000	0.000	0.000	20.278
12.500	2.815	-32.228	32.173
25.000	4.748	-64.829	0.000

r= 81.000 ft
****

z (ft)	P(r,z) (iwc)	Vr(r,z) (ft/day)	Vz(r,z) (ft/day)
0.000	0.000	0.000	19.205
12.500	2.545	-28.242	27.100
25.000	4.212	-55.091	0.000

r= 91.000 ft
****

z (ft)	P(r,z) (iwc)	Vr(r,z) (ft/day)	Vz(r,z) (ft/day)
0.000	0.000	0.000	18.133
12.500	2.307	-24.912	23.164

25.000	3.754	-47.238	0.000

r= 101.000 ft
****

z (ft)	P(r,z) (iwc)	Vr(r,z) (ft/day)	Vz(r,z) (ft/day)
0.000	0.000	0.000	17.041
12.500	2.096	-22.102	20.037
25.000	3.360	-40.820	0.000

Calculation of 'flushout time' vs distance from the well

r (ft)	t_flush(r) (days)
1.000	0.000
11.000	0.009
21.000	0.033
31.000	0.076
41.000	0.139
51.000	0.226
61.000	0.339
71.000	0.481
81.000	0.655
91.000	0.864
101.000	1.111

Time for run in minutes = 1.850

Appendix D

Groundwater Modeling Report

Introduction

A groundwater flow numerical model has been setup and calibrated for the former Sinclair Refinery site and adjacent areas. The purpose of this effort is to create a model as a tool to evaluate and compare alternative groundwater remedial options. The model can also be used to aid in the design of the selected options and to evaluate the understanding of the local and regional aquifer hydrodynamics.

Site Conditions and Setting

The site geology and hydrogeology are described in detail in the "Remedial Investigation Report" (Ebasco, 1991) and are summarized in this section. The former refinery site is located just south of the city of Wellsville, New York and is adjacent to the west bank of the Genesee River.

The Genesee River valley is physically bordered on both the west and east by till covered uplands consisting of Devonian-age shales and sandstones of the Conewango, Conneaut, and Canadaway Groups. Bedrock has a regional southward dip averaging between 30 and 60 feet/mile. Bedrock is found near the surface on the uplands and at depths of up to 300 feet in the Genesee River valley. Yields of bedrock wells are generally low with values typically less than 5 gallons per minute (gpm).

Overlying the bedrock is a sequence of unconsolidated gravels, sands silts, and clays. These unconsolidated deposits are mostly Pleistocene-age and glacial in origin. Overlying the glacial deposits is a relatively thin bed of Holocene-age alluvial sands and gravels.

A water budget was calculated for the entire Genesee River valley by Gilbert and Kammerer (1971). Based on this calculation, and data for the Scio station, the estimate for precipitation is 33 inches per year (in/yr), evapotranspiration is 19 in/yr, overland runoff is 9 in/yr, and recharge is 5 in/yr.

The flow modeling was conducted on the shallow, stratified sand and gravel deposits occurring within the valley of the Genesee River. These deposits are Holocene in age and alluvial in origin. Groundwater in the sand and gravel is under unconfined conditions.

Conceptual Model

The first step undertaken in this modeling effort was to develop a conceptual model of the aquifer system. The conceptual model was constructed after considerations of the following information:

- review of the available geological and hydrological literature and conversations with local U.S. Geological Survey staff;
- the nature of the site hydrogeology and types of boundary conditions;
- the quantity and quality of the available data; and,
- the primary objective of this stage of the project, which was to compare and contrast alternative groundwater containment options.

After reviewing the available information on both the local and regional hydrogeology, it was felt that a two-dimensional simulation could best represent this aquifer. The decision was made based on the following: the aquifer is thin compared to the areal extent of the model domain; the vertical gradients are minor compared to the horizontal gradients reported in the remedial investigation; the proposed extraction wells fully penetrate the aquifer; the Genesee River essentially fully penetrates the aquifer; most of the observation wells are screened across the majority of the aquifer, which makes the construction and calibration of a multilayer model subjective.

The aquifer is unconfined and the saturated thickness ranges from approximately 8 to 20 feet across the majority of the site, locally increasing to a thickness of over 80 feet in the vicinity of well MWD-47. The underlying glaciolacustrine clay is a confining bed and yields water at a rate ranging from zero to not more than a few gallons per minute (Gilbert and Kammerer, 1971). The glaciolacustrine clay is not considered in this model to be of any hydrologic significance and is modeled as a no-flow boundary. MODFLOW, a modular, three-dimensional, finite-difference flow model was selected to simulate groundwater flow conditions and to select the location, number, and pumping rates of wells. MODFLOW is a widely used model that was developed by McDonald and Harbaugh (1984) for the U.S. Geological Survey. The particle tracking code MODPATH (Pollack, 1988) is used to determine capture zones of the various pumping scenarios.

Figure D-1 illustrates the conceptual model used in this simulation. The modeled area is approximately two miles in length and one-half mile wide. This area encompasses the western side of the Genesee River valley beginning upstream of the site from the junction of Weidrick Road and the Genesee River and continues downstream of the site to the U.S. Geological Survey's stream gaging station in the center of Wellsville, NY. As depicted in this figure, the aquifer is simulated as a two-dimensional unconfined system.

Model Description

A detailed printout of the model design is included as an attachment to this appendix. The following discussion summarizes important aspects of the model including the model grid, initial conditions, and boundary conditions.

Model Grid

The model grid consists of 219 rows and 150 columns (Figure D-2). The modeled area extends along the Genesee River valley beginning upstream of the site from the junction of Weidrick Road and the Genesee River and continues downstream of the site to the U.S. Geological Survey's stream gaging station in the center of Wellsville, NY. This is a distance of approximately two miles in length. Only the western side of the valley is included in the model domain. The grid spacing is 25 by 25 feet within the site proper, and coarsens to 1100 by 1100 feet outward towards the edge of the modeled area. The use of this relatively large grid enabled RETEC to model a sufficiently large area so that the choice of boundary conditions could coincide with actual hydrogeologic boundaries in the valley. These boundaries are sufficiently distant from the refinery so that the hydraulic stresses simulated within the refinery are not affected by the boundary conditions. The highest node density coincides with the area of highest data density, which is within the former refinery property.

Boundary Conditions

The boundary conditions applied to this model are no-flow boundaries along the base of the model, specified-flux along the western edge, head-dependent flux along the eastern and southern edges, constant head to the north and south, and areal recharge across the top of the model.

The no-flow boundary represents the top of a prominent clay bed of glaciolacustrine origin, marking the lower boundary of the alluvial sediments. Across the top of the model, a specified-flux boundary is applied to all active nodes. This condition simulates average annual recharge across the modeled area. A value of 5 in/yr of recharge is used and was obtained from a water-budget calculation presented in a report of the U.S. Geological Survey (Gilbert and Kammerer, 1971).

The Genesee River is the major discharge boundary and is simulated as a head- dependent flux boundary (river package in MODFLOW) bounding the eastern and southern portions of the modeled domain. For the purposes of this model, the drainage swale is assumed to be the edge of the river. The model requires three input parameters to simulate the river: river stage (head), elevation of the riverbed bottom, and conductance of the river bed. Conductance is a measure of the transmissive nature of the river. Data for the river elevation was obtained from the U.S. Geological Survey's stream gaging station at Wellsville and the six river level measurement stations setup by RETEC. The average depth from the the river surface to the bottom of the riverbed varies from 5 to 10 feet. River conductance values were calculated using a streambed permeability (Kv) of 5.4 feet/day (40 gpd/ft^2) obtained from Gilbert and Kammerer (1971). Table D-1 lists the calculated values used for river conductance based on the size of each grid cell, a Kv of 5.4 feet/day, and a riverbed thickness (m) of 1 foot. The riverbed sediments generally consist of sand and gravel with some silt and clay.

Constant heads are used to simulate underflow into and out of the aquifer system along a small portion of the south and north ends of the model. Seepage into the aquifer system from the till covered bedrock uplands to the west of the site is simulated as a specified flux boundary.

Input Parameters

As one of the first steps in the modeling effort, a comprehensive modeling database was constructed in a Lotus spreadsheet. This database consisted of the coordinates of all known well locations, surface elevation, top of the glaciolacustrine clay, and any aquifer properties known for that well location. This was performed for all the wells installed in and around the site. In addition, information was gained from published sources (U.S. Geological Survey 1971).

The procedure used for exporting the required data from the groundwater modeling database into MODFLOW occurred in the following manner. The coordinates and value for each parameter was exported from the database and imported into SURFER®. A grid file was generated by SURFER using the kriging option, which assumes a linear variogram. Kriging is a geostatistical technique and is used to interpolate data values from known regions to areas where no data are available. Kriging was used to assign bottom elevations, hydraulic conductivity values, and initial water table elevations of the modeled aquifer. The grid file was then imported into the graphical modeling preprocessor, MODELCAD-386®. In this way, detailed statistically averaged values for many of the aquifer parameters were included in the model.

Aquifer bottom elevations (top of the glaciolacustrine clay) were input from well log data collected during the RI/FS, as well as more recent borings installed by RETEC. Hydraulic conductivity values were input based on the results of two aquifer pumping tests conducted at the Sinclair Refinery during the RI/FS (Ebasco, 1991). The pumping tests were conducted in the central refinery area using well MW-56 as the pumping well and in the northern oil/water separator area with well MW-57 as the pumping well. The pump test data is considered to be more reliable than that obtained from the slug tests; therefore, the slug test data was not input into the model. Generally, the hydraulic conductivities calculated from the slug tests are approximately one order of magnitude less than those obtained from the pump tests.

Figure D-2 is a map showing the values used for hydraulic conductivity throughout the model. This figure also depicts the finite difference grid and boundary conditions. Hydraulic conductivity varies from 5 to 245 feet/day based on pumping tests and these tests reveal that the aquifer is heterogeneous. Five zones of hydraulic conductivity are used in the model ranging from 20 to 110 feet/day. In order to simplify the procedure of entering hydraulic conductivities into the model and adhere to the zonation principle, the hydraulic conductivities reported for each of the observation wells surrounding a particular pumping well were averaged. A geometric mean was calculated for hydraulic conductivity based on the results determined for each observation well monitored during each test. The geometric mean value of 110 feet/day is used in the central refinery area and a geometric mean value of 40 feet/day is used in the area of the northern oil/water separator. In the areas of the model outside the influence of the pump tests, hydraulic conductivity was adjusted during model calibration.

Calibration

A prolonged calibration process was undertaken with the goal of matching simulated heads to measured heads within the former refinery site where the greatest amount of data existed. Model calibration was performed to steady-state conditions by a trial and error procedure. The measured water table for September 1993 was chosen as the calibration target because it is the most complete set of data available as well as the most recent.

The preconditioned gradient solver was used with the error criteria in heads set to 0.001 feet and the maximum residual set to 100 cubic feet per day (ft^3/day). The mass balance error for the calibrated simulation is -0.18 percent. Cumulative flow into the model came from specified heads (11,435 ft^3), specified flux (20,659 ft^3), areal recharge (25,813 ft^3), and river leakage (3,029 ft^3). Total inflow is 60,935 ft^3. Cumulative flow out of the model came from specified heads (60 ft^3) and river leakage (60,984 ft^3). Total outflow is 61,045 ft^3. The difference between inflow and outflow is -109 ft^3.

Figure D-3 is a map of the groundwater elevations for the calibration run. The calibration visually compares closely to that of the measured heads for September 1993. A quantitative calibration was also conducted. Figure D-4 is a scatterplot of measured heads plotted against simulated heads. The deviation of points from the line appears randomly distributed with a correlation coefficient of 0.93. An addendum to this appendix includes a printout of the calibration information. The calibration has a range in residual heads of -3.5 to 1.8 feet, with a root mean square error of 81 feet. The ratio of the residual standard deviation and the observed range in heads is 6.5 percent, which is acceptable.

Remedial Alternatives

For the purposes of this report, the Sinclair Refinery model is used as the basis for evaluating and comparing a number of different hydraulic containment options in the immediate vicinity of the northern oil/water separator. The primary objective of the modeled alternatives was to contain groundwater from migrating into the Genesee River in this area. All simulated runs employed a series of pumping wells in the vicinity of the northern oil-water separator which are placed perpendicular to groundwater flow, paralleling the Genesee River.

The placement of the pumping wells was chosen so as to minimize potential induced infiltration from the river. A number of simulations were run varying the number, placement, and pumping rate of wells. A series of simulations were conducted and consisted of between one to four wells pumping a total discharge ranging between 10 to 50 gpm.

Figures D-5 and D-6 present the results of the selected containment alternative for the northern oil-water separator area. Complete capture of the soluble plume in the northern oil-water separator area is attained in a scenario involving three wells pumping at 10 gpm each. The wells are aligned in a southeast to northwest direction spaced approximately 150 feet apart with the central well located at MWP-57. Maximum predicted drawdown is approximately 5 feet in the center of the three well system. This scenario did not induce any infiltration from the river.

This scenario achieves the goal of total hydraulic capture while minimizing pumping rates, induced flow from the Genesee River, and drawdown.

Calibration Statistics for Two Dimensional Simulation
of Sand and Gravel Aquifer
Wellsville, New York

══════════ Calibration Statistics ══════════

MODFLOW BCF File Name....: newcal.bcf
MODFLOW BAS File Name....: newcal.bas
Target Information in....: newcal.trg
Model-Computed Heads in..: newcal.hds

Well Name	Target Head	Model Head	Residual
MWR-10	1492.69	1493.29	-0.60
MWR-9	1493.54	1494.77	-1.23
MWR-7	1494.37	1494.16	0.21
MWR-6	1494.05	1493.41	0.64
MRW-5	1493.08	1492.74	0.34
MRW-4	1492.25	1492.18	0.07
MRW-3	1491.34	1491.98	-0.64
MRW-2	1491.31	1491.93	-0.62
MRW-1	1491.52	1492.05	-0.53
MW-1	1495.59	1495.33	0.26
MW-7	1487.32	1489.93	-2.61
MW-8	1492.79	1493.11	-0.32
MW-9	1485.91	1487.39	-1.48
MW-10	1483.75	1483.68	0.07
MW-11	1481.42	1483.00	-1.58
MW-25	1484.18	1485.53	-1.35
MW-26	1483.61	1483.29	0.32
MW-27	1483.92	1483.90	0.02
MW-28	1494.65	1493.73	0.92
MW-29	1493.34	1493.41	-0.07
MW-30	1492.14	1493.00	-0.86
MW-31	1491.03	1492.67	-1.64
MW-32	1486.85	1488.44	-1.59

MW-33	1487.24	1486.89	0.35
MW-34	1493.29	1491.51	1.78
MW-35	1490.93	1494.41	-3.48
MW-36	1494.07	1494.45	-0.38
MW-49	1486.46	1487.42	-0.96
MW-50	1490.79	1492.69	-1.90
MW-51	1489.77	1491.97	-2.20
MW-52	1492.85	1493.28	-0.43
MW-53	1491.84	1492.95	-1.11
MW-54	1493.43	1493.49	-0.06
MW-56	1491.66	1492.68	-1.02
MW-57	1484.85	1485.80	-0.95
MW-67	1483.70	1483.89	-0.19
MW-68B	1483.04	1484.55	-1.51
MW-69B	1483.39	1483.81	-0.42
MW-70	1481.97	1482.69	-0.72
MW-71	1483.37	1484.67	-1.30
MW-72	1490.65	1490.42	0.23
MW-73	1493.87	1494.19	-0.32
MW-74	1496.28	1495.15	1.13
MW-75	1489.08	1490.35	-1.27
MW-76	1492.40	1493.04	-0.64
MW-77	1493.06	1493.45	-0.39
MW-78	1481.70	1482.98	-1.28
MW-79	1491.22	1492.60	-1.38
MW-80	1491.78	1492.82	-1.04
MW-81	1492.27	1493.24	-0.97
MW-82	1492.97	1493.30	-0.33
MW-83	1489.65	1489.14	0.51
MW-84	1485.08	1485.70	-0.62
MW-85	1492.00	1492.45	-0.45
MW-86	1490.82	1494.16	-3.34
MW-87	1493.24	1493.93	-0.69
MW-88	1490.00	1491.54	-1.54
MW-89	1493.48	1493.45	0.03

----- Summary Statistics For Entire Model -----

Residual Mean = -0.674287
Residual Standard Dev. = 0.970710
Residual Sum of Squares = 81.022573

Absolute Residual Mean = 0.911794
Minimum Residual = -3.482598
Maximum Residual = 1.781699

Observed Range in Head = 14.860000
Res. Std. Dev./Range = 0.065324

----- Statistics for Layer 1 -----
Number of Targets = 58
Residual Mean = -0.674287
Residual Standard Dev. = 0.970710
Residual Sum of Squares = 81.022573

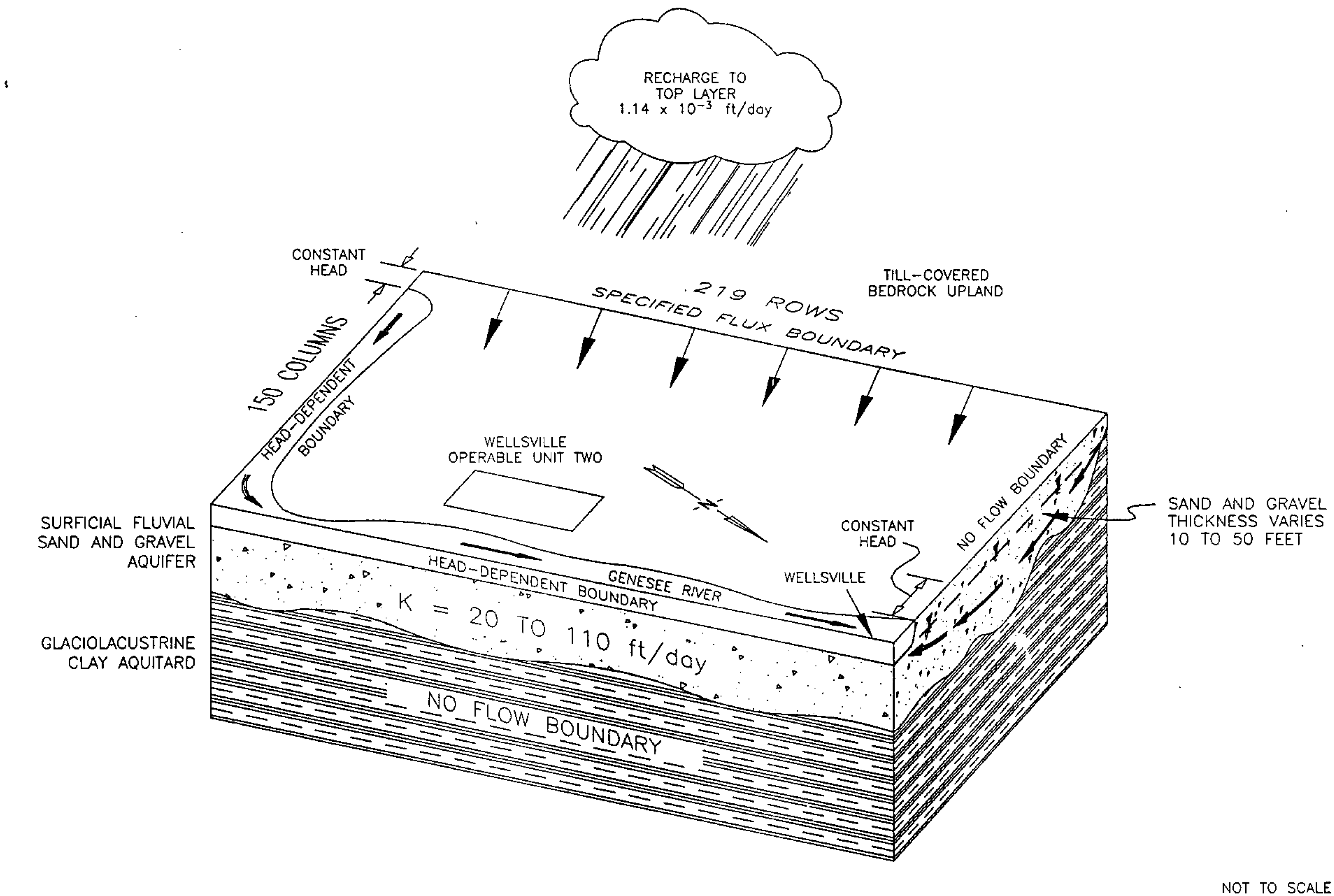
Absolute Residual Mean = 0.911794
Minimum Residual = -3.482598
Maximum Residual = 1.781699

Observed Range in Head = 14.860000
Res. Std. Dev./Range = 0.065324

TABLE D-1
CALCULATION OF MODFLOW RIVER CONDUCTANCES
WELLSVILLE, NEW YORK

Kv= 5 FT/DAY
M= 1 FT

GRID DIMENSIONS X (FT)	GRID DIMENSIONS Y (FT)	CRIV (1/DAY)	GRID DIMENSIONS X (FT)	GRID DIMENSIONS Y (FT)	CRIV (1/DAY)
25	25	3,375	140	140	105,840
25	35	4,725	140	200	151,200
25	50	6,750	140	280	211,680
25	70	9,450	140	400	302,400
25	100	13,500	140	560	423,360
25	140	18,900	140	785	593,460
25	200	27,000	140	1100	831,600
25	280	37,800	200	200	216,000
25	400	54,000	200	280	302,400
25	560	75,600	200	400	432,000
25	785	105,975	200	560	604,800
25	1100	148,500	200	785	847,800
35	35	6,615	200	1100	1,188,000
35	50	9,450	280	280	423,360
35	70	13,230	280	400	604,800
35	100	18,900	280	560	846,720
35	140	26,460	280	785	1,186,920
35	200	37,800	280	1100	1,663,200
35	280	52,920	400	400	864,000
35	400	75,600	400	560	1,209,600
35	560	105,840	400	785	1,695,600
35	785	148,365	400	1100	2,376,000
35	1100	207,900	560	560	1,693,440
50	50	13,500	560	785	2,373,840
50	70	18,900	560	1100	3,326,400
50	100	27,000	785	785	3,327,615
50	140	37,800	785	1100	4,662,900
50	200	54,000	1100	1100	6,534,000
50	280	75,600			
50	400	108,000			
50	560	151,200			
50	785	211,950			
50	1100	297,000			
70	70	26,460			
70	100	37,800			
70	140	52,920			
70	200	75,600			
70	280	105,840			
70	400	151,200			
70	560	211,680			
70	785	296,730			
70	1100	415,800			
100	100	54,000			
100	140	75,600			
100	200	108,000			
100	280	151,200			
100	400	216,000			
100	560	302,400			
100	785	423,900			
100	1100	594,000			

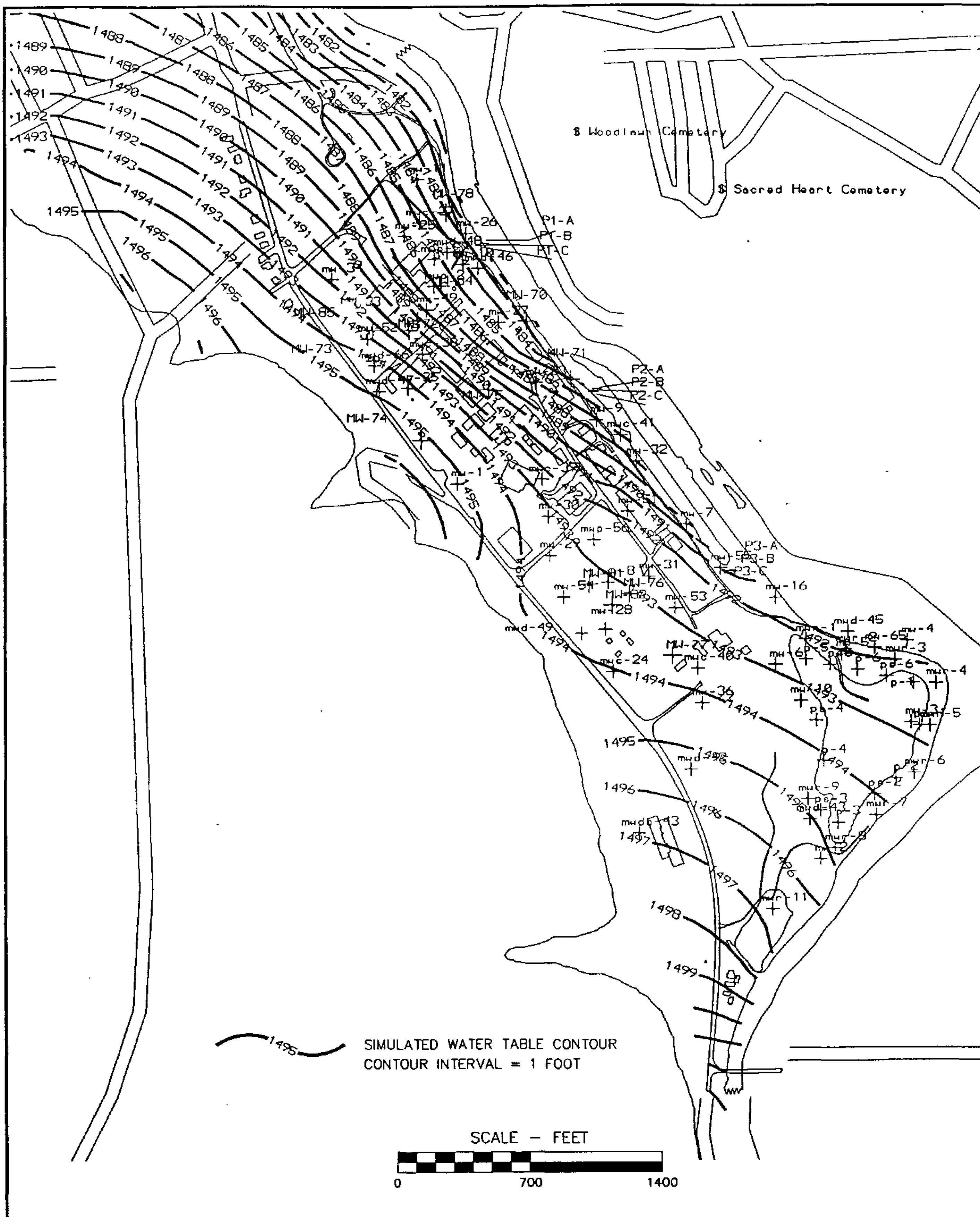


DRAWN BY	MMR
DATE	3/17/94
CHK'D BY	
DATE	
SCALE	NONE
CAD FILE:	1077AM01

CONCEPTUAL MODEL FOR FLOW SIMULATION

RETEC
REMEDIATION TECHNOLOGIES INC

FIGURE D-1



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SCALE	NOTED
CAD FILE:	1077AS06

STEADY-STATE CALIBRATION MAP

RETEC
REMEDIATION TECHNOLOGIES INC

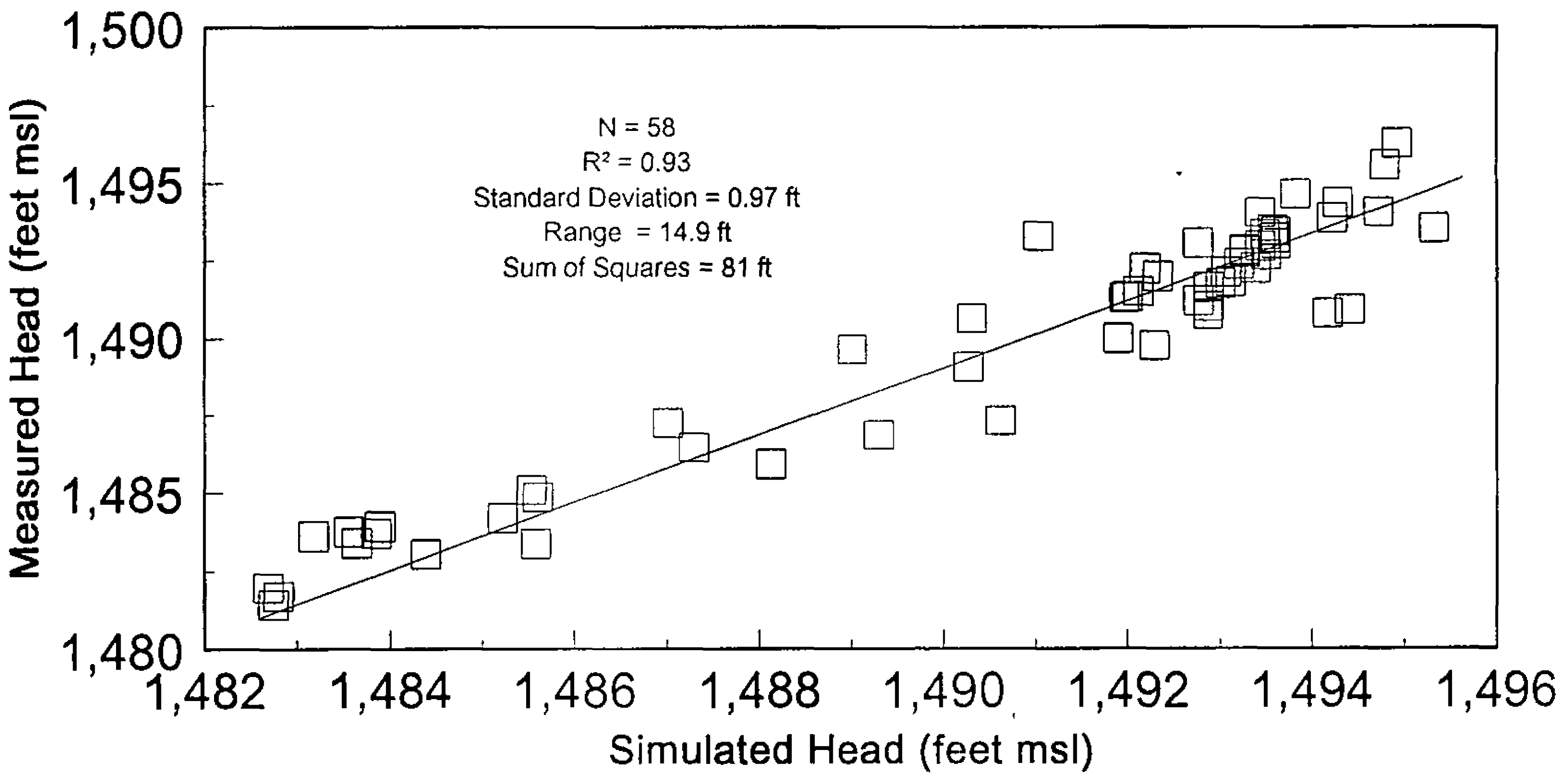
FIGURE D-3

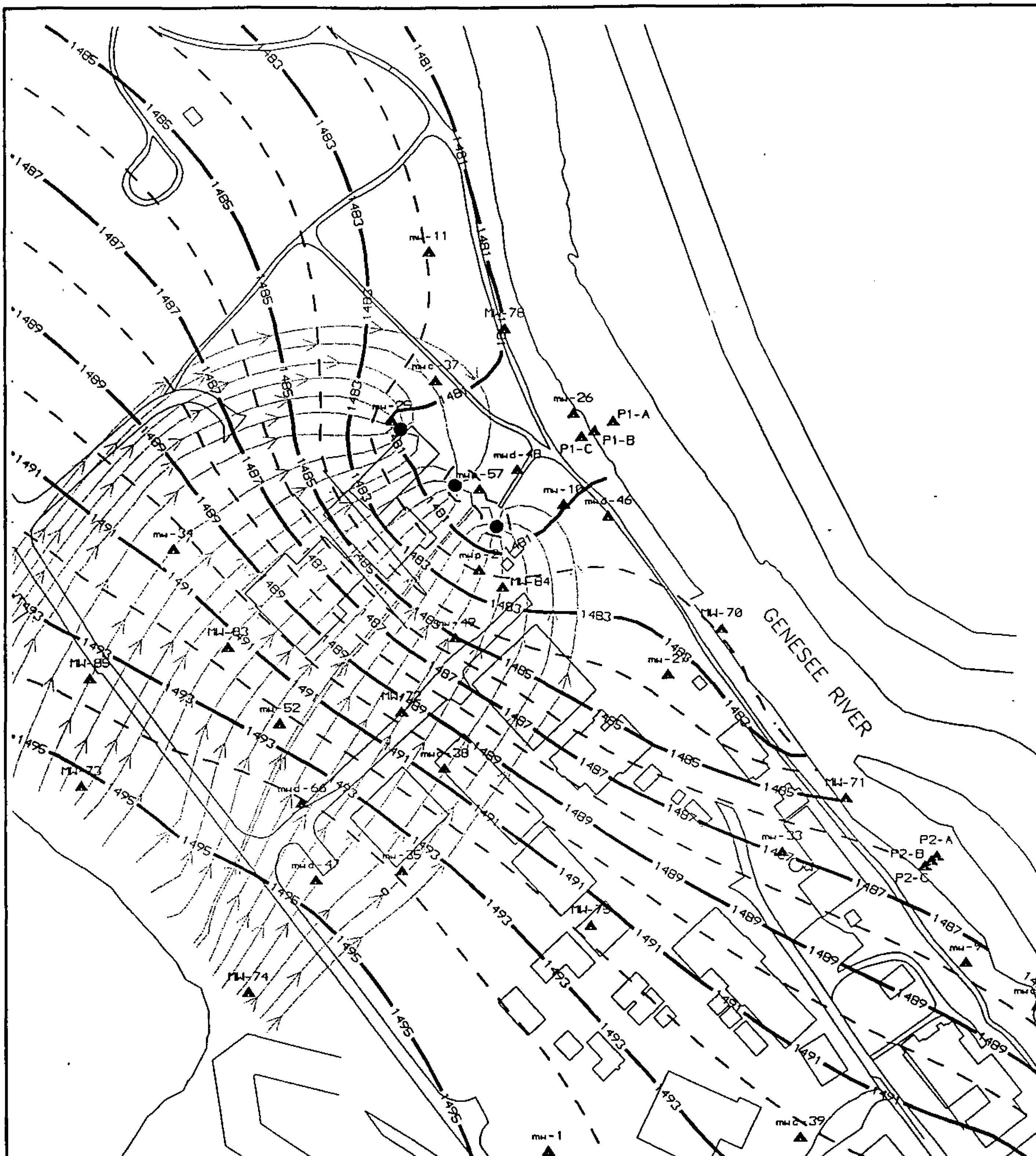
FIGURE D-4

Plot of Simulated versus Measured Heads

Sand and Gravel Alluvial Aquifer

Wellsville, New York





SIMULATED WATER TABLE CONTOUR
CONTOUR INTERVAL = 1 FOOT

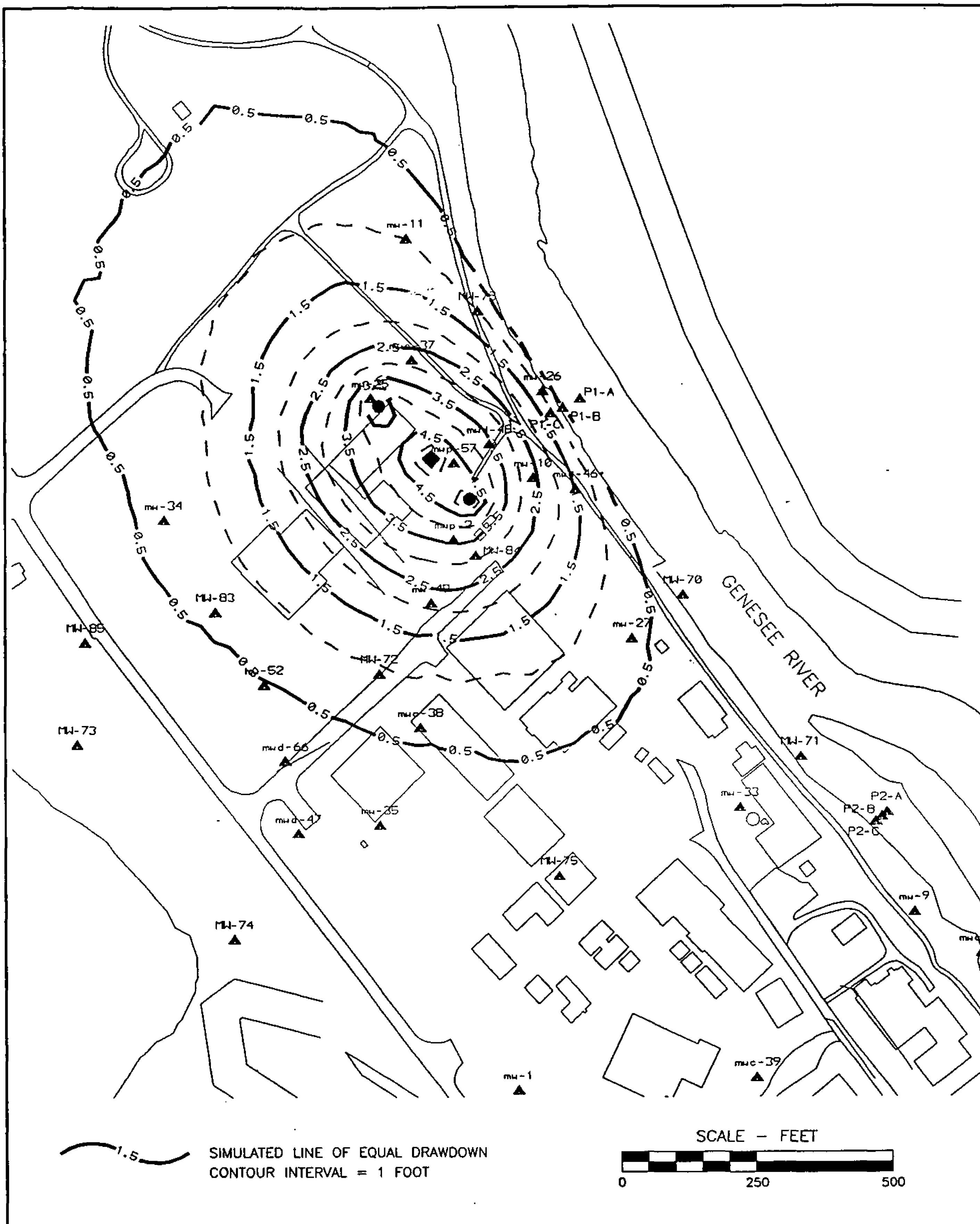
SCALE - FEET
0 250 500

DRAWN BY	MWR
DATE	3/17/94
CHK'D BY	--
DATE	
SCALE	NOTED
CAD FILE:	1077AS05

SIMULATED HEAD FOR THREE WELLS PUMPING 10 gpm EACH

RETEC
REMEDIATION TECHNOLOGIES INC

FIGURE D-5



DRAWN BY	MMR
DATE	3/17/94
CHK'D BY	-
DATE	
SCALE	NOTED
CAD FILE:	1077AS05

SIMULATED DRAWDOWN FOR THREE WELLS PUMPING 10 gpm EACH

RETEC
REMEDIATION TECHNOLOGIES INC

FIGURE D-6

==

ModelCad-386
Model Design Software for Extended-DOS

MODFLOW Input Data
for
Wellsville Operating Unit 2
Wellsville, New York

Date: 2/28/1994
Time: 17:25:43.80

==

Input File: WELSVIL2.GRD
Root Name : calbrat2

Map File 1 : WELLSVIL.MAP

==

GRID INFORMATION:

Number of Rows : 219
Number of Columns : 150
Number of Layers : 1

Total Cells : 32850
Total Active Cells: 10741
Percent Inactive : 67

GRID DIMENSIONS

>>>>> ROW SPACINGS (DELTA-Y) <<<<<

Row 1: 1100.000000
Row 2: 785.000000
Row 3: 560.000000
Row 4: 400.000000
Row 5: 280.000000
Row 6: 200.000000
Row 7: 140.000000
Row 8: 100.000000
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Row 11: 35.000000
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Row 14: 25.000000
Row 15: 25.000000
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Row 209: 25.000000
Row 210: 25.000000
Row 211: 25.000000
Row 212: 35.000000
Row 213: 50.000000
Row 214: 70.000000
Row 215: 100.000000
Row 216: 140.000000
Row 217: 200.000000

Row 218: 280.000000
Row 219: 400.000000

Minimum Delta-Y: 25.000000
Maximum Delta-Y: 1100.000000

>>>>> COLUMN SPACINGS (DELTA-X) <<<<<

Column 1: 1500.000000
Column 2: 1100.000000
Column 3: 785.000000
Column 4: 560.000000
Column 5: 400.000000
Column 6: 280.000000
Column 7: 200.000000
Column 8: 140.000000
Column 9: 100.000000
Column 10: 70.000000
Column 11: 50.000000
Column 12: 35.000000
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Column 143: 25.000000
Column 144: 25.000000
Column 145: 25.000000
Column 146: 35.000000
Column 147: 50.000000
Column 148: 70.000000
Column 149: 100.000000
Column 150: 140.000000

Minimum Delta-X: 25.000000
Maximum Delta-X: 1500.000000

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MODEL PARAMETER INFORMATION:

>>>>>>>>>> PARAMETER ZONES IN LAYER 1 <<<<<<<<<<

Hydraulic Cond Zone.. 1: Kx = 5.000e+000
Ky = 5.000e+000
Kz = 5.000e+000
Hydraulic Cond Zone.. 3: Kx = 2.000e+001
Ky = 2.000e+001
Kz = 2.000e+001
Hydraulic Cond Zone.. 4: Kx = 3.000e+001
Ky = 3.000e+001
Kz = 3.000e+001
Hydraulic Cond Zone.. 5: Kx = 4.000e+001
Ky = 4.000e+001
Kz = 4.000e+001
Hydraulic Cond Zone.. 6: Kx = 5.000e+001
Ky = 5.000e+001
Kz = 5.000e+001
Hydraulic Cond Zone.. 12: Kx = 1.100e+002
Ky = 1.100e+002
Kz = 1.100e+002

Storage Zone......... 2: S = 1.000e-004
Sy = 2.000e-001
Porosity = 2.500e+001

Bottom Zone.......... 1 Bottom = 1.405e+003
Bottom Zone.......... 2 Bottom = 1.410e+003
Bottom Zone.......... 3 Bottom = 1.415e+003
Bottom Zone.......... 4 Bottom = 1.420e+003
Bottom Zone.......... 5 Bottom = 1.425e+003
Bottom Zone.......... 6 Bottom = 1.430e+003
Bottom Zone.......... 7 Bottom = 1.435e+003
Bottom Zone.......... 8 Bottom = 1.440e+003
Bottom Zone.......... 9 Bottom = 1.445e+003
Bottom Zone.......... 10 Bottom = 1.[illegible]50e+003
Bottom Zone.......... 11 Bottom = 1.455e+003
Bottom Zone.......... 12 Bottom = 1.460e+003
Bottom Zone.......... 13 Bottom = 1.462e+003
Bottom Zone.......... 14 Bottom = 1.464e+003
Bottom Zone.......... 15 Bottom = 1.466e+003
Bottom Zone.......... 16 Bottom = 1.468e+003
Bottom Zone.......... 17 Bottom = 1.470e+003
Bottom Zone.......... 18 Bottom = 1.472e+003
Bottom Zone.......... 19 Bottom = 1.474e+003
Bottom Zone.......... 20 Bottom = 1.476e+003
Bottom Zone.......... 21 Bottom = 1.478e+003
Bottom Zone.......... 22 Bottom = 1.480e+003

Recharge Zone........ 4: R = 1.140e-003 Area = 8.936e+007
Concentration = 0.000e+000

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MODEL BOUNDARY CONDITIONS:

Constant Heads.....: 14
Rivers.............: 299
Drains.............: 0
General Heads......: 0
Wells..............: 167

RIVER CELLS:

Reach	Row	Column	Layer	Stage	Bottom	Conductance	Concentration	Starting Time	Ending Time
1	37	34	1	1479.980	1469.980	3.375e+003	0.000e+000	0.000	0.000
1	38	35	1	1480.010	1470.010	3.375e+003	0.000e+000	0.000	0.000
1	39	35	1	1480.020	1470.020	3.375e+003	0.000e+000	0.000	0.000
1	40	36	1	1480.060	1470.060	3.375e+003	0.000e+000	0.000	0.000
1	41	37	1	1480.090	1470.090	3.375e+003	0.000e+000	0.000	0.000
1	42	37	1	1480.110	1470.110	3.375e+003	0.000e+000	0.000	0.000
1	43	37	1	1480.140	1470.140	3.375e+003	0.000e+000	0.000	0.000
1	44	37	1	1480.150	1470.150	3.375e+003	0.000e+000	0.000	0.000
1	45	38	1	1480.190	1470.190	3.375e+003	0.000e+000	0.000	0.000
1	46	38	1	1480.210	1470.210	3.375e+003	0.000e+000	0.000	0.000
1	47	38	1	1480.230	1470.230	3.375e+003	0.000e+000	0.000	0.000
1	48	39	1	1480.260	1470.260	3.375e+003	0.000e+000	0.000	0.000
1	49	39	1	1480.290	1470.290	3.375e+003	0.000e+000	0.000	0.000
1	50	39	1	1480.310	1470.310	3.375e+003	0.000e+000	0.000	0.000
1	51	39	1	1480.330	1470.330	3.375e+003	0.000e+000	0.000	0.000
1	52	39	1	1480.350	1470.350	3.375e+003	0.000e+000	0.000	0.000
1	53	39	1	1480.380	1470.380	3.375e+003	0.000e+000	0.000	0.000
1	54	39	1	1480.400	1470.400	3.375e+003	0.000e+000	0.000	0.000
1	55	40	1	1480.430	1470.430	3.375e+003	0.000e+000	0.000	0.000

1	56	40	1	1480.450	1470.450	3.375e+003	0.000e+000	0.000	0.000
1	57	40	1	1480.470	1470.470	3.375e+003	0.000e+000	0.000	0.000
1	58	40	1	1480.490	1470.490	3.375e+003	0.000e+000	0.000	0.000
1	59	40	1	1480.520	1470.520	3.375e+003	0.000e+000	0.000	0.000
1	60	40	1	1480.540	1470.540	3.375e+003	0.000e+000	0.000	0.000
1	61	41	1	1480.590	1470.590	3.375e+003	0.000e+000	0.000	0.000
1	62	41	1	1480.600	1470.600	3.375e+003	0.000e+000	0.000	0.000
1	63	42	1	1480.640	1470.640	3.375e+003	0.000e+000	0.000	0.000
1	64	42	1	1480.650	1470.650	3.375e+003	0.000e+000	0.000	0.000
1	65	43	1	1480.690	1470.690	3.375e+003	0.000e+000	0.000	0.000
1	66	44	1	1480.720	1470.720	3.375e+003	0.000e+000	0.000	0.000
1	67	44	1	1480.730	1470.730	3.375e+003	0.000e+000	0.000	0.000
1	68	45	1	1480.770	1470.770	3.375e+003	0.000e+000	0.000	0.000
1	69	46	1	1480.800	1470.800	3.375e+003	0.000e+000	0.000	0.000
1	70	46	1	1480.820	1470.820	3.375e+003	0.000e+000	0.000	0.000
1	71	47	1	1480.850	1470.850	3.375e+003	0.000e+000	0.000	0.000
1	72	48	1	1480.880	1470.880	3.375e+003	0.000e+000	0.000	0.000
1	73	48	1	1480.900	1470.900	3.375e+003	0.000e+000	0.000	0.000
1	74	49	1	1480.930	1470.930	3.375e+003	0.000e+000	0.000	0.000
1	75	49	1	1480.950	1470.950	3.375e+003	0.000e+000	0.000	0.000
1	76	50	1	1480.980	1470.980	3.375e+003	0.000e+000	0.000	0.000
1	77	51	1	1481.010	1471.010	3.375e+003	0.000e+000	0.000	0.000
1	78	51	1	1481.030	1471.030	3.375e+003	0.000e+000	0.000	0.000
1	79	52	1	1481.060	1471.060	3.375e+003	0.000e+000	0.000	0.000
1	80	53	1	1481.090	1471.090	3.375e+003	0.000e+000	0.000	0.000
1	81	54	1	1481.120	1471.120	3.375e+003	0.000e+000	0.000	0.000
1	82	54	1	1481.140	1471.140	3.375e+003	0.000e+000	0.000	0.000
1	83	55	1	1481.170	1471.170	3.375e+003	0.000e+000	0.000	0.000
1	84	56	1	1481.210	1471.210	3.375e+003	0.000e+000	0.000	0.000
1	85	57	1	1481.230	1471.230	3.375e+003	0.000e+000	0.000	0.000
1	86	57	1	1481.260	1471.260	3.375e+003	0.000e+000	0.000	0.000
1	87	58	1	1481.290	1471.290	3.375e+003	0.000e+000	0.000	0.000
1	88	58	1	1481.310	1471.310	3.375e+003	0.000e+000	0.000	0.000
1	89	58	1	1481.320	1471.320	3.375e+003	0.000e+000	0.000	0.000
1	90	59	1	1481.360	1471.360	3.375e+003	0.000e+000	0.000	0.000
1	91	59	1	1481.380	1471.380	3.375e+003	0.000e+000	0.000	0.000
1	92	60	1	1481.410	1471.410	3.375e+003	0.000e+000	0.000	0.000
1	93	60	1	1481.430	1471.430	3.375e+003	0.000e+000	0.000	0.000
1	93	61	1	1481.430	1471.430	3.375e+003	0.000e+000	0.000	0.000
1	94	62	1	1483.380	1473.380	3.375e+003	0.000e+000	0.000	0.000
1	139	105	1	1491.150	1481.150	3.375e+003	0.000e+000	0.000	0.000
1	140	106	1	1491.180	1481.180	3.375e+003	0.000e+000	0.000	0.000
1	141	107	1	1491.200	1481.200	3.375e+003	0.000e+000	0.000	0.000
1	142	108	1	1491.230	1481.230	3.375e+003	0.000e+000	0.000	0.000
1	143	109	1	1491.250	1481.250	3.375e+003	0.000e+000	0.000	0.000
1	144	109	1	1491.270	1481.270	3.375e+003	0.000e+000	0.000	0.000
1	145	110	1	1491.290	1481.290	3.375e+003	0.000e+000	0.000	0.000
1	146	111	1	1491.320	1481.320	3.375e+003	0.000e+000	0.000	0.000
1	147	112	1	1491.350	1481.350	3.375e+003	0.000e+000	0.000	0.000
1	148	113	1	1491.370	1481.370	3.375e+003	0.000e+000	0.000	0.000
1	149	114	1	1491.390	1481.390	3.375e+003	0.000e+000	0.000	0.000
1	150	115	1	1491.420	1481.420	3.375e+003	0.000e+000	0.000	0.000
1	151	116	1	1491.440	1481.440	3.375e+003	0.000e+000	0.000	0.000
1	151	117	1	1491.460	1481.460	3.375e+003	0.000e+000	0.000	0.000
1	151	118	1	1491.480	1481.480	3.375e+003	0.000e+000	0.000	0.000
1	152	119	1	1491.500	1481.500	3.375e+003	0.000e+000	0.000	0.000
1	152	120	1	1491.510	1481.510	3.375e+003	0.000e+000	0.000	0.000
1	152	121	1	1491.530	1481.530	3.375e+003	0.000e+000	0.000	0.000
1	153	122	1	1491.560	1481.560	3.375e+003	0.000e+000	0.000	0.000
1	153	123	1	1491.570	1481.570	3.375e+003	0.000e+000	0.000	0.000
1	153	124	1	1491.590	1481.590	3.375e+003	0.000e+000	0.000	0.000
1	154	125	1	1491.620	1481.620	3.375e+003	0.000e+000	0.000	0.000
1	154	126	1	1491.630	1481.630	3.375e+003	0.000e+000	0.000	0.000
1	154	127	1	1491.640	1481.640	3.375e+003	0.000e+000	0.000	0.000
1	154	128	1	1491.660	1481.660	3.375e+003	0.000e+000	0.000	0.000

1	155	129	1	1491.690	1481.690	3.375e+003	0.000e+000	0.000	0.000
1	155	130	1	1491.700	1481.700	3.375e+003	0.000e+000	0.000	0.000
1	155	131	1	1491.720	1481.720	3.375e+003	0.000e+000	0.000	0.000
1	155	132	1	1491.740	1481.740	3.375e+003	0.000e+000	0.000	0.000
1	155	133	1	1491.750	1481.750	3.375e+003	0.000e+000	0.000	0.000
1	155	134	1	1491.780	1481.780	3.375e+003	0.000e+000	0.000	0.000
1	156	135	1	1491.800	1481.800	3.375e+003	0.000e+000	0.000	0.000
1	156	136	1	1491.810	1481.810	3.375e+003	0.000e+000	0.000	0.000
1	156	137	1	1491.830	1481.830	3.375e+003	0.000e+000	0.000	0.000
1	157	138	1	1491.850	1481.850	3.375e+003	0.000e+000	0.000	0.000
1	157	139	1	1491.870	1481.870	3.375e+003	0.000e+000	0.000	0.000
1	158	140	1	1491.890	1481.890	3.375e+003	0.000e+000	0.000	0.000
1	159	141	1	1491.920	1481.920	3.375e+003	0.000e+000	0.000	0.000
1	160	142	1	1491.940	1481.940	3.375e+003	0.000e+000	0.000	0.000
1	160	143	1	1491.960	1481.960	3.375e+003	0.000e+000	0.000	0.000
1	161	144	1	1491.980	1481.980	3.375e+003	0.000e+000	0.000	0.000
1	162	144	1	1492.000	1482.000	3.375e+003	0.000e+000	0.000	0.000
1	163	144	1	1492.020	1482.020	3.375e+003	0.000e+000	0.000	0.000
1	164	144	1	1492.070	1482.070	3.375e+003	0.000e+000	0.000	0.000
1	165	144	1	1492.140	1482.140	3.375e+003	0.000e+000	0.000	0.000
1	166	144	1	1492.200	1482.200	3.375e+003	0.000e+000	0.000	0.000
1	167	144	1	1492.270	1482.270	3.375e+003	0.000e+000	0.000	0.000
1	168	144	1	1492.340	1482.340	3.375e+003	0.000e+000	0.000	0.000
1	169	143	1	1492.410	1482.410	3.375e+003	0.000e+000	0.000	0.000
1	169	144	1	1492.380	1482.380	3.375e+003	0.000e+000	0.000	0.000
1	170	143	1	1492.480	1482.480	3.375e+003	0.000e+000	0.000	0.000
1	171	143	1	1492.540	1482.540	3.375e+003	0.000e+000	0.000	0.000
1	172	142	1	1492.630	1482.630	3.375e+003	0.000e+000	0.000	0.000
1	172	143	1	1492.590	1482.590	3.375e+003	0.000e+000	0.000	0.000
1	173	142	1	1492.680	1482.680	3.375e+003	0.000e+000	0.000	0.000
1	174	142	1	1492.740	1482.740	3.375e+003	0.000e+000	0.000	0.000
1	175	141	1	1492.830	1482.830	3.375e+003	0.000e+000	0.000	0.000
1	175	142	1	1492.800	1482.800	3.375e+003	0.000e+000	0.000	0.000
1	176	141	1	1492.880	1482.880	3.375e+003	0.000e+000	0.000	0.000
1	177	141	1	1492.950	1482.950	3.375e+003	0.000e+000	0.000	0.000
1	178	141	1	1493.010	1483.010	3.375e+003	0.000e+000	0.000	0.000
1	179	141	1	1493.080	1483.080	3.375e+003	0.000e+000	0.000	0.000
1	180	140	1	1493.150	1483.150	3.375e+003	0.000e+000	0.000	0.000
1	180	141	1	1493.110	1483.110	3.375e+003	0.000e+000	0.000	0.000
1	181	140	1	1493.220	1483.220	3.375e+003	0.000e+000	0.000	0.000
1	182	139	1	1493.300	1483.300	3.375e+003	0.000e+000	0.000	0.000
1	182	140	1	1493.270	1483.270	3.375e+003	0.000e+000	0.000	0.000
1	183	139	1	1493.360	1483.360	3.375e+003	0.000e+000	0.000	0.000
1	184	138	1	1493.450	1483.450	3.375e+003	0.000e+000	0.000	0.000
1	184	139	1	1493.410	1483.410	3.375e+003	0.000e+000	0.000	0.000
1	185	137	1	1493.550	1483.550	3.375e+003	0.000e+000	0.000	0.000
1	185	138	1	1493.510	1483.510	3.375e+003	0.000e+000	0.000	0.000
1	186	136	1	1493.640	1483.640	3.375e+003	0.000e+000	0.000	0.000
1	186	137	1	1493.590	1483.590	3.375e+003	0.000e+000	0.000	0.000
1	187	135	1	1493.730	1483.730	3.375e+003	0.000e+000	0.000	0.000
1	187	136	1	1493.680	1483.680	3.375e+003	0.000e+000	0.000	0.000
1	188	134	1	1493.820	1483.820	3.375e+003	0.000e+000	0.000	0.000
1	188	135	1	1493.780	1483.780	3.375e+003	0.000e+000	0.000	0.000
1	189	133	1	1493.920	1483.920	3.375e+003	0.000e+000	0.000	0.000
1	189	134	1	1493.870	1483.870	3.375e+003	0.000e+000	0.000	0.000
1	190	132	1	1494.010	1484.010	3.375e+003	0.000e+000	0.000	0.000
1	190	133	1	1493.960	1483.960	3.375e+003	0.000e+000	0.000	0.000
1	191	130	1	1494.150	1484.150	3.375e+003	0.000e+000	0.000	0.000
1	191	131	1	1494.100	1484.100	3.375e+003	0.000e+000	0.000	0.000
1	191	132	1	1494.050	1484.050	3.375e+003	0.000e+000	0.000	0.000
1	192	129	1	1494.240	1484.240	3.375e+003	0.000e+000	0.000	0.000
1	192	130	1	1494.190	1484.190	3.375e+003	0.000e+000	0.000	0.000
1	193	128	1	1494.330	1484.330	3.375e+003	0.000e+000	0.000	0.000
1	193	129	1	1494.280	1484.280	3.375e+003	0.000e+000	0.000	0.000
1	194	127	1	1494.420	1484.420	3.375e+003	0.000e+000	0.000	0.000

1	194	128	1	1494.370	1484.370	3.375e+003	0.000e+000	0.000	0.000
1	195	127	1	1494.470	1484.470	3.375e+003	0.000e+000	0.000	0.000
1	202	122	1	1494.790	1484.790	3.375e+003	0.000e+000	0.000	0.000
1	203	121	1	1494.900	1484.900	3.375e+003	0.000e+000	0.000	0.000
1	203	122	1	1494.860	1484.860	3.375e+003	0.000e+000	0.000	0.000
1	204	121	1	1495.050	1485.050	3.375e+003	0.000e+000	0.000	0.000
1	205	120	1	1495.210	1485.210	3.375e+003	0.000e+000	0.000	0.000
1	205	121	1	1495.150	1485.150	3.375e+003	0.000e+000	0.000	0.000
1	206	120	1	1495.280	1485.280	3.375e+003	0.000e+000	0.000	0.000
1	207	120	1	1495.420	1485.420	3.375e+003	0.000e+000	0.000	0.000
1	208	119	1	1495.550	1485.550	3.375e+003	0.000e+000	0.000	0.000
1	208	120	1	1495.480	1485.480	3.375e+003	0.000e+000	0.000	0.000
1	209	118	1	1495.720	1485.720	3.375e+003	0.000e+000	0.000	0.000
1	209	119	1	1495.650	1485.650	3.375e+003	0.000e+000	0.000	0.000
1	210	118	1	1495.820	1485.820	3.375e+003	0.000e+000	0.000	0.000
1	211	117	1	1495.950	1485.950	3.375e+003	0.000e+000	0.000	0.000
1	211	118	1	1495.890	1485.890	3.375e+003	0.000e+000	0.000	0.000
1	212	115	1	1496.250	1486.250	4.725e+003	0.000e+000	0.000	0.000
1	212	116	1	1496.250	1486.250	4.725e+003	0.000e+000	0.000	0.000
1	212	117	1	1496.250	1486.250	4.725e+003	0.000e+000	0.000	0.000
1	213	114	1	1496.490	1486.490	6.750e+003	0.000e+000	0.000	0.000
1	213	115	1	1496.490	1486.490	6.750e+003	0.000e+000	0.000	0.000
1	214	112	1	1496.820	1486.820	9.450e+003	0.000e+000	0.000	0.000
1	214	113	1	1496.820	1486.820	9.450e+003	0.000e+000	0.000	0.000
1	215	108	1	1496.310	1486.310	1.350e+004	0.000e+000	0.000	0.000
1	215	109	1	1496.310	1486.310	1.350e+004	0.000e+000	0.000	0.000
1	215	110	1	1496.310	1486.310	1.350e+004	0.000e+000	0.000	0.000
1	215	111	1	1496.310	1486.310	1.350e+004	0.000e+000	0.000	0.000
1	216	104	1	1497.640	1487.640	1.890e+004	0.000e+000	0.000	0.000
1	216	105	1	1497.640	1487.640	1.890e+004	0.000e+000	0.000	0.000
1	216	106	1	1497.640	1487.640	1.890e+004	0.000e+000	0.000	0.000
1	216	107	1	1497.640	1487.640	1.890e+004	0.000e+000	0.000	0.000
1	217	101	1	1499.170	1489.170	2.700e+004	0.000e+000	0.000	0.000
1	217	102	1	1499.170	1489.170	2.700e+004	0.000e+000	0.000	0.000
1	217	103	1	1499.170	1489.170	2.700e+004	0.000e+000	0.000	0.000
1	218	98	1	1501.530	1491.530	3.780e+004	0.000e+000	0.000	0.000
1	218	99	1	1501.530	1491.530	3.780e+004	0.000e+000	0.000	0.000
1	218	100	1	1501.530	1491.530	3.780e+004	0.000e+000	0.000	0.000
1	219	97	1	1503.040	1493.040	5.400e+004	0.000e+000	0.000	0.000
1	219	98	1	1503.040	1493.040	5.400e+004	0.000e+000	0.000	0.000
1	2	4	1	1474.220	1464.220	2.374e+006	0.000e+000	0.000	0.000
1	3	5	1	1474.940	1464.940	1.210e+006	0.000e+000	0.000	0.000
1	3	6	1	1475.570	1465.570	8.467e+005	0.000e+000	0.000	0.000
1	4	7	1	1476.150	1466.150	4.320e+005	0.000e+000	0.000	0.000
1	4	8	1	1476.480	1466.480	1.512e+005	0.000e+000	0.000	0.000
1	4	9	1	1476.790	1466.790	2.160e+005	0.000e+000	0.000	0.000
1	5	10	1	1477.030	1467.030	1.058e+005	0.000e+000	0.000	0.000
1	5	11	1	1477.180	1467.180	7.560e+004	0.000e+000	0.000	0.000
1	5	12	1	1477.310	1467.310	5.292e+004	0.000e+000	0.000	0.000
1	5	13	1	1477.400	1467.400	3.780e+004	0.000e+000	0.000	0.000
1	6	15	1	1477.760	1467.760	2.700e+004	0.000e+000	0.000	0.000
1	7	15	1	1477.910	1467.910	1.890e+004	0.000e+000	0.000	0.000
1	8	14	1	1478.120	1468.120	1.350e+004	0.000e+000	0.000	0.000
1	9	13	1	1478.280	1468.280	9.450e+003	0.000e+000	0.000	0.000
1	10	13	1	1478.350	1468.350	6.750e+003	0.000e+000	0.000	0.000
1	11	12	1	1478.450	1468.450	6.615e+003	0.000e+000	0.000	0.000
1	12	12	1	1478.780	1468.780	4.725e+003	0.000e+000	0.000	0.000
1	13	12	1	1478.780	1468.780	4.725e+003	0.000e+000	0.000	0.000
1	14	12	1	1478.780	1468.780	4.725e+003	0.000e+000	0.000	0.000
1	15	12	1	1478.780	1468.780	4.725e+003	0.000e+000	0.000	0.000
1	16	12	1	1478.780	1468.780	4.725e+003	0.000e+000	0.000	0.000
1	17	12	1	1478.780	1468.780	4.725e+003	0.000e+000	0.000	0.000
1	18	12	1	1478.780	1468.780	4.725e+003	0.000e+000	0.000	0.000
1	19	12	1	1478.780	1468.780	4.725e+003	0.000e+000	0.000	0.000
1	20	13	1	1478.830	1468.830	3.375e+003	0.000e+000	0.000	0.000

1	21	13	1	1478.870	1468.870	3.375e+003	0.000e+000	0.000	0.000
1	21	14	1	1478.890	1468.890	3.375e+003	0.000e+000	0.000	0.000
1	22	15	1	1478.950	1468.950	3.375e+003	0.000e+000	0.000	0.000
1	23	16	1	1479.010	1469.010	3.375e+003	0.000e+000	0.000	0.000
1	24	17	1	1479.060	1469.060	3.375e+003	0.000e+000	0.000	0.000
1	25	18	1	1479.110	1469.110	3.375e+003	0.000e+000	0.000	0.000
1	25	19	1	1479.160	1469.160	3.375e+003	0.000e+000	0.000	0.000
1	26	20	1	1479.200	1469.200	3.375e+003	0.000e+000	0.000	0.000
1	27	21	1	1479.270	1469.270	3.375e+003	0.000e+000	0.000	0.000
1	28	22	1	1479.330	1469.330	3.375e+003	0.000e+000	0.000	0.000
1	28	23	1	1479.360	1469.360	3.375e+003	0.000e+000	0.000	0.000
1	28	24	1	1479.410	1469.410	3.375e+003	0.000e+000	0.000	0.000
1	29	25	1	1479.500	1469.500	3.375e+003	0.000e+000	0.000	0.000
1	30	26	1	1479.550	1469.550	3.375e+003	0.000e+000	0.000	0.000
1	31	27	1	1479.610	1469.610	3.375e+003	0.000e+000	0.000	0.000
1	32	28	1	1479.680	1469.680	3.375e+003	0.000e+000	0.000	0.000
1	33	29	1	1479.730	1469.730	3.375e+003	0.000e+000	0.000	0.000
1	33	30	1	1479.760	1469.760	3.375e+003	0.000e+000	0.000	0.000
1	34	31	1	1479.820	1469.820	3.375e+003	0.000e+000	0.000	0.000
1	35	32	1	1479.890	1469.890	3.375e+003	0.000e+000	0.000	0.000
1	36	33	1	1479.940	1469.940	3.375e+003	0.000e+000	0.000	0.000
1	6	16	1	1477.760	1467.760	2.700e+004	0.000e+000	0.000	0.000
1	2	3	1	1473.000	1463.000	3.328e+006	0.000e+000	0.000	0.000
1	1	2	1	1472.000	1462.000	3.267e+006	0.000e+000	0.000	0.000
1	195	126	1	1494.000	0.000	3.375e+003	0.000e+000	0.000	0.000
1	196	126	1	1494.000	0.000	3.375e+003	0.000e+000	0.000	0.000
1	197	126	1	1494.000	0.000	3.375e+003	0.000e+000	0.000	0.000
1	197	125	1	1494.000	0.000	3.375e+003	0.000e+000	0.000	0.000
1	198	125	1	1494.000	0.000	3.375e+003	0.000e+000	0.000	0.000
1	198	124	1	1494.000	0.000	3.375e+003	0.000e+000	0.000	0.000
1	199	124	1	1494.000	0.000	3.375e+003	0.000e+000	0.000	0.000
1	200	123	1	1494.000	0.000	3.375e+003	0.000e+000	0.000	0.000
1	201	123	1	1494.000	0.000	3.375e+003	0.000e+000	0.000	0.000
1	201	122	1	1494.000	0.000	3.375e+003	0.000e+000	0.000	0.000
1	139	104	1	1490.000	1480.000	3.375e+003	0.000e+000	0.000	0.000
1	139	103	1	1490.000	1480.000	3.375e+003	0.000e+000	0.000	0.000
1	139	102	1	1490.000	1480.000	3.375e+003	0.000e+000	0.000	0.000
1	138	101	1	1490.000	1480.000	3.375e+003	0.000e+000	0.000	0.000
1	138	100	1	1490.000	1480.000	3.375e+003	0.000e+000	0.000	0.000
1	138	99	1	1490.000	1480.000	3.375e+003	0.000e+000	0.000	0.000
1	138	98	1	1490.000	1480.000	3.375e+003	0.000e+000	0.000	0.000
1	137	97	1	1490.000	1480.000	3.375e+003	0.000e+000	0.000	0.000
1	136	96	1	1490.000	1480.000	3.375e+003	0.000e+000	0.000	0.000
1	128	90	1	1487.410	1477.410	3.375e+003	0.000e+000	0.000	0.000
1	129	91	1	1487.830	1477.830	3.375e+003	0.000e+000	0.000	0.000
1	130	92	1	1488.200	1478.200	3.375e+003	0.000e+000	0.000	0.000
1	131	92	1	1488.510	1478.510	3.375e+003	0.000e+000	0.000	0.000
1	132	93	1	1488.860	1478.860	3.375e+003	0.000e+000	0.000	0.000
1	133	93	1	1489.180	1479.180	3.375e+003	0.000e+000	0.000	0.000
1	134	94	1	1489.580	1479.580	3.375e+003	0.000e+000	0.000	0.000
1	135	95	1	1489.900	1479.900	3.375e+003	0.000e+000	0.000	0.000
1	117	82	1	1487.040	1477.040	3.375e+003	0.000e+000	0.000	0.000
1	118	82	1	1487.070	1477.070	3.375e+003	0.000e+000	0.000	0.000
1	119	83	1	1487.110	1477.110	3.375e+003	0.000e+000	0.000	0.000
1	120	83	1	1487.130	1477.130	3.375e+003	0.000e+000	0.000	0.000
1	121	84	1	1487.170	1477.170	3.375e+003	0.000e+000	0.000	0.000
1	122	85	1	1487.210	1477.210	3.375e+003	0.000e+000	0.000	0.000
1	123	85	1	1487.240	1477.240	3.375e+003	0.000e+000	0.000	0.000
1	124	86	1	1487.280	1477.280	3.375e+003	0.000e+000	0.000	0.000
1	125	87	1	1487.320	1477.320	3.375e+003	0.000e+000	0.000	0.000
1	126	88	1	1487.360	1477.360	3.375e+003	0.000e+000	0.000	0.000
1	127	89	1	1487.400	1477.400	3.375e+003	0.000e+000	0.000	0.000
1	100	69	1	1484.310	1474.310	3.375e+003	0.000e+000	0.000	0.000
1	101	70	1	1484.520	1474.520	3.375e+003	0.000e+000	0.000	0.000
1	102	70	1	1484.610	1474.610	3.375e+003	0.000e+000	0.000	0.000

1	103	71	1	1484.810	1474.810	3.375e+003	0.000e+000	0.000	0.000
1	104	72	1	1484.990	1474.990	3.375e+003	0.000e+000	0.000	0.000
1	105	73	1	1485.160	1475.160	3.375e+003	0.000e+000	0.000	0.000
1	106	73	1	1485.280	1475.280	3.375e+003	0.000e+000	0.000	0.000
1	107	74	1	1485.480	1475.480	3.375e+003	0.000e+000	0.000	0.000
1	108	75	1	1485.650	1475.650	3.375e+003	0.000e+000	0.000	0.000
1	109	76	1	1485.820	1475.820	3.375e+003	0.000e+000	0.000	0.000
1	110	77	1	1486.020	1476.020	3.375e+003	0.000e+000	0.000	0.000
1	111	78	1	1486.190	1476.190	3.375e+003	0.000e+000	0.000	0.000
1	112	78	1	1486.310	1476.310	3.375e+003	0.000e+000	0.000	0.000
1	113	79	1	1486.500	1476.500	3.375e+003	0.000e+000	0.000	0.000
1	114	80	1	1486.670	1476.670	3.375e+003	0.000e+000	0.000	0.000
1	115	80	1	1486.810	1476.810	3.375e+003	0.000e+000	0.000	0.000
1	116	81	1	1486.950	1476.950	3.375e+003	0.000e+000	0.000	0.000
1	95	63	1	1483.160	1473.160	3.375e+003	0.000e+000	0.000	0.000
1	96	64	1	1483.330	1473.330	3.375e+003	0.000e+000	0.000	0.000
1	97	65	1	1483.480	1473.480	3.375e+003	0.000e+000	0.000	0.000
1	97	66	1	1483.620	1473.620	3.375e+003	0.000e+000	0.000	0.000
1	98	67	1	1483.800	1473.800	3.375e+003	0.000e+000	0.000	0.000
1	99	68	1	1483.940	1473.940	3.375e+003	0.000e+000	0.000	0.000

WELLS:

Reach	Row	Column	Layer	Flow Rate	Concentration	Starting Time	Ending Time
1	71	32	1	0.000	0.000e+000	0.000	0.000
1	75	36	1	0.000	0.000e+000	0.000	0.000
1	78	39	1	0.000	0.000e+000	0.000	0.000
1	95	7	1	338.000	0.000e+000	0.000	0.000
1	96	8	1	440.666	0.000e+000	0.000	0.000
1	97	9	1	266.000	0.000e+000	0.000	0.000
1	98	10	1	124.333	0.000e+000	0.000	0.000
1	99	10	1	51.000	0.000e+000	0.000	0.000
1	100	10	1	27.000	0.000e+000	0.000	0.000
1	101	11	1	177.000	0.000e+000	0.000	0.000
1	102	12	1	187.000	0.000e+000	0.000	0.000
1	103	12	1	45.000	0.000e+000	0.000	0.000
1	104	13	1	117.000	0.000e+000	0.000	0.000
1	105	14	1	156.000	0.000e+000	0.000	0.000
1	106	15	1	65.000	0.000e+000	0.000	0.000
1	107	16	1	66.000	0.000e+000	0.000	0.000
1	113	20	1	76.000	0.000e+000	0.000	0.000
1	114	21	1	74.000	0.000e+000	0.000	0.000
1	114	22	1	260.000	0.000e+000	0.000	0.000
1	115	23	1	237.000	0.000e+000	0.000	0.000
1	116	24	1	259.000	0.000e+000	0.000	0.000
1	117	24	1	82.000	0.000e+000	0.000	0.000
1	118	25	1	178.000	0.000e+000	0.000	0.000
1	119	26	1	242.000	0.000e+000	0.000	0.000
1	120	26	1	153.000	0.000e+000	0.000	0.000
1	121	26	1	225.000	0.000e+000	0.000	0.000
1	122	27	1	225.000	0.000e+000	0.000	0.000
1	123	28	1	225.000	0.000e+000	0.000	0.000
1	124	29	1	225.000	0.000e+000	0.000	0.000
1	125	29	1	225.000	0.000e+000	0.000	0.000
1	126	30	1	225.000	0.000e+000	0.000	0.000
1	127	31	1	225.000	0.000e+000	0.000	0.000
1	128	31	1	225.000	0.000e+000	0.000	0.000
1	129	32	1	225.000	0.000e+000	0.000	0.000
1	130	32	1	225.000	0.000e+000	0.000	0.000
1	131	32	1	225.000	0.000e+000	0.000	0.000
1	132	32	1	225.000	0.000e+000	0.000	0.000
1	133	33	1	150.000	0.000e+000	0.000	0.000
1	136	41	1	25.000	0.000e+000	0.000	0.000

1	137	42	1	25.000	0.000e+000	0.000	0.000
1	138	43	1	13.000	0.000e+000	0.000	0.000
1	139	44	1	42.000	0.000e+000	0.000	0.000
1	140	44	1	18.000	0.000e+000	0.000	0.000
1	141	45	1	42.000	0.000e+000	0.000	0.000
1	142	45	1	21.000	0.000e+000	0.000	0.000
1	143	45	1	37.500	0.000e+000	0.000	0.000
1	144	46	1	31.500	0.000e+000	0.000	0.000
1	145	47	1	42.000	0.000e+000	0.000	0.000
1	149	50	1	60.000	0.000e+000	0.000	0.000
1	160	59	1	60.000	0.000e+000	0.000	0.000
1	162	60	1	60.000	0.000e+000	0.000	0.000
1	163	60	1	60.000	0.000e+000	0.000	0.000
1	164	61	1	60.000	0.000e+000	0.000	0.000
1	165	61	1	50.000	0.000e+000	0.000	0.000
1	166	62	1	50.000	0.000e+000	0.000	0.000
1	167	62	1	50.000	0.000e+000	0.000	0.000
1	168	63	1	50.000	0.000e+000	0.000	0.000
1	169	63	1	50.000	0.000e+000	0.000	0.000
1	170	64	1	50.000	0.000e+000	0.000	0.000
1	171	64	1	50.000	0.000e+000	0.000	0.000
1	172	64	1	50.000	0.000e+000	0.000	0.000
1	173	65	1	50.000	0.000e+000	0.000	0.000
1	174	65	1	50.000	0.000e+000	0.000	0.000
1	177	66	1	46.000	0.000e+000	0.000	0.000
1	192	71	1	25.000	0.000e+000	0.000	0.000
1	193	71	1	25.000	0.000e+000	0.000	0.000
1	194	71	1	25.000	0.000e+000	0.000	0.000
1	195	71	1	25.000	0.000e+000	0.000	0.000
1	196	71	1	25.000	0.000e+000	0.000	0.000
1	197	71	1	25.000	0.000e+000	0.000	0.000
1	198	71	1	25.000	0.000e+000	0.000	0.000
1	199	72	1	25.000	0.000e+000	0.000	0.000
1	200	72	1	25.000	0.000e+000	0.000	0.000
1	201	73	1	25.000	0.000e+000	0.000	0.000
1	202	73	1	25.000	0.000e+000	0.000	0.000
1	203	73	1	25.000	0.000e+000	0.000	0.000
1	204	73	1	25.000	0.000e+000	0.000	0.000
1	205	73	1	25.000	0.000e+000	0.000	0.000
1	215	81	1	75.000	0.000e+000	0.000	0.000
1	216	82	1	100.000	0.000e+000	0.000	0.000
1	217	83	1	76.875	0.000e+000	0.000	0.000
1	217	84	1	101.063	0.000e+000	0.000	0.000
1	217	85	1	117.188	0.000e+000	0.000	0.000
1	217	86	1	100.000	0.000e+000	0.000	0.000
1	218	87	1	500.000	0.000e+000	0.000	0.000
1	108	17	1	60.000	0.000e+000	0.000	0.000
1	109	18	1	60.000	0.000e+000	0.000	0.000
1	110	18	1	60.000	0.000e+000	0.000	0.000
1	111	19	1	60.000	0.000e+000	0.000	0.000
1	112	20	1	60.000	0.000e+000	0.000	0.000
1	191	70	1	25.000	0.000e+000	0.000	0.000
1	190	70	1	25.000	0.000e+000	0.000	0.000
1	189	69	1	25.000	0.000e+000	0.000	0.000
1	188	69	1	25.000	0.000e+000	0.000	0.000
1	187	69	1	25.000	0.000e+000	0.000	0.000
1	186	69	1	25.000	0.000e+000	0.000	0.000
1	185	68	1	25.000	0.000e+000	0.000	0.000
1	184	68	1	25.000	0.000e+000	0.000	0.000
1	183	68	1	25.000	0.000e+000	0.000	0.000
1	176	66	1	50.000	0.000e+000	0.000	0.000
1	175	66	1	50.000	0.000e+000	0.000	0.000
1	182	67	1	50.000	0.000e+000	0.000	0.000
1	181	67	1	50.000	0.000e+000	0.000	0.000
1	180	67	1	50.000	0.000e+000	0.000	0.000

1	179	67	1	50.000	0.000e+000	0.000	0.000
1	178	67	1	50.000	0.000e+000	0.000	0.000
1	161	60	1	60.000	0.000e+000	0.000	0.000
1	158	59	1	60.000	0.000e+000	0.000	0.000
1	159	59	1	60.000	0.000e+000	0.000	0.000
1	157	58	1	60.000	0.000e+000	0.000	0.000
1	156	57	1	60.000	0.000e+000	0.000	0.000
1	155	56	1	60.000	0.000e+000	0.000	0.000
1	154	55	1	60.000	0.000e+000	0.000	0.000
1	153	55	1	60.000	0.000e+000	0.000	0.000
1	152	54	1	60.000	0.000e+000	0.000	0.000
1	151	53	1	60.000	0.000e+000	0.000	0.000
1	150	52	1	60.000	0.000e+000	0.000	0.000
1	149	51	1	60.000	0.000e+000	0.000	0.000
1	148	49	1	60.000	0.000e+000	0.000	0.000
1	147	48	1	60.000	0.000e+000	0.000	0.000
1	146	48	1	60.000	0.000e+000	0.000	0.000
1	134	37	1	50.000	0.000e+000	0.000	0.000
1	134	36	1	50.000	0.000e+000	0.000	0.000
1	134	35	1	50.000	0.000e+000	0.000	0.000
1	134	34	1	50.000	0.000e+000	0.000	0.000
1	135	40	1	50.000	0.000e+000	0.000	0.000
1	135	39	1	50.000	0.000e+000	0.000	0.000
1	135	38	1	50.000	0.000e+000	0.000	0.000
1	68	5	1	333.334	0.000e+000	0.000	0.000
1	69	5	1	333.334	0.000e+000	0.000	0.000
1	70	5	1	333.334	0.000e+000	0.000	0.000
1	71	5	1	333.334	0.000e+000	0.000	0.000
1	72	5	1	333.334	0.000e+000	0.000	0.000
1	73	5	1	333.334	0.000e+000	0.000	0.000
1	74	5	1	333.334	0.000e+000	0.000	0.000
1	75	5	1	333.334	0.000e+000	0.000	0.000
1	76	5	1	333.334	0.000e+000	0.000	0.000
1	77	5	1	333.334	0.000e+000	0.000	0.000
1	78	5	1	333.334	0.000e+000	0.000	0.000
1	79	5	1	333.334	0.000e+000	0.000	0.000
1	80	5	1	333.334	0.000e+000	0.000	0.000
1	81	5	1	333.334	0.000e+000	0.000	0.000
1	82	5	1	333.334	0.000e+000	0.000	0.000
1	83	6	1	333.334	0.000e+000	0.000	0.000
1	84	6	1	333.334	0.000e+000	0.000	0.000
1	85	6	1	333.334	0.000e+000	0.000	0.000
1	86	6	1	333.334	0.000e+000	0.000	0.000
1	87	6	1	333.334	0.000e+000	0.000	0.000
1	88	6	1	333.334	0.000e+000	0.000	0.000
1	89	6	1	333.334	0.000e+000	0.000	0.000
1	90	6	1	333.334	0.000e+000	0.000	0.000
1	91	6	1	333.334	0.000e+000	0.000	0.000
1	92	6	1	333.334	0.000e+000	0.000	0.000
1	93	6	1	333.334	0.000e+000	0.000	0.000
1	94	6	1	333.334	0.000e+000	0.000	0.000
1	206	74	1	25.000	0.000e+000	0.000	0.000
1	207	74	1	25.000	0.000e+000	0.000	0.000
1	208	74	1	25.000	0.000e+000	0.000	0.000
1	209	74	1	25.000	0.000e+000	0.000	0.000
1	214	81	1	50.000	0.000e+000	0.000	0.000
1	214	80	1	50.000	0.000e+000	0.000	0.000
1	213	79	1	50.000	0.000e+000	0.000	0.000
1	213	78	1	50.000	0.000e+000	0.000	0.000
1	212	77	1	50.000	0.000e+000	0.000	0.000
1	211	77	1	50.000	0.000e+000	0.000	0.000
1	210	76	1	50.000	0.000e+000	0.000	0.000
1	210	75	1	50.000	0.000e+000	0.000	0.000

==

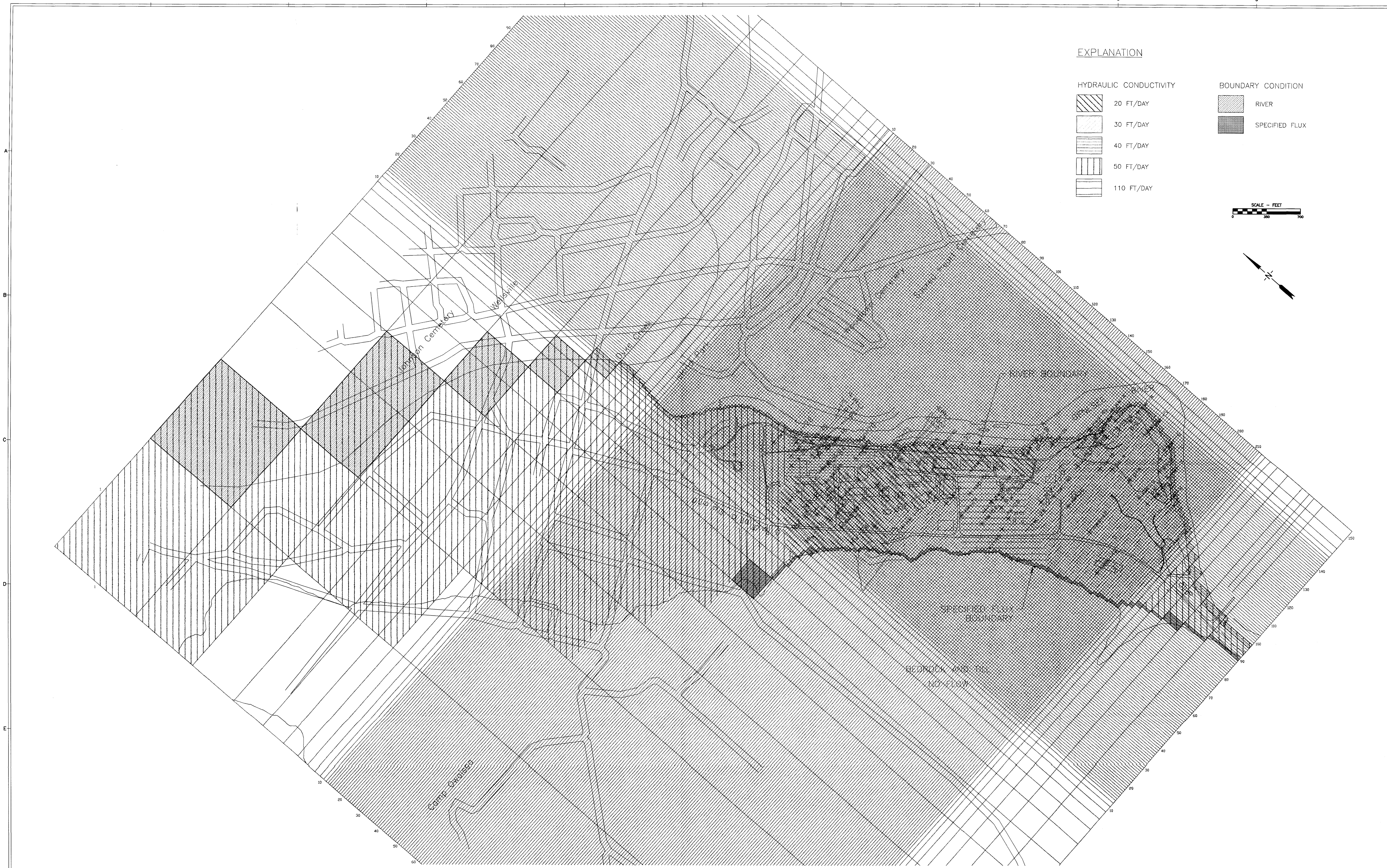
CALIBRATION TARGETS:

Head Targets..........: 58
Flux Targets..........: 0
Concentration Targets..: 0

HEAD TARGET DATA:

Well Name	Row	Column	Layer	Head	Standard	Deviation	Time
MWR-10	167	113	1	1492.690	1.000	0.000	0.000
MWR-9	187	114	1	1493.540	1.000	0.000	0.000
MWR-7	190	128	1	1494.370	1.000	0.000	0.000
MWR-6	182	136	1	1494.050	1.000	0.000	0.000
MRW-5	172	139	1	1493.080	1.000	0.000	0.000
MRW-4	163	140	1	1492.250	1.000	0.000	0.000
MRW-3	158	132	1	1491.340	1.000	0.000	0.000
MRW-2	156	122	1	1491.310	1.000	0.000	0.000
MRW-1	154	113	1	1491.520	1.000	0.000	0.000
MW-1	121	39	1	1495.590	1.000	0.000	0.000
MW-7	131	88	1	1487.320	1.000	0.000	0.000
MW-8	143	73	1	1492.790	1.000	0.000	0.000
MW-9	109	70	1	1485.910	1.000	0.000	0.000
MW-10	75	43	1	1483.750	1.000	0.000	0.000
MW-11	59	35	1	1481.420	1.000	0.000	0.000
MW-25	71	32	1	1484.180	1.000	0.000	0.000
MW-26	73	43	1	1483.610	1.000	0.000	0.000
MW-27	88	52	1	1483.920	1.000	0.000	0.000
MW-28	155	72	1	1494.650	1.000	0.000	0.000
MW-29	137	60	1	1493.340	1.000	0.000	0.000
MW-30	130	62	1	1492.140	1.000	0.000	0.000
MW-31	140	83	1	1491.030	1.000	0.000	0.000
MW-32	119	79	1	1486.850	1.000	0.000	0.000
MW-33	99	55	1	1487.240	1.000	0.000	0.000
MW-34	79	16	1	1493.290	1.000	0.000	0.000
MW-35	101	29	1	1490.930	1.000	0.000	0.000
MW-36	170	90	1	1494.070	1.000	0.000	0.000
MW-49	86	36	1	1486.460	1.000	0.000	0.000
MW-50	144	89	1	1490.790	1.000	0.000	0.000
MW-51	129	77	1	1489.770	1.000	0.000	0.000
MW-52	94	25	1	1492.850	1.000	0.000	0.000
MW-53	148	85	1	1491.840	1.000	0.000	0.000
MW-54	143	63	1	1493.430	1.000	0.000	0.000
MW-56	134	71	1	1491.660	1.000	0.000	0.000
MW-57	78	35	1	1484.850	1.000	0.000	0.000
MW-67	84	49	1	1483.700	1.000	0.000	0.000
MW-68B	76	40	1	1483.040	1.000	0.000	0.000
MW-69B	70	39	1	1483.390	1.000	0.000	0.000
MW-70	87	55	1	1481.970	1.000	0.000	0.000
MW-71	99	65	1	1483.370	1.000	0.000	0.000
MW-72	89	30	1	1490.650	1.000	0.000	0.000
MW-73	96	23	1	1493.870	1.000	0.000	0.000
MW-74	112	33	1	1496.280	1.000	0.000	0.000
MW-75	102	47	1	1489.080	1.000	0.000	0.000
MW-76	144	77	1	1492.400	1.000	0.000	0.000
MW-77	157	86	1	1493.060	1.000	0.000	0.000
MW-78	65	38	1	1481.700	1.000	0.000	0.000
MW-79	148	93	1	1491.220	1.000	0.000	0.000
MW-80	137	72	1	1491.780	1.000	0.000	0.000
MW-81	142	68	1	1492.270	1.000	0.000	0.000
MW-82	147	73	1	1492.970	1.000	0.000	0.000
MW-83	87	32	1	1489.650	1.000	0.000	0.000
MW-84	80	37	1	1485.080	1.000	0.000	0.000
MW-85	89	22	1	1492.000	1.000	0.000	0.000
MW-86	99	28	1	1490.820	1.000	0.000	0.000
MW-87	125	52	1	1493.240	1.000	0.000	0.000

MW-88	124	74	1	1490.000	1.000	0.000	0.000
MW-89	155	81	1	1493.480	1.000	0.000	0.000



REFERENCE DWG	DESCRIPTION	NO	DRWN	DATE	REVISION	CHKD	DATE	APPVD	DATE
		6							
		5							
		4							
		3							
		2							
		1							
		0	MMR	3/6/94					

ARCO

SINCLAIR REFINERY SITE
OPERABLE UNIT 2
3–1077

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CURRENT DATE: 3/22/94 CAD FILE 1077AS04

FINITE DIFFERENCE GRID
AND HYDRAULIC CONDUCTIVITY ZONATION

WELLSVILLE, NEW YORK

RETEC
REMEDIATION TECHNOLOGIES INC

DRAWING NO. FIGURE D–2 REV. 0

Appendix E

New York State Building Code Provisions

ARTICLE 7

Structural Requirements

PART 800

GENERAL REQUIREMENTS

(Statutory authority: Executive Law, §§ 375, 377)

Historical Note

Part (§§ 800.1-800.4) repealed by L. 1981, ch. 707, § 12, eff. Dec. 31, 1983; new (§§ 800.1-800.8) filed Dec. 13, 1983 eff. Jan. 1, 1984.

Section 800.1 Weights and loads. Buildings and parts thereof shall be capable of sustaining safely their own weight and the loads to which they may be subject, as set forth in this Part of this code.

Historical Note

Sec. amd. filed Oct. 4, 1972; repealed by L. 1981, ch. 707, § 12, eff. Dec. 31, 1983; new filed Dec. 13, 1983 eff. Jan. 1, 1984.

800.2 Transmitted loads. Buildings shall be constructed and integrated so that loads are transmitted to the soil without undue differential settlement, unsafe deformation or movement of the building or of any structural part.

Historical Note

Sec. repealed by L. 1981, ch. 707, § 12, eff. Dec. 31, 1983; new filed Dec. 13, 1983 eff. Jan. 1, 1984.

800.3 Protection against deterioration. Wherever structural material or assemblies are subject to deterioration and might become structurally unsound if unprotected, protection in conformity with generally accepted standards for the material involved shall be provided. Causes of such deterioration include, among others, action of freezing and thawing, dampness, corrosion, wetting and drying, and termites and other destructive insects.

Historical Note

Sec. amd. filed Oct. 4, 1972; repealed by L. 1981, ch. 707, § 12, eff. Dec. 31, 1983; new filed Dec. 13, 1983 eff. Jan. 1, 1984.

800.4 Protection against condensation. Crawl spaces and unheated concealed spaces below roofs shall be ventilated by openings so located and of such area as to minimize deterioration of the structural members from condensation or other causes, in conformity with generally accepted standards.

Historical Note

Sec. repealed by L. 1981, ch. 707, § 12, eff. Dec. 31, 1983; new filed Dec. 13, 1983 eff. Jan. 1, 1984.

800.5 Protection against water. Buildings shall be constructed so that ground and surface water will not penetrate into habitable spaces, basements and cellars. Surface adjoining buildings shall be arranged so as to divert surface water away from the building.

Historical Note

Sec. filed Dec. 13, 1983 eff. Jan. 1, 1984.

800.6 Protection against destructive insects. Where local conditions require protection against termites and other destructive insects, the construction, soil treatment, and protection of openings shall prevent their access to vulnerable parts of the structure, in conformity with generally accepted standards.

Historical Note

Sec. filed Dec. 13, 1983 eff. Jan. 1, 1984.

800.7 Stability. Materials, assemblies, connections, fastenings and structural members to which they are attached, shall be structurally stable, with allowances made for differences in the expansion and contraction coefficients of connected materials, in conformity with generally accepted standards for the material involved.

Historical Note

Sec. filed Dec. 13, 1983 eff. Jan. 1, 1984.

800.8 Materials requirements. All structural units of natural or manufactured materials shall comply with applicable specifications of authoritative agencies, or shall be subject to test in conformity with generally accepted standards in order to determine their characteristics.

Historical Note

Sec. filed Dec. 13, 1983 eff. Jan. 1, 1984.

PART 801

SOIL-BEARING VALUE

(Statutory authority: Executive Law, §§ 375, 377)

Historical Note

Part (§§ 801.1-801.8) repealed by L. 1981, ch. 707, § 12, eff. Dec. 31, 1983; new (§§ 801.1-801.4) filed Dec. 13, 1983 eff. Jan. 1, 1984.

Section 801.1 General requirements. The bearing value of the soil shall be determined in order that foundations may be proportioned so as to provide a minimum of absolute and differential settlement. Soil or pile tests, presumptive bearing values of the soil, reduction factors for pile groups, and pile-driving formulas, referred to in this code, shall be in conformity with generally accepted standards. When it can be conclusively proved that the presumptive soil-bearing value is adequate for the proposed load, the enforcement officer may accept such proof in lieu of the determination prescribed in section 801.2 (a)(2) and (b)(2) of this Part.

Historical Note

Sec. amd. filed Oct. 4, 1972; repealed by L. 1981, ch. 707, § 12, eff. Dec. 31, 1983; new filed Dec. 13, 1983 eff. Jan. 1, 1984.

801.2 Determination. (a) *One- and two-family dwellings.*

(1) For buildings 40 feet or less in height, the allowable bearing value of the soil upon which the building rests shall be the presumptive bearing value, or shall be determined by field-loading tests made in conformity with generally accepted standards.

(2) For buildings more than 40 feet in height, where the footing load on the soil exceeds 1,000 psf, there shall be a minimum of one test pit or boring for every 2,500 square feet or part thereof of grade-floor building area, carried sufficiently into acceptable bearing material to establish its character and thickness. At least one boring shall be carried to a minimum depth below grade equal to the height of building, or to that minimum depth which shows 25 continuous feet of fine sand, or better bearing material than fine sand, or five feet of bedrock, below the deepest proposed footing. A record of all borings made by core drill or spoon, showing the foot-by-foot character of the soil, the ground water level, and the number of blows required for each foot of penetration of the spoon, shall be kept and certified by the architect or engineer in charge. The subsurface exploration apparatus, including the size of spoon, weight and the drop, shall be in conformity with generally acceptable standards. Wash borings shall be deemed unacceptable. Boring samples taken at each significant change of soil strata, and at five-foot intervals thereafter, shall be retained and made available to the enforcement officer. When in his opinion additional subsurface information is required because of the variable geology of the site, additional test pits or borings shall be made.

(3) For buildings more than 40 feet in height, when the building load is transferred to the soil by spread footings, the allowable bearing values of the successive layers of soil, determined by test pits or borings, shall be the presumptive bearing values and, if required by the enforcement officer, shall be substantiated by field-loading soil tests made on undisturbed, natural soil at the level of the proposed foundation with fill, if any, removed.

(4) For buildings more than 40 feet in height, when the building load is transferred to the soil through the medium of friction or bearing piles, the capacity of a pile group shall be the number of piles multiplied by the capacity of one pile and by a reduction factor for friction piles. The capacity of a pile shall be determined by either of the following methods, or by an approved combination of them, with a limit determined by the strength of the pile as a structural member: a field-loading pile test, with a minimum of two test piles, or a generally accepted pile-driving formula.

(b) *Multiple dwellings and general building construction.* (1) For buildings in which the sum of the snow load and those live loads of all the floors which are transferred by columns or walls to the soil, divided by grade-floor area, is 200 psf or less, the allowable bearing value of the soil upon which the building rests shall be the presumptive bearing value, or shall be determined by field-loading tests made in conformity with generally accepted standards.

(2) For buildings in which the sum of the snow load and those live loads of all the floors which are transferred by columns or walls to the soil, divided by grade-floor area, exceeds 200 psf, there shall be a minimum of one test pit or boring for every 2,500 square feet or part thereof of grade-floor building area, carried sufficiently into acceptable bearing material to establish its character and thickness. At least one boring for every 10,000 square feet or part thereof of building area shall be carried to a minimum depth below grade equal to the height of building but need not be carried more than 100 feet below grade, or to the minimum depth which shows 25 continuous feet of fine sand, or better bearing material than fine sand, or five feet of bedrock,

below the deepest proposed footing. A record of all borings made by core drill or spoon, showing the foot-by-foot character of the soil, the ground water level and the number of blows required for each foot of penetration of the spoon, shall be kept and certified by the architect or engineer in charge. The subsurface exploration apparatus, including the size of spoon, weight and the drop, shall be in conformity with generally accepted standards. Wash borings shall be deemed unacceptable. Boring samples taken at each significant change of soil strata, and at 5-foot intervals thereafter, shall be retained and made available to the enforcement officer. When in his opinion additional subsurface information is required because of the variable geology of the site, additional test pits or borings shall be made.

(3) For buildings referred to in paragraph (2) of this subdivision, when the building load is transferred to the soil by spread footings, the allowable bearing values of the successive layers of soil determined by test pits or borings shall be the presumptive bearing values and, if required by the enforcement officer, shall be substantiated by field-loading soil tests made on undisturbed, natural soil at the level of the proposed foundation with fill, if any, removed.

(4) For buildings referred to in paragraph (2) of this subdivision, when the building load is transferred to the soil through the medium of friction or bearing piles, the capacity of a pile group shall be the number of piles multiplied by the capacity of one pile and by a reduction factor for friction piles. The capacity of a pile shall be determined by either of the following methods, or by an approved combination of them, with a limit determined by the strength of the pile as a structural member: a field-loading pile test, one such pile test for each 15,000 square feet or part thereof of grade-floor building area, with a minimum of two test piles, or a generally accepted pile-driving formula.

Historical Note

Sec. amd. filed Oct. 4, 1972; repealed by L. 1981, ch. 707, § 12, eff. Dec. 31, 1983; new filed Dec. 13, 1983 eff. Jan. 1, 1984.

801.3 Performance criteria for field-loading soil test. Under field-loading soil test, the total settlement caused by the proposed load on the soil, measured after a period during which no settlement has occurred for 24 hours, shall not exceed three-fourths inch. The additional settlement caused by a 50-percent increase in the proposed load, measured after a period during which no settlement has occurred for 24 hours, shall not exceed 60 percent of the total settlement as previously measured under the proposed load.

Historical Note

Sec. repealed by L. 1981, ch. 707, § 12, eff. Dec. 31, 1983; new filed Dec. 13, 1983 eff. Jan. 1, 1984.

801.4 Performance criteria for pile test. (a) The test load shall be twice the proposed pile load applied in increments of one quarter of the proposed pile load, with readings of settlements taken to the nearest 1/32 inch and plotted against load. The test load may be increased to more than twice the proposed pile load value until the gross settlement is approximately one inch. At each step, the load shall remain unchanged until there is no settlement in a two-hour period, and the test load shall remain in place until there is no settlement in 48 hours.

(b) The total test load shall then be removed in decrements not exceeding one quarter of the total test load at intervals of not less than one hour, with rebound read after each removal of load and plotted against load, and with the final rebound recorded 24 hours after removal of the last decrement. The allowable pile load shall be the lesser of one half of the load which caused:

(1) a gross settlement of one inch; or

(2) a net settlement (gross settlement minus total rebound) equal to 0.01 inch per ton times total test load in tons, with a limit determined by the strength of the pile as a structural member.

Historical Note

Sec. repealed by L. 1981, ch. 707, § 12, eff. Dec. 31, 1983; new filed Dec. 13, 1983 eff. Jan. 1, 1984.

801.5-801.6

Historical Note

Secs. repealed by L. 1981, ch. 707, § 12, eff. Dec. 31, 1983.

801.7

Historical Note

Sec. filed Jan. 25, 1962; amd. filed Oct. 4, 1972; repealed by L. 1981, ch. 707, § 12, eff. Dec. 31, 1983.

801.8

Historical Note

Sec. filed Oct. 4, 1972; repealed by L. 1981, ch. 707, § 12, eff. Dec. 31, 1983.

PART 802

ALLOWABLE STRESSES OF MATERIALS

(Statutory authority: Executive Law, §§ 375, 377)

Historical Note

Part (§§ 802.1-802.2) repealed by L. 1981, ch. 707, § 12, eff. Dec. 31, 1983; new (§§ 802.1-802.3) filed Dec. 13, 1983 eff. Jan. 1, 1984.

Section 802.1 General requirements. Safe working stresses shall be assigned to materials in accordance with their classification either as controlled materials or ordinary materials, and these stresses shall not be exceeded unless specifically permitted in section 803.10 of this code.

Historical Note

Sec. repealed by L. 1981, ch. 707, § 12, eff. Dec. 31, 1983; new filed Dec. 13, 1983 eff. Jan. 1, 1984.

802.2 Controlled materials. Where controlled materials are identified and certified for quality and strength by a recognized authoritative inspection service, grading organization or testing laboratory acceptable to make such tests, such materials shall conform to the specifications and stresses for controlled materials as set forth in generally accepted standards. When a material is formed and cast in the field, tests prior to the construction and during the construction shall be made, and the composition and strength of the material shall be certified by any of the above appropriate agencies or by the architect or engineer responsible for the design.

Historical Note

Sec. repealed by L. 1981, ch. 707, § 12, eff. Dec. 31, 1983; new filed Dec. 13, 1983 eff. Jan. 1, 1984.

802.3 Ordinary materials. Materials which do not conform to the requirements for controlled materials shall be considered ordinary materials, and their quality and safe working stresses shall conform to the specifications and stresses for ordinary materials in generally accepted standards. When quality and safe working stresses are not so specified, they shall be determined by test in conformity with Part 804 of this code. When a material is formed and cast in the field, tests during the construction shall be made and its composition and strength certified by any of the appropriate agencies designated under section 802.2 of this Part, or by the architect or engineer responsible for the design.

Historical Note

Sec. filed Dec. 13, 1983 eff. Jan. 1, 1984.

802.4 Unmarked structural lumber. Lumber which is not grade-marked nor certified by a recognized grading organization designated under section 802.2 of this Part shall be classified as an ordinary material. Such lumber is not required to meet the test requirements of Part 804 of this code and may be authorized for use by the authority having jurisdiction under the following conditions:

(a) The producing mill shall sell or provide the lumber directly to the ultimate consumer or his contract builder for use in an approved structure.

(b) The producing mill shall certify in writing to the consumer or builder on a form to be provided by the local authority having jurisdiction that the quality and safe working stresses of such lumber are equal to or exceed No. 2 grade in accordance with the conditions set forth in the American Softwood Standard PS20-70. This certification shall be filed with the local authority having jurisdiction as part of the building permit application.

(c) Such lumber shall be used in accordance with Part 705 of this code, limited to:

(1) one- and two-family and multiple dwellings not exceeding three stories in height;

(2) general building construction not exceeding 10,000 square feet of cumulative floor area or 35 feet in height.

(d) Such unmarked lumber shall be permitted to be used as provided in subdivisions (a)-(c) of this section except when it has been determined by the local authority having jurisdiction that only lumber which is graded according to the American Softwood Standard PS0-70 must be used in such municipality.

Historical Note

Sec. filed March 4, 1986 eff. March 25, 1986.

PART 803

DESIGN LOADS

(Statutory authority: Executive Law, §§ 375, 377)

Historical Note

Part (§§ 803.1-803.3) repealed by L. 1981, ch. 707, § 12, eff. Dec. 31, 1983; new (§§ 803.1-803.12) filed Dec. 13, 1983 eff. Jan. 1, 1984.

Section 803.1 General requirements. A building and all parts thereof shall be of sufficient strength to support the design loads and to resist the deformations caused by such loads to which they may be subjected, without exceeding the allowable stresses as described in Part 804 of this code. Such loads shall include the dead load and the following imposed loads where applicable: live, snow, wind, soil pressure including surcharge, hydrostatic head, and impact loads.

Historical Note

Sec. repealed by L. 1981, ch. 707, § 12, eff. Dec. 31, 1983; new filed Dec. 13, 1983 eff. Jan. 1, 1984.

803.2 Live loads. (a) *General.*

(1) Loads set forth in tables I-803, II-803 and III-803 do not include unusual concentrations, such as but not limited to heavy machinery, equipment, water tanks, elevator machine loads, swimming pools, storage units, and floor-to-ceiling bookracks. Where such loads occur, suitable provisions shall be made for their support.

(2) Where such unusual concentrations do not occur, structural members, and flooring spanning between the supporting structural members, shall be designed to support the uniformly distributed loads or the concentrated loads set forth in tables I-803, II-803 and III-803, whichever produce the greater stress.

TABLE I-803
UNIFORMLY DISTRIBUTED AND CONCENTRATED LIVE LOADS
FOR ONE- AND TWO-FAMILY DWELLINGS

Occupancy or use	Uniformly distributed loads, psf	Concentrated loads in pounds
First floor of each dwelling unit	40	
Other floors	30	
Stair treads	75[1]	
Attics:		
Accessible by stair or ladder in areas where the ceiling height is:		
4 feet 6 inches or more	30	
less than 4 feet 6 inches	20	150
Accessible by scuttle or means other than a stair, and of such height that household goods may be stored therein	20	150
Inaccessible (load for emergency access)	10	
Roofs used as promenades	30	
Other roofs	(2)	200
Garages for passenger cars	50	2,000[3]

[1] Stringers of stairs need be designed only for uniform load.
[2] For minimum imposed load, see section 803.10(c).
[3] Or actual wheel load increased 50 percent for impact, whichever is larger.

(3) Uniformly distributed live loads on beams or girders supporting other than storage areas and motor vehicle parking areas, when such structural member supports 150 square feet or more of roof area or floor area per floor, may be reduced as follows:

(i) When the dead load is not more than 25 psf, the reduction shall be not more than 20 percent.

(ii) When the dead load exceeds 25 psf and the live load does not exceed 100 psf, the reduction shall be not more than the least of the following three criteria:

(*a*) 60 percent;
(*b*) 0.08 percent for each square foot of area supported; or
(*c*) 100 percent times (dead load psf plus live load psf) divided by (4.33 times live load psf).

No reduction is permitted for snow loads.

(4) For columns, girders supporting columns, bearing walls and foundation walls, supporting 150 square feet or more of roof area or floor area per floor other than storage areas and motor vehicle parking areas, the uniformly distributed live loads on these members shall be not less than the following percentages of the total live loads on the following levels:

(i) 80 percent on the roof;

(ii) 80 percent on the floor immediately below the roof;

(iii) 80 percent on the second floor below the roof;

(iv) 75 percent on the third floor below the roof;

(v) 70 percent on the fourth floor below the roof;
(vi) 65 percent on the fifth floor below the roof;
(vii) 60 percent on the sixth floor below the roof;
(viii) 55 percent on the seventh floor below the roof; and
(ix) 50 percent on the 8th, 9th, 10th and subsequent floors below the roof.

No reduction is permitted for snow loads.

TABLE II-803

UNIFORMLY DISTRIBUTED AND CONCENTRATED LIVE LOADS FOR MULTIPLE DWELLINGS

Occupancy or use	Uniformly distributed loads, psf	Concentrated loads in pounds
Dwelling units and public corridors on same floor	40	
Private interior stairs	75[1]	
Business offices, excluding storage areas	50	
Light storage	120	
Public rooms, public corridors, public lobbies, public entrance halls, stores	100	
Public stairs and exterior stairs: treads, balcony platforms	100[1]	
Kitchens, other than domestic	100	
Attics:		
Accessible by stair or ladder in areas where the ceiling height is:		
4 feet 6 inches or more	30	
less than 4 feet 6 inches	20	150
Accessible by scuttle or means other than a stair, and of such height that household goods may be stored therein	20	150
Inaccessible (load for emergency access)	10	
Roofs used as promenades	40	
Other roofs	([2])	200
Skylight screens		100[5]
Garages, ramps and driveways, for passenger cars	50	2,000[6]
Garages, ramps and driveways, for buses, trucks and mixed usage	175	12,000[6]
Sidewalks over vaults	300	12,000[6]
Air conditioning space	200	2,000
Elevator machine rooms	([3])	300
Exitways	100	
Fan rooms	100	
Ladders, fixed:		
Rungs		250
Verticals		80[4]
Locker rooms	75	
Marquees	60	
Terraces, yards for pedestrians	60	
Toilet rooms, public	60	
Workshops	80	

[1] Stringers of stairs need be designed only for uniform load.
[2] See section 803.10(c) for minimum imposed loads for roofs.
[3] For loads see section 803.11.
[4] Side rails of ladders need be designed only for 80 pounds at center of every rung, applied simultaneously.
[5] Skylight screen to have ¾-inch to 1-inch mesh, upper screen to be 4 to 10 inches above glass and to overhang an identical amount. No uniform load need be figured.
[6] Or actual wheel load increased 50 percent for impact, whichever is larger. Where clear height of garage entrance exceeds 7 feet, load for buses, trucks and mixed usage shall be used.

(b) *Uniformly distributed and concentrated live loads.* (1) Uniformly distributed and concentrated live loads shall be the greatest loads produced by the intended occupancy and use, but in no case less than the minimum live load in conformity with tables I-803, II-803 and III-803.

(2) Minimum loads for occupancies and uses not included in the table shall be in conformity with generally accepted standards.

(3) Where a concentrated load is not given, load shall be at least 250 pounds on an area one-inch in diameter. Other concentrated loads shall be applied as follows: 100 pounds on upper and lower skylight screens, on an area 12 inches square; 150 pounds on an area one-inch in diameter; 200 pounds on an area one-inch in diameter; 250 pounds on ladder rung, at center of rung for moment, and at end of rung for shear; 300 pounds on elevator machine roof floor grating, on an area of two inches square; 2,000 pounds on an area 30 inches square; 12,000 pounds on an area 30 inches square.

TABLE III-803

UNIFORMLY DISTRIBUTED AND CONCENTRATED LIVE LOADS FOR GENERAL BUILDING CONSTRUCTION

Occupancy or use	Uniformly distributed loads, psf	Concentrated loads in pounds
C1 Business		
Business machine equipment	100	
Office space (not including storage areas)	50[1]	
Record storage	120	
C2 Mercantile		
Stores, shops for display and sale		
Retail		
On ground floor	100	
On upper floors	75	
Wholesale	120	
C3 Industrial		
Bakeries	150	
Laundries	100	
Manufacturing or processing	125	
Light manufacturing, assembly, etc.	75	
C4 Storage		
Cold storage		
No overhead system	400	12,000
Overhead system		
Floor	150	2,000
Roof	250	2,000
Light storage	120	
Heavy storage	250	
Paper	([2])	
C5 Assembly		
Assembly halls, auditoriums, balconies, clubrooms, dance halls, exhibition halls, grandstands, gymnasiums, lodge rooms, museums, restaurants, fallout shelters, stadiums, theaters		
Aisles, crossovers, lobbies, vomitories	100	

TABLE III-803 (*continued*)

Occupancy or use	Uniformly distributed loads, psf	Concentrated loads in pounds
Main floors, balconies		
Fixed seats	60[3]	
Movable seats	100	
Dressing rooms	40	
Projection rooms	100	
Stage floors	150	
C5 Assembly		
Colleges, schools (exclusive of dormitories)		
Classrooms	40	
Laboratories	60	
Lecture halls		
Fixed seats	60	
Movable seats	100	
Places of worship		
Fixed seats	60	
Movable seats	100	
C6 Institutional		
Hospitals		
Clinics	60	
Corridors, above first floor	40	
Examination rooms	60	
Laboratories, darkrooms	100	
Operating rooms	60	
Private rooms	40	
Public space	75	
Solariums	60	
Wards	40	
X-ray rooms, transfer rooms, control spaces	100	
Nurseries	40	
Orphanages, infirmaries	40	
Penal institutions, police lockups, reformatories		
Cell blocks	40	
Shops	80	
Spaces common to above occupancies		
Air conditioning space	200	2,000
Corridors		
First floor	100	2,000
Other floors	([4])	2,000
Elevator machine rooms	([5])	300
Exitways	100	
Fan rooms	100	
Garages and ramps, open deck parking structures:		
Cars, passenger	50[6]	2,000[10]
Buses, trucks, mixed usage	175	12,000[10]
Incinerator charging floor	100	
Kitchens (other than domestic)	100	

TABLE III-803 (*continued*)

Occupancy or use	Uniformly distributed loads, psf	Concentrated loads in pounds
Ladders		250[11]
Laboratories	100	
Libraries		
Reading rooms	60	
Stacks	(7)	
Lobbies	100	2,000[12]
Locker rooms	75	
Marquees	60	
Pr nenades	60	
Restrooms	60	
Roofs used as promenades	60	
Other roofs	(8)	200
Sidewalks over vaults	300	12,000[10]
Skylight screens		100[13]
Stairways	100[9]	
Terraces, yards, for pedestrians	60	
Toilet rooms	60	
Vaults, in office space	250	2,000
Workshops	80	

[1] Dead load is to be increased by 20 psf for possible shifting of masonry partitions.
[2] 50 psf per foot of clear story height.
[3] Grandstands, 100 psf, section 804.9(e) for horizontal impact loads.
[4] Unless noted elsewhere in this table, 100 psf; corridors within a tenancy not less than occupancy served.
[5] For loads, see section 803.11.
[6] Where clear height of garage entrance exceeds 7 feet, load for buses, trucks and mixed usage shall be used.
[7] 20 psf per foot of height, with a minimum of 150 psf.
[8] See section 803.10(c) for minimum imposed loads for roofs.
[9] Stringers of stairs need be designed only for uniform load.
[10] Or actual wheel load increased 50 percent for impact, whichever is larger.
[11] Side rails or ladders need be designed only for 80 pounds at center of every rung, applied simultaneously.
[12] For any building where a floor safe may be brought into building.
[13] Skylight screens to have ¾-inch to 1-inch mesh; upper screen to be 4 to 10 inches above glass and to overhang an identical amount. No uniform load need be figured.

Historical Note

Sec. repealed by L. 1981, ch. 707, § 12, eff. Dec. 31, 1983; new filed Dec. 13, 1983; amd. filed Oct. 25, 1985 eff. Nov. 15, 1985. Amended (b)(1) and Table III-803.

803.3 Snow loads. (a) Minimum snow loads shall be in conformity with table IV-803 and the snow map in this section, and shall be applied normal to the roof surface.

(b) Minimum snow loads in table IV-803 and the snow map in this section shall be:

(1) increased due to nonuniform accumulation on pitched or curved roofs;

(2) increased in the valleys formed by multiple series roofs;

(3) increased due to snow sliding off sloping roof areas onto adjacent roof areas;

(4) increased due to drifting snow on the lower levels of multilevel roofs and on roof areas adjacent to projections.

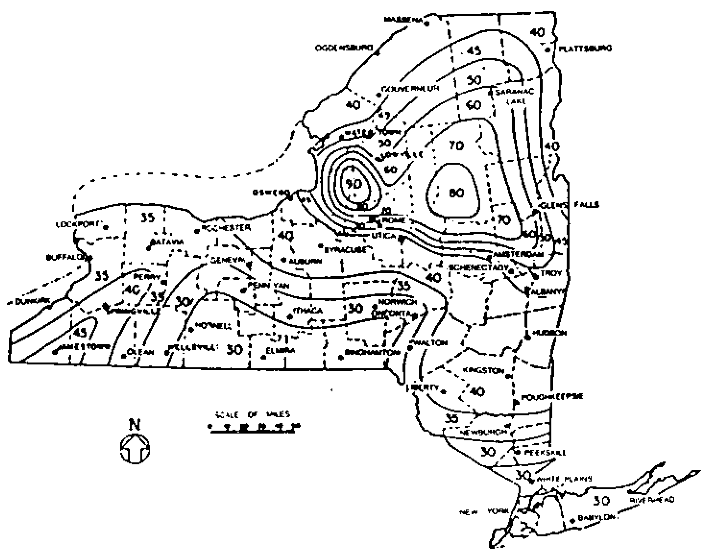
TABLE IV-803

SNOW LOADS[1]
In pounds per square foot

Zone numbers on snow map	Roof slope from horizontal[2] 0°	20°	30°	40°	50°	60° or more
30	30	27	17	9	3	0
35	35	31	20	10	4	0
40	40	35	23	12	4	0
45	45	40	25	13	5	0
50	50	44	28	15	5	0
60	60	53	34	18	6	0
70[3]						
80[3]						
90[3]						

[1] For minimum imposed loads see 803.10(c).
[2] For slopes between those tabulated, compute loads by straight-line interpolation.
[3] For snow zones 70, 80 and 90 or snow map, use same tabular values as for zone 60.

SNOW MAP OF NEW YORK STATE



Numbers Indicate Zones Within Lines

Historical Note

Sec. amds. filed: Jan. 25, 1962; Oct. 4, 1972; Feb. 5, 1979; April 5, 1983; repealed by L. 1981, ch. 707, § 12, eff. Dec. 31, 1983; new filed Dec. 13, 1983; amd. filed Oct. 25, 1985 eff. Nov. 15, 1985. Amended Table IV-803.

803.4 Wind loads. Minimum wind loads shall be in conformity with tables V-803 and VI-803, and shall be applied normal to the surface. These loads are based on a design wind velocity of 75 miles per hour at a height of 30 feet above grade level. Minimum wind loads on signs shall be in conformity with generally accepted standards.

TABLE V-803

WIND LOADS: WALLS, EAVES, CORNICES, TOWERS, MASTS AND CHIMNEYS
(In pounds per square foot)

At height above grade in feet	Walls[1, 4]	Eaves and cornices[2]	Towers, masts and chimneys[4]
501 to 600[3]	34	68	60
401 to 500	33	66	58
301 to 400	32	64	56
201 to 300	30	60	53
101 to 200	28	56	49
61 to 100	24	48	42
41 to 60	21	42	37
26 to 40	18	36	32
0 to 25	15	30	26

[1] Exterior walls shall be capable of withstanding wind load on both the interior and exterior surfaces, acting nonsimultaneously.

[2] Load acting upward.

[3] For heights above grade greater than 600 feet, add 1 psf to load for walls for each interval or part of interval of 200 feet above 600 feet; for eaves and cornices, and towers, masts and chimneys, corresponding loads are in proportion to those for walls.

[4] Tabular values are for square and rectangular structures. For structures hexagonal or octagonal in plan, use projected area and multiply tabular values by 0.8; for structures round or elliptical in plan, use projected area and multiply values by 0.6.

TABLE VI-803

WIND LOADS: ROOFS
In pounds per square foot

Mean elevation of roof above grade level in feet	Direction of load[1]	Slope from horizontal[2]			
		0° to 20°	20° to 30°	30° to 60°	Over 60°
501 to 600[3]	Downward	8	8	8 to 24	24
	Upward	29	29 to 24	24	24
401 to 500	Downward	8	8	8 to 23	23
	Upward	28	28 to 23	23	23
301 to 400	Downward	7	7	7 to 22	22
	Upward	27	27 to 22	22	22
201 to 300	Downward	7	7	7 to 21	21
	Upward	25	25 to 21	21	21

TABLE VI-803 (*continued*)

Mean elevation of roof above grade level in feet	Direction of load[1]	Slope from horizontal[2]			
		0° to 20°	20° to 30°	30° to 60°	Over 60°
101 to 200	Downward	6	6	6 to 20	20
	Upward	24	24 to 20	20	20
61 to 100	Downward	5	5	5 to 17	17
	Upward	20	20 to 17	17	17
36 to 60	Downward	5	5	5 to 15	15
	Upward	19	19 to 15	15	15
21 to 35	Downward	5	5	5 to 14	14
	Upward	17	17 to 14	14	14
0 to 20	Downward	5	5	5 to 11	11
	Upward	14	14 to 11	11	11

[1] Downward and upward loads act nonsimultaneously.

[2] For slopes between 20° and 30° with wind acting upward, and between 30° and 60° with wind acting downward, compute loads by straight-line interpolation.

[3] For heights above greater than 600 feet, add 1 psf to upward load for 0° to 20° slope for each interval or part of interval of 200 feet above 600 feet; for upward loads on other slopes, and downward loads on all slopes, corresponding loads are in proportion to those for upward load for 0° to 20° slope.

Historical Note

Sec. filed Dec. 13, 1983 eff. Jan. 1, 1984.

803.5 Overturning force and moment due to wind. (a) The overturning force shall be the wind load. The wind load shall be the load set forth in table V-803, and shall be applied only to the windward vertical surface above the horizontal plane under consideration, and to the rise of the roof. The resisting force shall be the dead load of the structure above the horizontal plane under consideration, plus the strength of material and fastenings establishing continuity with thc structure below.

(b) The moments of stability and overturning shall be computed about the leeward edge of the horizontal plane under consideration.

(c) The moment of stability of the structure above the horizontal plane under consideration shall be not less than 1½ times the overturning moment due to wind.

Historical Note

Sec. filed Dec. 13, 1983 eff. Jan. 1, 1984.

803.6 Sliding force due to wind. The sliding force due to wind load, equal to the overturning force, determined in conformity with section 803.5 of this Part, shall be resisted by the dead load of the structure above tne horizontal plan under consideration, by anchors and, where applicable, by soil friction, providing a total resisting force equal to not less than 1½ times the sliding force. Anchors used to resist overturning may also provide resistance to sliding.

Historical Note

Sec. filed Dec. 13, 1983 eff. Jan. 1, 1984.

803.7 Uplift force. Uplift force due to wind or hydrostatic head shall be resisted by dead load, acting directly or through anchors or fastenings, equal to not less than 1¼ times the uplift force.

Historical Note

Sec. filed Dec. 13, 1983 eff. Jan. 1, 1984.

803.8 Soil pressures and hydrostatic head loads. (a) *General.* Retaining walls and parts of the building below ground shall be designed to withstand the following loads, if applicable, and such loads shall be in addition to other imposed loads: lateral load, from adjacent soil; lateral load, from hydrostatic head; lateral load, from surcharge of fixed or moving loads; uplift from hydrostatic head.

(b) *Freestanding retaining walls.* (1) The moments of stability and overturning shall be computed about the bottom base edge on the low earth side. The moment of stability shall be not less than 1½ times the overturning moment.

(2) The resisting force due to soil friction shall be not less than 1½ times the sliding force.

Historical Note

Sec. filed Dec. 13, 1983 eff. Jan. 1, 1984.

803.9 Horizontal impact loads. (a) Nonbearing partitions enclosing dwelling units shall be designed to resist without displacement at top or bottom a minimum linear load of 10 pounds per foot, applied at mid-height.

(b) Parapet walls and railings, other than those for parking decks, including hand-railings, both interior and exterior, shall be designed to resist a lateral impact at the top equivalent to a minimum linear load of 50 pounds per foot.

(c) Where motor vehicles are parked by a driver, as differentiated from mechanical parking, enclosure walls, parapet walls, or barriers, at perimeter of area and around floor openings, shall be designed to resist a minimum linear load of 150 pounds per foot for level floors and 500 pounds per foot for ramps, applied 21 inches above the floor or ramp. Parapet or dwarf guard walls which are less than 42 inches high shall be surmounted by a railing to a minimum height of 42 inches above the roof or deck, and the horizontal impact loads shall be as required in subdivision (b) of this section. A continuous wheel bumper block at least eight inches high shall be fastened to the floor, four feet or more from the walls, and shall be designed to resist a minimum linear load of 300 pounds per foot.

(d) Where motor vehicles are parked mechanically, as differentiated from parking by a driver, barriers at the outer edge of deck shall be designed to resist a minimum linear load of 150 pounds per foot applied 21 inches above the deck. Wheel bumper blocks at least four inches high, designed to resist a minimum load of 300 pounds per tire, shall be fastened to decks in front of the front wheels and in the rear of the rear wheels, not more than 124 inches clear distance apart.

(e) Grandstands shall be designed to resist a horizontal load of 24 pounds per foot, applied to each row of seat platforms in a direction parallel to the length of row, and 10 pounds per foot in a direction perpendicular to the length of row.

(f) Craneways shall be designed to resist a horizontal load of 12.5 percent of the sum of the crane capacity and the weight of the trolley, applied against and perpendicular to the top of each runway rail, or 25 percent applied similarly to one runway rail, and also to resist a horizontal load equal to 12.5 percent of the maximum wheel loads applied against and parallel to the top of each runway rail.

Historical Note

Sec. filed Dec. 13, 1983 eff. Jan. 1, 1984.

803.10 Combined loads. (a) The stress due to wind may be ignored if it is less than one third of the stress due to dead load plus imposed load excluding wind load.

(b) If the stress due to wind exceeds one third of the stress due to dead load plus imposed load excluding wind load, the allowable stress of the material may be increased by one third.

(c) On roofs where the slope is such that the snow load plus the wind load total less than 20 psf, the minimum imposed load shall be 20 psf perpendicular to the roof surface.

(d) On roofs and eaves, snow or live load, and the wind load, shall be considered as acting simultaneously in such combination as imposes the greater stress.

Historical Note

Sec. filed Dec. 13. 1983 eff. Jan. 1, 1984.

803.11 **Elevator machine loads.** The loads on, and the safe working stresses and permissible deflections of, the supports of elevator machines and guiderail brackets shall be in conformity with generally accepted standards.

Historical Note

Sec. filed Dec. 13, 1983 eff. Jan. 1, 1984.

803.12 **Loads imposed during construction or demolition.** Loads imposed during construction or demolition on flooring, structural members, walls, bracing, scaffolding, sidewalk sheds or bridges, hoists and temporary supports of any kind, incidental to the erection, alteration or repair of any structure, shall not subject the structure, or elements thereof, to loads beyond the design capacity.

Historical Note

Sec. filed Dec. 13. 1983 eff. Jan. 1, 1984.

PART 804

ANALYSIS AND TEST OF STRUCTURAL ASSEMBLIES

(Statutory authority: Executive Law, §§ 375, 377)

Historical Note

Part (§§ 804.1-804.2) repealed by L. 1981, ch. 707, § 12, eff. Dec. 31, 1983; new (§ 804.1) filed Dec. 13, 1983 eff. Jan. 1, 1984.

Section 804.1 Determination. The capacity of an assembly to sustain dead and imposed loads without exceeding the allowable stresses shall be determined by any one of the procedures described in this section, or by an approved combination thereof:

(a) design analysis in conformity with generally accepted engineering practice to establish that stresses in component structural material will not exceed safe working stresses defined in generally accepted standards or, in the absence of such standards, exceed safe working stresses interpreted and established from test results with due consideration given to the reliability, durability and uniformity of the material and its behavior under stress. In no case shall the assigned safe working stress exceed two thirds of the yield strength nor one half of the ultimate strength of the material unless specifically permitted in section 803.10 of this code. When safe working stresses are assigned to a material, the structural characteristics and reasonable uniformity of the material, as utilized, shall be assured by conformity with generally accepted standards;

(b) tests made in conformity with generally accepted standards of assemblies truly representative of the construction to be used, in order to establish that such assemblies conform to the performance criteria set forth in Part 805 of this code;

(c) comparison with an approved assembly of known characteristics and behavior under load, which assembly is directly comparable, in all essential characteristics, to the assembly under consideration.

Historical Note

Sec. amd. filed Oct. 4, 1972; repealed by L. 1981, ch. 707, § 12, eff. Dec. 31, 1983; new filed Dec. 13, 1983 eff. Jan. 1, 1984.

804.2

Historical Note

Sec. repealed by L. 1981, ch. 707, § 12, eff. Dec. 31, 1983.

PART 805

PERFORMANCE CRITERIA UNDER TEST

(Statutory authority: Executive Law, §§ 375, 377)

Historical Note

Part (§ 805.1) filed May 7, 1980; repealed by L. 1981, ch. 707, § 12, eff. Dec. 31, 1983; new (§§ 805.1-805.7) filed Dec. 13, 1983 eff. Jan. 1, 1984.

805.1 General requirements. Buildings and their structural components subject to this code shall, when submitted to the tests set forth in this section, meet the performance criteria prescribed for each test. Failure to meet the test criteria shall be evidence of noncompliance with this code.

Historical Note

Sec. filed May 7, 1980; repealed by L. 1981, ch. 707, § 12, eff. Dec. 31, 1983; new filed Dec. 13, 1983 eff. Jan. 1, 1984.

805.2 Under imposed load. When the assembly reacts by bending under the uniformly distributed imposed load, excluding impact, the deflection shall not exceed 1/360 of the span when the inside is to be plastered. When the inside is not to be plastered, the deflection shall not exceed 1/240 of the span. When a roof is not to be used as a promenade, and the underside is not to be plastered, the deflection shall not exceed 1/180 of the span.

Historical Note

Sec. filed Dec. 13, 1983 eff. Jan. 1, 1984.

805.3 Under 1½ times imposed load. (a) Under its dead load and 1½ times the uniformly distributed imposed load, excluding impact, the assembly shall sustain the load without structural damage. In testing floor assemblies and assemblies in compression, the load shall be applied twice.

(b) For floor assemblies, the residual deflection from first application of the load shall not exceed 25 percent of the maximum deflection under load. After the second application of the load, the total residual deflection shall be not more than 1.1 times the residual deflection resulting from the first application of the load.

Historical Note

Sec. filed Dec. 13, 1983 eff. Jan. 1, 1984.

805.4 Under two times imposed load. Under its dead load and two times the uniformly distributed imposed load, excluding impact, the floor, roof and wall assembly shall sustain load without structural failure, for a minimum of 24 hours.

Historical Note

Sec. filed Dec. 13, 1983 eff. Jan. 1, 1984.

805.5 Impact loads. Under an impact load of 60 pounds falling four feet for floors, 1½ feet for walls, roofs and nonbearing partitions enclosing dwelling units or separate tenancies, on an area 10 inches in diameter, applied perpendicular to the assembly at its center, the assembly shall sustain no structural damage.

Historical Note

Sec. filed Dec. 13, 1983; amd. filed Oct. 25, 1985 eff. Nov. 15, 1985.

805.6 Racking loads. Where exterior walls and partitions react by racking, the racking deformation, while the assembly is sustaining the imposed load, shall not exceed 1/400 of the height of the wall. Under 1½ times the load there shall be no structural damage, and under two times the load there shall be no structural failure.

Historical Note

Sec. filed Dec. 13, 1983 eff. Jan. 1, 1984.

805.7 Transmitted loads. Fastenings and connections shall be capable of transmitting, without failure, twice the loads for which they are designed.

Historical Note

Sec. filed Dec. 13, 1983 eff. Jan. 1, 1984.

PART 806

EXTERIOR PROTECTION

(Statutory authority: Executive Law, §§ 375, 377)

Historical Note

Part (§§ 806.1-806.5) filed Dec. 13, 1983 eff. Jan. 1, 1984.

Section 806.1 General requirements. Whenever structural materials or assemblies are subject to deterioration and may become structurally unsound under the proposed condition of use, adequate protection shall be provided.

Historical Note

Sec. filed Dec. 13, 1983 eff. Jan. 1, 1984.

806.2 Exterior materials. The exterior facing or covering of walls and roofs shall be resistant to the causes of deterioration, as set forth in section 800.3 of this code, without loss of strength or attachment which may render it unfit for use. The materials of such exterior facing or covering shall be treated if necessary to give the required protection.

Historical Note

Sec. filed Dec. 13, 1983 eff. Jan. 1, 1984.

806.3 Flashing. Whenever water can penetrate the exterior or cause damage to the interior of the assembly or structure, flashing or other barrier shall be provided to prevent its entrance or to redirect it outward.

Historical Note

Sec. filed Dec. 13, 1983 eff. Jan. 1, 1984.

806.4 Waterproofing. (a) Foundation walls of cellars or basements, and floors in contact with the soil, shall be constructed or treated so as to prevent the penetration of ground and surface water.

(b) Metallic structural elements in exterior walls not inherently corrosion-resistant shall be protected against the effects of rain and moisture.

Historical Note

Sec. filed Dec. 13, 1983 eff. Jan. 1, 1984.

806.5 Grade protection. Materials and assemblies subject to deterioration when in continued contact with surface water or melting snow shall be so treated as to withstand such deterioration, or be placed so that they will not be in contact with such elements.

Historical Note

Sec. filed Dec. 13, 1983 eff. Jan. 1, 1984.

PART 807

WOOD FOUNDATION

(Statutory authority: Executive Law, §§ 375, 377)

Historical Note

Part (§§ 807.1-807.4) filed Dec. 13, 1983 eff. Jan. 1, 1984.

Section 807.1 General requirements. The foundation of a one-family dwelling of type 5 construction is permitted to be constructed of preservative-treated wood where the soil characteristics have been proven to be suitable for a wood foundation, subject to approval from the local authority having jurisdiction that the adequacy of the site and soil for a wood foundation has been determined. The material, design and construction of such foundation, including the pressure-treated wood, moisture and drainage control, and corrosion-resistant fasteners, shall conform to the generally accepted standards applicable to wood foundations.

Historical Note

Sec. filed Dec. 13, 1983 eff. Jan. 1, 1984.

807.2 Restrictions. A concrete basement or cellar slab, concrete steps or landing, exterior masonry veneer or masonry fireplace are permitted but shall not be supported by the wood foundation.

Historical Note

Sec. filed Dec. 13, 1983 eff. Jan. 1, 1984.

807.3 Grade marking. The preservative-treated wood shall be permanently and legibly marked to identify that it conforms to the generally accepted standard applicable to pressure-treated wood used for ground contact in residential foundations. Wood cut after treatment shall have preservative applied to the cut surfaces.

Historical Note

Sec. filed Dec. 13, 1983 eff. Jan. 1, 1984.

807.4 Fire safety requirements. An interior thermal barrier, vapor barrier and smoke detector shall be installed in the cellar or basement as set forth in section 717.6 of this code.

Historical Note

Sec. filed Dec. 13, 1983; amd. filed Oct. 25, 1985 eff. Nov. 15, 1985.

PART 810

Historical Note

Part (§§ 810.1-810.2) repealed by L. 1981, ch. 707, § 12, eff. Dec. 31, 1983.

Sections 810.1-810.2

Historical Note

Secs. repealed by L. 1981, ch. 707, § 12, eff. Dec. 31, 1983.

ARTICLE 8

General Provisions for Systems and Equipment

PART 850

GENERAL REQUIREMENTS

(Statutory authority: Executive Law, §§ 375, 377)

Historical Note

Part repealed, new (§§ 850.1-850.8) filed Oct. 4, 1972; repealed by L. 1981, ch. 707, § 12, eff. Dec. 31, 1983; new (§§ 850.1-850.12) filed Dec. 13, 1983 eff. Jan. 1, 1984.

Section 850.1 Design, installation and location. Plumbing, heating, electrical, ventilating, air conditioning, refrigerating, fire protection, radiation production equipment, elevators, dumbwaiters, escalators and other mechanical additions, installations or systems for the use of the building shall be designed, installed and located so that under normal conditions of use such equipment and systems will not be a potential danger to health or welfare, a danger because of structural defects, or a source of ignition or a radiation hazard, and will not create excessive noise or otherwise become a nuisance. Equipment and systems include, but are not limited to, apparatus, devices, fixtures, piping, pipe hangers, pipe covering, wiring, fittings and materials used as part of, or in connection with, such installations.

Historical Note

Sec. repealed, new filed Oct. 4, 1972; amd. filed Feb. 14, 1975; repealed by L. 1981, ch. 707, § 12, eff. Dec. 31, 1983; new filed Dec. 13, 1983 eff. Jan. 1, 1984.

850.2 Quality. Equipment and systems shall be made of approved materials, shall be free from defective workmanship, and shall be designed and installed so as to be durable, without need for frequent repairs or major replacements. Equipment requiring operation, inspection or maintenance shall be located so that easy access to it is provided.

Historical Note

Sec. repealed, new filed Oct. 4, 1972; amd. filed Feb. 14, 1975; repealed by L. 1981, ch. 707, § 12, eff. Dec. 31, 1983; new filed Dec. 13, 1983 eff. Jan. 1, 1984.

850.3 Acceptability. The design and installation of equipment and systems shall conform to the requirements of Part 610 of this code.

Historical Note

Sec. repealed, new filed Oct. 4, 1972; amd. filed Feb. 14, 1975; repealed by L. 1981, ch. 707, § 12, eff. Dec. 31, 1983; new filed Dec. 13, 1983; amd. filed Oct. 25, 1985 eff. Nov. 15, 1985.

850.4 New installation and alteration. New installation of equipment in existing buildings shall conform to the requirements of this code. Alterations and extensions to existing equipment and systems shall conform to the requirements of this code except as set forth in section 774.10 of this code.

Historical Note

Sec. repealed, new filed Oct. 4, 1972; amds. filed: Feb. 14, 1975; Feb. 25, 1976; April 5, 1983; repealed by L. 1981, ch. 707, § 12, eff. Dec. 31, 1983; new filed Dec. 13, 1983; amd. filed June 12, 1990 eff. June 27, 1990.

850.5 Testing and approval. Equipment and systems shall be subjected to such applicable tests as will disclose defects and leaks. No equipment or part of a system shall be covered or concealed until it has been tested and approved.

Historical Note

Sec. repealed, new filed Oct. 4, 1972; repealed by L. 1981, ch. 707, § 12, eff. Dec. 31, 1983; new filed Dec. 13, 1983 eff. Jan. 1, 1984.

850.6 Performance. Equipment and systems shall be capable of performing their functions satisfactorily, without being forced to operate beyond the safe design capacity.

Historical Note

Sec. repealed, new filed Oct. 4, 1972; repealed by L. 1981, ch. 707, § 12, eff. Dec. 31, 1983; new filed Dec. 13, 1983 eff. Jan. 1, 1984.

850.7 Protection against freezing. Equipment and systems subject to damage from freezing shall be adequately protected against freezing.

Historical Note

Sec. repealed, new filed Oct. 4, 1972; repealed by L. 1981, ch. 707, § 12, eff. Dec. 31, 1983; new filed Dec. 13, 1983 eff. Jan. 1, 1984.

850.8 Protection from damage. Equipment shall be protected from mechanical damage. Equipment within garages shall be protected from damage by motor vehicles.

Historical Note

Sec. filed Oct. 4, 1972; repealed by L. 1981, ch. 707, § 12, eff. Dec. 31, 1983; new filed Dec. 13, 1983 eff. Jan. 1, 1984.

850.9 Service facilities. Each building shall be provided with equipment to serve its own requirements, except that buildings designed to remain permanently under a single ownership may have common service facilities.

Historical Note

Sec. filed Feb. 14, 1975; repealed by L. 1981, ch. 707, § 12, eff. Dec. 31, 1983; new filed Dec. 13, 1983 eff. Jan. 1, 1984.

850.10 Equipment guards. Moving parts of equipment which may be a potential hazard shall be guarded to protect against accidental contact.

Historical Note

Sec. filed Dec. 13, 1983 eff. Jan. 1, 1984.

850.11 Piping, conduits and ducts. Pipng, conduits or ducts which may be a potential hazard shall not be permitted in exits, stairways or hoistways.

Historical Note

Sec. filed Dec. 13, 1983 eff. Jan. 1, 1984.

850.12 Structural safety. Floors, walls, ceilings, partitions, beams, studs, and any other parts of the building or premises which are cut, notched or altered in the installation of equipment and systems shall be left in a safe structural condition.

Historical Note

Sec. filed Dec. 13, 1983 eff. Jan. 1, 1984.

PART 855

Historical Note

Part (§§ 855.1-855.11) repealed by L. 1981, ch. 707, § 12, eff. Dec. 31, 1983.

Sections 855.1-855.11

Historical Note

Secs. repealed by L. 1981, ch. 707, § 12, eff. Dec. 31, 1983.