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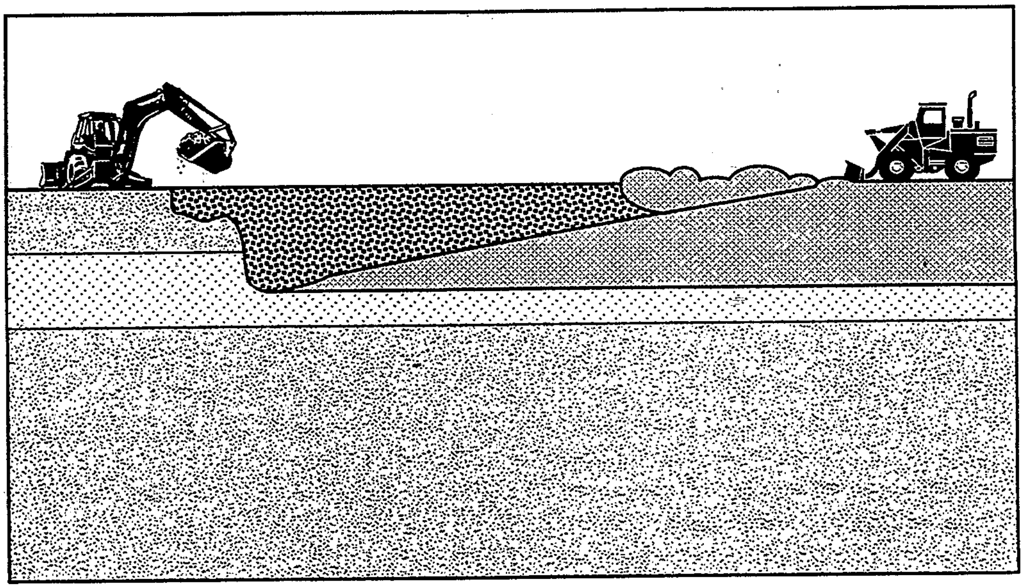
EPA Evaluation of Subsurface Engineered Barriers at Waste Sites

Volume II

Appendix B



Appendix B

Site Summaries

NOTICE

This document was prepared for the U.S. Environmental Protection Agency's (EPA) Office of Solid Waste and Emergency Response (OSWER) under Contracts No. 68-W5-0055 and No. 68-W4-0007. The work assignments preparing this document were led by the EPA Office of Research and Development's (ORD) National Center for Environmental Assessment (NCEA), in cooperation with the EPA Office of Emergency and Remedial Response (OERR).

Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not constitute or imply endorsement, recommendation, or favoring by EPA.

SITE 1

Barrier Type	SB
Remedial Objective	SC
Performance	2

1.0 SITE DESCRIPTION AND HISTORY

Site 1 is located in the northeastern United States. The site is bordered on the north by a waterway; to the east is a sparsely populated area of single-family homes. Agricultural and vacant land lies to the south and west. The site covers about 38 acres and is immediately bounded by industrial and commercial properties, city streets, and recreational facilities.

The site historically functioned as a municipal solid waste landfill that received residential, commercial, and institutional solid wastes. Initial investigations identified significant contamination from landfill leachate that was clearly visible in wetlands and the waterway adjacent to the site.

The 38-acre landfill site is contained by a subsurface barrier wall. The soil-bentonite wall is about 5,400 feet long; it ranges from about 10 to 20 feet in depth and averages about 15 feet in depth. The barrier was constructed in November 1989. A site plan showing basic site features is shown in Figure 1.

2.0 GEOLOGIC AND HYDROGEOLOGIC SETTING

The geologic setting of the site is characteristic of the Kittatinny Valley Sub-Province of the Appalachian Valley and Ridge Physiographic Province. The site lies atop glacial lake deposits. The glacial lake deposits have the following soil sequence; 1 to 2 feet of black, organic topsoil; 2 to 6 feet of peat; and a 70- to 90-foot strata of clay and silt. Underlying the clay and silt is Martinsburg Formation shale bedrock 80 to100 feet below grade. The subsurface barrier wall was keyed into the strata of clay and silt, which exhibit low hydraulic conductivity.

The hydrogeologic setting includes one unconfined, unconsolidated, water-bearing zone and a deeper bedrock aquifer. The unconfined aquifer is limited by the glacial lake clay deposits. Groundwater flow in the unconfined zone is in a northerly direction, while the direction of flow in the deeper zone is undetermined.

3.0 NATURE AND EXTENT OF CONTAMINATION

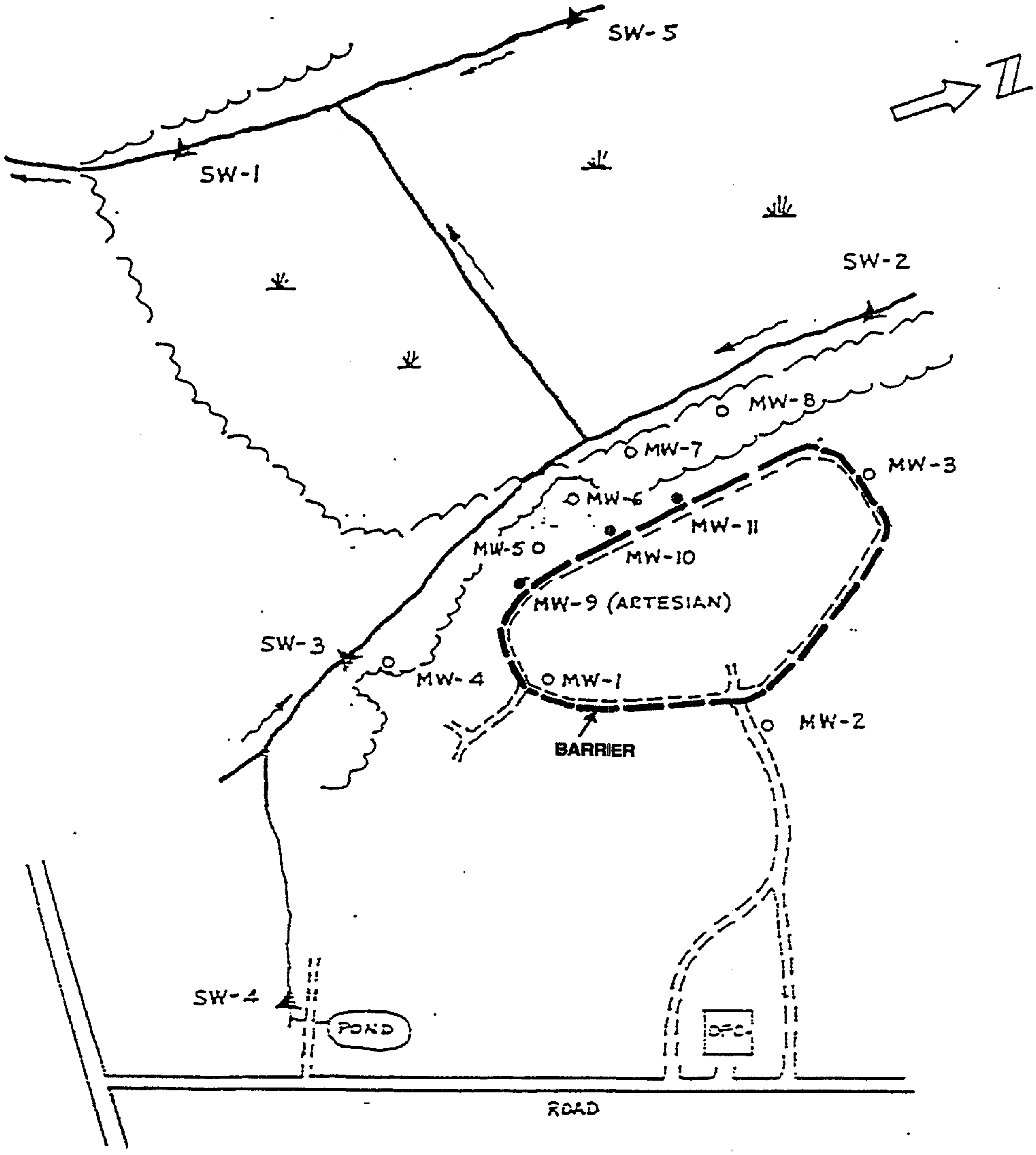
Wetlands located downgradient of the site were contaminated by leachate from the landfill. Both groundwater and surface water contamination was limited to an area downgradient of the site. Indicator chemicals included metals and volatile organic compounds (VOC) as listed below:

- 1,2-Dichloroethene at about 2 mg/L
- 1,1,2,2-Tetrachloroethane at about 6 mg/L
- 1,1,1-Trichloroethane at about 4 mg/L

4.0 CONTAINMENT REMEDY

The landfill improvement objectives were to provide (1) source control and (2) reduce the risk of contamination of groundwater and surface water around the site. The implemented remedy involved active containment and included the following general features:

Key: SB=Soil Bentonite SC=Source Control Performance Rating : 2=Evidence suggests objective may be met



Site 1

FIGURE 1
Site Plan

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- A soil-bentonite barrier that is about 5,400 linear feet long; 15 feet deep (on average); and 3 feet thick and that has a 2-foot soil key

- A leachate collection system pumping to onsite storage and trucked to an offsite treatment system

- Three groundwater quality monitoring points downgradient of the site and two surface water monitoring points, one upgradient and one downgradient of the site

- A cap consisting of a compacted clay liner (CCL) on the side slopes, and a geomembrane (GM) and a drainage layer on the landfill top surface. A protective soil cover exists over the CCL and GM.

- An active gas venting system.

5.0 PERFORMANCE EVALUATION

Performance monitoring of the containment remedy was established by a state permit to include quarterly groundwater and surface water quality monitoring for metals, biochemical oxygen demand (BOD), and chemical oxygen demand (COD) and annual monitoring for VOCs, metals, and base/neutral compounds.

The hydraulic head across the barrier was not measured. Groundwater quality improved outside the barrier since 1990, indicating the general effectiveness of the containment. Surface water quality adjacent to the site also improved, further indicating the general effectiveness of the remedy.

The leachate collection system presently removes the amount of leachate predicted during its design, indicating the effectiveness of both the barrier and the cap.

Containment system performance and contributing factors are described further in the following subsections.

5.1 Design

The barrier design was given a below average rating relative to industry practices as discussed in Section 3, Volume I. No design-level groundwater modeling was performed for the barrier.

The cap design was also given a below average rating. The design included a standard, state-prescribed cap for landfill closure as described in Section 4.0.

Leachate collected from the landfill drains to sumps located at the pumping stations. The pumping system includes conventional piping and pumping stations.

5.2 Construction Quality Assurance and Construction Quality Control

Barrier construction quality assurance (CQA) and construction quality control (CQC) were rated slightly below average. Generally, CQA/CQC procedures conformed to established standard protocols. The barrier key was visually confirmed along the alignment during construction. The barrier met the permeability requirement of less than 1×10^{-7} centimeters per second (cm/sec) based on test results for undisturbed samples collected from the completed barrier every 500 linear feet.

SWMU 19 and SWMU 20-SWMU 19 is a 0.5-acre lagoon that was breached and used for burning and disposal of lewisite. SWMU 20 consists of two 75 by 300 foot pits that were used as a disposal area for mustard agent and as a burning yard. Contamination consists of heavy metals (arsenic, cadmium, barium, mercury, lead, and zinc in a metallic crust), mustard agent, mustard sulfone, and mustard sulfoxide. Media contaminated at these SWMUs include soil and groundwater. The primary indicator contaminants in groundwater are arsenic and mercury which were detected at preremediation levels of 4.9 and 0.31 mg/L, respectively.

SWMU 21-SWMU 21 is a 0.5-acre area used for mustard agent demilitarization and burning. The contaminants in this SWMU are similar to those found in SWMUs 19 and 20.

SWMU 62-SWMU 62 is a 5-acre site that formerly contained a 1.5-acre lagoon used for testing smoke pots and grenades. Zinc oxide and hexachloroethane along with metals are the contaminants at this SWMU. Media contaminated at this SWMU include soil, groundwater, and surface water. The primary indicator contaminant in groundwater is hexachloroethane, which was detected at a preremediation level of 0.207 mg/L.

SWMU 63-SWMU 63 is a 4-acre site which was used as a dump for munition materials. Contaminants include metals and some volatile organic compounds. Media contaminated at this SWMU include soil and groundwater. The primary indicator contaminant in groundwater is lead, which was detected at a preremediation concentration of 0.4 mg/L.

SWMU 66-SWMU 66 is a 0.25-acre site that was used for disposal of munition wastes and for production of a paraffin binder. Metals and organic compounds contaminate the SWMU. No specific information was available regarding the environmental media contaminated at this SWMU.

SWMU 27-SWMU 27 is a 40-acre site that was used in the 1940s to manufacture chlorine. Contaminants at this SWMU include metals and chlorinated organic chemicals. Media contaminated includes soil and groundwater. The primary indicator contaminant in groundwater is lead, which was detected at a preremediation level of 0.37 mg/L.

4.0 CONTAINMENT REMEDY

The objective of the containment remedy for the eight SWMUs was to minimize groundwater contamination by diverting groundwater around or underneath contaminated materials, thus isolating the sources of contamination and preventing off-site migration of contaminants. The containment remedy for each SWMU consisted of the following elements:

- A circumferential slurry cutoff wall
- A high density polyethylene (HDPE) 60-mil cover overlain by 18 inches of compacted, random fill and 4 inches of topsoil, seeded
- Groundwater monitoring wells irregularly spaced outside each slurry cutoff wall

The containment systems are passive and involve no active groundwater pumping. The slurry cutoff walls at SWMUs 25, 27, 62, 63, and 66 were keyed at least 2 ft into the clay-shale unit. The slurry cutoff walls are at least 30 inches wide, except for SWMUs 19 and 20 where the wall is 36 inches wide. The five keyed slurry cutoff walls were constructed as follows:

SITE 2

Barrier Type	SB
Remedial Objective	Containment dewatering
Performance	1

1.0 SITE DESCRIPTION AND HISTORY

Site 2 is a municipal solid waste landfill operated under a state permit. The site occupies a total of 230 acres, but only 107 acres is designated for solid waste disposal. The active part of the site is subdivided into the West Tract, which consists of Phase I (11 acres) and Phase II (59 acres), and the East Tract, which contains Phase III (37 acres). Waste disposed of at the site is predominantly residential solid waste generated within city limits. The site was permitted in 1980. From 1980 until 1982, landfilling occurred in Phase I. Construction of Phase II was completed in 1981, and included a soil-bentonite cutoff wall. The purpose of the wall was to allow dewatering of the landfill, not to prevent migration of potential leachate. Disposal of waste in Phase II began in 1982 and continues today. No groundwater contamination at this site has been documented. Figure 1 shows the layout of the Phase II cutoff wall.

2.0 GEOLOGIC AND HYDROGEOLOGIC SETTING

The site is located on Quaternary alluvial deposits associated with a river located 500 to 2,000 feet south of the site. The river flows from west to east. The site is located within the current flood plain of the river, although embankment fill around the landfill prevents surface water encroachment onto the site. The alluvial deposits consist of clay, silt, sand, and gravel and generally coarsen with depth. The alluvial deposits are 17 to 27 feet thick at the site. The alluvium is fairly permeable, although previous sand and gravel mining has destroyed much of the original depositional structure.

Groundwater is present in a perched alluvial aquifer at shallow depths, typically within 5 to 10 feet of the ground surface. Field testing of the perched alluvial aquifer indicates that the groundwater flows to the north and northeast at a rate of 0.046 feet per day. Permeability coefficients for the alluvial aquifer at the site range from 1×10^{-3} to 1×10^{-7} cm/sec. The quaternary alluvial deposits are underlain by a bluish-gray, slightly calcareous clay shale. The shale formation contains occasional thin beds of bentonite and, to a lesser extent, limestone and claystone thin beds and stringers. The shale formation is about 140 feet thick in the site area. Site investigations have shown that permeability coefficients for the shale average 1×10^{-9} cm/sec. A sand aquifer is located under the shale, lying at a depth of about 140 feet below ground surface (bgs) in the site area. The aquifer is separated from the base of the landfill excavation by about 100 feet of shale.

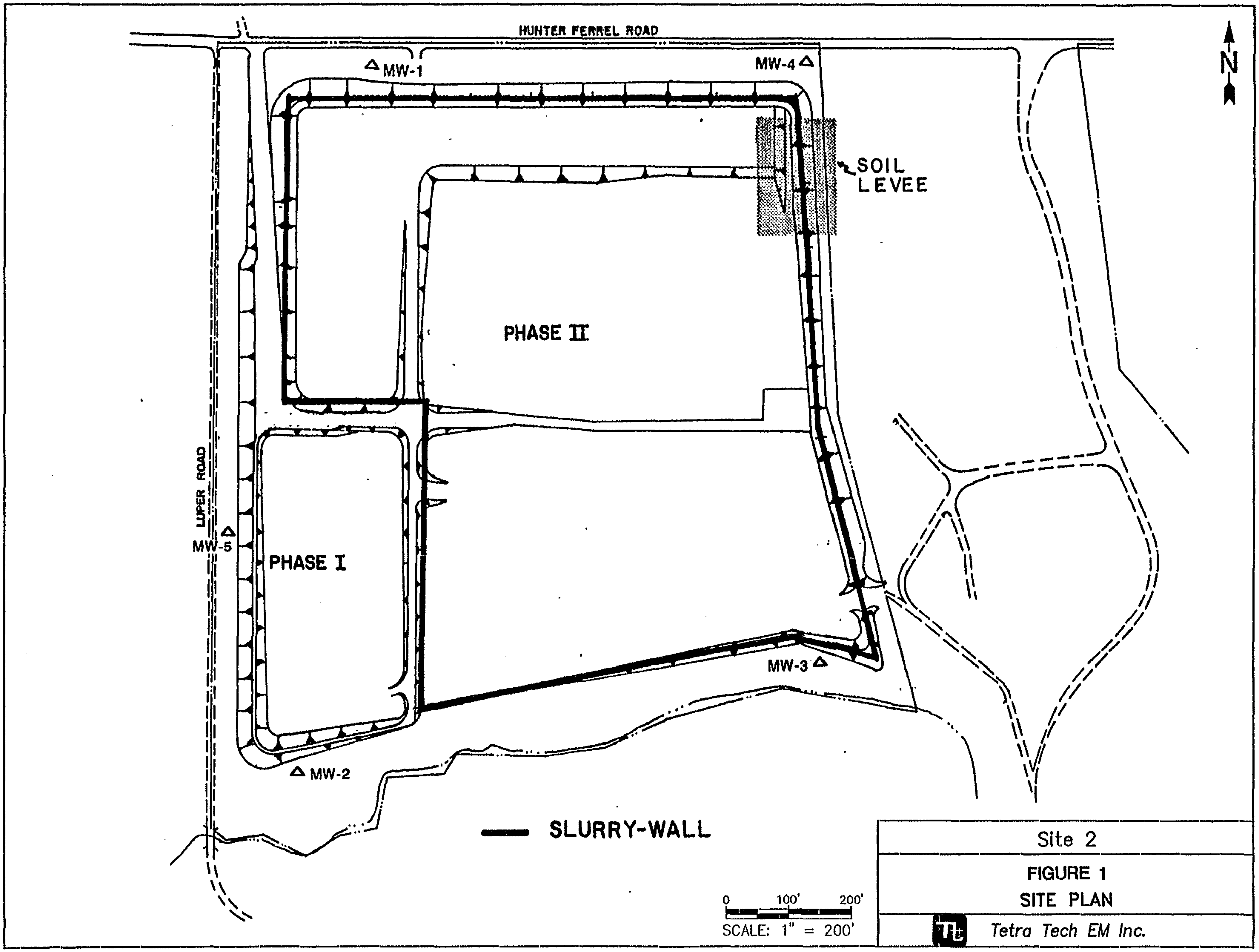
3.0 NATURE AND EXTENT OF CONTAMINATION

No contamination at this site has been documented.

4.0 CONTAINMENT REMEDY

Under the original permit, the top of the shale formation was to be the base of the landfill. Subsequent investigations and permit modifications have allowed the landfill floor to be excavated about 50 feet into the shale. Before landfilling activities could begin, the site had to be dewatered and the alluvial overburden removed. From August to November 1981, a soil-bentonite slurry wall was built around

Key: SB=Soil Bentonite Wall Performance Rating: 1=Remedial objective was met



Site 2

FIGURE 1
SITE PLAN

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Phase II to dewater the landfill excavation. The intention was to create a cutoff barrier in order to prevent the alluvial groundwater from flowing into the landfill excavation. The soil-bentonite slurry wall surrounds Phase II and extends about 7,100 linear feet. The barrier is 3 feet wide and ranges from about 22 to 30 feet bgs in depth. After the barrier was built, the landfill excavation was dewatered using three 6-inch-diameter pumps. The pumps were placed in the bottom of excavation trenches where water accumulated. The pumps were moved around the site as needed. Dewatering took about 1 year.

Compacted soil liners have been installed along the sides of the landfill above the shale. When completed, the landfill will have an engineered clay cap.

A second soil-bentonite slurry wall was recently completed around the future Phase III site, and this area is currently being dewatered.

5.0 PERFORMANCE EVALUATION

As noted in Section 1.0, the slurry wall was designed to allow the landfill excavation to be dewatered, not to prevent migration of potential leachate. The barrier has achieved its design objective, as construction of the slurry wall around Phase II has allowed the excavation to be successfully dewatered for landfill construction purposes. The slurry wall and shale maintain a head differential of about 60 to 80 feet from the alluvial water table to the landfill base. Specific barrier performance attributes are evaluated in the following subsections.

5.1 Design

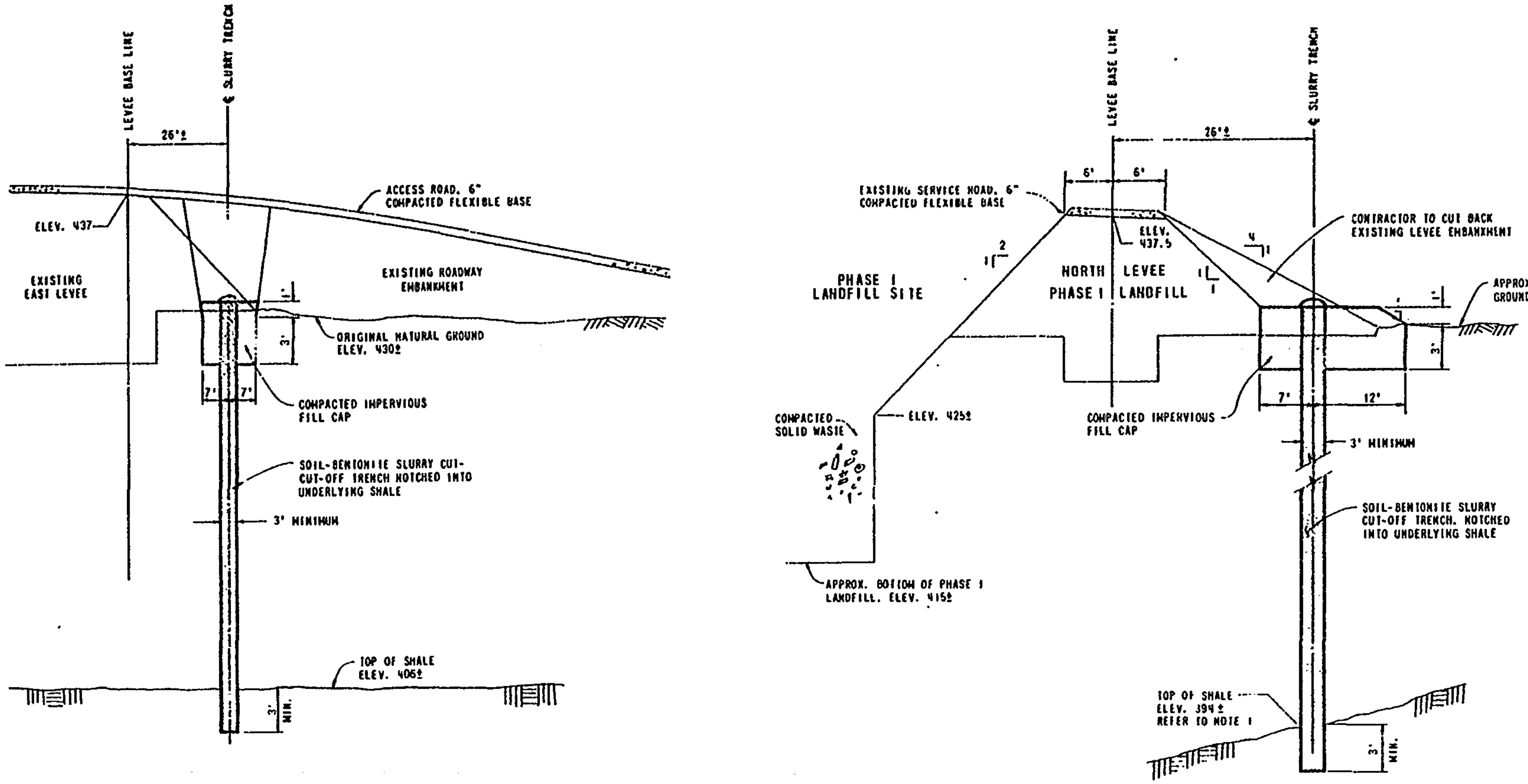
Evaluation of the barrier design generated a rating slightly above average, based on the criteria outlined in Section 3 of Volume I. The design included a target permeability of 1×10^{-7} cm/sec. Significant positive attributes of the design effort included a thorough geotechnical and hydrological investigation and a 3-foot key into a competent, impermeable shale stratum.

The overall design investigation was thorough. Although the number of soil borings along the barrier alignment (about one boring every 300 linear feet) was less than the average evaluation of one boring every 100 to 200 linear feet, the number of borings along, inside, and outside the alignment was deemed sufficient. Figure 1 shows the distribution of design investigation borings. In addition, the alluvial deposits and shale were thoroughly tested for physical parameters.

The design also included an impervious fill cap overlying the cutoff wall. The fill cap consisted of a compacted, impervious fill layer that was placed along the center line of the cutoff wall. This layer, shown in Figure 2, was 14 feet wide and 3 feet deep. The excavation for the cutoff wall was dug through this cap layer.

5.2 Construction Quality Assurance and Construction Quality Control

Evaluation of the construction quality assurance (CQA) and construction quality control (CQC) procedures resulted in an average rating. The field and laboratory inspection and testing procedures included trench bottom soundings every 10 feet and sampling and analysis for sand content, viscosity, density, filtrate loss, and permeability. The testing protocols generally met the evaluation standard;



SHALE APPEARS TO FORM A POCKET IN AREA OF TRENCH STATION 66+80 TO 71+27. ELEVATION OF TOP OF SHALE VARIES FROM 408 TO 390.

Site 2

FIGURE 2
SLURRY WALL CROSS SECTIONS

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however, the testing frequency was generally less than the evaluation standard established in Section 3, Volume I.

Laboratory tests of the trench backfill indicated permeability coefficients ranging from 2.2×10^{-7} to 1.2×10^{-9} cm/sec, with an average of 6.3×10^{-8} cm/sec; therefore, the design target permeability was achieved.

5.3 Monitoring

Evaluation of the monitoring program resulted in an above average rating based on the criteria outlined in Section 3 of Volume I. Groundwater elevations in the alluvium adjacent to the landfill range from 405 to 425 feet. At the bottom of the landfill where the clay shale is exposed (the approximate elevation is 350 feet), the excavation is dry, indicating that the barrier has achieved its objective of maintaining a dewatered excavation.

Protection of groundwater quality was not a design objective of the Site 2 cutoff wall. However, groundwater monitoring at the site is conducted on a semiannual basis in accordance with the site's municipal solid waste permit, and available groundwater monitoring data can be used as an indicator of barrier performance. Groundwater samples for the West Tract are collected from one upgradient and four downgradient monitoring wells and are analyzed for general water quality parameters. The data are then evaluated based on a statistical procedure. Groundwater data from April 1981 through April 1993 was reviewed. As might be expected for groundwater from 55 to 75 feet higher than the elevation of the excavation, the excavation has had no discernable effect on groundwater quality.

An electrical resistivity survey has been performed annually since 1982 to evaluate potential leachate migration from the landfill. The survey includes a profile of Wenner array soundings with A-spacings of 15 and 33 feet. The resistivity measurements are made at established stations located outside the perimeter of the cutoff wall. The resistivity surveys conducted from 1982 through 1995 have not revealed any leachate migration.

5.4 Operation and Maintenance

No specific operation and maintenance (O&M) protocols exist for the cutoff wall. The top of the wall is below the perimeter embankment berm and is not visible for inspection. Currently, while the shale floor is exposed, groundwater leakage from the sidewalls or floor would be a visible indicator of cutoff wall performance. When landfilling at Phase II is completed, and a leachate collection system is operational, excessive leachate production will indicate problems with barrier performance.

5.5 Other Considerations

The 7,100-foot-long cutoff wall cost an estimated $399,000 in 1981. Additionally, an estimated $45,000 in costs were incurred for (1) an engineering firm to provide construction inspection and quality control testing and (2) the services of the design engineering firm during construction.

5.6 Remedy Performance

The cutoff wall at Site 2 has met its design objective. Barrier performance has been adequate to allow dewatering of the landfill excavation.

6.0 SUMMARY

The cutoff wall, a soil-bentonite slurry wall, has been in place at Site 2, a municipal solid waste landfill, for 15 years. Construction of the slurry wall around Phase II has allowed the excavation to be successfully dewatered for landfill construction purposes. The slurry wall is about 7,100 feet long and 3 feet wide; 22 to 30 feet in depth; and is keyed into a competent shale formation. The cutoff wall and the shale formation maintain a head differential of about 60 to 80 feet from the alluvial water table to the landfill base. Design, CQA/CQC, and performance monitoring data for the site is well documented. Evaluation of the design and CQA/CQC procedures generated slightly above average and average ratings respectively. Evaluation of the monitoring program generated an above average rating. The barrier system includes monitoring components (visual observation, monitoring wells, annual resistivity surveys, and a leachate collection system) capable of monitoring long-term barrier performance.

SITE 3

Barrier Type	SB
Remedial Objective	SC; Groundwater flow modification
Performance	X

1.0 SITE DESCRIPTION AND HISTORY

Site 3 is located in the central southern United States in a semirural area. The site occupies about 15,000 acres and is bordered on the east by a river and on the west by a bayou. Highways border the site on the south and north. The site contains more than 20 solid waste management units (SWMU) of various sizes. Of the more than 20 SWMUs at the site, this evaluation was limited to eight SWMUs that have perimeter subsurface barrier slurry walls. Of those eight, two lie within one perimeter subsurface barrier.

The site historically functioned as an Army testing and disposal facility. Wastes at the site contained heavy metals and organic compounds. These wastes were either placed in land disposal units or directly discharged to the ground surface. Investigation of contaminated site areas began in the 1960s. Site closures were designed to comply with a consent agreement and a hazardous waste management permit issued by the U.S. Environmental Protection Agency (EPA) and the state.

2.0 GEOLOGIC AND HYDROGEOLOGIC SETTING

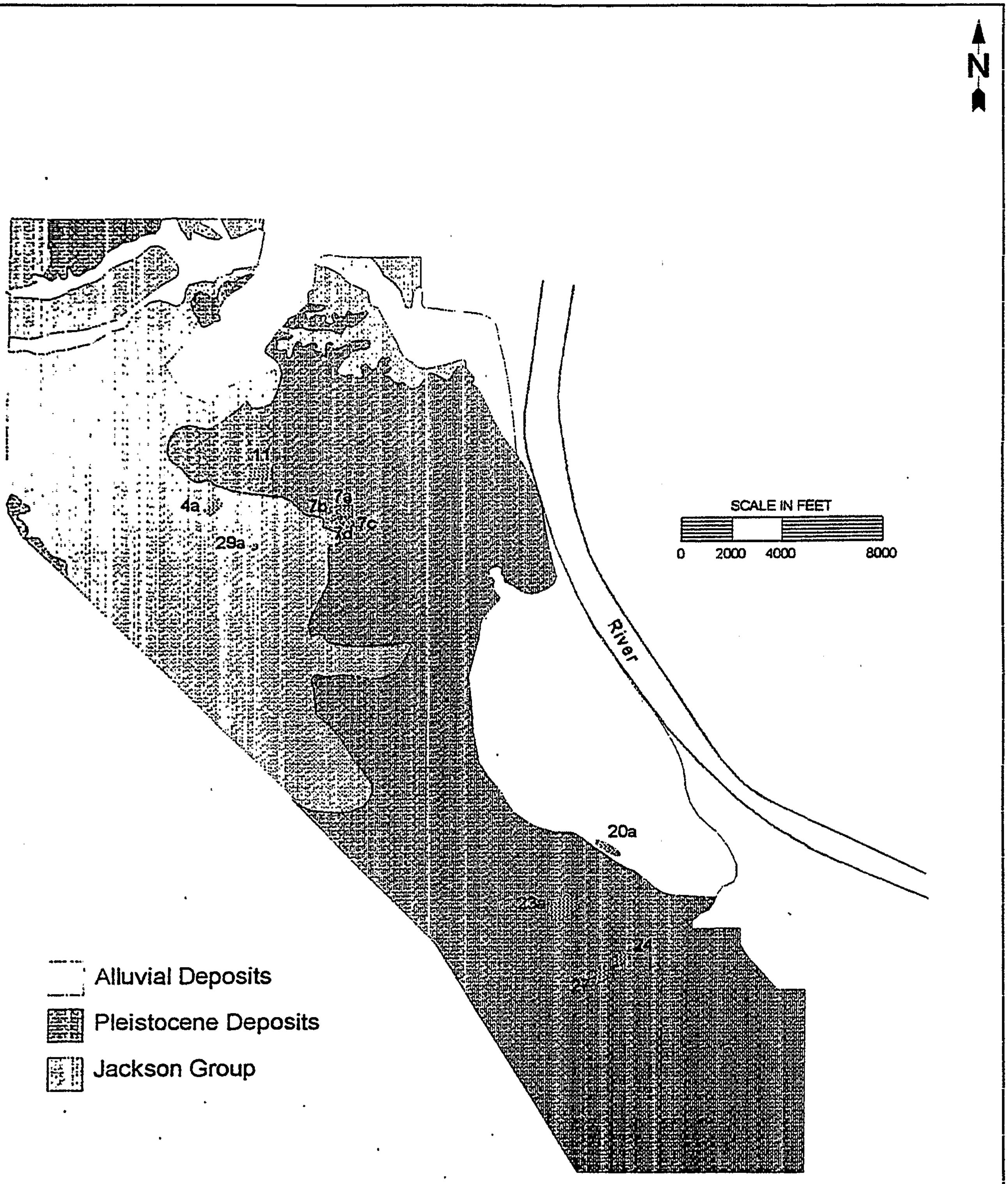
The site geology is characteristic of the West Gulf Coastal Plain Physiographic Province in the southern United States. The site lies within the Mississippi Embayment Structure, a southerly plunging syncline filled with sedimentary rocks and sediments ranging in age from Jurassic to Quaternary and reaching a maximum thickness of about 18,000 feet (ft) in the southern part of the gulf coastal region. Soils present on the site surface are Eocene Period sediments composed of marine and nonmarine sands, silts, and clays. These sediments dip gently east toward the Arkansas River and are about 2,600 ft thick. Figure 1 shows the generalized surface geology of Site 3.

Three major geologic units are present at the site. Surface soils on the central, eastern edge of the site consist of recent alluvial deposits from the river flood plain. These deposits consist of silts and clays underlain by higher-plasticity, lower-permeability clays and some silts. Low-permeability layers within these deposits act as confining units that separate perched water from underlying soils.

Pleistocene-age Terrace deposits are generally located in the central portion of the site. These deposits are fluvial sediments that consist of silty sands and silts. The deposits are a few ft thick along the western edge of the site and are nearly 60 ft thick at the eastern edge of the site near the Arkansas River alluvial deposits. The river alluvial deposits and the Pleistocene Terrace deposits make up the alluvial aquifer. This aquifer is composed of soils ranging from coarse gravel to clays. Groundwater in this alluvial aquifer tends to be of poor quality (that is, it is high in chlorides, sulfate, and iron); therefore, it is used only for irrigation purposes.

Underneath the alluvial aquifer deposits and outcropping in the western portion of the site are marine and nonmarine clays deposited during the late Eocene Period. These clays are characterized as over consolidated, laminated clay with silty sand lenses. Laboratory testing of this clay revealed an acceptable permeability of 1.7×10^{-7} centimeters per second (cm/sec). Silt and sand lenses within this group have an acceptable permeability of 1×10^{-5} cm/sec. These clays act as a regional confining unit preventing perched water in the alluvial aquifer from migrating downward.

Key: SB=Soil Bentonite Wall SC=Source Control Performance Rating: X=Insufficient data to determine if remedial objectives were met



Site 3

FIGURE 1
GEOLOGY OF SITE 3

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Underlying the marine and nonmarine clays is a clay-shale confining unit. Under the confining unit is an unconsolidated water bearing unit. This unit is located in a sand formation and is the primary source of drinking water in the vicinity of the site. Wells within the sands unit are screened 800 to 1,000 ft below ground surface (bgs).

Groundwater flow across the site is typically toward the southeast; some flow reversal occurs in times of high river levels. Rates of groundwater flow across the site tend to be very low because of a low hydraulic gradient and low-permeability soils.

As stated in Section 1.0, the subsurface barriers associated with eight SWMUs were evaluated. Of the eight SWMUs, two are located within the boundaries of one subsurface barrier wall containment system. Because the eight SWMUs are not grouped together in one area of the site but are located in various areas across the site, their geologies and hydrogeologies differ. Following are summaries of the SWMU-specific geologic and hydrogeologic settings.

SWMU 25-This SWMU is underlain by a clay-shale unit. The approximate depth to groundwater is 19 ft bgs.

SWMU 19 and SWMU 20-These SWMUs are underlain by alluvial Terrace deposits varying in thickness from 1 to 10 ft. The approximate depth to groundwater is 15 ft bgs.

SWMU 21-This SWMU is underlain by alluvial Terrace deposits varying in thickness from 1 to 10 ft. These deposits thicken east of the site. The approximate depth to groundwater is 21 ft bgs.

SWMU 62-This SWMU is located on Terrace deposits that range in depth from 18 to 24 ft in thickness. The approximate depth to groundwater is 24 ft bgs.

SWMU 63-This SWMU is located on Terrace deposits consisting of sand and silt with some sandy clay. The approximate depth to groundwater is 30 ft bgs.

SWMU 66-This SWMU is underlain by Terrace deposits. The perched and permanent groundwater tables are at approximately 18 and 35 ft depths, respectively.

SWMU 27-This SWMU lies within an outcrop area of the marine and nonmarine clays. A continuous clay bed underlies the SWMU at a thickness from 2 to 20 ft. The approximate depth to groundwater is 20 ft.

3.0 NATURE AND EXTENT OF CONTAMINATION

Contamination at this site varies from SWMU to SWMU, depending on the waste management practices used at each SWMU. In general, only the shallow alluvial aquifer is contaminated. There is no evidence that the deep sand aquifer is contaminated. Groundwater contamination also appears to be confined within the boundaries of Site 3. The nature and extent of contamination at each of the SWMUs are summarized below.

SWMU 25-SWMU 25 is a former burning pit for production wastes. This area was also used for burial of barrels, railroad ties, and other debris. Contaminants at this SWMU include heavy metals (arsenic, barium, cadmium, lead, and zinc). Media contaminated at this SWMU include soil and groundwater. The primary indicator contaminants at this SWMU are cadmium and lead, which were detected in groundwater at preremediation levels of 0.01 and 0.06 mg/L, respectively.

SWMU 19 and SWMU 20-SWMU 19 is a 0.5-acre lagoon that was breached and used for burning and disposal of lewisite. SWMU 20 consists of two 75 by 300 foot pits that were used as a disposal area for mustard agent and as a burning yard. Contamination consists of heavy metals (arsenic, cadmium, barium, mercury, lead, and zinc in a metallic crust), mustard agent, mustard sulfone, and mustard sulfoxide. Media contaminated at these SWMUs include soil and groundwater. The primary indicator contaminants in groundwater are arsenic and mercury which were detected at preremediation levels of 4.9 and 0.31 mg/L, respectively.

SWMU 21-SWMU 21 is a 0.5-acre area used for mustard agent demilitarization and burning. The contaminants in this SWMU are similar to those found in SWMUs 19 and 20.

SWMU 62-SWMU 62 is a 5-acre site that formerly contained a 1.5-acre lagoon used for testing smoke pots and grenades. Zinc oxide and hexachloroethane along with metals are the contaminants at this SWMU. Media contaminated at this SWMU include soil, groundwater, and surface water. The primary indicator contaminant in groundwater is hexachloroethane, which was detected at a preremediation level of 0.207 mg/L.

SWMU 63-SWMU 63 is a 4-acre site which was used as a dump for munition materials. Contaminants include metals and some volatile organic compounds. Media contaminated at this SWMU include soil and groundwater. The primary indicator contaminant in groundwater is lead, which was detected at a preremediation concentration of 0.4 mg/L.

SWMU 66-SWMU 66 is a 0.25-acre site that was used for disposal of munition wastes and for production of a paraffin binder. Metals and organic compounds contaminate the SWMU. No specific information was available regarding the environmental media contaminated at this SWMU.

SWMU 27-SWMU 27 is a 40-acre site that was used in the 1940s to manufacture chlorine. Contaminants at this SWMU include metals and chlorinated organic chemicals. Media contaminated includes soil and groundwater. The primary indicator contaminant in groundwater is lead, which was detected at a preremediation level of 0.37 mg/L.

4.0 CONTAINMENT REMEDY

The objective of the containment remedy for the eight SWMUs was to minimize groundwater contamination by diverting groundwater around or underneath contaminated materials, thus isolating the sources of contamination and preventing off-site migration of contaminants. The containment remedy for each SWMU consisted of the following elements:

- A circumferential slurry cutoff wall
- A high density polyethylene (HDPE) 60-mil cover overlain by 18 inches of compacted, random fill and 4 inches of topsoil, seeded
- Groundwater monitoring wells irregularly spaced outside each slurry cutoff wall

The containment systems are passive and involve no active groundwater pumping. The slurry cutoff walls at SWMUs 25, 27, 62, 63, and 66 were keyed at least 2 ft into the clay-shale unit. The slurry cutoff walls are at least 30 inches wide, except for SWMUs 19 and 20 where the wall is 36 inches wide. The five keyed slurry cutoff walls were constructed as follows:

- SWMU 25-The slurry cutoff wall at this SWMU is a perimeter slurry wall estimated to be 1,675 ft in length. This slurry wall varies in depth from 10 to 20 ft bgs, with an acceptable depth of 14 ft bgs.

- SWMU 27-The slurry cutoff wall at this SWMU is estimated to be 2,000 ft in length. The slurry wall varies in depth from 5 to 14 ft bgs and has an acceptable depth of 12 ft bgs.

- SWMU 62-The slurry cutoff wall at this SWMU is a perimeter slurry wall estimated to be 1,800 ft in length. The slurry wall appears to be set at an approximate depth of 16 to 18 ft bgs.

- SWMU 63- The slurry cutoff wall at this SWMU is a perimeter slurry wall estimated to be 2,100 ft in length. The slurry wall appears to be set at an approximate depth of 15 to 17 ft bgs.

- SWMU 66- No information was available on the depth or length of the slurry cutoff wall at this SWMU.

Hanging slurry cutoff walls exist at SWMUs 19 and 20. The depths of the hanging slurry cutoff walls were designed to cut off several interbedded sand and sandstone lenses. The acceptable wall depth of the hanging slurry cutoff walls at these SWMUs is 40 ft bgs.

Design of the closure systems was completed in the mid-1980s, and construction of the closure systems took place between 1987 and 1989.

5.0 PERFORMANCE EVALUATION

The purpose of the monitoring program at the site is to determine the effectiveness of the slurry cutoff wall containment systems in isolating the sources of contamination. Residual groundwater contamination exists, making containment system effectiveness difficult to determine. The results from the current monitoring program, which tracks trends in groundwater contamination levels across the site using statistical methods, have been inconclusive, and data gaps may exist for several of the SWMUs. A revised monitoring program that includes the installation of new monitoring wells and revision of analytical sample collection frequencies is being proposed by the facility. Details of the revised program were not available.

Although the current monitoring program does not appear to be adequate, current data show no indication that leakage of contamination is occurring from any of the closure sites. Groundwater quality data indicates that threshold limit values for certain contaminants are occasionally exceeded, but no trends are apparent that would indicate potential leakage from any of the closure sites. The occasional exceedances may be attributed to residual groundwater contamination that existed before SWMU closure. Containment system performance and contributing factors are discussed further in the following subsections.

5.1 Design

An evaluation of the design information generated an acceptable rating relative to the industry practices discussed in Section 3, Volume I. No design-level groundwater modeling was performed for any of the barriers.

No information was available on the leachate generation and management practices. The design called for a HDPE cover overlain by 18 inches of topsoil and vegetative cover. The cover and walls are not physically connected.

5.2 Construction Quality Assurance and Construction Quality Control

Evaluation of the barrier construction quality assurance (CQA) and construction quality control (CQC) generated an acceptable rating. All the soil-bentonite cutoff walls were installed using standard trenching and backfilling methods. The design called for a wall permeability of 1×10^{-7} cm/sec or less, a minimum bentonite content of 3 percent, a minimum fines content of 48 percent, and a minimum plasticity of 7 percent. The underlying stratum was tested for thickness and permeability continuity across each SWMU site. Soil borings, that penetrated at least 5 ft into the underlying stratum, were used to determine continuity. Falling head permeability tests in wells and laboratory tests were used to determine in situ stratum permeability. The minimum design requirements were a stratum thickness of 5 ft and a permeability of less than 1×10^{-7} cm/sec. Soil borings were completed at 100-foot centers along the alignments of the slurry cutoff walls to ensure that low-permeability stratum had been properly keyed before backfill placement. In the case of the hanging slurry cutoff wall, the borings were used to determine the depths at which the walls would penetrate stratum that was below the contaminated zone.

Full time CQA/CQC was completed during the installation of the slurry cutoff walls and caps. The CQA/CQC program used was the standard U.S. Army Corps of Engineers Regulation ER-1180-1-6 program.

Slurry trench backfill and slurry was tested before and during construction. No reference to postconstruction testing of the slurry wall materials was found in the information reviewed.

5.3 Monitoring

Long-term monitoring was rated below acceptable. Currently monitoring of the SWMUs consists of semiannual collection of groundwater samples outside the perimeter of the cutoff walls. Groundwater is monitored for quality analysis only.

Figure 2 shows groundwater quality data for lead associated with SWMUs 19, 20, and 21. The figure shows periodic increases of lead concentrations for one or more sampling rounds; however, data for subsequent sampling rounds show decreases or leveling off of contaminant levels. This figure is representative of similar analytical data for the site and an overall site trend of declining or steady contaminant levels near the SWMUs.

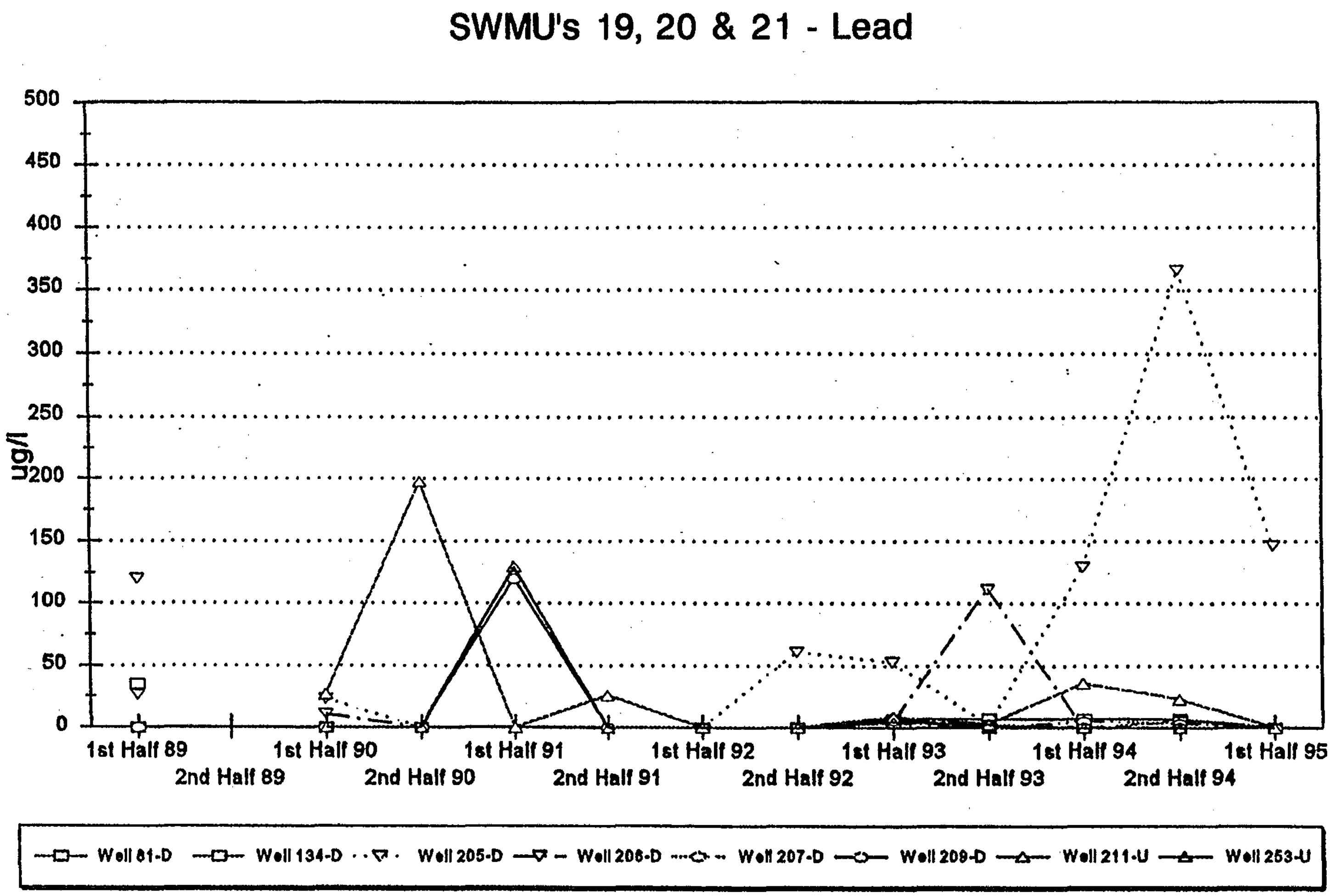
5.4 Operation and Maintenance

An operation and maintenance program is in place at the site; however, no specific information on this program was available.

5.5 Other Considerations

No specific cost information for remedial actions at the eight SWMUs was available.

7



Site 3

FIGURE 2

LEAD LEVELS AT SWMU's 19, 20 & 21

Tetra Tech EM Inc.

5.6 Remedy Performance

The overall performance of the containment system could not be determined based on available data.

6.0 SUMMARY

Site 3 occupies about 15,000-acres and is part of a U.S. Army testing and disposal operation. The site geology is characteristic of the West Gulf Coastal Plain Physiographic Province. The eight SWMUs used in this evaluation were land disposal facilities before the 1970s. Past disposal operations at these SWMUs resulted in groundwater contamination with heavy metals, semivolatiles, volatile organics, and other contaminants. Remedial actions at the eight SWMUs consisted of construction of circumferential slurry cutoff walls overlain by a flexible membrane liner and soil cover. Groundwater monitoring wells were installed to evaluate the effectiveness of the containment systems. The remedial design was rated acceptable, CQA/CQC was rated acceptable, and long-term monitoring was rated below acceptable. There was insufficient data to determine if the remedial objectives had been met.

SITE 4

Barrier Type	SB
Remedial Objective	SC
Performance	X

1.0 SITE DESCRIPTION AND HISTORY

Site 4 is located in the midwestern United States and contains a landfill. The site lies in a valley less than 1 mile from a major river. The site has rugged topography with high relief. Slopes in the area are generally steep with narrow ridge tops. An earthen dam was constructed near the head of the valley to contain wastes. The dam is about 350 feet long, 16 feet wide at its crest, and 45 feet high. The valley up-slope of the earthen dam was used as a landfill and covers about 3 acres. Vegetation over the landfill consists of poor grass and shrubs. The adjacent valley sides are heavily wooded. Figure 1 shows the locations of significant site features.

The landfill received solids, liquids, and sludges. The landfilling of wastes started in 1969 and ceased in 1980. Construction activities for a remedial action at the site began in July 1992 and were completed in August 1993.

The site containment consists of a soil-bentonite slurry wall above a grout curtain. The slurry wall extends around most of the landfill, with improvements to an earthen dam completing the perimeter barrier. The slurry wall was not keyed-in to the earthen dam. The earthen dam improvement included the building of a granular berm on a 3H:1V slope and a terrace at mid-height. A Resource Conservation and Recovery Act (RCRA) Subtitle C cap is tied into the slurry wall.

2.0 GEOLOGIC AND HYDROGEOLOGIC SETTING

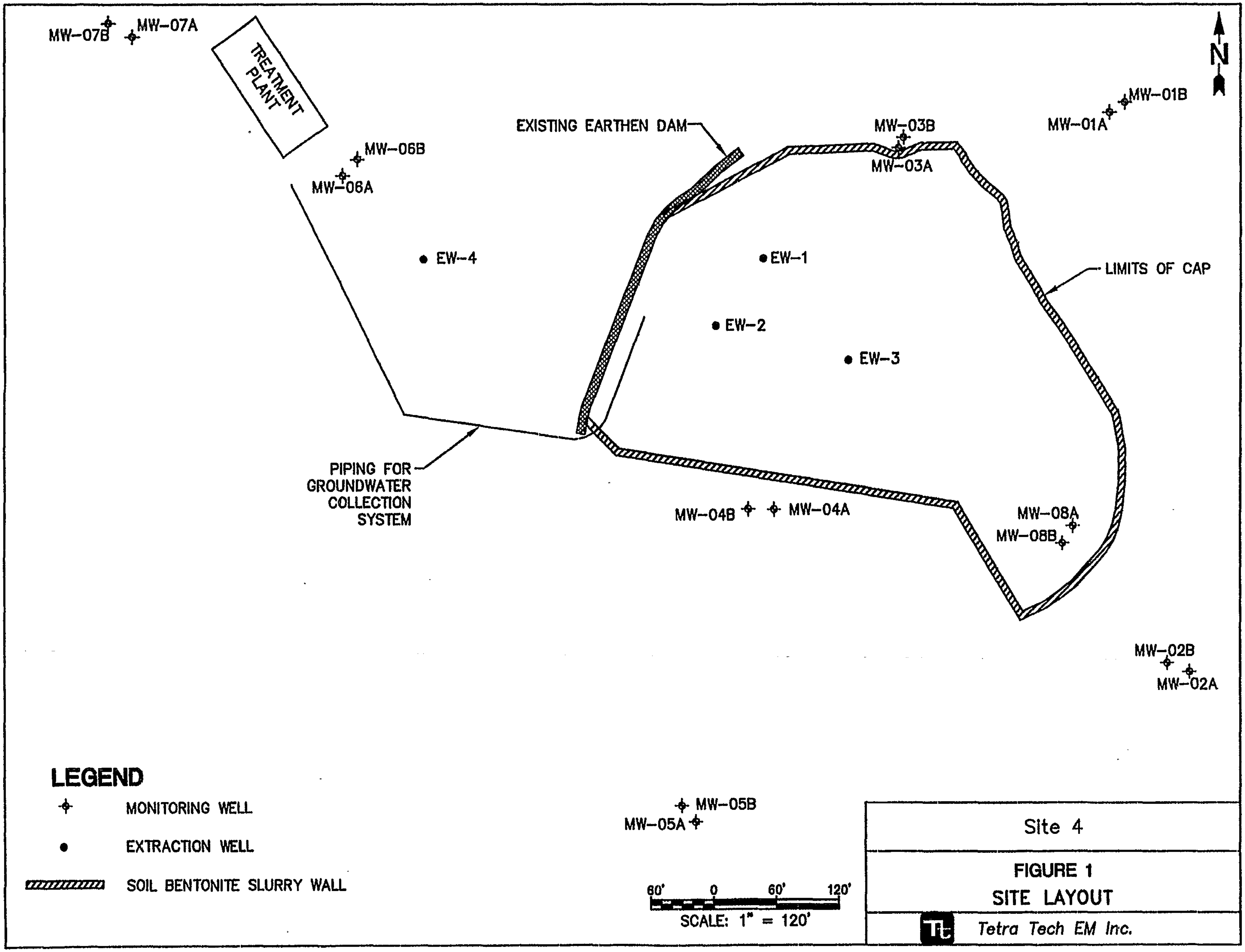
Site 4 is located in the nonglaciated Central Groundwater Region of the United States. The subsurface stratigraphy within the site boundary generally consists of residual soils, which extend 5 to 10 feet below ground surface (bgs), grading into partially weathered rock and underlying parent bedrock. Typically, the bedrock lies at a depth of 10 feet bgs and consists of alternating layers of sandstone, shale, and coal with occasional limestone and iron ore. In situ weathering of the parent bedrock has formed the residual soils. Some sedimentary deposits (colluvium) are found along the valley floor.

Shallow and deep water-bearing zones exist beneath the site in two sandstone units, one above and the other below the shale. Shale permeability at the site averaged 1×10^{-6} centimeters per second (cm/sec), and sandstone permeability averaged 1×10^{-5} cm/sec. The local groundwater flow is to the west; however, regional flow is toward the valleys with some component of vertical flow through rock fractures. The slurry wall was keyed into the shale to control lateral flow of groundwater into the landfill.

3.0 NATURE AND EXTENT OF CONTAMINATION

Analyses of landfill wastes revealed 13 volatile organic compounds (VOC), 13 semivolatile organic compounds (SVOC), 20 metals, four pesticides, and cyanide. Soil cleanup required lowering the concentrations of benzo(a)pyrene, ethylbenzene, phenol, arsenic, manganese, and nickel. Groundwater cleanup required lowering the concentrations of 1,2-dichloroethane (DCA); benzene; phenol; arsenic; manganese; and nickel. Groundwater contained the following concentrations of contaminants:

Key: SB=Soil Bentonite Wall SC=Source Control Performance Rating: X=Insufficient data to determine if remedial objectives were met


N
MW-07B
MW-07A
TREATMENT PLANT
EXISTING EARTHEN DAM
MW-03B
MW-03A
MW-01A
MW-01B
MW-06B
MW-06A
EW-4
EW-1
EW-2
EW-3
LIMITS OF CAP
PIPING FOR GROUNDWATER COLLECTION SYSTEM
MW-04B
MW-04A
MW-08A
MW-08B
MW-02B
MW-02A
LEGEND
MONITORING WELL
EXTRACTION WELL
SOIL BENTONITE SLURRY WALL
MW-05B
MW-05A
60' 0 60' 120'
SCALE: 1" = 120'
Site 4
FIGURE 1
SITE LAYOUT
Tetra Tech EM Inc.

CONTAMINANT	CONCENTRATION micrograms per liter ($\mu g/L$)
Acetone	12
Benzene	5
Carbon disulfide	13
Chloroethane	17
1,4-Dichlorobenzene	10
Aluminum	9,480
Arsenic	5.2
Barium	42.8
Beryllium	3.8
Cobalt	81.5
Copper	5.3
Iron	13,100
Manganese	2,610
Nickel	108
Vanadium	5.5
Zinc	378

4.0 CONTAINMENT REMEDY

Key components of the implemented remedy included the following:

- Collection of leachate using one large-diameter extraction well and of contaminated groundwater using three extraction wells and eight dual-well clusters

- An on-site leachate and groundwater treatment system

- Containment of on-site wastes using (1) a RCRA cap and (2) barrier wall (about 1,451 feet long and 40 feet deep) with a grout curtain 15 feet below the lowest elevation of the landfill The barrier wall is keyed into the shale bedrock.

- Improvements to the earthen dam located at the western end of the landfill in order to increase the factor of safety to greater than or equal to 1.5 and improve drainage

- Excavation of contaminated soils and sediments and their consolidation into the landfill before capping

5.0 PERFORMANCE EVALUATION

Performance monitoring of the containment includes quarterly groundwater monitoring that began in 1994. The objectives of the containment system are to prevent groundwater flow into the landfilled materials and to minimize the amount of contaminated groundwater pumped to the treatment plant.

5.1 Design

The barrier design was rated better than acceptable compared to industry practice as described in Section 3, Volume I. The design for the containment system at the site included improvements to an earthen dam, a barrier wall extending three-quarters of the way around the landfill, a landfill cover, a leachate collection system, and a leachate and groundwater treatment system. The barrier wall system consists of a grout curtain extending at least 15 feet below the lowest elevation of the landfill and a soil-bentonite barrier wall in the soils above the grout curtain. The grout curtain is not part of the earthen dam. The design calculations, drawings, and specifications indicate that the design effort was slightly better than acceptable. Geotechnical physical testing was conducted, and borings were aligned along the barrier at less than 100-foot intervals.

5.2 Construction Quality Assurance and Construction Quality Control

The construction quality assurance (CQA) and construction quality control (CQC) for barrier wall construction were rated better than acceptable. The CQA/CQC for grout curtain installation could not be determined based on available data; however, the U.S. Army Corps of Engineers performed independent tests on the grout and grout curtain in addition to the construction engineer's testing of the grout curtain. Inspections of the trench excavation, width, verticality, and continuity were conducted periodically, and trench sounding was conducted every 10 to 20 feet. The key was confirmed about every 20 feet. The landfill cover geomembranes were independently tested by the installer in addition to the engineer's destructive testing. The CQA/CQC for the landfill cover was rated better than acceptable.

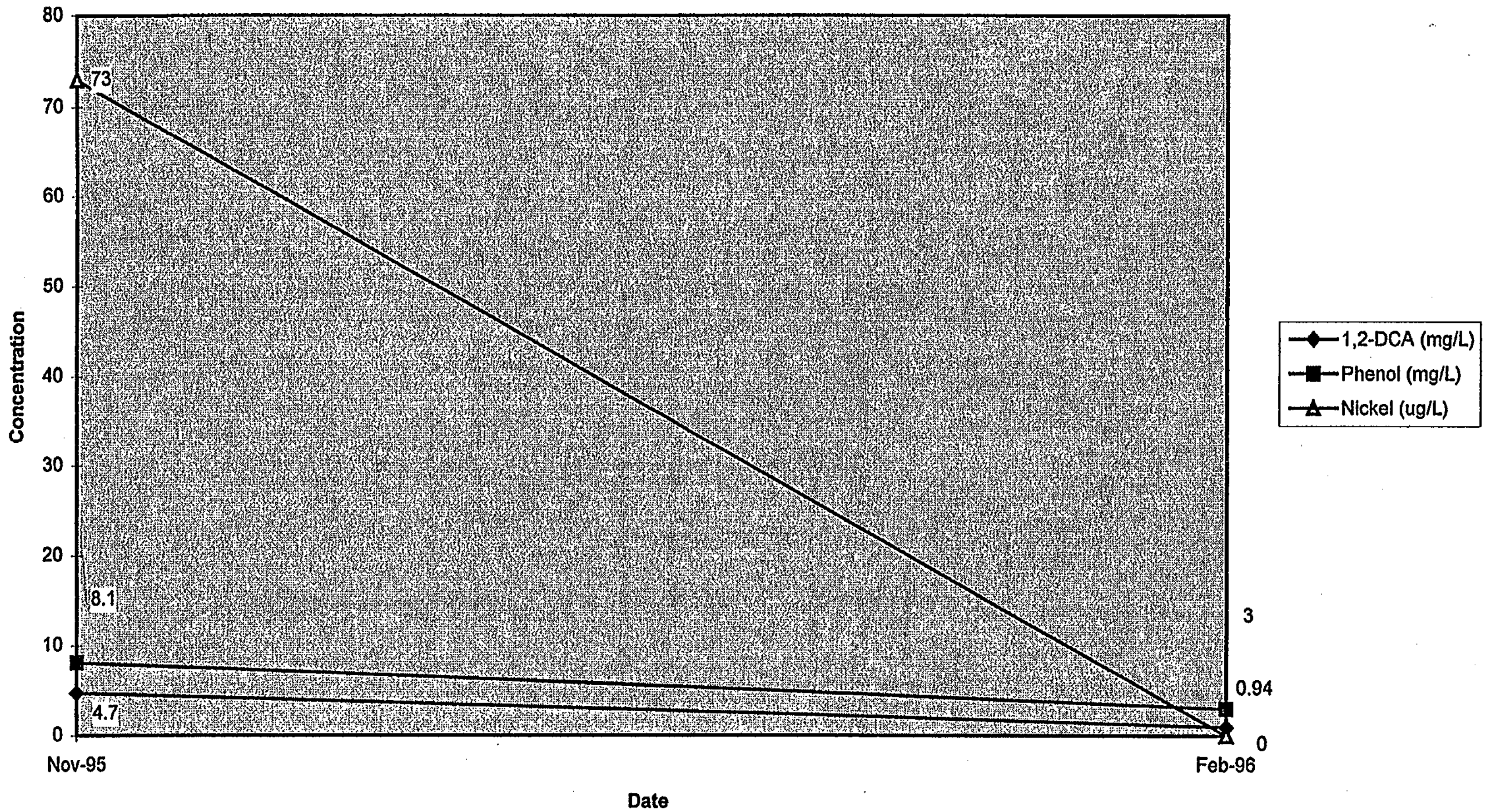
5.3 Monitoring

Long-term monitoring was rated less than acceptable because it did not include hydraulic stress tests or paired piezometers along the wall. Eight pairs of nested groundwater monitoring wells with screens in the shallow and deep aquifers are located at the site. The water levels in three extraction wells (EW-1, EW-2, and EW-3) located within the landfill limits and one extraction well (EW-4) located at the base of the earthen dam are monitored monthly. The quantity of water pumped from these wells is also monitored monthly. Water from these wells and from the eight monitoring well nests (MW-1A and MW-1B through MW-8A and MW-8B) located in and around the landfill is treated in an on-site treatment plant.

Water level measurements in the extraction wells indicate that water levels dropped about 7 feet in EW-1, 2.5 feet in EW-2, 4 feet in EW-3, and 1.75 feet in EW-4 from October 1994 to April 1995. No paired piezometers are located inside and outside the barrier wall. Available water level data is not presented in terms of mean sea level. Because of the data deficiencies, the hydraulic gradient across the wall could not be determined.

Groundwater quality downgradient of the barrier wall appears to be improving. However, data for only two sampling rounds was available for this evaluation. Contaminant concentrations in downgradient well MW-6A were plotted to show the changing concentrations of three contaminants over time (see Figure 2). The data from this well is representative of downgradient water quality. The concentrations of all three contaminants decreased from the fourth quarter of 1995 to the first quarter of 1996. MW-6B, the deeper well of the nest, did not have any organic contamination, but the concentration of nickel increased from 76 to 426 μg/L.

Downgradient Monitoring Well 6A



Site 4

FIGURE 2
CONTAMINANT CONCENTRATIONS

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5.4 Operation and Maintenance

Groundwater pumped from the extraction and monitoring wells is treated in an on-site treatment system consisting of a primary collection tank, a heavy metal removal system, a biological treatment system, and a sand and carbon filtration system before being discharged to a nearby creek. Treatment system effluent samples are collected weekly in accordance with the site's National Pollution Discharge Elimination System (NPDES) permit.

5.5 Other Considerations

The total cost of the grout curtain, slurry wall, landfill cap, and treatment plant was $6,800,000. The cost of the slurry wall was about $16.00 per square foot, and the cost of the grout curtain was $265.00 per linear foot, resulting in a total cost of $850,000.

5.6 Remedy Performance

Based on limited evidence available to date, the remedy appears to be performing as planned, and the barrier wall has reduced the pumping rates of the extraction wells to those rates specified in the design objective. The water quality downgradient of the barrier wall is improving slightly.

6.0 SUMMARY

Site 4 is a 3-acre landfill situated in a valley. The site has primarily organic contamination in soils and groundwater. A 1,451-foot-long barrier wall extends around most of the landfill. However, the barrier was not keyed into the 350-foot-long earthen dam. The barrier wall system consists of a grout curtain extending at least 15 feet below the lowest elevation of the landfill and a soil-bentonite barrier wall in the soils above the grout curtain. Three extraction wells are located under a RCRA cap, and one extraction well is located downgradient of the earthen dam.

The design was rated better than acceptable, and barrier CQA/CQC was rated better than acceptable. Long-term monitoring was rated below average. No paired piezometers are located at the site; therefore, the presence of a hydraulic gradient across the wall could not be determined. Groundwater quality downgradient of the barrier wall appears to be improving, but only two rounds of sampling data were available for evaluation. Based on the limited data available, it could not be determined if the remedial objectives had been met.

SITE 5

Barrier Type	CC
Remedial Objective	SC
Performance	1

1.0 SITE DESCRIPTION AND HISTORY

Site 5 is located in northeastern United States. The site is a closed municipal solid waste landfill and covers about 86 acres. The site is bordered on the north by a residential development, on the east and south by secondary roads, and on the west by a dirt road. The site and its basic features are shown in Figure 1.

The township operated the landfill from the mid-1950s until 1968, when it was leased to a solid waste hauling and disposal company. Seepage from the landfill was detected in late 1977 and early 1978, when excavation began for the construction of nearby homes. The containment system installed at the site includes a leachate collection drain coupled with a 10-foot-wide, 700-foot-long, rectangular, subsurface clay barrier extending around the perimeter of the site. The barrier was keyed into a formation which exhibits low hydraulic conductivity.

2.0 GEOLOGIC AND HYDROGEOLOGIC SETTING

The site consists of interbedded layers of sand, silt, and clay along the residential development perimeter. Figure 2 shows the soil layers through which the barrier wall was constructed.

Groundwater occurs on site as perched groundwater overlying the unweathered clays and as unconfined groundwater in the deeper sand layers. The perched groundwater table aquifer is not present in all portions of the site. The clayey layer overlying the silty sands was used as the low permeability zone for the barrier wall key-in.

3.0 NATURE AND EXTENT OF CONTAMINATION

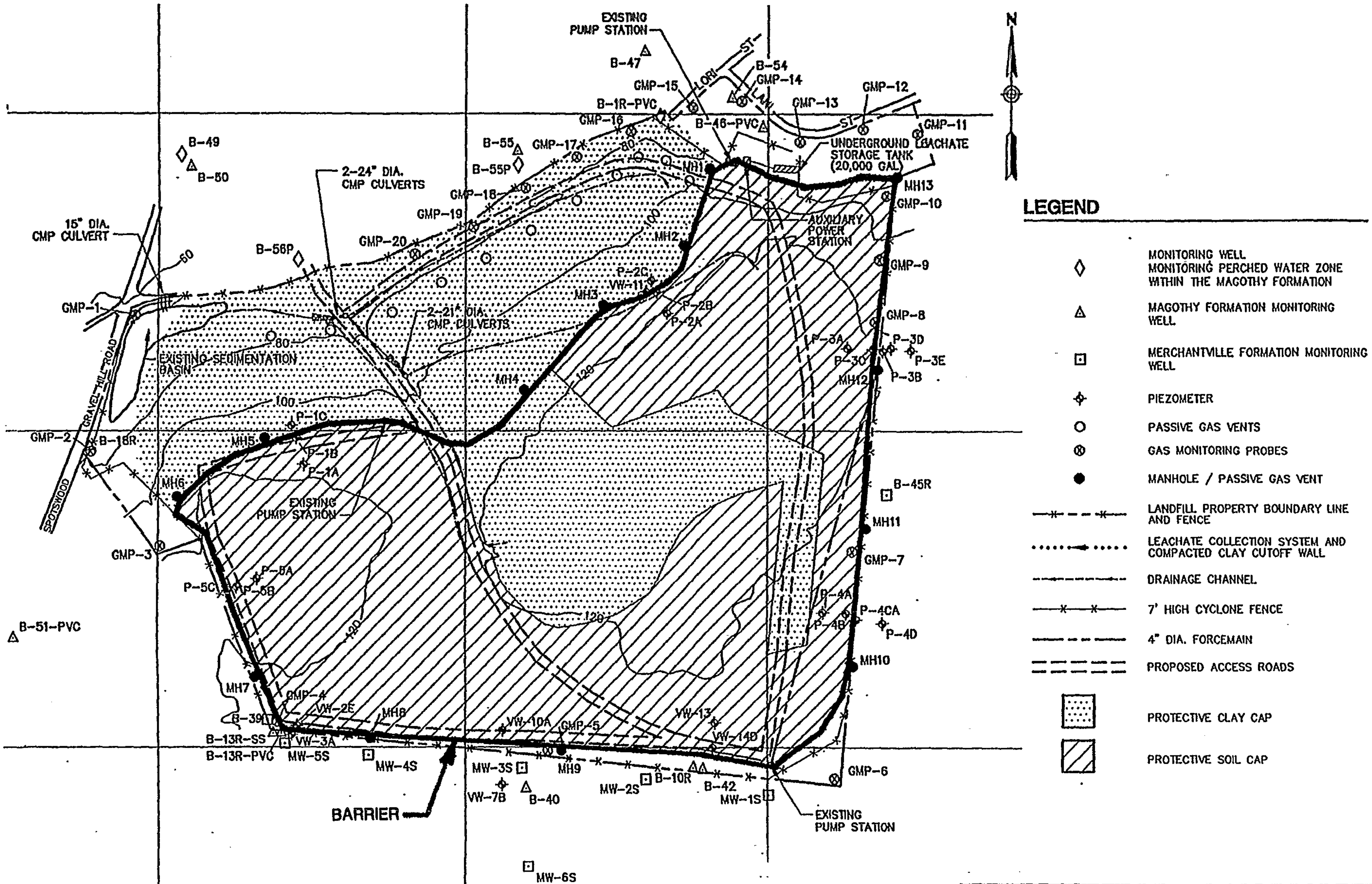
Although the exact extent of contamination was not fully documented, indicator chemicals for leachate contaminations included heavy metals and volatile organic compounds (VOC).

4.0 CONTAINMENT REMEDY

On the basis of hydrogeologic findings, a leachate collection system and barrier cutoff wall were designed and installed around the perimeter of the site. The containment remedy for the site includes the following:

- A 7,000-foot-long; 10-foot-wide, 10-foot-deep rectangular, compacted clay barrier wall and leachate collection system surrounding most of the site
- A leachate management system with an emergency power supply
- A protective soil cap for the area encircled by the wall and a clay cap for the portion of the landfill not underlain by the clay formation
- Surface water and erosion control systems
- Security fencing surrounding the entire site
- An active landfill gas collection and treatment system

Key: CC=Compacted Clay SC=Source Control Performance Rating: 1=Remedial objective was met



Site 5

FIGURE 1
SITE PLAN

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5.0 PERFORMANCE

In 1993, after numerous environmental investigations, the state and federal regulatory agencies determined that no further action except for maintenance and monitoring was needed to supplement the containment remedy. Factors contributing to the performance of the containment remedy are further discussed below.

5.1 Design

The compacted clay barrier wall design was rated acceptable with respect to industry practices described in Section 3, Volume I. The collection system was designed to handle the maximum anticipated flows from the perched groundwater table so as to provide a preferential hydraulic gradient to the collection line as opposed to radial discharge from the site.

A schematic of the containment remedy is shown in Figure 2. The containment remedy has proven to be effective in reducing landfill leachate generation and in mitigating lateral migration of leachate. Subsequently, additional remedial measures were constructed at the site, including surface water management systems, a perimeter security fence, a leachate storage facility that ultimately discharges to the county wastewater treatment plant, and an active landfill gas extraction and treatment system. No design-level groundwater modeling was performed for the containment.

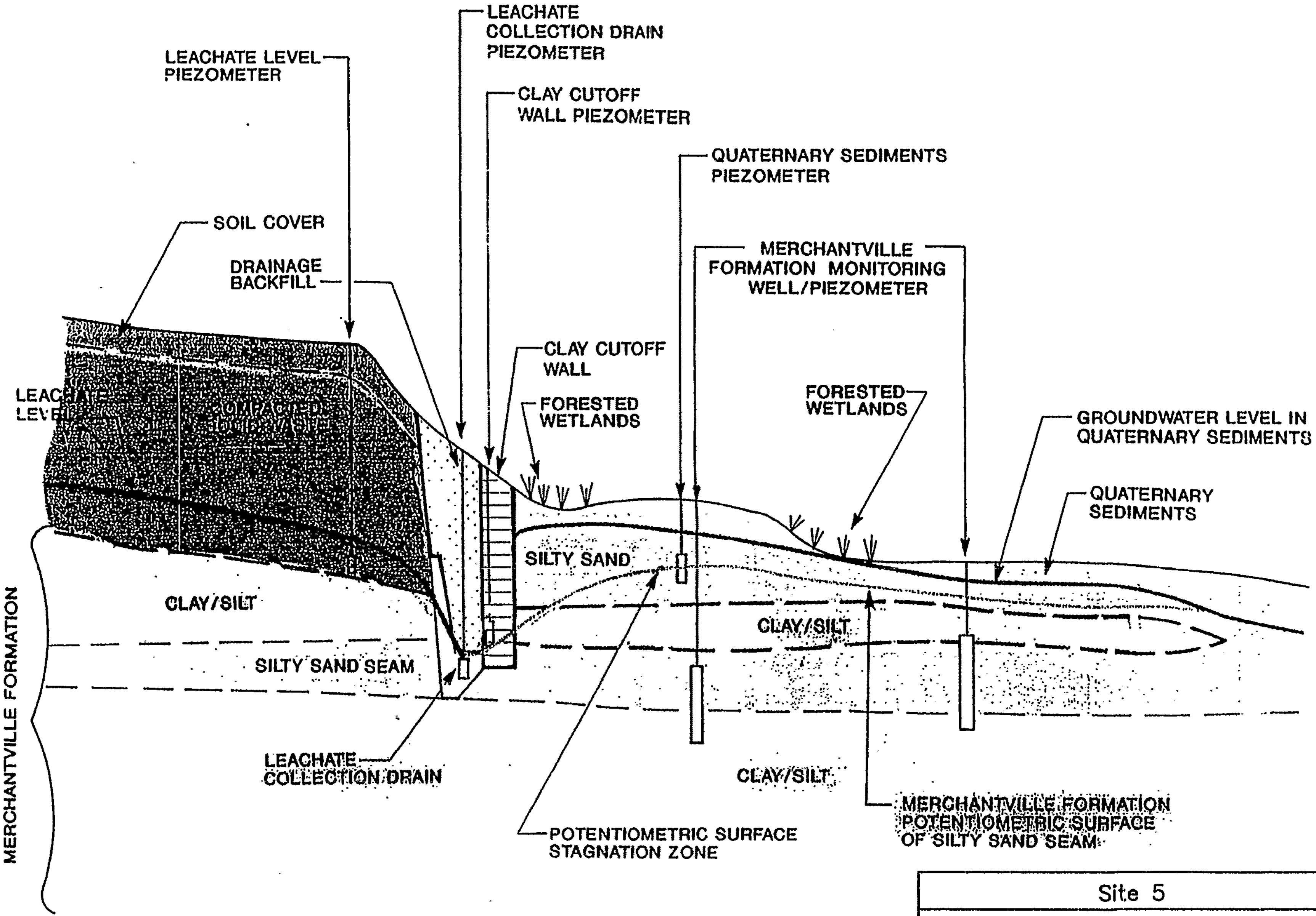
The cap design was rated less than acceptable. The design included a state regulatory agency-approved cap consisting of 1 foot of compacted clay, 6 inches of sand above the compacted clay, and 6 inches of soil suitable for vegetative growth above the sand.

5.2 Construction Quality Assurance and Construction Quality Control

The construction quality assurance (CQA) and construction quality control (CQC) procedures used during construction of the clay barrier cutoff wall were rated better than acceptable. Generally, the CQA/CQC procedures conformed to established industry practices. The wall key was confirmed by visual inspection of the soil and resistance to excavation at key depths. Based on testing of undisturbed samples collected from the completed wall every 400 linear feet, the wall met the design permeability requirement of less than 1×10^{-7} centimeters per second (cm/sec).

The permeability of the compacted clay barrier and compacted clay cap was determined through laboratory testing of undisturbed (shelby tube) samples. For the cut-off wall, two types of permeability tests were performed. The first test was used to verify an overall effective permeability of 1×10^{-7} cm/sec. The second test was performed on samples of the key-in material. In each test sample of the key-in material, the permeabilities were less than the maximum horizontal and vertical values of 1.1×10^{-4} and 2.6×10^{-6} cm/sec, respectively.

Cap CQA/CQC was rated slightly better than acceptable. Notably, the clay sources were thoroughly tested for physical properties, including permeability. Also, a small version of the compacted clay layer was constructed and tested by performing permeability measurements on six undisturbed samples. The final cap permeability test results are consistent with the wall permeability test data.



Site 5

FIGURE 2

SCHEMATIC SECTION

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5.3 Monitoring

The performance monitoring of the barrier was rated better than acceptable and involved postconstruction sampling, paired piezometers across the barrier wall, ample groundwater quality monitoring, and regular inspections.

The results of the groundwater monitoring indicate that organic chemicals detected in groundwater do not exceed state or federal groundwater quality standards. Refer to Figure 3 for a summary plot of groundwater quality.

5.4 Operation and Maintenance

A maintenance plan is used for scheduled preventive maintenance and repair of remedial components to ensure the continued effectiveness of the site remedy. Repairs performed as part of maintenance activities are summarized in an annual report submitted to the state regulatory agency.

5.5 Other

The capital and annual O&M costs for the containment remedy are not available.

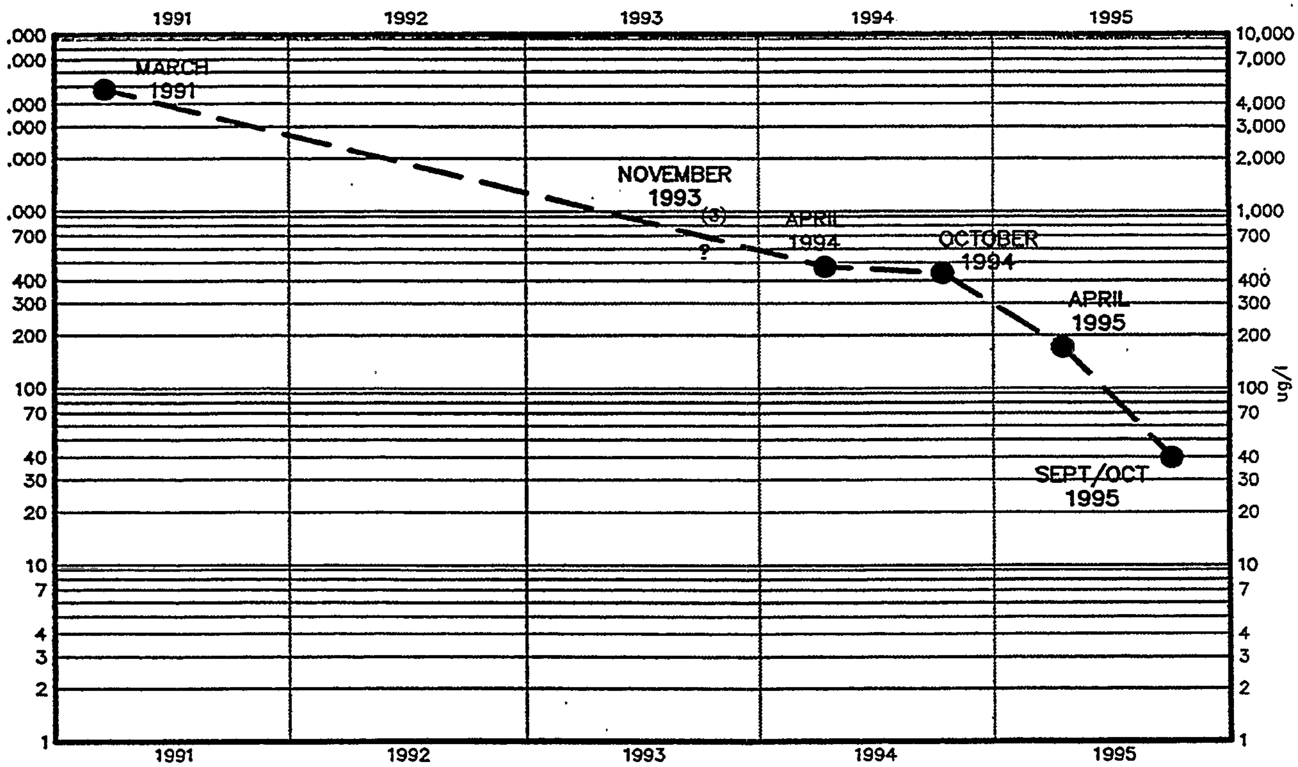
5.6 Remedy Performance

The overall performance of the containment suggests that the remedial objective was met.. Hydraulic head criteria were easily met by the leachate collection and removal system, and groundwater quality outside the containment has improved significantly relative to original on-site concentrations. The barrier wall was determined to be of low permeability, adequately keyed, continuous, and intact based on the measurements of groundwater table elevations and groundwater quality data. The cap has functioned effectively and has a proper erosion control system.

6.0 SUMMARY

Site 5 is a 86-acre closed landfill contaminated with heavy metals and VOCs. The site's hydrogeology and shallow, pervasive aquitard provided the base for a clay barrier wall. The compacted clay barrier wall was augmented with a leachate collection and management system with an emergency power supply, a compacted clay cap, surface water and erosion control systems, security fencing, and a groundwater monitoring system. The site containment has met the site's remedial objectives and is considered a protective remedy.

SAMPLING DATE	MARCH 1991	NOVEMBER 1993	APRIL 1994	OCTOBER 1994	APRIL 1995	SEPT/OCT 1995
TVOC (1),(2) ug/l	4,895	(3)	476.94	439.58	173.20	40.21



NOTES

1.) TVOC = TOTAL VOLATILE ORGANIC COMPOUNDS.

2.) FOR COMPARISON, DATA PRIOR TO MARCH 1991 WAS NOT USED BECAUSE KETONES WERE NOT ANALYZED.

Site 5

FIGURE 3

TOTAL VOC's vs TIME

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SITE 6

Barrier Type	SB
Remedial Objective	SC; Facilitate dewatering
Performance	1

1.0 SITE DESCRIPTION AND HISTORY

Site 6 is located in the southeastern United States. The site is about 5 acres in size and was initially operated as a borrow area for sand. A site plan is shown in Figure 1. When borrow operations ceased, excavated pits at the site were used for disposal of wastes including construction and demolition debris, cement kiln dust, battery wastes, waste from an automobile shredder, and household waste. Waste disposal as a business operation ceased at the site in 1976; however, unauthorized dumping of waste occurred at the site beyond 1976. Waste disposal activities at the site contaminated on- and off-site groundwater with several metals.

The original site remedy included solidification of contaminated soil and noncement waste, extraction and treatment of contaminated on-site groundwater, extraction and treatment of off-site contaminated groundwater, and installation of a cap. The site remedy did not address solidification of the contaminated cement kiln dust because it was naturally solidified following disposal when it contacted water. Although not part of the original remedy, a subsurface barrier wall was installed to (1) facilitate dewatering during site remediation and (2) minimize long-term migration of groundwater through solidified materials and cement waste after site remediation. The extraction and treatment of off-site groundwater originally required as part of the site remedy became unnecessary because the quality of off-site groundwater improved to an acceptable level following installation of the barrier wall and cap in 1993 and 1995, respectively.

2.0 GEOLOGIC AND HYDROGEOLOGIC SETTING

The site geology is relatively simple. About 15 to 20 feet (ft) of fine- to medium-grained, undifferentiated sediments form the surficial aquifer. These sediments overlie a 9-foot-thick, sandy, phosphatic clayey deposit, that forms a confining layer beneath the surficial aquifer. The confining layer separates the surficial aquifer from a deeper, regional aquifer that is an artesian aquifer in the site area and can yield large quantities of fresh water. The soil-bentonite barrier wall is keyed into the clayey, confining layer.

The surficial aquifer at the site extends from the water table, which was 3 to 8 ft below ground surface (bgs) during the design studies, to the top of the clayey, confining layer. The hydraulic conductivity of the surficial aquifer is about 30 ft per day. The groundwater in the surficial aquifer flows from the west to the east and southeast with an average hydraulic gradient of 0.005.

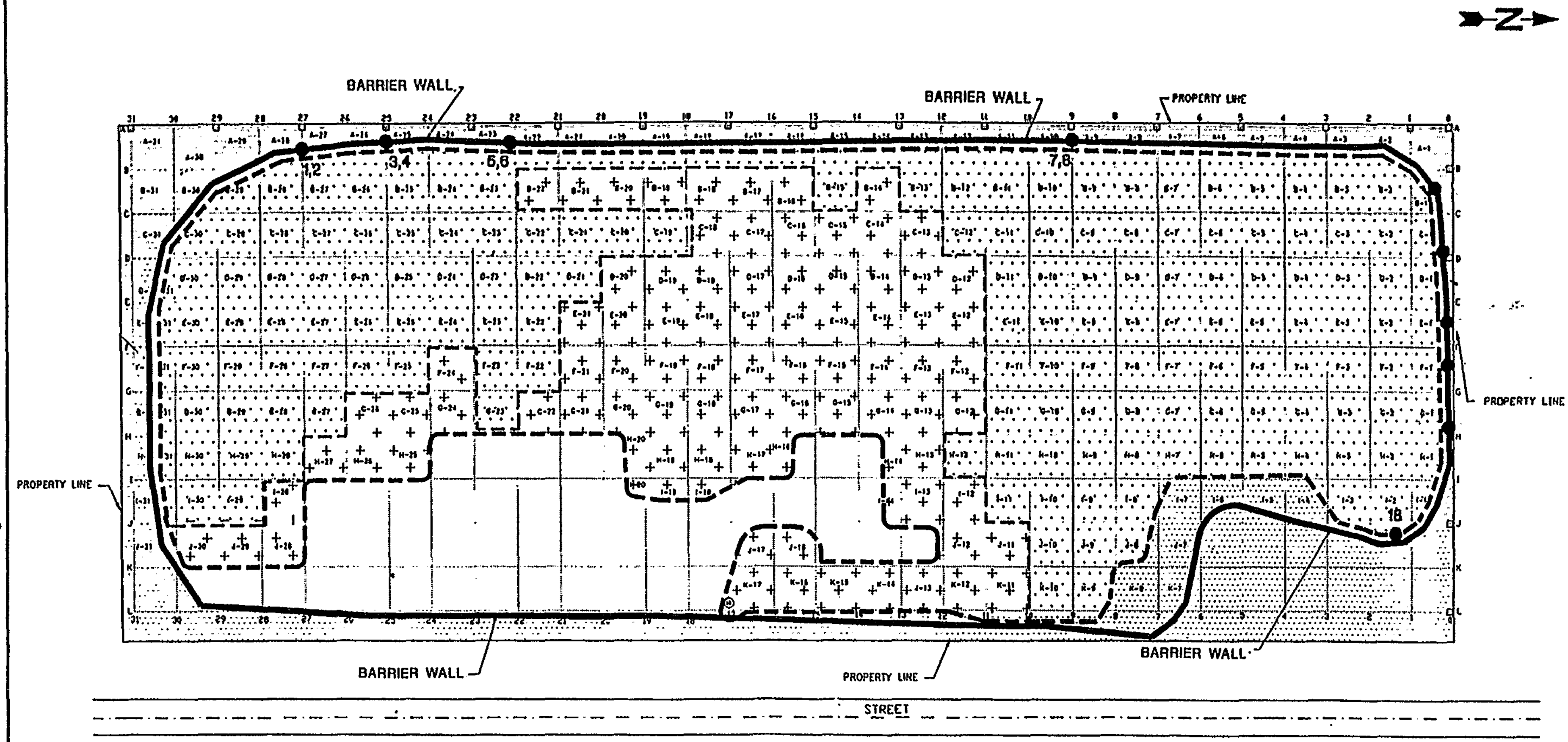
During the design studies, the elevation of the potentiometric surface of the deeper, artesian aquifer in the site area was about 20 ft below the water table. The regional direction of groundwater flow in the artesian aquifer in the site area is primarily from northeast to southwest.

3.0 NATURE AND EXTENT OF CONTAMINATION

The wastes disposed of at the site are classified as cement and noncement wastes. The noncement waste occupied most of the site disposal area and contained antimony, arsenic, cadmium, chromium, lead, nickel, and PCBs. The on-site and off-site groundwater in the surficial aquifer was contaminated

Key: SB=Soil Bentonite Wall SC=Source Control Performance Rating: 1=Remedial objective was met

Site 6



LEGEND

(NORTH - SOUTH COORDINATE) 1 A (EAST - WEST COORDINATE)

G-3 GRID NUMBER

25 FT. X 25 FT. GRID (TYPICAL)

APPROXIMATE LIMITS OF EXCAVATION

1 ● VERIFICATION SAMPLE LOCATION

UNDISTURBED AREA

NON-CEMENT WASTE AREA

AREA WHERE NON-CEMENT WASTE EXISTED ABOVE CEMENT WASTE

CEMENT WASTE AREA

0 60' 120'

SCALE: 1" = 60'±

Site 6

FIGURE 1
SITE FEATURES

Tetra Tech EM Inc.

primarily with chromium and lead. On-site groundwater had maximum, unfiltered chromium and lead concentrations of 560 and 1,600 micrograms per liter (μg/L), respectively. The maximum, unfiltered concentrations of chromium and lead in off-site groundwater were 18 and 16 μg/L, respectively. The groundwater in the artesian aquifer was not contaminated.

4.0 CONTAINMENT REMEDY

The containment remedy originally consisted of (1) solidification of contaminated soil and noncement waste, (2) installation of a composite cap over the solidified, waste and the cement waste, and (3) extraction and treatment of on- and off-site contaminated groundwater. The site remedy did not address solidification of the contaminated cement waste because it was naturally solidified following disposal when it contacted water. The original site remedy was modified to include installation of a subsurface barrier wall. The final site remedy had the following features:

- A soil-bentonite barrier wall that is about 2,100-ft-long; 2.5-ft-thick; is 15 to 25-ft-deep; is keyed at least 3 ft into the clayey, confining layer and has a design permeability of less than 1×10^{-7} centimeter per second (cm/sec)

- A composite cap with the following six components (in ascending order): (1) a prepared, random fill base for site grading and for supporting the soil liner; (2) a 1-foot-thick, compacted clay liner with a permeability of 1×10^{-7} cm/sec; (3) a 40-mil-thick, high-density polyethylene geomembrane; (4) a 2.5-foot-thick, sand drainage layer; (5) a 0.5-foot-thick topsoil layer; and (6) a vegetative cover

- Extraction and treatment of on-site contaminated groundwater in excess of that needed for solidification of purposes

- Extraction and treatment of off-site groundwater with contaminant concentrations above the cleanup levels

- A storm water retention basin

5.0 PERFORMANCE EVALUATION

The objectives of the barrier wall design and installation were to (1) facilitate dewatering of soils and wastes to be solidified during site remediation and (2) minimize the long-term migration of groundwater through solidified materials and cement waste after site remediation. The objectives of the cap design and installation were to (1) minimize rainfall infiltration into the solidified materials and (2) promote drainage from the surface while providing an aesthetic cover that would minimize water and wind erosion at the site following site remediation.

The performance of the containment system was monitored by evaluating the water quality in six off-site wells. The first four rounds of quarterly groundwater monitoring showed significant improvement in off-site groundwater quality. The concentrations of chromium and lead dropped below cleanup levels within 1.5 years of containment system installation, demonstrating that the containment system had achieved its design objective. The improvements in off-site groundwater quality following containment system installation were the sole reason for not performing the extraction and treatment of off-site groundwater included in the original site remedy. Containment system performance and contributing factors are discussed further in the following subsections.

5.1 Design

The barrier wall design was rated better than acceptable. The barrier design was based on the results of thorough hydrogeologic and geotechnical investigations. The bentonite content of the slurry wall was selected after thorough testing of the permeabilities of several soil-bentonite mixtures. However, no groundwater modeling was performed to support the barrier wall design.

The cap design was rated acceptable.

5.2 Construction Quality Assurance and Construction Quality Control

The construction quality assurance (CQA) and construction quality control (CQC) for the barrier wall were rated better than acceptable. The trench contractor was experienced, trench excavation was constantly inspected, and barrier continuity was checked. Based on the results of postconstruction permeability testing of barrier wall samples, the hydraulic conductivity of the barrier wall ranged from 4.0×10^{-8} to 6.3×10^{-7} cm/sec, values below the design hydraulic conductivity of 1.0×10^{-7} cm/sec.

The CQA/CQC for cap installation was not available.

5.3 Monitoring

The performance monitoring program for the containment system was rated acceptable and consists of monitoring wells to collect and analyze groundwater samples downgradient and side gradient of the site. The entire contained area has been solidified and monitoring water levels inside the contained area is unnecessary.

5.4 Operation and Maintenance

The cap is periodically inspected to evaluate the adequacy of surface water drainage and to identify any erosion or land subsidence that could affect cap performance. Only visual inspections are performed.

5.5 Other Considerations

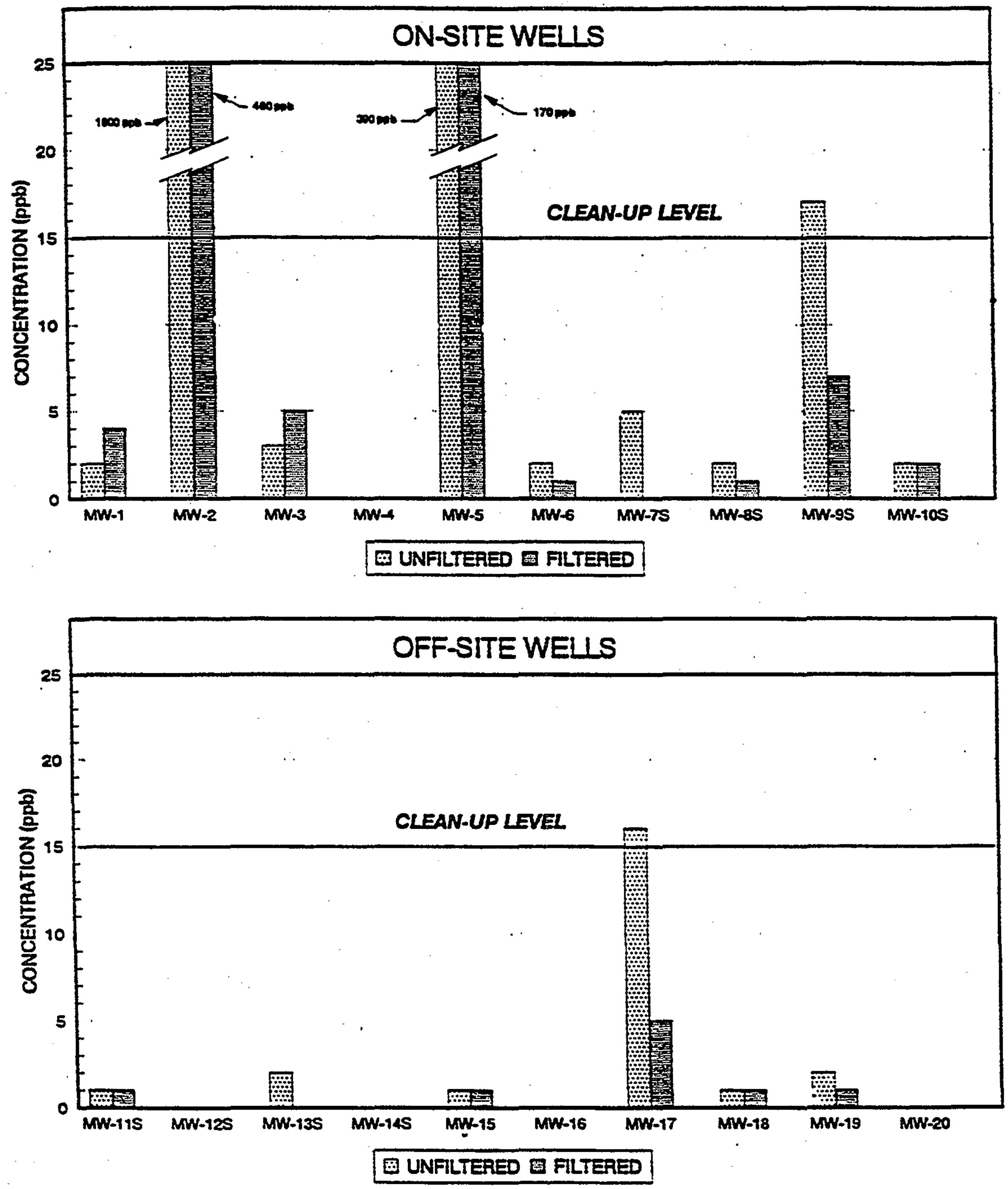
Construction and operation and maintenance costs for the barrier wall and cap were not available for review.

5.6 Remedy Performance

The barrier wall; the composite cap; and the natural, clayey deposits that underlie the site form a sound containment system for the cement and the noncement wastes. The containment system in conjunction with waste solidification has performed effectively, as is indicated by the lowering of contaminant concentrations in off-site groundwater to below cleanup levels following the installation of the containment system (see Figure 2).

6.0 SUMMARY

Site 6 is located in the southeastern United States. The site is about 5 acres in size and was initially operated as a borrow area for sand. When borrow operations ceased, excavated pits at the site were used for disposal of wastes, including construction and demolition debris, cement kiln dust, battery wastes,



Site 6

FIGURE 2
LEAD CONCENTRATION IN GROUNDWATER SAMPLES

Tetra Tech EM Inc.

waste from an automobile shredder, and household waste. Waste disposal activities at the site contaminated on- and off-site groundwater with several metals.

A soil-bentonite barrier wall was installed on site in 1993 to encircle the solidified noncement waste and cement waste. A composite cap was installed at the site in 1995. The designs of the barrier wall and cap were rated better than acceptable and acceptable , respectively. The CQA/CQC for the barrier wall was rated better than acceptable. The CQA/CQC for the cap was not evaluated because of lack of information. The performance monitoring program for the site was rated acceptable. The barrier wall; the composite cap; and the natural, clayey deposits that underlie the site form a sound containment system for the cement and the solidified noncement wastes. The containment system has performed effectively and met the remedial objectives.

SITE 7

Barrier Type	SB
Remedial Objective	SC; Lower water table
Performance	2

1.0 SITE DESCRIPTION AND HISTORY

Site 7 is located in northeastern United States. The site includes a 66-acre refuse area and an 11-acre stressed vegetation area. Both areas lie adjacent to a perennial stream that is a tributary to a major river.

The site was originally a sand and gravel quarry and was operated as a landfill from 1963 until 1981. The landfill received indiscriminately dumped municipal, chemical, and hospital wastes. This dumping resulted in contaminated surface water and shallow groundwater. A subsurface barrier wall, cap, and leachate collection and pretreatment system were constructed at the site in 1990. Figure 1 shows the general features of the site.

2.0 GEOLOGIC AND HYDROGEOLOGIC SETTING

The site is located on the Atlantic and Gulf Coastal Plain. The site area is underlain by unconsolidated layers of sands and clays deposited in a relatively extensive horizontal sequence with a gentle southeastern dip. The unconsolidated formations underlying the landfill (in descending order) are the Mount Laurel Sand and Wenonah, Marshalltown, Englishtown, Woodbury, Merchantville, and Magothy and Raritan Formations. The adjacent stream valley also contains recently deposited alluvium.

The landfill is located within an outcrop of the Mount Laurel Sand and Wenonah Formation. The upper Mount Laurel Sand consists of light-gray to tan, medium- to coarse-grained, quartz sand with glauconite and ranges in thickness from 0 to 65 feet in the area of the site. The Marshalltown Formation underlies the Mount Laurel Sand and has a thickness of about 20 to 30 feet. The Marshalltown Formation is composed of medium to dark olive-gray, fossiliferous and micaceous, very fine-grained, silty sand and sandy to clayey silt.

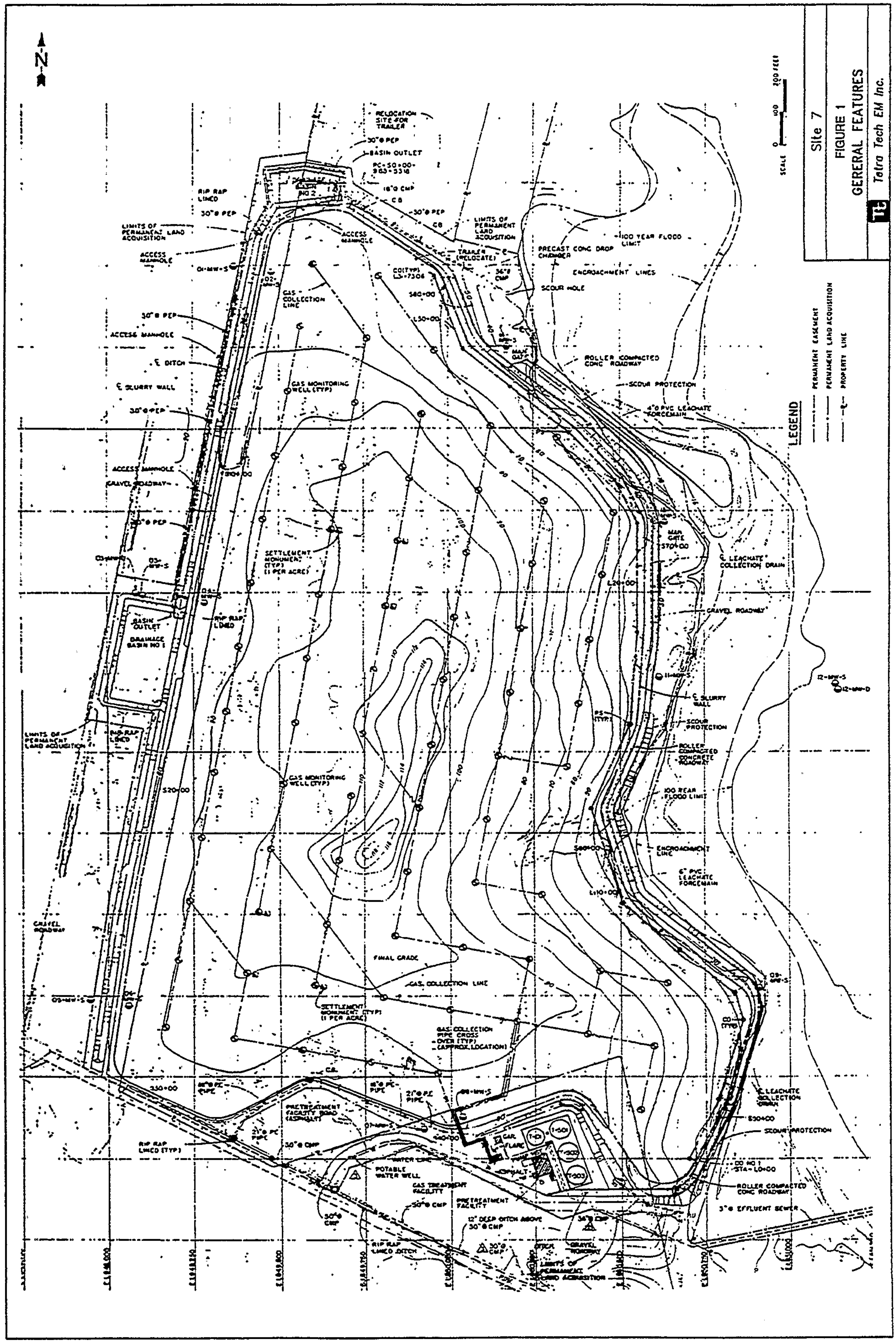
Groundwater in the Mount Laurel Sand aquifer flows east under the landfill and discharges to the adjacent stream. The aquifer's hydraulic conductivity ranges from 9.1×10^{-4} to 2.0×10^{-2} centimeters per second (cm/sec). The amount of groundwater flowing through the site area and discharging to the stream is about 80,000 gallons per day (gpd).

The Marshalltown Formation's hydraulic conductivity tends to decrease with depth and ranges from 1.8×10^{-4} to 3.9×10^{-4} cm/sec; values of 1.8×10^{-2} cm/sec or less were found in more than half the samples collected from the formation.

The Englishtown Formation is a confined aquifer whose piezometric surface lies about 10 feet above the top of the Marshalltown Formation. Groundwater in the Englishtown Formation flows east and appears to be unaffected by the adjacent stream. In this formation, the hydraulic gradient across the site area appears to be constant, and the hydraulic conductivity ranges from 1.2×10^{-2} to 4.2×10^{-3} cm/sec. The amount of groundwater flowing through this formation under the site area is about 101,000 gpd.

Because of the piezometric heads in the Mount Laurel Sand and the Englishtown Formation, the vertical leakage from the Mount Laurel Sand through the Marshalltown Formation into the Englishtown

Key: SB=Soil Bentonite Wall S=Source Control Performance Rating: 2=Evidence suggests objective may be met


Site 7
FIGURE 1
GERERAL FEATURES
Tetra Tech EM Inc.
LEGEND
PERMANENT EASEMENT
PERMANENT LAND ACQUISITION
PROPERTY LINE
SCALE
0 100 200 FEET
N

Formation under the site is estimated to have been 10,000 gpd before construction of the barrier wall. In the area of the stream, the piezometric head of the Englishtown Formation is greater than that of the Mount Laurel Sand or the stream. Therefore, vertical leakage occurs upward from the Englishtown Sand through the Marshalltown Formation into the stream valley at an estimated rate of 19,000 gpd.

3.0 NATURE AND EXTENT OF CONTAMINATION

The Mount Laurel Sand aquifer is heavily contaminated with organic compounds, including dichloroethanes, dichloroethenes, trichloroethanes, trichloroethenes, benzene, toluene, xylenes, ketones, and phenols. Inorganic chemicals found in the aquifer include arsenic, cobalt, iron, magnesium, sodium, and calcium. Hospital wastes have also been found on site.

Indicator analyte concentrations at the site include:

- Total volatile organics: 400 mg/L
- Total organic carbon: 1,200 mg/L
- Total organic halides: 65 mg/L
- Chemical oxygen demand: 3,900 mg/L
- Chromium: 5.4 mg/L
- Lead: 0.197 mg/L
- Iron: 300 mg/L
- Nickel: 5.4 mg/L

Organic contaminants have been found in the Marshalltown Formation to depths of 40 feet below ground surface (bgs). No evidence of contamination has been found in the Englishtown Formation aquifer.

4.0 CONTAINMENT REMEDY

The objective of the containment remedy for the site is the prevention or mitigation of the off site migration of hazardous substances. The following remedial measures were implemented:

- A subsurface barrier wall that is about 8,350 linear feet long; 20 to 70 feet deep; and 3-feet thick and that has a 5-foot key

- A roller-compacted concrete retaining wall

- A leachate collection and pretreatment system

- A cap that has a 2-foot clay barrier layer, drainage layer, cover soil, and vegetative layer

- Active landfill gas collection and treatment (one gas collection well per acre)

- Dewatering, excavation, and filling of lagoons

- Monitoring

5.0 PERFORMANCE EVALUATION

The performance of the containment systems was evaluated based on quarterly and annual groundwater monitoring results.

Groundwater quality data has shown that the barrier is functioning as intended. Only one downgradient monitoring well has consistently shown contamination. The contaminant levels in this well have been gradually decreasing over time. For example, from September 1994 to June 1995, contaminant levels in the well decreased as follows:

- Benzene: 4.29 to 3 mg/L
- Chlorobenzene: 16 to 4 mg/L
- Vinyl chloride: 0.3 to 0 mg/L
- Arsenic: 44 to 10 mg/L

By comparison, typical contaminant levels in the leachate within the barrier wall are significantly higher:

- Benzene: up to 6,260 mg/L
- Chlorobenzene: up to 23 mg/L
- Vinyl chloride: up to 141 mg/L
- Arsenic: up to 190 mg/L

Containment system performance and contributing factors are described further in the following subsections.

5.1 Design

The barrier design was rated better than acceptable with respect to industry practices as described in Section 3, Volume I. The design followed protocols established by the U.S. Army Corps of Engineers. Significant positive features of the design included leachate-backfill compatibility testing. The bottom of the barrier was keyed 5 feet into the Marshalltown Formation. Additionally, detailed hydrogeologic models of the area were completed. A roller-compacted concrete retaining wall was constructed along a steep slope of the site to permit the barrier to be constructed.

5.2 Construction Quality Assurance and Construction Quality Control

The barrier construction quality assurance (CQA) and construction quality control (CQC) were rated better than acceptable. Generally, CQA/CQC procedures conformed to established industry practices. Significant positive features of the CQA/CQC program included use of a remote backfill mixing area and postconstruction borings. These borings showed that the in-place backfill had a permeability in the range of 1×10^{-8} to 9×10^{-9} cm/sec.

5.3 Monitoring

Monitoring at the site was rated less than acceptable. Monitoring wells currently exist only outside the hydraulic barrier at the downgradient region of the containment, whereas monitoring well pairs are used at the upgradient region. Two wells are sampled quarterly, and the samples are analyzed for volatile and semivolatile organic compound (VOC and SVOC, respectively), pesticide and PCBs, and inorganic contaminants. Six additional wells are sampled semiannually, and the samples are analyzed for VOCs and arsenic only. Surface water in the adjacent stream is sampled quarterly at upstream, midstream, and downstream locations, and the samples are analyzed for VOCs, SVOCs, pesticide and PCBs, and inorganic contaminants. The leachate is sampled quarterly, and the samples are analyzed for VOCs, SVOCs, pesticide and PCBs, and inorganic contaminants. The filtercake produced by leachate pretreatment on site is sampled annually, and the samples are analyzed for pH, flashpoint, RCRA metals, "D" code organics, total cyanide, total sulfide, and PCBs. Figure 2 provides a summary plot of select indicator analyte concentrations in shallow groundwater and changes over time for a typical downgradient monitoring well.

Hydraulic head monitoring of the leachate collection system indicates that water levels in the system are maintained below the top of the hydraulic barrier.

5.4 Operation and Maintenance

Operation and maintenance activities at the site include maintaining the on-site leachate pretreatment facility and the multilayer cap. Cap maintenance includes vegetation and erosion control and repair of any damage.

5.5 Other Considerations

The construction costs of the remedial measures were as follows:

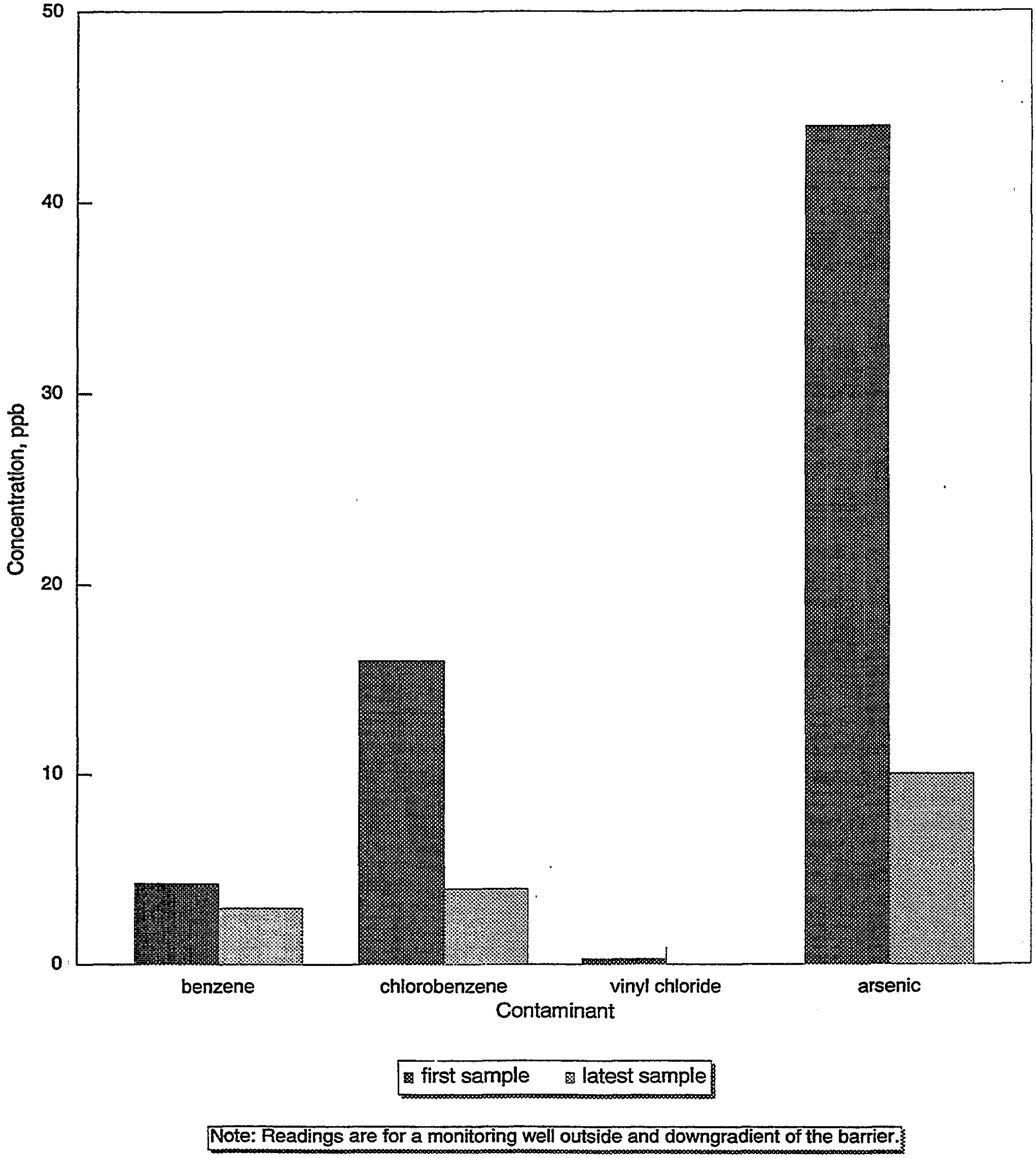
- Barrier: $3,120,885 ($7.81 per square foot of the barrier wall)
- Multilayer cap: $17,073,616
- Gas collection system: $4,154,859
- Leachate collection system: $1,833,841
- Roller-compacted concrete wall: $3,563,023

5.6 Remedy Performance

Monitoring has shown the concentrations of site contaminants to be decreasing in the shallow groundwater outside the barrier. The leachate collection system is functioning to remove contaminated groundwater from the site. However, one of the objectives of the site remedy was to lower the water table elevation in the Mount Laurel Sand to substantially reduce the potential for downward vertical migration through the Marshalltown Formation into the Englishtown Formation. Figure 3 shows the intended impact of containment on water table elevations within the contained area of the site. No water level data was available within the barrier wall. Therefore, it is not possible to determine if the downgradient vertical migration has been reduced. However, the water quality outside the wall indicates that the remedial objectives may have been met.

6.0 SUMMARY

Site 7 is located in northeastern United States. The site includes a 66-acre refuse area and an 11-acre stressed vegetation area. Both areas lie adjacent to a perennial stream that is a tributary to a major river. The Mount Laurel Sand aquifer beneath the site is heavily contaminated with organic compounds, including dichloroethanes, dichloroethenes, trichloroethanes, trichloroethenes, benzene, toluene, xylenes, ketones, and phenols. Inorganic contaminants found in the aquifer include chromium, nickel, and lead. Hospital wastes have also been found on site. Organic contaminants have been found in the



Site 7

FIGURE 2
SHALLOW GROUNDWATER CONTAMINANTS

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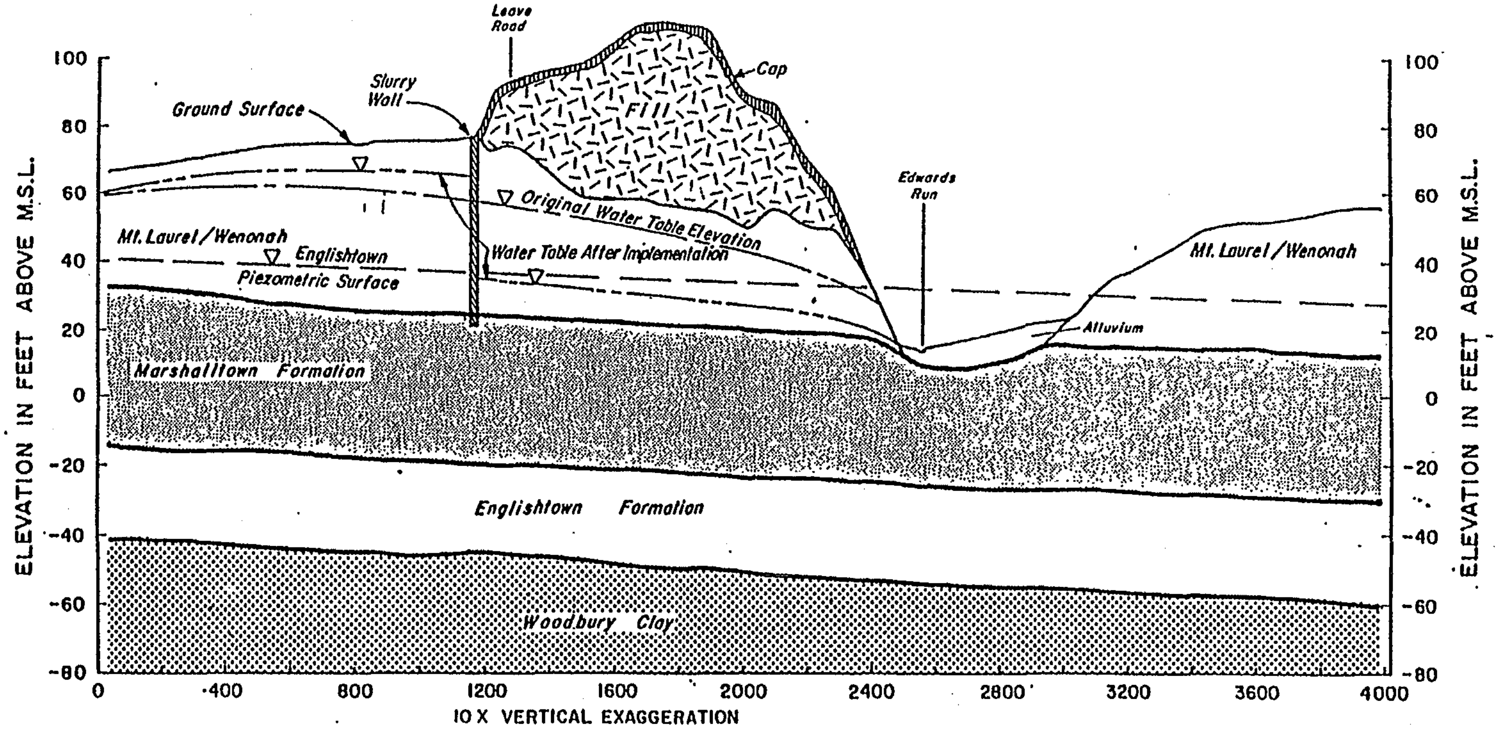

LEGEND

- WATER LEVEL IN MT. LAUREL/WENONAH PRIOR TO CAPPING & SLURRY WALL
- WATER LEVEL IN MT. LAUREL/WENONAH AFTER CAPPING & SLURRY WALL
- ENGLISHTOWN PIEZOMETRIC SURFACE

Site 7

FIGURE 3
PIEZOMETRIC LEVELS

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Marshalltown Formation to depths of 40 feet bgs. No evidence of contamination has been found in the Englishtown Formation aquifer. To minimize off-site migration of contaminants, a soil-bentonite barrier was included as part of the overall containment system, which also included a leachate collection and pretreatment system, a landfill gas collection system, and a multilayer cap.

The design and CQA/CQC of the barrier were rated better than acceptable. The performance monitoring of the barrier involved construction inspections, use of piezometers, and leachate monitoring. The performance of the containment in limiting the vertical leakage through Marshalltown Formation into the Englishtown Formation is not known. However, the remedial objective of improving downgradient water quality may have been met.

SITE 8

Barrier Type	SP
Remedial Objective	SC
Performance	X

1.0 SITE DESCRIPTION AND HISTORY

Site 8 is a 22.5-acre tract of land. The site area was extensively used for sand mining in the 1950s and 1960s. From about 1966 until 1971, the site was permitted by the state to accept industrial waste material from a variety of generators, including refineries and chemical plants. An estimated 80 million gallons of industrial waste was disposed of in the main waste lagoon, and an estimated 300,000 cubic yards of contaminated sludge and soil was present on site. The site's disposal permit was eventually revoked, and the site was closed in 1971. The closure settlement required the operator to remove on-site tankage and other aboveground structures, but the lagoon liquids and sludges were not addressed. The site layout is shown in Figure 1.

Site activities and releases have resulted in contamination of the shallow aquifer beneath the site. Site remediation has included in situ bioremediation for the lagoon sludges and shallow alluvial groundwater. A sheet-pile barrier was built in 1989 to control flood waters around the lagoon and to prevent migration of contamination below the lagoon. A second sheet-pile barrier was built in 1994 to contain an area of known dense nonaqueous-phase liquid (DNAPL).

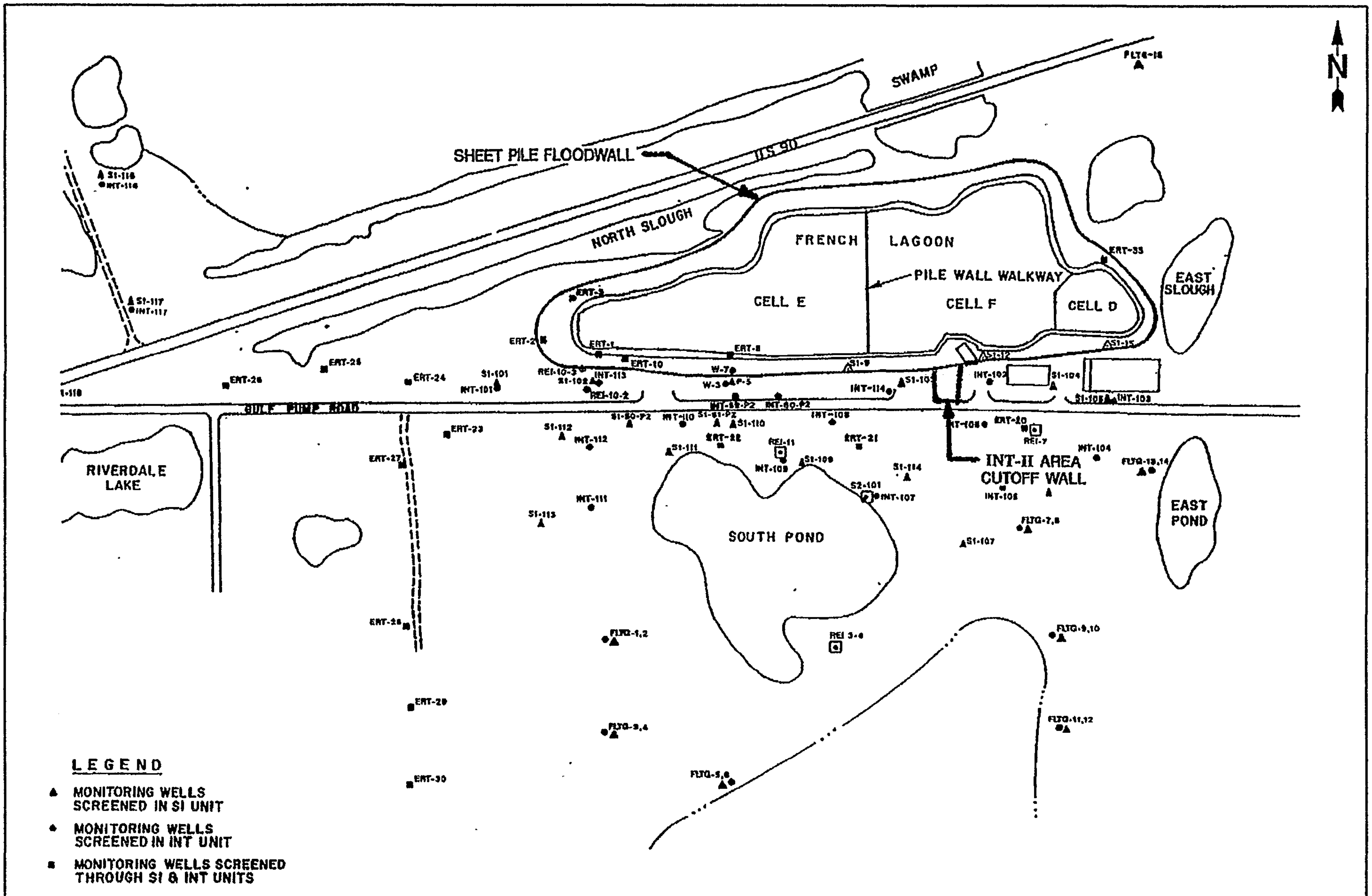
2.0 GEOLOGIC AND HYDROGEOLOGIC SETTING

The site is located in the flood plain of a large river and is situated on the associated alluvial soils, which consist of interbedded clay, silt, and sand that are common throughout the Gulf Coastal Plain. The site was extensively mined for sand in the 1950s and 1960s. Three aquifers exist below the site. The shallow alluvial aquifer has been extensively contaminated by waste disposal at the site. The shallow aquifer consists of two permeable zones referred to as the S1 (shallower) and INT (intermediate) zones. The S1 zone is encountered from about 15 to 30 feet below ground surface (bgs) and has a permeability on the order of 1×10^{-3} to 1×10^{-4} cm/sec. The INT zone is located from approximately 35 to 45 feet bgs and has a permeability on the order of 1×10^{-4} to 1×10^{-5} cm/sec. The two units are separated by a discontinuous clay stratum referred to as C1 that ranges from 0 to 7 feet in thickness. Although they are separated by a clay stratum, aquifer tests have shown that the two units are hydraulically connected. Groundwater flows to the south in the two shallow alluvial zones.

The second aquifer is the Riverdale sand, which is encountered about 110 feet bgs. This aquifer is separated from the alluvial aquifer by an approximately 70-foot-thick clay stratum referred to as C2. The sheet piles at Site 8 are keyed into the C2 stratum. This zone historically contained low concentrations of several volatile organic compounds that were attributed to the cracked casing of a monitoring well, which has since been plugged.

The third aquifer is a major aquifer for the region. This aquifer is present several hundred feet below the site and has not been impacted by site activities.

Key: SP=Sheet Pile SC=Source Control Performance Rating: X=Insufficient data to determine if remedial objectives were met



Site 8

FIGURE 1
SITE PLAN

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3.0 NATURE AND EXTENT OF CONTAMINATION

Liquids and sludges disposed of on site contained a wide variety of organics, metals, and polychlorinated biphenyls (PCB), including the following:

- Volatile organic compounds (VOC), including benzene, toluene, ethylbenzene, chloroform, dichloroethanes, and vinyl chloride (up to 400 mg/L for a single contaminant)

- Pentachlorophenol (up to 750 mg/L)

- Numerous base/neutral organics (up to 5,000 mg/L)

- Pesticides (up to 20 mg/L)

- Metals (up to 5,000 mg/L for a single metal)

The shallow aquifer is contaminated with dissolved phase and DNAPL to a depth of approximately 50 feet bgs. The dissolved-phase plume extends about 1,000 feet off site to the south.

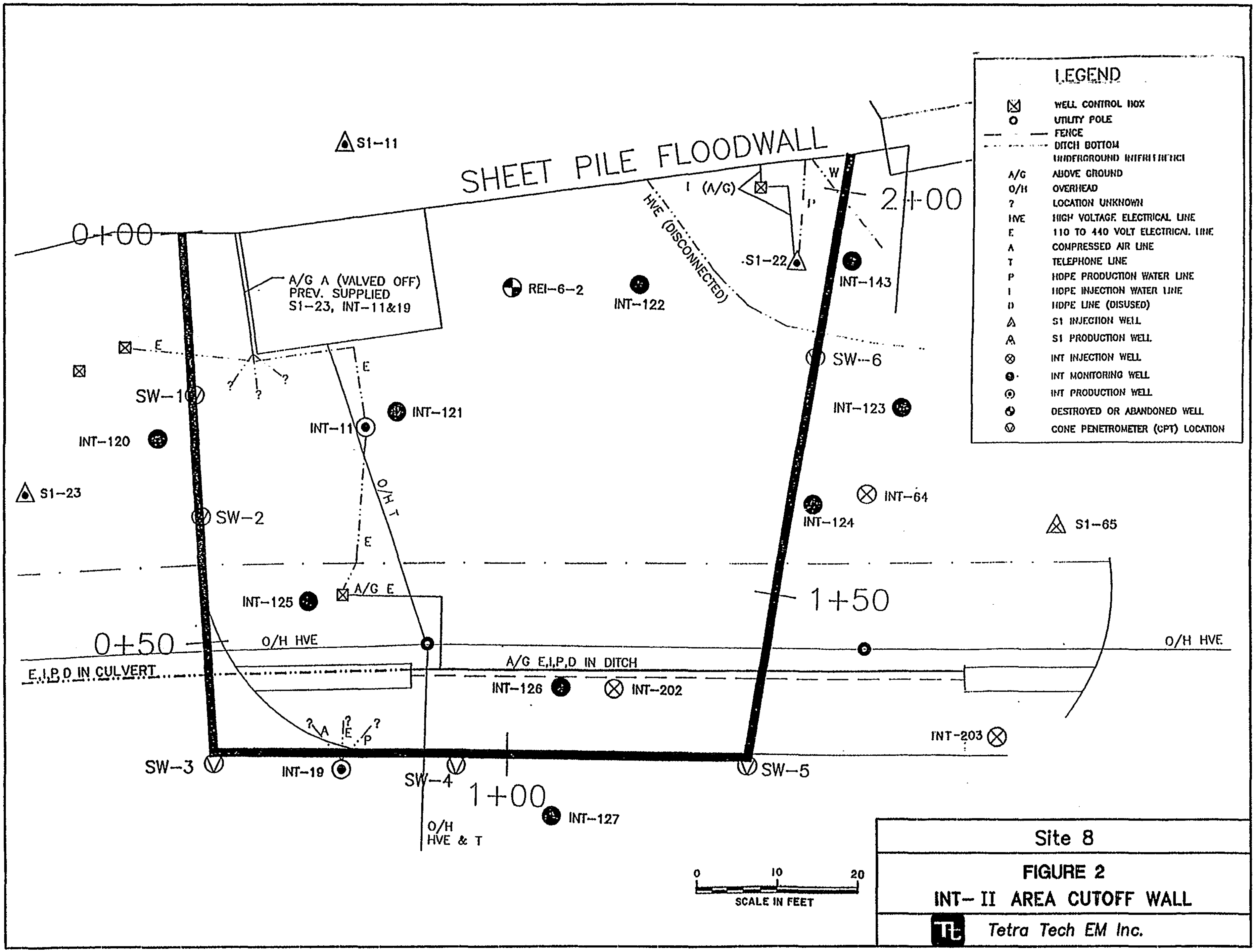
4.0 CONTAINMENT REMEDY

A record of decision (ROD) for the site was signed on March 24, 1988. The remedy for the site includes (1) in situ biodegradation of sludges and contaminated soils, (2) recovery and treatment of contaminated groundwater, (3) flood control measures to isolate the site from the 100-year flood plain of the nearby river, and (4) a slurry wall to restrict migration of contamination in the shallow aquifer below the main waste lagoon. In 1989, flood waters from the river inundated the site. As a result, plans for flood control were accelerated. A combined flood and migration control wall to be built of steel sheet piling was designed.

The sheet-pile barrier, which surrounds the lagoon as shown in Figure 1, was completed in 1990 and is referred to as the flood wall. The flood wall consists of 16 H-piles for the access gate foundation and 996 sheet-pile pairs for the perimeter. The total length of the flood wall is approximately 2,900 feet. The top of the flood wall is 3 feet higher than the 100-year flood level. The bottoms of the 65- to 75-foot-long sheet piles are keyed into the clay stratum underlying the INT zone.

In 1993, DNAPL was discovered in recovery well INT-11, which is south and outside of the flood wall. Following this discovery, a focused investigation and feasibility study concluded that a second sheet-pile wall referred to as the INT-11 area cutoff wall should be built to contain potential DNAPL migration from this area. The second wall, which is shown in Figure 2, is 205 feet long and is keyed a minimum of 5 feet into the C2 stratum underlying the INT zone. This wall was completed in June 1994.

Remediation of the lagoon sludges has been completed, and in situ bioremediation of the alluvial groundwater in the S1 and INT zones continues. The groundwater remediation system includes a network of pumping and injection wells located inside and outside both walls; nutrient levels in the subsurface are maintained through use of the injection wells.



Site 8

FIGURE 2
INT- II AREA CUTOFF WALL

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5.0 PERFORMANCE EVALUATION

The primary design objective for the flood wall was flood control, and consequently most of the design effort was apparently focused on flood control. No specific monitoring procedures have been identified that evaluate the effect of the flood wall on contaminant or DNAPL migration. The primary design objective for the INT-11 area cutoff wall, however, was to prevent DNAPL migration from this area. Focused testing has been conducted to evaluate the performance of the INT-11 area barrier.

The following subsections summarize flood wall and INT-11 area cutoff wall performance.

5.1 DESIGN

The design of the flood wall was rated below average in terms of being a subsurface containment barrier, and the INT -11 cutoff wall was rated average with respect to the industry practices described in Section 3, Volume I. The design report for the flood wall acknowledges that there are inherent difficulties in sealing the interlock between piles. Thus the designs for both walls did not include sealing of the sheet interlocks. The flood wall design report does not address potential subsurface dissolved-phase or DNAPL contaminant migration through the sheet-pile interlocks. However, the design report does assume that (1) installation of the sheet piling through the depth of the shallow aquifer would immediately reduce the flow of groundwater under the lagoon; and (2) within 2 to 4 months, groundwater flow through the sheet-pile joints would be further reduced to a minimum by the natural rust formation and silt blockage that would occur in the joints.

The design report addresses the corrosion potential of the steel pilings and determines that cathodic protection would be unnecessary.

The flood wall design effort included a thorough geotechnical investigation involving drilling of soil borings and cone penetrometer testing along the barrier alignment. Soil samples were collected and tested for electrical resistivity, gradation, plasticity, moisture content, undrained shear strength, and unconsolidated-undrained triaxial compression. The geotechnical evaluation focused on the following items:

- Lateral stability
- Sheet-pile driveability
- Construction considerations
- H-pile foundations
- Earthwork

For the INT-11 area cutoff wall, a target permeability of 1×10^{-7} cm/sec was established.

5.2 CONSTRUCTION QUALITY ASSURANCE AND CONSTRUCTION QUALITY CONTROL

CQA could not be rated from the available information. For the flood wall, construction quality control (CQC) activities consisted of (1) observing the driving of H-piles and sheet piles, including the numbers of blows, general placement, batter, and vertical alignment; and (2) observing the driving resistance of the bottom 15 feet of selected sheet-pile pairs (the frequency was not specified). Driving resistances generally ranged from 50 to 150 blows per foot but were as high as 300 blows per foot in a few rare cases.

The visual observations indicated that the high driving resistances did not appear to cause damage to the sheet piles. However, damage to the top of sheet piles was generally associated with a sheet-pile pair that had become interlocked with an adjoining sheet. In these cases, twisting and bending of the top 6 to 12 inches of the sheet piles were observed.

5.3 MONITORING

Monitoring was rated below average because specific monitoring protocols to evaluate the performance of both walls as migration control barriers do not appear to have been established. Monitoring for DNAPL migration is limited to detection of DNAPL in site wells.

Both walls create hydraulic barriers, and water levels are typically lower inside the walls than outside. However, gradient reversals resulting from use of groundwater recovery wells inside and outside both walls, variable pumping rates, as well as intermittent pumping have been documented.

Mobile DNAPL is known to exist in the shallow aquifer within the flood wall, and nonmobile DNAPL residue exists within the INT-11 area cutoff wall. Additionally, the remediation system designers have acknowledged that additional areas of DNAPL may be identified through normal system operation and that such areas may require other remedial actions in the future.

A permeability certification test was conducted on the INT-11 area cutoff wall after construction was completed. On August 22, 1994, all recovery and injection wells within a 120-foot radius of the INT-11 cutoff wall were turned off to establish baseline conditions. The test was conducted from August 31 through September 14, 1994. Tests were conducted on each of the three sides of the wall (east, south, and west). For each test, one well near the center of each side was either pumped or injected, and groundwater elevations on both sides of the wall were monitored. Each test consisted of a pumping or injection phase followed by a recovery phase. However, this test was inconclusive because cyclic pumping at wells outside the 120-foot radius affected groundwater levels in the S1 and INT zones during the test. Therefore, a modeling approach was used to evaluate the wall's permeability. The field test was simulated using Visual MODFLOW and by applying a sensitivity analysis for the wall's effective permeability to determine the best fit for the observed data. The modeled permeability certification test indicated that the effective permeability of the INT-11 area cutoff wall is 1×10^{-10} cm/sec. The certification test further indicated that this result is equivalent to 1×10^{-9} cm/sec for a conventional, 2.5-foot-thick, slurry wall. Based on this test, the INT-11 area cutoff wall meets the target permeability value of 1×10^{-7} cm/sec. However, an oversight contractor for the U.S. EPA reviewed the sensitivity analysis and determined that (1) the 1×10^{-10} cm/sec result is not necessarily conclusive and (2) a result of 2.3×10^{-7} cm/sec is also valid but not necessarily conclusive.

In June 1995 (five years after installation), a section of the flood wall was exposed by excavation and inspected using visual and ultrasonic techniques. The inspectors reached the following conclusions:

- No evidence of seepage was observed at wall joints despite a 103-inch head differential across the wall.
- No evidence of corrosion was observed.
- Ultrasonic surveys provided no evidence of wall corrosion.

- The wall thickness equaled or exceeded the original wall thickness; in some areas, wall swelling had been caused by pile driving.

5.4 Operation and Maintenance

The corrosion potential of site soils has been evaluated, and it has been determined that the corrosion potential is not significant. However, the remediation system designers have acknowledged that cathodic protection may be needed in the future.

5.5 Other Considerations

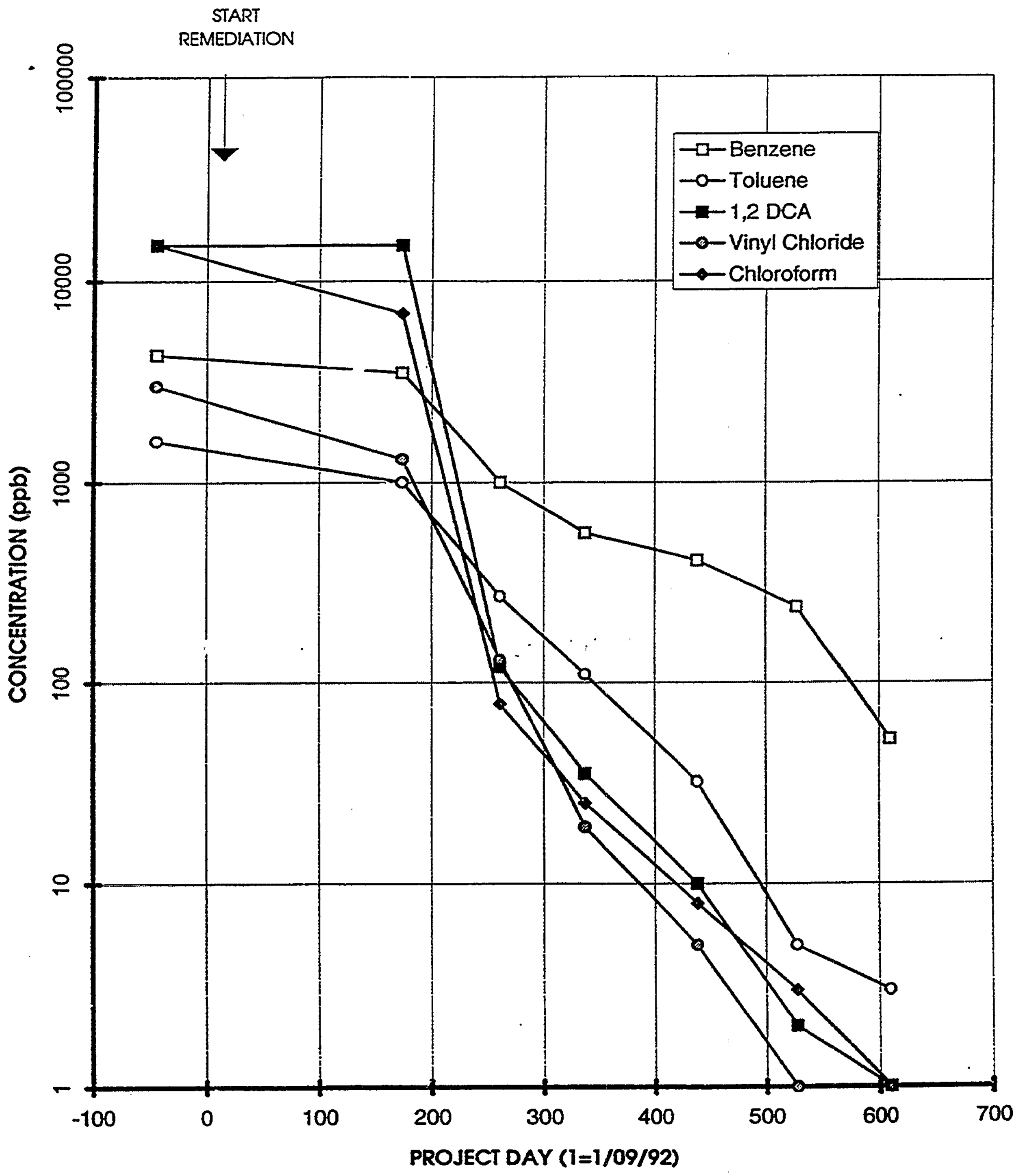
No other significant performance factors were identified or evaluated.

5.6 Remedy Performance

Overall, groundwater chemistry and elevation data indicate that the groundwater remediation system at the site is successful in terms of both contaminant migration control and contaminant recovery. Figure 3 illustrates how VOC concentrations have decreased since groundwater remediation began in 1992. The site's first 5-year review has been completed, and the 5-year review report indicates that DNAPL and DNAPL residues are contained by the flood wall and the INT-11 area cutoff wall. Remediation of the lagoon sludges and soils is complete. The former lagoon has been filled with soil and vegetated. The groundwater remediation system is operating. However, future remedial actions may be necessary to address the continued presence of DNAPL in the subsurface.

6.0 SUMMARY

Two sheet-pile walls have been used at the site in conjunction with a groundwater remediation system to prevent migration of contaminated groundwater and DNAPL away from source areas. Overall, the entire remediation system at this site, of which the barriers are only part, is achieving its objectives. However, there does not appear to be an adequate monitoring system to determine the effectiveness of the barriers in controlling contaminant migration. In addition, the sheet-pile wall designers have acknowledged inherent difficulties in sealing the underground interlocks, although modeling and visual inspection indicate low permeability and no evidence of leaking.



Site 8

FIGURE 3
VOC REDUCTION IN GROUNDWATER
WELL S-106

Tetra Tech EM Inc.

SITE 9

Barrier Type	SB
Remedial Objective	SC; Hydraulic containment
Performance	X

1.0 SITE DESCRIPTION AND HISTORY

Site 9 is located in northeastern United States and covers about 371 acres. The site is bounded by a residential community, primary and secondary roadways, and wetlands.

The site functions as a sanitary landfill for waste disposal. Landfilled materials included vegetable and animal wastes as well as food processing and industrial wastes. Fill was placed at the site from the early 1960s until the mid-1970s. The current operating authority began operations at the site in 1980. To support continued landfilling operations at the site, a subsurface barrier wall and a leachate collection system were proposed and constructed in 1995 to contain on-site leachate and groundwater. The site location is shown in Figure 1.

2.0 GEOLOGIC AND HYDROGEOLOGIC SETTING

The site is located on the Atlantic and Gulf Coastal Plain. The site is underlain by Triassic sedimentary rocks. These rocks consist of reddish-brown sandstone, shale, siltstone, and conglomerate.

The regional geology of the site area is characterized by a deep bedrock trough that is about 1 mile wide in the vicinity of the landfill. Glacial till covers the bedrock over most of the region and averages 25 feet in thickness. Varved silts and clays were deposited over the glacial till. A "sand sheet" of glaciofluvial sediments lies over the varved silts and clays.

The groundwater system in the site area consists of a series of alternating aquifers and aquicludes conforming to the dip of the bedding planes. The water-bearing fractures in each aquifer are generally continuous, but hydraulic connection between individual aquifers is poor. Pumping test data indicates that the direction of highest hydraulic conductivity parallels the strike of the beds.

The average laboratory permeability of the varved silts and clays is 9×10^{-7} centimeters per second (cm/sec). The average laboratory permeability of the sand sheet is 1×10^{-6} cm/sec.

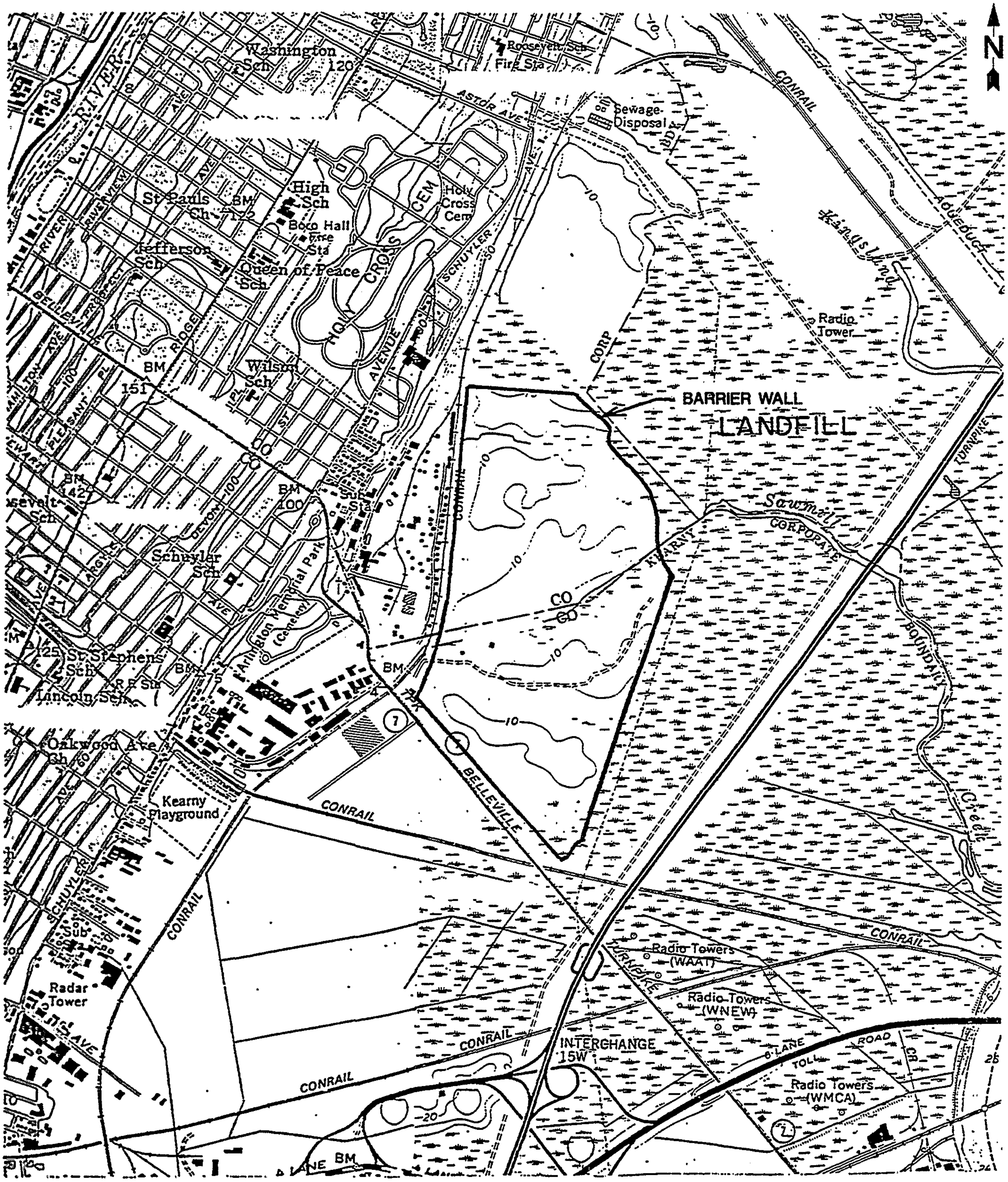
3.0 NATURE AND EXTENT OF CONTAMINATION

Site groundwater contains elevated levels of total dissolved solids, chemical oxygen demand (COD), chlorides, and metals, as shown below.

- Total dissolved solids up to 7,800 mg/L
- COD up to 2,500 mg/L
- Chlorides up to 4,600 mg/L
- Iron up to 89 mg/L
- Lead up to 2,000 mg/L
- Copper up to 100 mg/L

Off-site groundwater contamination has not been found at levels requiring remedial action.

Key: SB=Soil Bentonite Wall SC=Source Control Performance Rating: X=Insufficient data to determine if remedial objectives were met



Site 9

FIGURE 1
SITE LOCATION

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4.0 CONTAINMENT REMEDY

The remediation objective was to prevent off-site migration of leachate and groundwater. Therefore, a leachate collection system, pumping station, transfer line, and slurry trench cutoff wall were constructed at the site in 1995. The implemented remedy involved active containment and had the following general features:

- A subsurface barrier wall that is about 18,000 linear feet; 15 to 45 feet deep; 3 feet wide and that has a 3-foot key
- A leachate collection system that is about 9 to 17 feet deep and that has a 16- and 20-inch diameter high density polyethylene (HDPE) pipe
- A leachate transfer line (12-inch diameter, HDPE pipe)
- A leachate pumping station structure
- Four inclinometers

5.0 PERFORMANCE EVALUATION

The performance of the barrier is not monitored because of the current active status of the landfill. The operating authority is connecting the site leachate collection system to the local wastewater treatment system. Until the connection is completed, leachate will not be collected. Containment system performance and contributing factors are described further in the following subsections.

5.1 Design

The barrier design was rated acceptable with respect to industry practices described in Section 3, Volume I. The design generally followed established U.S. Army Corps of Engineers guidance. Significant positive features of the design effort included constant trench-side inspections of the trench and key depth. Additionally, the backfill was completely composed of off-site soil and sodium montmorillonite bentonite. Backfill was mixed in a mobile pugmill, which was used to optimize the characteristics of the backfill. No cap has been constructed at the site.

5.2 Construction Quality Assurance and Construction Quality Control

Barrier construction quality assurance (CQA) and construction quality control (CQC) were rated acceptable. Generally, the CQA/CQC procedures conformed to established industry practices. Before construction, the contractor performed backfill-leachate compatibility testing to determine the optimum backfill mixture for the site.

5.3 Monitoring

For an operating solid waste landfill, site groundwater quality must be monitored according to a plan approved by the state regulatory agency. Monitoring wells have been installed outside the barrier, but no monitoring of the barrier or groundwater is being performed to assess the containment system's performance. Leachate is not currently being pumped from the site.

5.4 Operation and Maintenance

Cost or any other significant information for the site is not available.

5.5 Other Considerations

The operation and maintenance related information of the site is not available.

5.6 Remedy Performance

The overall performance of the barrier could not be determined because of the lack of monitoring.

6.0 SUMMARY

Site 9 is located in northeastern United States and covers about 371 acres. The site functions as a sanitary landfill for waste disposal. Landfilled materials include vegetable and animal waste, as well as food processing and industrial wastes. The site is underlain by Triassic sedimentary rocks. The groundwater system in the site area consists of a series of alternating aquifers and aquicludes conforming to the dip of the bedding planes. The water-bearing fractures in each tabular aquifer are generally continuous, but hydraulic connection between individual tabular aquifers is poor. Pumping test data indicates that the direction of highest permeability parallels the strike of the beds. Site groundwater contains elevated levels of total dissolved solids, COD, chlorides, and metals. To prevent further contamination of nearby wetlands and off-site groundwater, a soil-bentonite barrier was installed as part of a containment system that also included a leachate collection and transfer system. The design and CQA/CQC of the barrier were acceptable. Leachate collection and treatment are not yet underway. No performance monitoring of the barrier is currently performed.

SITE 10

Barrier Type	SB
Remedial Objective	SC; Hydraulic gradient
Performance	2

1.0 SITE DESCRIPTION AND HISTORY

Site 10 is located on a several thousand acre facility in the western United States. Hazardous wastes have been deposited on 1,750 acres of the facility. The facility was established in 1942 and has been used to manufacture, test, package, and dispose of various chemical warfare agents, and munitions, rocket fuels, herbicides, and pesticides. In 1947, portions of the facility were used for the manufacture of chlorinated benzenes and the pesticide DDT. After 1970, the facility activities focused on activation of chemical warfare materials by caustic neutralization and incineration. Facility operations ended in the early 1980s.

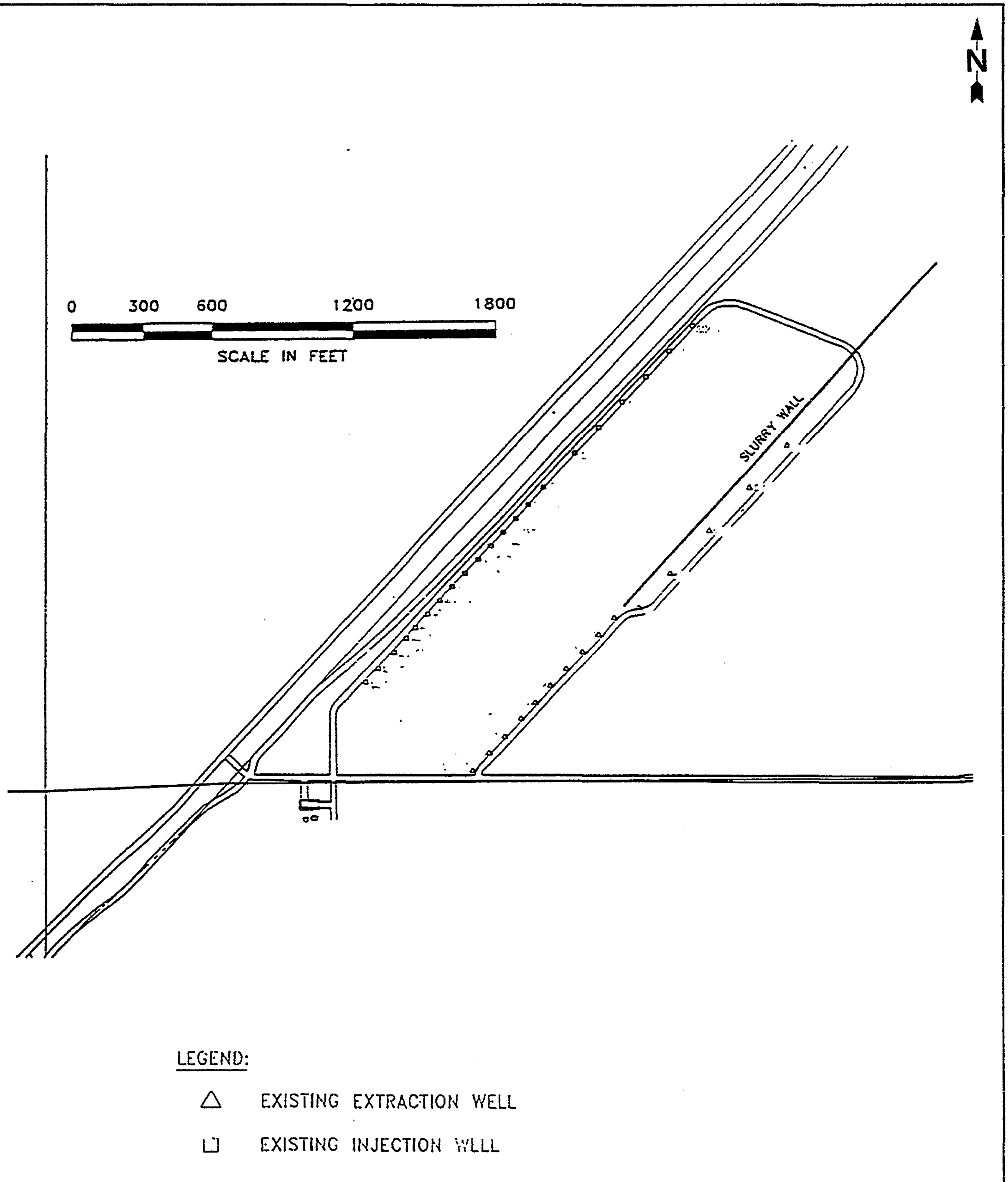
Facility activities resulted in widespread on- and off-site groundwater contamination. The site remedy included installing a hydraulic cutoff wall and a groundwater extraction and recharge system to curtail a contaminant plume migrating off site at the northwestern site boundary (see Figure 1). The cutoff wall was installed in 1983. The groundwater extraction and recharge system became operational in 1984. No cap is present on site.

2.0 GEOLOGIC AND HYDROGEOLOGIC SETTING

The site is located in the high plains groundwater region. The topographic relief at the site is about 200 feet, and the land surface generally slopes northwest toward a nearby river. The overburden consists primarily of alluvial clays, sands, silts, gravels, and some cobbles ranging in thickness from 0 to 70 feet. The underlying bedrock units consist of deltaic shales, claystones, sandstones, and conglomerates. The uppermost bedrock formation lies about 250 to 400 feet below the site and contains occasional lignite beds. The bedrock surface reflects the erosional development of a local river valley during the Quaternary period. Consequently, the bedrock surface is characterized by isolated bedrock highs and numerous paleochannels. The primary contaminant pathway in the site area coincides with two intersecting, alluvium-filled paleochannels in the bedrock surface.

Groundwater is obtained from alluvial deposits and bedrock aquifers, including the underlying bedrock formations in the site area. Bedrock formations constitute important aquifers in the area and are tapped by a large number of stock, domestic, and municipal wells. The alluvial deposits are capable of yielding large supplies of water where they are sufficiently thick and saturated. The uppermost bedrock unit and alluvial aquifers are interconnected and act as a single aquifer regionally, although greater transmissivities generally exist in the alluvial aquifer. The bedrock aquifer is frequently under artesian conditions, causing groundwater in the bedrock to recharge the local alluvial aquifer. Flow in the alluvial aquifers below the site varies from artesian to semiconfined to unconfined. The regional groundwater flow direction is from south to north toward the river. Primary groundwater flow and contaminant transport are in an alluvial sand and gravel aquifer overlying the bedrock unit. This alluvial aquifer is 5 to 20 feet thick in the site area. Transmissivities in the alluvial aquifer range from 33,000 to 405,000 gallons per day per square foot (gpd/ft^2). Hydraulic conductivity values in the alluvial aquifer average 2,365 feet per day (ft/day). A slug test conducted in a bedrock sand lens indicated a hydraulic conductivity of 0.14 ft/day.

Key: SB=Soil Bentonite Wall SC=Source Control Performance Rating: 2=Evidence suggests objective may be met



Site 10

FIGURE 1
SITE FEATURES

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3.0 NATURE AND EXTENT OF CONTAMINATION

Wastes generated from various military and industrial operations were routinely discharged into several unlined evaporation ponds at the facility. This practice continued until 1956 when an evaporation basin with an asphalt liner was constructed. Solid wastes have been burned at various site locations. Chemical spills have occurred in and around the site. These actions have resulted in widespread contamination of groundwater by a host of inorganic and organic contaminants, such as chloride, fluoride, diisopropylmethyl phosphonate (DIMP), dicyclopentadiene (DCPD), dibromochloropropane (DBCP), organosulfur compounds, organichlorine pesticides, volatile aromatic compounds, and volatile organohalogen compounds.

In 1980, a groundwater study indicated that a narrow plume of groundwater containing several contaminants, including DIMP, DBCP, chloride, fluoride, endrin, and dieldrin, was leaving the site from its northern and northwestern areas. Although the contaminants detected in the plume could not be traced back to a particular source on site, they were known to be associated with operation of the disposal basins, chemical manufacturing plants, and waste handling systems.

4.0 CONTAINMENT REMEDY

The remedial objective at the site was to capture and remove organic contaminants, particularly DBCP, from the groundwater crossing the site boundary. A combination of groundwater extraction and recharge system and a 1,425-foot-long, 3-foot-wide soil-bentonite cutoff wall was installed along the northwestern site boundary to intercept the contaminated groundwater. The cutoff wall is keyed at least 5 feet into the unfractured and unweathered shale of the bedrock. Any sandstone encountered below the alluvium was removed. The average depth of the cutoff wall was about 52 feet below ground surface (bgs). Groundwater is pumped from a row of extraction wells on the northwestern side of the site, treated by a carbon adsorption system, and returned to the aquifer through recharge wells.

A total of 15 wells are used to extract groundwater. Ten extraction wells have a design pumping rate of 100 gallons per minuet (gpm) each. The remaining extraction wells are designed to pump at 25 gpm each. A total of 21 recharge wells are drilled 5 feet into bedrock. The cutoff wall was installed in 1983. The groundwater extraction and recharge system became operational in 1984.

In 1989, low concentrations of contaminants were detected in off-site groundwater near the cutoff wall. Field investigations conducted in 1990 revealed that (1) an alluvial channel was acting as a pathway for groundwater in the alluvial aquifer to move around the cutoff wall and (2) a plume containing low concentrations of dieldrin was present southwest of the cutoff wall. As a result, the existing cutoff wall was extended about 650 feet to the northeast in 1990, and two additional extraction wells were installed south of the cutoff wall in 1991. The cutoff wall extension was 3 feet wide and was keyed at least 5 feet into the underlying bedrock (or less if the bedrock could not be excavated to this depth). Pumping rates for the two additional extraction wells averaged about 1 and 2 gpm.

5.0 PERFORMANCE EVALUATION

The cutoff wall and the groundwater extraction, treatment, and recharge system were jointly designed to intercept and treat contaminated and potentially contaminated groundwater that flows toward and across the northwestern site boundary and to return treated groundwater to the aquifer. Groundwater quality data indicates that the initial systems were only partially effective: contaminants were flowing around the wall and off site. Modifications to the systems appear to have halted off site migration of contaminants. Containment system performance and contributing factors are described further in the following subsections.

5.1 Design

The cutoff wall design was rated acceptable based on industry standards discussed in Section 3, Volume I. Evaluation of the groundwater extraction and recharge system is not within the scope of this study; however, the design of the groundwater extraction and recharge system appears to be acceptable. The design of the cutoff wall and the groundwater extraction and recharge system was based on the results of a groundwater modeling effort.

5.2 Construction Quality Assurance and Construction Quality Control

The construction quality assurance (CQA) and construction quality control (CQC) of the cutoff wall were rated better than acceptable. Backfill slump and gradation testing were measured once for every 300 cubic yards. Trench depth soundings were conducted every 10 feet. Bentonite slurry density, filtration, slump, and sand content were measured at least twice each day. A slump of 3 to 6 inches was considered acceptable. Slurry viscosity was determined once or twice each day with a minimum required reading of 40 seconds. Backfill's hydraulic conductivity was measured every 200 feet.

5.3 Monitoring

The performance monitoring program was rated acceptable. Groundwater elevation is measured in 150 wells; groundwater quality data is obtained for 21 monitoring wells located on both sides of the cutoff wall. Both groundwater elevation and quality data is collected quarterly.

5.4 Operation and Maintenance

No information on operation and maintenance activities and associated costs was available for review.

5.5 Other Considerations

The construction cost estimate for the 650-foot cutoff wall extension was $242,000. The construction costs for the original cutoff wall were not available.

5.6 Remedy Performance

The original containment remedy system—a combination of groundwater extraction and recharge wells and a 1,425-foot-long cutoff wall—was only partially effective. Site investigations following implementation of the original containment remedy revealed (1) an alluvial channel that was allowing contaminants to flow around the existing wall and off site and (2) an additional dieldrin plume located southwest of the groundwater extraction wells. Modifications to the original containment remedy—including extension of the cutoff wall 650 feet to the northeast—appear to have halted contaminant migration off site.

6.0 SUMMARY

Site 10 is located on a 17,000-acre facility that was used to manufacture, test, package, and dispose of various warfare agents and munitions as well as to manufacture chlorinated benzenes and pesticide. Past waste disposal practices resulted in widespread on- and off-site groundwater contamination with a host of inorganic and organic compounds. The site containment remedy included installation of a 1,425-foot-long cutoff wall and a series of groundwater extraction and recharge wells. Groundwater extracted from the site was treated in a carbon adsorption system before its reinjection. The cutoff wall was installed in 1983; and the groundwater extraction treatment system became operational in 1984. In 1989, contaminants were detected off-site groundwater near the northwestern site boundary; site investigations revealed an additional dieldrin plume southwest of the extraction wells as well as an alluvial channel around the northeastern edge of the cutoff wall. The containment remedy was expanded in 1990 to extend the cutoff wall 650-feet to the northeast and again in 1991, to add two extraction wells. The cutoff wall design and the performance monitoring program were rated about average. The CQA/CQC was rated above average. Contaminant plume migration around the cutoff wall has been controlled through the addition of the northeast wall extension, and recent groundwater quality and hydraulic data indicates that the wall is performing as intended.

SITE 11

Barrier Type	SB,CB
Remedial Objective	SC
Performance	X

1.0 SITE DESCRIPTION AND HISTORY

Site 11 is a Superfund site located in northeastern United States. The site, which contains a landfill, covers about 60 acres. The landfill occupies about 30 acres in roughly an L-shape. The site is bounded to the east by a creek and to the north and west by an operating solid waste complex. A site plan showing basic site features is included in Figure 1.

The landfill operated from 1973 through late 1981 as a municipal solid waste landfill. During its operation, the landfill was permitted to accept sanitary and nonchemical industrial wastes, including sewage sludge. In 1975, an investigation by a state regulatory agency disclosed landfilling of about 95 tons of hazardous chemicals, including heavy metals, phthalates, and vinyl chloride monomers.

The selected remedy for the site includes a composite cap, a subsurface barrier wall, an upgradient groundwater interceptor, a leachate collection and treatment system, disposal of lagoon liquids and sediments, and a gas collection and treatment system. Installation of the containment system was completed in fall 1992.

2.0 GEOLOGIC/HYDROGEOLOGIC SETTING

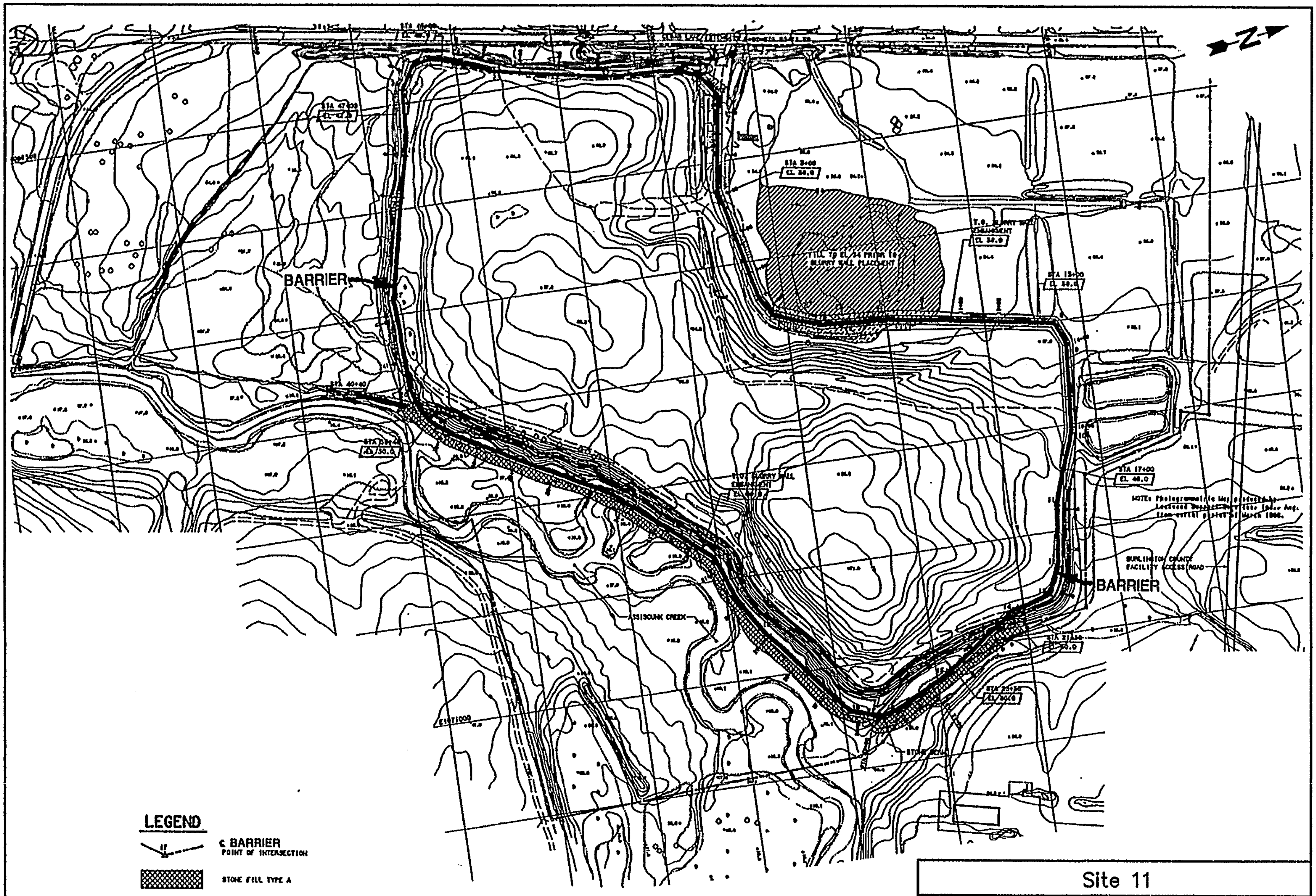
The geologic setting of the site is characteristic of the Atlantic Coastal Plain Physiographic Province and consists of Pleistocene deposits, the Merchantville Formation, and the Raritan-Magothy Formation. During the remedial design, soil borings were drilled at 100-foot intervals along the proposed barrier wall alignment to define subsurface conditions. Three main formations were encountered along the wall alignment. From the ground surface to 10 to 25 feet below ground surface (bgs), a silty clay to clayey sand fill was encountered. The fill was underlain by a 10- to 15-foot-thick, natural alluvial deposit of sandy silt clay to clayey sand. Below this soil was a hard, low-hydraulic-conductivity clay of the Merchantville Formation ranging up to 68 feet in thickness. The subsurface barrier wall was keyed into this clay.

The hydrogeology of the site is characterized by a dual aquifer system consisting of a shallow, water table aquifer in Pleistocene deposits separated from a deep, regional aquifer in the Raritan-Magothy Formation by a relatively impermeable layer of Merchantville Formation. The general flow direction of groundwater within the Raritan-Magothy Formation aquifer is southeast. Because the Merchantville Formation acts as a confining layer, the hydraulic head within the Raritan-Magothy aquifer is artesian, and the potentiometric surface occurs in the Merchantville Formation. The water observed in the Pleistocene deposits was found to occur 12 to 30 feet above mean sea level (msl), and the potentiometric surface in the Raritan-Magothy Formation occurred 2 to 7 feet above msl. However, because the hydraulic conductivity of the Merchantville Formation is low and its thickness is up to 68 feet, any significant hydraulic interconnection between the shallow and deep aquifers was considered unlikely.

3.0 NATURE AND EXTENT OF CONTAMINATION

The main source of environmental concern related to the landfill has been the reported deposition of about 95 tons of hazardous chemicals at the site, including heavy metals, phthalates, and vinyl chloride

Key: SB=Soil Bentonite Wall CB=Cement Bentonite Wall SC=Source Control Performance Rating: X=Insufficient data to determine if remedial objectives were met



Site 11

FIGURE 1
SITE PLAN

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monomers. Sampling and analysis of leachate in landfill wells indicated the presence of volatile organic compounds (VOC) and heavy metals. Leachate seeps have been observed in several areas of the site. Monitoring wells screened for Pleistocene deposit contained VOCs at concentrations ranging from 3 to 232 g/L; in addition, several inorganic constituents were detected at elevated levels. However, monitoring wells screened in the Raritan-Magothy Formation aquifer exhibited groundwater quality similar to that of regional wells, indicating that the overall water quality in the Raritan-Magothy Formation had not been impacted by the waste in the landfill. A limited air quality investigation was performed to determine whether VOCs were being emitted from the site. Two surveys performed to monitor on-site manholes, monitoring wells, and leachate lagoons indicated the presence of total VOCs in air at concentrations ranging from 0 to 40 parts per million (ppm).

4.0 CONTAINMENT REMEDY

The selected remedy for the site involved active containment and had the following general features:

- A soil-bentonite barrier that is about 5,240 linear feet long; 20 feet deep (on average); and 3 feet thick and that has a 3-foot soil key
- A soil-cement-bentonite (SCB) barrier that is about 300 linear feet long; 20 feet deep (on average); and 3 feet thick and that has a 3-foot soil key
- An upgradient groundwater interceptor system
- A manhole network supplemented by four wells drilled into the landfill to reduce leachate levels near the slurry wall
- Removal and disposal of lagoon liquids and sediments
- Landfill gas collection and treatment
- A geomembrane standard RCRA-type cap consisting of compacted clay, a geonet, and protective soil cover

5.0 PERFORMANCE

The performance monitoring plan for the containment is currently being reviewed and is awaiting approval to be implemented. The postconstruction monitoring plan includes initial, quarterly groundwater quality monitoring followed by annual groundwater quality monitoring.

Surface water quality adjacent to the site has improved since installation of the containment system, indicating the general effectiveness of the remedy.

The leachate collection system presently removes the amount of leachate predicted after the completion of the containment system, indicating the effectiveness of the barrier wall and the cap.

Containment system performance and contributing factors are described further in the following subsections.

5.1 Design

The barrier design was rated acceptable compared to industry practices described in Section 3, Volume I. The barrier wall consists of 300 feet of SCB wall along the 10 percent grade alignment and 5,240 feet of soil-bentonite wall around the rest of the site along the alignment grade of less than 2 percent. During SCB wall construction, panels were designed to maintain slurry levels. SCB material is self-hardening, while soil-bentonite materials remain soft and plastic. Significant positive features of the design included installation of alignment borings at 100-foot intervals, testing of more than 54 soil samples, use of a 3-foot soil key, and thorough compatibility testing. No design-level groundwater modeling was performed. Tests of hydraulic conductivity of the backfill material were performed for both the soil-bentonite and SCB walls.

The cap design was rated acceptable. The design included a standard RCRA-type cap. Significant positive aspects of the cap design included installation of enough on-site borings to characterize the fill and its stability and settlement potential.

The pumping system design effort involved conventional piping and pumping design activities.

5.2 Construction Quality Assurance and Construction Quality Control

Barrier construction quality assurance (CQA) and construction quality control (CQC) were rated better than acceptable. The barrier was constructed using centralized mixing and a computerized pugmill to feed and monitor backfill mix components. For the soil-bentonite wall, confirmation testing included drilling and collecting one undisturbed sample for each 100 feet of wall installed. For the SCB wall, one confirmation sample was collected for each 50 feet of wall installed. Based on testing of undisturbed samples collected from the completed barrier, the soil-bentonite and SCB walls met the permeability requirement of less than 1×10^{-7} cm/sec.

5.3 Monitoring

The performance monitoring plan for the site was not evaluated because no formal monitoring of groundwater, surface water, or sediment is currently conducted at the site. The postconstruction containment monitoring plan is presently under review by the state regulatory organization.

5.4 Operation and Maintenance

The operation and maintenance (O&M) plan for the site is being reviewed by the state regulatory organization.

5.5 Other

The costs for the containment totaled $8,900,000. The estimated annual O&M costs total about $1,200,000.

5.6 Remedy Performance

Based on limited evidence, it appears that the remedial objectives may be met. The barrier was determined to be of low permeability, adequately keyed, continuous, and intact based on available CQA/CQC data. Visual surface water monitoring has indicated improvement since barrier completion. The cap has functioned effectively to minimize infiltration. The long-term performance of the containment system can only be evaluated after extended hydraulic head and groundwater quality monitoring is performed.

6.0 SUMMARY

Site 11 is the 60-acre site that includes a 30-acre, former municipal solid waste landfill. Various heavy metals, phthalates, and vinyl chloride monomers contaminate site soils, surface water, and groundwater and some contamination is present in off-site groundwater. The site lies in the Atlantic Coastal Plain Physiographic Province and the geology consists of Pleistocene deposits, the Merchantville Formation, and the Raritan-Magothy Formation. The containment remedy consisted of a soil-bentonite and SCB barrier, a composite cap, a leachate collection and removal system, landfill gas collection and treatment, and groundwater collection and monitoring. The design and CQA/CQC of the barrier were rated acceptable and better than acceptable, respectively. No data is available on CQA/CQC of the cap. Performance monitoring of the barrier has involved a minimal effort to date: only postconstruction sampling and visual inspection of surface water quality have been performed. The remedy's long-term protectiveness can only be measured through future monitoring efforts.

SITE 12

Barrier Type	VBG
Remedial Objective	SC; Reduce leachate generation
Performance	2

1.0 SITE DESCRIPTION AND HISTORY

Site 12 is located on a 17,000-acre facility in the western United States. The facility was established in 1942 and has been used to manufacture, test, package, and dispose of various chemical warfare agents and munitions. In 1947, portions of the facility were used for the manufacture of chlorinated benzenes and the pesticide (DDT). After 1970, primary activities focused on demilitarization of chemical warfare materials. Site operations ceased in the early 1980s.

Site 12 covers a portion of about 1,750 acres of the facility. The site consists of trenches that were used from 1952 to 1965 to dispose of liquid and solid wastes generated from the manufacture of pesticide. Waste disposal in trenches resulted in widespread, on- and off-site groundwater contamination. A cap and a barrier wall were installed at the site in 1991 as a temporary remedy to limit off-site migration of contaminated groundwater. The barrier wall was installed using a vibrating beam technique. The final remedy for the site has not yet been selected. The general site layout, including the locations of the barrier wall and groundwater quality monitoring wells, is shown in Figure 1.

2.0 GEOLOGIC AND HYDROGEOLOGIC SETTING

The site is located within the High Plains Groundwater Region. The topographic relief at the site is about 200 feet, and the land surface generally slopes northwest toward a nearby river. The overburden consists primarily of alluvial clays, sands, silts, gravels, and some cobbles ranging in thickness from 0 to as much as 70 feet. In some places the alluvium is overlain in places by more recent deposits of windblown silt and sands. The underlying bedrock units consist of deltaic shales, claystones, sandstones, and conglomerates. The bedrock displays a gentle regional dip to the southeast.

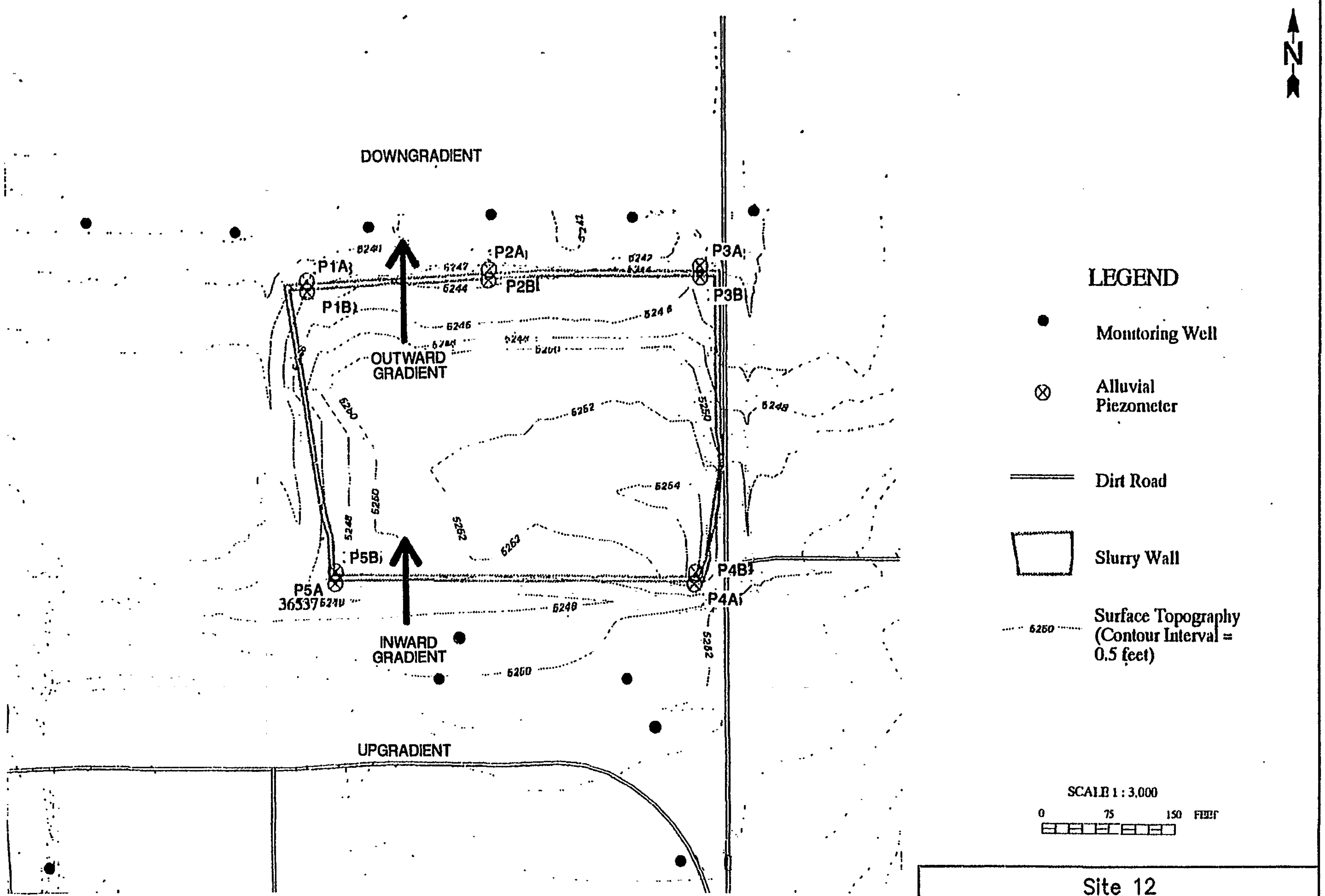
Groundwater is obtained from alluvial deposits and bedrock aquifers in the region. Bedrock formations constitute important aquifers in the area and are tapped by several thousand stock, domestic, and municipal wells. The alluvial deposits are capable of yielding large supplies of water where they are sufficiently thick and saturated. The regional groundwater flow direction is from south to north toward a nearby river.

The site is underlain by up to 10 feet of moderately well sorted, fine-grained, unconsolidated sand of eolian origin. This eolian sand unit is underlain by about 8 to 15 feet of silty clay of eluvial origin. The eluvial clay unit forms a low-permeability layer underlying the eolian sand unit. Bedrock underlies the eluvial clay unit and is composed of siltstones and claystones. The depth to bedrock along the barrier wall ranges from 19 to 26 feet below ground surface. The barrier wall is keyed into the clay unit or the bedrock.

3.0 NATURE AND EXTENT OF CONTAMINATION

Wastes generated from various military and industrial operations were routinely discharged into several unlined evaporation ponds at the facility. This practice continued until 1956, when an evaporation basin with an asphalt liner was constructed. Solid wastes have been burned at various site locations. Chemical spills have occurred in and around the site manufacturing complexes. These actions have resulted in widespread introduction of a host of organic and inorganic contaminants. The organic contaminants detected on site include volatile organic compounds (VOC) such as (1) benzene, (2) ethylbenzene,

Key: VGB=Vibrating Beam Groutwall SC=Source Control Performance Rating: 2=Evidence suggests objective may be met



Site 12

FIGURE 1
SITE FEATURES

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(3) chlorobenzene, (4) xylenes, (5) toluene, (6) 1,1-dichloroethane and 1,2-dichlorethane, (7) methyl chloride, (8) methylene chloride, (9) chloroform, and (10) trichoroethene.

Other site contaminants include chloride, fluoride, diisopropylmethyl phosphonate, dicyclopentadiene, dibromochloropropane, organosulfur compounds, and organochlorine pesticides.

4.0 CONTAINMENT REMEDY

A passive containment system was selected as a temporary site remedy with the objective of reducing generation and lateral migration of leachate from the trenches. A final site remedy has not yet been selected. The passive containment system consists of a barrier wall encircling the disposal trenches and a cap over the area encircled by the barrier wall. The passive containment system has the following features:

- A subsurface barrier wall that is about 2,500 feet long; 19 to 29 feet deep; and 4 inches thick. To minimize generation of strong odors associated with excavation of trenches for installing a subsurface barrier, the barrier wall was constructed using the vibrating beam technique. The southern side and the southern half of the eastern side of the barrier wall were keyed at least 3 feet into the eluvial clay unit, and the rest of the wall was keyed into bedrock to a depth beyond which the vibrating beam could not penetrate.

- A soil and vegetative cover cap for the area encircled by the barrier wall. The cap has about 12 inches of compacted soil fill overlain by 20 inches of uncompacted soil planted with crested wheat grass. The intent of the vegetative cover was to reduce erosion and consumptively utilize soil moisture.

No groundwater extraction or recharge wells are present within the contained area. Construction of the containment system was completed in 1991.

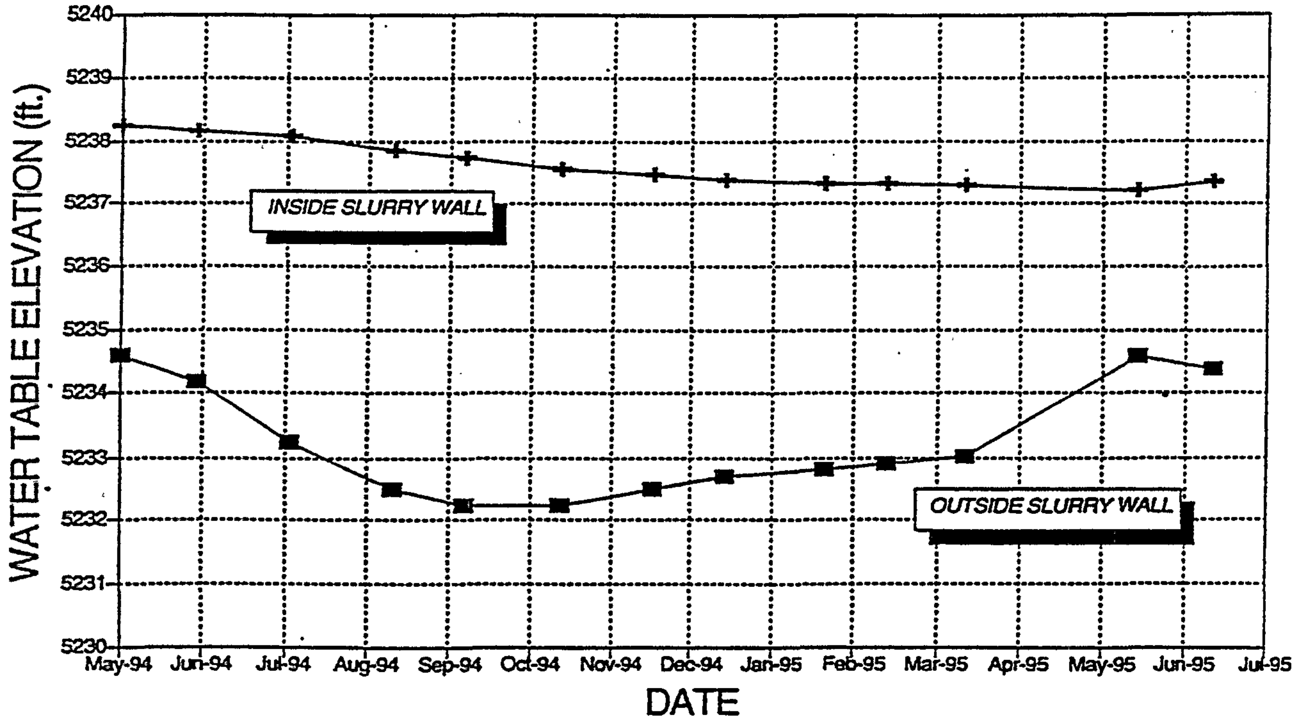
5.0 PERFORMANCE EVALUATION

The objective of the cap and barrier wall are to reduce generation and off-site, lateral migration of leachate from the wastes disposed of in the trenches. The performance of the containment system is monitored using five pairs of piezometers (PW1A/PW1B through PW5A/PW5B) and several groundwater quality monitoring wells located upgradient and downgradient of the contained area.

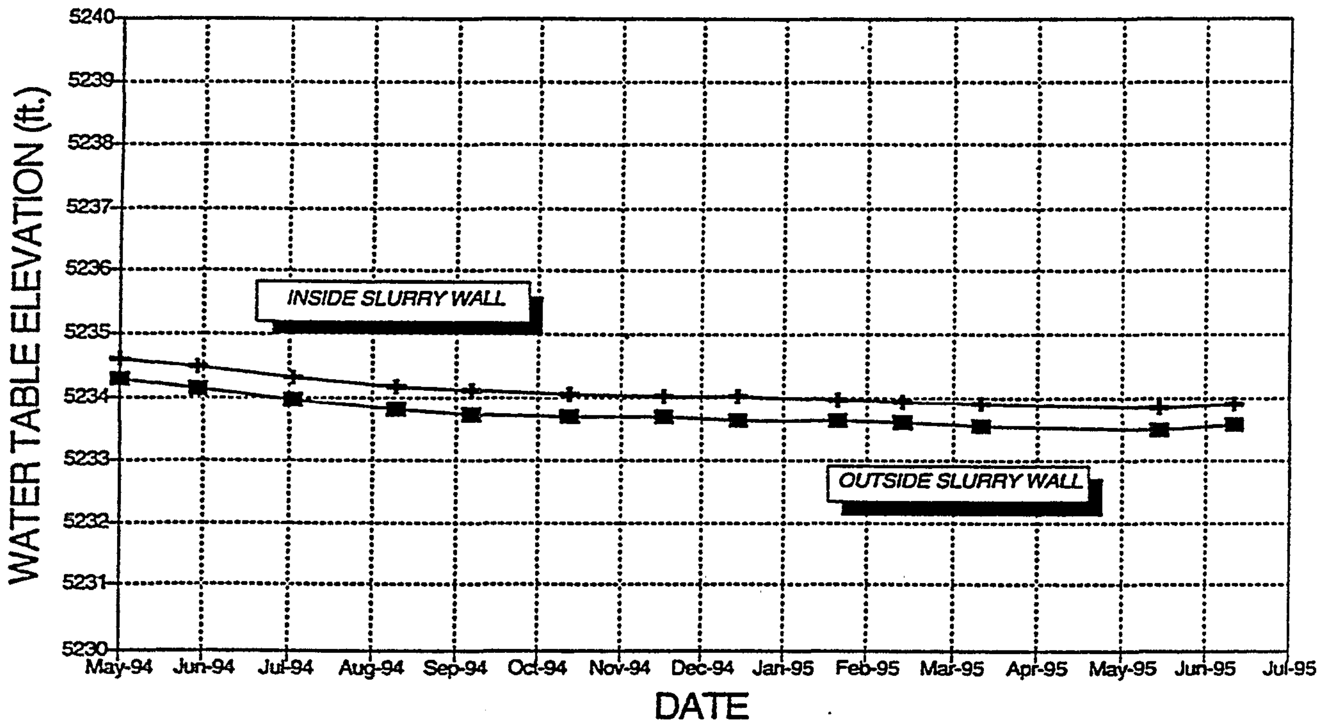
The water level within the contained area has risen because groundwater is not extracted from the contained area. Groundwater levels in piezometer pairs indicate an inward gradient along the southern side of the barrier wall and an outward gradient along the northern side (see Figure 2). The extent of groundwater mounding against the northern side of the barrier wall varies depending on whether the wall intercepts the eolian sand or the eluvial clay. Groundwater quality data for locations upgradient of, within, and downgradient of the barrier wall shows little change in contaminant concentrations over time.

The presence of stable contaminant concentrations downgradient of the wall, and mounding of the groundwater against the northern barrier wall suggest that the cap and wall are limiting the generation and migration of leachate across the site. Containment system performance and contributing factors are discussed further in the following subsections.

PIEZOMETER PAIR 1A/1B



PIEZOMETER PAIR 3A/3B



Site 12
FIGURE 2 **WATER TABLE ELEVATIONS** **VERSUS TIME**
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5.1 Design

The barrier wall design was rated acceptable. A geophysical screening survey was conducted to determine a barrier wall alignment that would minimize the chance of encountering unexploded ordnance or subsurface obstructions during construction. Borings along the alignment appear to have been drilled at spacings of less than 100 feet, based on review of the engineering drawings. The barrier wall was constructed using the vibrating beam technique. The slurry consisted of a stable, colloidal suspension of IMPERMIX, a self-hardening grout. The barrier wall was keyed (1) into bedrock on the northern side, western side, and northern half of the eastern side of the barrier wall to a depth beyond which the vibrating beam could not penetrate, and (2) at least 3 feet into the eluvial clay unit on the southern side and southern half of the eastern side of the barrier wall. No information was available on (1) geotechnical testing, (2) groundwater modeling, or (3) protection from surface loading.

Insufficient data was available to evaluate the design of the soil and vegetative cap. The cap over the area surrounded by the barrier wall was constructed using compacted fill for the bottom 12 inches overlain by 20 inches of uncompacted soil suitable for supporting vegetation. No geomembrane barriers were used. The compacted soil layer was placed before the barrier wall was constructed. The uncompacted soil layer was placed after barrier wall construction was completed; the 20-inch, uncompacted soil layer covers the barrier wall.

5.2 Construction Quality Assurance and Construction Quality Control

The construction quality assurance (CQA) and construction quality control (CQC) for the barrier wall were rated better than acceptable. The wall's continuity and depth were checked by pulling a steel bar (that extended to the bottom of the barrier wall) horizontally during wall installation. Slurry density and viscosity were measured every 2 hours during wall construction, and filtrate loss in the slurry was tested once each day. Hydraulic conductivity was determined at minimum wall spacings of 200 feet. No as-built records for the barrier wall were available for review.

The CQA/CQC for the cap was not evaluated because of lack of information.

5.3 Monitoring

The monitoring program for the site was rated better than acceptable. The monitoring program consists of 11 groundwater monitoring wells and soil moisture, soil erosion, and vegetation monitoring. Water table elevations and groundwater quality are monitored to evaluate the effectiveness of the barrier wall in minimizing lateral flow of contaminated groundwater. Water level measurements from the piezometers paired across the barrier wall are used to determine hydraulic gradients across the wall at five locations. The paired piezometers are located about 10 feet inside and outside the barrier wall. In addition, six soil moisture monitoring stations have been installed inside and outside the wall to evaluate variations in soil moisture in the plant root zone. Soil erosion and vegetation development are monitored because consumption of soil moisture by vegetation is the primary means of minimizing water infiltration at the site.

5.4 Operation and Maintenance

Visual inspections are periodically conducted at the site to evaluate the adequacy of surface water drainage and to identify any erosion or land subsidence that could affect the performance of the cap.

5.5 Other Considerations

The capital cost of installing the barrier wall, cap, and monitoring wells as well as associated road work is estimated to be $1,775,000. The cost of installing the barrier wall is estimated to be $456,000; the cost of installing the cap is estimated to be $432,000. Annual monitoring and maintenance costs, including the costs of sample collection and analysis, water table monitoring, data reporting, health and safety supplies, vegetative cover maintenance, and waste handling, are estimated at $59,000.

5.6 Remedy Performance

Substantial head differences have been established across the northern side of the barrier wall, indicating that the area enclosed by the barrier wall is hydraulically isolated from its surroundings. Although water quality data shows no observable change in the distributions and concentrations of groundwater contamination, water level data suggests that the barrier wall is reducing lateral migration of contaminants emanating from the trenches.

6.0 SUMMARY

Site 12, which is located in the western United States, is part of a 17,000-acre facility that was used to manufacture, test, package, and dispose of various chemical warfare agents and munitions and to manufacture chlorinated benzenes and pesticide. The site consists of trenches that were used from 1952 to 1965 to dispose of liquid and solid wastes generated from pesticide manufacturing. In 1991, a containment system consisting of a barrier wall surrounding the trenches and a vegetated soil cap over the area inside the barrier wall was installed.

The design and CQA/CQC of the barrier wall were rated acceptable and better than acceptable, respectively. The design and CQA/CQC of the cap were not evaluated because of lack of information. The performance monitoring program for the site was rated better than acceptable. Soil moisture data indicates that the cap is appropriate for this climate and is preventing water infiltration into the trenches. Water quality data does not indicate any reductions in contaminant concentrations in groundwater downgradient of the barrier wall; however, water level data indicates that the barrier wall is reducing lateral migration of contaminants emanating from the trenches, which was the principal objective of the containment system.

SITE 13

Barrier Type	SB
Remedial Objective	SC
Performance	2

1.0 SITE DESCRIPTION AND HISTORY

Site 13 is located in the northeastern United States. The site occupies approximately 16 acres of a former gravel pit.

Between 1958 and 1971, household wastes, liquid and semi-solid chemical wastes, and other industrial wastes were buried at the site. The landfill was closed by the State in 1971. The site is bordered on two sides by streams. The wastes have leached out of the embankments of the streams contaminating the surface waters and marsh areas around the streams and the lake into which they discharge. A subsurface barrier wall, cap, and groundwater flushing and treatment system were constructed at the site between 1983 and 1992. Figure 1 shows the general features on the site.

2.0 GEOLOGIC/HYDROLOGIC SETTING

The site is located in the Atlantic and Gulf Coastal Plain. The landfill is underlain by unconsolidated to poorly consolidated fluvial and marine deposits of Cretaceous and Tertiary age. The surficial geologic material is of Upper Miocene age and belongs to the Cohansey Sand Formation. Flow through the Cohansey Sands into the adjacent stream is in the range of 20,000 to 62,000 gallons per day. This layer ranges in thickness from 16 to 55 feet and is separated into the upper and lower Cohansey at the site. Underlying this formation are the silty and clayey sands of Middle Miocene age known as the Kirkwood Formation. This layer is approximately 51 feet thick. Between the two sand units and serving as the top member of the Kirkwood Formation is a dense silty clay zone known as the Kirkwood Clay. Hydraulic conductivity of this layer is approximately 2.8×10^{-4} feet/day. This layer ranges in thickness from 9 to 17 feet and dips to the southeast.

3.0 NATURE AND EXTENT OF CONTAMINATION

The unlined landfill is reported to have received millions of gallons of toxic and hazardous wastes including solvents, paint thinners, formaldehyde, paints, phenol and amine wastes, dust collector residues, resin, and ester press cakes. The contaminants of concern are various volatile organic compounds, semi-volatile organic compounds, and heavy metals.

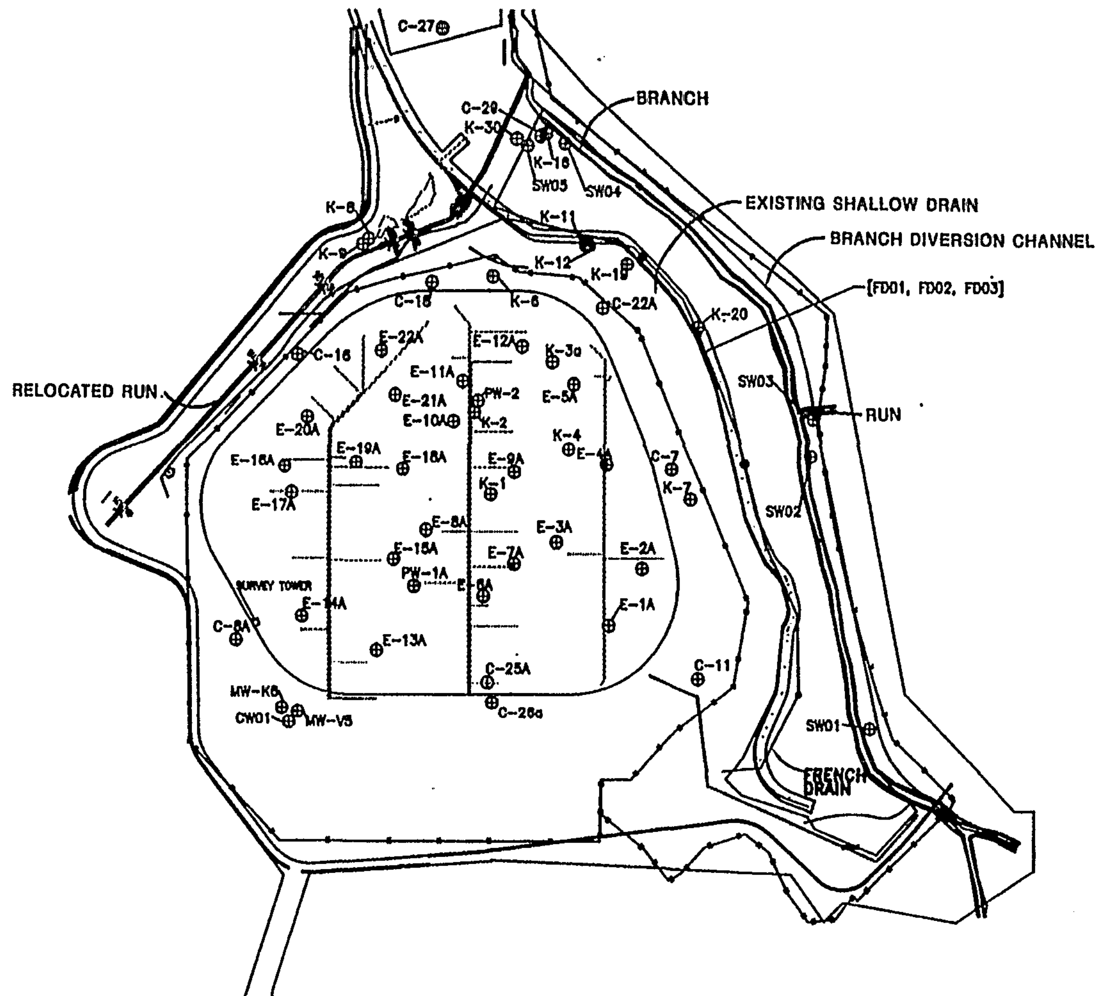
4.0 CONTAINMENT REMEDY

The remedial design outlined by the United States Environmental Protection Agency (USEPA) in their Record of Decision (ROD) called for the mitigation and minimization of the migration of hazardous substances. The following remedial measures were implemented:

- Slurry wall (~8,350 lf, ~20 - 70 ft. deep, ~ 3 ft. thick, 2 ft. minimum key),
- Groundwater flushing/treatment system, Cap (40 mil HDPE, drainage layer, cover soil, vegetative layer),

Key: SB=Soil Bentonite Wall SC=Source Control Performance Rating: 2=Evidence suggests objective may be met

N



LEGEND:

E – Extraction Well
C – Cohansey Well
K – Kirkwood Well
SW – Surface Water Sample
FD – French Drain Sample

Not To Scale

Site 13

FIGURE 1
SITE MAP

Tetra Tech EM Inc.

- Collector system (for seeps and shallow groundwater).

The system was designed to contain waste and allow extraction of contaminated groundwater, treatment, and flushing of the landfill contents with water. The flushing process was intended to accelerate waste degradation and reduce contained source material.

5.0 PERFORMANCE

The performance of the containment system will be determined based on the quarterly and annual groundwater monitoring program of both inside and outside monitoring locations.

The containment system performance and contributing criteria are described further in the following sections.

5.1 Design

Barrier design achieved an average rating relative to established standards. The design followed protocol established by the U.S. Army Corps of Engineers (COE) and was performed by a consultant. Some significant positive features of the design included backfill compatibility testing utilizing site leachate. Additionally, a detailed hydrogeologic investigation of the area was performed. The key at the bottom of the barrier was two feet into the clay layer.

Barrier and containment design were complicated by the site's elevation change and potential differential hydraulic heads across the barrier. The design considered the eventual upgradient mounded water, creating an inward gradient and the down slope outward gradient, creating potential leakage. Head differential was also a design concern because of impacts associated with groundwater extraction and flushing.

Additionally, several remediation systems have been installed outside the barrier to capture leakage. French drain and trench drain systems were installed northeast of the landfill area to capture contaminated groundwater downgradient and outside the barrier. The french drain system replaced an earlier well point system. The french drain was installed to limit the movement of contaminated groundwater into the adjacent marsh area. The french drain captures groundwater from the Lower Cohansey Sands, and as such, shallow groundwater is seeping to the surface along the slope northeast of the containment area. A separate trench drain was installed to capture seepage in the Upper Cohansey and shallow subsurface soils.

The flushing and treatment system removes contaminated groundwater from extraction wells located in the containment area. Water is pumped from the a local clean aquifer and is used to flush the contaminants from the site. This clean water is injected into the contained landfill through injection wells and infiltration trenches. Subsequently, water is extracted and treated at the onsite facility. This water is discharged to the local sanitary sewer. The onsite treatment includes precipitation, flocculation, settling, clarification and filtration for removal of metals; air stripping for removal of volatile organic compounds; and carbon polishing of the liquid stream to remove the remaining less volatile organic compounds.

The cap consists of an HDPE membrane with a drainage layer directly above. A layer of cover soil and top soil were then placed. Access roads are surfaced with crushed stone.

5.2 CQA/CQC

Barrier CQA/CQC was rated slightly above average. Generally, the procedures conformed to the established standard protocol. CQA was performed by the COE. Some significant positive features of the CQA program included backfill sampling performed at a frequency of one per 100 lineal feet of trench, or one sample per 324 cubic yards of backfill. This is an above average frequency for backfill testing. Additionally, preconstruction borings were completed by the Contractor on 100 foot maximum centers along the centerline of the trench alignment. However, slurry viscosity was permitted to be used at 35 seconds, which is less than the industry standard of 40 seconds.

Cap CQA was rated average. The HDPE geomembrane and cover soil cap were installed based on an industry standard specification. Destructive and non-destructive testing was performed to verify the seaming of the geomembrane.

5.3 Monitoring

Monitoring at the site includes quarterly and annual monitoring of wells and surface water locations. Groundwater is tested for metals, volatiles, and semivolatiles. Water in the pumping system is tested daily or weekly at various sampling points for VOAs and BNAs. Figure 2 provides a summary plot of select indicator compounds and changes over time. These are maximum values for the series of wells sampled. The data show a general decrease in contaminant concentrations over time in the zone immediately outside the containment system. This suggests that dissolved contaminant mass outside the containment system has decreased over time and that contaminant migration from the containment system has been limited.

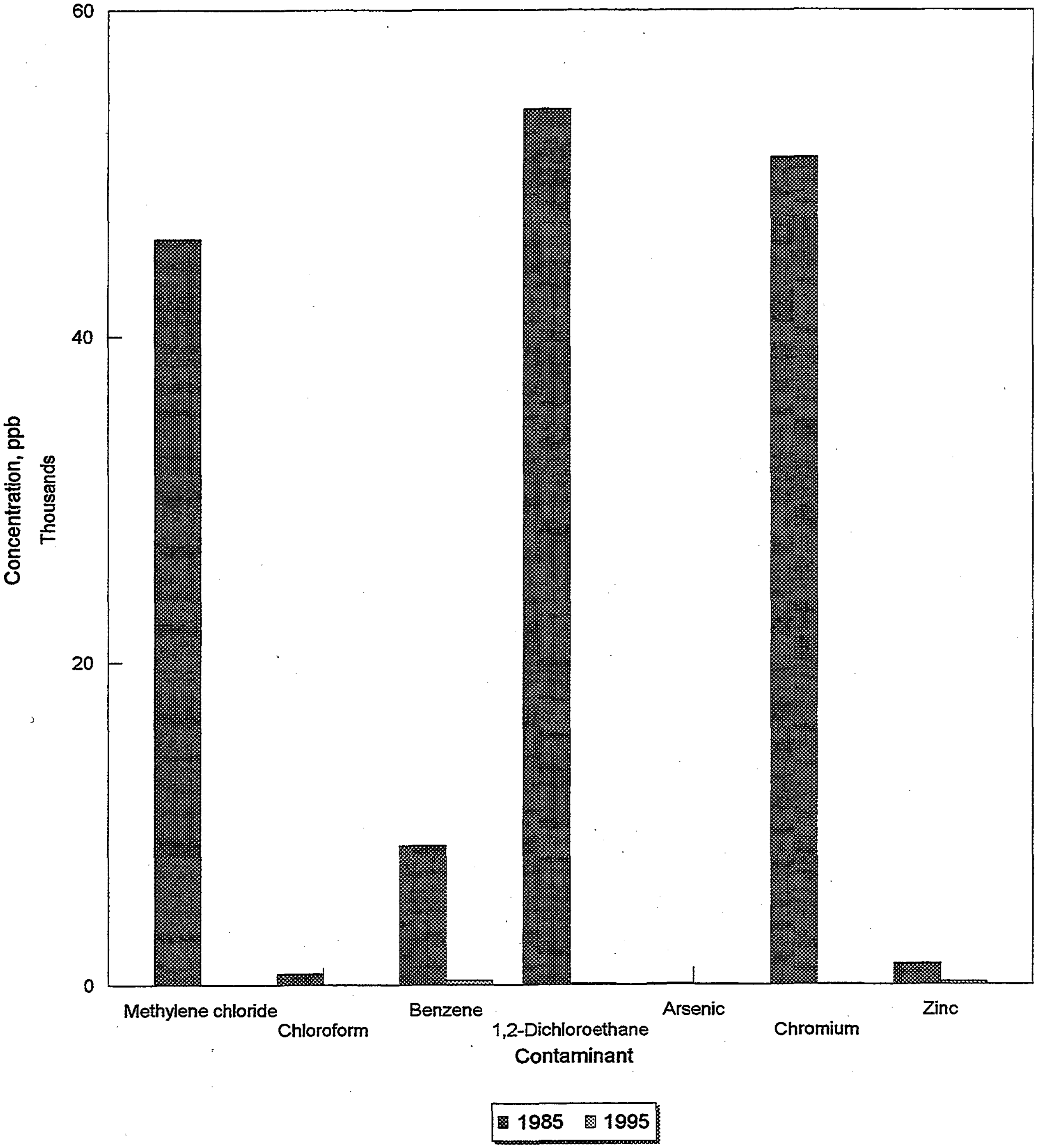
The hydraulic head monitoring indicated an inward gradient is being maintained on the west side of the site. However, an outward gradient is evident on the east side of the site. The outward gradient is primarily due to the site topography and the use of the groundwater flushing system. The flushing system artificially raises the interior groundwater levels, which are subsequently lowered during groundwater extraction. Groundwater levels are measured continuously using a computer system connected to paired piezometers. Figure 3 presents a summary of the hydraulic head across the barrier for select monitoring locations during periods of high hydraulic head differential.

5.4 Operation and Maintenance

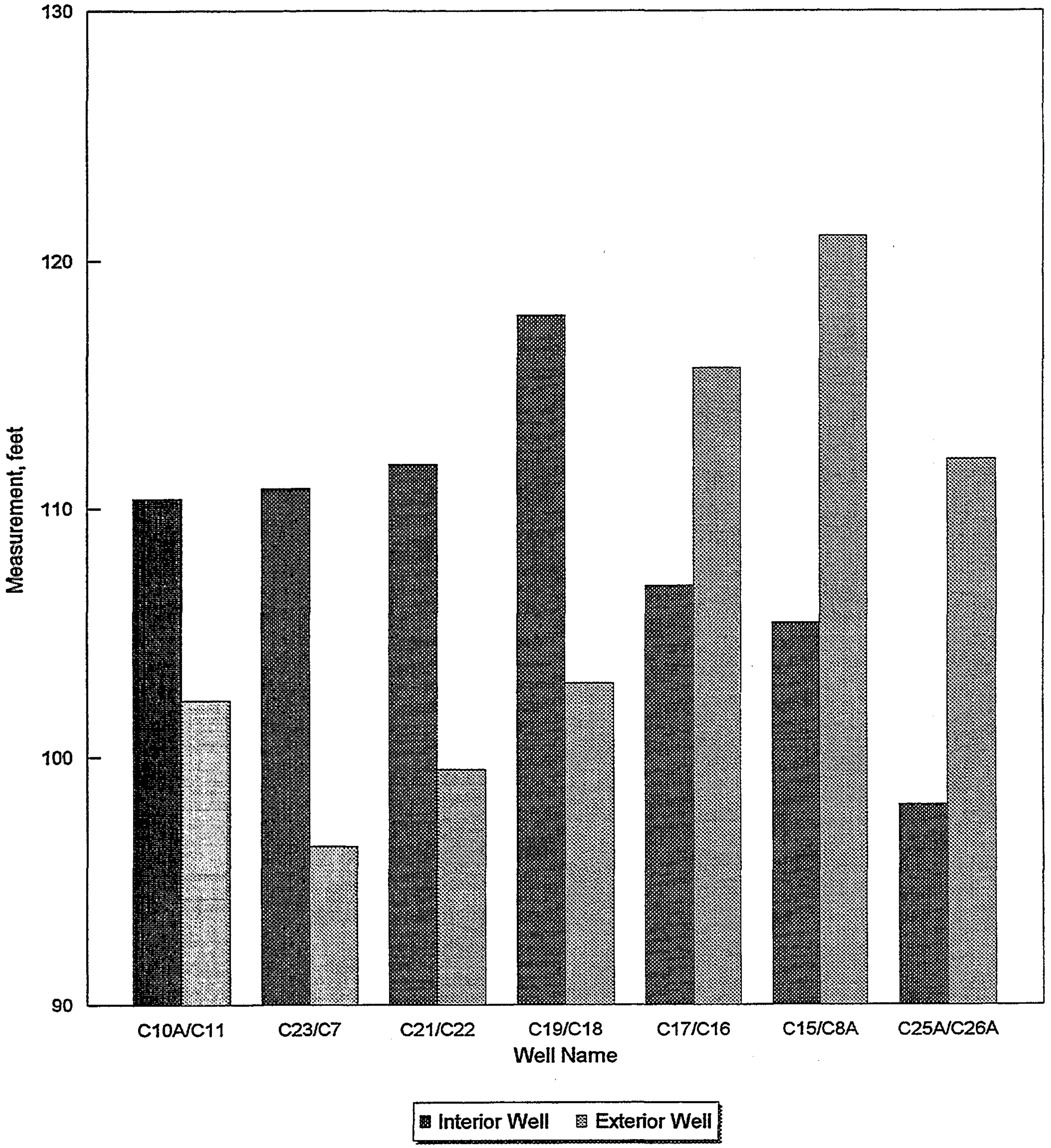
Operation and Maintenance at the site consists of maintaining the groundwater flushing and treatment system and the associated equipment. Regular maintenance of the cap consists of vegetation and erosion control and repair of any damage. No barrier maintenance is performed.

5.5 Cost

Design cost for the barrier and cap was $1.45 million. Construction costs were $3.09 million.



Site 13
FIGURE 2
CONTAMINANT CONCENTRATION vs TIME
Tetra Tech EM Inc.



Site 13

FIGURE 3

MAX HEAD DIFFERENCES ACROSS BARRIER

Tetra Tech EM Inc.

5.6 Remedy Performance

The monitoring system was rated slightly better than acceptable. Monitoring has shown the concentration of site contaminants to be decreasing in the shallow groundwater outside of the barrier while the groundwater flushing and treatment system is functioning to remove contaminated groundwater from the site. The contaminant levels have been gradually decreasing over time as shown above. Decreases are shown on Figure 2. Groundwater head differentials across the barrier are apparently greater than anticipated and have created some operational restrictions and perhaps increased barrier leakage. Groundwater extraction rates have not achieved predicted rates. Reduced groundwater extraction may lengthen predicted cleanup time needed to flush the landfill. Seeps and leakage down gradient from the barrier have been greater than expected but have been controlled with drain systems. Despite operational difficulties, the containment and flushing system continues to manage contamination offsite and slowly reduce contaminants inside the barrier.

6.0 SUMMARY

Site 13 is located in New Jersey and occupies approximately 16 acres of former gravel pit. Between 1958 and 1971, household wastes, liquid and semi-solid chemical wastes, and other industrial wastes were buried at the site. The landfill is reported to have received a variety of hazardous wastes including solvents, paint thinners, formaldehyde, paints, phenol and amine wastes, dust collector residues, resin, and ester press cakes. The landfill was closed by the State in 1971. The remedial design, which called for the mitigation and minimization of the migration of hazardous substances, included a slurry wall, groundwater flushing/treatment system, and cap. Additional groundwater collection systems have been installed outside the barrier to prevent further offsite contamination. Design was acceptable and CQA/CQC of the barrier involved a slightly above acceptable effort. The cap CQA rated average. Despite operational difficulties, the containment and flushing system continues to manage contamination offsite and slowly reduce contaminants inside the barrier.

SITE 14

Barrier Type	PC
Remedial Objective	Hydraulic cutoff
Performance	1

1.0 SITE DESCRIPTION AND HISTORY

The site is an open pit mine in British Columbia, Canada. The depth of the open pit was 850 feet, and was scheduled to reach 1,000 feet. The south pit wall was adjacent to the shore line. Waste rock from the mining operation was disposed in the sea inlet, thereby extending the shore line out up to 3,000 feet. The mine operator wanted to find a way to mine the body of ore behind the south pit wall in order to extend the mining operation. This would require moving the south pit wall through the highly pervious rock waste dump.

2.0 GEOLOGIC AND HYDROLOGIC SETTING

At the location of the remedy, the site geological formations consist of:

- Waste rock dump, with a very an extremely variable matrix from clay size to 4 to 5 feet in diameter. The thickness of this layer was approximately 60 feet

- Beach deposits of 5 to 10 feet thick

- A glacial till layer, approximately 40 feet thick. The very dense till consisted mostly of impervious clay silt material, with some pervious outwash ream

- The bedrock, a massive tuff

The waste fill was extremely pervious. In some zones, its permeability was in the range of 1×10^{-2}cm/sec.

3.0 NATURE AND EXTENT OF CONTAMINATION

No known contamination existed at the site.

4.0 CONTAINMENT REMEDY

The extension of the mining operation southward toward the inlet required the design and installation of a vertical barrier to control seepage into the open pit through the highly pervious waste fill and the somewhat pervious outwash.

The mine operators considered using the grouting or slurry wall technology and after extensive review with specialty designers and contractors decided to control the seepage by means of a slurry wall. The design was based on pushing back the south wall of the pit by 300 feet, thereby allowing the recovery of an additional 83 million tons or ore. The final pit depth was 1,200 feet below sea level (or the lowest point in the world).

Key: PC=Plastic Concrete Wall   Performance Rating: 1=Remedial objective was met

The physical characteristics of the seepage barrier were:

Type of wall: Plastic concrete built by the panel method
Length: 4,100 feet
Depth: 73 feet average, 110 feet maximum
Thickness: 30 inches
Key: 15% of the wall was built on the top of bedrock, the remaining had an 8 foot key in the till material

5.0 PERFORMANCE EVALUATION

5.1 Design

In view of the complexity of the project and the risk involved relative to a safe operation of the mine, the design effort was very extensive. Factors to consider were the stability of the south slope and its deformation, the deformability of the barrier, the risk of piping or blowout through the wall where it was installed through very porous waste, and the overall seepage (in case the wall would fissure as a result of the anticipated slope movement). In addition, the design needed to address the constructability of the wall with respect to the very difficult site conditions. The design included:

- Deformation analysis performed using a finite element analysis stress-strain model. (A onsite test pad was used to determine the elastic modules to use for the loose waste rock dump.) The deflection and settlement of the top of the barrier were determined to be on the order of 1 to 2 and 0.5 inches, respectively

- Seepage analysis

- An extensive backfill mix design including special testing designed to subject the backfill to erosion testing

Final design consisted of the selection of a low strength plastic concrete slurry wall, (28 day unconfined compressive strength of 220 psi), down to bedrock, or with an 8 foot key into the impervious till.

5.2 CQA/CQC

The cutoff wall was installed by a specialized slurry wall contractor, after a very extensive selection process. Severe slurry losses were expected during the wall installation through the very pervious fill. Special procedures were developed and tested in the laboratory as well as in the field prior to the wall installation.

Compatibility tests between the bentonite slurry, mixed with fresh water, and the sea water were conduced prior to the start of the project.

The quality control program during installation of the wall was very extensive to ensure the success of the project, and involved for each slurry wall panel:

- Frequent testing of the new and trench slurry to ensure trench stability

- Control of the verticality and thickness of the wall

- Control of the minimum joint thickness between adjacent panels
- Cleaning of joints between panels
- Examination of the cuttings to ensure proper key
- Cleanliness of the trench bottom prior to backfilling the excavated panels
- Control of the mixing and placement process of the backfill
- Testing of the backfill (for strength, deformability, and permeability)

5.3 Monitoring

The vertical barrier was heavily instrumented including:

- Inclinometers
- Vibrating wire and standpipe piezometers
- Settlement/movement monitoring of the top of the wall and slope
- Measurement of the rates and flow to pump the water from the bottom of the pits

4.4 Performance

This exceptional project was successfully completed. The waste material and beach sand were dewatered in approximately 2 months, corresponding to a drawdown between 40 and 50 feet. Deflection of the barrier and settlement of its top compared with the design predictions. The excavation slope as well as the water flow remained stable during the life of the project.

5.0 SUMMARY

This site is a nonhazardous project.

A highly deformable low strength plastic concrete wall was installed to a maximum depth of 110 feet through very difficult subsurface conditions to prevent sea seepage into a 1,200 feet deep open pit mine. The slurry wall performed as expected for the four year life of the project.

SITE 15

Barrier Type	SB
Remedial Objective	SC
Performance	1

1.0 SITE DESCRIPTION AND HISTORY

Site 15 is a sanitary landfill located in the northeastern United States. It is bounded on the south by a gas pipeline and electrical towers and on the north by railroad tracks and electrical towers. The landfill occupies about 137 acres. A site plan showing basic site features is presented in Figure 1.

The site lies within the Sawmill Creek Basin, which drains into a river located a little over 1 mile east of the site. Originally the entire site was composed of tidal wetlands and mud flats, but portions of the site have been filled over the years. The site vicinity is generally composed of lagoons, mud flats, and marshes.

Phase I of a two-phase landfill improvement program was completed in June 1984 and included construction of the soil-bentonite barrier along the northern, eastern, and southern perimeter of the landfill; leachate drains parallel to the cutoff wall; two leachate pump stations; and a stormwater management system. Phase II of the landfill improvements, which was completed in July 1989, included completion of the barrier; completion of the leachate drain parallel to the wall; and installation of groundwater monitoring wells, piezometers, and inclinometers.

2.0 GEOLOGIC AND HYDROGEOLOGIC SETTING

Subsurface conditions at the site are the result of at least three glacial advances, the last of which created a lake as the glacier melted and retreated northward. Sands and silts were deposited on the bed of the lake, with the fine-grained, suspended clay settling out. The nature of the on-site strata is as follows:

Stratum 1 — Fill on-site is refuse such as paper products, plastics, textiles, and rubber. This fill is 78 to 110 feet thick at the top of the landfill, tapering off to between 9 and 23 feet thick around the landfill. Beyond the limits of the landfill, the first 5 to 12 feet is made up of fill containing primarily soil (sand, silt, gravel, and organic silt) with concrete, brick, wood, and cinder debris.

Stratum 2 — This stratum contains black-brown organic silt, peat, and varying amounts of fibrous material. It is about 15 feet thick. Strata 1 and 2 are often intermixed, as the fill sinks into Stratum 2 because of its softness.

Stratum 3 — This stratum contains gray-silty to clayey sand varying in thickness from 0 to 23 feet.

Stratum 4 — This stratum contains gray-brown varved clay and silt, silty clay, and silt and varies in thickness from 100 to more than 180 feet. This stratum is medium to very stiff 20 feet below mean seal level (msl), medium stiff from 20 to 40 feet below msl, and soft or very soft beneath 60 feet below msl.

Key: SB=Soil Bentonite Wall   SC = Source Control   Performance Rating: 1 = Remedial objective was met


Site 15
FIGURE 1
SITE PLAN
Tetra Tech EM Inc.
EXISTING BARRIER
BARRIER
SOUTH SEDIMENT BASIN

The subsurface cutoff wall was keyed into the Stratum 4 varved clay, which exhibits low hydraulic conductivity. Based on 25 tests, the vertical permeability of Stratum 4 is 1×10^{-7} centimeters per second (cm/sec).

The hydrogeologic setting includes a water-bearing zone overlying the varved clay in Stratum 4. Groundwater flow in Strata 3 is in a westerly direction. Eleven groundwater monitoring wells are installed at the site; some of these are shallow wells, while the rest extend to or into the underlying clay layer. The highest gradient for leachate is in a westerly direction because of the existence of Stratum 3, which is in contact with the landfill refuse.

3.0 NATURE AND EXTENT OF CONTAMINATION

A landfill investigation report evaluated subsurface geology at the site and made recommendations for construction of landfill improvements. One such recommendation included construction of a leachate management system, with a cutoff wall and leachate drain. Also, the state required the site owner to construct landfill improvements in order to contain leachate within the landfill and minimize leachate migration. Significant leachate contaminants include ammonia, arsenic, and some volatile organic compounds (VOC) which are present at levels higher than state groundwater standards.

The primary improvements consisted of measures for leachate management; landfill expansion; and landfill closure, including gas venting and groundwater monitoring. The landfill expansion involved excavating an existing lagoon to about 40 feet below existing grades and raising existing landfill grades.

4.0 CONTAINMENT REMEDY

The remedy for the site consists of achieving an inward gradient and prevent migration of site contaminants. The 3-foot-thick cutoff wall is keyed into the varved clay in Stratum 4. The leachate collection drain is below the normal water level in the adjacent meadowlands. The leachate collection drain was designed to maintain an inward gradient along the perimeter of the landfill and act as a hydraulic barrier to outward movement of leachate. The implemented remedy involved active containment and the following general features:

- A soil-bentonite cutoff wall that is 11,230 linear feet long; 20 feet deep; and 3 feet thick and that has a 2-foot soil key

- A leachate collection system

- Clusters of three piezometers installed both inside and outside the wall at five locations to determine the groundwater response to leachate collection and pumping

- Eleven groundwater monitoring wells, some of which are shallow while the rest extend to or into the underlying clay layer

5.0 PERFORMANCE EVALUATION

Laboratory tests conducted on the cutoff wall samples showed that its permeability meets the 1×10^{-7} cm/sec requirement of the state regulatory organization. Similarly, the subsurface clay that constitutes the base of the landfill meets the permeability requirement of the state regulatory organization. The cutoff wall also is keyed 2 feet into an impervious stratum as required by the state regulatory organization.

The perimeter leachate drain, located inside the cutoff wall, captures leachate and conveys it to a pumping station, which is connected to a sanitary sewer system and treatment plant. The leachate drain creates an inward gradient relative to the surrounding waters. Pumping records indicate that the volume of leachate handled at the pumping station is consistent with the design of the system.

5.1 Design

The barrier design was rated acceptable relative to industry practices discussed in Section 3, Volume I. No design-level groundwater modeling was performed for the containment.

The closure and postclosure plan for the landfill proposes a final cover layer of 1- to 2-foot thick soil. Vegetation support is to be installed over 88 acres of the side slopes of the landfill.

5.2 Construction Quality Assurance and Construction Quality Control

Barrier construction quality assurance (CQA) and construction quality control (CQC) was rated better than acceptable. Cutoff wall and leachate drain construction was completed along the perimeter of the landfill. In addition, installation of groundwater monitoring wells, piezometers, and inclinometers was completed.

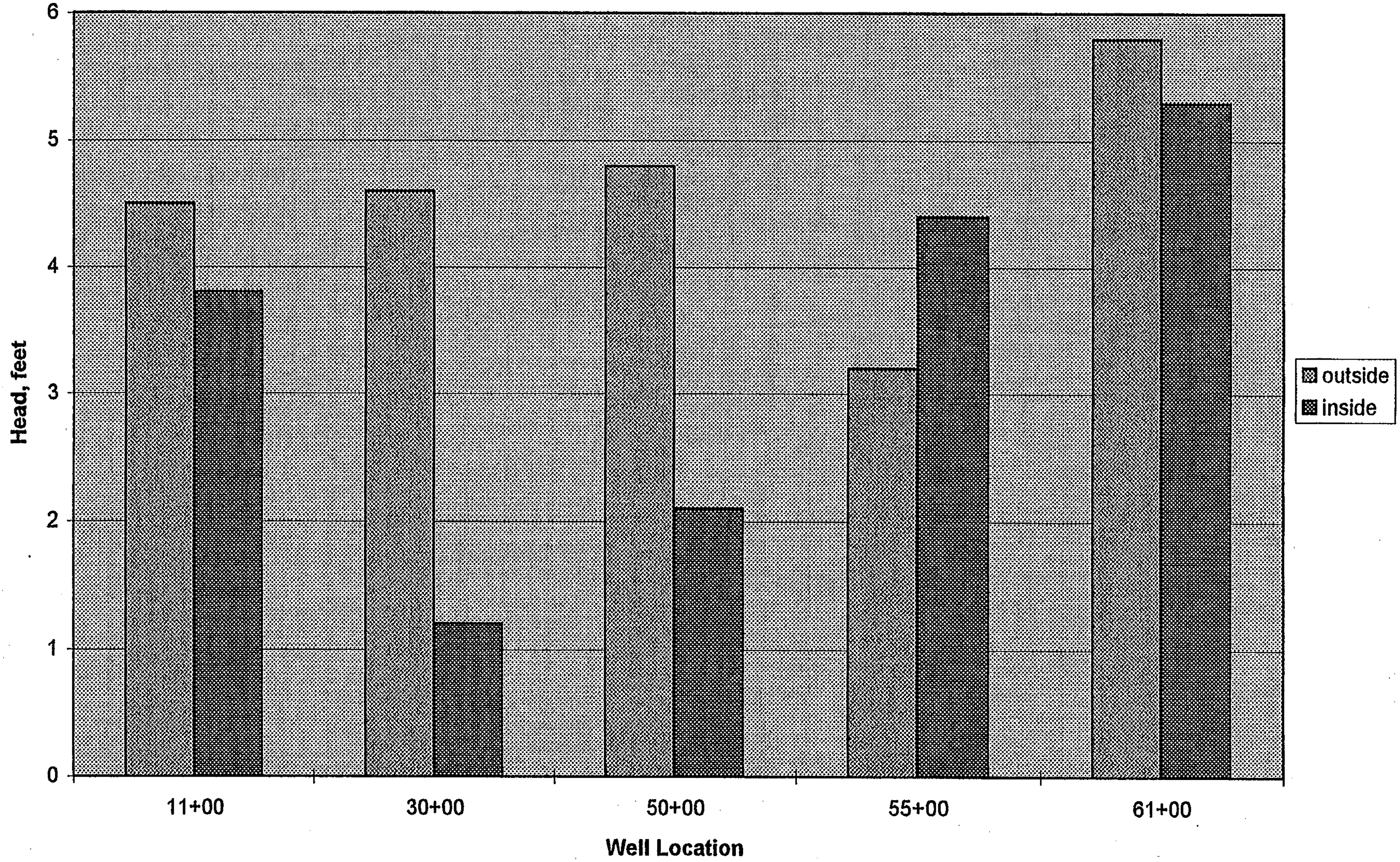
Permeability tests were conducted on samples of the soil-bentonite mix during construction and on undisturbed samples from the completed wall. A total of 135 soil-bentonite mix permeability tests were performed, and an average permeability of 3.4×10^{-8} cm/sec was obtained. Also, a total of 50 permeability tests were performed on undisturbed soil-bentonite wall samples, but one test was performed in the varved clay below the key. The average permeability of undisturbed soil-bentonite wall samples was 5.3×10^{-8} cm/sec.

5.3 Monitoring

Performance monitoring of the barrier conducted since 1990 was rated better than acceptable. Piezometers were installed at five locations. At each location, a cluster of three piezometers was installed inside the cutoff wall, and a cluster of three was installed outside the cutoff wall. Based on measurements taken, an inward gradient existed to inhibit leachate flow through the soil-bentonite cutoff wall. With the exception of one location, both the shallow and intermediate piezometers showed an inward gradient through the cutoff wall (see Figure 2).

The deep piezometers in the varved clay showed about 1-foot-higher head inside the landfill than outside, indicating an outward flow condition. This higher head in the varved clay inside the landfill also caused an upward flow condition from the base of the landfill and was attributed to excess pore pressure in the clay stratum, which is higher than the leachate mound. However, the outward flow seems to be very limited and the impact on the deeper groundwater is being studied.

Eleven groundwater monitoring wells were installed: some of the wells are shallow wells, while the rest extend to or into the underlying clay layer. Groundwater quality monitoring data for only one period is available. Ammonia, arsenic, and VOCs were detected at levels higher than the groundwater standards set by the state regulatory organization; however, their concentrations have decreased from their initial levels.



Site 15

FIGURE 2

HEAD DIFFERENCE ACROSS BARRIER

Tetra Tech EM Inc.

5.4 Operation and Maintenance

Operation and maintenance (O&M) requirements for the containment system involved monthly site inspections, quarterly effluent sampling and well water level readings, and annual well water sampling since 1990.

Leachate levels in the manholes are monitored weekly, while all pipes, manholes, and cleanout risers, and the leachate force main are inspected monthly.

5.5 Other Considerations

No information on cost was available.

5.6 Remedy Performance

Remedy objectives regarding hydraulic head were easily met, and groundwater quality outside the containment is improving. The barrier was determined to be of low permeability, adequately keyed, continuous, and intact based on available data.

6.0 SUMMARY

Site 15 is a 137-acre former sanitary landfill. Leachate and groundwater are mixed in three strata overlying a varved clay stratum that varies in thickness from 100 to over 180 feet. The containment remedy consisted of a soil-bentonite barrier, leachate collection and removal system, and monitoring. The design and CQA/CQC of the barrier were rated acceptable and slightly better than acceptable, respectively. Performance monitoring of the barrier was rated better than acceptable and involved post construction sampling, installation of clustered piezometers across the barrier, ample groundwater quality monitoring, and regular inspections. The site containment generally met closure plan requirements. Groundwater quality outside the barrier has improved, and gradients are inward except at one location in the varved clay layer; however, the low permeabilities at this location make the outward flow negligible.

SITE 16

Barrier Type	CB
Remedial Objective	SC; contain DNAPL
Performance	2

1.0 SITE DESCRIPTION AND HISTORY

Site 16 is located in a lightly industrialized setting in the glaciated portion of the Appalachian Mountains. The site covers about 12 acres and is located at the confluence of two shallow rivers. The site topography is relatively flat except for flood control levees constructed along the rivers.

The site is the location of a former manufactured gas plant. A variety of waste by-products were generated by coal gasification conducted at the site. These were stored in on-site lagoons. The waste by-products are tarlike, dense non aqueous phase liquid (DNAPL) substances that caused contamination in the on-site soils, groundwater, and adjacent surface water bodies. Contamination was identified in 1980 during repairs of the flood control levees along the rivers. Starting in 1981, the site underwent a series of emergency actions, investigations, and subsequent remediation to remove and control migration of the DNAPL. A cement-bentonite hydraulic cutoff wall was constructed at the site in 1981 to impede the flow of DNAPL and allow DNAPL extraction by pumping. DNAPL extraction by enhanced recovery techniques as well as further investigation were subsequently conducted at the site. A site plan with basic site features is shown in Figure 1.

2.0 GEOLOGIC/HYDROLOGIC SETTING

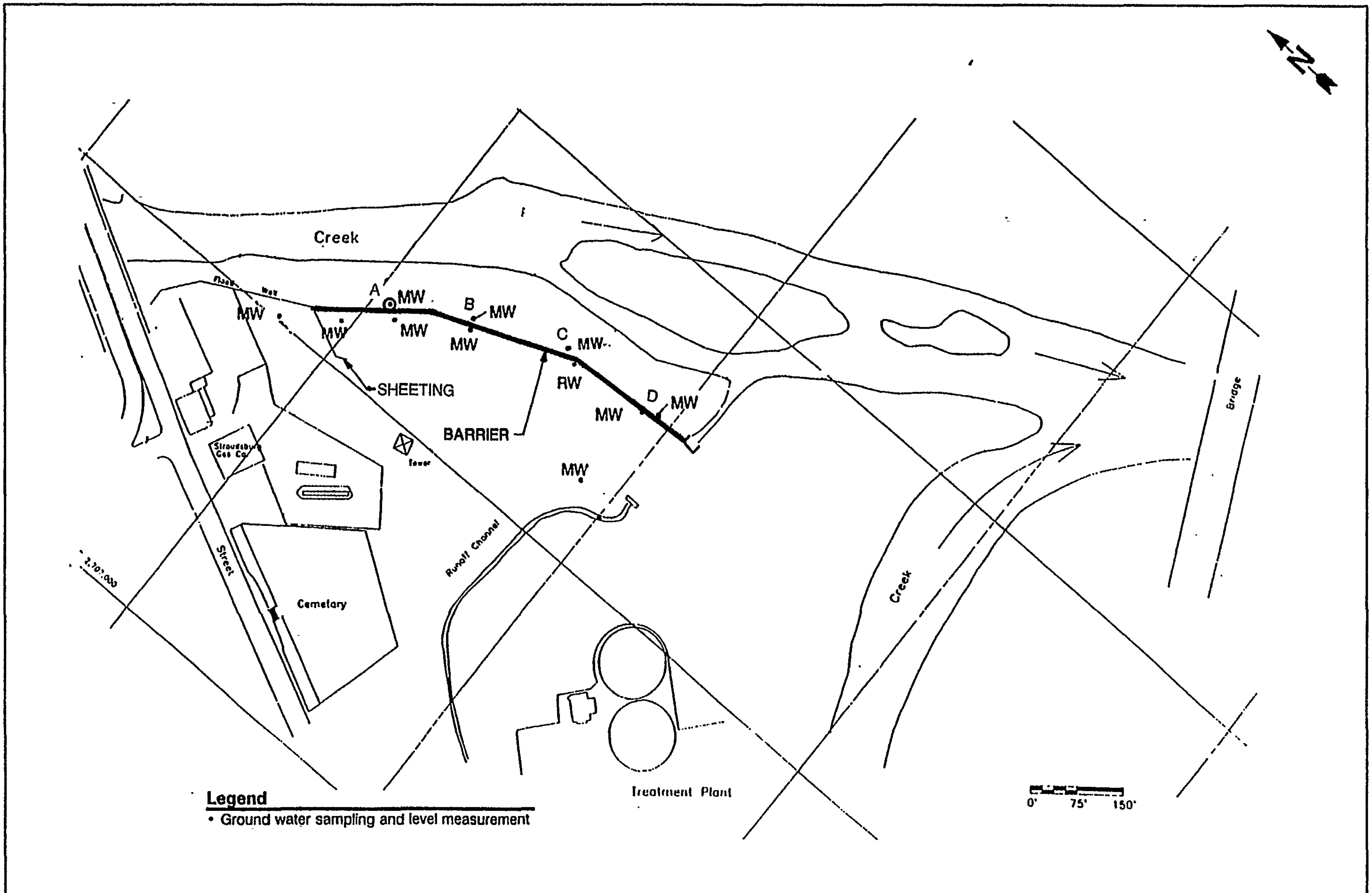
The local geologic setting consists of unconsolidated glacial and fluvial soils overlying Devonian-age bedrock. The bedrock shale and underlying limestone of this region is characterized by intense, broad, structural folds with associated minor folding. The unconsolidated soils generally consists of varying fluvial deposits of sands and gravels underlying glacial outwash sands and gravels; a fine-grained, sand to silt layer with some clay attributed to glacial lake deposition; and finally a dense till above bedrock. The permeable gravels extend to about 20 to 40 feet below grade before the lower-permeability, silty sands are encountered. The silty sand unit forms the relatively low-permeability unit below the site and provided the suitable material for keying the cutoff wall.

The unconsolidated soils above the till act as a single, unconfined unit transmitting flow from upland areas to the adjoining rivers. The preremediation flow pattern was from west to east and has been significantly altered by the remedial measures. Bedrock hydraulic heads indicate an upward flow into the unconsolidated aquifer. The upper fluvial and glacial sands and gravels have hydraulic conductivities on the order of 1×10^{-2} to 1×10^{-3} centimeters per second (cm/sec). This is in contrast to the underlying silty sand, which has conductivities orders of magnitude lower, making the basal silty sand an impediment to flow but not a confining interval or bottom. However, the silty sand interval is believed to be a barrier to DNAPL migration.

3.0 NATURE AND EXTENT OF CONTAMINATION

On-site soil and groundwater and off-site groundwater are contaminated with free-phase, tar-like DNAPLs, BTEX compounds, and several metals such as arsenic. These contaminants have been grouped, for purposes of groundwater remediation, into free-phase and dissolved-phase constituents. This report addresses containment of the free-phase (DNAPL) contaminants at the site.

Key: CB=Cement Bentonite Wall SC=Source Control Performance Rating: 2-Evidence suggests objective may be met



Site 16

FIGURE 1
SITE PLAN

Tetra Tech EM Inc.

Coal tar was disposed of on-site in a shallow tar pit, providing a source of DNAPL contamination in the shallow and permeable sands and gravels. DNAPL migrated by gravity flow and either was contained in a minor subsurface depression on the silty sand layer or migrated to discharge to the adjoining river. Contamination therefore existed on site and off site in subsurface soils, groundwater, and adjacent surface water and sediments. Partial analysis of the coal tar compounds yielded the following composition:

- Naphthalenes 3.6 %
- Acenaphthenes 0.72 %
- Fluoranthene 3.2 %
- Phenanthrene 2.3 %
- Anthracene 2.3 %
- Dimethyl naphthalenes 2.15 %

Identification of the contamination in 1981 prompted emergency remedial action to cut off the flow of DNAPL to the adjacent river and to contain the DNAPL within the site boundary, for later removal.

4.0 CONTAINMENT REMEDY

The remedial objective was to intercept the DNAPL by active containment before its discharge to the adjacent river. The active containment includes installation of a hydraulic cutoff wall, excavation of some source material, and active pumping of DNAPL. The remedy was implemented as an emergency removal action. The implemented remedy included the following general features:

- A hanging cement-bentonite hydraulic cutoff wall that is 650 linear feet long; 23 feet deep; and 1 foot thick and that has a 2-foot soil key
- Four DNAPL extraction well nests
- Four pairs of groundwater level monitoring locations paired across the wall
- Several groundwater quality monitoring locations upgradient and downgradient
- Multiple surface water quality monitoring points along the adjacent waterways
- Select on-site source excavation

The hydraulic cutoff wall is notable in several respects. The cutoff wall is not circumferential. It is effectively a hanging wall, being keyed into silty sands of moderate permeability. The cutoff wall is tied to an existing sheet-pile barrier at one end and is connected to the clay core of a flood levee with a grout curtain on the opposite end. The cutoff wall was constructed using a specially designed, 12-inch-wide backhoe arm and bucket to reduce quantities of contaminated spoil.

5.0 PERFORMANCE

Based on the head difference measurements across the wall, the containment system at the site appears to be effective in limiting migration of DNAPL to the adjacent river. Monitored groundwater quality and surface water quality do not show discernible trends from 1982 to 1995. The cutoff wall has allowed extraction of upgradient DNAPL by preventing migration beyond the wall.

5.1 Design

The barrier design effort was rated acceptable with respect to industry practices discussed in Section 3, Volume I. Several hydrogeologic and feasibility studies were performed before barrier construction. The barrier mix was designed and tested to achieve a maximum permeability of less than or equal to 1×10^{-6} cm/sec target permeability. A thick, earthen cover was placed over the top of the barrier. (No cap was installed at the site.) No known groundwater modeling was performed at the site before construction to forecast the eventual major changes to groundwater flow patterns. The barrier is only 12 inches thick, however, the cement-bentonite mixture provided sufficient strength. Detailed specifications for construction testing were not available and, if not prepared, would be considered a shortcoming of the design.

5.2 Construction Quality Assurance and Construction Quality Control

Overall, the barrier construction quality assurance (CQA) and construction quality control (CQC) were rated less than acceptable. CQA/CQC information was limited, due probably in part to the installation being an emergency action. The contractor possessed significant experience, and the trench sounding and key confirmation were acceptable. As a cement-bentonite wall was installed, backfill CQA parameters are not applicable. A possible problem associated with CQA/CQC for this site was that the construction of the barrier had to be interrupted when a gas line was encountered, requiring hand excavation. Also, no postconstruction sampling or testing was identified.

5.3 Monitoring

The postconstruction monitoring effort relative to DNAPL containment was better than acceptable in several respects. Many DNAPL and groundwater quality monitoring points were installed. Four pairs of wells were located across the barrier to monitor hydraulic head and groundwater quality. Geophysical methods were used in an attempt to characterize barrier integrity. Also, adjacent surface water quality was monitored over time.

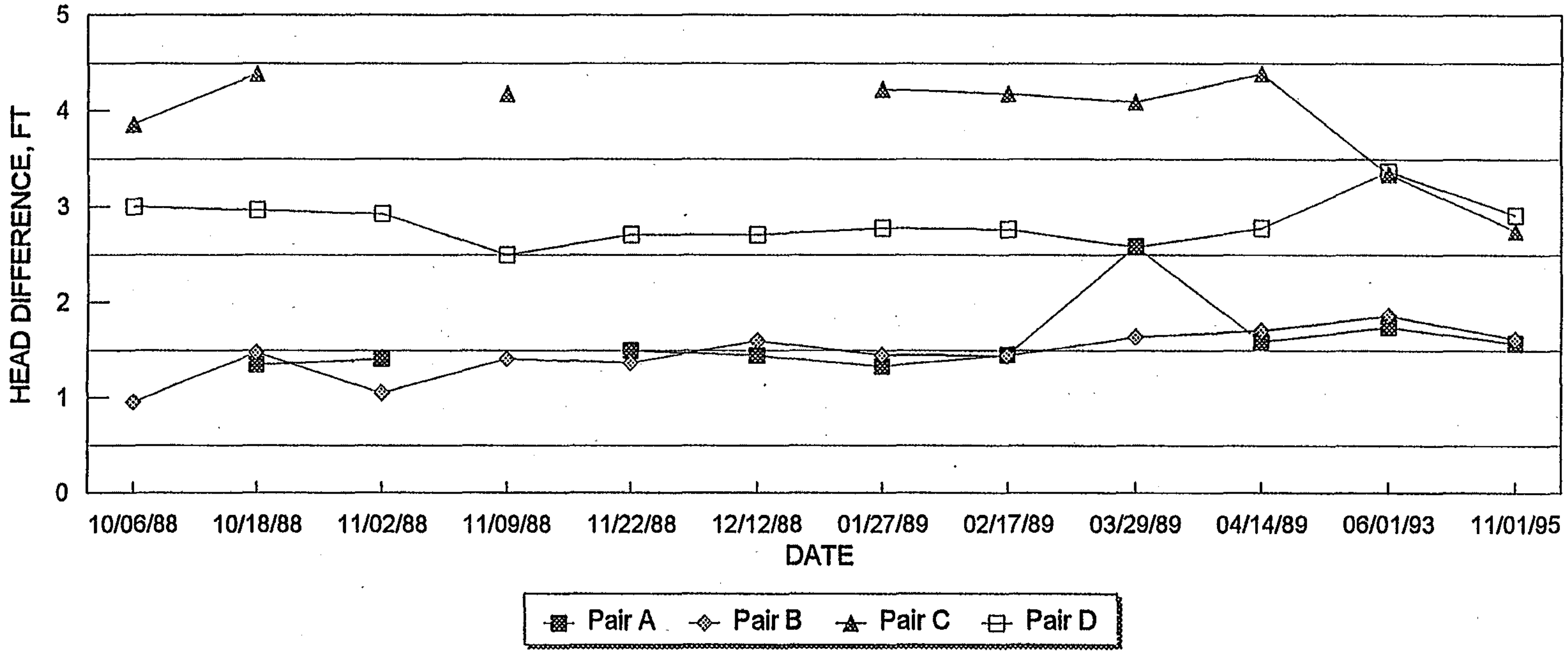
Head measurements were taken across the barrier wall at the four paired monitoring locations over time. Those data are displayed in Figure 2 for biweekly intervals in 1988 and 1989 and for more recent periods. The data indicate that the head loss across the wall was between 1 to 4 feet through the measured period. While this is not a conclusive measure of the wall's integrity, it does indicate the consistent effectiveness of the wall in impeding groundwater flow.

Groundwater quality was measured and reviewed over the past 7 years. The results of these measurements, shown in Figure 3, show no conclusive trend indicating a decline in downgradient concentrations. However, the objective of the wall was not to contain dissolved-phase contamination but rather to intercept gravity-driven DNAPL contamination.

An attempt was made to measure physical integrity of the wall using self-potential geophysical methods. The streaming self-potential method was used. This method measures changes in electrical potential as a result of ions in solution passing through a porous medium. The survey was performed on 25-foot centers along the cutoff wall and was intended to measure leakage. Background noise and poor response resulted in inconclusive data. In areas believed to have some possible leakage based on geophysical findings, hydraulic head measurements revealed no unusual head loss, and presumably no leakage.

Site 16

5



Site 16

FIGURE 2

HEAD DIFFERENCE vs TIME

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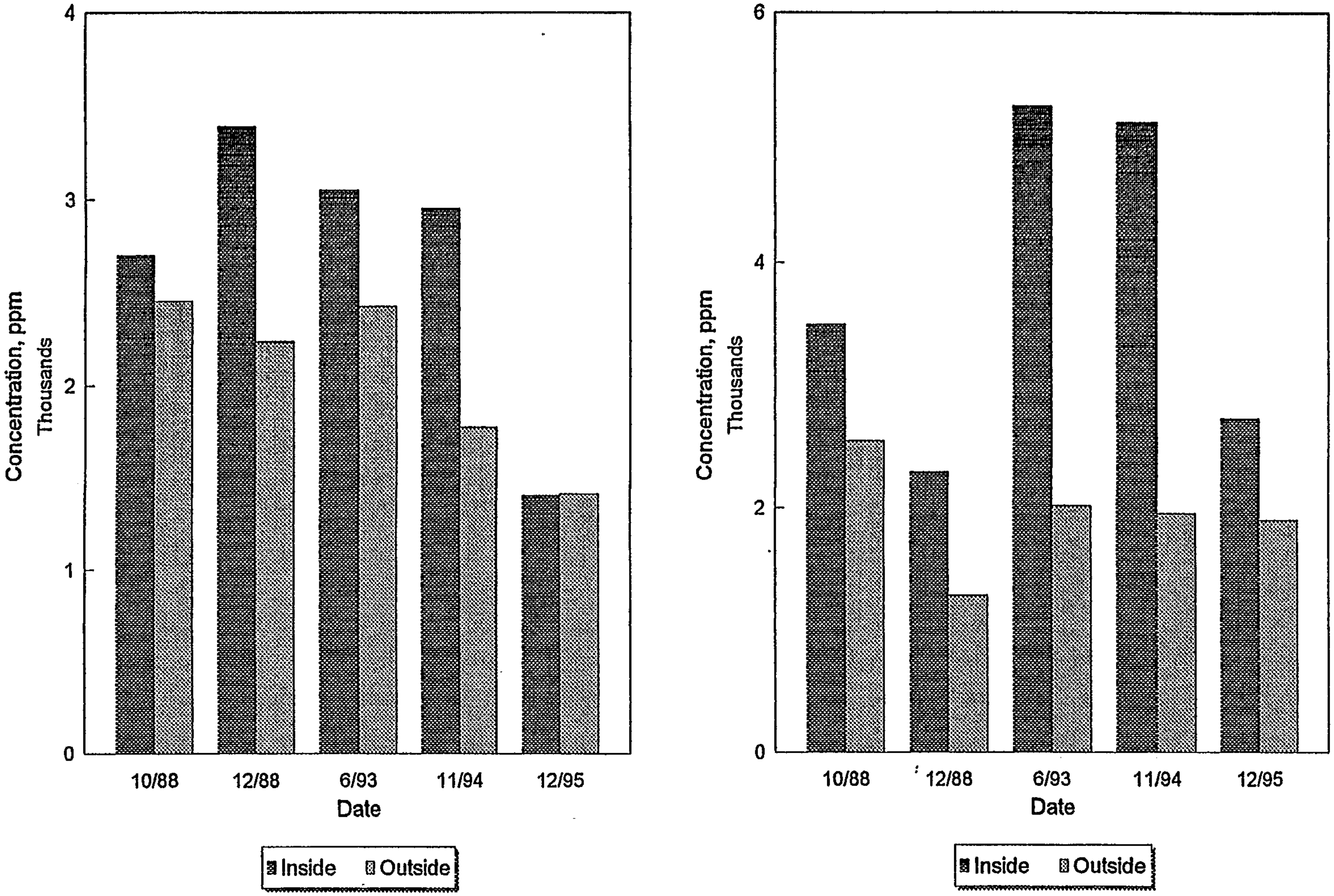


Site 16

FIGURE 3
CONCENTRATION vs TIME

Tetra Tech EM Inc.

5.4 Operation and Maintenance

No operation and maintenance (O&M) information was available. O&M of the active portions of the remediation is not addressed in this evaluation.

5.5 Other

Costs for cutoff wall construction and associated work exceeded the original estimates. Originally, the estimate for cutoff wall construction, select excavation, and monitoring well installation and associated work totaled $180,000 to $280,000. Subsequently, increased excavation and disposal costs increased the overall cost to about $500,000. Also, the cost to install the cutoff wall (including a 50-foot grout curtain and monitoring wells) increased to $290,000 because of wider trench widths than expected, additional handling of material, and the additional cement and bentonite used. This makes the total project cost equal to about $25 per square foot of the wall.

5.6 Remedy Performance

The objective of the remedy to cut off DNAPL migration was met. The cutoff wall impeded groundwater flow, prevented further DNAPL migration to the river, and allowed subsequent DNAPL extraction by other means.

6.0 SUMMARY

Site 16 is a 12-acre, former manufactured gas plant with DNAPL contamination in site soils and groundwater. The site's location adjacent to two rivers, the absence of an impermeable bottom, and the need to stop DNAPL migration led to the use of a noncircumferential, hanging cutoff wall. This partial containment was augmented by select excavation of source material, and DNAPL extraction. Cutoff wall installation was performed as an emergency action.

The design was rated acceptable and CQA/CQC of the cutoff wall was rated less than acceptable. However, the hydraulic, chemical, and physical monitoring of the cutoff wall involved better than acceptable efforts. Measurements of hydraulic head over time have shown consistently lower head inside the wall. The groundwater quality data does not show discernible trends and actually shows increased concentrations downgradient of the cutoff wall at some locations, presumably because of the presence of source material and dissolved constituents. Overall, the cutoff wall and associated elements appear to have been effective in meeting the original objectives of intercepting DNAPL migration and allowing free-phase DNAPL removal by other means.

SITE 17

Barrier Type	SB
Remedial Objective	SC
Performance	2+

1.0 SITE DESCRIPTION AND HISTORY

Site 17 is located in the northeastern United States. Site 17 is a 57-acre landfill that rises about 45 feet above the natural grade and is located on a 144-acre property; a river runs north of and adjacent to the site (see Figure 1). The landfill began operation in 1959 and was closed by a state regulatory agency in 1979. During its operation, the landfill accepted more than 17,000 drums of chemical waste; municipal refuse; and millions of gallons of bulk liquid chemical wastes.

Remedial activities at Site 17 included the construction of a soil-bentonite slurry wall and a multi-layer cap. The remedial objective for the containment system was to prevent migration of contaminants from the site by limiting horizontal and vertical flow of precipitation and groundwater through the landfill.

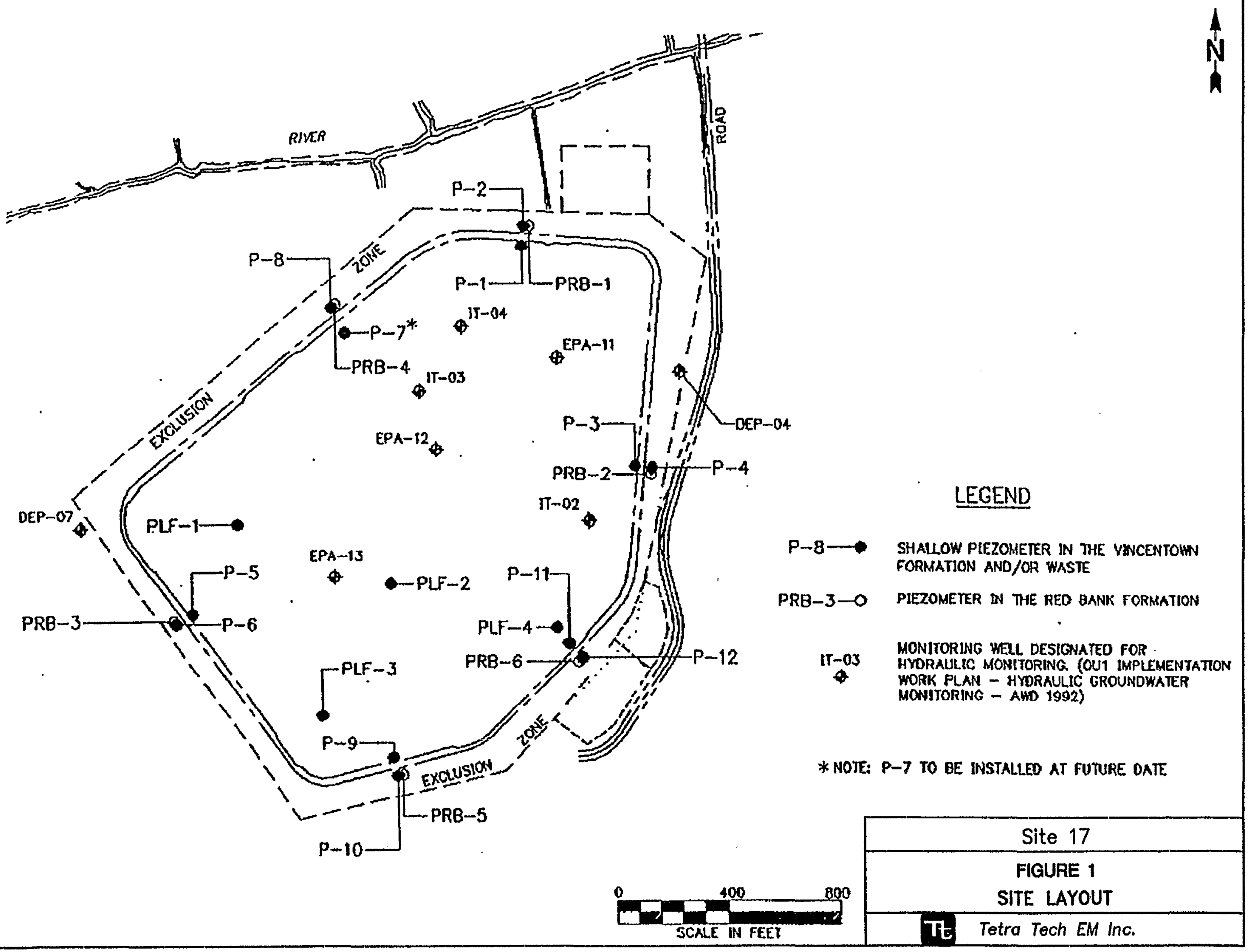
2.0 GEOLOGIC AND HYDROGEOLOGIC SETTING

Site 17 lies in the northern part of the Atlantic Coastal Plain physiographic province. It lies on relatively flat land that gradually slopes toward the river to the north. The surrounding terrain is predominantly gently rolling coastal plain with marshes and small ridges. Beneath the site area lie the following geologic formations (in ascending order): Bedrock, the Potomac Group, Raritan Formation, Englishtown Formation, Marshalltown Formation, Wenonah Formation, Mount Laurel Sand, Navesink Formation, Red Bank Sand, Hornerstown Sand, and Vincetown Formation. Site remedial activities did not involve investigation of units deeper than the Red Bank Sand.

The Red Bank Sand, which is 50 to 60 feet thick in the Site 17 area, is a complex formation containing four units. The lowest unit is a massive, silty, fine-grained sand that is 10 to 20 feet thick. This unit is overlain by a poorly sorted, medium- to coarse-grained sand that is the principal water-yielding layer in the Red Bank Sand. This layer is overlain by the Tinton Sand, which is a 5- to 10-foot-thick, compact, cemented sandstone with a high percentage of coarse-grained detritus. The upper unit of the Red Bank Sand is an 8- to 12-foot-thick, partially cemented, silty, fine sand. The Hornerstown Sand overlies the Red Bank Sand and is generally considered to be a confining layer. The slurry wall is keyed into the Hornerstown Sand. This layer is an approximately 12-foot-thick, silty, fine sand that has various amounts of clay. The uppermost formation in the landfill area is the Vincetown Formation, a medium-grained sand that ranges in thickness from a few inches just north of the landfill to about 30 feet on the south side of the landfill.

Two primary aquifers exist in the area around Site 17, one shallow and one deep. The uppermost saturated units (the Vincetown and the Hornerstown Sand Formations) comprise what is referred to as the Water Table Aquifer. The horizontal flow direction in the Water Table Aquifer is north from Site 17 toward the river. The calculated groundwater flow velocity from Site 17 to the river ranges from 80 to 740 feet per year. The horizontal flow direction in the underlying Red Bank Aquifer is also north from Site 17 toward the river, and the calculated groundwater flow velocity ranges from 12 to 91 feet per year. Vertical groundwater flow in the vicinity of Site 17 is downward from the Water Table Aquifer to the

Key: SB=Soil Bentonite Wall SC=Source Control Performance Rating: 2+=Evidence suggests objective may be met



Site 17

FIGURE 1
SITE LAYOUT

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Red Bank Aquifer beneath the landfill and is upward in the valley of the river. Over the entire site area, vertical groundwater flow is also upward from the Navesink Formation to the Red Bank Aquifer.

3.0 NATURE AND EXTENT OF CONTAMINATION

Groundwater samples collected from monitoring wells located at Site 17 and screened in the Water Table Aquifer contained a large number of volatile organic compounds (VOC). The dominant VOCs present at the site, with the maximum concentration reported, are as follows:

- 2-Butanone: 190,000 μg/L
- Methylene chloride: 125,000 μg/L
- Acetone: 1,000 μg/L
- Toluene: 1,000 μg/L
- 1,2-Dichloroethane: 1,000 μg/L
- Benzene: 1,000 μg/L
- Trichloroethene: 1,000 μg/L

Metals including aluminum, chromium, barium, cadmium, cobalt, copper, iron, lead, nickel, manganese, zinc, vanadium, arsenic, antimony, mercury, and tin have also been found in groundwater samples from on-site wells.

Monitoring results indicate that off-site groundwater contamination in the Water Table Aquifer is confined to (1) a narrow zone north and northeast of Site 17 between the site and the river with a total area of about 20 acres and (2) a very narrow zone along the eastern perimeter of Site 17. In the deeper Red Bank Aquifer, off-site groundwater contamination is found only in the zone north and northeast of the landfill between the landfill and the river. No groundwater contamination was found in wells completed in the lower part of the Red Bank Sand below the Red Bank Aquifer.

4.0 CONTAINMENT REMEDY

The U.S. Environmental Protection Agency (EPA) signed a record of decision (ROD) for the site in September 1984. The remedial objective for the site as stated in the ROD is to contain site contaminants and clean up contaminated groundwater and leachate directly below the landfill. A hydraulic gradient performance criteria for maintaining a gradient of -0.5 feet inward gradient was also included in the ROD. Remedial construction began in July 1991 and included the following features:

- A slurry wall that is approximately 5,965 feet long; 15 to 33-1/2 feet deep; and 3 feet thick with a 2-foot soil key depth

- A leachate collection trench that is about 5,800 feet long; 2 feet wide; and 10 to 18 feet deep

- Leachate collection wells (21 wells installed at approximately 300 foot intervals)

- A methane gas collection system and methane gas flare

- A water treatment plant

- A interceptor drain that is approximately 2,800 feet long and extraction wells to collect contaminated groundwater from the shallow and deep aquifers respectively

- A 57-acre, multilayered cap consisting of a prefabricated bentonite mat; a 40-mil, very low density polyethylene (VLDPE) geomembrane; a coarse sand drainage layer; filter fabric; an 18-inch soil cover, and at least 6 inches of topsoil

- A perimeter drainage system

- A hydraulic monitoring system which is described in detail below

Six pairs of piezometers were installed inside and outside the perimeter of the slurry wall. These piezometers were screened in the Vincetown Formation, the waste, or both. A Red Bank Aquifer piezometer was also installed outside the slurry wall at each of the six locations. The diameter of each Vincetown Formation and waste piezometer is 4 inches each, and the Red Bank Formation piezometer was installed with 2-inch-diameter screen and riser pipe. Four piezometers were installed in the central landfill area and are screened in the Vincetown Formation, the waste, or both.

Six monitoring wells are located in or near the central landfill area and are being used to monitor water levels to above the top of the Hornerstown Formation within the landfill material. Two additional monitoring wells are located beyond the landfill slurry wall and are being used for hydraulic monitoring. All eight wells are screened in either the waste or the Vincetown Formation.

5.0 PERFORMANCE EVALUATION

The groundwater monitoring program was designed to monitor the effectiveness of the barrier containment system by (1) determining the piezometric level of the shallow water-bearing zone within the landfill material along the landfill perimeter and outside the slurry wall barrier and (2) monitoring the upward gradient underneath the landfill by determining the piezometric level within the Red Bank Aquifer in the central area of the landfill.

Monthly monitoring of the hydraulic head across the barrier indicates that an inward gradient exists. A groundwater status report dated December 28, 1995, indicates that inward hydraulic gradients were present at all paired monitoring points around the landfill. In addition, the inward hydraulic gradients at all pairs exceeded the performance criterion of less than -0.5 feet. Particularly significant inward gradients of -8.9 feet were observed at pairs P9-P10 and P11-P12.

The leachate collection system presently removes the amount of leachate predicted, and according to the remedial project manager, the leachate level has dropped since the system began operation.

5.1 Design

The barrier containment system design was given an acceptable rating relative to industry practices as described in Section 3, Volume I. The containment system was designed to contain and recover contaminated groundwater within the landfill. A 15-foot wide by 3-foot deep clay bench was installed around the landfill along the centerline of the slurry wall. Before the slurry wall construction began, 27 soil borings were drilled at about 200-foot intervals along the alignment of the slurry wall to obtain native soil samples for use in the design of the slurry wall mix and to better define the depth to and elevation of the Hornerstown Sand. The slurry wall is keyed into the Hornerstown Sand. The appropriate soil-bentonite backfill mix was established by laboratory testing. The approved slurry mix was 62 percent excavated soil, 35 percent borrowed clay, 2 percent dry bentonite, and 1percent bentonite. The mix, which had a permeability of 1 x 10^{7} centimeter per second (cm/sec) or less, was blended beside the trench using a power harrow mixer attached to a backhoe and was further blended using with a bulldozer to obtain the specified composition.

The cap design was given an acceptable rating relative to industry practices. The 57-acre, multilayered cap was constructed over the entire landfill. The cap consists of a prefabricated bentonite mat overlain by a 40-mil, VLDPE geomembrane. Two types of VLDPE were employed for the project based on friction angle measurements of the material interfaces, which were measured in the laboratory. A smooth geomembrane was installed in areas having a slope no steeper than 15:1 (horizontal to vertical), and a textured geomembrane was installed on slopes steeper than 15:1 but no steeper than 6:1. In areas where slopes exceeded 6:1, a 2-foot-thick, compacted clay liner was constructed. Once the liner system was completed, a coarse sand drainage layer, filter fabric, 18 inches of soil cover, and at least 6 inches of topsoil to support vegetation were installed.

5.2 Construction Quality Assurance and Construction Quality Control

Barrier construction quality assurance (CQA) and construction quality control (CQC) were given a better than acceptable rating relative to industry practices. Notably, various tests of the slurry and backfill were performed. For example, tests were conducted on the bentonite powder (one test per shipment), the bentonite slurry-plant (fourtests per day for viscosity and density and one test per day for filtrate loss and pH), the mix water (one test per source for chemical analysis), the bentonite slurry-trench (four tests per day for viscosity and density), and the backfill (three tests per day for slump and density; one test per 2000 cubic yards for gradation; and three tests per 400 feet for permeability). All test results indicated permeabilities equal to or less than the required 1 x 10^{7} cm/sec.

The slurry wall backfill profile was measured and recorded at the end of each workday and at the beginning of the next workday to verify that the trench had not caved in over the backfill. The slope of the backfill in the trench was typically 10:1. After the completion of the slurry wall, a drill rig was used to obtain samples of the placed backfill for permeability analysis. Laboratory results indicated that all samples had permeabilities equal to or less than 1 x 10^{7} cm/sec.

Cap CQA/CQC was given a better than acceptable relative to industry practices. The rigorous CQC program used during liner installation included both field testing (destructive and nondestructive) of production welding and laboratory testing of production welding at all seams. All seams were subjected to 100 percent CQC testing, and only one 100-foot seam failed the CQC testing and required reseaming. No vehicular traffic was permitted on the geomembrane at any time after its installation. The drainage layer was compacted to a minimum relative density of 65 percent. Testing was performed at a frequency of five tests per acre to verify proper drainage layer compaction. All seaming operations for the filter fabric were inspected for compliance with specifications. Testing was also performed to verify proper compaction of the 18-inch-thick soil cover layer.

5.3 Monitoring

The groundwater monitoring program for the site was given an acceptable rating relative to industry practices. The monitoring program was intended to evaluate the hydraulic performance of the landfill cap, the slurry wall, and the leachate collection system with respect to groundwater quality, leachate generation rates, and the maintenance of an inward hydraulic gradient. Twelve piezometers located inside and outside the containment wall are used to determine water levels in the shallow water-bearing zone within the landfill material along the landfill perimeter and outside the slurry wall. Information provided by the RPM for the site indicates that an inward gradient exists and that the slurry wall is containing on-site contamination. The RPM also stated that the leachate level inside the landfill has dropped, which indicates that the system is operating correctly.

Another objective of the groundwater monitoring program was to monitor the upward gradient underneath the landfill by determining the piezometric levels within the Red Bank Aquifer and within the shallow water-bearing zone in the central area of the landfill. No information pertaining to this objective was available for review.

5.4 Operation and Maintenance

The main operation and maintenance (O&M) manual for the site includes O&M activities for the leachate collection system, the multilayered cap, and other systems, but no information detailing barrier O&M was available. Monthly monitoring of groundwater levels and quarterly monitoring of groundwater quality are performed.

5.5 Other Considerations

According to EPA, the cost of remedy design and the remedy for both the landfill and downgradient contaminated groundwater outside of the slurry wall was $55 million to $60 million.

5.6 Remedy Performance

Groundwater levels inside and outside the containment indicate that an inward gradient exists. Leachate levels reportedly have dropped inside the landfill indicating that the wall and the leachate extraction systems are operating as designed.

6.0 SUMMARY

Site 17 is located in the northeastern United States. The site is a 57-acre landfill contained by a soil-bentonite barrier and a multilayered cap. The site operated as a landfill from 1959 to 1979 and received various amounts of municipal and chemical wastes, which resulted in VOC, semivolatile organic compounds (SVOC), and metal contamination. The geology of the site includes the Hornerstown Sand Formation, which is considered to be a confining layer and which the barrier wall is keyed into. This layer is about 12 feet thick and contains silty, fine-grained sand with varying amounts of clay. Extraction pumping inside the landfill has created an inward gradient of less than -0.5 feet (the performance criteria) to control off-site migration of contaminants. Monitoring results and post-construction evaluations also indicate that the barrier containment has been successful in reducing leachate volume to levels predicted during the system design phase.

Barrier Type	SB
Remedial Objective	SC
Performance	2

SITE 18

1.0 SITE DESCRIPTION AND HISTORY

Site 18 is located in the midwestern United States. The site is a former sand and gravel borrow pit covering about 4 acres. The site was used for disposal of industrial and municipal wastes from 1945 to 1977. In 1979 and 1980, the site was capped with compacted clay as an interim measure. Construction of a barrier wall was completed in December 1994 and a permanent site cap was completed in July 1995. Pumping of groundwater from PW-1 and PW-2, which are located outside the barrier wall, began in September 1995. Pumping of groundwater from PW-3 and PW-4 began in July 1995. Figure 1 shows the significant features of the site.

2.0 GEOLOGIC AND HYDROGEOLOGIC SETTING

Site 18 is located in the Central Groundwater Region of the United States. The site consists of alluvial deposits of gravel, sand, and silt over bedrock. The alluvial deposits are about 90 feet thick, and the bedrock consists of sandstone, siltstone, and shale. The sand and gravel materials are fairly continuous across the site.

The saturated thickness of the sand and gravel aquifer beneath the site varies from 30 to 45 feet. The sand and gravel aquifer materials range in permeability from 1×10^{-2} to 1×10^{-4} centimeters per second (cm/sec). The water table is 35 to 40 feet below ground surface (bgs), and groundwater flows to the southwest toward a major river. Bedrock permeability varies from 4.4×10^{-5} to 9.5×10^{-5} cm/sec.

3.0 NATURE AND EXTENT OF CONTAMINATION

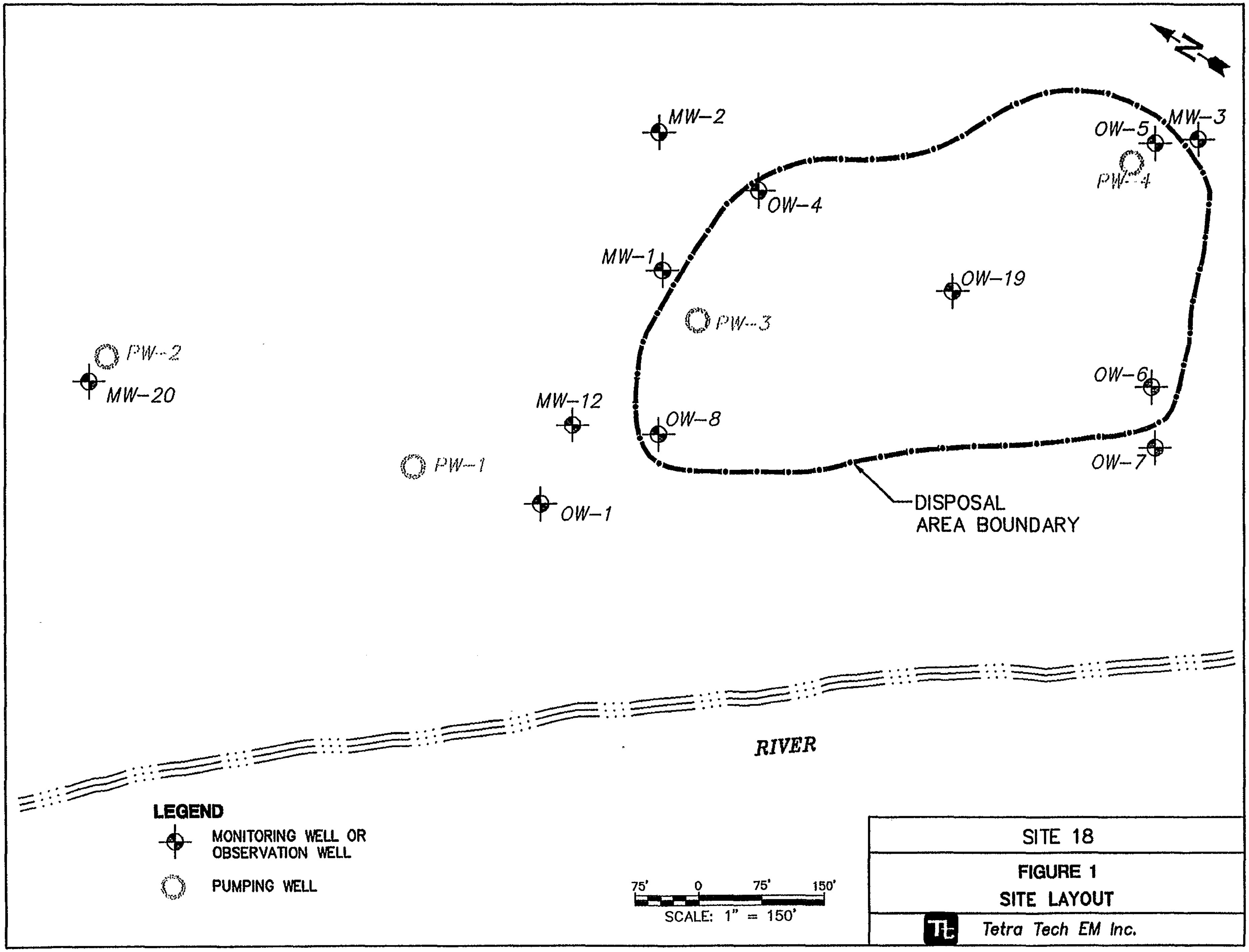
The site contains anthracene residue, salts, and miscellaneous process wastes from an adjoining tar plant; foundry sand containing heavy metals, phenols, and oils; and other wastes. Site contaminants consist primarily of benzene, toluene, ethylbenzene, and xylene (BTEX); polynuclear aromatic hydrocarbons (PAH); nonaqueous-phase substances (NAPS); and arsenic. The contaminants have moved off site through the unconfined sand and gravel horizon. The concentrations of selected contaminants in the groundwater are as follows:

- Benzene: 750 - 5,600 μg/L
- Toluene: 1,400 - 3,500 μg/L
- Ethylbenzene: 440 - 1,000 μg/L
- Xylene: 990 - 3,200 μg/L
- Arsenic: 12 - 59 μg/L

4.0 CONTAINMENT REMEDY

The perimeter barrier forms a closed loop around the 4-acre waste disposal area. The barrier is intended to enclose the capped wastes and provide a low-permeability barrier to groundwater flow. During barrier construction, excavated on-site soil was mixed with imported clay and bentonite slurry to make the soil-bentonite mix that was placed in the excavated trench. General features of the corrective action include the following:

Key: SB=Soil Bentonite Wall SC=Source Control Performance Rating: 2=Evidence suggests objective may be met



SITE 18

FIGURE 1
SITE LAYOUT

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- A soil-bentonite perimeter barrier that is about 2,000 linear feet long; 80 to 86 feet deep; and 30 inches thick with a 0.1-foot key into bedrock

- Resource Conservation and Recovery Act (RCRA) Subtitle C Cap consisting of a 12-inch thick layer of soil overlain by a geosynthetic clay liner, a 40-mil high density polyethylene liner, geonet and 24-inch thick soil cover.

- Four groundwater extraction wells (two inside and two outside the barrier)

- 24 wells to monitor remedial action performance; however, only 9 wells are being used

- Delineation of the NAPS layer

Groundwater pumped from the four extraction wells is treated in an on-site treatment plant.

5.0 PERFORMANCE EVALUATION

The objectives for the containment system were to maintain a slight inward groundwater gradient into the barrier wall and to minimize the pumping rate for contaminated groundwater. The performance of the containment system is evaluated in the following subsections.

5.1 Design

The design was rated better than acceptable compared to the standard industry practice as discussed in Section 3, Volume I. Seventeen soil borings (about one boring every 100 feet) were installed along the barrier wall alignment to define the subsurface stratigraphy and top-of-bedrock profile. The trench slurry compatibility was tested to determine the effect of the viscous, oily NAPS fluids on the backfill materials. Based on the testing results, borrow clay with a plasticity of up to 25 percent was mixed with 0.21 to 0.91 percent dry bentonite and uncontaminated excavated trench and soils. The RCRA Subtitle C cap is connected to the barrier.

5.2 Construction Quality Assurance and Construction Quality Control

Barrier construction quality assurance (CQA) and construction quality control (CQC) were rated better than acceptable, but there were several problems. The verification of the key-in depth was insufficient during trench excavation and backfilling. A total of 23 borings were advanced along the centerline of the wall. It was determined that the bedrock key-in was not accomplished from stations 1+00 through 5+00, and several sand seams and lenses were present along the rest of the wall. In situ soil mixing (ISSM) was performed along the entire length of the wall to incorporate the sand into the backfill. After the ISSM operations, 28 backfill samples were collected. These samples met the 1×10^{-7} cm/sec permeability requirement of the design. Sediment erosion control measures were not well maintained during construction of the wall, possibly allowing sediments to run into the trench and causing permeable zones along the bottom of the wall.

5.3 Monitoring

Long-term monitoring was rated better than acceptable compared to standard industry practice. The monitoring program includes measuring groundwater elevations, monitoring for the presence of NAPS, and sampling and analysis of the groundwater. A total of 24 wells are installed at the site to monitor groundwater elevations; five of these wells are also used for NAPS monitoring. Groundwater samples are collected from nine well locations on a quarterly basis and analyzed for BTEX, PAH, total petroleum hydrocarbon (TPHC), pH, total and amenable cyanide, total phenols, ammonia-nitrogen, and arsenic.

Data for four pairs of wells was compared to determine the existence of an inward gradient. MW-2/OW-4, OW-5/MW-3, OW-6/OW-7, and OW-8/MW-12 are located at the "corners" of the perimeter wall, with one well of each pair located inside the barrier and the other located outside. Figure 2 shows the water level elevations in well pair OW-5/MW-3 beginning on May 8, 1995 (to represent conditions before pumping began), and continuing with monthly measurements from July 1995 through March 1996. Figure 2 demonstrates that an inward gradient has developed across the barrier wall. The site contractor noted that the rising groundwater levels inside and outside the containment area between December 1995 and February 1996 was likely due to higher than expected leakage into the containment area.

The groundwater monitoring program at the site includes sampling at two well locations inside and seven well locations outside the perimeter barrier. The two interior wells are PW-3 and PW-4; the wells located outside the barrier wall are PW-1, PW-2, MW-2, and four others.

The groundwater quality in the pumping wells inside the wall show an increase in contaminant concentrations, except for a 50 percent decrease in naphthalene concentration. The quality of water from pumping wells outside the wall has improved slightly. The concentration of contaminants has decreased slightly in MW-2, located just outside the barrier wall. These water quality results, coupled with the inward gradient discussed earlier, indicate that the containment system is performing as designed.

5.4 Operation and Maintenance

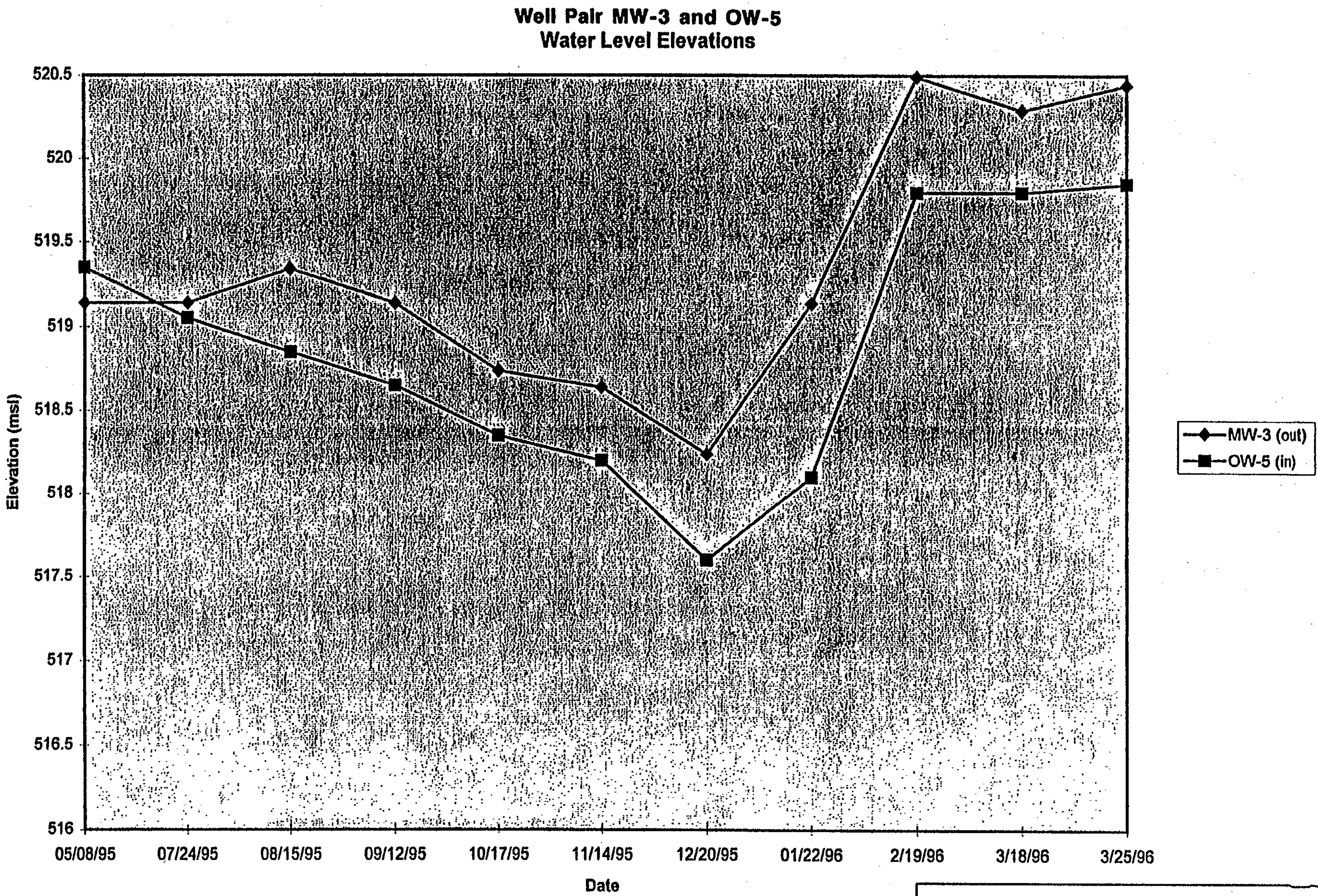
Operation and maintenance (O&M) activities at the site include measuring groundwater levels, and sampling groundwater wells and gas vents. Groundwater pumped from outside the barrier is treated using an activated carbon filter and is then discharged off site. Groundwater pumped from within the barrier is treated in an off-site wastewater treatment facility.

5.5 Other Considerations

The approximate costs associated with design and construction of the barrier wall, cap, and pump and treat system were $5.5 million, $2.7 million, and $1.3 million, respectively. O&M costs are minimal for the barrier wall; $10,000 per year for the cap; and $500,000 per year for the pump and treat system.

5.6 Remedy Performance

The remedy is performing as designed, with pumping from the extraction well operating at design rates. An inward gradient has developed, and will be maintained through pumping the wells within the barrier wall. The water quality in pumping and monitoring wells outside the barrier wall are improving.



Site 18

FIGURE 2
GROUNDWATER ELEVATIONS

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6.0 SUMMARY

Site 18 is a 4-acre, former sand and gravel borrow pit in the midwestern United States that was used for disposal of industrial and municipal wastes. BTEX, PAHs, NAPS, and arsenic are the primary site contaminants. A 2,000-foot soil-bentonite barrier wall and a RCRA Subtitle C cap was constructed to control the source of contamination. Groundwater is extracted from inside the barrier wall using two wells and is treated using a bioremediation process. Groundwater from outside the barrier is pumped using two wells and treated with activated carbon.

The design, CQA/CQC, and long-term monitoring were rated above average. An inward gradient was established and maintained at the site, although the water level within the barrier has fluctuated with water levels outside the barrier, indicating slight leakage. Water quality monitoring of the pumping wells indicates that contaminant concentrations are decreasing, while monitoring well concentrations do not show any particular trends. Based on the results of two water quality monitoring events, the barrier wall cap and associated water management system appear to be effective in meeting the containment and remediation objectives.

Barrier Type	SB
Remedial Objective	SC;zero gradient
Performance	3

SITE 19

1.0 SITE DESCRIPTION AND HISTORY

Site 19 covers about 32 acres and is located in the northeastern United States. The site was a sand and gravel pit that later became the repository for various household and hazardous wastes. The site received wastes for at least 20 years until the early 1980s, when complaints about volatilizing compounds emanating from an adjacent stream caused alarm among local residents. Another stream located downgradient drains to the surrounding city's water supply reservoir.

The site is bordered by two streams, and a river is located within 1 mile of the site. A municipal solid waste landfill is operating adjacent to and just upgradient from the site. Mobile home communities border the site on its remaining sides.

The selected site remedy called for containment of a 20-acre area by hydrodynamic isolation, including a subsurface barrier wall and a pump and treat system with recharge. The barrier wall was constructed in 1982, and a geomembrane cap was installed as well. One year later, the pump and treat system was installed to augment the containment. The site remedy was evaluated between 1990 and 1993 for compliance with regulatory requirements. Recent studies have been performed to evaluate the effectiveness of the remedy. Figure 1 shows the site and basic features.

The site represents a good application of containment in a difficult hydrogeologic environment without the advantage of a pervasive, confining layer or bottom. The barrier and recirculation approach was a pragmatic method of controlling source migration and evaluating off-site contamination in a phased fashion.

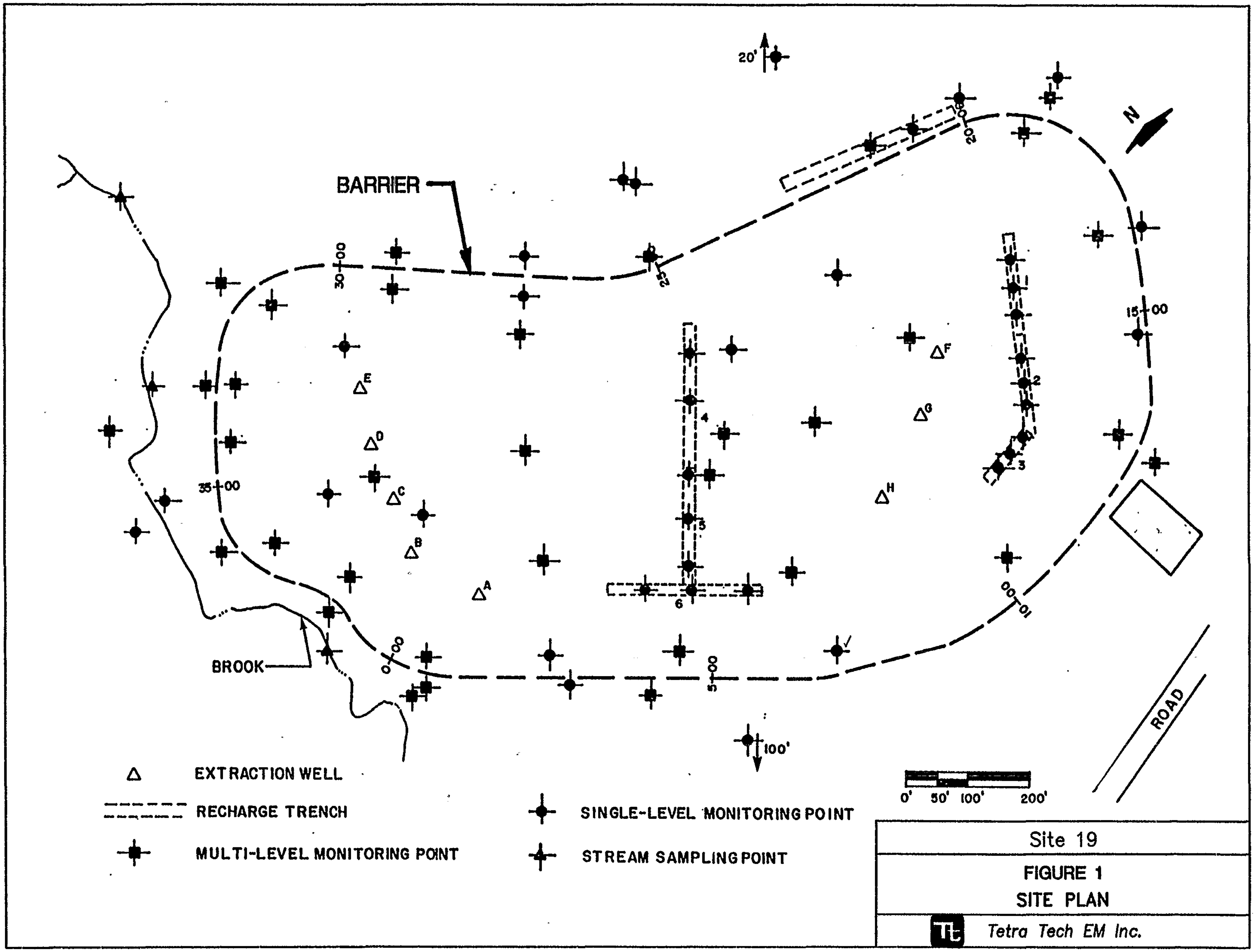
2.0 GEOLOGIC/HYDROLOGIC SETTING

The site lies in the Glaciated Appalachian Region of the United States, and the site geology reflects recent glaciation. The site area is underlain by a sequence of fine to coarse sands and lenses of silts and silty, fine sands that are outwash and glacial lake deposits. This unconsolidated sequence is underlain by dense glacial till, which is generally thin and not always continuous. Although it is low in permeability, the till is an imperfect aquiclude. The till is founded on a bedrock of weathered schist of varying competency and permeability. The bedrock's shallower layers are highly fractured.

The unconsolidated sands range in permeability from 10^{-5} to 10^{-1} centimeters per second (cm/sec) and have an average hydraulic conductivity of about 10^{-2} cm/sec. The lower till permeability is on the order of 10^{-5} cm/sec. The rock has widely varying hydraulic conductivities within a range of 10^{-3} to 10^{-5} cm/sec; some rock testing has revealed hydraulic conductivities as high as 10^{-1} cm/sec.

The regional groundwater flow direction is east to west, and discharge occurs downgradient into the streams and the river near the site. This flow was interrupted by the installation of the circumferential barrier wall, which significantly altered the local flow pattern. After the barrier wall was installed and before any groundwater was pumped, groundwater rose 2 to 3 feet, mounding against the upgradient (eastern) portion of the barrier, a general east to west gradient in the containment and a downgradient outward flow condition. In addition, interior shallow water levels within the contained area were

Key: SB=Soil Bentonite Wall SC=Source Control Performance Rating: 3=Evidence suggests objective may not be met



Site 19

FIGURE 1
SITE PLAN

artificially higher than underlying intervals, causing downward gradients. However, water levels in the wells screened in the bedrock both inside and outside the containment area were similar, implying the presence of permeable bedrock. Gradient values and the corresponding flow through the containment varied depending on subsequent pumping activities.

3.0 NATURE AND EXTENT OF CONTAMINATION

The site received household and hazardous wastes for at least 20 years. Reportedly, tanker trucks dumped liquids in open pits at the site. Consequently, the site displayed elevated concentrations of several compounds, but volatile organic compounds (VOC) were most prevalent. Total VOC concentrations were as high as 2,000 mg/L. Of the VOCs detected, tetrahydrofuran (THF) was the most common. In samples containing VOCs, over 90 percent could be attributed to THF. Therefore, THF became the indicator compound for the site.

Before the remedial action, the concentrations of THF at the site ranged from detection limits to about 170 mg/L. The highest concentrations were detected downgradient toward the adjoining streams. Concentrations were highest in the shallow, overburden soils. After the remedial action, the concentrations were generally lower but the distribution of THF had changed.

4.0 CONTAINMENT REMEDY

The site remedy consists of an active containment system consisting of a circumferential hydraulic barrier wall, a pumping system, a site-wide cap, and a monitoring program. General features of the remedy included:

- A soil-bentonite hydraulic barrier wall that is about (on average) 4,000 linear feet long; to 110 feet deep (50 foot average); 3-foot thick; and keyed into weathered rock (with minimal penetration)
- Eight recharge and extraction wells
- Six recharge trenches at two locations
- Several pairs of groundwater level monitoring locations paired across the barrier
- Many groundwater quality monitoring wells upgradient and downgradient
- More than three surface water quality monitoring locations along the adjacent waterways
- A cap (geomembrane)
- A treatment system

It was determined that the original 6-acre source area and an additional 14 acres were underlain by the contaminant plume to be contained. An early feasibility study determined that neither hydraulic isolation alone nor containment alone would be practical or effective in containing the contamination, primarily because of the local geology and the absence of a suitable and pervasive confining bottom at the site. Therefore, the remedy called for hydrodynamic isolation or active containment and a "zero net gradient" condition across the barrier wall. It was also realized that controlling the inward gradient condition might not be feasible in all cases and that the effectiveness of the containment should be re-evaluated.

5.0 PERFORMANCE

Overall remedy performance has been the subject of several studies during and after remedial construction. Performance was measured based on groundwater quality and maintenance of a zero net gradient across the barrier wall. Generally the containment has been successful in reducing shallow groundwater contamination on site. However, barrier underflow and off-site bedrock contamination may have been exacerbated by the remedy.

Containment system performance and contributing factors are described further in the following subsections.

5.1 Design

The barrier design was rated slightly better than acceptable with respect to industry practices described in Section 3, Volume I. The feasibility of implementing different systems was studied, adequate numbers of borings were drilled along the barrier wall alignment, significant compatibility testing was performed, a geophysical survey was performed along the entire barrier alignment, and detailed barrier and testing specifications were developed. The barrier construction specifications were both performance- and design-based. The barrier was designed to incorporate excavated material and was constructed using trench-side mixing. Feasibility study- and design-level groundwater modeling were performed. However, modeling and keying requirements apparently underestimated the impact of groundwater flow in the bedrock and under the key.

The geomembrane cap consisted of 40-mil HDPE material. Insufficient design information was available to evaluate the cap design.

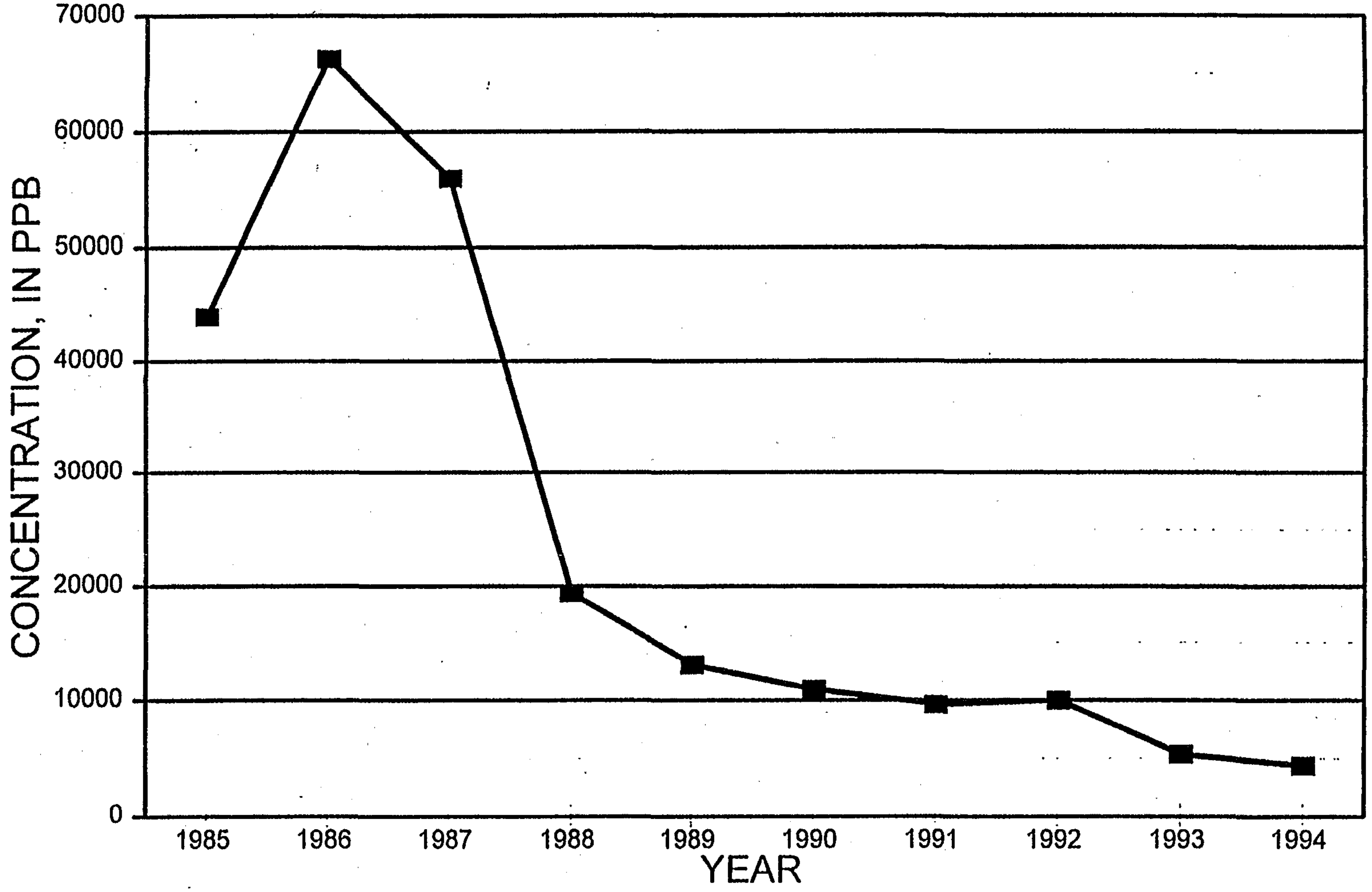
5.2 Construction Quality Assurance and Construction Quality Control

Barrier construction quality assurance (CQA) and construction quality control (CQC) were rated slightly better than acceptable because of the thorough and detailed controls placed on construction. The barrier was continuously inspected during construction. Rigorous testing was performed, including parallel fixed-ring and flexible-wall permeameter studies as well as testing using bentonite content methylene blue titration. Periodic, documented testing of groundwater quality and measurement of hydraulic head were performed during and after construction. In addition, postconstruction peizocone testing was performed for window detection, undisturbed barrier samples were collected and tested, pump testing across the barrier was performed, and geophysical methods were used to measure barrier integrity.

Insufficient information was available to evaluate cap CQA/CQC.

5.3 Monitoring

The monitoring program for Site 19 involved a better than acceptable effort. Groundwater and surface water quality was measured periodically to assess plume migration and the effectiveness of the pumping and recirculation system. Hydraulic head was also measured at nested piezometers inside and outside the barrier to evaluate the pumping system's effectiveness in maintaining a zero gradient condition, not only for lateral flow but also for vertical flow and barrier underflow.



Site 19

FIGURE 2
AVG. CONCENTRATION – TOTAL VOCs INSIDE BARRIER WALL

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Groundwater quality data for overburden monitoring wells within the barrier, summed to display total VOC concentrations over time, is shown graphically in Figure 2. The figure shows the dramatic decrease in shallow overburden concentrations. However, groundwater quality monitoring outside the barrier wall and downgradient has indicated increasing concentrations of VOCs in bedrock. Increasing VOC concentrations in bedrock were detected in some places for several years immediately after installation of the barrier, and more recently were detected in an area downgradient of the barrier. At some downgradient locations, interior bedrock concentrations are greater than two orders of magnitude more than the overlying shallow concentrations, and the bedrock concentrations of VOCs outside the barrier are two to three times higher than the bedrock concentrations inside the barrier.

Additional barrier performance monitoring was conducted during a regulatory agency-required remedial action evaluation study. This monitoring is described in Section 5.4.

5.4 Operation and Maintenance

The O&M activities of the remedial action conducted since 1983 were examined in detail by revisiting the containment system 10 years after its installation and evaluating barrier integrity, groundwater quality, and the overall effectiveness of the remedy. The study involved extensive monitoring of hydraulic head for horizontal and vertical gradients at the barrier, pumping tests at the barrier, drilling of 11 barrier confirmation borings to test for extent of the barrier and physical parameters, and an evaluation of groundwater flow and impact on the surrounding area. The results of the study are discussed in Section 5.6.

5.5 Other

The capital cost of the containment as estimated in a predesign document is outlined below:

- Slurry wall: $2,100,000 (about $10 per square foot of the barrier wall)
- Cap: $436,000
- Wells: $50,000
- Gas Vents: $65,000
- Groundwater treatment: $1,644,000

Postconstruction documents indicate that the barrier wall construction cost was actually $4.65 per square foot. Annual O&M costs were not available for the site.

5.6 Remedy Performance

Early performance monitoring conducted since installation in 1982 was rigorous in attempting to define the effectiveness of the containment system. The site's lack of a pervasive, low-permeability aquitard layer has caused difficulties in meeting the initial zero net gradient objective.

Recent investigation has shown that about one-third of the barrier is subject to outward flow. Undisturbed sample collection and testing indicates that the current barrier permeability is about one order of magnitude above the constructed values, and chemical results indicate the possibility of bentonite degradation, although the data is not conclusive. More importantly, the additional flow occurs by underflow beneath the barrier in the bedrock. Recent head measurements and groundwater quality data indicate that a downward gradient exists in places from the shallow aquifer to the bedrock. Contaminants are apparently migrating through fractured bedrock and under the barrier; these contaminants may present a risk to downgradient receptors.

The barrier, geomembrane cap, and recirculation system have proven effective in reducing contaminant concentrations in the shallow overburden soils. Downward gradients and migration of contamination in the bedrock apparently result in contamination moving outside the containment. Impacts of such migration may be evaluated by establishing a groundwater management zone. Further monitoring is likely in the future.

6.0 SUMMARY

Site 19, located in the northeastern United States, has a 20-acre area contained by a soil-bentonite barrier wall, and is equipped with a geomembrane cap and pumping system. The site is a former sand and gravel pit that received various municipal and hazardous wastes, resulting in VOC contamination. The geology of the site consists of permeable, glacial sands and gravel overlying fractured schist with locally high permeability. Recirculation (extraction and infiltration) pumping has attempted to achieve a zero gradient condition to control off-site migration of contaminants. Monitoring and postconstruction evaluations indicate that the containment has been successful in significantly reducing shallow groundwater contaminant concentrations. However, downward groundwater flow and permeable fractured bedrock have created conditions under which site contaminants can apparently migrate to bedrock downgradient of the barrier. Therefore, the containment has been only partially effective in meeting the remedial objectives. The site is undergoing further evaluation that may lead to establishing a groundwater management zone and conducting further monitoring.

SITE 20

Barrier Type	SB
Remedial Objective	SC
Performance	2

1.0 SITE DESCRIPTION AND HISTORY

Site 20 is located in the eastern United States. The site covers 20 acres in an area of industrial, commercial, and warehousing operations on a peninsula near a river estuary.

For more than a century, the site was used to process chromium ore to produce a number of chromium-containing chemical compounds. Chromium ore processing at the site generated large quantities of process residuals containing soluble chromium. These process residuals were used as fill material enlarging the peninsula upon which at the site is located. Perimeter bulkheads stabilize the site at the water's edge. In addition, large quantities of water were used for processing and plant housekeeping.

A subsurface hydraulic barrier was completed at the site in 1996, and cap and groundwater pumping system construction has begun. The site and basic site features are shown in Figure 1.

2.0 GEOLOGIC/HYDROLOGIC SETTING

The site is located on the Atlantic and Gulf Coastal Plain. The site is underlain by Precambrian rock overlain by a layer of Lower Cretaceous sediments (the Patuxent Formation). The Cretaceous sediments form the central core of the peninsula where the site lies. Above this core are layers of coarse-grained Pleistocene sediments, marine silts, and heterogeneous fill materials. The top fill layer on which the industrial facilities were built consists of construction debris, brick, wood fragments, silts, and sands.

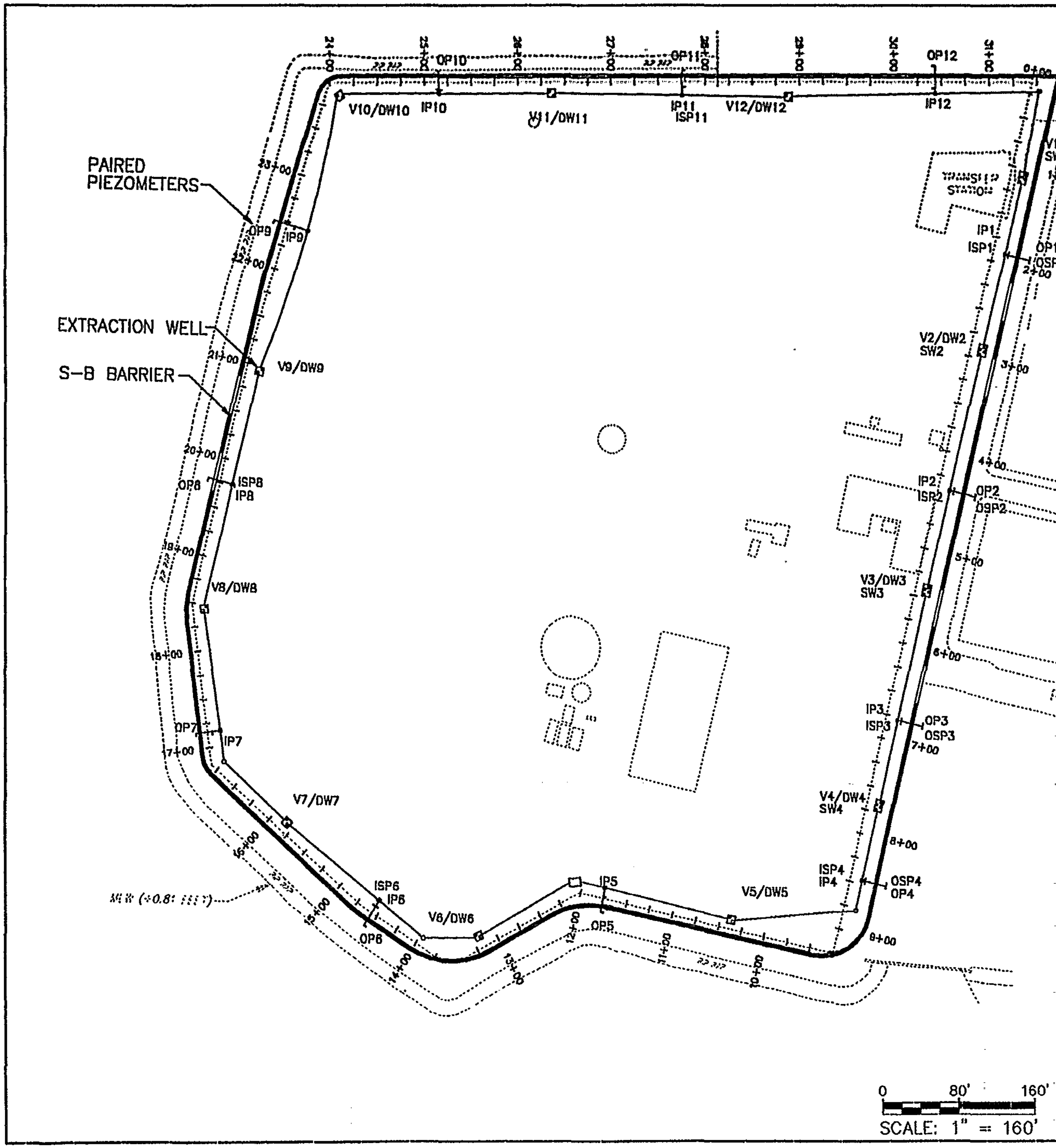
Contamination was found at the site in two groundwater-yielding layers, one shallow and one deep. The shallow, unconfined groundwater lies above low-permeability silts near the site perimeter and flows radially off the site through the perimeter bulkheads to the north, west, and south. Deep, partially confined groundwater lies within the Cretaceous sands; it flows from northwest of the site to the southeast. Precambrian rock underlies the site soils. The uppermost layer of rock extends beneath the entire site and ranges in thickness from 5 to 20 feet. This layer is made up of decomposed rock and consists of clayey, fine to coarse sand. The permeabilities of this material ranges from 3.8×10^{-4} to 3.8×10^{-7} centimeters per second (cm/sec). The next lower rock layer consists of fine to coarse sand in a clay silt matrix with a high quantity of feldspar and biotite, and the next lower layer is a weathered to medium-hard gneiss with quartz seams. The barrier wall was keyed a minimum of 3 feet and up to 6 feet into the uppermost layer of rock.

3.0 NATURE AND EXTENT OF CONTAMINATION

The site soils and groundwater were contaminated primarily with chromium. Chromium levels in groundwater were found to range from 0.01 to 14,500 mg/L. Computer modeling of contaminant migration from the site indicated that about 62 pounds per day of chromium was released into adjacent surface water and groundwater. The deep groundwater flow has resulted in off-site groundwater contaminant concentrations of up to 200 mg/L.

It was determined that reducing recharge of the deep groundwater from above would reduce chromium migration from the shallow groundwater to the deep groundwater. Additionally, it was determined that

Key: SB=Soil Bentonite Wall SC=Source Control Performance Rating: 2=Evidence suggests objective may be met



Site 20

FIGURE 1
SITE FEATURES

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the site soils would not be excavated, but rather would remain in place and be contained by the remedial measures. This was the intent in constructing the containment barriers at the site.

4.0 CONTAINMENT REMEDY

The containment remedy had the following general features:

- A rock outboard embankment to allow waterside soil-bentonite barrier construction
- A subsurface barrier wall that is about 3,200 linear feet long; 65 to 80 feet deep; 3 feet thick and that has a 3-foot rock key
- A cap (including a capillary break, geomembrane clay liner, FML 60 mil low density polyethylene [LDPE], geonet, cover)
- Groundwater extraction system consisting of 12 perimeter deep wells and 4 landside shallow wells
- Monitoring (hydraulic head, groundwater quality, and surface water quality)

The rock embankment constructed around the waterside perimeter of the site reinforced the bulkheads and provided a structural platform for constructing the soil-bentonite barrier. The embankment also provided some reduction of groundwater flow off site.

The multilayer geosynthetic cap was designed to facilitate future use of the site for residential, commercial, or recreational purposes.

The groundwater monitoring system for the site includes 32 piezometers paired at 12 locations. Four of these locations have nested, paired piezometers in shallow and deep aquifers whereas the remaining eight locations have paired piezometers only in deep aquifers. Each piezometer pair has one piezometer installed on the inner side of the barrier and one piezometer on the outer side of the barrier. Sixteen extraction wells will remove groundwater from the two aquifers. The water will be pumped to an on-site transfer station, where it will be stored until it is transported to a treatment facility. Groundwater levels inside the barrier must be kept at 0.01 foot lower than the outside groundwater levels (based on averaged hourly readings). The system will be operated by an on-site computer system capable of changing pumping rates to accommodate changes in groundwater levels.

The multimedia cap and groundwater extraction system have not yet been constructed.

5.0 PERFORMANCE

The long-term performance of the barrier will be determined based on periodic monitoring of hydraulic head, groundwater quality, and surface water quality.

Hydraulic head across the barrier has been significantly influenced by the installation of the barrier. After the completion of the barrier wall, groundwater levels inside the barrier rose by several feet. Because the groundwater extraction system had not been constructed, the groundwater rise was managed using a series of sumps. Excess groundwater was pumped to an on-site treatment facility.

Containment system performance and contributing factors are described further in the following subsections.

5.1 Design

The barrier design was rated better than acceptable based on industry practice as discussed in Section 3, Volume I. The design specifications generally followed the guidance established by the U.S. Army Corps of Engineers. Significant positive features of the design included rigorous compatibility testing of both slurry and backfill with on-site groundwater and the brackish surface water surrounding the site. A salt water-resistant bentonite was used as a dry addition to the backfill in order to counteract potential effects of the brackish surface water. The slurry used in the trench was a conventional, untreated bentonite. Borings were drilled every 90 feet along the barrier alignment. Trench stability analysis was performed to determine an acceptable depth for the slurry above the groundwater table elevation because of the tidal surface water fluctuation. Additionally, planned barrier penetrations and vehicle crossing slabs, as well as surface capping details and the cap interface were all designed before barrier construction.

The cap design was rated better than acceptable. The site is planned for development after the remedial construction is complete. A significant positive feature of the cap design is its inclusion of future utility locations in preparation for development. This feature will allow cap layers to be removed in only those areas where utility or development construction is necessary.

5.2 Construction Quality Assurance and Construction Quality Control

Barrier construction quality assurance (CQA) and construction quality control (CQC) were rated better than acceptable. Significant positive features of the CQA/CQC program included constant inspection of trench excavation and backfilling. Inspections included sounding of the trench bottom and verification of key depth. Backfill mixing was inspected constantly, and testing was performed to determine the permeability, slump, and gradation of each batch of backfill (200 to 500 cubic yards) before its placement. Backfill was mixed in a central location. Slurry was tested both before and after placement in the trench. The viscosity and sand content of the slurry were tested, and modifications were made as necessary. Backfill testing was performed by the design engineer. A minimum of one permeability and gradation test was performed for each batch. Slurry testing was performed by the contractor with random, duplicate testing by the design engineer; duplicate testing was performed daily at the discretion of the design engineer.

As part of CQA/CQC monitoring, the slurry levels in the trench were closely inspected to determine whether slurry was being lost to the adjacent surface water. Because the barrier was being constructed within a previously constructed rock embankment, slurry loss through the larger stones in the base of the embankment was a possibility. Slurry loss occurred at one location during barrier construction, and a plugging agent was used to seal the leak. The barrier alignment was shifted slightly at this location to avoid additional leakage. No additional slurry loss occurred at this location during construction.

A construction completion report was written detailing the various aspects of the construction, CQA/CQC, as-built plans, modifications, and final data.

The CQA/CQC for cap is not evaluated because the cap is yet to be constructed.

5.3 Monitoring

Hydraulic head monitoring was performed at least weekly and often three to four times weekly during construction. Monitoring of this site has been performed since 1988 as part of the remedial action. Existing monitoring wells both inside and outside the barrier were used. As part of the construction contract, an additional 16 pairs of piezometers were installed. Monitoring of these piezometers revealed an increase in the groundwater level inside the barrier after the barrier was completed. The increase was due to infiltration of precipitation and the lack of a groundwater extraction system. Sumps were installed at several locations around the perimeter of the site to manage the elevated groundwater until the permanent groundwater extraction system became operational.

Hydraulic head measurements were plotted over time. This plot details the rise in shallow groundwater levels within the barrier over time as the barrier was constructed. As the groundwater levels after the completion of the barrier indicate, groundwater pumping was not being performed during this period.

Continuous monitoring of water levels was performed at several paired piezometer locations around the site to compare tidal influence inside and outside the barrier. Shallow locations showed no tidal influence inside the barrier, indicating barrier integrity. However, deep locations inside the barrier showed minor, dampened tidal response, presumably because of pressure waves emanating from the underlying, tidally influenced rock.

Hydraulic testing was also performed at several locations around the site perimeter to measure distance-drawdown response inside the barrier and check for impact outside the barrier. At each location tested, the outside piezometer showed no pumping-induced influence, even when head differentials were on the order of 20 to 30 feet during active pumping. Such testing confirmed the integrity of the barrier in the immediate vicinity of the locations tested.

Groundwater quality was monitored around the site perimeter on a quarterly basis before, during, and immediately after construction. Quarterly data showed no distinct decrease in contaminant concentrations outside the barrier; in fact, some concentrations increased. This finding has been attributed to changes in groundwater flow during construction and the flow equilibration processes after construction. This well is located about 15 feet outside and downgradient of the barrier.

Surface water lies immediately adjacent to the barrier along 2,200 feet of its alignment. Surface water samples from several locations, including locations along the barrier were sampled and analyzed for total chromium. Sample results showed an immediate improvement in water quality at some locations upon barrier completion. Since completion of the barrier, average chromium concentrations in surface water have been below the 0.050-mg/L standard.

5.4 Operation and Maintenance

Operation and maintenance (O&M) activities consisted of observing the barrier for signs of settlement, erosion, or other damage. Settlement plates were installed in the surface of the barrier during construction and were surveyed to determine whether settlement had occurred. No abnormal settlement has occurred to date. Ongoing future O&M for the barrier will include review of pumping and monitoring data.

5.5 Other

The construction cost of the containment is estimated to be about $28,000,000. Barrier construction, excluding embankment construction, cost about $5,000,000, or $22 per square foot of wall. Annual O&M costs, excluding water treatment costs, for the completed containment are estimated to be $400,000.

5.6 Remedy Performance

Water levels inside and outside the barrier were at significantly different hydraulic heads upon barrier completion. Minimal postconstruction monitoring has been performed. However, testing and monitoring indicate that no leakage is occurring and that when an active, inward gradient is maintained, no leakage will occur. Long-term monitoring will be used to track containment performance.

6.0 SUMMARY

Site 20 is a 20-acre site located in eastern United States. For more than a century, chromium ore was processed at the site to produce many chromium-containing chemical compounds. Contamination was found at the site in two groundwater-yielding layers, one shallow and one deep. The shallow groundwater lies above low-permeability silts near the site perimeter and flows radially off the site through bulkheads to the north, west, and south. Deep groundwater within Cretaceous sands flows from northwest of the site to the southeast. To minimize further contamination of the adjacent harbor and off-site groundwater, a soil-bentonite barrier was designed as part of the overall containment system, which also included a groundwater extraction system and a multilayer cap.

The design and CQA/CQC of the barrier were rated better than acceptable. Performance monitoring of the barrier was also rated better than acceptable involving intensive construction inspection, postconstruction sampling, installation of paired piezometers across the barrier, and extensive groundwater quality monitoring. Early results indicate that the barrier is a protective remedy. The effectiveness of the entire containment will be determined based on future monitoring data.

SITE 21

Barrier Type	SB, DSM
Remedial Objective	Inward gradient
Performance	X

1.0 SITE DESCRIPTION AND HISTORY

Site 21 is located in the Midwestern United States. The site covers about 60 acres and contains three waste disposal areas (see Figure 1). The Old Site, which operated from 1967 to 1974, covers 5 acres and is the disposal area described in this site summary. The New Site, which was operated from 1974 to 1983, covers 40 acres and was closed in 1983. The low-level radioactive waste (LLRW) site operated from 1967 to 1978, and closure activities were completed in 1989. The tritium plume associated with the LLRW site has been remediated, and the chemically contaminated plume is being monitored by the U.S. Environmental Protection Agency.

The Old and New Sites were investigated from 1985 to 1989, and a remedial plan was selected in 1990. In 1994, construction of the barrier wall and a Resource Conservation and Recovery Act (RCRA)-type cap to cover the areas bounded by the barrier wall was completed for the Old Site. A groundwater extraction system from within the containment area began operating in 1996. Extracted groundwater is treated at an on-site treatment plant.

2.0 GEOLOGIC AND HYDROGEOLOGICAL SETTING

Site 21 is in the Glaciated Central Region of the United States. Overburden soils in the area consist of glacial drift (till and outwash), loess, dune sand, and alluvium. The thickness of the overburden soils ranges from 20 to 75 feet. The Toulon Sand member of the Glasford Formation is an average of 15 feet thick at the site and forms an unconfined aquifer at the site. The low-permeability till units underlying the sand member impede vertical groundwater flow and contaminant migration through the till unit.

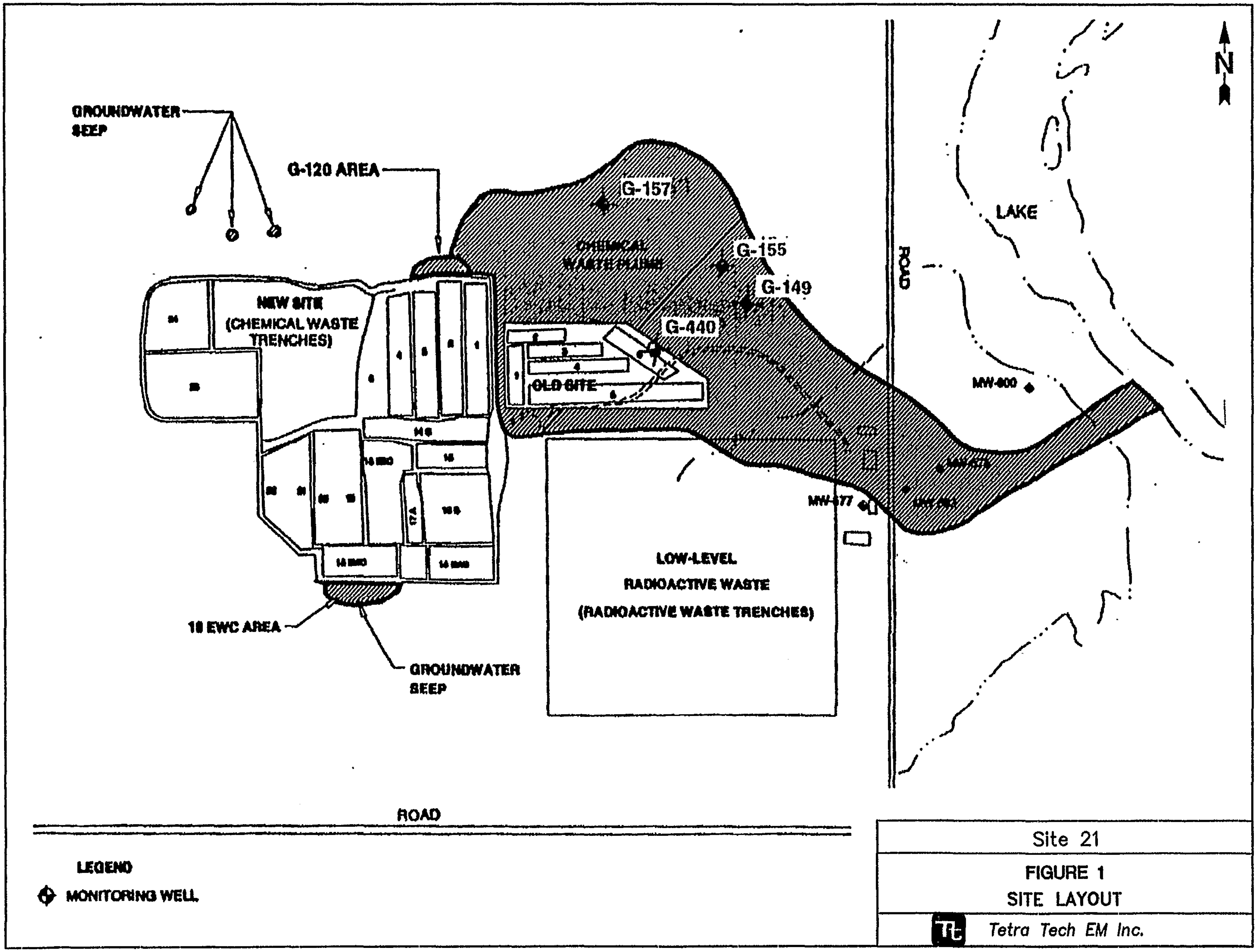
Bedrock underlying the soils is about 65 feet deep and consists of interlayered and weathered Silurian-age shale, siltstone, limestone, sandstone, and coal. The upper surface of the bedrock has been altered by glacial erosion and excavation activities associated with site construction and coal mining. The lateral continuity of the Toulon Sand provides a preferential pathway for groundwater flow to a lake located southeast of the site. The average hydraulic conductivity of the aquifer is 24 feet per day. Fractured zones in the bedrock also provide pathways for contaminant migration from the site.

3.0 NATURE AND EXTENT OF CONTAMINATION

The plume associated with the old disposal area contains trichloroethene; chloroform; benzene; tetrachloroethene; 1,1-dichloroethane; 1,2-dichloroethane; 1,2-dichloropropane; methylene chloride; xylene; and arsenic. Analysis of groundwater samples collected within the glacial formation beneath the Old Site indicates organic and inorganic contaminants in the following concentrations:

- Trichloroethene: 200 to 7,800 micrograms per liter ($\mu g/L$)
- Chloroform: 410 to 100,000 $\mu g/L$
- Benzene: 340 to 10,000 $\mu g/L$
- Tetrachloroethene: 100 to 50,000 $\mu g/L$
- 1,1-Dichloroethane: 7 to 170 $\mu g/L$

Key: SB=Soil Bentonite Wall Performance Rating: 3=Evidence suggests objective may not be met



Site 21

FIGURE 1
SITE LAYOUT

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- 1,2-Dichloroethane: 1,400 to 10,000 μg/L
- 1,2-Dichloropropane: 6 to 110 μg/L
- Methylene chloride: 200 to 40,000 μg/L
- Xylene: 10 to 210 μg/L
- Arsenic: 10 to 70 μg/L

4.0 CONTAINMENT REMEDY

The selected corrective measures for source control at Site 21 consist of the following components:

- Placement of soil-bentonite barrier walls around the Old Site that are 2,900 feet long; 40 to 70 feet deep; and 3 feet wide with a 3-foot key

- Construction of a RCRA Subtitle C cap over the Old Site consisting of a geosynthetic clay liner, 40-mil high density polyethylene liner, geonet, and cover soils.

- Installation of extraction wells within areas encircled by the barrier walls

Deep soil mixing technology was used to construct the soil-bentonite barrier walls. The barrier was keyed into till or shale bedrock.

5.0 PERFORMANCE EVALUATION

The objective of the containment system is to maintain an inward groundwater gradient at the Old Site. Performance monitoring began at the site in April 1996 and consists of monthly water-level monitoring of paired monitoring wells within and outside the barrier walls. Also, beginning in 1992, quarterly water quality was monitored in wells located outside the wall within the contaminated plume.

An evaluation of containment system design, construction quality assurance and construction quality control (CQA/CQC), monitoring, operation and maintenance, other considerations, and remedy performance are discussed in the following subsections.

5.1 Design

The hydrogeologic investigation and geotechnical design investigation for the site was better than acceptable with respect to industry practices described in Section 3, Volume I, with borings spaced 100 feet apart along the barrier wall alignment. Groundwater modeling, trench slurry compatibility, and the backfill permeability testing were conducted by the engineer in coordination with the contractor. The cap design was thorough, with the provision for erosion control measures.

5.2 Construction Quality Assurance and Construction Quality Control

The CQA/CQC was rated better than acceptable. The specialty contractor selected for the barrier wall construction had completed more than 10 such comparable projects, and conducted all the standard tests to ensure that the slurry mix was within the design specifications. Post construction barrier sampling and testing was conducted to verify the depth of the key-in and the permeability of the barrier wall. The EPA provided oversight of the CQA/CQC activities, and independently verified the depth of the key-in.

5.3 Monitoring

The monitoring for the site was rated less than acceptable. Monitoring consists of four pairs of monitoring wells, with one well in each pair located within the barrier wall and the other located outside the wall. Monitoring of water quality downgradient of the barrier wall is conducted quarterly. However, hydraulic stress tests, settlement monitoring and barrier wall movement monitoring was not done. Figure 2 shows a downgradient well pair where the water level within the barrier wall has been 0.35 to 1.4 feet higher than the outside water level. However, results are available for only 2 months; continued pumping is expected to produce an inward gradient.

Figure 3 shows the concentrations of two organic compounds detected in the influent to the on-site wastewater treatment plant. Groundwater from a series of wells located in the contaminant plume is collected and treated in the on-site treatment plant. After peaking between August 1993 and January 1995, contaminant concentrations have stabilized at lower concentrations.

5.4 Operation and Maintenance

The extraction wells and the treatment plant are properly maintained. The influent and effluent groundwater concentrations are monitored monthly at the treatment plant.

5.5 Other Considerations

The cost for the containment system was approximately $4,300,000. Barrier wall costs equaled $3,000,000. Operation and maintenance costs are approximately $10,000 per year for the cap.

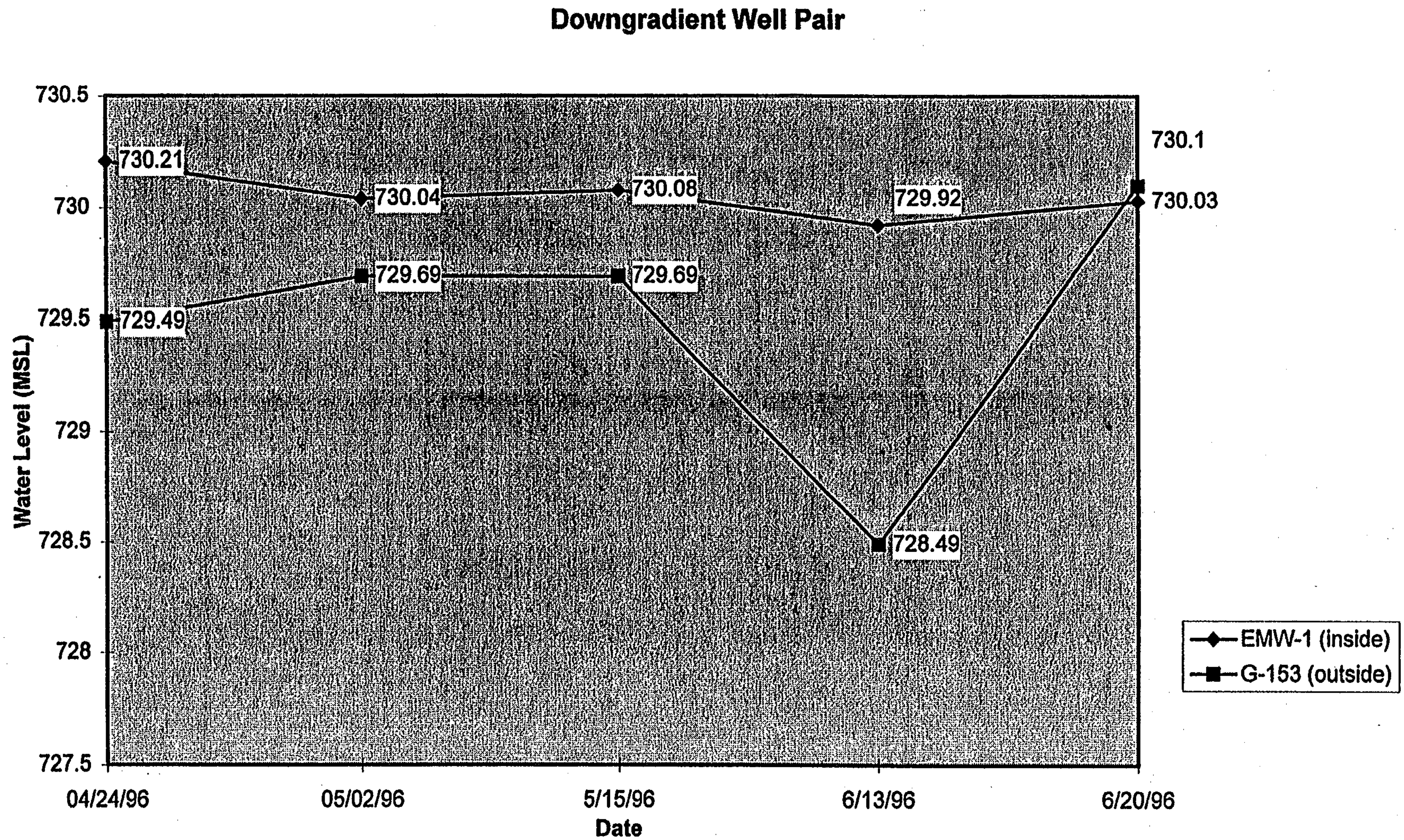
5.6 Remedy Performance

Because the extraction system just started operating in April 1996, there is not yet convincing evidence that an inward groundwater gradient has developed.

6.0 SUMMARY

Site 21 consists of three disposal areas, two of which received hazardous chemical wastes and occupy a total of about 60 acres. In 1994, construction of a soil-bentonite barrier wall and RCRA Subtitle C cap was completed. A contaminated groundwater plume containing organic compounds at concentrations near or above 10,000 g/L is associated with the Old Site. Six extraction wells are located within the plume, and four are located within the barrier wall. Currently, water from all extraction wells is treated in an on-site treatment plant. Design and CQA/CQC of the barrier wall were both determined to be significantly above average. Monitoring of the barrier wall was rated below average. Monthly measurements of groundwater levels do not indicate that an inward gradient has been established at the site yet.

Groundwater quality data is collected quarterly and indicates that contaminant concentrations are decreased rapidly after construction of the wall and cap, but remain in the mg/L range. Overall, there is insufficient data to determine if remedial objectives had been met.



Site 21

FIGURE 2
GROUNDWATER ELEVATIONS

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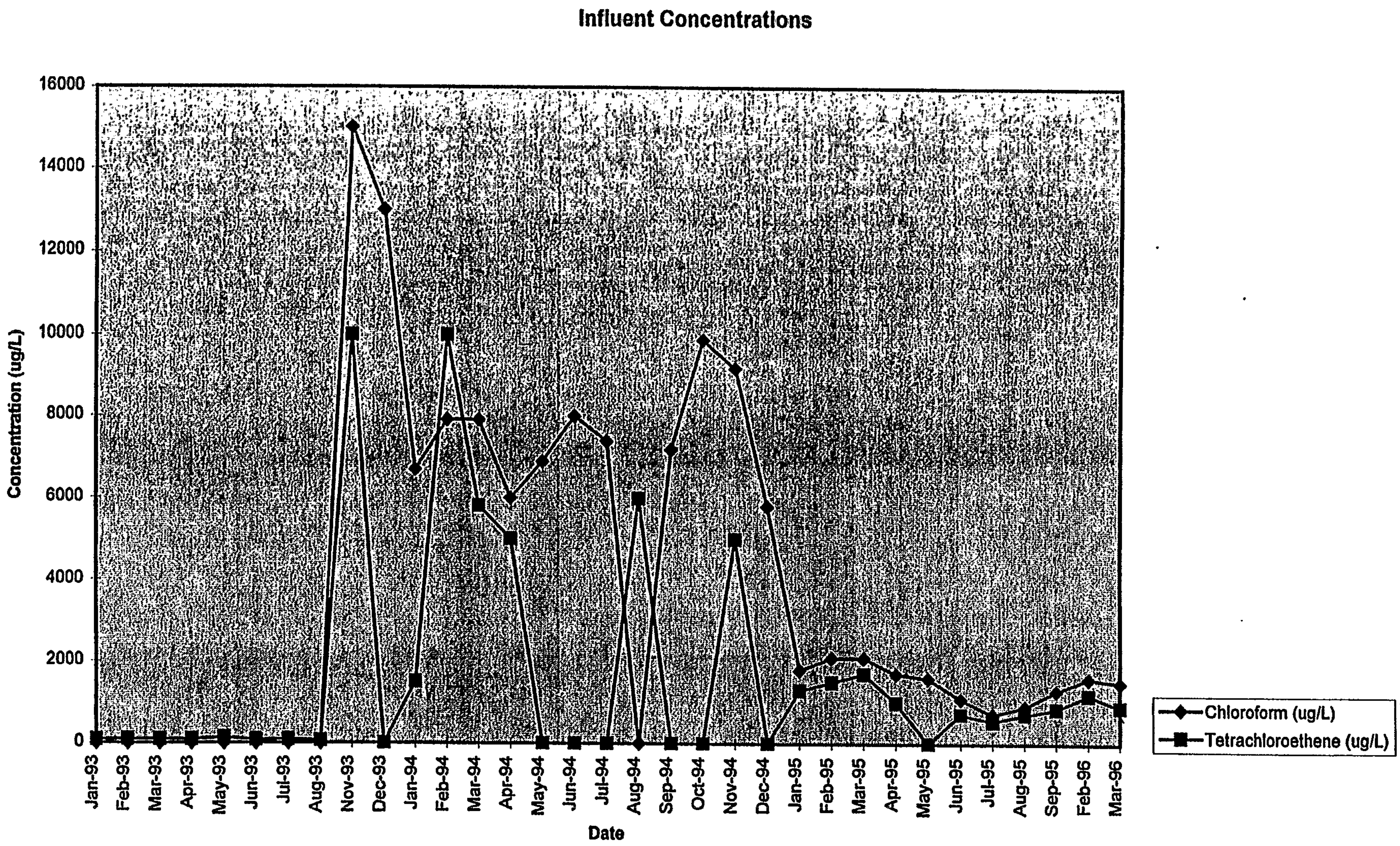

Site 21

FIGURE 3
INFLUENT TO WASTEWATER
TREATMENT PLANT

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SITE 22

Barrier Type	SB
Remedial Objective	SC
Performance	3

1.0 SITE DESCRIPTION AND SUMMARY

Site 22 is located in northeastern United States. The site is a corner property bound by a road on the south, a highway on the west, a creek on the north, and an industrial facility on the east. The site was first used for solvent refining and recovery and then was used to process industrial wastes before it was shut down in 1980. In 1991, the site was assigned two operable units (OU) for remediation purposes. OU1 is the designation given to the 5.9-acre site currently contained within a slurry wall. OU1 includes contaminated soils and groundwater above the clay layer at the site. OU2 refers to all other areas on and off site that require remediation. Each OU has its own record of decision (ROD).

An initial feasibility study (FS) for OU1 was conducted in 1989. The FS evaluated remediation and treatability alternatives for OU1 groundwater and soil or sludge. A total of nine monitoring wells were installed off site in 1988: five shallow monitoring wells (MW-8S to MW-12S) were screened in the fill, and four deeper monitoring wells were installed (MW-8D, MW-11D, MW-12D, and MW-13D). A deep bedrock monitoring well (MW-2R) was installed on site in 1989. Also, 23 test pits were excavated in July 1989 to evaluate the nature of the fill material. Figure 1 shows the site layout.

2.0 GEOLOGIC AND HYDROGEOLOGIC SETTING

Site 22 is located within the Atlantic and Gulf Coastal Plain and the Piedmont Geologic Province of New Jersey. The area is underlain by the Triassic-age Newark Supergroup bedrock, which is predominantly shales and sandstones. The advancing ice front of the Wisconsinan Glacial event eroded valleys into underlying rocks. As the glacier retreated, a glacial lake formed between the ice front and the terminal moraine. Fine-grained sediments were deposited in this lake, and till was deposited over the scoured bedrock. Overlying the glacial sediments is a sequence of moraines and marsh sediments. Fill was placed above the marsh deposits to develop the land where the site is located.

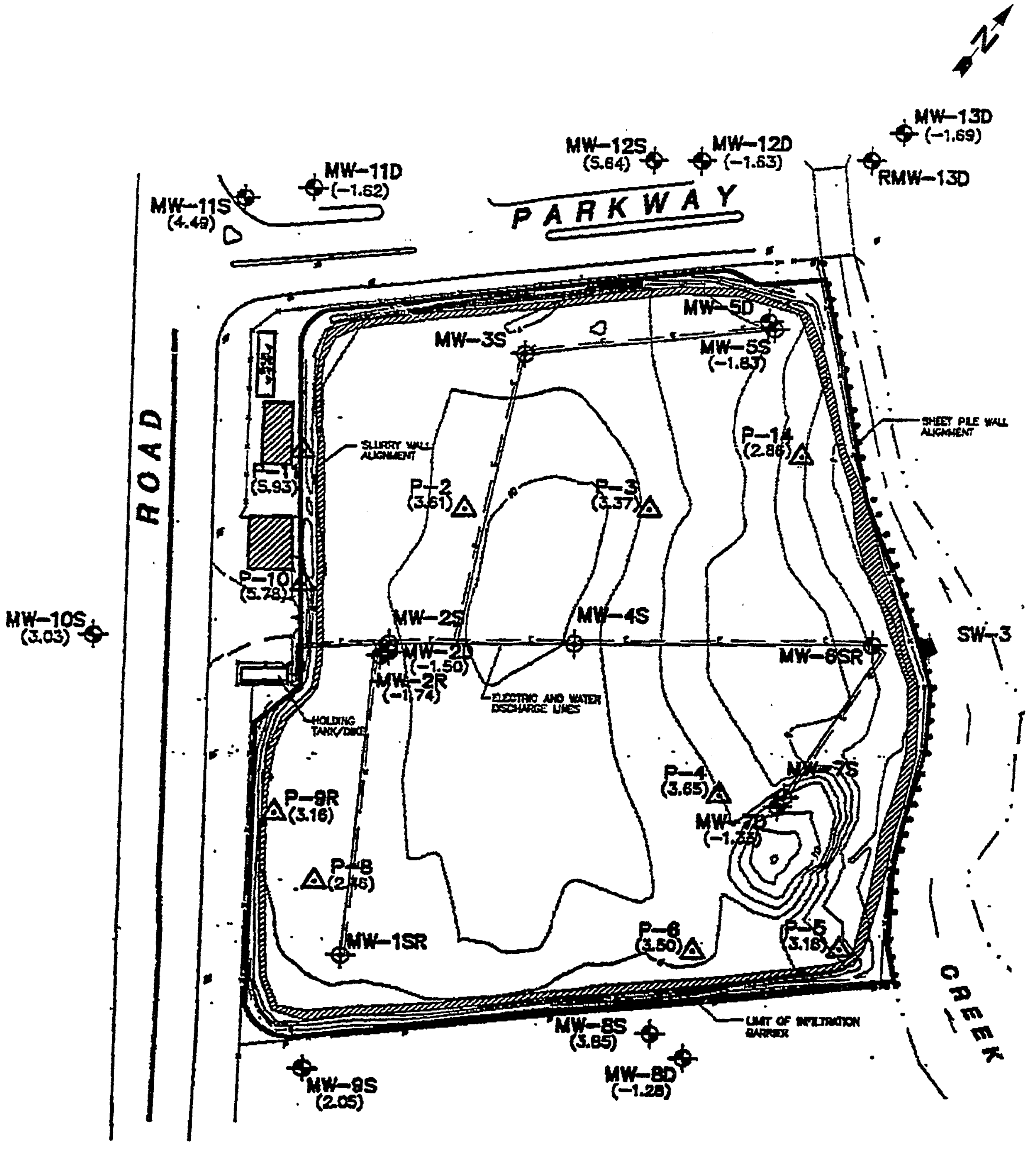
Based on information collected from soil borings, the stratigraphy at he site is as follows (in descending order): fill, peat, gray silt, varved clay, till, and bedrock. The fill is composed of soil mixed with construction fill. The fill is thinnest near an on-site creek and increases in thickness toward the road that borders the south side of the site. The fill thickness ranges from 3 to 11 feet and averages about 8.4 feet.

The peat is the youngest of the naturally occurring materials at the site. Its thickness decreases from the creek that borders the north side of the site to the road that borders the south side of the site. In some places, the peat is completely absent. This could be the result of the high water content of peat, which causes the peat to be displaced when fill is placed over it. The peat's thickness ranges from 0 to 7 feet and averages 1.8 feet. At one location, fine sand that appears to be natural overlies the peat, indicating the occurrence of localized channel scouring and filling.

The gray silt is about 2 feet thick across the site. Bedding is not present except for rare laminations. The material is extensively mottled, indicating reduced conditions.

The varved clay layer is a wedge-shaped clay unit that is thickest toward the creek that borders the north side of the site and thinner toward the road that borders the south side of the site. The unit's thickness ranges from 0 to 18 feet. The unit's upper surface is horizontal, while the lower surface is inclined. From the creek to the road, the varved clay yields to a massive red clay unit and a sand unit that is 0 to 8 feet thick.

Key: SB=Soil Bentonite Wall SC=Source Control Performance Rating: 3=Evidence suggests objective may not be met



NOT TO SCALE

Site 22
FIGURE 1 SITE LAYOUT
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The Wisconsinian till is 20 feet thick and is the deepest unconsolidated unit in the strata. It is composed of three members: (1) clean sand, (2) massive clay, and (3) sand and gravel. The bedrock is reddish-brown shale of the Brunswick Formation. A seismic study was conducted to determine the approximate depth of the bedrock: its depth was estimated to be 59.6 feet.

Three aquifer systems are present at the site. They are (in descending order) the water table aquifer (shallow), the till aquifer (intermediate), and the bedrock aquifer (deep). The water table aquifer is very shallow, usually lying 1 to 2 feet below ground surface (bgs), and occurs under perched conditions on the underlaying clay. Its lateral flow is toward the center of the site as well as toward the creek, the highway, the road, and the adjoining property to the east. The till aquifer is thought to be connected to the water table aquifer because of the presence of unconsolidated recent and Holocene-age fluvial deposits and the underlying glacial deposits. The bedrock aquifer in the site is generally confined by the overlying mantle of unconsolidated deposits. However, the possibility exists that all three aquifers beneath the site are connected. Not enough information was available to reach a definition conclusion in this regard.

3.0 NATURE AND EXTENT OF CONTAMINATION

On-site operational areas included a tank farm, drum storage areas, a still and boiler house, a staging platform, and a thin-film evaporator. The tank farm had an unlined containment area that was depressed 1 to 2 feet with respect to the surrounding surface elevations. At one time the farm contained 18 tanks, but only one tank remains on site. This tank contains sludge with extremely high polychorinated biphenyl (PCB) levels. The structural integrity of the tank is suspect because of discoloration observed on the outside of the tank.

During the remedial investigation (RI), various contaminants, including volatile organic compounds (VOC), acid extractable compounds, base neutral compounds, PCBs, metals, petroleum hydrocarbons, and pesticides, were detected at high levels at all soil depths sampled.

4.0 CONTAINMENT REMEDY

A baseline risk assessment (BRA) for the site was conducted in 1990 for the U.S. Environmental Protection Agency (EPA). The BRA followed the EPA guidance for conducting risk assessments that was current at the time. On September 14, 1990, EPA issued a ROD selecting an interim remedy for OU1 based on the RI/FS and BRA. The ROD defined OU1 as "contaminated soils and groundwater above the clay layer" and selected a remedy composed of the following elements: a slurry wall that encompasses the entire site, an infiltration barrier to be placed over the site, a groundwater extraction and collection system for OU1, and off-site treatment and disposal of extracted groundwater.

The design of the interim remedy was presented in the interim remedy remedial design report (IRRDR) in 1991. The construction of the interim remedy began in August 1991 and was completed in June 1992. As part of the design effort, 18 soil borings were installed to evaluate subsurface conditions in the vicinity of the proposed slurry wall.

An "upgraded" slurry wall was installed at the site in August 1991, and a steel sheet-pile wall was constructed along the creek to facilitate installation of the slurry wall. An upgraded slurry wall is a soil-bentonite slurry wall with a high-density polyethylene (HDPE) membrane inserted vertically through the center of the completed wall. The purpose of this liner is to ensure a slurry wall permeability of less than 1×10^{-7} centimeters per second (cm/sec).

The total length of the slurry wall installed at the site is 1,890 feet. The depth of the slurry wall ranges from 11.8 to 18.8 feet bgs. The width of the slurry wall is 36 inches, which allowed sufficient space for installation of the vertical HDPE membrane. The slurry wall is keyed into a gray silt or varved clay-red clay unit that has a permeability of 7.6×10^{8} cm/sec. After the completion of the slurry wall, a temporary cap made of HDPE was installed. The total area of cap coverage is 238,285 square feet.

A dewatering system was installed to manage the groundwater within OU1. The is being extracted by the dewatering system to achieve and then maintain the required water level in OU1. The collected groundwater is transported to a facility in southern New Jersey for treatment and disposal. The total amount of groundwater extracted from the site between June 1992 and March 1996 is about 278,280 gallons.

5.0 PERFORMANCE EVALUATION

As part of the interim remedy for OU1, a slurry wall was installed adjacent to and inside the perimeter of the 5.9-acre site. The wall extends from the ground surface into the silt and clay layers. A sheet-pile retaining wall was installed along the on-site creek. A temporary infiltration barrier was installed across the entire surface of the area surrounded by the slurry wall. The backfill mix of off-site soil and bentonite was designed to achieve and maintain a permeability of no more than 1×10^{7} cm/sec. After 3 years of pumping, the water level within the slurry wall had not decreased significantly compared to the water levels outside the wall.

5.1 Design

The design was assigned an average rating. Hydrogeologic and FSs were performed. Geotechnical physical testing was performed, and test borings were spaced between 100 and 200 feet apart. In addition, groundwater design performance modeling was performed. Backfill permeability was tested, but the number of tests performed is unknown.

5.2 Construction Quality Assurance and Construction Quality Control

Barrier construction quality assurance (CQA) and construction quality control (CQC) were assigned a slightly above average rating as a result of an 18-hour slurry mixing period and the trench, slurry, and backfill testing, which was performed. However, although CQA and CQC testing was performed, the results of that testing were not available. For example, sand was added to the slurry mixture, but the final sand content is not known.

5.3 Monitoring

The site monitoring program involves sampling of 13 groundwater wells and four surface water sampling points in the on-site creek. Target analytes are tested for annually, and VOCs are tested for quarterly. Quarterly sampling reports are generated for the site. Sampling data has shown that an inward gradient exists at the site, but this gradient has been sporadic and sometimes insignificant. The exact location and extent of site contamination are still under investigation. Since the slurry wall was installed, no performance or stress tests have been conducted on it.

The site monitoring program was assigned a slightly below average rating because (1) no hydraulic stress tests were performed and (2) no physical samples were collected and no permeability tests were performed after the wall was installed.

5.4 Operation and Maintenance

No information was available concerning operation and maintenance of the slurry wall containment system at the site.

5.5 Other Considerations

Following is a breakdown of the estimated cost for implementing the interim remedy based on the OU1 ROD. The actual cost of the interim remedy is unknown because it was facilitated by a potentially responsible party group and EPA does not have the actual cost information.

Conceptual Items	Cost Estimates in Thousands of Dollars
Total construction cost:	2,097,000
Engineering and construction oversight:	460,000
Monitoring (quarterly for 3 years):	109,000
Subtotal:	2,666,000
Contingency (about 10 percent):	267,000
TOTAL COST:	**$2,933,000**

5.6 Remedy Performance

Overall, remedial objectives have not been met because of the low or nonexistent inward gradient provided by the pumping system.

6.0 SUMMARY

Site 22 is a 5.9-acre site with an "upgraded" slurry wall (an HDPE membrane was inserted vertically through the center of the wall). The site was used for industrial waste processing from 1971 to 1980, when a court order shut down the site. The geology of the site consists (in descending order) of fill, peat, gray silt, varved clay, till, and bedrock. The slurry wall is keyed into the gray silt and varved clay layers. A pumping system was installed to induce an inward gradient, but after 3 years, the water level inside the slurry wall had not decreased significantly compared to the water levels outside the wall.

SITE 23

Barrier Type	SB
Remedial Objective	SC
Performance	2+

1.0 SITE DESCRIPTION AND HISTORY

Site 23 is located in the northeastern United States. The site is adjacent to a river to the north, a river to the east, undeveloped land to the south, and a road to the west. The road provides access to the site along its western border. A site map showing basic site features is provided in Figure 1.

The site covers about 315 acres and contains an active municipal waste landfill fully surrounded by a soil-bentonite subsurface barrier wall. The wall was designed and built for subsurface leachate containment. The wall was constructed in two phases and completed in late 1984. The barrier wall is about 3 miles long and ranges from about 10 to 60 feet deep, averaging about 38 feet in depth. Other site features include a leachate collection and disposal system, withdrawal wells, piezometers, and groundwater monitoring wells. The existing leachate management system includes a perimeter and interior leachate collection system.

2.0 GEOLOGIC/HYDROGEOLOGIC SETTING

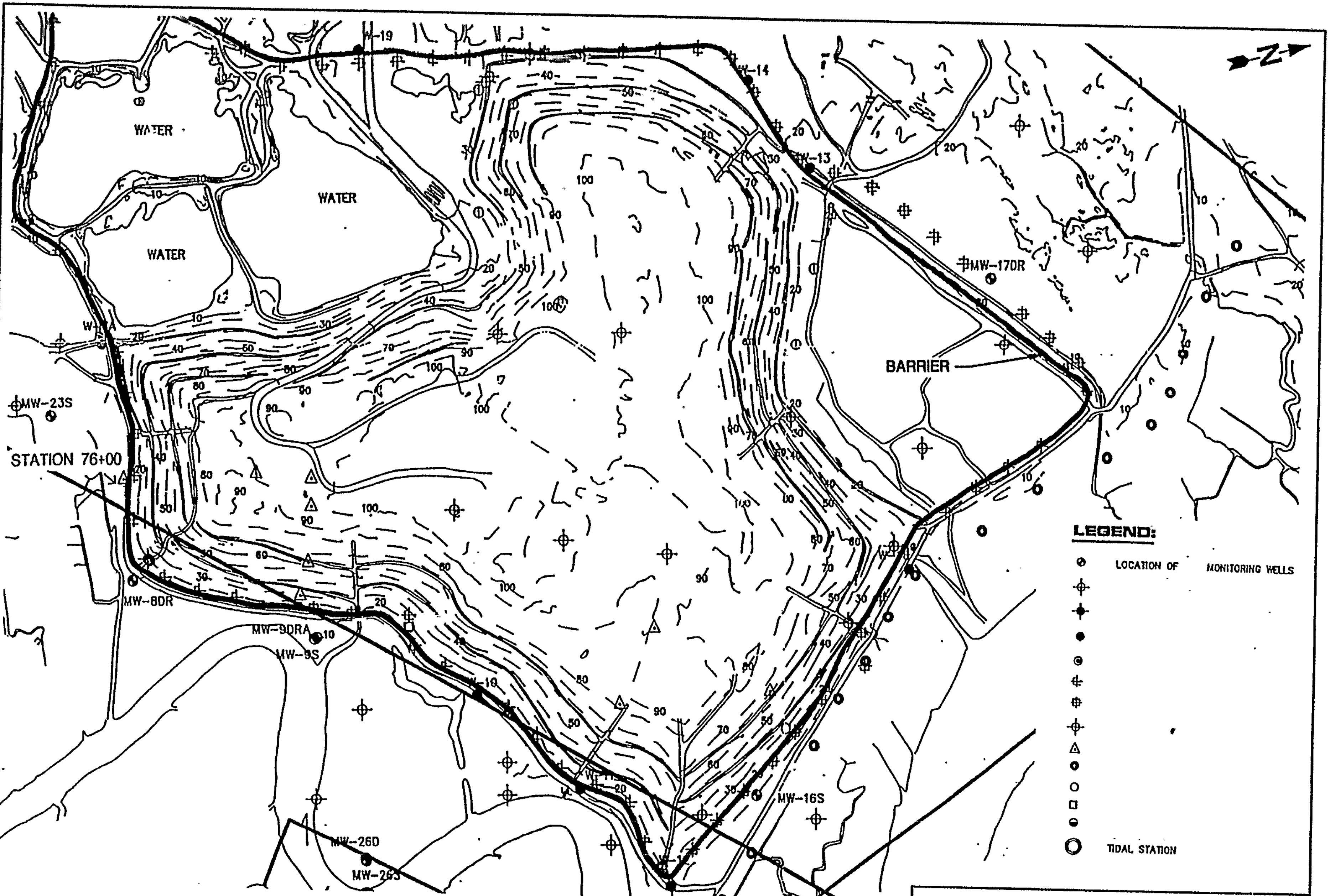
The landfill is located near the western edge of the Atlantic Coastal Plain. At the landfill, the geology is generally composed of the following six strata (in descending order):

- Fill from 40 years of sanitary landfill operations and from general improvements at the landfill perimeter (for example, roads, caps, and berms)
- Organic marine tidal marsh deposits consisting of organic silts and clays with interbedded peat (meadow mat) near the surface and frequently under the fill
- A sand unit, which typically has only a small amount of fines and is consequently very permeable
- A clay unit, which acts to inhibit the flow of water (The subsurface barrier wall was keyed into this low hydraulic conductivity clay unit and into the underlying residual soil)
- Residual soil, typically a dense, clayey soil with weathered rock fragments
- Shale bedrock

The sand unit and the bedrock form two distinct aquifers separated by the clay unit. The sand aquifer is a major groundwater resource in the region and the groundwater flows primarily to the southeast toward the adjacent rivers.

The bedrock aquifer system is not considered to be a major source of water in the site area. Water in the bedrock aquifer is stored in and transmitted through fissures and fractures in the bedrock. The general flow directions of the groundwater in the bedrock aquifer are north toward the river and east toward the other river. Pump tests conducted at the site have indicated that the upper bedrock is not highly fractured and has low hydraulic conductivity; thus it yields little or no water.

Key: SB = Soil Bentonite SC = Source Control Performance Rating: 2+ = Evidence suggests objective may be met



Site 23

FIGURE 1
SITE PLAN

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3.0 NATURE AND EXTENT OF CONTAMINATION

The landfill had been constructed within a marshland environment located directly above the outcrop area of the sand aquifer. Several volatile organic compounds (VOC) were detected in groundwater from the sand and bedrock aquifers (for example, 1,1,1-trichloroethane at 400 µg/L).

4.0 CONTAINMENT REMEDY

The barrier wall was designed as part of the overall hydraulic containment system, which also includes the leachate collection system. The objective of the containment system was to prevent possible leachate migration from the landfill into the surrounding groundwater. The containment system has the following general features:

- A soil-bentonite subsurface barrier wall that is about 15,480 linear feet long; 38 feet deep (on average); and 3 feet thick and that has a 3-foot soil key
- A leachate collection system
- 21 piezometers installed both inside and outside of the wall to determine the groundwater response to pumping
- 15 groundwater monitoring wells screened in the sand aquifer adjacent to the barrier wall

5.0 PERFORMANCE

The evaluation of the barrier wall's integrity was based on its: (1) physical presence, (2) conformance to design specifications, (3) performance as a hydraulic barrier, and (4) effect on surrounding groundwater quality.

The physical presence of the barrier wall was investigated after construction and was verified at all tested locations except one reach. A physical and geotechnical investigation was conducted using piezocone testing as well as pumping tests at three locations along the wall to assess the wall's overall hydraulic effectiveness. Generally, the results of hydraulic testing showed the wall to be hydraulically adequate.

Available groundwater quality data does not indicate any contaminant plume emanating from the area enclosed by the barrier wall. One potentially problematic area was located where a leak was detected during the postconstruction investigation. This area had experienced some difficulties during construction because of trench failure. New soil-bentonite backfill was used to fill the failed area. The trench was reexcavated for more than 600 feet. No contaminants were found to have migrated through this portion of the barrier wall.

Future installation of a slot drain and withdrawal well system to maintain an inward, 1-foot hydraulic head differential across the barrier wall is planned in order to provide adequate leachate collection throughout the contaminated area.

5.1 Design

The barrier design was rated average with respect to industry practices as discussed in Section 3, Volume I. The design generally followed the requirements of the governing state organization.

The wall was designed to (1) be 3 feet wide, (2) consist of a soil-bentonite backfill mixture capped with soil, and (3) extend vertically from the ground surface to at least 3 feet into clay or bedrock. The soil-bentonite wall is about 3 miles long and ranges from about 10 to 60 feet deep, averaging about 38 feet in depth.

Because the landfill is currently operating, the cap has not been designed.

5.2 Construction Quality Assurance and Construction Quality Control

Barrier construction quality assurance (CQA) and construction quality control (CQC) were rated better than acceptable. Based on testing of undisturbed barrier samples collected every 500 linear feet, the barrier met the design permeability requirement of less than 1×10^{-7} cm/sec.

Piezocone testing was performed at approximately 400-foot intervals along the centerline of the barrier wall to provide overall profiling coverage of the wall. Seventeen dissipation tests were performed during profiling to estimate the in situ permeability of the wall. The estimated permeability ranged from 1×10^{-7} to 1×10^{-9} cm/sec, indicating that the soil-bentonite backfill material met the design objective with respect to hydraulic conductivity.

5.3 Monitoring

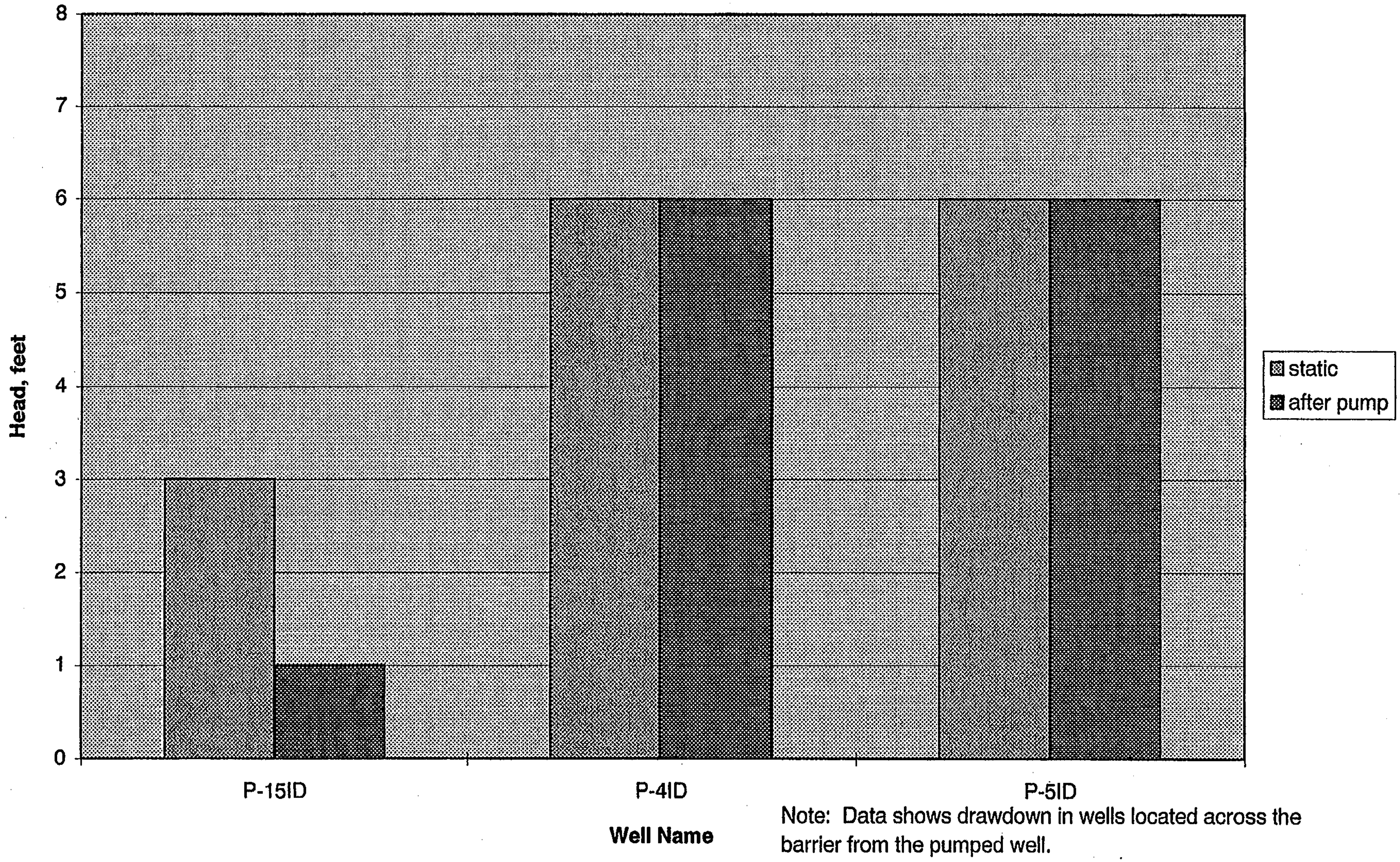
Containment monitoring was rated slightly better than acceptable. The monitoring involved taking quarterly readings of hydraulic head at 21 pairs of monitoring locations around the barrier and on either side of the barrier. An additional 15 monitoring locations outside the barrier were sampled quarterly (samples were analyzed for metals, BOD, and COD) and annually (samples were analyzed for metals, VOCs, and semivolatile organic compounds).

The quarterly groundwater hydraulic head data available for several years showed that in most cases, the head differential was maintained at greater than a 1-foot difference across the barrier, thereby achieving inward flow.

Pumping tests were conducted at three piezometer locations along the outside of the wall. These locations were selected based on the findings of the piezocone testing, test boring information, and construction records. At two of the three piezometer locations, piezometers located inside the wall showed no change in static head, while at the third location, the piezometer located inside the wall indicated a hydraulic connection between the inside and outside of the wall. The results of the testing are summarized in Figure 2.

5.4 Operation and Maintenance

Operation and maintenance (O&M) requirements for the containment involved monthly site inspections, quarterly effluent sampling and well water level readings, and annual well water sampling since 1984.



Note: Data shows drawdown in wells located across the barrier from the pumped well.

Site 23

FIGURE 2

DRAW DOWN ACROSS BARRIER

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5.5 Other

No additional information about the site, including the capital and O&M costs, is available.

5.6 Remedy Performance

The overall remedy is performing as designed. Hydraulic head objectives were easily met using the leachate collection and pumping system. Groundwater quality outside the containment has improved significantly based on the decrease in contaminant concentrations. The barrier was determined to be of low permeability, adequately keyed, continuous, and intact based on the groundwater table elevation measurements.

6.0 SUMMARY

Site 23 is a 315-acre active municipal solid waste landfill. The landfill was constructed within a marshland environment located directly above the outcrop area of an aquifer, which serves as a major groundwater resource in the region. To prevent possible migration of leachate into the aquifer, a barrier wall and leachate collection system were designed as part of the overall containment system. The containment remedy consisted of a soil-bentonite barrier and a leachate collection system.

The design and CQA/CQC of the barrier were rated acceptable and better than acceptable, respectively. The performance monitoring of the barrier was rated better than acceptable involving postconstruction sampling, use of the piezometers paired across the barrier, ample groundwater quality monitoring, and regular inspections. The site containment has met containment objectives.

SITE 24

Barrier Type	SW
Remedial Objectives	SC
Performance	3

1.0 SITE DESCRIPTION AND HISTORY

Site 24 is an abandoned refinery that manufactured biphenyl, polychlorinated biphenyls (PCB), phenyl phenol, naphtha, and fuel oils from 1967 until the early 1980s. The site occupies about 13 acres, and the nearest residences lie 50 feet from the site. Site activities have resulted in contamination of the shallow groundwater-bearing zones under the site. The remedy outlined in the 1986 record of decision (ROD) includes construction of a soil-bentonite slurry wall around the site and a groundwater pump and treat system for the shallow groundwater-bearing zone. Figure 1 presents a current site plan.

2.0 GEOLOGIC AND HYDROGEOLOGIC SETTING

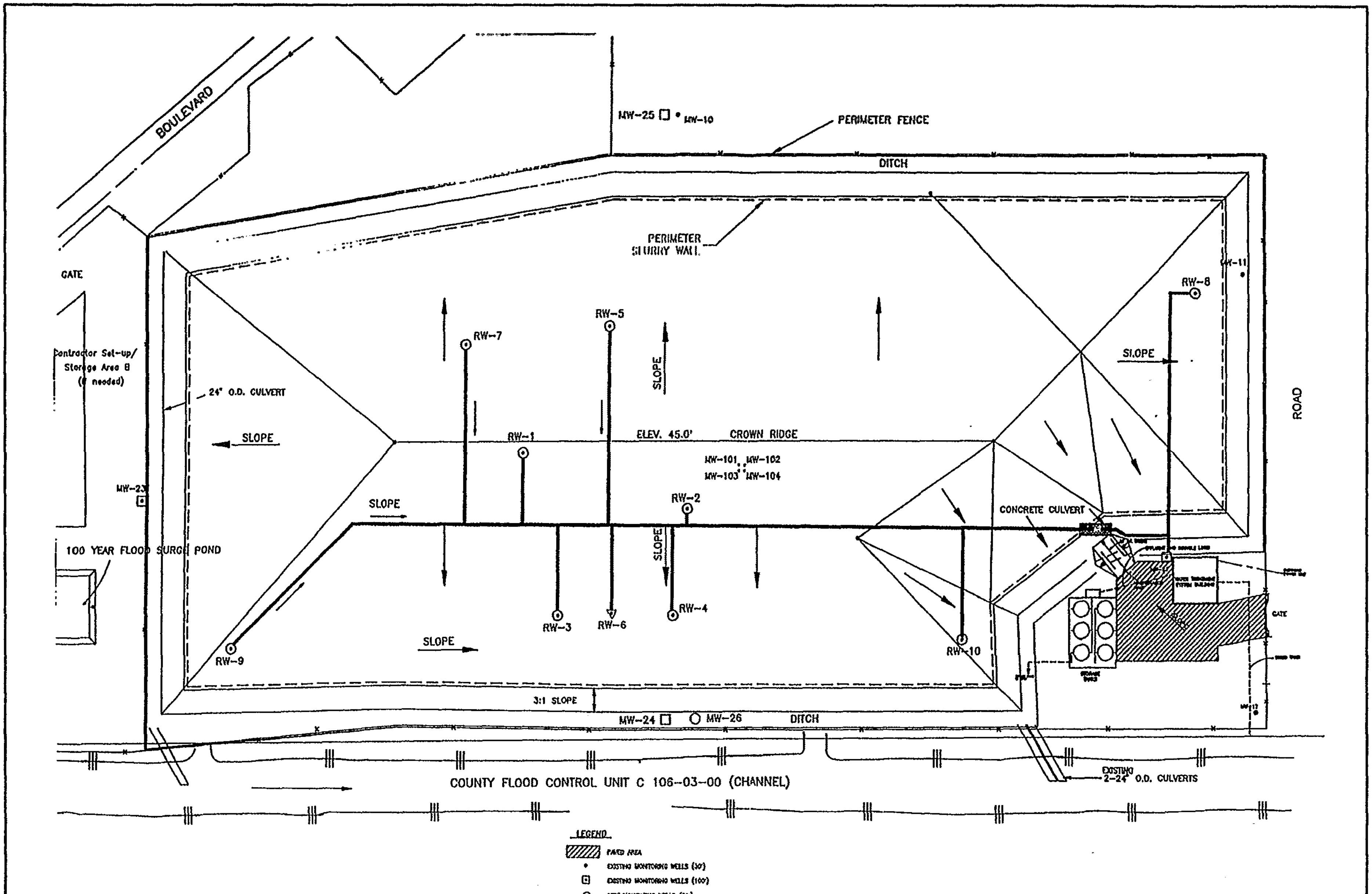
Site 24 is located within the Gulf Coastal Plain and overlies an outcrop of Pleistocene-age alluvial sediments. These sediments are composed of clays and silts with occasional sand zones. Two shallow groundwater-bearing zones have been identified at the site: the 30-foot sand and the 100-foot sand. The 30-foot zone is a sandy silt and silty sand layer that occurs from about 10 to 40 feet below ground surface (bgs) at the site and has an estimated permeability of 1×10^{-4} to 1×10^{-5} cm/sec. The transmissivity of this zone is estimated to be 2 to 3 square feet per day. The groundwater in the 30-foot zone is unusable and has a chloride content ranging from 2,000 to 10,000 mg/L. Groundwater in this zone flows east toward an adjacent flood control channel at a rate of about 5 feet per year.

The 100-foot sand is a well-sorted sand that occurs from about 50 to 140 feet bgs. This 100-foot sand is separated from the 30-foot sand by a 13- to 27-foot-thick clay stratum with a permeability on the order of 1×10^{-9} cm/sec (based on laboratory permeability tests of three samples). The slurry wall around the site perimeter is keyed into this stratum. The 100-foot sand contains the shallowest usable groundwater in the site vicinity. This groundwater is used locally on a limited basis by residents and industry. Groundwater in this zone flows to the west and southwest at a rate of about 20 to 30 feet per year.

A remedial investigation (RI) report for the site suggests that the 30-foot and 100-foot sands may be connected as a result of growth faulting in the south half of the site. Although this hypothesis was not specifically investigated during the RI, or illustrated on any cross sections or maps reviewed, it was used to explain (1) features of the potentiometric surface of the 30-foot sand and (2) the presence of contaminants in the 100-foot sand.

Before 1967, petroleum production was common in the area, and oil production wells were known to be present on site. However, the number, age, and location of on-site oil wells are not known. One former on-site oil well was investigated and found to be plugged and abandoned in accordance with state requirements. However, it is not known whether any other on-site oil wells were adequately plugged and abandoned. The site area still contains several active oil wells. The depth of the shallowest oil-producing zone is not known.

Key: SW = Slurry Wall SC = Source Control Performance Rating: X = Insufficient data to determine if remedial objectives were met



Site 24

FIGURE 1
SITE PLAN

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3.0 NATURE AND EXTENT OF CONTAMINATION

The principal sources of contaminants at the site include waste lagoons and ponds, buried drums, landfills, landspreading areas, waste piles, and spill areas. The main contaminants include PCBs, solvents, chlorinated solvents, and polynuclear aromatic hydrocarbons (PAH). In soil, PCBs were present at levels up to 12,000 mg/kg. Former oil production wells on and near the site may also have been a source of site contaminants or migration pathways between groundwater zones.

The 30-foot sand was estimated to contain 23 to 41 million gallons of groundwater containing the following contaminants:

- PCBs (up to 714 µg/L)
- benzene (610 µg/L)
- ethylbenzene (1,500 µg/L)
- toluene (17 µg/L)
- xylene (4,300 µg/L)
- trichloroethene (TCE) (420µg/L)
- naphthalene (720 µg/L)
- fluorene (800 µg/L).

The 100-foot sand was estimated to contain at least 6 million gallons of groundwater contaminated with TCE, but the extent of contamination in the 100-foot sand is not known.

4.0 CONTAINMENT REMEDY

On September 18, 1986, EPA issued a ROD for the site that specifies preventing further degradation of the 30-foot sand as one of the remedial objectives. The ROD describes the containment portion of the selected remedy to include a slurry trench cutoff wall, cap, and a groundwater recovery and treatment system. The implemented remedy includes the following elements:

- A perimeter slurry wall that is about 3,300 feet long, 35 feet deep, and 2.5 feet wide and that has a key depth of 5 feet
- A permanent, multilayer surface cap including 3feet of compacted clay overlain by 60-mil HDPE, a 2-foot-thick sand drainage layer, and 2 feet of vegetated topsoil
- A TCE-contaminated groundwater recovery and treatment system consisting of nine recovery wells in the 30-foot sand and one recovery well in the 100-foot sand
- A monitoring network of three monitoring wells in the 30-foot sand outside the slurry wall, and four monitoring wells in the 100-foot sand

The slurry wall was designed to be a containment barrier that prevents off-site migration of contaminants by maintaining a negative inward gradient. The barrier is keyed 5 feet into the clay aquitard between the 30- and 100-foot aquifers to prevent leakage. In addition to the slurry wall, a groundwater recovery system was designed to recover contaminated groundwater for treatment and to provide a lower hydraulic head within the perimeter slurry wall than outside it, thus maintaining a horizontal gradient into the containment area. However, no performance standard (minimum negative gradient across the wall) was specified.

The construction activities for the slurry wall were certified on September 21, 1990. According to the certification report, all quality control tests and parameters were in accordance with the quality assurance plan. However, the groundwater monitoring and recovery system was not placed in operation until May 1993.

The Resource Conservation and Recovery Act (RCRA) cap, which was completed in April 1990, consisted (from bottom to top) of (1) a 3-foot-thick, clay layer; (2) a 60-mil high density polyethylene (HDPE) liner; (3) a 2-foot thick, sand drainage layer; and (4)2 feet of topsoil with a vegetative cover. The cap slopes gently away from the center of the site. The cap covers the entire site, including the slurry wall.

5.0 PERFORMANCE EVALUATION

Groundwater elevations in the monitoring and recovery wells are monitored monthly. Groundwater samples for chemical and water quality parameter analyses have been collected quarterly since the groundwater monitoring and recovery system became operational in May 1993. The following subsections summarize containment system performance.

5.1 Design

Based on the criteria outlined in Section 3, Volume I, the barrier design evaluation generated an average rating, but it was based on limited design information. Most of the available design information was associated with the groundwater extraction system, not with the slurry wall. The slurry wall design objective was to maintain a negative inward gradient in conjunction with the 30-foot sand recovery wells. No specific performance standard was identified. Positive attributes of the design included a 5-foot key into the clay aquitard below the 30-foot sand and the construction quality control (CQC) sampling. Negative attributes included limited collection of geotechincal design data along the barrier alignment. Also, no information regarding slurry compatibility testing or analysis of long-term chloride degradation of the bentonite was found.

The cap design was evaluated as being above average. Positive attributes of the cap design include the following: (1) the cap covers the waste disposal areas and slurry wall, and (2) the cap components (3 feet of compacted clay overlain by 60-mil HDPE; a 2-foot-thick sand drainage layer; and 2 feet of vegetated topsoil) are substantial.

5.2 Construction Quality Assurance and Construction Quality Control

Evaluation of the construction quality assurance (CQA) and construction quality control (CQC) information generated an average rating. CQA/CQC documents indicated that field testing of slurry trench materials was conducted in accordance with the project CQA/CQC plans. The backfill was tested for liquid limit, gradation, and permeability. The slurry was tested for slump, density, Marsh viscosity, and filtrate loss. Samples were collected from the completed trench for permeability testing. No documentation was available to establish the adequacy of the key depth.

5.3 Monitoring

The groundwater monitoring system was evaluated to be below average based on the criteria described in Section 3, Volume I. Three groundwater monitoring wells are located approximately 30 feet outside the barrier in the 30-foot sand zone: MW-26 is located on the east side of the site between the slurry wall and the drainage ditch, MW-10 is located on the west side of the site, and MW-11 is located near the northwest corner of the site. Before remedial activities began, the groundwater gradient was determined to be to the east toward the flood control channel next to the site. Only one monitoring well, MW-26, is located on this side of the site. Therefore, downgradient groundwater monitoring appears to be inadequate.

The monitoring system is also deficient because no monitoring wells or piezometers are located within the containment barrier perimeter. Groundwater elevations are monitored monthly in the nine 30-foot sand recovery wells, all of which are located within the barrier perimeter. The use of recovery wells to monitor interior groundwater elevations may not generate data that is representative of hydraulic conditions at the barrier interface. These conditions would be best monitored by well or piezometer pairs straddling the barrier.

Figure 2 illustrates groundwater elevation data for monitoring well MW-26 and recovery well RW-4. These two wells are located about 100 feet apart along the east side of the site. The data shows that a outward gradient was present from December 1994 through March 1995. The cause of the outward gradient is not known, although it may be associated with the surface water level in the adjacent flood control channel. The 30-foot sand zone is believed to be in hydraulic communication with the surface water in the channel.

Figure 3 illustrates groundwater elevation data for monitoring well MW-11 and recovery well RW-8. These two wells are located about 50 feet apart on the north side of the site. Available data from May 1993 through December 1995 shows that an inward gradient existed between these two wells.

Monitoring wells MW-26 and MW-10 were located in areas of known contamination. TCE concentrations in groundwater have not changed significantly since the recovery system began operation in 1993. Groundwater samples collected from MW-26 have consistently contained about 100 µg/L TCE, and in December 1995, a concentration of 3,000 µg/L PCB was detected (see Figure 4 and 5).

5.4 Operation and Maintenance

No operation and maintenance (O&M) specific procedures for the slurry wall are specified in the O&M plan. The slurry wall is covered by the edge of the cap and is therefore not accessible for visual inspection. However, the O&M plan indicates that the hydraulic gradient across the slurry wall will be evaluated after each monthly monitoring event to confirm the presence of an inward gradient.

The O&M plan specifies cap maintenance procedures that include (1) quarterly visual inspections of the vegetative cover and side slopes for erosion, (2) quarterly inspections of the cap for surface water ponding and infiltration, (3) annual benchmark surveys to detect potential cap subsidence, and (4) mowing of the vegetative cover on a monthly basis from April to October and on an as-needed basis during the rest of the year.

GROUNDWATER ELEVATION COMPARISON

RW-4 AND MW-26

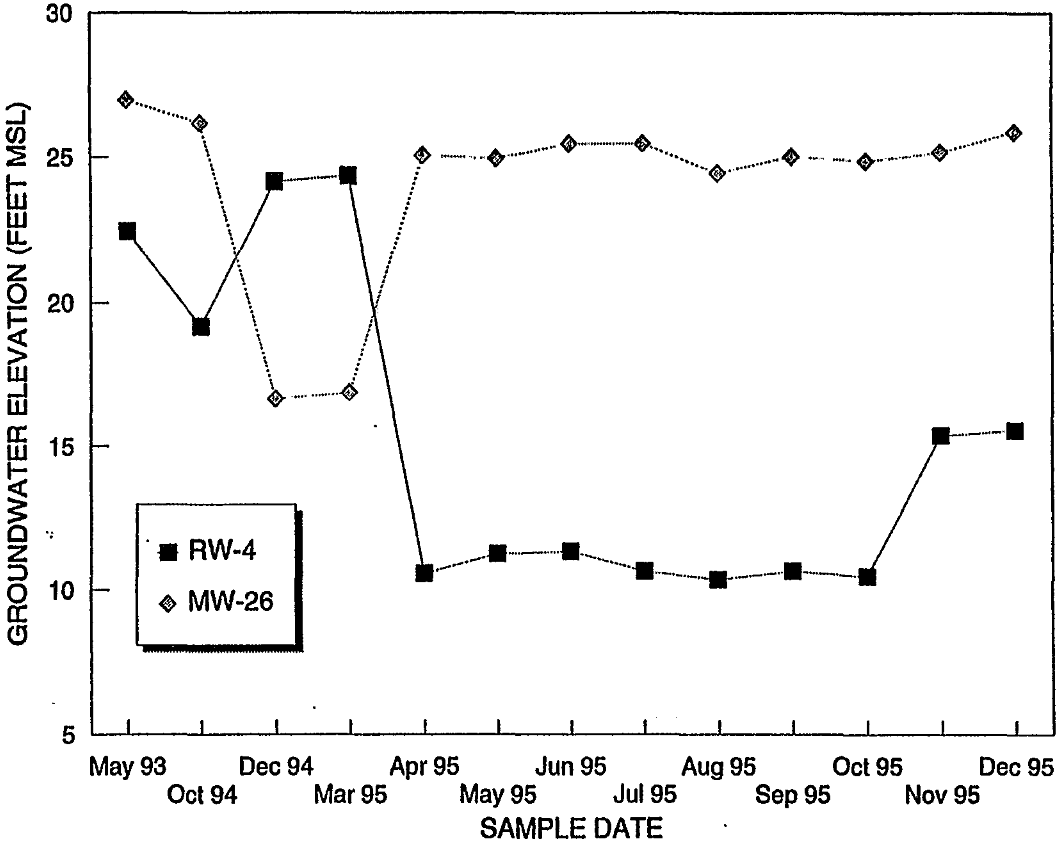

Figure 2

Site 24
FIGURE 2 **GROUNDWATER ELEVATION COMPARISON**
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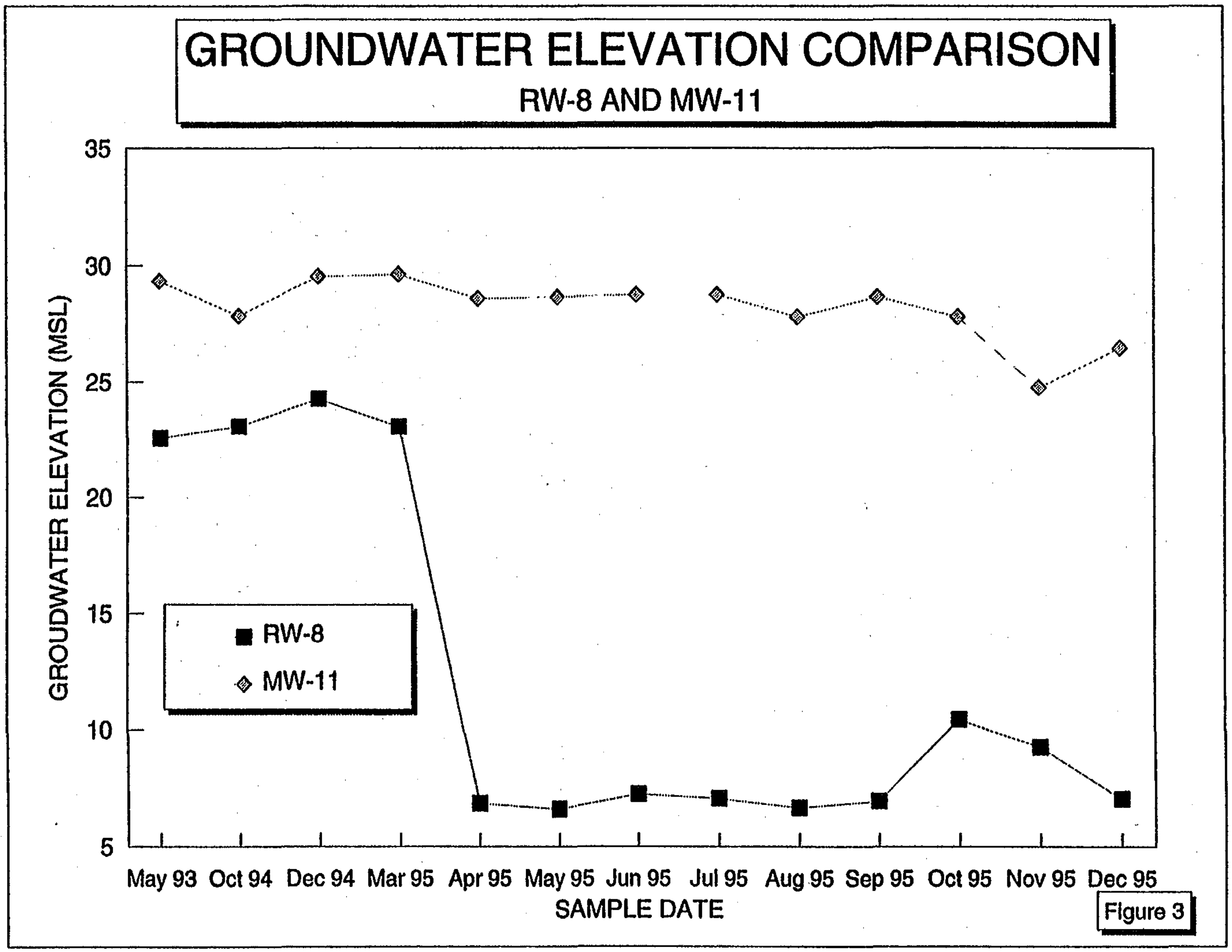
Site 24

7

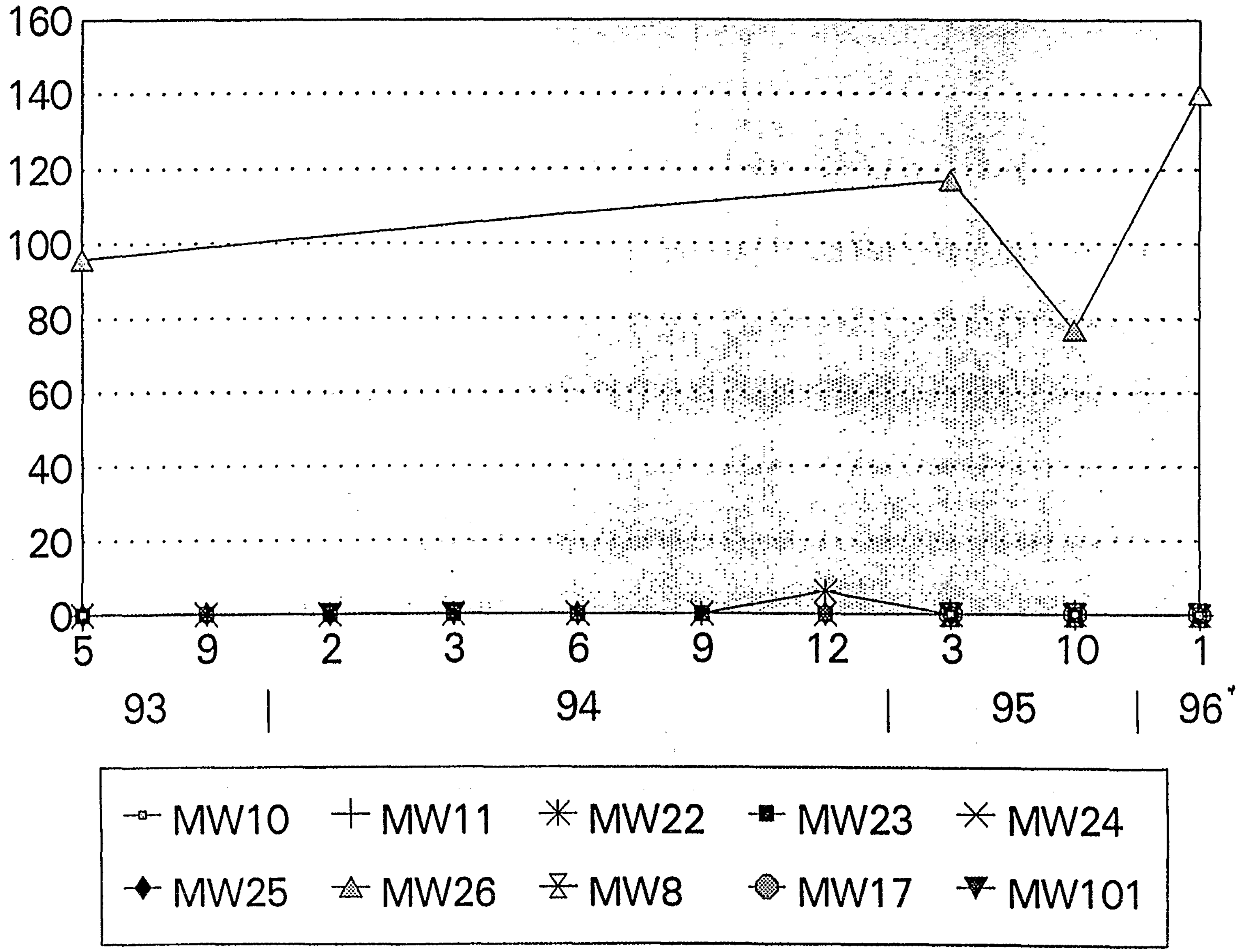


Site 24

FIGURE 3

GROUNDWATER ELEVATION COMPARISON

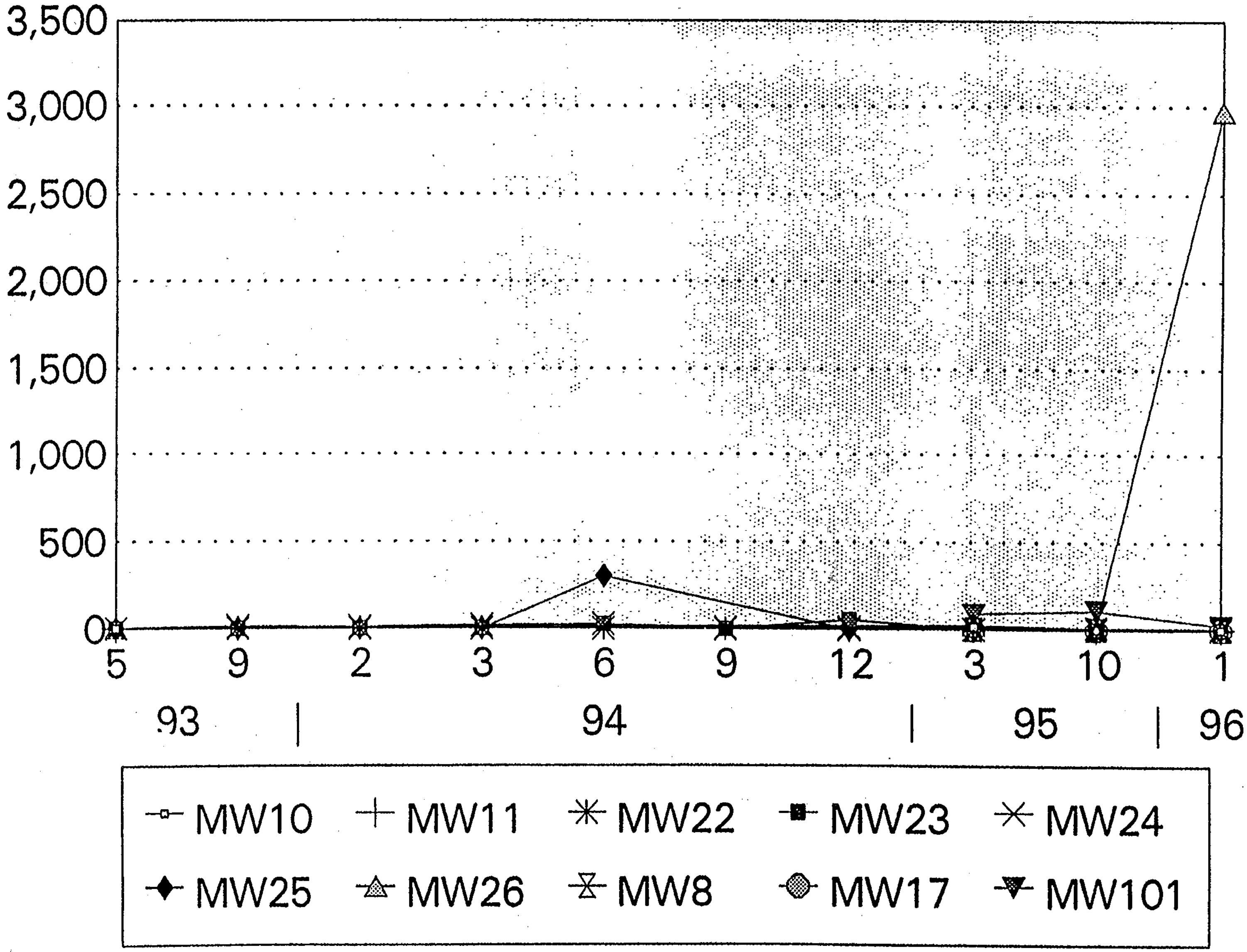
Tetra Tech EM Inc.



Site 24

FIGURE 4
MONITORING WELL TCE (ppb)
CHEMICAL ANALYSIS SUMMARY

Tetra Tech EM Inc.



Site 24

FIGURE 5
MONITORING WELL PCB (ppb)
CHEMICAL ANALYSIS SUMMARY

Tetra Tech EM Inc.

5.5 Other Considerations

The installed quantity of slurry wall was 101,668.89 ft^2. The total cost was $374,142.52.

5.6 Remedy Performance

Because there is only one downgradient monitoring well and no monitoring wells are located within the containment barrier perimeter, it is impossible to evaluate the performance of the remedy.

6.0 SUMMARY

Site 24 is an abandoned refinery that manufactured biphenyl, PCBs, phenyl phenol, naphtha, and fuel oils from 1967 until the early 1980s. Site activities have resulted in contamination of the shallow groundwater-bearing zones under the site. The remedy outlined in the 1986 ROD included construction of a soil-bentonite slurry cutoff wall around the site and a groundwater pump and treat system for the shallow groundwater-bearing zone. The slurry wall is approximately 3,300 feet long, 35 feet deep, and 2.5 feet wide and has a key depth of 5 feet into a clay aquitard. Evaluation of the design and CQA/CQC generated average ratings. The site's monitoring system was rated below average because (1) there is insufficient downgradient monitoring; and (2) interior groundwater elevations are monitored using active recovery wells, not well or piezometer pairs. From December 1994 through March 1995, an outward gradient was observed between monitoring well MW-26 and recovery well RW-4 that may have been associated with the hydraulic interconnection of the 30-foot sand and the flood control channel adjacent to the site. The limitations of the monitoring system precluded further evaluation of this condition.

SITE 25

Barrier Type	SB
Remedial Objective	SC
Performance	2

1.0 SITE DESCRIPTION AND HISTORY

Site 25 is located in the Alluvial Basins groundwater region in the Pacific Northwest. The site is composed of a 12.3-acre property, and seven off-property remedial action areas totaling 18 acres located adjacent to or near the property. The site has been divided into ten remedial action areas for management and tracking purposed (see Figure 1); the barrier wall encircles Areas I, II, IX, and X. Past activities at this site include recycling and reprocessing of solid and liquid waste materials from over 300 industries and other businesses located primarily in the Pacific Northwest.

Site operations ceased in 1983. Remediation of site soil and groundwater contamination also began in 1983. Surface removal of contaminated material was completed in 1985. Remediation of subsurface and groundwater began in 1987 and continues to date. Subsurface remediation has included construction of (1) monitoring wells, (2) a groundwater extraction and treatment system, and (3) a subsurface barrier wall to a depth of about 40 feet (ft) below ground surface (bgs) around the site. Portions of the site have been capped. The rest of the site is scheduled to be capped by 1999.

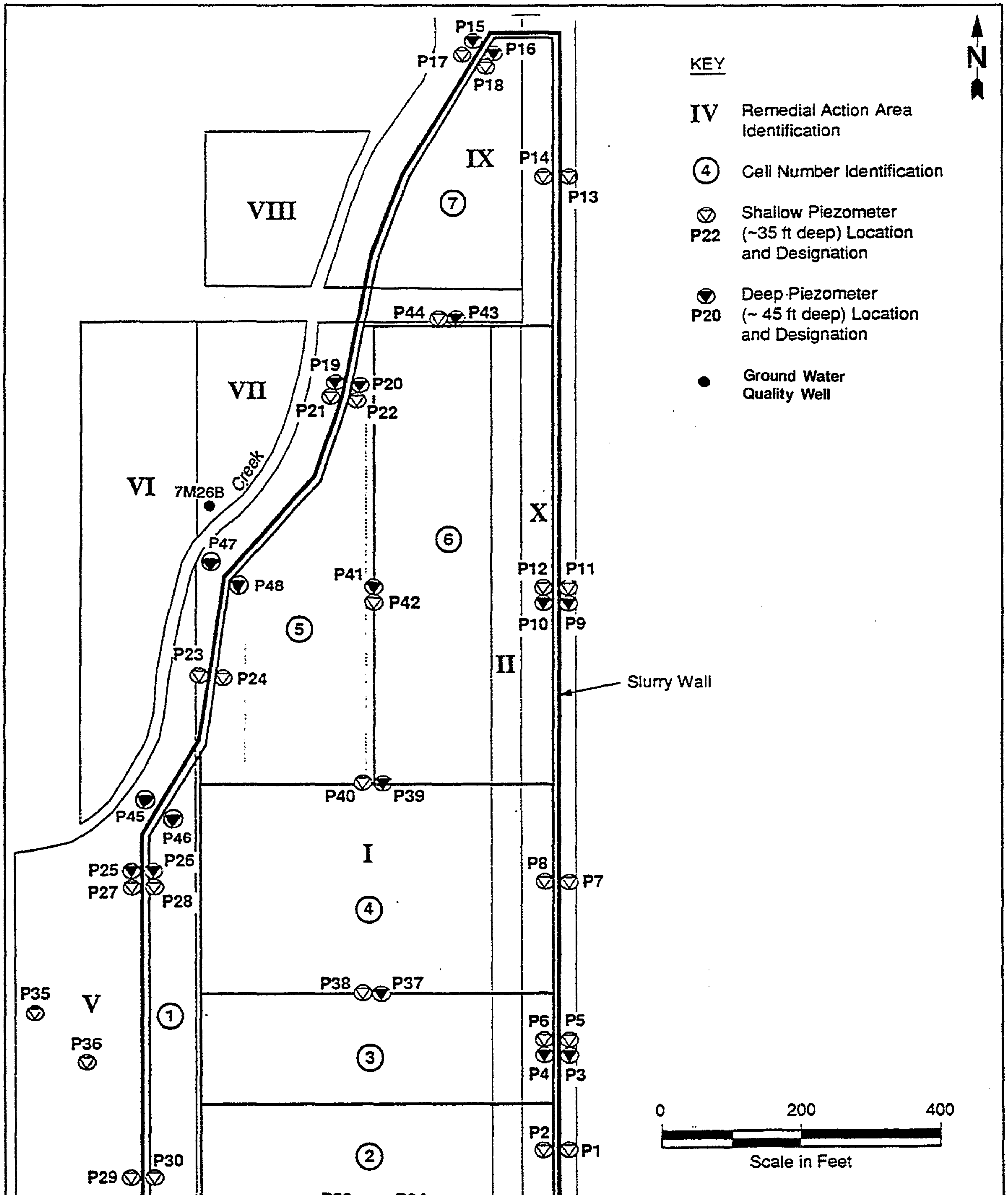
2.0 GEOLOGIC AND HYDROGEOLOGIC SETTING

The site is underlain by fill, alluvial, and postglacial unconsolidated deposits consisting of sand, gravel, silt, and clay. Fill occurs in localized areas of the site to a depth of about 15 ft bgs. Underlying soils extending from the base of the fill to depths of about 50 ft are primarily composed of silty sand, silt, clay, and peat. At depths greater than 50 ft bgs, the soils are typically poorly graded sand with some silt. Water-bearing zones beneath the site are referred to as Zones A, B, C, and D that are identified by their respective depths; 10 to 30 ft, 40 to 60 ft, 80 to 100 ft, and 120 to 140 ft. Aquitards are generally present between these zones; however, they tend to be discontinuous. Zone A, the uppermost aquifer, is unconfined; Zone B is semi-confined to confined; and Zones C, and D are confined. Groundwater at and near the site occurs 5 to 10 ft bgs within the unconfined, upper alluvial aquifer. Groundwater within this aquifer flows predominantly to the northwest at a rate of about 100 ft per year. No known water supply wells lie within the immediate vicinity of the site. The local municipality obtains a portion of its drinking water from a deep artesian aquifer located more than 1 mile upgradient from the site; this aquifer is hydraulically isolated from the shallow and intermediate-depth aquifers beneath the site.

3.0 NATURE AND EXTENT OF CONTAMINATION

Site investigations conducted by state, federal, and private organizations identified the presence of more than 80 priority pollutants in the soil and groundwater at the site. Three volatile organic compounds (VOC) —the solvents trichloroethene (TCE), *cis*-1,2-dichloroethene and vinyl chloride—and six heavy metals—cadmium, chromium, copper, nickel, lead, and zinc—are currently considered to be the most important contaminants because of their concentrations, toxicities, and potential effects on human health and the environment. The VOCs of concern are primarily sorbed onto soil particles, and are to a lesser degree dissolved in groundwater. Heavy metals are primarily dissolved in groundwater, but are also adsorbed on soil particles.

Key: SB = Soil Bentonite SC = Source Control Performance Rating: 2 = Evidence suggests objective may be met



Site 25

FIGURE 1
SITE FEATURES

Tetra Tech EM Inc.

The initial contaminant sources were the on-site tanks, drums, waste piles, and impoundments that were present at the time the site ceased operations in 1983. These sources were removed in 1984. However, contaminants that remained in the soil leached into the shallow groundwater and migrated further to an adjacent creek, a drain, and deeper off-site groundwater units.

4.0 CONTAINMENT REMEDY

Remediation efforts at the site have thus far included the following: (1) excavation and off-site disposal of 21,900 cubic yards (yd^3) of contaminated soil and sludge; (2) removal of 24,000 pounds (lb) of VOCs and 78,000 lb of metals from groundwater via groundwater extraction and treatment; (3) elimination of storm water runoff from contaminated portions of the site; (4) removal of contaminated sediments from the creek; and (5) containment of contamination remaining at the site through installation of a slurry wall and maintenance of an inward gradient through groundwater pumping.

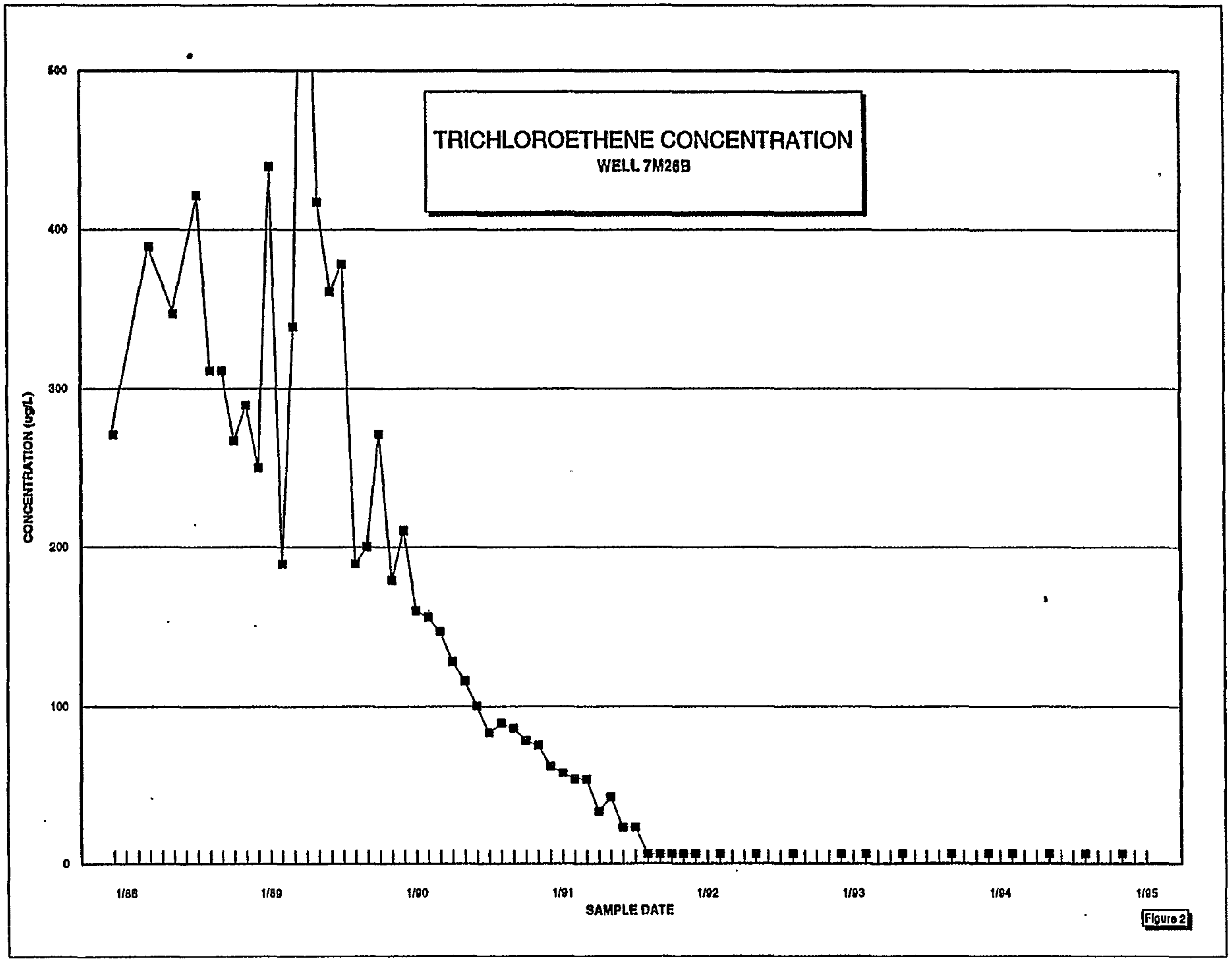
The original groundwater extraction system consisted of 206 well points (each 30 ft deep) connected by header pipes. This vacuum-operated system was organized into seven cells for operational efficiency. The extraction system was expanded twice after 1988: in 1992, two extraction wells were installed between the barrier wall and the creek; and in 1994, 80 well points were installed on 10-foot centers between the slurry wall and the east drain adjacent to Cells 3, 4, and 6. The infiltration system, which was also installed in 1988, consists of about 13,000 linear ft of buried, perforated pipe through which varying amounts of water can be infiltrated to enhance flushing of the site. Since 1988, the groundwater extraction system has pumped over 600 million gallons of contaminated groundwater. Extraction rates averaged about 200 gallons per minute (gpm) during 1994.

The barrier wall serves as a flow control device for the extraction system by restricting lateral flow of water from the creek and surrounding areas and intercepting water within Zone A. In addition, the wall isolates the area of highest contamination. By blocking inward lateral flow from outside the contaminated area, the wall substantially increases the efficiency of the pump and treat system. While contaminated groundwater is being extracted, relatively uncontaminated groundwater from outside the wall is drawn inward underneath the wall; this effect forms a hydraulic barrier that prevents contaminants from migrating away from the contained area. The barrier wall is not keyed into a subsurface horizon but is designed to extend into or through a silt and clay layer near the base of the wall. This layer is generally present between 10 ft below mean sea level (msl) and the base of the wall at 22 ft below msl. The wall is a 4,400-ft-long; 40- to 50-ft-deep; 30-inch-thick hanging wall that surrounds the site. Construction of the slurry wall was completed in 1989.

5.0 PERFORMANCE EVALUATION

The site remedy calls for creation of an inward gradient in the water-bearing Zone A. An inward gradient is considered to exist under the following conditions: (1) the piezometric heads in the shallow and deep piezometers outside the wall are higher than the piezometric heads in the corresponding piezometers inside the barrier wall; (2) each deep piezometer inside the wall has a higher piezometric head than its corresponding shallow piezometer; and (3) the piezometric heads in the shallow piezometers and well points in the western part of Area V are higher than those in the eastern part of Area V. The locations of piezometers P1 through P48 are shown in Figure 1.

Based on the established inward gradient and groundwater quality data, the containment system has been successful in containing and reducing the contamination in on-site shallow groundwater. Figure 2 displays TCE concentrations in groundwater from an off-site monitoring well; the location of this well is



Site 25

FIGURE 2
TRICHLOROETHENE CONCENTRATION

Tetra Tech EM Inc.

shown in Figure 1. Containment system performance and contributing factors are described further in the following subsections.

5.1 Design

The barrier design was rated slightly better than acceptable with respect to industry practices as described in Section 3, Volume I. More than 3 tests were performed to determine the long-term compatibility of backfill with the contaminated groundwater. However, the wall protection from surface loading or subsurface breach was either below standard or nonexistent. No information was available on any hydrogeologic investigation, groundwater modeling, or trench stability analysis.

5.2 CQA/CQC

Barrier construction quality assurance and construction quality control (CQA/CQC) were rated better than acceptable. Backfill slump testing and slope testing was performed on every 250 to 300 yd^3 of backfill. However, although a desander was used to control slurry sand content, slurry sand percentages ranged from 17 to as much as 40 percent. Trench sounding was done up to 10 times per day, daily profiles of trench bottom were obtained, slurry was tested continuously, and backfill permeability samples were obtained for every 100 lf of the wall.

Backfill samples were initially tested for permeability using the rigid wall permeameter. Permeabilities for six of the first nine samples tested were higher than the 1×10^{-7} cm/sec specification. As a result, the amount of dry bentonite added to the backfill was immediately increased to decrease backfill permeability. Three backfill samples were then tested using the flexible wall permeameter, and were found to meet the 1×10^{-7} cm/sec specification. All further testing was done using the flexible wall permeameter.

5.3 Monitoring

Long-term monitoring was rated slightly better than acceptable. Groundwater and surface water quality samples are routinely collected in numbers that exceed the industry standard. Piezometer pairs across the wall are located at reasonably spaced intervals. The railroad embankment parallel to the eastern side of the wall was monitored for settlement by using monuments evenly spaced along the 1,700-ft length of the embankment. No movement of the embankment was detected during construction of the barrier wall.

Based on a 1994 annual evaluation report, requirements of maintaining an inward gradient across the barrier wall has been consistently met at all measuring points since August 1989 except in two deep piezometer pairs (P15-P16 and P19-P20) located in the northwestern portion of the site. These piezometer pairs, each made up of one piezometer located inside and one outside the slurry wall, have historically displayed either predominantly neutral or outward gradients. Piezometer pair P15-P16 displayed exclusively outward gradients in 1994 compared with 63 percent outward gradients (with 37 percent neutral gradients) in 1993 and 88 percent outward gradients (with 12 percent neutral gradients) in 1992. Piezometer pair P19-P20 showed a predominantly neutral gradient in both 1994 and 1993; however, inward gradients were displayed more frequently than outward gradients in this piezometer pair in 1994. This indicates a change in conditions from 1993, when outward gradients occurred more frequently than inward gradients. However, upward gradients have been consistently measured at these locations.

Piezometer data collected on May 8, 1996, indicates that an inward gradient continues to exist at most monitoring points along the wall. However, outward gradients are present at piezometer pairs P18-P17 and P28-P27 (shallow), and at pairs P16-P15 and P46-P45 (deep). The lack of a consistent inward gradient around these piezometers may be related to (1) groundwater withdrawal rates, which were reduced in these areas because of lower concentrations of groundwater contaminants; or (2) possible leaks in the barrier caused by several underground pipelines that pass through the slurry wall in this area. As a result of low concentrations of groundwater contaminants in the northern portion of the site, the organizations conducting site remediation have proposed to remove the barrier wall around Cell 7 and construct a new northern barrier wall segment.

5.4 Operation & Maintenance

The slurry wall is covered by a mounded fill for run-on and run-off control. Current operations and maintenance costs are estimated to exceed 5 million dollars per year.

5.5 Other

The as-built barrier wall consists of over 192,000 square ft of excavation and backfill. About 1,788,000 pounds of dry bentonite was added directly to the backfill. Wall construction costs were not available.

5.6 Remedy Performance

In spite of the presence of a neutral or outward gradient at certain piezometers, the barrier wall appears to have achieved its intended purpose of assisting in contaminant removal from groundwater. The site owners seek to change the remediation system at the site, from active to passive by (1) capping the site, (2) installing about 15 extraction wells, and (3) abandoning the well point system. The long-term goals are to stop treating the metals in the groundwater, and to reduce the volume of groundwater being pumped.

6.0 SUMMARY

Site 25 is primarily made up of a 12.3-acre property that was used to recycle and reprocess solid and liquid waste materials. Past waste management practices at the site resulted in widespread contamination of site soil and groundwater with more than 80 priority pollutants, including VOCs and heavy metals. Contamination has also been detected in the adjacent creek and in off-site groundwater units. Cleanup actions have included installation of monitoring wells; a groundwater extraction and treatment system; and a 4,400-ft-long barrier wall that completely surrounds the site. Although this 30-inch-thick wall penetrates a silty clay layer near its base, it is considered to be a hanging wall. This wall serves as a flow control device that (1) enhances the efficiency of the extraction system by restricting inward lateral flow of water from the creek and surrounding areas, (2) intercepts lateral, off-site, migration of contaminated groundwater within the shallow aquifer, and (3) isolates the area of highest contamination. The design, CQA/CQC of the barrier, and monitoring activities were rated better than acceptable. Piezometer pairs have generally displayed inward and upward gradients except along the northwestern portion of the barrier wall, where neutral or outward gradients have been documented. The neutral and outward gradients are considered to be a result of very low groundwater extraction rates in these areas; high extraction rates are localized in areas of the site with relatively high contaminant concentrations. Limited groundwater quality data indicates that contaminant concentrations are decreasing over time. Overall, the barrier wall appears to be meeting its objectives.

SITE 26

Barrier Type	SB
Remedial Objective	Hydraulic containment
Performance	2

1.0 SITE DESCRIPTION AND HISTORY

Site 26 is located at the northern boundary of a large facility in the western United States. Hazardous wastes have been deposited on 1,750 acres of the 17,000-acre facility. The topographic relief is about 200 feet (ft), with the land surface generally sloping northwest toward a nearby river. The facility was established in 1942 and has been used by both government and industry to manufacture, test, package, and dispose of various chemical warfare agents, rocket fuels, herbicides, pesticides, nerve gases, mustard gases, and incendiary munitions. In 1947, portions of the facility were used for the manufacture of chlorinated benzenes and the pesticide, DDT. After 1970, primary activities at the facility focused on demilitarization of chemical warfare materials by caustic neutralization and incineration. The last military operation at the facility ended in the early 1980s.

The site remedy included a hydraulic cutoff wall and a withdrawal-recharge system to curtail a contaminant plume migrating across the north boundary. No cap is present on site.

2.0 GEOLOGIC AND HYDROGEOLOGIC SETTING

There are two major geologic units at Site 26: an alluvial unit and a bedrock unit. The alluvium consists of about 15 ft of fine-grained eolian silt and clay deposits that mantle a 0- to 15-ft-thick lower unit of well sorted fluvial sand and gravel. The maximum alluvial thickness in the area is about 30 ft. The bedrock units consist of deltaic shales, claystones, sandstones, and conglomerates. The uppermost bedrock unit below the site is about 250 to 400 ft thick and contains occasional lignite beds. The bedrock surface reflects the erosional development of a local river valley during the Quaternary period. Consequently the bedrock surface is characterized by isolated bedrock highs and numerous paleochannels. Three significant, alluvium-filled paleochannels can be traced throughout the site area.

Groundwater occurs in alluvial deposits and bedrock aquifers, including the underlying bedrock formations. Bedrock formations are important aquifers in the area, where they are tapped by several thousand stock, domestic, and municipal wells. Where they are sufficiently thick and saturated, the alluvial deposits are capable of yielding large supplies of water. The uppermost bedrock unit and the alluvial aquifers are interconnected and act as a single aquifer regionally, although greater transmissivities generally exist in the alluvial aquifer. Transmissivities in the alluvial aquifer range from 6,000 to as high as 79,000 gallons per day per ft (gpd/ft); hydraulic conductivities range from 84.7 to 7,500 gpd/ft^2. Transmissivity and hydraulic conductivity values in the bedrock aquifer ranges from 0.16 to 1,022 gpd/ft and from 0.04 to 256 gpd/ft^2, respectively. The bedrock aquifer is frequently under artesian conditions, causing groundwater in the aquifer to recharge the local alluvial aquifer. Groundwater flow in the alluvial aquifers below the site varies from artesian to semiconfined to unconfined. The regional groundwater flow direction is from south to north toward the river. The primary groundwater flow and contaminant transport are in the alluvial sand and gravel aquifer overlying bedrock. The total groundwater flow in the site area ranges from 250 to 325 gallons per minute (gpm). Estimates of the average linear groundwater velocity in the site area range from 1.5 to 10.0 ft/day. The saturated thickness of the alluvial aquifer varies from 0 to 30 ft in the site area.

Key: SB=Soil Bentonite Wall   Performance Rating: 2=Evidence suggests objective may be met

3.0 NATURE AND EXTENT OF CONTAMINATION

Wastes generated from various military and industrial operations were routinely discharged into several unlined evaporation ponds located on site. This practice continued until 1956, when a basin was constructed with an asphalt liner. Solid wastes have been burned at various on-site locations. Chemical spills have occurred in and around the site manufacturing complexes. These actions have resulted in widespread introduction of a host of organic and inorganic contaminants such as chloride, fluoride, diisopropylmethyl phosphonate (DIMP), dicyclopentadiene (DCPD), dibromochloropropane, organosulfur compounds, organochlorine pesticides, volatile aromatic compounds, and volatile organohalogen compounds to the on- and off-site groundwater. In the mid-1970s, DIMP and DCPD as well as other organic compounds were detected in groundwater migrating across the north boundary of the site.

The present pattern of contaminant distribution in groundwater extends from south to north along existing paleochannels (see Figure 1). Downgradient of the site area, the contaminant flow path splits into two separate pathways as a result of the presence of an area of unsaturated alluvium.

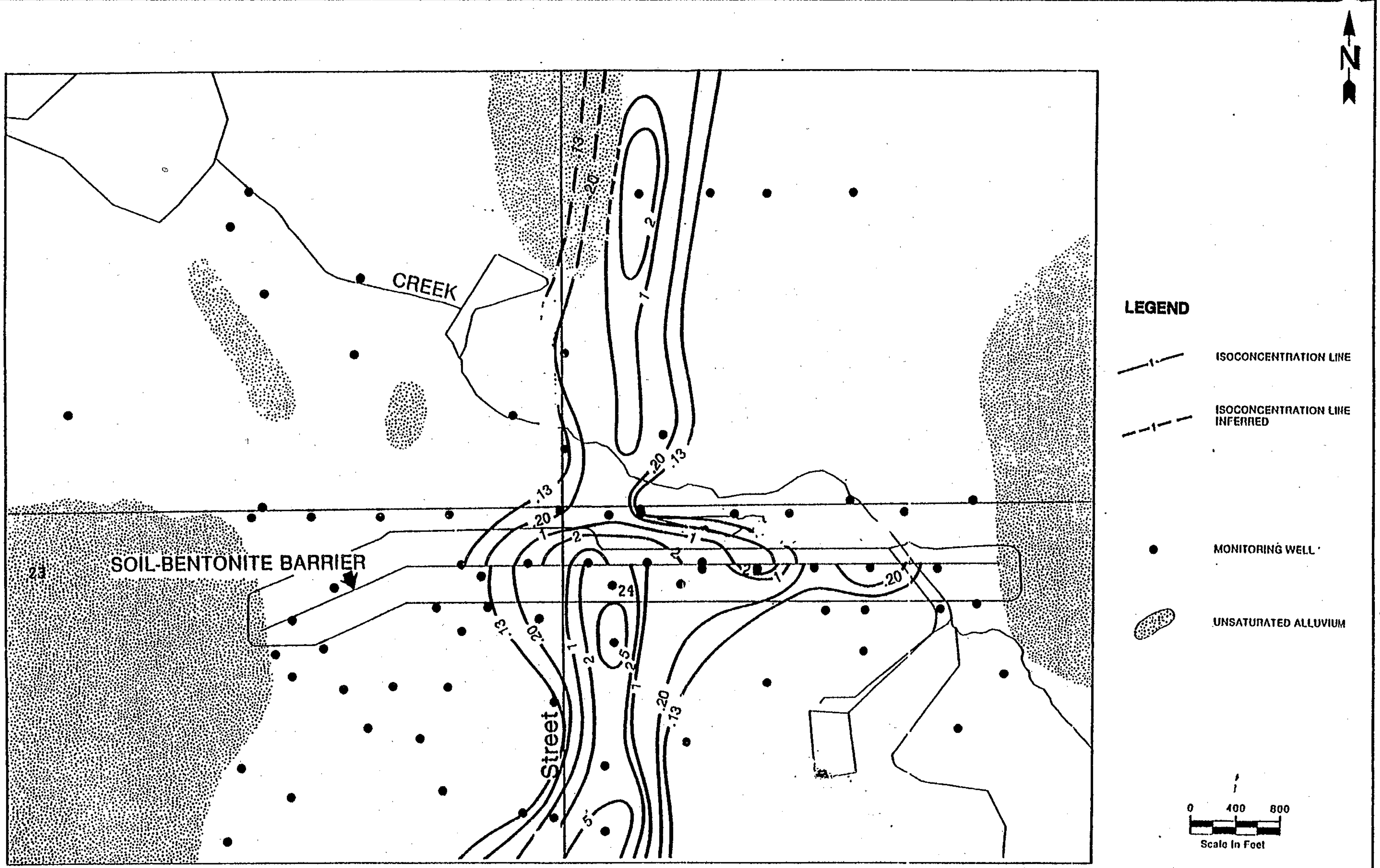
4.0 CONTAINMENT REMEDY

To curtail migration of site contaminants across the site's northern boundary, the North Boundary Containment System (NBCS) was constructed. The objective of the system was to provide hydraulic containment using a soil-bentonite cutoff wall and a series of extraction and recharge wells. The system was assembled in two phases. The first phase involved a pilot system that began operation in June 1978. The pilot system consisted of a 1,500-ft-long, soil-bentonite cutoff wall; six dewatering wells; and 12 recharge wells. The cutoff wall ranged in depth from 23 to 27 ft and was designed to be keyed 2 ft into bedrock.

The second phase involved expansion of the pilot system to its present configuration; the expanded system began operation in January 1982. The extensions of the cutoff wall were constructed in 1981 as wings to the original pilot system wall and extend 3,840 ft due east and 1,400 ft to the west-southwest. The extended portions of the cutoff wall are about 3 ft wide and up to 45 ft deep.

The completed NBCS consists of the following elements: (1) a series of 54 groundwater withdrawal wells to extract contaminated groundwater; (2) a 6,740-ft-long, soil-bentonite cutoff wall to impede groundwater flow and separate contaminated and treated groundwater; (3) a carbon adsorption treatment system to remove organic contaminants from groundwater; and (4) a recharge system of 38 wells to return treated groundwater to the alluvial aquifer. The withdrawal wells are divided into three collection manifolds designated as A, B, and C; the wells discharge water to a common sump before its treatment. The average flow through the system is 200 to 300 gpm.

Thirty-five of the withdrawal wells are screened in the alluvium, and 19 wells are screened in the Denver Formation sandstone units. The Denver Formation dewatering wells have not been used since the autumn of 1984 because their operation was suspected of inducing contamination in the formation. In October 1988, the NBCS recharge trenches interim response action was implemented to increase the recharge capacity of the system. A total of 10 trenches, each 160 ft long, were installed downgradient of the west section of the barrier. In 1991, five additional trenches were constructed along the east portion of the barrier system. All 15 trenches (T1 through T15) recharge treated water into the alluvial aquifer.



Site 26

FIGURE 1
SITE PLAN AND DBCP CONCENTRATION DISTRIBUTION

Tetra Tech EM Inc.

5.0 PERFORMANCE EVALUATION

The NBCS was designed to intercept, treat, and discharge contaminated and potentially contaminated groundwater that flows toward and across the northern boundary of the site. Groundwater quality and hydraulic data indicate that the cutoff wall was ineffective during its first 10 years of operation.

Insufficient recharge capacity created a large hydraulic gradient across the cutoff wall, which allowed contamination to move under or through the pilot system portion of the wall. Subsequent system modifications to the recharge system appear to have reduced the gradient to zero or less, which should reduce or prevent further off-site migration. Containment system performance and contributing factors are described further in the following subsections.

5.1 Design

Design procedures used generally exceeded the established industry standards as discussed in Section 3, Volume I, and the design was rated better than acceptable. The existing soil-bentonite cutoff wall is 6,470 ft long; is about 3 ft wide; has a design conductivity of 1×10^{-7} centimeters per second (cm/sec) or less; and ranges from 20 to more than 45 ft bgs in depth. The bottom of the entire cutoff wall was keyed into the bedrock. The east and west extensions were keyed into bedrock at their ends, where the alluvial aquifer was unsaturated. The extensions were also keyed into the existing pilot system section of the cutoff wall. The entire barrier was covered with a 1.5-ft-thick, clay cover.

A report completed in February 1989 evaluates the soil-bentonite cutoff wall and concludes that the most critical deficiency of the cutoff wall design was the depth of the pilot system portion of the barrier. The pilot system barrier was designed to penetrate about 2 ft into bedrock. The presence of high hydraulic gradients across the barrier in this area was considered to be likely to promote flow underneath the barrier wall through highly weathered claystone and sandstone in the upper bedrock. Groundwater flow through the bedrock directly beneath the extensions of the cutoff wall was considered to be negligible because these sections were keyed an average of 12 ft into bedrock and because head differences across these sections are less than those across the pilot system wall. The depth of the weathered bedrock is generally considered to be less than 12 ft bgs. Contractors were hired to fracture hard bedrock zones using explosives during trenching operations. However, the use of explosives may have increased the secondary permeability of the upper bedrock beneath the barrier. Also, the ground vibrations caused by use of explosives may have sloughed material into the slurry trench.

5.2 Construction Quality Assurance and Construction Quality Control

No information was available on the following factors: (1) the inspection frequency during trench excavation, (2) trench bottom cleaning, (3) trench key confirmation, (4) mixing and testing of slurry, (5) the sand content of the slurry, (6) backfill slump and permeability testing, and (7) as-built records. Without this data, the adequacy of the construction quality assurance (CQA) and construction quality control (CQC) methods used cannot be evaluated.

According to the response action assessment final report, the subcontractor performing trench backfilling operations during construction of the barrier extensions changed the procedure used for gradation testing without the knowledge of the site owner. Subsequent testing of the barrier revealed many backfill gradation values significantly outside of the specified range. In some areas, more than 50 percent of the backfill was finer than the 200 sieve size. In addition, the water used for slurry mixing during the barrier extension project consisted of treated sewage water from the site treatment plant. It is not known what effect the use of this water had on the final hydraulic conductivity of the extended cutoff wall.

5.3 Monitoring

Long-term monitoring was rated acceptable. Groundwater samples are routinely collected in numbers that exceed the industry standard. Ten equally spaced, alluvial piezometers were installed about 25 ft from the cutoff wall to monitor water levels on both sides of the wall. Hydraulic conductivities measured in wall samples averaged 3 x 10^{-7} cm/sec for the pilot system wall and 2 x 10^{-8} cm/sec for the extensions. Although laboratory hydraulic conductivity tests indicate that the design permeability has been achieved in many zones of the barrier, hydrologic data suggests that the overall hydraulic conductivity of the barrier could be as much as two orders of magnitude higher, or about 2 x 10^{-5} cm/sec. This maximum value was determined based on aquifer tests performed within 300 ft of the cutoff wall. No information on settlement, movement, geophysical integrity, or dessication or earth stress was available.

Comparison of contaminant distributions prepared for DIMP and DCPD for September 1977 (presystem conditions) and for spring and summer 1987 indicates that the distribution patterns of these compounds upgradient of the NBCS have not been significantly altered by the presence of the NBCS. Similarly, based on comparison of 1979 data and the distributions observed in 1987, the pattern of DBCP distribution seems to have been relatively unaffected (see Figure 1). Using DIMP, DBCP, and DCPD as indicators, the upgradient distribution of contaminants has not been dramatically altered by the presence of the NBCS.

Head differences of up to 9 ft have developed across the cutoff wall since the pilot system was installed in 1977 (see Figure 2). These head differences have created the potential for northward groundwater flow through the cutoff wall and the upper bedrock beneath the wall (see Figure 2). The head differences were attributed to problems with the recharge wells located near the western side of the pilot system, including limited recharge capacity and inadequate recharge distribution.

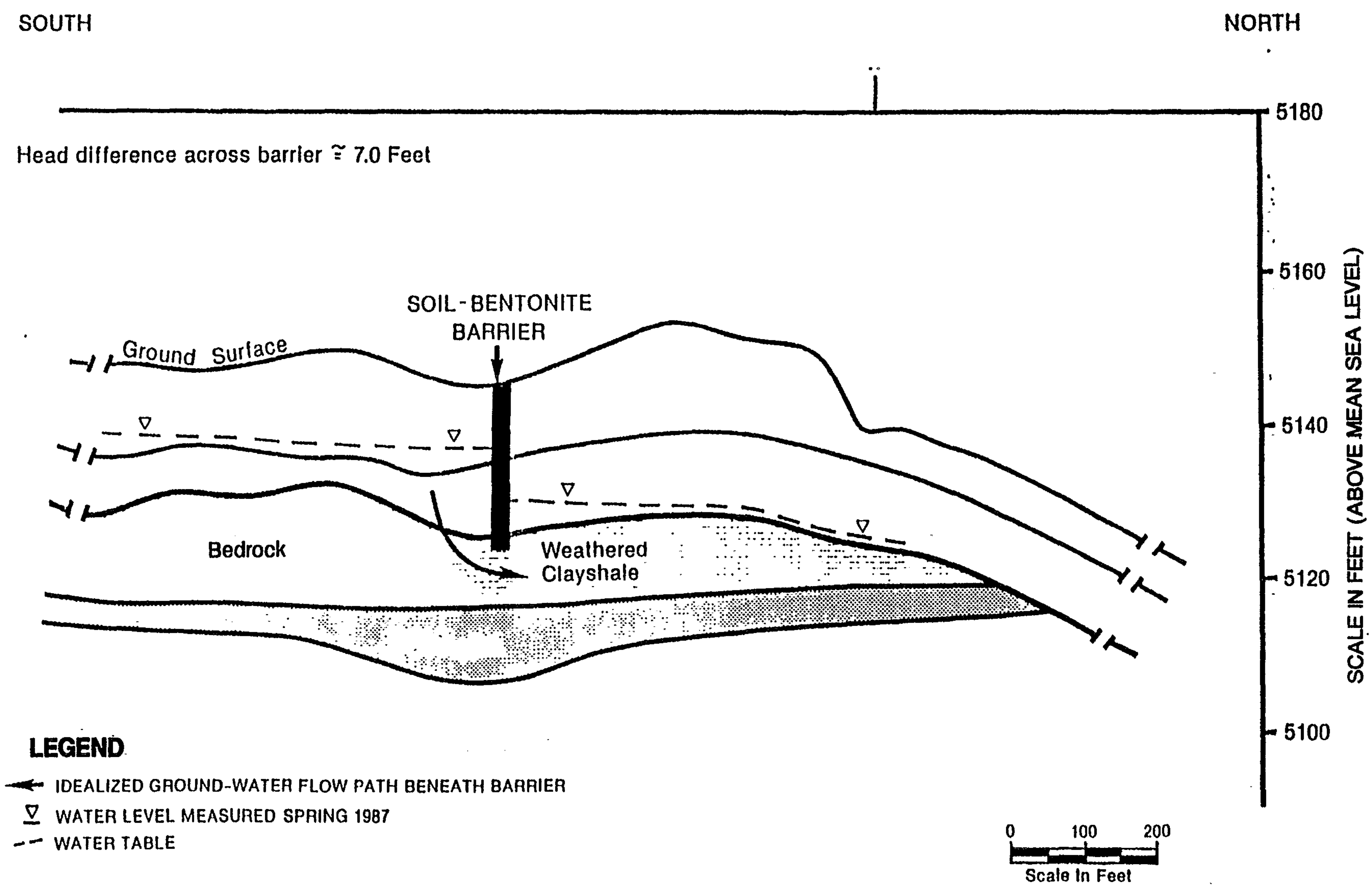
By 1991, the recently constructed recharge trenches were reducing the large outward gradient within the alluvial and bedrock aquifers. Water level data collected during 1993—the most recent available monitoring data—indicates that a reverse gradient was established along the entire barrier during most of this monitoring period (see Figure 3). Water level data collected from well pairs drilled in 1993 proved for the first time that a reverse gradient was also present in the upper bedrock across the west part of the cutoff wall. Water level hydrographs for alluvium and upper bedrock well pairs indicate a hydraulic connection between the units along the western and eastern parts of the wall. Therefore, if a reverse gradient is maintained in the alluvium, a reverse gradient should also be present in the upper bedrock, and contamination movement underneath the cutoff wall should be significantly reduced.

5.4 Operation and Maintenance

Problems have been encountered with both the withdrawal and recharge systems at this site. The performance problems of the withdrawal system were attributed to adverse weather conditions and poor well placement; certain wells were located in partially cemented or clayey sands, which have diminished dewatering capacity. The buildup of a large hydraulic head across the cutoff wall was attributed to an inadequate recharge system. These problems were addressed through modification of the withdrawal wells and addition of 15 recharge trenches.

5.5 Other Considerations

No cost information was available for the NBCS at the site.



Site 26

FIGURE 2
GENERALIZED NORTH–SOUTH CROSS SECTION SHOWING POTENTIAL GROUND–WATER FLOW PATH

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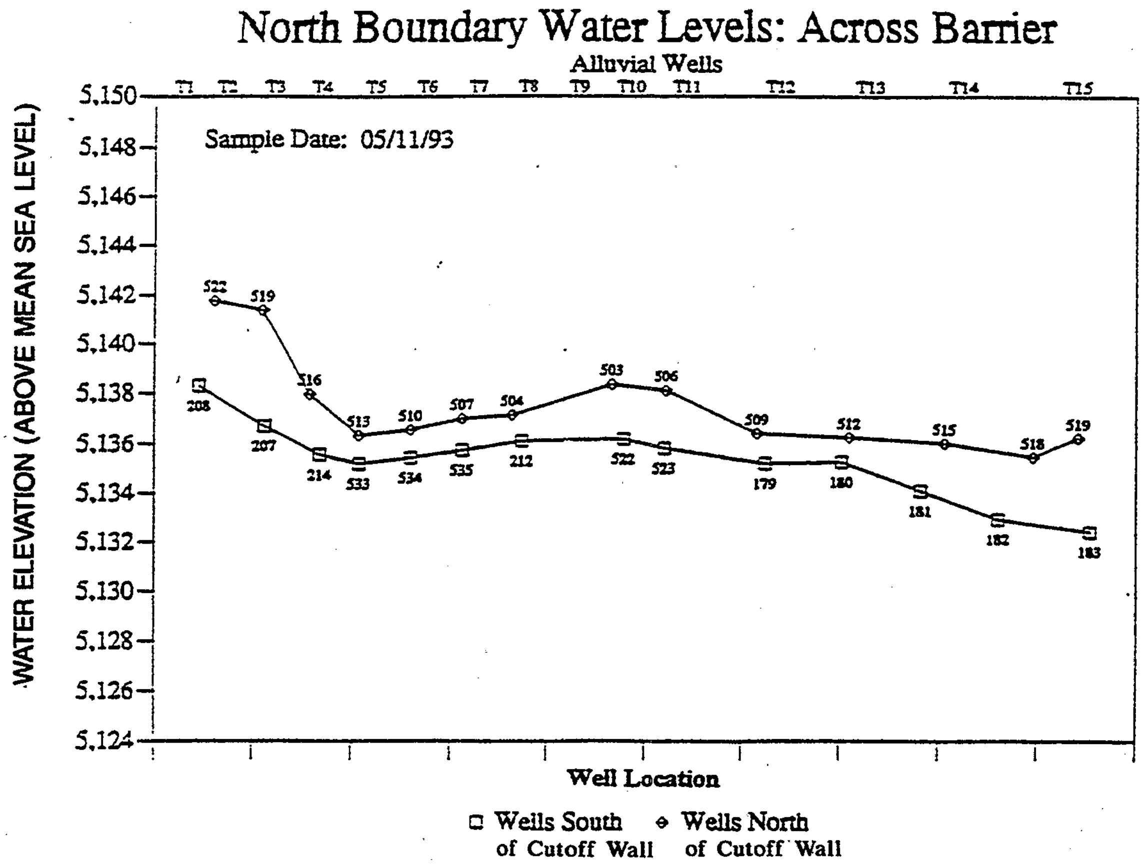
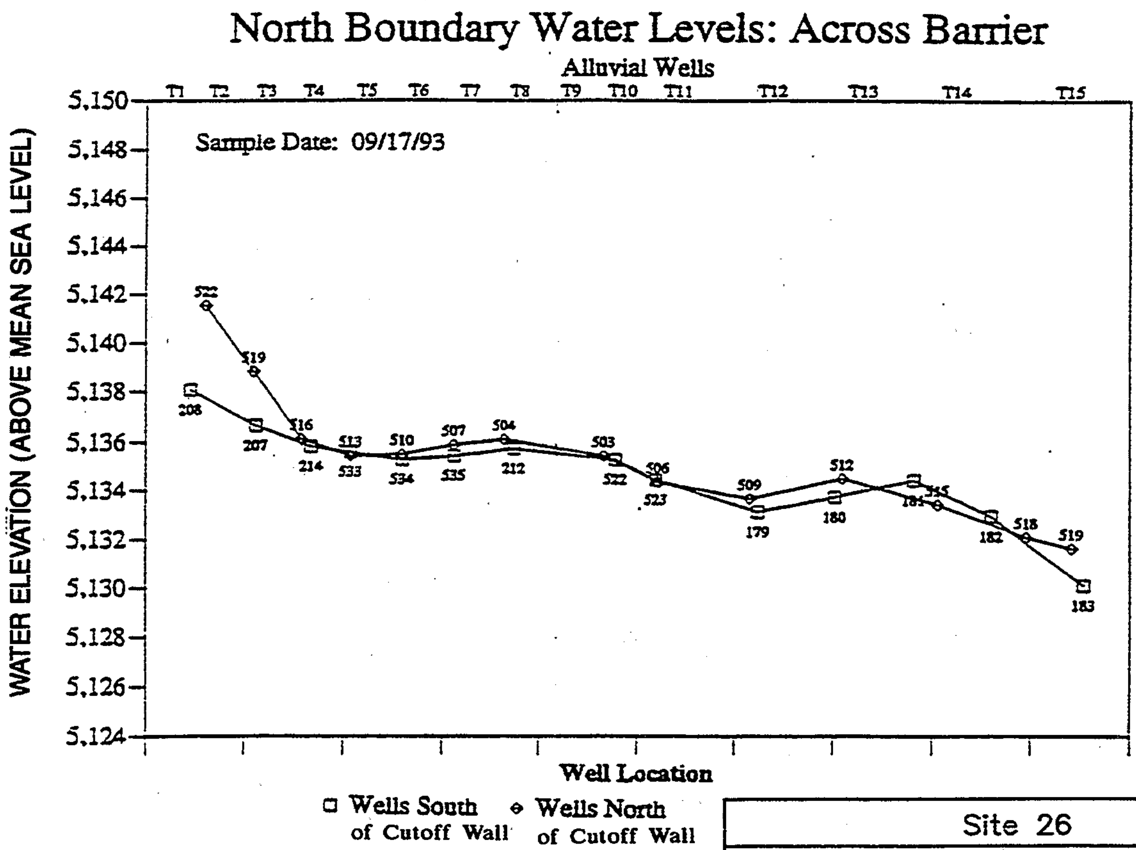




Site 26

FIGURE 3
VARIATION IN WATER TABLE ELEVATIONS WITH TIME

Tetra Tech EM Inc.

5.6 Remedy Performance

The original NBCS, including both the pilot system and its extensions, was not effective in preventing groundwater contamination from migrating off site because of groundwater recharge system deficiencies. Through addition of recharge trenches and other modifications of the NBCS, the large outward gradient across the barrier was reduced to zero or reversed to an inward gradient by 1993. If a reverse gradient is maintained in the alluvium, a reverse gradient should also be present in the upper bedrock, and contamination movement underneath the cutoff wall should be significantly reduced.

6.0 SUMMARY

Site 26 is part of a 17,000-acre facility that was used to manufacture, test, package, and dispose of various chemical warfare agents, rocket fuels, herbicides, pesticides, nerve gases, mustard gases, and incendiary munitions. Past waste management practices at the site resulted in widespread, on- and off-site groundwater contamination with a host of organic and inorganic compounds. Cleanup actions involved the installation of monitoring wells and a groundwater extraction and treatment system, which included a 6,740-ft-long cutoff wall. The treatment system was designed to intercept, treat, and discharge contaminated and potentially contaminated groundwater that was flowing toward and across the northern boundary of the site.

Design performance was rated better than acceptable. CQA/CQC could not be evaluated because of lack of information regarding trench, slurry, and backfill testing. Long-term monitoring was rated acceptable. Contaminant plume migration under and through the pilot system wall have been controlled though addition of recharge trenches that appear to have reduced the large outward hydraulic gradient across the cutoff wall. Although no recent groundwater quality data was available, the cutoff wall and its associated treatment system appear to be performing as intended.

SITE 27

Barrier Type	SB
Remedial Objectives	SC
Performance	2+

1.0 SITE DESCRIPTION AND HISTORY

Site 27 is located in eastern United States. The site covers about 10 acres and is bounded by industrial and commercial properties, city streets, and recreational facilities.

The site functioned as a burning ground and a landfill for wastes from about 1962 to 1984. The site received household, construction, and industrial wastes, including over 1,000 drums of various materials. Initial site investigations identified significant contamination, and a removal action was performed in 1984. The site's active containment remedy consists of a soil-bentonite subsurface barrier wall, a multimedia cap, and a two-well groundwater extraction system. Remedial construction was completed at the site in 1990. A site plan showing basic site features is presented in Figure 1.

2.0 GEOLOGIC/HYDROGEOLOGIC SETTING

The site is underlain by about 20 to 40 feet of fill and silty clay to clayey silt. This shallow interval includes lenses of sand typical of the area. The base of this shallow stratum includes a clay-silt interval that forms the key for the subsurface barrier wall, and forms the base of the uppermost water-bearing zone. The aquifer is underlain by a 25- to 80-foot thick clay-silt aquitard. Underlying the clay-silt aquitard are unconsolidated, sand and silt-clay sequences that continue to crystalline bedrock 100 to 200 feet below grade.

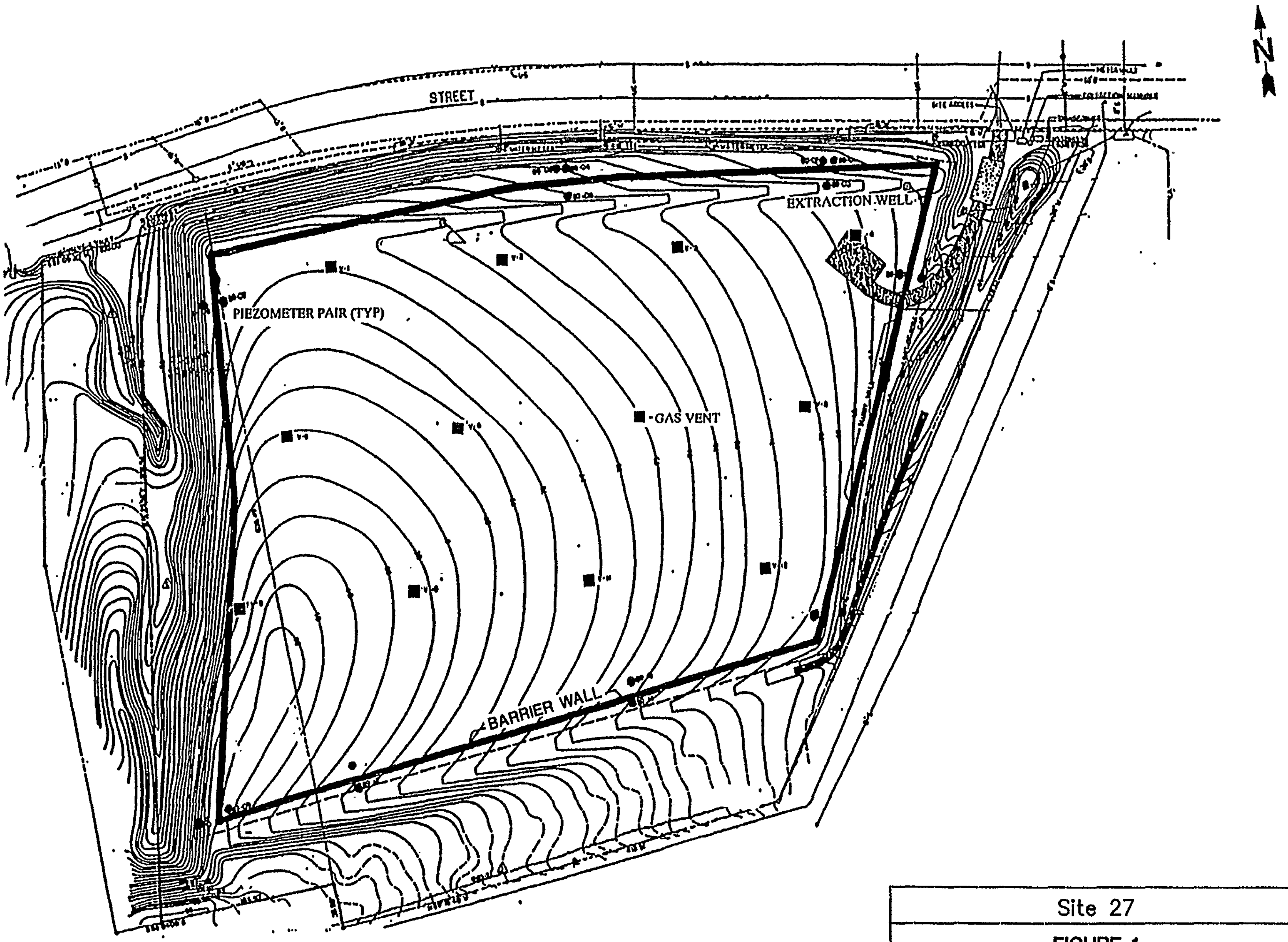
The hydrogeologic setting includes three water-bearing zones. The uppermost, unconfined zone is limited in areal extent and is not a potential source of drinking water because of its insufficient yield. The underlying two zones are either current or potential sources of drinking water. The groundwater flow direction in the upper zone is northeasterly; the direction of flow in the deep zone is to the east-south east. The typical hydraulic conductivity of the shallow zone soils ranges from 1×10^{-3} to 1×10^{-5} centimeters per second (cm/sec). The horizontal gradient in the uppermost zone is about 0.05.

3.0 NATURE AND EXTENT OF CONTAMINATION

The on-site soil and groundwater as well as off-site groundwater were contaminated with several organic compounds and metals. Groundwater contamination was limited to the shallow and intermediate water bearing zones. Contaminants included benzene, toluene, ethylbenzene, and xylene (BTEX); vinyl chloride, trichloroethene (TCE); dichloroethene (DCE); beryllium; chromium; and nickel. The ranges of concentrations of those contaminants were reported as follows:

- TCE: 0 to 3,000 μg/L
- DCE: 0 to 20,000 μg/L
- Chromium: 0 to 1,600 μg/L
- Nickel: 0 to 750 μg/L

Key: SB = Soil Bentonite Wall SC = Source Control Performance Rating: 2+ = Evidence suggests objective may be met



Site 27

FIGURE 1
SITE PLAN

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Also, although the emergency removal action included removal of many of the drums from the site, wastes remaining on site were a significant source of contaminants.

4.0 CONTAINMENT REMEDY

The objectives of the containment remedy are to provide source control and prevent further contamination of groundwater in the off-site, intermediate water-bearing zone. Therefore, the site remedy required hot spot removal, a subsurface diversion or containment structure, a multilayer cap, surface drainage control, and periodic groundwater monitoring. The implemented remedy involved active containment and had the following general features:

- A soil-bentonite barrier that is about 2,200 liner feet long; 25 feet deep (on average); and 3 feet thick and that has a 5-foot soil key
- Two shallow extraction wells pumping groundwater for off-site treatment
- Eight water level monitoring locations with wells paired across the barrier
- Five additional groundwater quality monitoring locations on site
- A cap with compacted clay liner (CCL) side slopes and geomembrane (GM) on the top, a drainage layer, and a protective soil cover
- An active gas venting system

5.0 PERFORMANCE

The performance monitoring requirements for the containment include quarterly groundwater quality monitoring for the first year after construction and annual monitoring thereafter as well as quarterly measurement of groundwater table elevations to check the gradient across the barrier wall at designated locations.

The hydraulic gradient across the barrier wall was maintained in excess of the natural hydraulic gradient present. Prior to barrier construction, based on the rationale that as long as this original gradient could be maintained the containment would function. A head differential greater than 1 foot was easily maintained across the barrier wall by the two-well extraction system. In fact, the pumping required to maintain the needed head differential significantly decreased over time.

Groundwater contaminant concentrations decreased outside the containment and increased inside the containment over time, indicating the general effectiveness of the containment.

A 5-year regulatory review required for the site indicated that containment performance was adequate and that the remedy was protective of human health and the environment.

Containment system performance and contributing factors are described further in the following subsections.

5.1 Design

The barrier wall design was rated better than acceptable with respect to industry practices described in Section 3, Volume I. The design generally followed established U.S. Army Corps of Engineers guidance. Significant positive features of the design effort included drilling of alignment borings at less than 100-foot intervals, testing of more than 60 soil samples, use of a 5-foot soil key, and thorough compatibility testing. No design-level groundwater modeling was performed for the containment. The barrier was constructed using trench-side mixing.

The cap design was rated slightly less than acceptable. The design included a standard RCRA-type cap as described in Section 4.0. Significant positive aspects of the design effort included ample use of on-site borings to characterize the fill and its stability and settlement potential. Drawbacks of the design included neglect of seismic considerations in the stability analysis, lack of interface friction testing to evaluate interface stability, and failure to include a leachate management system.

5.2 Construction Quality Assurance and Construction Quality Control

Barrier wall construction quality assurance (CQA) and construction quality control (CQC) were rated better than acceptable. Generally, the CQA/CQC procedures used conformed to established standard protocols. The barrier key was deepened during construction based on the results of confirmation sampling every 25 linear feet, resulting in another 3 to 5 feet of excavation over about 60 percent of the alignment. Based on testing of undisturbed samples collected from the completed barrier at 250-foot intervals, the barrier met the permeability requirement of less than 1×10^{-7} cm/sec. The average permeability from confirmation permeability tests was about 2×10^{-8} cm/sec.

Cap CQA/CQC was rated slightly better than acceptable. Notably, the CCL clay sources were thoroughly tested for physical properties, including permeability. A CCL test pad was constructed and tested; one sealed, double-ring infitrometer (SDRI) and six undisturbed samples were used for permeability measurements. Compaction-permeability relationships were confirmed in the field.

CQA/CQC requirements for installing the geomembrane liner generally followed industry standards. Notably, all extrusion seams were vacuum box-tested, and double-wedge welded seams were air pressure-tested. Shear and peel destructive testing was performed for every 750 feet of seam.

5.3 Monitoring

Containment monitoring was rated slightly better than acceptable. The monitoring involved taking quarterly measurements of groundwater table elevations at eight pairs of monitoring wells spaced about every 300 feet around the barrier and about 10 feet on either side of the barrier. An additional five monitoring locations inside and outside the barrier were sampled to assess groundwater quality, quarterly for the first year after construction and then annually. Two wells inside the barrier were used to monitor pumping activities. In addition, the amount of groundwater extracted was monitored and reported along with the water quality data to the receiving publicly-owned treatment works (POTW). No separate monitoring of the cap other than periodic inspection was performed.

The quarterly measurements of groundwater table elevations were available for several years including the period of groundwater extraction. This data showed that in most cases the hydraulic head differential was maintained above the specified 1-foot difference across the barrier to achieve the design gradient of greater than 0.05. However, maintaining this hydraulic head differential allowed both inward (negative) and outward (positive) gradients across the barrier. Hydraulic head changes were generally as expected.

pairs showed outward gradients and a trend toward decreasing water levels as the downgradient recharge from groundwater flow was interrupted by the barrier. Upgradient monitoring well pairs showed inward gradients and fluctuating exterior water levels but not much mounding against the barrier wall. Summary plots of water levels are shown in Figure 2.

Figure 3 shows groundwater quality data collected immediately after construction and for several consecutive quarters thereafter. The wells outside the containment showed generally decreasing contaminant concentrations while some wells inside the barrier show stabilizing or increasing concentrations. In two cases where monitoring after barrier construction showed contamination outside the barrier, the wells were located on the downgradient side of the containment, in an area where positive gradients existed across the barrier.

5.4 Operation and Maintenance

Operation and Maintenance (O&M) requirements for the containment involved monthly site inspections, quarterly effluent sampling and well water level readings, and annual well water sampling since 1991. Barrier O&M was designed to respond to any breaching or degradation revealed by water level monitoring. According to the 5-year regulatory review, required O&M activities included correcting surface erosion problems with the cap and adjusting pumping requirements. One significant O&M problem involved addressing increasing constituent concentrations in extracted groundwater; a carbon pretreatment process had to be installed in order to meet POTW permit requirements.

5.5 Other

The containment has performed well and has been cost-effective. The capital cost of the containment was about $4,500,000. Annual O&M costs were estimated to total about $30,000.

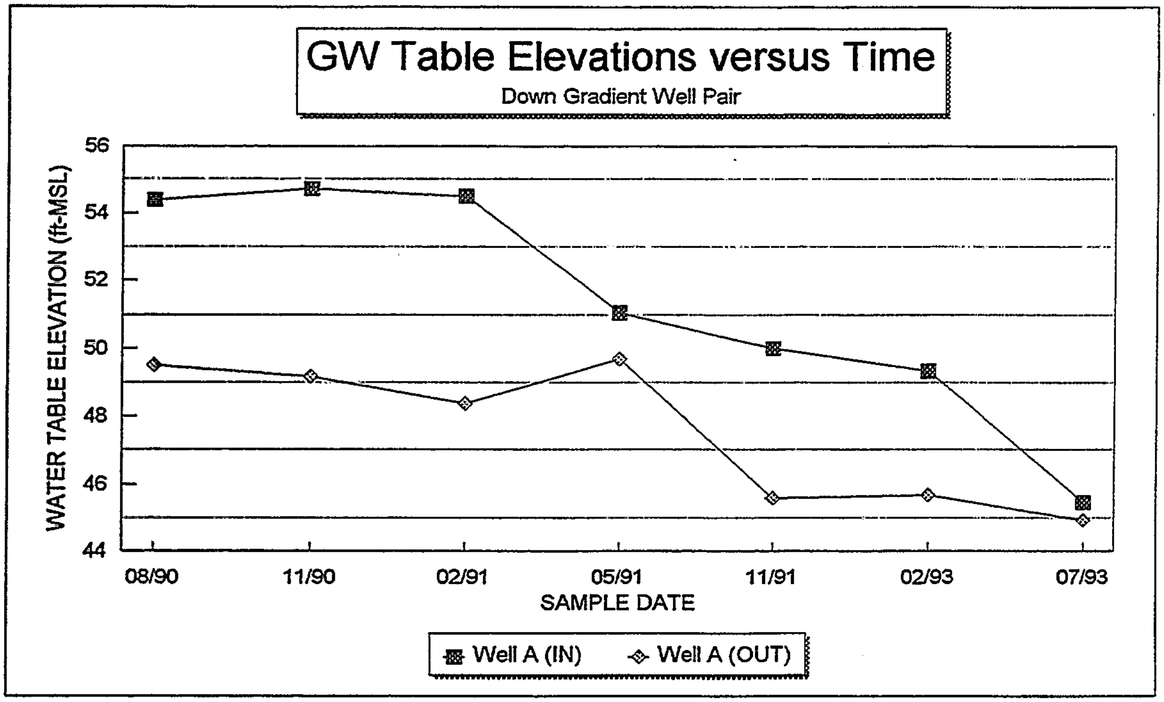
5.6 Remedy Performance

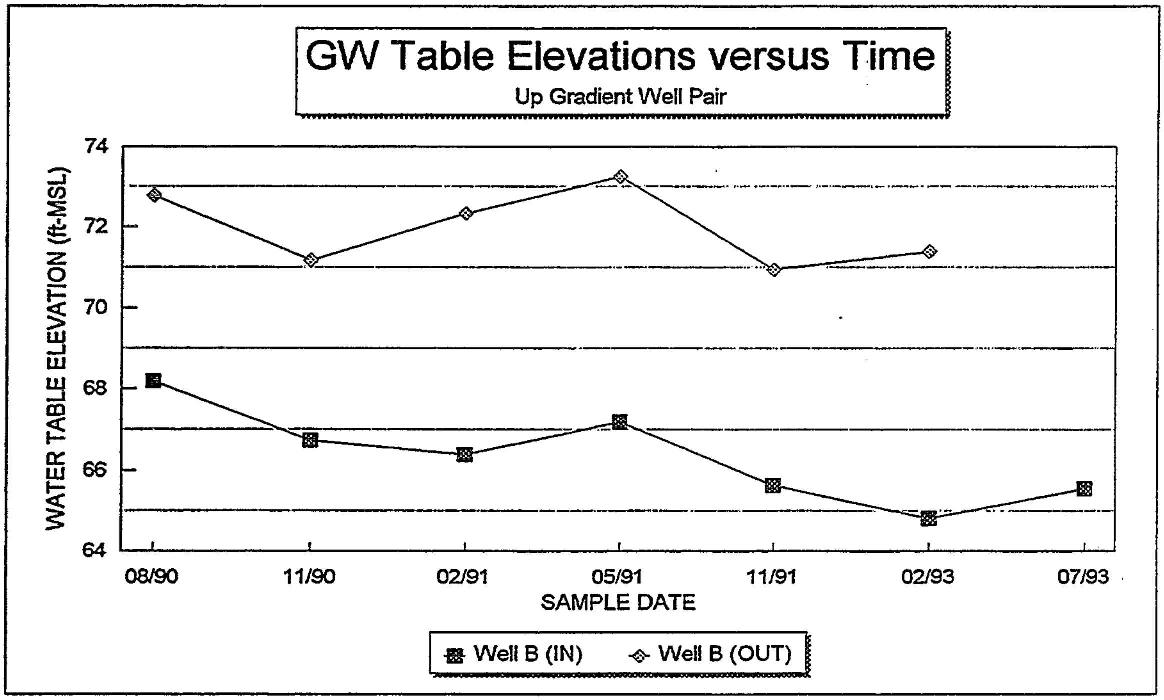
The hydraulic gradient design criterion was easily met by the pumping system, and groundwater quality outside the containment has improved in some cases relative to the original on-site concentrations. The barrier was determined to be of low permeability, adequately keyed, continuous, and intact based on hydraulic head monitoring and pumping quantities. The cap also functioned effectively; only typical erosion concerns were raised during the 5-year regulatory review.

6.0 SUMMARY

Site 27 is the 10-acre site of a former landfill. Various chlorinated solvents and metals are present in the on-site soils and groundwater, and contamination is present in off-site groundwater. The sites hydrogeology and shallow, aquitard allowed for containment of contaminated soil and groundwater on site. The containment remedy consisted of installing a soil-bentonite barrier, a cap, active pumping using two on-site wells, and monitoring. The design and CQA/CQC of the barrier involved a better than acceptable effort, but the cap design effort was rated less than acceptable. Cap CQA/CQC rated slightly better than acceptable based on the limited data available. The pumping system was a conventional installation.

The performance monitoring of the barrier involved post construction sampling of barrier use of paired piezometers across the barrier, ample groundwater quality monitoring, and regular inspections. Containment performance was consistent with remedial objectives of the remedy, and the containment is considered to be a protective remedy.





Site 27

FIGURE 2

GW TABLE ELEVATIONS versus TIME

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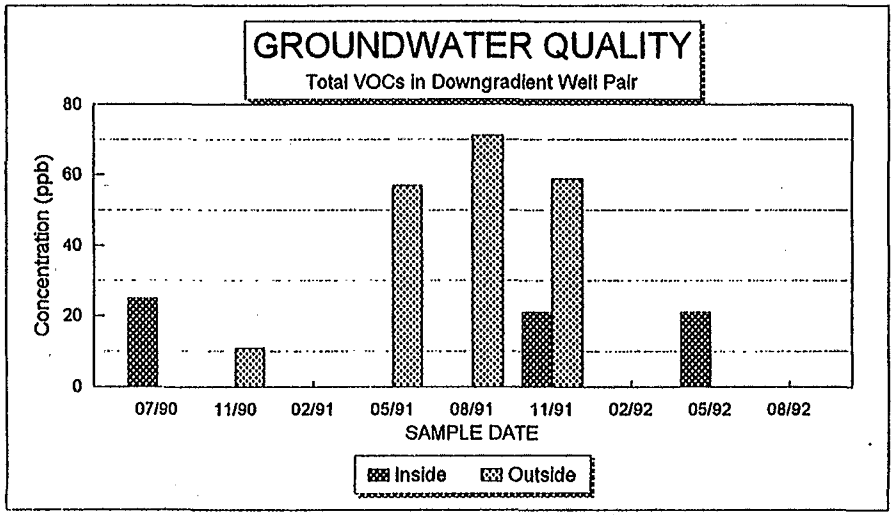

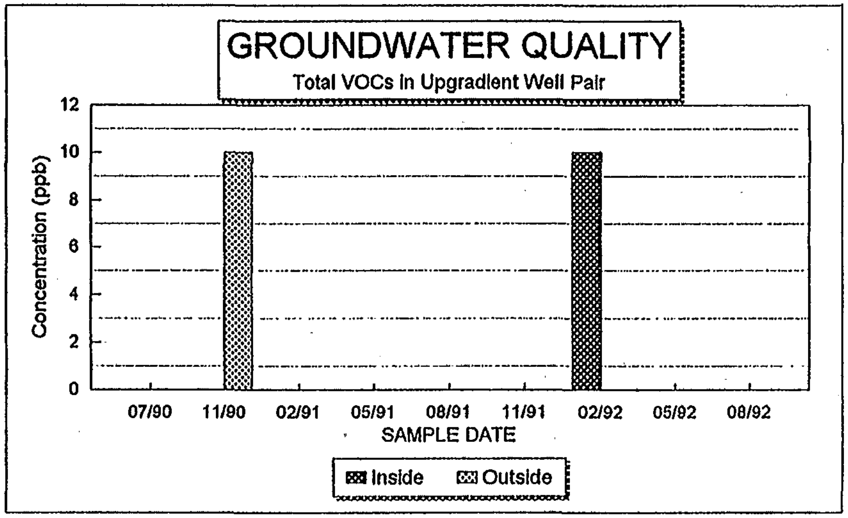

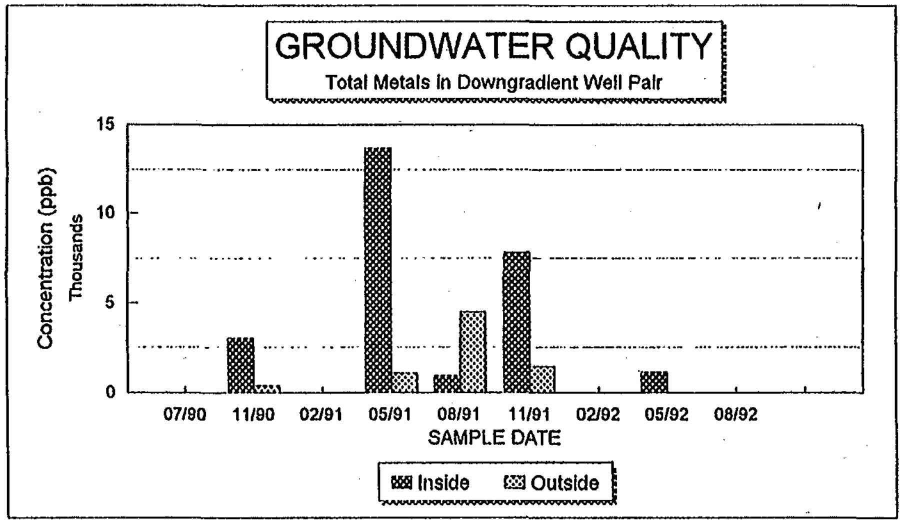

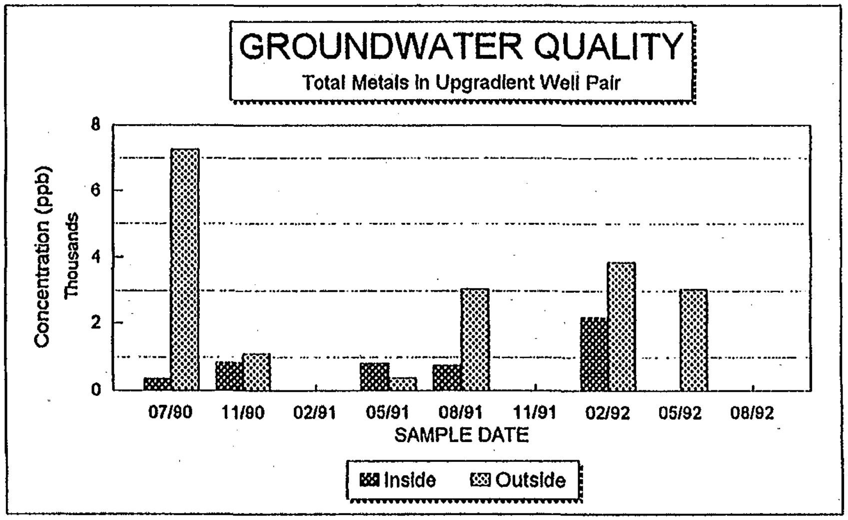

Site 27

FIGURE 3

GROUNDWATER QUALITY versus TIME

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SITE 28

Barrier Type	SB
Remedial Objective	SC
Performance	2+

1.0 SITE DESCRIPTION AND HISTORY

Site 28 is located immediately upgradient from a drinking water well field in the western United States. The site spans about 22 acres. The site formerly held a manufacturing facility that generated waste solvents. Release of waste solvents from a failed storage tank contaminated site soils and groundwater in the early 1980s.

A soil-bentonite barrier wall encircling about 17.5 acres of the site and a groundwater extraction system to maintain an inward hydraulic gradient across the wall were installed in 1986 as an interim remedy. Components of the final remedy included excavation and off-site disposal of highly contaminated soil; soil vapor extraction (SVE); maintenance of an inward hydraulic gradient across the wall; and extraction, treatment, and off-site disposal of on-site groundwater from a deep aquifer.

The layout of the barrier wall and the locations of site monitoring wells are shown in Figure 1.

2.0 GEOLOGIC AND HYDROGEOLOGIC SETTING

Alluvial deposits extend from the ground surface to the bedrock, which lies about 330 to 360 feet below ground surface (bgs). Within the alluvium, sand and gravel layers form four aquifers that are generally separated by aquitards formed by silt and silty clay layers. For the purposes of this evaluation, the aquifers are referred to as Aquifers 1 through 4, and the aquitards are referred to as Aquitards 1-2, 2-3, and 3-4. Aquifer 1 is the topmost aquifer and is separated from Aquifer 2 by Aquitard 1-2; Aquitard 2-3 separates Aquifer 2 from Aquifer 3, and Aquitard 3-4 separates Aquifer 3 from Aquifer 4. At some site locations, Aquifer 1 either merges with Aquifer 2 or is absent.

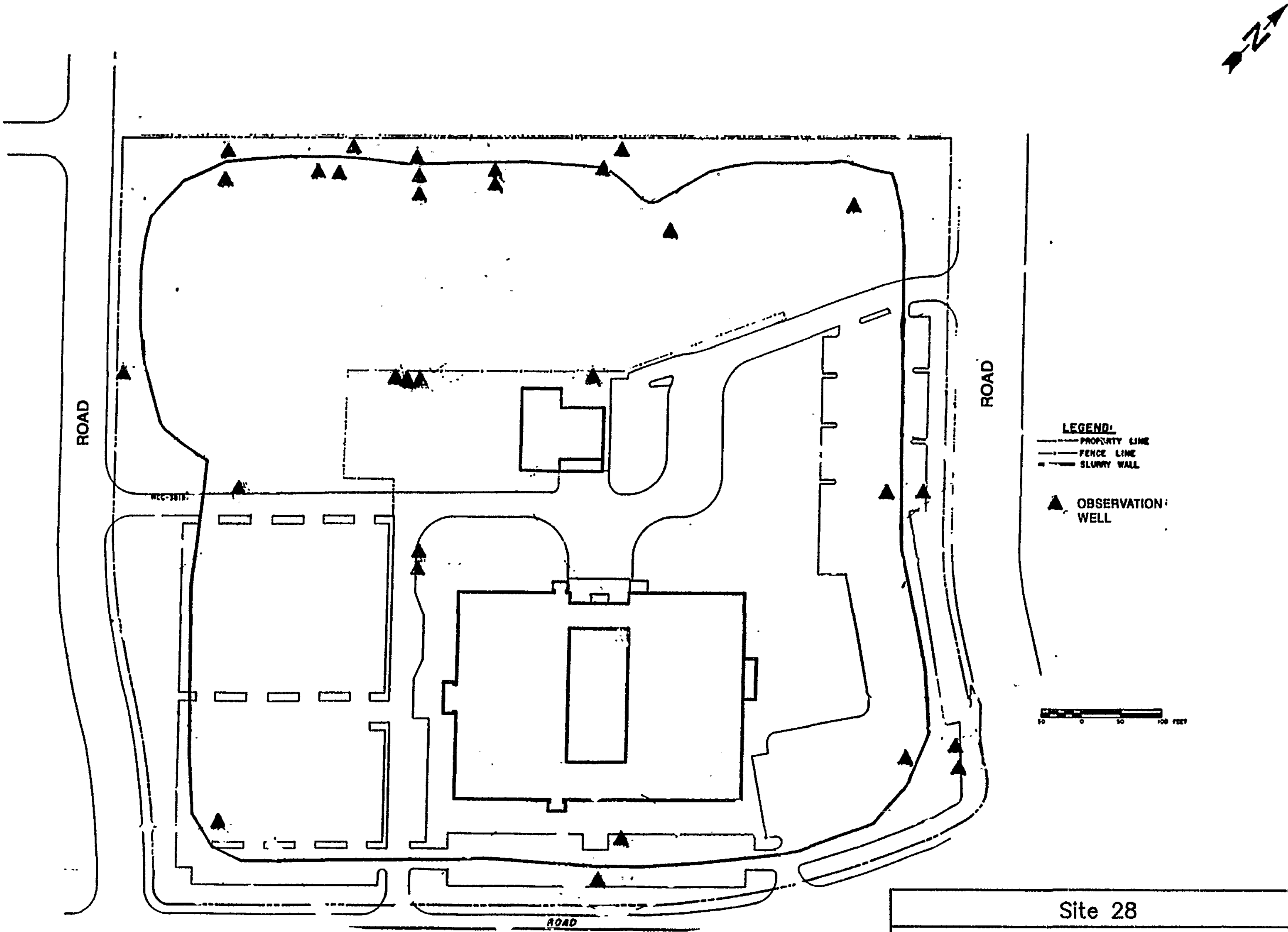
Aquifer 1 is about 15 to 20 feet thick, is located about 35 to 40-feet bgs, and is absent at some site locations. Aquitard 1-2 is about 5 to 30 feet thick. Aquifer 2 spans the site and is located between 60 and 120 feet bgs. The barrier wall is keyed into Aquitard 2-3, which spans the site and is about 40 feet thick. Aquifer 3 also spans the entire site and is located between 150 and 190 feet bgs. Aquitard 3-4 and Aquifer 4 are not continuous across the site. Aquifer 4, where it is distinguishable from Aquifer 3, is located between 220 and 270 feet bgs.

Aquifer 1 has generally been dry since the installation of the barrier wall. Aquifers 2, 3, and 4 are all high-yielding aquifers. Based on aquifer performance tests, the average hydraulic conductivities are 0.014 centimeters per second (cm/sec) for Aquifer 1, 0.33 cm/sec for Aquifer 2, and about 0.20 cm/sec for Aquifers 3 and 4. The general groundwater flow direction in all the aquifers is northwesterly.

Before the barrier wall installation, the hydraulic gradient in Aquifer 2 ranged from 0.0016 to 0.0020 foot/foot. Following the barrier wall installation, the hydraulic gradient within the contained area became 0 foot/foot, while outside the wall it varied between 0.006 and 0.025 foot/foot.

Aquifers 2, 3, and 4 were confined aquifers before installation of the barrier wall. However, following the barrier wall installation and pumping of groundwater to maintain an inward hydraulic gradient across

Key: SB=Soil Bentonite Wall SC=Source Control Performance Rating: 2+=Evidence suggests objective may be met



Site 28

FIGURE 1

SITE FEATURES

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the barrier wall, Aquifer 2 became unconfined. The downward vertical gradient from Aquifer 2 to Aquifer 3 ranges from 0.063 to 0.160 foot/foot. The net vertical gradient between Aquifers 3 and 4 is 0 foot/foot.

3.0 NATURE AND EXTENT OF CONTAMINATION

Following the release of waste solvents from the failed storage tank, site soils and groundwater were contaminated, primarily with trichloroethane (TCA); 1,1-dichloroethene (1,1-DCE); acetone; isopropyl alcohol (IPA); xylenes; Freon-113; and tetrachloroethene (PCE). The groundwater in Aquifer 1 had the highest concentrations of contaminants, including 1,900 μg/L TCA; 76,000 μg/L xylenes; 99,000 μg/L acetone; and 45,000 μg/L IPA. TCA was the primary contaminant in on- and off-site groundwater in Aquifer 2 with a maximum on-site concentration of 670 mg/L and a maximum off-site concentration of about 1 μg/L. On-site groundwater contamination in Aquifer 3 was limited; this aquifer's highest TCA concentration was about 7 μg/L. However, contaminant concentrations in off-site groundwater in Aquifer 3 were higher, indicating that contaminants had migrated from Aquifer 2 to Aquifer 3 at locations off site. Aquifer 4 was not sampled.

4.0 CONTAINMENT REMEDY

The containment remedy includes the following features:

- A soil-bentonite barrier wall that is about 3,425 feet long; 3 feet thick; 100 to 180 feet deep; and keyed at least 2 feet into Aquitard 2-3
- Extraction of groundwater from Aquifers 1 and 2 to maintain an inward hydraulic gradient across the barrier wall
- Treatment and off-site disposal of extracted groundwater
- Excavation and off-site disposal of highly contaminated soil
- SVE

The containment remedy did not include installation of a cap to reduce infiltration into the contained area. However, infiltration is expected to be very low in the contained area because (1) over one-third of the contained area is covered by buildings, driveways, and parking lots; (2) one-third of the contained area is covered by an approximately 1-foot-thick layer of soil-bentonite mixture resulting from soil-bentonite mixing operations for barrier wall installation; and (3) the rest of the contained area is covered by vegetation that removes soil moisture via evapotranspiration.

5.0 PERFORMANCE EVALUATION

The objectives for the containment system design and installation were to (1) contain the most contaminated, on-site groundwater and (2) reduce the volume of off-site groundwater to be remediated and its remediation time by substantially reducing downgradient migration of on-site contaminants.

The performance of the containment system was evaluated by monitoring (1) the water levels in 10 pairs of piezometers almost equally spaced along the length of the barrier wall and (2) the quality of off-site groundwater. The water table elevation measurements from all piezometer pairs indicated an inward gradient across the slurry wall. The maximum differences in water level between piezometers located outside and inside the barrier wall ranged from less than 1 foot (downgradient of the barrier) to about 16 feet (upgradient of the barrier). The concentrations of contaminants in off-site groundwater downgradient of the barrier wall decreased significantly after installation of the containment system.

Containment system performance and contributing factors are further discussed in the following subsections.

5.1 Design

The containment system design was rated better than acceptable with respect to industry practices described in Section 3, Volume I. The design was based on a thorough investigation of the site geology and hydrogeology. Extensive groundwater monitoring was used to support the design effort, and the trench-slurry compatibility was investigated. Grain size analyses of more than 50 soil samples and laboratory tests of soil permeability were performed to determine the composition of the soil-bentonite mix used in the slurry trenches. The design considered the seismic stability of the slurry wall, the potential impact of the barrier wall on the foundations of structures expected to be built in the vicinity of the barrier wall, and the maximum allowable head difference across the barrier wall. The groundwater extraction system design was based on the results of groundwater modeling.

5.2 Construction Quality Assurance and Construction Quality Control

The construction quality assurance (CQA) and construction quality control (CQC) of the containment system were rated better than acceptable. After construction, the integrity of the barrier wall was evaluated using a hydraulic stress test. The test was conducted within the contained area, and it lasted for more than 1 year. During the test, the water levels were measured in 20 paired piezometers located inside and outside the barrier wall at 10 almost equally spaced locations. The water level measurements indicated an inward hydraulic gradient across the barrier wall at all 10 locations.

5.3 Monitoring

The performance monitoring program was rated better than acceptable because in addition to periodic monitoring of water table elevations and water quality across the barrier wall, a pump test was conducted for more than 1 year to stress the wall for performance evaluation purposes.

5.4 Operation and Maintenance

Following the performance evaluation stress test, pumping of groundwater was continued to maintain an inward gradient across the barrier wall. Periodic measurement of water table elevations in paired monitoring wells has been ongoing since 1987.

5.5 Other Considerations

The construction and operation and maintenance costs for the containment remedy were not available for review.

5.6 Remedy Performance

The containment system achieved its design objectives and performed well. Its effectiveness was demonstrated (1) during a performance evaluation pump test conducted for more than 1 year and (2) by improvements in off-site groundwater quality.

6.0 SUMMARY

Site 28 is located immediately upgradient from a drinking water well field in the western United States. The site spans about 22 acres. The site formerly held a manufacturing facility that generated waste solvents. Release of waste solvents from a failed storage tank contaminated site soils and groundwater in the early 1980s. A soil-bentonite barrier wall encircling about 17.5 acres of the site and a groundwater extraction system to maintain an inward hydraulic gradient across the wall were installed in 1986 as an interim remedy. Components of the final remedy included excavation and off-site disposal of highly contaminated soil; SVE; maintenance of an inward hydraulic gradient across the wall; and extraction, treatment, and off-site disposal of on-site groundwater from a deep aquifer.

The design, CQA/CQC, and performance monitoring program for Site 28 were rated better than acceptable. After construction, the integrity of the barrier wall was evaluated using a pump test that lasted for more than 1 year. The containment system at Site 28 achieved its design objectives and performed well. Its effectiveness was demonstrated (1) during the performance evaluation pump test and (2) by improvements in off-site groundwater quality.

SITE 29

Barrier Type	SB
Remedial Objective	SC
Performance	2

1.0 SITE DESCRIPTION AND HISTORY

Site 29 is located in the northeastern United States. The site is bordered on the south by a road and on the east, north, and west by wetlands lying along the stream channels of two creeks. Industrial and semiresidential lands surround the site, which is 15 acres in size. Historically the site was used to house a hazardous waste incineration facility. The facility contained a high-temperature liquid waste incinerator, storage tanks, drums, and lagoons. Figure 1 shows the site layout.

Initial remedial investigations (RI) identified significant contamination at the site. In 1982, a state environmental agency performed a surficial cleanup at the site, which included removal of about 80,000 gallons of liquid chemical waste from 10 bulk storage tanks; demolition of the incinerator; and closure of the lagoons.

The 15-acre site is contained by a subsurface barrier wall installed in 1986. The soil-bentonite slurry wall is 2,700 feet (ft) long, 4 ft thick, and 14 to 16 ft deep.

2.0 GEOLOGIC AND HYDROGEOLOGIC SETTING

The site is located in the Erie-Ontario Plain subsection of the glaciated central region of the Great Lakes Physiographic Province. The topography in the site area reflects the glaciation that most of the glaciated central region underwent during the Pleistocene epoch.

Site 29 lies near the crest of a large drumlin. The uppermost soil at the site consists of a variety of fill and refuse materials. Below these materials is a sequence of glacial drift. Pleistocene-age glacial lake deposits make up the youngest unit. The clay and silt content of this unit increases to the west as the unit extends into an interdrumlin lowland. This unit is underlain by a discontinuous mantle of ablation (oxidized) till that has been removed by erosion in the southeastern section of the site. Underlying the ablation till is a variably thick layer of dense lodgement (reduced) till.

Localized areas of outwash have also been intercepted in site borings. The extent and configuration of the outwash channels are quite variable, and the outwash sand and gravel are as much as 20 ft thick in the central portion of the site. Glaciolacustrine sediments have also been found overlying the outwash at the site. These sediments are as much as 15 ft thick.

The bedrock in the site area consists of nearly flat-lying Ordovician- and Silurian-age sedimentary rocks. The average bedrock dip is about 40 ft per mile. Site-specific investigations have involved drilling of borings through at least the upper 40 ft of the Oswego Sandstone, which is suspected to be at least 400 ft thick.

The hydrogeologic setting includes overburden units with large groundwater yields in localized channel-in filling stratified outwash sand and gravel. Most of the large industrial and commercial wells in the site area are located within this outwash unit. The ablation till is used for residential wells in the site area, has permeabilities ranging from 1.2×10^{-4} to 4×10^{-5} centimeters per second (cm/sec), and extends from the surface to 15 ft below ground surface (bgs). The lodgement till and the glaciolacustrine

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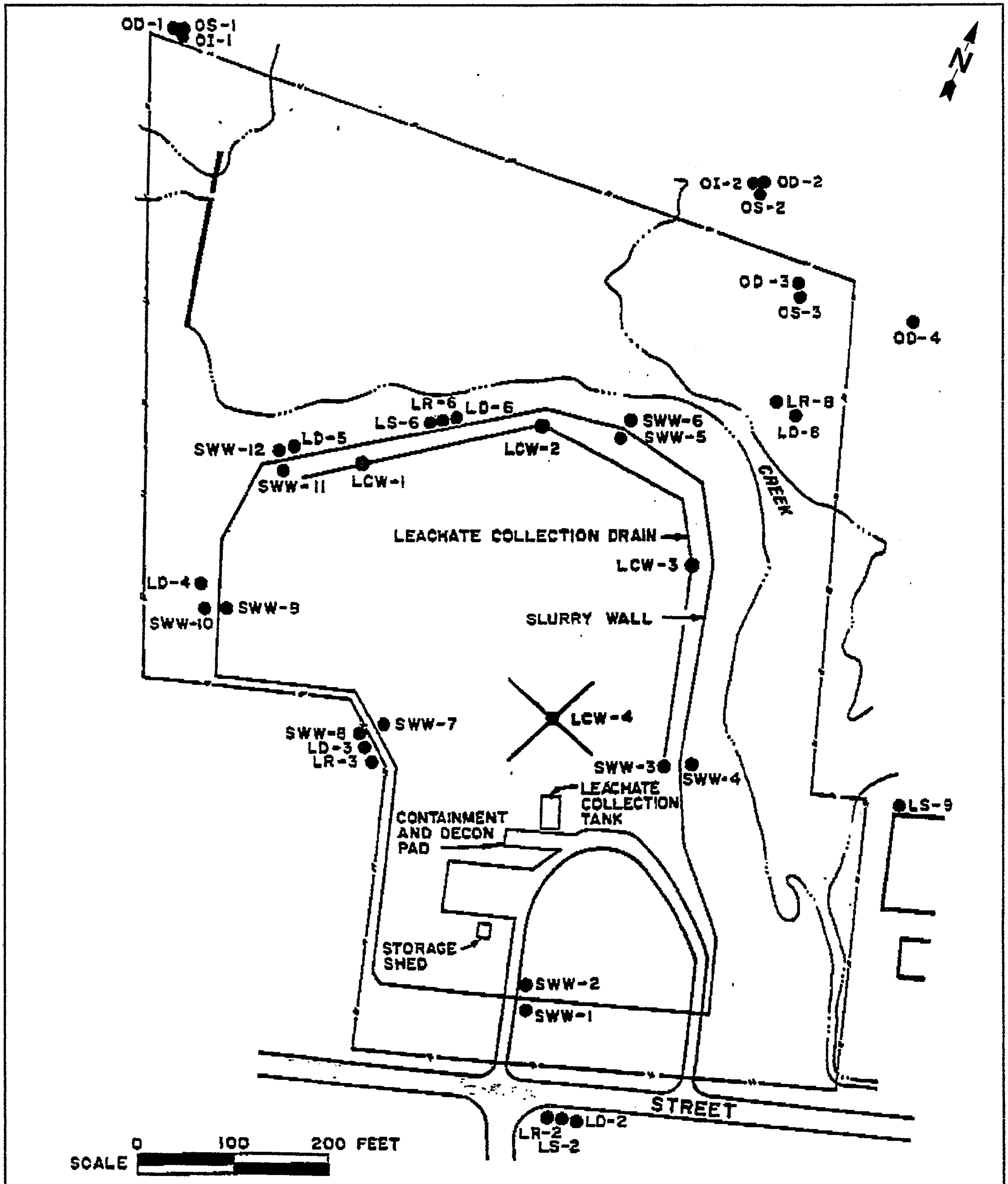

Site 29

FIGURE 1

SITE FEATURES

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sediments are the poorest aquifers and serve locally as aquitards; their permeabilities range from 7×10^{-5} to 6×10^{-6} cm/sec, and they lie from 15 to 36 ft bgs. The bedrock aquifer is not very useful as a water-bearing unit and it lies at depths beneath 36 ft bgs. The sandstone bedrock has very low permeability, although fractures within this unit slightly increase its permeability.

Groundwater in the unconsolidated aquifer flows west in the western portion of the site and north in the northeastern portion of the site. A horizontal hydraulic gradient of about 0.01 ft/ft exists in the bedrock aquifer to the northwest, and a downward hydraulic gradient ranging from 0.004 to 0.19 ft/ft exists between the water table zone and the upper bedrock zone.

3.0 NATURE AND EXTENT OF CONTAMINATION

Liquid waste spills and lagoon overflow into a nearby creek are the primary sources of groundwater and surface water contamination, respectively. Contamination at the site includes metals, volatile organic compounds, and semivolatile organic compounds. Indicator chemicals at the site include the following:

- Benzene at between 5 and 6 mg/L
- Toluene at about 16 mg/L
- Ethylbenzene at about 5 mg/L
- Xylene at about 36 mg/L
- Methylene chloride at about 120 mg/L
- Nickel at about 11 mg/L
- Cyanide at about 7 mg/L

Soil contamination is widespread and nonuniform across the site. During the initial RIs, groundwater contamination was identified in areas of the overburden aquifer that lie outside the current containment system. Therefore, at the time of slurry wall construction, impacted overburden groundwater was not completely enclosed by the containment system.

4.0 CONTAINMENT REMEDY

The objectives for the remedy were to provide source control and minimize or prevent migration of the existing contaminant plume. The primary design considerations for the slurry wall were the following: (1) use of slurry wall components that were compatible with the groundwater, (2) alignment of the wall in a manner that would provide containment of the contaminant plume, (3) reduction of the leaching potential of contaminants inside the containment structure by preventing infiltration or precipitation with a Resource Conservation and Recovery Act (RCRA) cap, and (4) attainment of a permeability of 1×10^{-7} cm/sec for slurry wall materials. The implemented remedy involved active containment and included installation of the following features:

- A soil-bentonite barrier wall that is about 2,700 ft long; is keyed a minimum of 2 ft into the lodgement till layer; and is 3 to 11 ft thick. The top of the wall lies 3 ft below the existing site grade. The wall was constructed using the trench and backfill method to achieve the design permeability of 1×10^{-7} cm/sec.

- A leachate collection sump system within the barrier wall

- A RCRA Subtitle C cap consisting of a 2-foot-thick clay layer, a 40-mil high density polyethylene (HDPE) liner, and 3 ft of cover soil

- Groundwater monitoring well nests at six locations around the site. Each nest consists of two wells, one inside the barrier and one outside the barrier.

- Paired piezometers to monitor water levels at six locations surrounding the barrier

Implementation of the remedy was completed in 1986. At that time, it was suspected that the barrier wall as designed and installed did not enclose all of the existing contaminant plume.

5.0 PERFORMANCE EVALUATION

Remedial activities were completed at the site in 1986 shortly after completion of the barrier system. At that time, the U.S. Environmental Protection Agency (EPA) reported that contaminants had been detected outside the slurry wall and that contamination was present in the bedrock aquifer system. A supplemental RI and feasibility study (FS) were completed to determine whether the barrier wall was intact. This supplemental study showed that the permeability of the barrier wall was consistently less than the maximum design permeability of 1 x 10-7 cm/sec. The study concluded that a vertical gradient may exist at the site and that a stratigraphic depression near the center of the site may permit migration of contaminants from the site.

In order to control contaminant migration, the state environmental agency intermittently removed leachate from 1986 through 1990. Beginning in May 1991, the potentially responsible party (PRP) for the site assumed responsibility for leachate removal and disposal. From February 1992 through March 1993, leachate was removed from the site at a rate of 20,000 gallons per month. The leachate removal rate was increased to 30,000 gallons per month in April 1993 and remains at that level. The pumping rate is sufficient to maintain an inward gradient at the site.

5.1 Design

The barrier design was rated acceptable relative to industry practices described in Section 3, Volume I. Limited groundwater modeling was completed before the design of the barrier.

The cap design was also given an acceptable rating. The cap design involved a standard RCRA composite cap as described in Section 4.0, Containment Remedy.

5.2 Construction Quality Assurance and Construction Quality Control

Trench sounding, backfill slump, and backfill permeability tests were performed. No detailed information was available on other aspects of construction quality assurance and construction quality assurance (CQA/CQC).

5.3 Monitoring

Containment system monitoring was rated acceptable relative to the standard for active containment. Six paired monitoring wells and six pairs of piezometers are used to collect water quality samples and water level measurements. Groundwater data in quarterly sampling reports indicates that contaminant concentrations inside the slurry wall are being reduced, and an inward groundwater gradient has been established and maintained for more than 3 years.

5.4 Operation and Maintenance

No information was available on operation and maintenance (O&M) activities for the barrier system.

5.5 Other Considerations

No information was available on the costs associated with construction and O&M of the barrier system.

5.6 Remedy Performance

An inward gradient has been consistently maintained for more than 3 years. In addition, groundwater quality data has shown a decrease in contaminant levels within the barrier wall; contaminant concentrations in groundwater outside the barrier wall have also decreased. The barrier appears to be properly keyed, of sufficiently low permeability, continuous, and intact based on available data. The maintenance of an inward hydraulic gradient by means of pumping appears to be effective in preventing formation of a vertical hydraulic gradient and migration of contaminants under the site. Therefore, the remedy is performing as designed.

6.0 SUMMARY

Site 29 is located in the northeastern United States. At the 15-acre site, a soil-bentonite slurry wall was constructed using a trench and backfill method. The wall is keyed at least 2 ft into lodgement till, and a RCRA Subtitle C cap has been installed at the site. A pumping system was installed, and an inward gradient has been maintained for more than 3 years. Barrier design, CQA/CQC, and containment system monitoring were rated acceptable based on the evaluation criteria. The site containment generally met the remedial objectives. Groundwater quality outside the barrier has improved.

SITE 30

Barrier Type	SB
Remedial Objective	SC; contain LNAPL
Performance	3

1.0 SITE DESCRIPTION AND HISTORY

Site 30, a former dump, is located in the Midwestern United States. During the 1970s the site accepted dry industrial, construction, chemical, and demolition wastes. Industrial wastes accepted at the site included waste oil, resins, flammable materials, caustics, and arsenic-contaminated materials. Land use before dumping began at the site has not been documented. A soil-bentonite slurry wall encompasses the 17-acre site to surround the known area of contamination. An intermediate slurry wall, located within the primary wall, separates the primary containment area (PCA) from surface water ponds and wetlands located on the west and south sides of the site within the primary slurry wall. The intermediate wall was installed after it was determined that not all of the area within the primary slurry wall was contaminated and that consequently not all of the area needed to be capped.

When the primary slurry wall was constructed in 1991, eight clusters of four groundwater monitoring wells were located equidistant around the site at 400-foot intervals. Each cluster consisted of two well nests: one inside and one outside the slurry wall. Each well nest consisted of a shallow and a deep well. The wells were located approximately 10 feet from the slurry wall centerline. The shallow wells were screened at the water table and the deep wells were screened at the base of the aquifer directly above the clay till formation. Fourteen pumping wells were located at the site in a pumping well field. Eight pairs of piezometers were also located along the slurry wall midway between the monitoring well pairs.

Currently, only six monitoring wells outside of the barrier wall and two pumping wells remain at the site. All interior monitoring wells and piezometers have been removed. Figure 1 shows the locations of the monitoring wells, pumping wells, and piezometers when the barrier walls were first constructed. Figure 2 shows the current site layout.

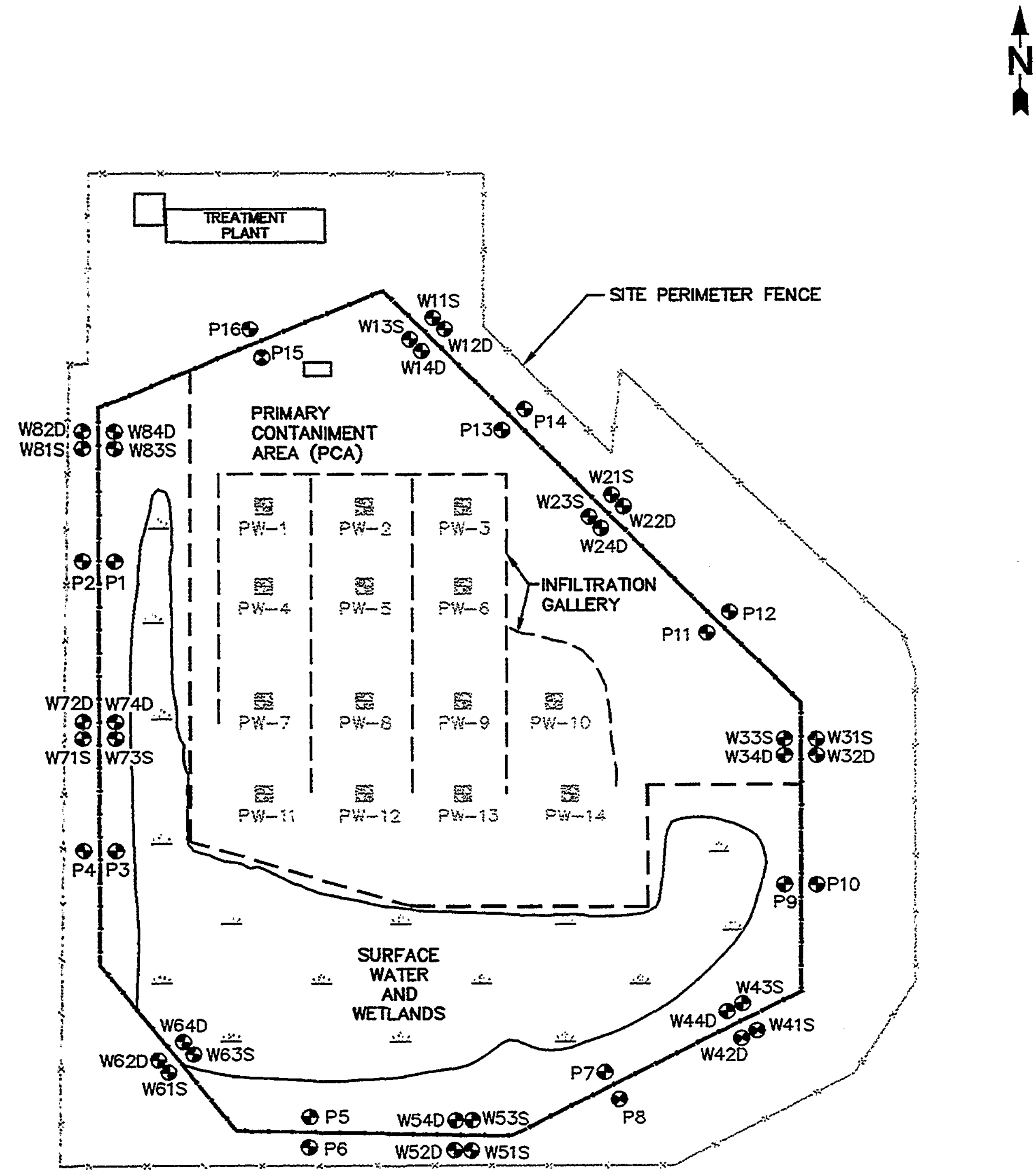
Groundwater from the PCA was treated in an on-site treatment plant to remove nonaqueous-phase liquids (NAPL), inorganics, and organics. Effluent from the treatment system was returned to the PCA through an infiltration gallery to flush NAPLs and contamination from the soil and fill.

Construction of the primary slurry wall, pumping well field, and treatment plant was completed in November 1991. Extraction and treatment of oil and groundwater within the PCA began in February 1992. Surface water from the ponds outside of the PCA was also extracted, treated, and discharged off site intermittently from April 1992 through December 1995. Ten rounds of groundwater sampling were conducted from April 1992 through October 1995. In February 1995, oil and groundwater extraction was discontinued. A Resource Conservation and Recovery Act (RCRA)-type cap and soil vapor extraction (SVE) system was installed in the PCA in August 1995, and the SVE system began operating in October 1995.

2.0 GEOLOGIC AND HYDROGEOLOGIC SETTING

Site 30 is located in an area of the Glaciated Central Groundwater Region which is characterized by east-west trending sandy ridges and dunes separated by marshy lowlands. The ridge complexes are predominantly composed of well sorted fine- to medium-grained sand and occasionally contain minor amounts of coarse sand, gravel, and silt. These sand deposits are 20 to 30 feet thick in the site area.

Key: SB=Soil Bentonite Wall SC=Source Control Performance Rating: 3=Evidence suggests objective may not be met



LEGEND

- OIL/GROUNDWATER RECOVERY PUMPING WELL
- PERIMETER MONITORING WELL
- PIEZOMETER
- PRIMARY WALL
- INTERMEDIATE WALL

100' 0 100' 200'

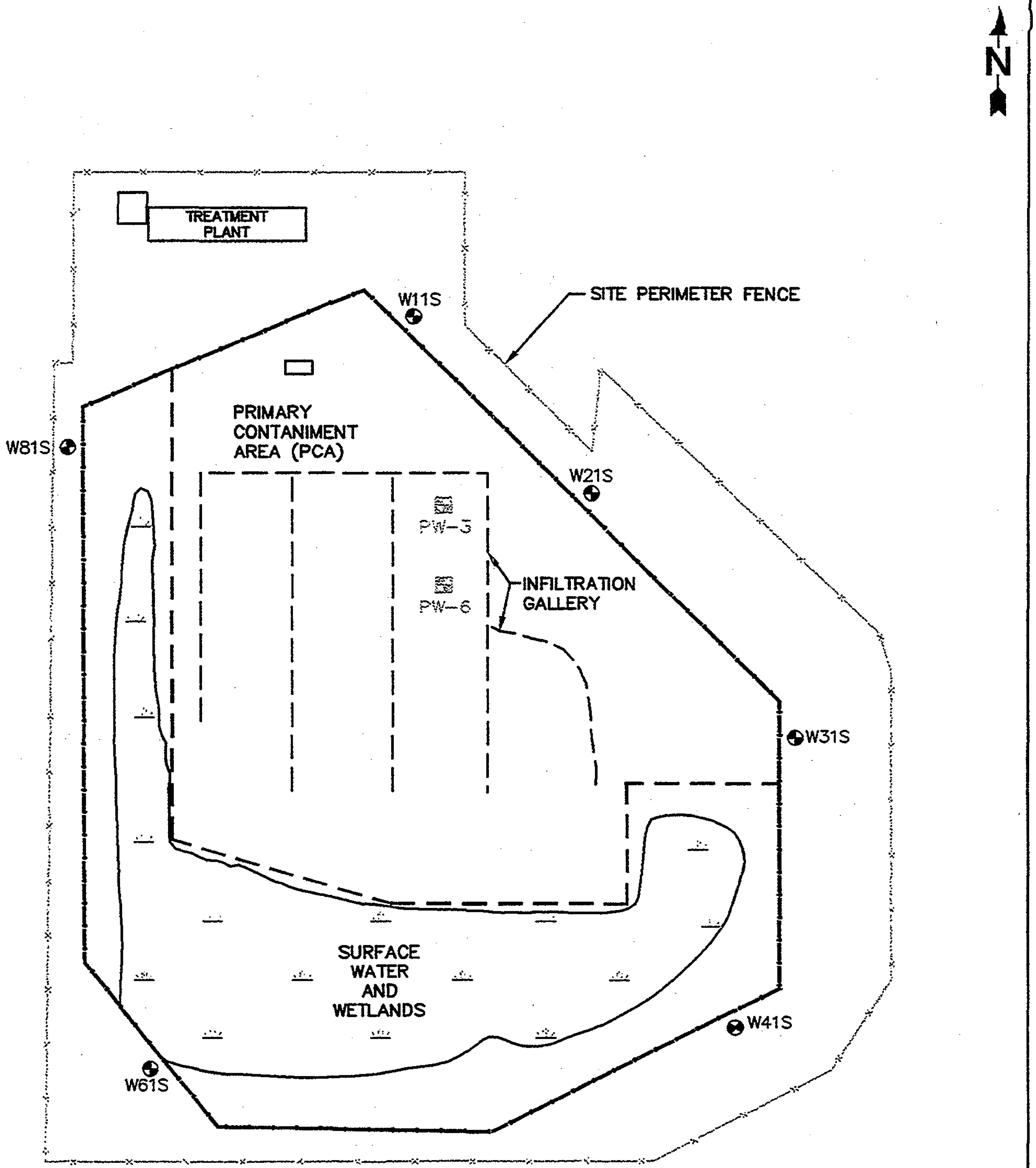
SCALE: 1" = 200'

Site 30

FIGURE 1
FORMER SITE LAYOUT

Tetra Tech EM Inc.

SOURCE: MODIFIED FROM FLUOR DANIEL ENGINEERING 1995



LEGEND

- OIL/GROUNDWATER RECOVERY PUMPING WELL
- PERIMETER MONITORING WELL
- PRIMARY WALL
- INTERMEDIATE WALL

100' 0 100' 200'

SCALE: 1" = 200'

Site 30

FIGURE 2
CURRENT SITE LAYOUT

Tetra Tech EM Inc.

SOURCE: MODIFIED FROM FLUOR DANIEL ENGINEERING 1995

The sand deposits are underlain by a gray, argillaceous till that occasionally contains cobbles or pebbles. The till layer is approximately 100 feet thick and directly overlies bedrock in the area.

Bedrock in site area is predominantly composed of the Late Silurian Racine Dolomite Formation, which is characterized by relatively flat lying, massive, thick-bedded dolomite that contains very few fractures.

The sand deposits below the site form an unconfined aquifer that is separated from the deeper, bedrock aquifers by the till layer. The unconfined aquifer extends from a river south of the site to a major, fresh water lake north of the site. The unconfined aquifer is generally saturated within 10 feet of the ground surface, making it highly susceptible to contamination. Groundwater flow in the immediate vicinity of Site 30 is generally to the northeast, and groundwater discharges into the fresh water lake and a regional river. South of the site, a local groundwater high divides the unconfined aquifer. Flow north of the groundwater high appears to be toward a major regional river, and flow south of the groundwater high appears to be toward a river south of the site.

The shallow depth to groundwater and the numerous ponds in the site area combine to provide localized influences on groundwater flow. The unconfined aquifer is generally not used for water supply purposes; however, the aquifer is used for limited industrial and residential purposes. Deeper bedrock aquifers are generally used for high-capacity industrial purposes.

3.0 NATURE AND EXTENT OF CONTAMINATION

The primary contaminants of concern affecting groundwater are benzene, trichloroethene, toluene, polynuclear aromatic hydrocarbons (PAH), and lead. The concentrations of these contaminants in the pumping wells during Round 1 of sampling conducted in April 1992 are as follows:

Benzene	130 to 1,900 micrograms per liter (μg/L)
Trichloroethene	230 to 1,700 μg/L
Toluene	21 to 20,000 μg/L
PAHs	15 to 6,910 μg/L
Lead	4 to 60 μg/L

4.0 CONTAINMENT REMEDY

The containment remedy consists of the following general features:

- A soil-bentonite slurry wall about 3,400 feet long, 3 feet wide, and 30 feet deep keyed 3 feet into the clay till formation

- Fourteen pumping wells for extracting groundwater (reduced to two pumping wells)

- An on-site groundwater treatment plant (not operational since February 1995)

- Thirty-two groundwater monitoring wells (currently reduced to six monitoring wells) and groundwater monitoring

- RCRA-type cap (installed in 1994)

- SVE system and monitoring (installed in 1995)

5.0 PERFORMANCE EVALUATION

The design goals for the containment system include confinement of the floating hydrocarbon layer and containment or recovery of groundwater that poses a risk to humans of greater than 1 in 100,000. The primary design considerations include the following:

- Low permeability and compatibility with the contaminated groundwater
- Alignment to confine contaminated groundwater
- Interface with the RCRA cap and underlying till aquiclude

The barrier design, construction quality assurance and construction quality control (CQA/CQC), monitoring, operation and maintenance, other considerations, and remedy performance are discussed below.

5.1 Design

The barrier design was rated above average compared to industry practices as described in Section 3, Volume I. The primary slurry wall was constructed using trenching-and-backfill method. The intermediate slurry wall was constructed using a vibrating beam method. The Waterways Experiment Station of the U.S. Army Corps of Engineers conducted a compatibility study of two soil-bentonite slurry wall backfill mixtures. Geophysical testing was conducted and borings were drilled along the barrier alignment at a frequency of approximately one boring per 100 to 200 feet. Suitable clay borrow material was obtained and mixed with bentonite slurry and, if necessary, dry bentonite to produce a soil-bentonite backfill mix. The backfill was mixed in batches of 100 cubic yards and transported by dump truck to the trench.

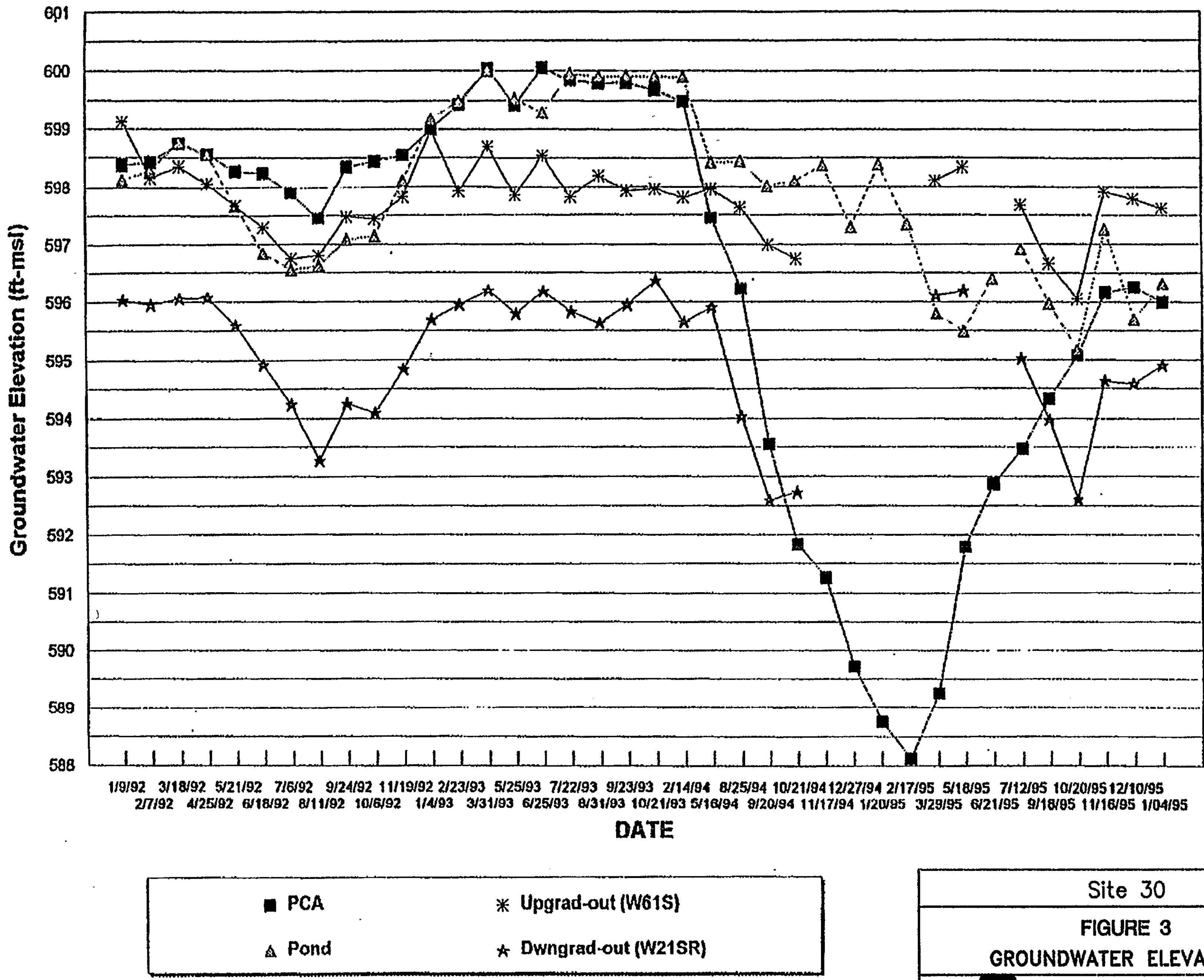
The RCRA Subtitle C cap consisted of a 2-foot-thick clay layer, a 40-mil high-density polyethylene liner, and 3 feet of cover soil. The cap covers the site area enclosed by the intermediate slurry wall (the PCA).

5.2 CQA/CQC

Barrier CQA/CQC was rated slightly above average. The CQA Plan for the site discusses the following elements: work platform, slurry preparation, trench excavation, backfill preparation and placement, clay cap over the slurry wall, and sampling and testing after slurry wall completion. The CQA plan was reviewed by U.S. Army Corps of Engineers personnel. Sampling and testing of the backfill materials after primary slurry wall completion consisted of obtaining undisturbed Shelby tube samples at 400-foot intervals along the wall and testing the permeability of samples obtained near the water table, near the bottom, and from midway between these two samples.

5.3 Monitoring

Long-term monitoring was rated average compared to standard industry practice. Groundwater elevation measurements were compared to determine the existence of an inward gradient. Figure 3 shows water level elevations in down- and upgradient perimeter wells, in a pumping well within the PCA under the RCRA cap, and in the ponds beginning in January 1992.



Site 30

FIGURE 3
GROUNDWATER ELEVATIONS

Tetra Tech EM Inc.

The figure shows that an inward gradient has not been established across the site. Water levels within the slurry wall were higher than those outside the wall after slurry wall completion and before pumping began.

The water level elevations in the upgradient well located outside of the slurry wall reflect an inward gradient beginning in August 1994 and remaining through March 1996 monitoring. The downgradient well does not indicate an inward gradient except perhaps between October 1994 and July 1995. The graph clearly shows that once groundwater extraction was stopped in February 1995, the water level within the PCA rebounded or leveled out. Figure 4 shows the water levels for a downgradient well pair. Again, this figure shows that an inward gradient was not established. The infiltration gallery and the existence of surface water in on-site ponds and wetlands may influence the water level within the PCA. The surface water level in the ponds and wetlands fluctuated between 595.5 to 600 feet above mean sea level from January 1992 to October 1995.

Benzene, total PAHs, lead, and nickel were selected to represent on-site contamination because groundwater was analyzed for these chemicals during all sampling rounds and they represent several primary contaminants of concern. Figure 5 shows the concentration of contaminants detected in well W21S, the downgradient well outside the barrier. Well W21S is located along the primary slurry wall (only one barrier between the pumping well field and W21S). Benzene concentrations appear to be declining since January 1993, and total PAHs remained below detection limits until October 1995. Lead levels, when detected, are stable. Nickel concentrations vary from below detection limits to 183 μg/L, with no apparent correlation with time. Additional results from sampling round 10 indicate no significant changes in groundwater chemistry outside of the primary slurry wall.

5.4 Operation and Maintenance

Site 30 operation and maintenance components include routine operation, monitoring, and maintenance of the SVE system; inspections of the RCRA cap; measurements of surface water and groundwater elevations; control of water levels in the on-site pond; and sampling of groundwater, surface water (for National Pollutant Discharge Elimination System permit), and soil gas.

5.5 Other Considerations

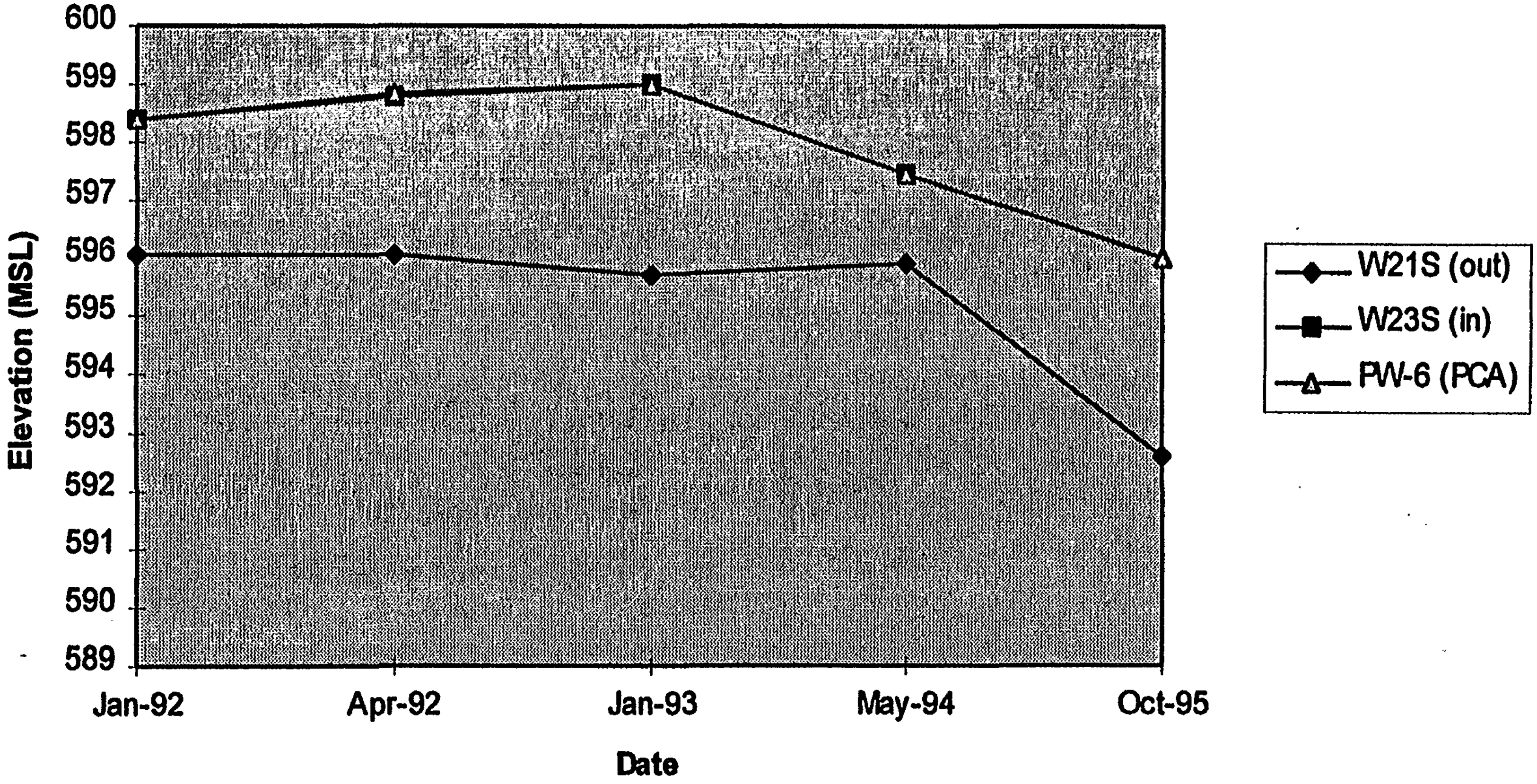
Approximate costs for the design and construction of the slurry wall and treatment systems are presented below.

Activity		Approximate Cost
Design		$5,900,000
Construction		$8,300,000
	Subtotal	$14,200,000
Operation and Maintenance (for a 2-year operational period)		$4,450,000
	Total	$18,650,000

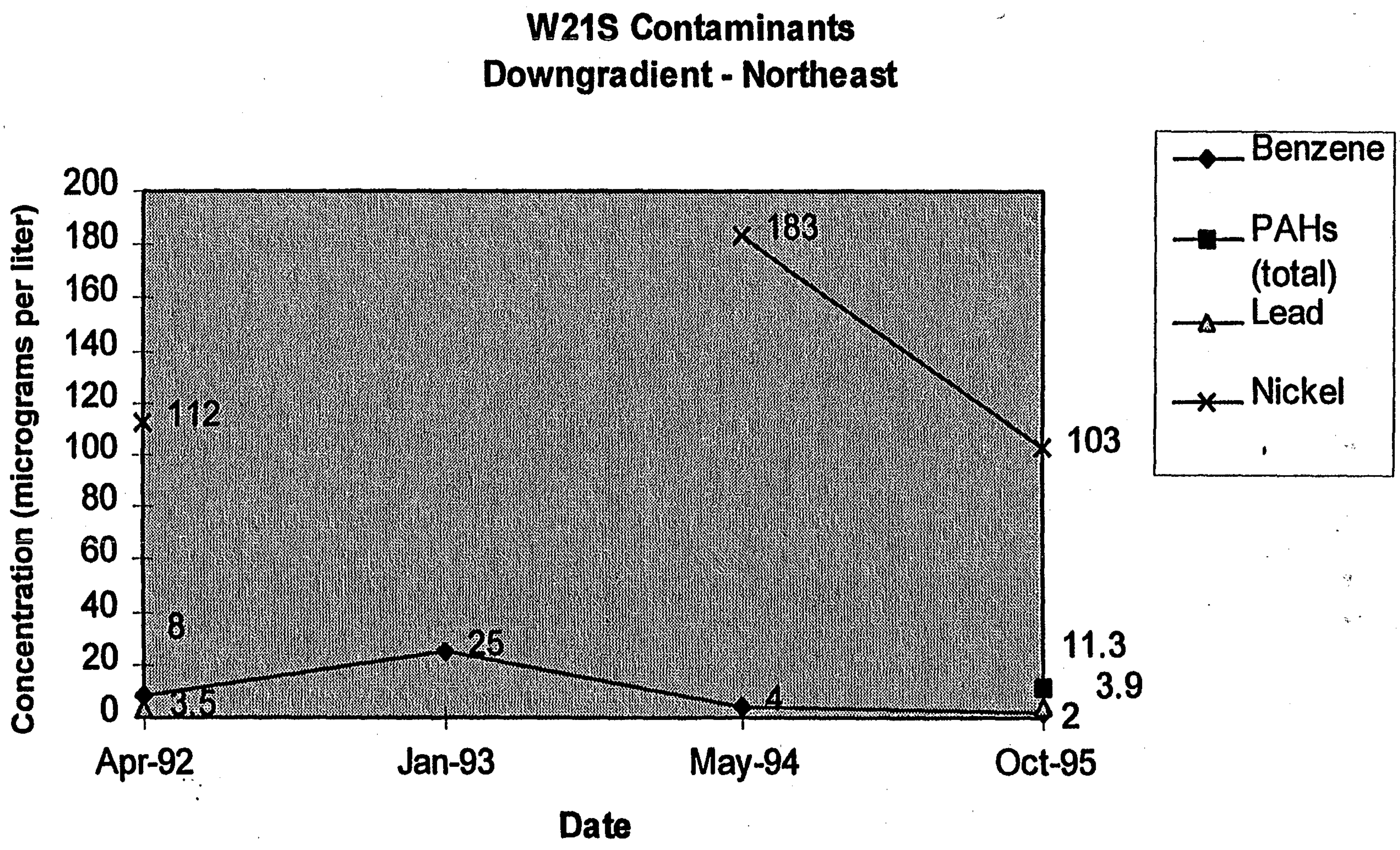
Site 30

8

Well Pair W21S and W23S
Downgradient - Northeast



Site 30
FIGURE 4 GROUNDWATER ELEVATIONS
Tetra Tech EM Inc.



Site 30
FIGURE 5 CONTAMINANT CONCENTRATIONS
Tetra Tech EM Inc.

5.6 Remedy Performance

Although primary barrier CQA/CQC testing indicates that barrier wall design specifications were met, the remedy is not yet performing as designed. An inward gradient has not developed downgradient of the site and after 10 rounds of sampling over 2.5 years, contaminant levels outside of the barrier wall have not decreased. The primary reason for the absence of an inward gradient downgradient of the site seems to be related to the stoppage of pumping. The soil vapor extraction system is still being evaluated as part of the overall remedy for the site.

6.0 SUMMARY

Site 30 is a 17-acre hazardous waste landfill that accepted waste oil, resin, flammable materials, caustics, and arsenic-contaminated wastes, as well as industrial, construction, chemical, and demolition wastes. The primary groundwater contaminants are benzene, trichloroethene, toluene, PAHs, and lead at concentrations of up to 20,000 μg/L. A 3,400-foot-long soil-bentonite barrier wall encompasses the site, and an intermediate barrier wall separates an uncontaminated wetland from the PCA. The PCA has a RCRA cap that was installed in 1994. An extraction system operated from February 1992 through February 1995 to remove contaminated groundwater for subsequent on-site treatment. The treated water was recirculated through an infiltration gallery until August 1994.

Design and CQA/CQC objectives were both rated above average; long-term monitoring was rated average. Hydraulic head monitoring was conducted monthly and indicates that an inward gradient has not yet developed or been maintained consistently across the PCA. Water quality monitoring conducted quarterly or annually has not shown any significant change in contaminant concentration outside of the primary barrier wall.

SITE 31

Barrier Type	SB
Remedial Objective	SC
Performance	2

1.0 SITE DESCRIPTION AND HISTORY

Site 31 is located within the northern Rocky Mountains in the Western Mountain Ranges groundwater region. The site began operation in 1886 and treated railroad ties and other wood products until 1983. Wood preserving agents used at the site included (1) zinc chloride, (2) a creosote and oil mixture, and (3) pentachlorophenol (PCP). Process wastes were initially disposed of in a number of locations in the vicinity of the site plant, including low areas and sloughs immediately north and west of the plant. This occurred until two evaporation ponds were constructed on site in 1958. Solid wastes generated from retort cleaning were reportedly buried south of the plant. Contamination outside the evaporation ponds was discovered in 1981 during groundwater monitoring.

The groundwater beneath about 140 acres of the 700-acre site property contains numerous polynuclear aromatic hydrocarbons (PAH), including PCP. Contaminated groundwater is prevented from moving off site by a subsurface barrier wall and collection drains. A 10,410-foot-long barrier wall surrounds the site and is keyed into the underlying bedrock (see Figure 1). Contaminated groundwater within the barrier wall is collected in horizontal drains, remediated by an on-site activated carbon treatment system, and discharged into an adjacent river. No cap is present at this site.

2.0 GEOLOGIC AND HYDROGEOLOGIC SETTING

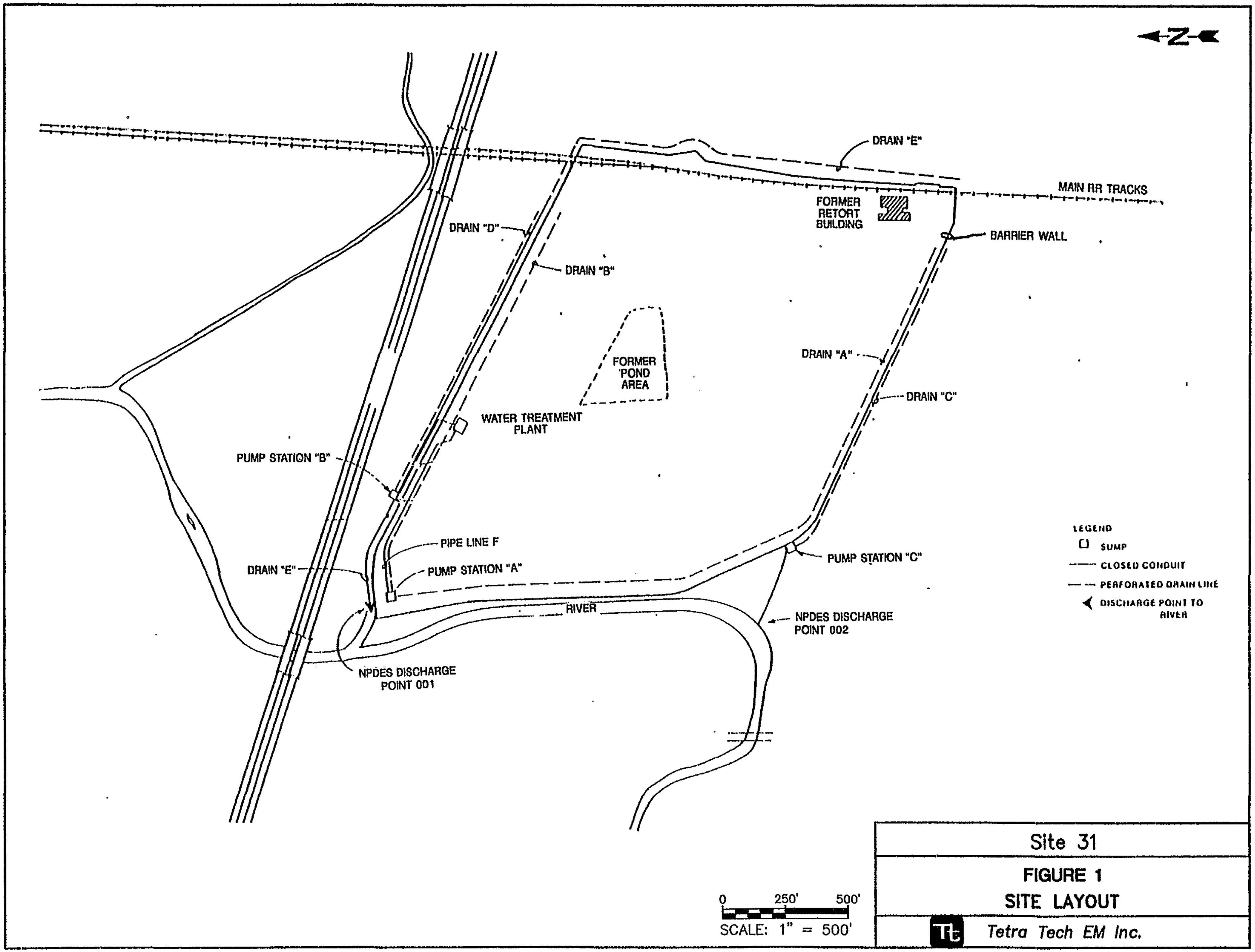
The site stratigraphy consists of a thin, surficial layer of recent alluvial flood plain deposits that directly overlie the bedrock units beneath the site. The alluvial deposits consist of unconsolidated silts, sands, and gravels that are typically 5 to 12 feet thick. The hydraulic conductivities of these deposits range from 0.1 to 5 x 10-3 centimeters per second (cm/sec). The underlying bedrock dips about 4 degrees to the west-northwest, which results in three bedrock units (the Morrison, Sundance, and Chugwater units) subcropping directly beneath the alluvium within the site boundary (see Figure 2).

The Morrison unit consists of siltstones, shales, and fine sandstones with individual beds typically less than 10 feet thick. Beneath the site, the thickness of the Morrison unit ranges from 0 (at the subcrop margin) to about 70 feet thick. The western segment of the barrier wall was installed through the Morrison unit to cut off dense nonaqueous-phase liquid (DNAPL) migration along these joints. According to aquifer tests, hydraulic conductivities in the Morrison unit range from 1 x 10^{-4} to 1 x 10^{-2} cm/sec.

The Sundance unit contains well sorted, massive, fine- to medium-grained sandstone that is poorly to moderately consolidated. Because of the dips of the beds beneath the site, the thickness of the Sundance unit ranges from 0 (at the subcrop margin) to about 120 feet. Hydraulic conductivities in this unit range from 1 x 10^{-4} to 1 x 10^{-3} cm/sec.

The Chugwater unit consists of shale with sandstone, limestone, and gypsum interbeds. The Chugwater unit is about 900 feet thick beneath the site, where it serves as an extensive confining layer for the high artesian heads present in the underlying Casper aquifer. Based on aquifer tests, the hydraulic conductivity of the Chugwater unit beneath the site ranges from 1 x 10^{-6} to 1 x 10^{-4} cm/sec. The Casper aquifer is considered to be the primary source of groundwater in the region and is found at a depth of over 900 feet below ground surface (bgs).

Key: SB=Soil Bentonite Wall SC=Source Control Performance Rating: 2=Evidence suggests objective may be met



Site 31

FIGURE 1
SITE LAYOUT

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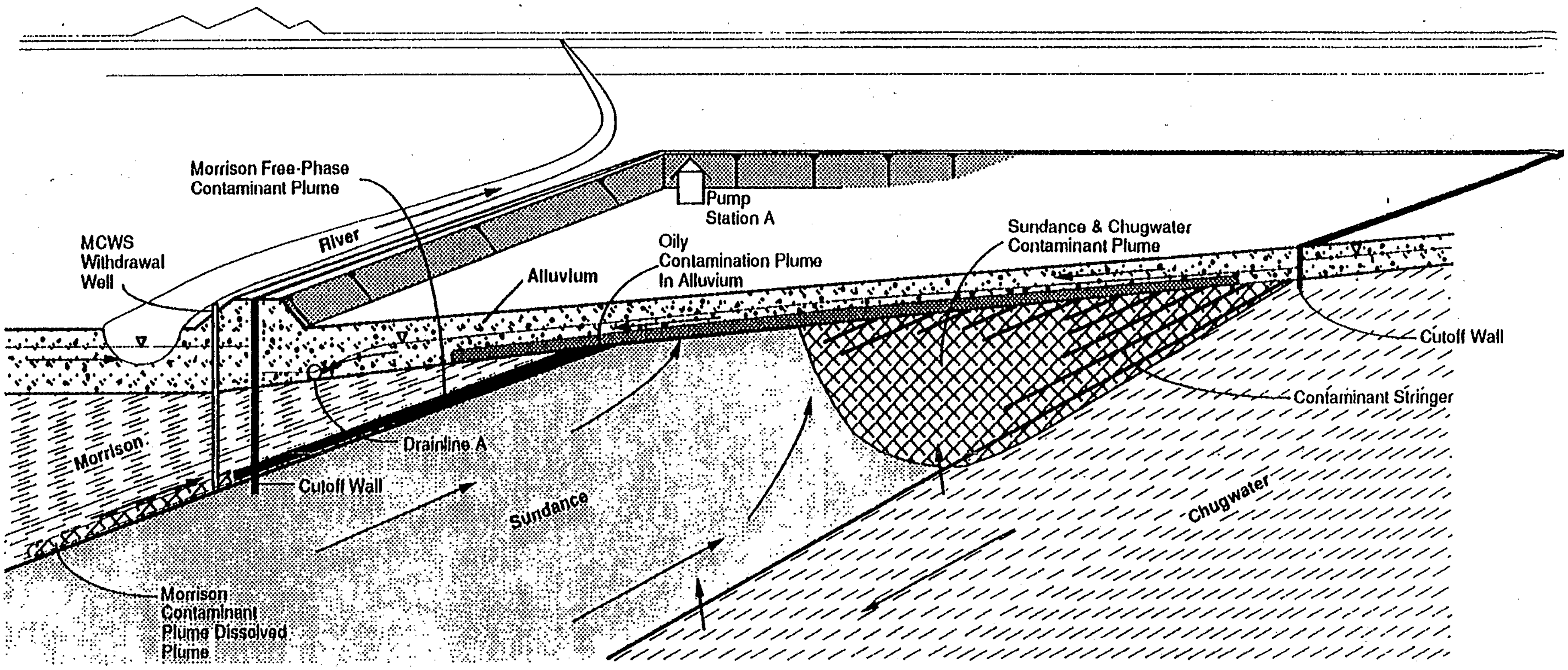


Site 31

FIGURE 2
CONCEPTUAL SITE CROSS SECTION SHOWING ESTIMATED BEDROCK CONTAMINANT PLUMES

Tetra Tech EM Inc.

As a result of the low topographic position of the alluvium along the adjacent river, water in the Morrison, Sundance, and Chugwater units discharges to the alluvium and then to the river in the vicinity of the site. Local precipitation and losses from the river during periods of high flow also contribute water to the alluvium.

3.0 NATURE AND EXTENT OF CONTAMINATION

The contaminants found at the site result from its historical use for wood preserving operations. Compounds associated with creosote and PCP wood preserving agents are found in soils and in the alluvial and bedrock groundwater systems beneath the site. The wood preserving wastes largely consist of an immiscible, heavier-than-water mixture of creosote and PCP in carrier oil. Contamination at the site ranges from oil-saturated sands and gravel to groundwater contamination in the parts per billion range; site contaminants have been discharged to the river.

DNAPLs have been observed in the alluvium and in portions of the Morrison and Sundance units at the site. No evidence exists that the contamination has entered the Chugwater unit. The largest mass of DNAPL resides in the alluvium, where as much as 7 million gallons has been estimated to have contaminated an area of about 90 acres. Most of the potential 7 million gallons is considered to be present at residual, immobile saturations. The thickness of DNAPL in the alluvium ranges from less than a few inches to about 4.5 feet. Individual pools are perched above the Morrison and Sundance units at various locations around the site. The DNAPL generally resides in the coarser-grained alluvial gravels and sands.

Relative to the large DNAPL mass in the alluvium, the amount of contamination within the underlying bedrock is limited. Discrete, thin layers of DNAPL have been identified in the lower portion of the Morrison unit, where DNAPL has migrated along select joints that occur within a siltstone layer near the base of the unit. Because of DNAPL movement along the slope of the beds, the contamination has migrated a lateral distance of about 850 feet from the likely source; the DNAPL contamination is about 60 feet bgs at this point. DNAPL contamination within the Morrison unit has been observed to extend just beyond the western alignment of the barrier wall; this contamination lies within the capture zone of three Morrison unit groundwater extraction wells.

DNAPL in the Sundance unit occurs in two distinct patterns. Localized DNAPL penetration has occurred within the top 2 feet of the unit, although the depth is more commonly limited to 1 inch or less. The second pattern of Sundance unit contamination consists of occasional, discrete, thin stringers oriented parallel to the bedding. The Sundance unit stringers have been observed at a lateral distance of about 1,100 feet from the source area. Because their lateral migration follows the slope of the beds, the stringers have been observed as deep as 70 feet bgs.

4.0 CONTAINMENT REMEDY

Wood-preserving operations at the site ceased in 1983, and the site was placed on the National Priorities List (NPL) in the same year. Also in 1983, a dike was built along the river to isolate the site from the 100-year flood plain. In fall 1983, a section of sheet pile was installed to cut off the flow of oil from the site into the river along a subsurface flow path. Surface impoundments containing hazardous waste were remediated, and the site plant was demolished in 1984. The removal actions involved processing more than 700,000 gallons of wood preserving oils and treating about 250,000 gallons of contaminated pond water.

The EPA selected an interim remedy in 1986 to control the source of contamination and to provide for groundwater cleanup. The objective of this remedy, called the Contaminant Isolation System (CIS), is to prevent contaminant migration to the river using a barrier wall, and to extract and treat contaminated water within the barrier wall. Because the contamination extended up to and beneath the river, the river channel had to be relocated about 150 feet to the west to allow the barrier wall to be installed around this contamination.

The barrier consists of a 10,410-foot-long, soil-bentonite wall that encloses an area of about 144 acres. In the areas where the Sundance and Chugwater units subcrop, the wall was extended completely through the alluvium and at least 2 feet into bedrock. The typical depth of the barrier wall in these areas is 10 to 15 feet below the original ground surface. In areas where the Morrison unit subcrops, the wall's depth was extended through the alluvium, and the Morrison unit, and into the upper 2 feet of the underlying Sundance unit. In these areas, the wall extends as much as 77 feet bgs.

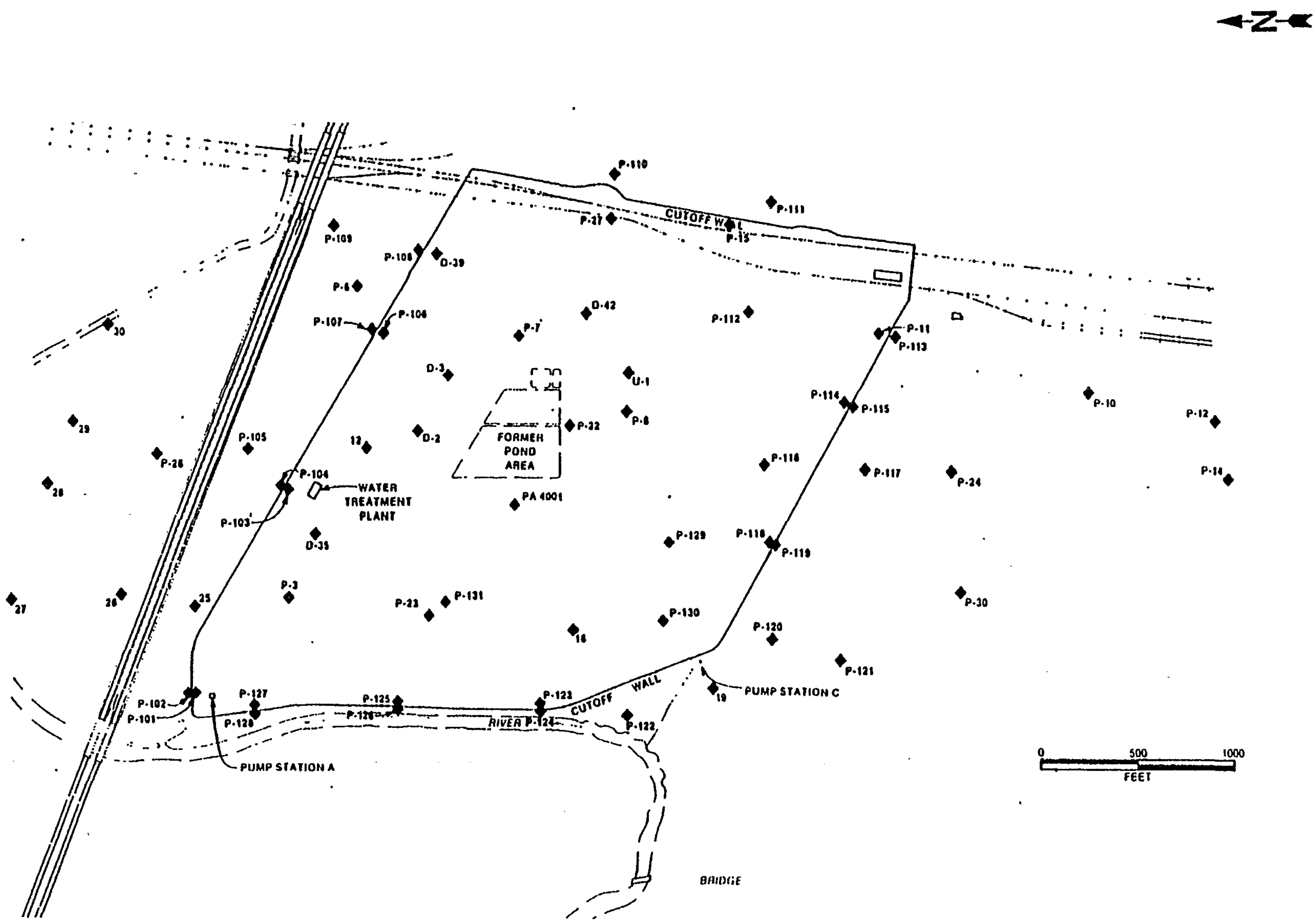
Alluvial groundwater levels are managed by a series of horizontal collection drainlines. This collection system consists of about 18,000 feet of buried, horizontal drainlines; three pump stations; and two discharge points to the river (see Figure 1). The purpose of the drainlines is to ensure that water levels inside the barrier wall are lower than levels outside the wall. The reverse gradient is monitored through collection of about 100 water level measurements each month from the alluvium, Sundance, and Chugwater units (see Figure 3). Water collected within the internal drainlines is treated by a series of activated carbon columns that adsorb contaminants. About 57 million gallons of water had been treated after the first year of system operation. The treatment system is capable of processing contaminated water at flow rates up to 400 gpm. The treated water is then discharged to the river under a National Pollutant Discharge Elimination System (NPDES) permit.

Contaminated bedrock groundwater, which is considered to be limited in occurrence, is located both on and off site. On-site DNAPL contamination is contained by the CIS and the upward gradients within the bedrock units. Off-site contamination is being removed by three withdrawal wells and treated in the CIS activated carbon water treatment plant. Twenty-one wells and piezometers are monitored as part of this system: six inside the wall and 15 outside the wall. Data on water levels, groundwater flow paths, gradients, and the capture zone is evaluated monthly. This data shows that the capture zone extends beyond the limits of the groundwater contaminant plume.

5.0 PERFORMANCE EVALUATION

The objective of the alluvial water level monitoring program is to confirm that the water management system is maintaining an inward flow gradient at the barrier wall. The water level monitoring network includes paired piezometers located immediately inside and outside the barrier wall to allow direct observations of water levels near the wall. Since CIS startup, potentiometric maps have shown lower alluvial water levels inside the barrier wall and alluvial groundwater flowing into the interior drains (see Figure 4). Water level gauging and potentiometric surface maps for the alluvium are generated on either a monthly or quarterly basis. As long as inward groundwater flow gradients are maintained within the water management system, additional alluvial water quality monitoring is not performed. However, limited sampling of river sediments and fish tissue is conducted. In addition, NPDES samples are collected from the north and south drains on a weekly basis.

The containment system has been successful in reducing on-site levels of contamination and in preventing contaminants from reaching the river. Specific performance factors are evaluated in the following subsections.



Site 31

FIGURE 3
PLAN VIEW SHOWING CIS ALLUVIAL WATER LEVEL MONITORING WELLS

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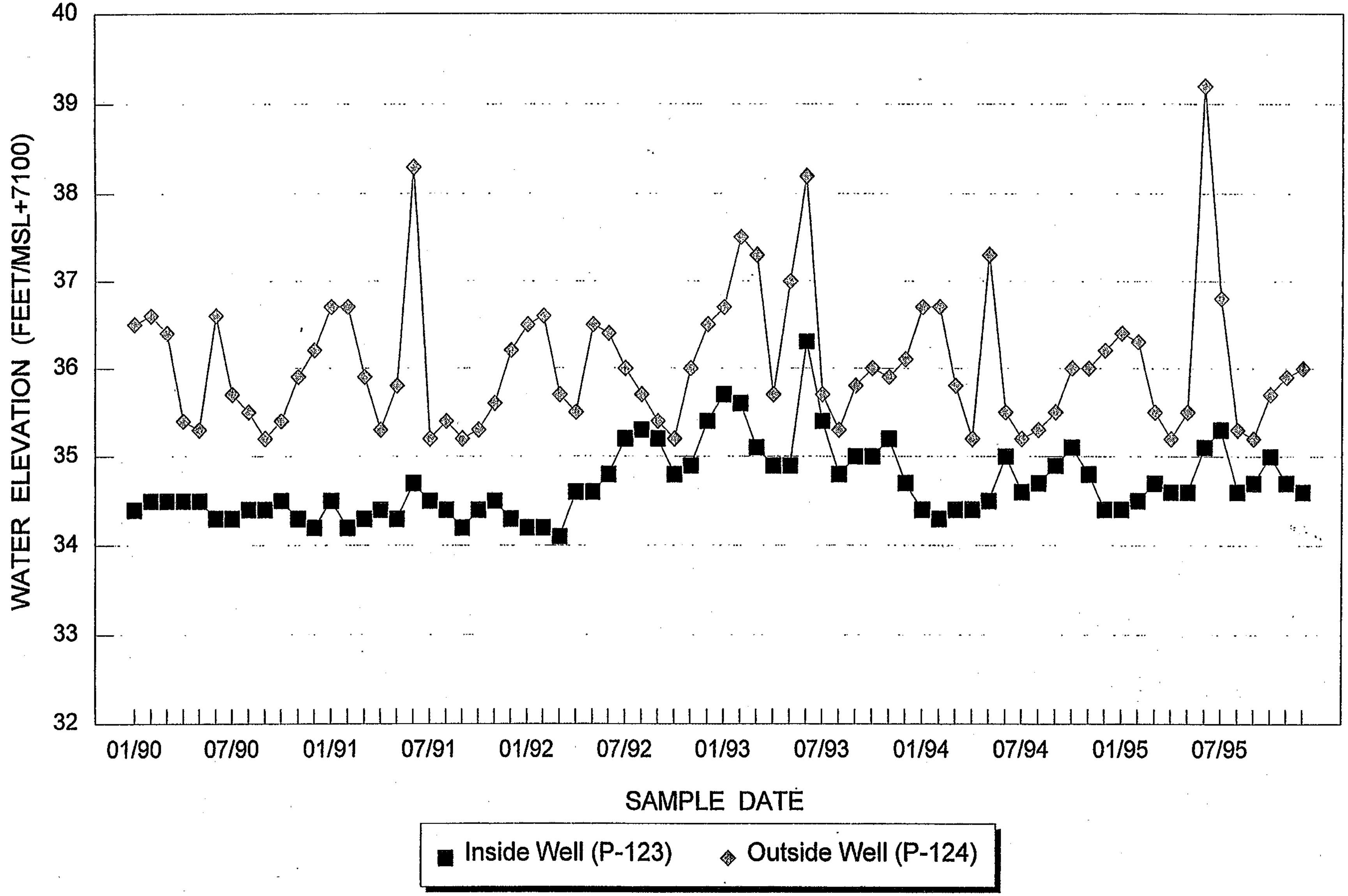


Site 31

FIGURE 4
WEST WALL HYDROGRAPHS

Tetra Tech EM Inc.

5.1 Design

The barrier design was rated acceptable as compared to established industry practices described in Section 3, Volume I. The design objectives for the barrier wall were to provide a (1) physical barrier that reduces the potential for outward movement of contamination and (2) hydraulic barrier that reduces the flow of water into the containment area. On average, less than one preconstruction soil boring was installed every 200 feet along the barrier alignment, except along the western wall, where the boring density increased to about one every 75 feet because of the proximity of the river. The top of the barrier wall is protected from damage and desiccation by 2-foot-thick, protective fill. The fill is a granular soil separated from the wall by a geotextile fabric. A gravel road was constructed on top of the barrier wall on the western two-thirds of the site to allow access and maintenance. The barrier wall is composed of a mixture of the following: (1) up to 85 percent by weight selected backfill material consisting of suitable on-site-excavated sand, gravel, and bedrock fragments and imported sand and gravel; (2) not less than 10 percent by weight imported silt and clay; and (3) not less than 2.5 percent by weight commercial bentonite. Compatibility tests were conducted to evaluate the effect of contact between the soil-bentonite mixture and contamination on the permeability of the wall materials.

5.2 Construction Quality Assurance and Construction Quality Control

Barrier construction quality assurance (CQA) and construction quality control (CQC) were rated better than acceptable because the procedures used generally exceeded the established standard protocols. The permeability of the soil-bentonite backfill was measured as 1×10^{-7} cm/sec (fixed-ring), and 6×10^{-8} cm/sec (triaxial), which met the design criteria. The depth of the completed trench before backfilling was measured at 25-foot intervals. Visual analysis of trench bottom samples along with evaluation of subsurface data verified that the wall was keyed into the specified geologic formations.

5.3 Monitoring

Long-term monitoring was rated acceptable as compared to established standard protocols. Hydraulic head measurements are routinely collected from at least eight sets of paired piezometers. However, information regarding barrier settlement, movement, continuity, and integrity is generally not collected.

Alluvial water level data from December 1986 indicates that water levels were higher inside the barrier wall than outside along the western and most of the northern segments of the wall. This finding reflects conditions before the startup of the CIS. By April 1987, groundwater elevations had dropped along the southern, northern, and western segments of the wall, as a result of CIS operation. An inward gradient was detected at three of the eight alluvial monitoring well pairs straddling the barrier wall. Groundwater levels measured during May 1987 indicate the presence of an inward gradient at all eight alluvial monitoring well pairs straddling the barrier wall. According to quarterly monitoring reports, this inward gradient has been maintained through the most recent sampling date (June 15, 1995). The most recent alluvial potentiometric map shows groundwater at the site flowing toward the interior drains and shows lower alluvial water levels inside the barrier wall than outside.

Alluvial water quality data collected to meet NPDES permit conditions suggests that no organic contamination concentrations above the method detection limits are leaving the site. Inorganic concentrations in groundwater being discharged from the site are within the range specified in the NPDES permit. In addition, sampling and analysis of river sediment indicated no statistical difference between contaminant concentrations upstream of and adjacent to the site. The results of 1987 and 1988 fish sampling events generally show nondetectable or trace levels of PAHs in whole fish samples, and no contaminants were detected in fish fillet samples collected during this period.

Bedrock groundwater elevations measured in May 1987 indicated that water levels within the Morrison unit inside the barrier wall were lower than outside the wall. Water levels in the Sundance and Chugwater units are higher than in the alluvium, suggesting a potential for upward flow from the Chugwater unit, through the Sundance unit, into the alluvium. Except for Morrison unit removal wells, contamination was detected in only two Morrison unit wells (BR-29 and BR-35) and one Sundance unit well (BR-5).

5.4 Operation and Maintenance

Contaminated site areas are surrounded by a barbed-wire fence and locked gates. Once each week, the site facilities are inspected for damage, evidence of intrusion, and other problems. The inspection includes examination of the fence and gates, pump stations, and buildings. Each month, the entire length of the barrier wall is inspected for signs of damage or erosion, including the following: (1) excessive settlement at the ground surface, (2) rodent or beaver holes in the flood-plain dike, (3) nearby erosion, and (4) broken or leaking water lines. The top of the barrier wall is protected from damage and desiccation by a 2-foot-thick, protective fill. The fill is granular soil separated from the wall by geotextile fabric. In addition, the river channel is inspected for signs of erosion.

5.5 Other Considerations

The construction and CQA/CQC costs for the barrier wall totaled about $2.5 million.

5.6 Remedy Performance

Based on almost 10 years of monitoring data, the CIS (including the barrier wall) appears to be preventing contaminant migration from the site to the surrounding alluvium and the river. CQA/CQC testing performed during and after barrier wall construction indicated that the design specifications were met. Monthly monitoring of the water management system has demonstrated that alluvial water levels are consistently lower inside the barrier wall, thus providing a reverse-gradient hydraulic barrier to help prevent contaminant migration to the river. Since the CIS was installed, contaminant concentrations in the river have been about one to two orders of magnitude below proposed sediment criteria for protection of aquatic life and concentrations corresponding to ambient water quality criteria.

6.0 SUMMARY

Site 31 is a 700-acre wood treatment facility where past operations have caused widespread DNAPL contamination of soil and groundwater. Site contamination ranges from oil-saturated sands and gravels to groundwater contamination in the parts per billion range, and discharged to the adjacent river. A 10,410-foot-long, soil-bentonite barrier wall was constructed around the contaminated portion of the site to control the source of contamination and prevent further contaminant discharges to the river. To remediate the groundwater, a system was installed to collect, manage, and treat contaminated groundwater within the barrier wall.

The barrier wall design was rated acceptable, and CQA/CQC was rated better than acceptable. Long-term monitoring was rated acceptable. Hydraulic head monitoring is conducted monthly to quarterly, but available water quality data is limited to the bedrock aquifers. Alluvial hydrographs for paired piezometers along the barrier wall indicate that a continuous inward gradient has been maintained since the treatment system was put in operation. Three groundwater extraction wells appear to be limiting the movement and reducing the levels of contamination in the bedrock aquifers outside the barrier wall. Overall, the barrier wall and associated water management system appear to be meeting the remediation objectives.

SITE 32

Barrier Type	SB
Remedial Objective	SC
Performance	1

1.0 SITE DESCRIPTION AND HISTORY

Site 32 is a 35-acre former sand and gravel quarry that was subsequently used as a landfill. The site is located in the northwestern United States. Landfilling operations at the site, including open burning of refuse, started in the early 1960s. The layout of the site is shown in Figure 1.

2.0 GEOLOGIC AND HYDROGEOLOGIC SETTING

No site investigation was performed before the start of the landfilling operations. However, a geologic and hydrologic investigation was performed later to support selection of the remedial action and closure requirements. The site stratigraphy is summarized below (in descending order).

- Upper soils consisting of very permeable sand and gravel. The thickness of this deposit ranges from 4 to 30 feet.
- Some very dense glacial till lenses (silty sands)
- A very dense layer of silty, sandy gravel that ranges from 12 to 30 feet in thickness
- Older, undifferentiated deposits consisting of layers of sand, gravel, and silt

A shallow aquifer exists in the sand and gravel deposits. During the rainy season, this aquifer rises and saturates the lower zone of landfill refuse, thereby generating leachate. This shallow aquifer is perched on top of the older, undifferentiated deposits. Groundwater in the aquifer flows southwest toward a river. The vertical permeability of the older, undifferentiated deposits is less than or equal to 1 x 10-6 centimeters per second (cm/sec). A deep aquifer also exists below the site at a depth of 130 to 150 feet below ground surface.

3.0 NATURE AND EXTENT OF CONTAMINATION

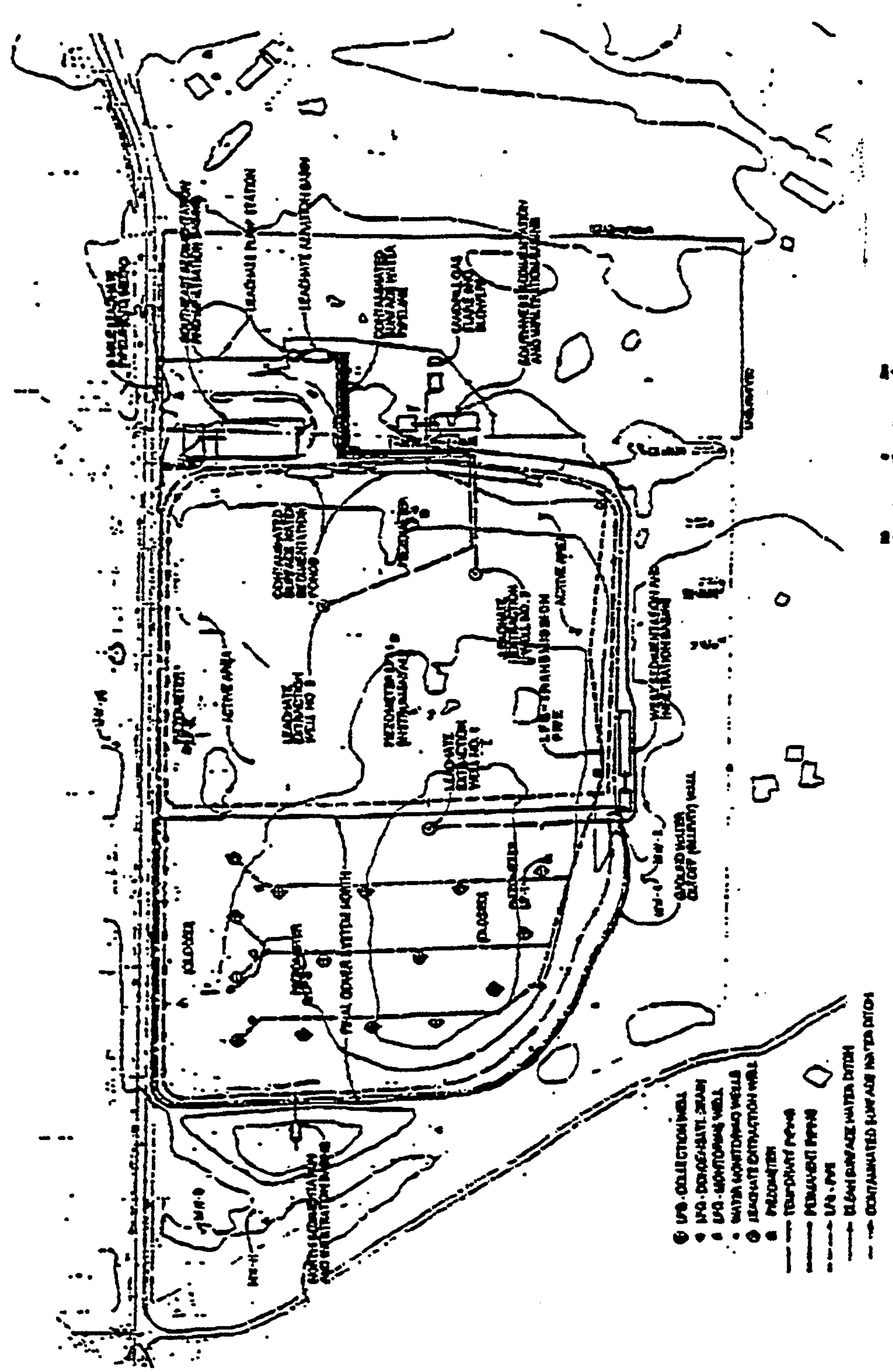
No information exists on the nature and quantities of refuse deposited in the landfill until 1977. Approximately 270,000 tons of municipal solid waste were received between 1977 and 1993 when final closure took place. Sixteen monitoring wells have been installed throughout the site. Organic compounds were detected in the shallow aquifer downgradient of the landfill. Concentrations of iron and manganese in the aquifer exceeded secondary drinking water standards. Benzene was also detected in the shallow aquifer at concentrations in excess of 5 micrograms per liter. Sampling of off-site, domestic wells revealed no groundwater contamination in the shallow aquifer. No contaminants were detected in the deep aquifer.

4.0 CONTAINMENT REMEDY

The containment remedy for the site includes the following features:

- A soil-bentonite cutoff wall that is 4,750 feet long; 3 feet wide; and 50 feet deep on average

Key: SB=Soil Bentonite Wall SC=Source Control Performance Rating: 1=Remedial objective was met



Site 32

FIGURE 1
SITE PLAN

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- A leachate extraction well system and pump station
- A leachate aeration basin
- A gas control and disposal system
- A geomembrane final cover system that includes a 60-mil, high-density polyethylene liner and a 3-foot thick soil section

5.0 PERFORMANCE EVALUATION

The cutoff wall and leachate extraction facilities were designed to maintain the groundwater level inside the containment at least 3 feet below the deepest refuse (to minimize the amount of leachate generated) and at least 1.5 feet below the groundwater level outside the containment. Extracted leachate is pumped first to an aeration basin then to a wastewater treatment facility through a new, 6-inch-diameter, 8-mile-long force main to an existing treatment plant.

5.1 Design

Several remedies were evaluated based on their technical adequacy and cost. Soil borings were drilled along the cutoff alignment at 2-foot intervals. The design of the selected remedy was (at least) rated acceptable relative to industry practices discussed in Section 3, Volume I. Hydraulic modeling was done to estimate the drawdown and pumping requirements for the system. The cutoff wall was designed to be keyed 3 feet into the layer of low-permeability, older, undifferentiated deposits. This layer is continuous beneath the site. The design permeability was less than or equal to 1 x 10-7 cm/sec.

The design included a final cover (high density polyethylene geomembrane) and a landfill gas system.

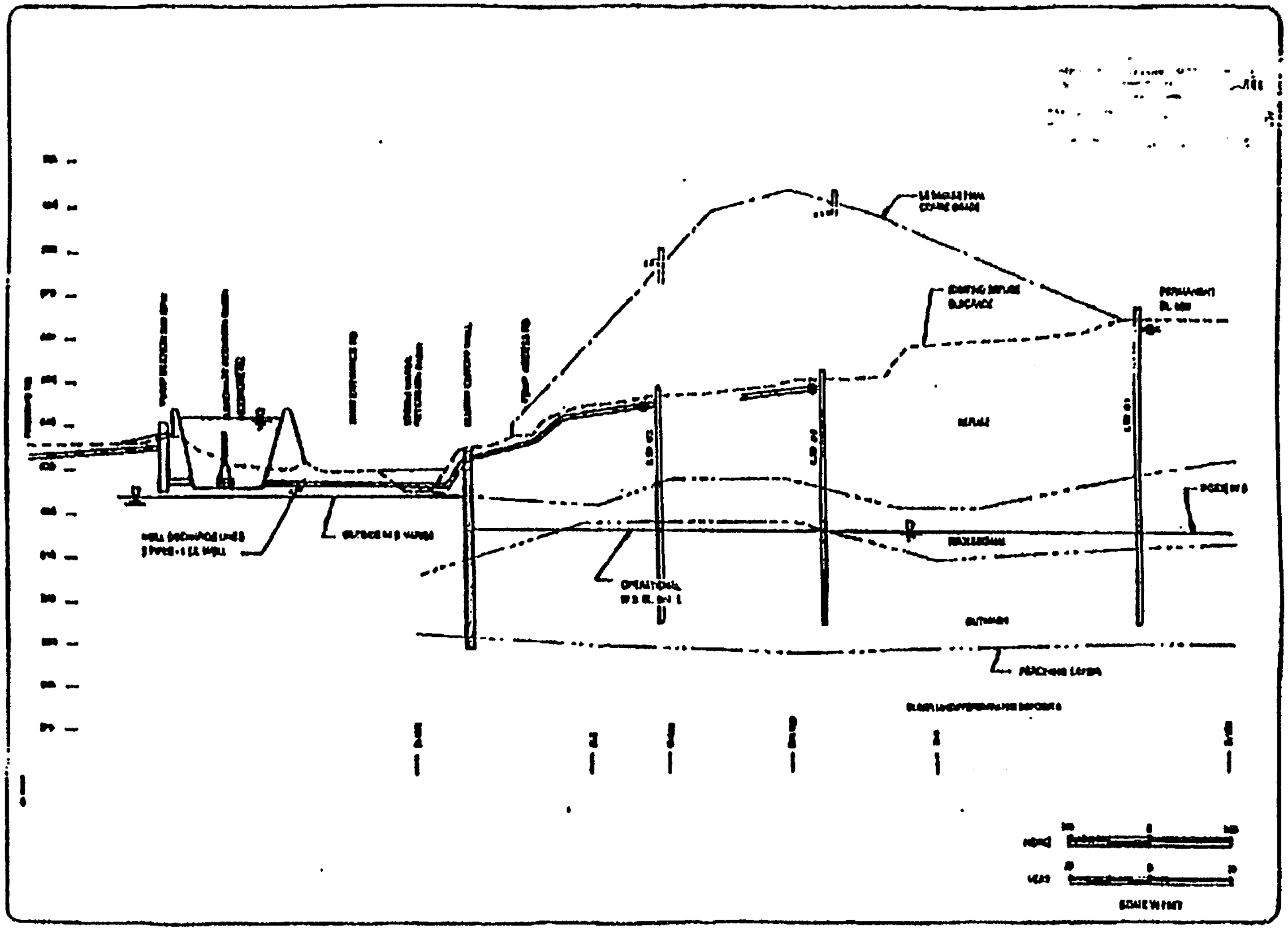
The system of leachate extraction wells was designed for an initial drawdown of 30 million gallons of leachate and then a maintenance rate of 80 gallons per minute (gpm). After full closure of the landfill, the pumping rate was expected to drop to 20 gpm. The extracted leachate was to be pumped through the force main to an existing treatment plant. A typical cross section of the site is shown in Figure 2.

5.2 Construction Quality Assurance and Construction Quality Control

No rating for construction quality assurance (CQA) and construction quality control (CQC) was assigned because no CQA or CQC data was available for our review.

Installation of the cutoff wall was performed by a slurry wall specialty contractor. Excavation was more difficult than expected. The contractor claimed that a very hard, cemented layer not shown in the soil boring logs was present. The engineer and owner maintained that the logs indicated the presence of a very dense layer with a blow count in excess of 100 per 6 inches. In any case, all parties agreed that the work was more difficult than anticipated, and an agreement was reached to extend the work schedule and increase the contract value. To increase the rate of excavation, the contractor predrilled 28-inch-diameter holes at 10 foot centers.

The cap was constructed in two phases. The northern part of the landfill, approximately 15 acres was covered in 1989, and the remaining 20 acres in 1994.



Site 32

FIGURE 2

TYPICAL SITE CROSS SECTION

Tetra Tech EM Inc.

The three leachate extraction wells were tested to evaluate their capacity and the drawdown before extraction operations began.

5.3 Monitoring

Monitoring was given an above average rating. Piezometers and monitoring wells were installed inside and outside the containment area. Ten wells outside the barrier wall, seven in the shallow aquifer, and three in the deep one are presently, (almost 7 years of operation), monitored quarterly. They were monitored daily upon the start of operation. Samples are analyzed for about 150 chemical parameters. In addition, the elevation of the groundwater is monitored inside and outside the wall (see Figure 3).

5.4 Operation and Maintenance

A particularity of this site is the installation of an automatic control system for the operation of the extraction wells. The system is controlled by one of the piezometers which is instrumented. A remote monitoring system has also been installed for the landfill gas control system. These systems are connected to the owner operation centers via modem, eliminating the need for a site attendant. Hence, past closure care and reporting are automated, ensuring continuous monitoring of the groundwater levels, leachate extraction flow rates, and flare temperature.

5.5 Other Considerations

No cost information was available about either barrier installation or O&M. The closure cost was estimated at $110,000 per acre.

5.6 Remedy Performance

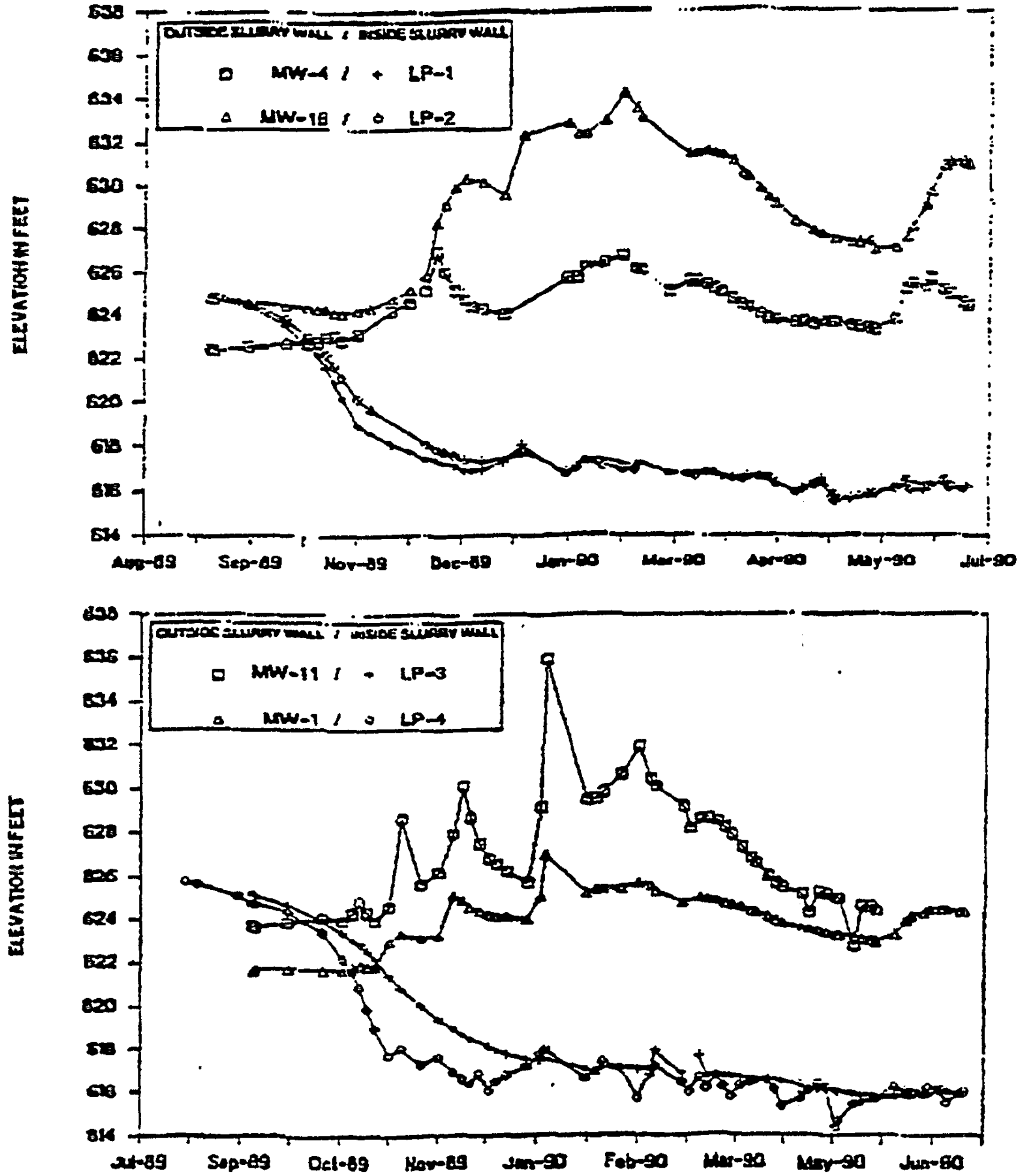
Initial drawdown occurred faster than expected. After 3 months of system operation, the water table inside the containment had been lowered 8 feet. During the same period, the water table outside the containment rose to 5 feet as a result of rainfall. Only 9.5 million gallons of leachate was pumped to achieve the 8-foot lowering of the water table inside the containment instead of the expected 30 million gallons. This indicates that the soil was much less porous than anticipated.

After the initial drawdown, leachate extraction took place only as required to maintain the level of the water table inside the containment 3 feet below the refuse.

In a recent publication, after analysis of the available data, representatives of the operators concluded that the inward hydraulic gradient has been maintained as per design objective and that the groundwater monitoring shows "ten statistically significant reductions in the selected leachate indicator parameters, two increases (neither statistically significant) and are unchanged condition", thereby demonstrating that "the shallow aquifer remediations have reduced off-site migration".

6.0 SUMMARY

Site 32 is a former sand and gravel quarry that was subsequently used as a landfill. Organic compounds were detected in the shallow aquifer downgradient of the landfill. The deep aquifer was not contaminated. A remediation plan was implemented to contain contaminated leachate and maintain the level of the water table within the containment below the waste. The remedy consisted of a soil-bentonite cutoff wall around the landfill, a cap, and a leachate extraction system. The leachate is pumped to a municipal treatment plant 8 miles away. Water quality in the shallow aquifer has improved and is presently good. Future increase of contamination is not expected with continued operation and maintenance of the remedial system.



Site 32
FIGURE 3 **GROUNDWATER DRAWDOWN ELEVATIONS**
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SITE 33

Barrier Type	FG
Remedial Objective	SC; insitu treatment
Performance	2

1.0 SITE DESCRIPTION AND HISTORY

Site 33 is located in the western United States. A single-story structure occupies 20,000 square feet of the 1.5-acre site. The site is bounded by industrial and commercial properties and a city street. Semiconductors were manufactured on site from the late 1970s to 1983. Volatile organic compound (VOC) contamination of site soil and groundwater occurred as a result of manufacturing operations. A groundwater extraction and treatment system approved as a final remedy for the site by the state has been in operation since 1987. The in situ treatment system was installed in late 1994 and early 1995 (see Figure 1).

2.0 GEOLOGIC AND HYDROGEOLOGIC SETTING

The site investigation identified two water-yielding zones. Zone A consists of fine- to medium-grained sands and silty sands lying 10 to 15 feet below ground surface (bgs). Groundwater in this shallow aquifer flows northwest. A low-permeability layer of silt and clay that is about 65 feet thick separates Zone A from the deep aquifer, Zone B.

3.0 NATURE AND EXTENT OF CONTAMINATION

VOCs were detected in Zone A groundwater beneath the site. These VOCs include trichloroethene; *cis*-1,2-dichloroethene; and Freon 113. No VOCs were detected in Zone B groundwater.

4.0 CONTAINMENT REMEDY

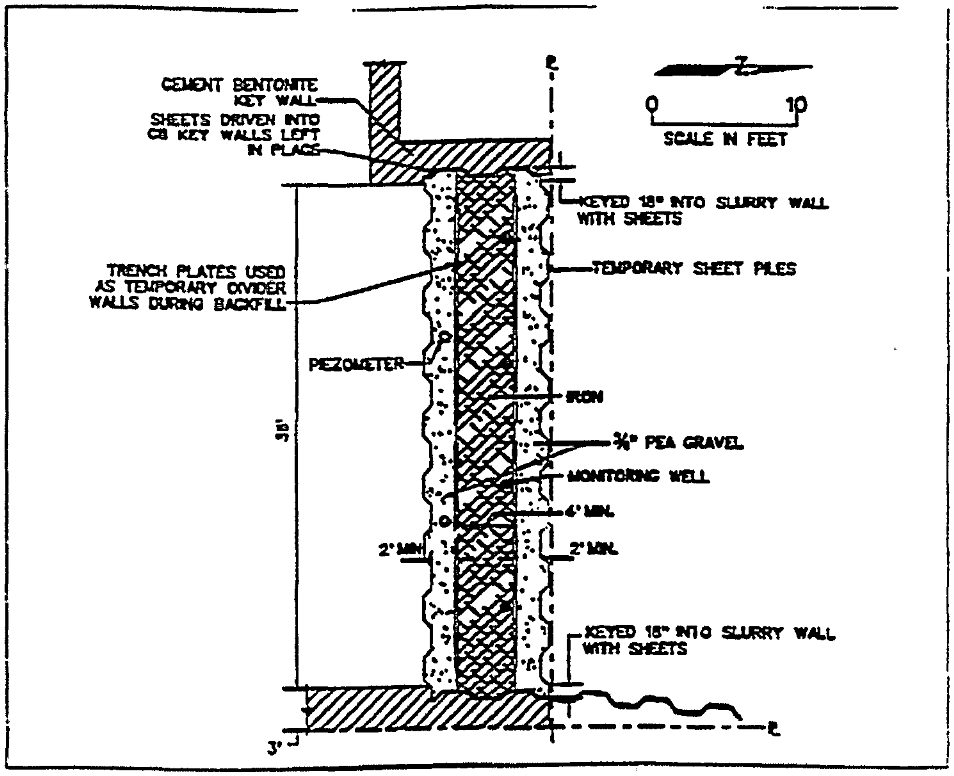
The objective of the barrier wall was to provide a cheaper treatment alternative than the existing groundwater extraction and treatment system at the site. An in situ treatment process based on metal-enhanced dehalogenation of VOCs was selected for further study and implementation. The remedy had the following features:

- Construction of a cement-bentonite wall on one side and a soil-bentonite wall on the other side of the site. The purpose of these barrier walls was to channel (or "funnel") contaminated groundwater toward a permeable reactive barrier.
- Construction of a 38-foot-long, 22-foot-deep, permeable reactive barrier, also known as a treatment wall (or "gate").
- Installation of monitoring wells inside and outside the treatment wall.

5.0 PERFORMANCE EVALUATION

The in situ treatment system was installed in late 1994 and early 1995. The treatment wall has been in operation since January 1995. Subsequent monitoring indicated that the chemical concentrations in the influent to the treatment wall were higher than those anticipated in the design effort. However, the contaminant concentrations in the effluent downgradient of the treatment wall were below regulatory levels.

Key: FG=Funnel Gate SC=Source Control Performance Rating: 2=Evidence suggests objective may be met



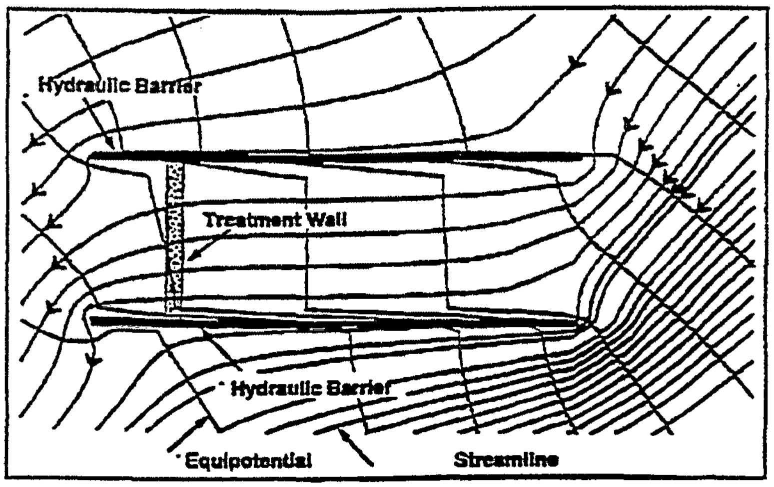


Figure - Groundwater flow modeling of treatment wall and slurry wall system.

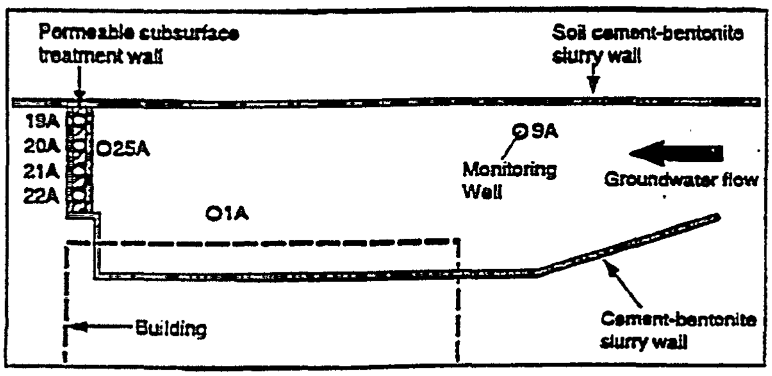


Figure - Plan view, treatment wall and slurry wall system.

Site 33

FIGURE 1
PLAN VIEWS AND GROUNDWATER FLOW MODELING OF TREATMENT WALL

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5.1 Design

The design of the containment system rated better than acceptable relative to industry practices discussed in Section 3, Volume I. The design effort included evaluation of the in situ treatment process. Laboratory tests indicated that the VOCs in the site groundwater were degrading in the presence of granular iron. In addition, a 9-nine month, pilot-scale test was conducted on site during which site groundwater was pumped through a 7-foot-high canister filled with granular iron. These tests demonstrated that complete degradation of the influent VOCs occurred when the groundwater flowed through the iron pellets.

The design effort also included a geotechnical investigation and design of the funnel and treatment wall system. The geotechnical investigation was substantial: 49 cone penetration tests were performed to develop a geotechnical model. This model was used to determine the alignment of the slurry wall and its depth. In addition, the design laboratory evaluated and optimized cement-bentonite slurry mixes. Long-term compatibility tests were performed on selected cement-bentonite slurry mixes.

A numerical groundwater flow model was developed to determine the maximum flow velocity through the in situ treatment wall. The model was calibrated using historical hydraulic data. Hydraulic and bench-scale tests provided the data required to determine the dimensions of the treatment wall. Trenchability was thoroughly evaluated to select the type of barriers to be installed as well as the location of the braced excavation for the treatment wall.

5.2 Construction Quality Assurance and Construction Quality Control

The construction quality assurance (CQA) and construction quality control (CQC) program was rated better than acceptable. The barrier installation work was done by a specialty slurry wall contractor. A CQA/CQC program was established by the contractor before the start of the project. The program included the following activities:

- Continuous visual inspection of the cuttings to ensure at least 2 feet of penetration into the aquitard
- Depth sounding at 25-foot intervals
- Certification of materials
- Daily testing of the bentonite and cement-bentonite slurries
- Daily testing of the soil-cement backfill before backfilling
- Unconfined, compressive testing and triaxial permeability testing of the soil-cement backfill and hardened cement-bentonite. The specified unconfined, compressive strength was 17.5 pounds per square inch at 28 days, and the required permeability was less than or equal to 5×10^{-6} cm/sec.

The treatment wall was installed inside a temporary, sheet-pile cofferdam with temporary bracing. A temporary form system was installed inside the cofferdam to ensure that the iron pellets and pea-gravel filter would not mix together during backfilling operations. Some permanent sheet piles were left in place to connect the slurry walls with the treatment wall, thereby ensuring that no contaminated groundwater would flow on the edges of the wall.

5.3 Monitoring

The monitoring system at the site was rated acceptable and included the following elements:

- Four monitoring wells in the iron filter at the downgradient edge of the treatment wall
- Two piezometers in the upgradient pea-gravel filter
- One monitoring well upgradient of the treatment wall to measure chemical concentrations. Groundwater samples collected from this well contained some chemicals at concentrations higher than expected

5.4 Operation and Maintenance

No operation and maintenance data was available.

5.5 Other Considerations

No cost data was available.

5.6 Remedy Performance

Groundwater samples collected downgradient of the treatment wall show that contaminant concentrations have been reduced to below regulatory levels. The treatment performance is notable because influent contaminant concentrations have been higher than planned for in the design.

6.0 SUMMARY

Site 33 is believed to be the first commercial application of a subsurface reactive barrier for treating groundwater contaminated with VOCs. Based on the monitoring performed for 1.5 years after the installation of the system, the in situ treatment wall has met the remedial objectives.

SITE 34

Barrier Type	SB
Remedial Objective	Hydraulic Barrier
Performance	1

1.0 SITE DESCRIPTION AND HISTORY

Site 34 involved the construction of reservoir facilities at a site in the mid-atlantic United States. In 1987 and 1988, an earthen dam and a dike were constructed using a soil-bentonite slurry wall extending through the dam and dike embankments and through the site overburden. This wall was intended to serve as the barrier to seepage through the previous embankment and overburden. The reservoir covers about 760 acres, and its storage capacity is close to 4.2 billion gallons.

2.0 GEOLOGIC AND HYDROGEOLOGIC SETTINGS

As shown in Figure 1, the dams and dike are underlain by Coastal Plain sediments consisting of the following formations in descending order:

- The upper Kirkwood Formation is predominantly a sandy formation lying above the lower Kirkwood Formation, which consists of interlayer silt, clay, and sand.
- The Manasquan Formation, which lies below the Kirkwood Formation, is the major clay layer below the reservoir. It contains highly plastic, glauconitic clay at its top and becomes sandy toward its bottom.
- The Vincentown Formation is mostly sandy.

Acidic soils exist within all of these formations. The level of the groundwater table within the Kirkwood Formation varies greatly depending surface topography. The hydraulic conductivity of the Kirkwood Formation varies from 1 x 10^{6} to 5 x 10^{-7} cm/sec. The Vincentown Formation is the main regional aquifer present below the reservoir. Some artesian conditions exist in the vicinity of the dam.

3.0 NATURE AND EXTENT OF CONTAMINATION

No known contamination exists at the site.

4.0 CONTAINMENT REMEDY

The containment design was unique as it incorporated a soil-bentonite cutoff wall for the initial construction of the impervious dam core. Several other alternatives for the impervious core were studied, including a cement-bentonite cutoff wall and a clay core. The soil-bentonite cutoff wall was more economical than the cement-bentonite cutoff wall and the clay core. No economical source of clay for the clay core was available locally. The embankment fill material for the dam and dike consisted mostly of fine sand from the Upper Kirkwood formation obtained from on-site borrow areas. This material was mostly sandy (classified as SW, SP-SM, and SM). The soil-bentonite wall is subject to a very high gradient, particularly at the lower elevation of the valley across which the dam was installed. This gradient warranted an increase in the thickness of the soil-bentonite wall in this deep zone. The soil-bentonite

Key: SB=Soil Bentonite Wall Performance Rating: 1=Remedial objective was met

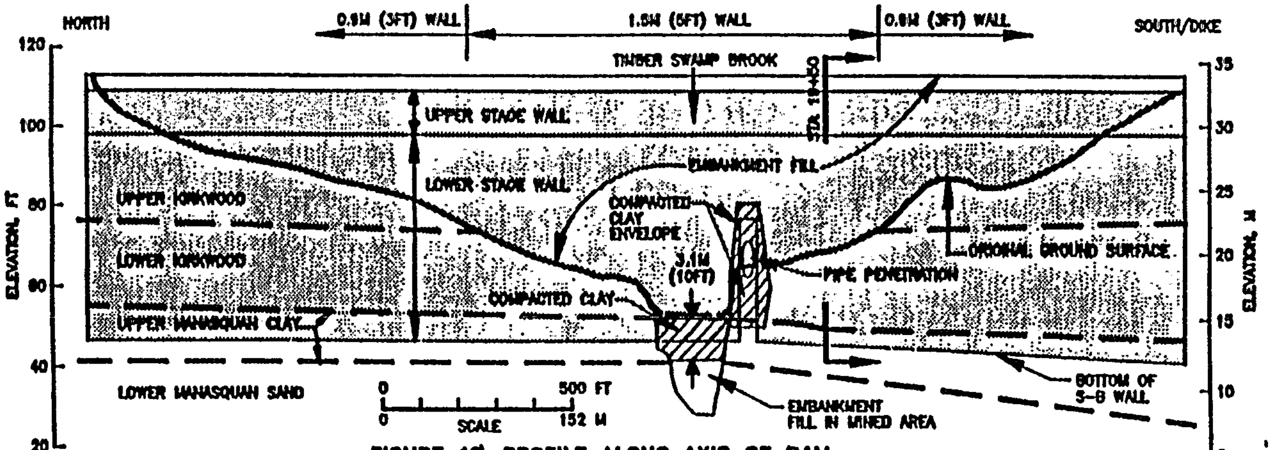

FIGURE 1a-PROFILE ALONG AXIS OF DAM

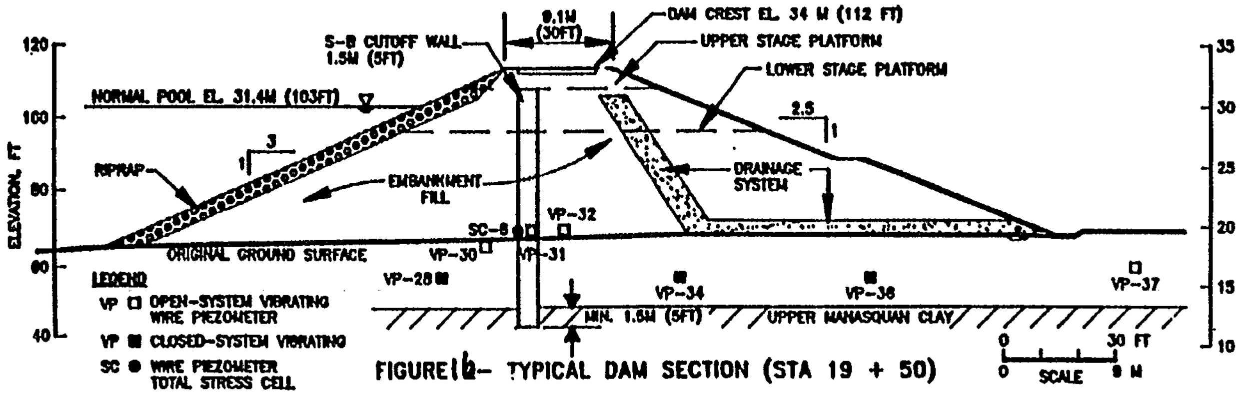

FIGURE 1b- TYPICAL DAM SECTION (STA 19 + 50)

Site 34

FIGURE 1
DAM CROSS SECTIONS

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wall also extended below the dam through the previous overburden. The soil-bentonite cutoff wall is about 4,000 feet long; is 3 to 4 feet thick; has a maximum depth of 76 feet with a key depth of 5 feet; and has an area of 333,000 square feet.

5.0 PERFORMANCE

Barrier performance and contributing factors are discussed further in the following subsections.

5.1 Design

The design was rated better than acceptable relative to industry practices described in Section 3, Volume I. A site soil investigation and the design of the soil-bentonite cutoff wall were performed by a geotechnical engineer. A thorough investigation of the site, including the subsurface conditions along the barrier alignment, was performed. The design effort included hydraulic simulations as well as stability settlement analyses of the dam and overburden. The design was based on a long-term permeability of less than or equal to 1×10^{-6} cm/sec for the cutoff wall. The design key in the Manasquan Formation clay was 5 feet.

An extensive laboratory study of the soil-bentonite backfill was performed that included the following activities:

- Testing of various soil-bentonite backfill mixes and site materials representing all expected soil conditions through which the excavation would take place.
- Compatibility testing of backfill mixes and the site groundwater, which was acidic
- A study of the compressibility of the backfill
- Evaluation of the potential for hydraulic fracturing of the cutoff wall in view of the high gradient

5.2 Construction Quality Assurance and Construction Quality Control

Construction quality assurance (CQA) and construction quality control (CQC) was rated better than acceptable. The installation of the soil-bentonite cutoff wall was performed by a specialized slurry wall contractor. Because the soil-bentonite wall was a critical element for the long-term stability of the dam, its installation was subjected to stringent procedures. The installation of the key material into the aquitard was continuously inspected by the slurry wall contractor and a representative of the owner.

Samples of the bottom of the trench and of the interface of the slurry and backfill were collected every day before the trench was backfilled. This sampling was performed to ensure that no sand deposit was present in the key. (Most of the trench excavation took place in sand materials.)

Slurry properties were monitored two or three times per 8-hour shift, both in the storage ponds for new slurry and in the trench. In addition, the trench slurry was desanded continuously.

The backfill mixed along the trench with a bulldozer was subjected to daily gradation density and slump testing. Fixed wall permeability tests were conducted by the contractor every day. Flexible-wall triaxial testing was performed by an independent laboratory twice each week. The slope of the backfill in the trench was also measured on a daily basis.

5.3 Monitoring

An extensive monitoring system was implemented at the site resulting in a better than acceptable rating. The system included the following elements:

- Settlement plates in the soil-bentonite backfill
- Piezometers upstream of, downstream of, and inside the soil-bentonite barrier (vibrating wire)
- Inclinometers
- Stress cells, including cells inside the soil-bentonite barrier
- Flow measuring devices to measure seepage through the dam

In addition, an automated data acquisition system was installed to provide fast and efficient collection and interpretation of the monitoring data.

5.4 Operation and Maintenance

Because the monitoring system is automated and measurements are taken continuously, operation and maintenance is largely restricted to drain clean out and embankment slope repair following particularly heavy rains.

5.5 Other Considerations

The construction of the cutoff wall (exclusive of design costs) was approximately $6 per square foot.

5.6 Remedy Performance

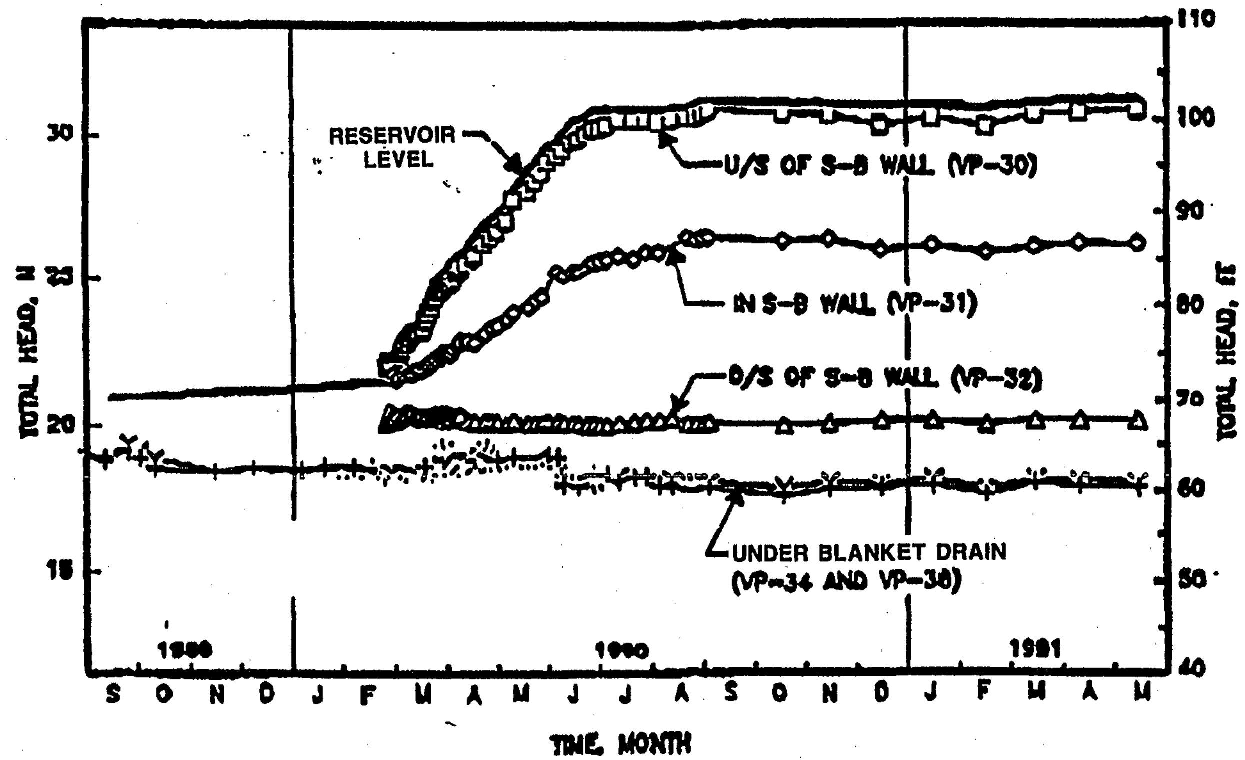
All monitoring instruments were monitored manually before and during the initial filling of the reservoir in 1990 and automatically thereafter. The results of the monitoring system indicate that:

- No appreciable settlement of the top of the backfill has been noted.
- The total flow rate of seepage measured at the flow weirs at the base of the dam has remained below 12 gallons per minute. This flow rate did not increase as the reservoir was filled.
- The piezometers have registered a head drop across of nearly 30 feet across the wall.

Typical piezometer and horizontal stress readings are shown in Figures 2 and 3, respectively.

6.0 SUMMARY

Site 34 is an earthen dam and dike located in the mid-atlantic United States. The design for the dam and dike incorporated a soil-bentonite cutoff wall for the impervious dam core. The success of the project was ensured by a thorough design and an intensive CQA/CQC program during cutoff wall construction. Postconstruction monitoring, which has been performed for more than 7 years, indicates that the cutoff wall has been very effective in minimizing seepage through the sandy embankment and its foundation.



Site 34

FIGURE 2
PIEZOMETRIC HEADS AT STA. 19+50

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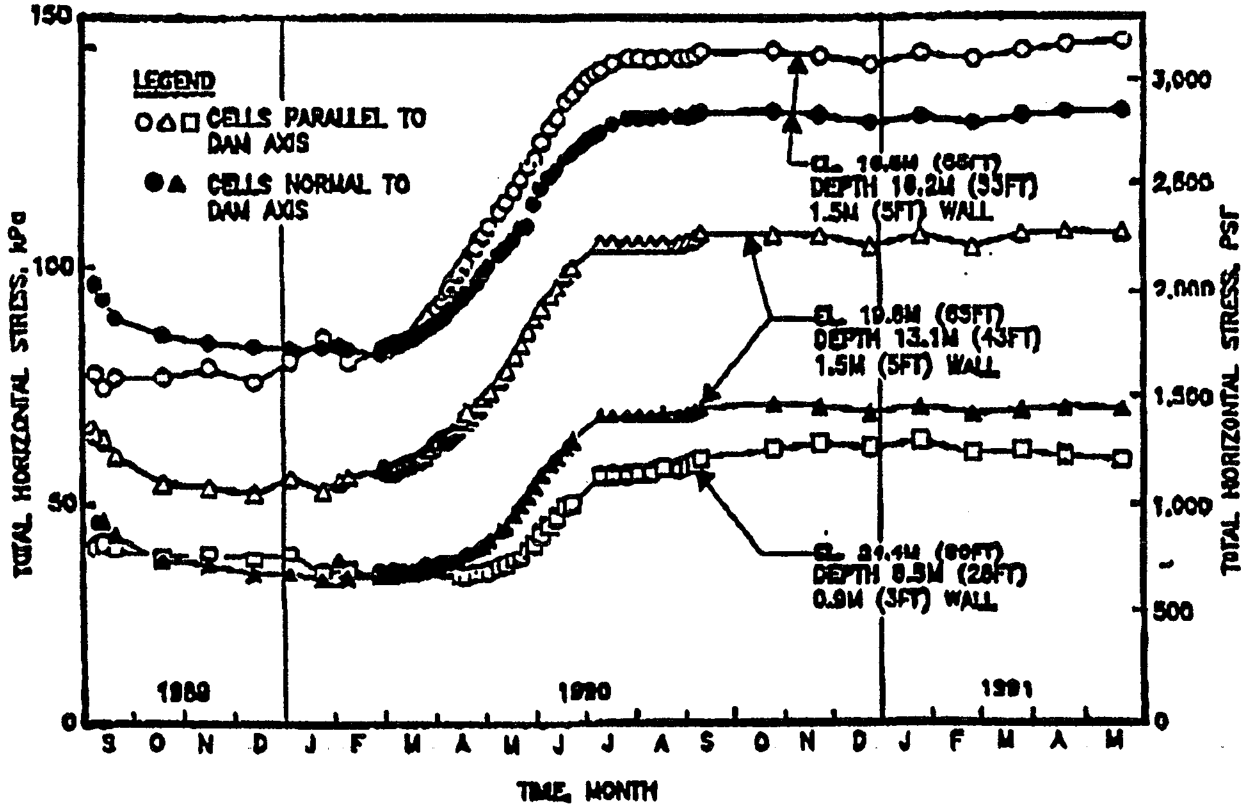

Site 34

FIGURE 3

TOTAL HORIZONTAL STRESSES IN S--B WALL

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Barrier Type	PC
Remedial Objective	Seepage control
Performance	1

SITE 35

1.0 SITE DESCRIPTION AND HISTORY

Site 35 is located in the south central United States adjacent to a river and a flood control dam built by the U.S. Army Corps of Engineers in 1962. The barrier well was constructed in 1994 as a prerequisite for a deep excavation for the construction of a hydroelectric power plant.

2.0 GEOLOGIC AND HYDROGEOLOGIC SETTING

The site is located within the flood plain of the river and is underlain by recent alluvial sediments made up of clays, silts, and predominantly fine-grained sands. The alluvial sediments are underlain by a gravel layer lying above the Tertiary-age Jackson Formation. The Jackson Formation is made up of indurated, highly plastic clay of low permeability. The soil strata are summarized below (in descending order):

- Sandy clay fill (about 9 feet thick)
- Silty sand (48 to 65 feet thick)
- Clay (3 to 10 feet thick)
- Fine sand (32 feet thick)
- Gravel (2 feet thick)
- Tertiary-age dense clay

The water table is approximately 20 feet below ground surface (bgs).

3.0 NATURE AND EXTENT OF CONTAMINATION

No contamination exists on site.

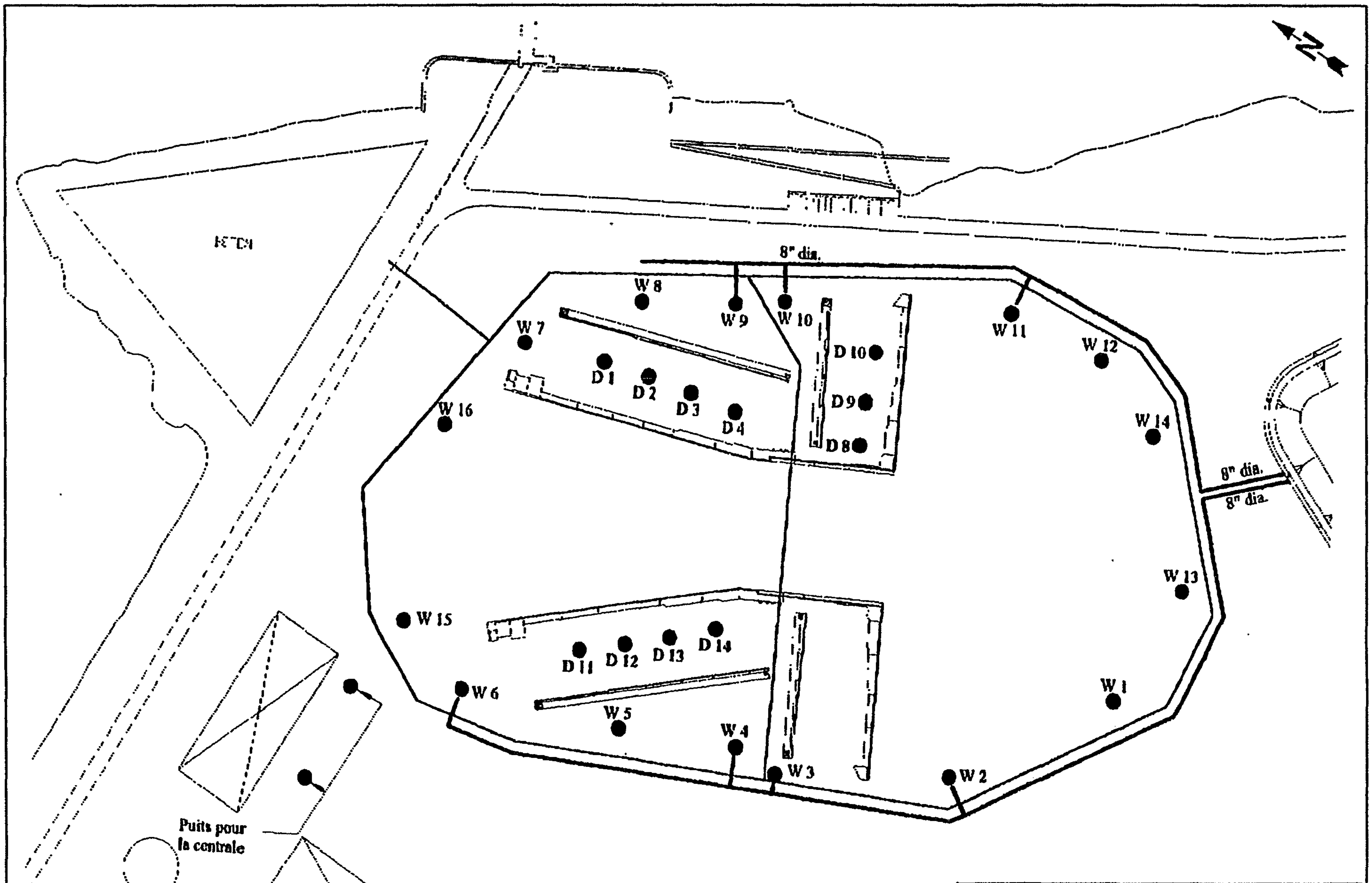
4.0 CONTAINMENT REMEDY

A dry excavation, about 100 feet in depth, was required within a few hundred feet of a large river for the construction of the hydroelectric power plant. The project included installation of a deep cutoff wall on the perimeter of the excavation and a deep dewatering system inside the excavation.

The cutoff wall is made of plastic concrete and is 3,810 feet long; is 2 feet, 8 inches thick; averages 138 feet in depth; and has an area of 564,000 square feet. A 140-foot deep reinforced-concrete slurry wall was installed within the cutoff wall to support the 90-foot-deep mass excavation, thereby drastically decreasing the volume of the excavation. Tiebacks provided lateral support of the concrete slurry wall. Some soil-bentonite sections were also installed on the back of the cutoff wall as protection against wall penetration at locations where the tiebacks would be drilled through the plastic concrete.

The dewatering system, which is shown in Figure 1, included 16 wells installed to a depth of 130 feet and sand drains installed to a depth of 110 feet bgs. The purpose of the drains was to allow drainage of the upper water table through the intermediate clay layer and to allow dewatering from the lower pumped interval.

Key: PC=Plastic Concrete Wall Performance Rating: 1-Remedial objective was met



Site 35

FIGURE 1
LOCATION FOR DEWATERING WELLS AND SAND DRAINS

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5.0 PERFORMANCE EVALUATION

The dewatering flow rate indicates excellent performance by the cutoff wall. The pumping system inside the excavation uses conventional deep wells.

5.1 Design

The design was rated better than acceptable based on industry standards discussed in Section 3, Volume I. A specialized geotechnical engineering firm assisted the structural engineer in the design of the dewatering and excavation support systems. The site was thoroughly investigated to ensure the continuity of the aquitard and determine the geotechnical characteristics of the soil formations. Modeling was performed to determine the dimensions of the pumping system as well as to predict the deformation of the reinforced-concrete slurry wall during mass excavation. The characteristics of the plastic concrete were specified, including slump, the nature of the aggregate and cement, strength after 7 days of pressure equal to or greater than 200 pounds per square inch (psi), and a permeability less than or equal to 1×10^{-7} centimeters per second (cm/sec).

5.2 Construction Quality Assurance and Construction Quality Control

The construction quality assurance (CQA) and construction quality control (CQC) for the cutoff wall were rated better than acceptable. Prior to the start of the project, the plastic concrete mix was designed and tested with the materials and mixing plant to be used for the slurry wall construction. The plastic concrete cutoff wall was installed using the panel method; that is, the wall consists of 136 panels whose lengths vary from 9 to 35 feet. The cutoff wall was installed by a specialized slurry wall contractor. An extensive CQA/CQC program was developed to ensure the following:

- The quality of the bentonite slurry during excavation and before plastic concrete mixing
- A slurry storage capacity sufficient to handle large slurry losses
- The verticality of panel installation in the aquitard (the contractor had to maintain panel verticality within 0.15 percent)
- Cleaning of the joints between the panels
- Cleaning and probing of the bottom of each panel before plastic concrete pouring
- The quality of the plastic concrete and of the tremie placement

In addition, a test plastic concrete panel was installed using the same equipment, materials, and methodology as were to be used for the remaining panels. This test was performed to demonstrate that the contractor could maintain the verticality tolerance and construct the wall in accordance with the specifications.

5.3 Monitoring

Monitoring for Site 35 was rated better than acceptable. A monitoring plan was implemented to monitor the following items:

- Head across the plastic concrete cutoff wall
- Dewatering rates
- Deformation of the reinforced-concrete slurry wall during and after mass excavation
- Tieback loads

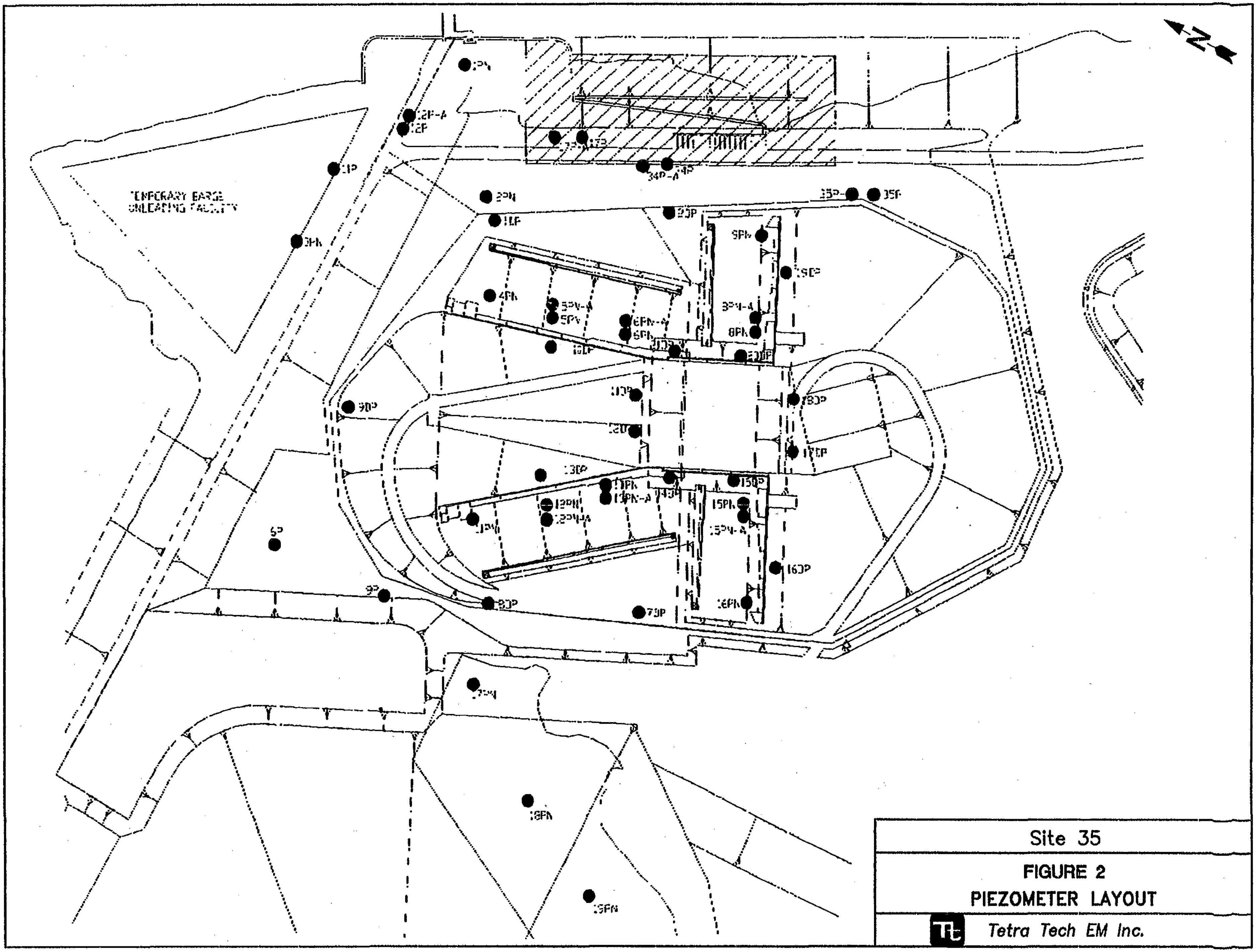
Flow through the cutoff wall and underlying aquitard and the performance of the overall system after rainfall are closely monitored with a network of piezometers installed inside and outside the wall (see Figure 2). Groundwater contours inside the perimeter of the cutoff wall are shown in Figure 3.

5.4 Remedy Performance

The cutoff wall was completed in mid-1994. Dewatering has been performed for more than 1.5 years. The water table inside the cutoff wall has been lowered 95 feet. The average pumping rate has stabilized at about 100 gallons per minute, reflecting the excellent performance of the cutoff wall.

6.0 SUMMARY

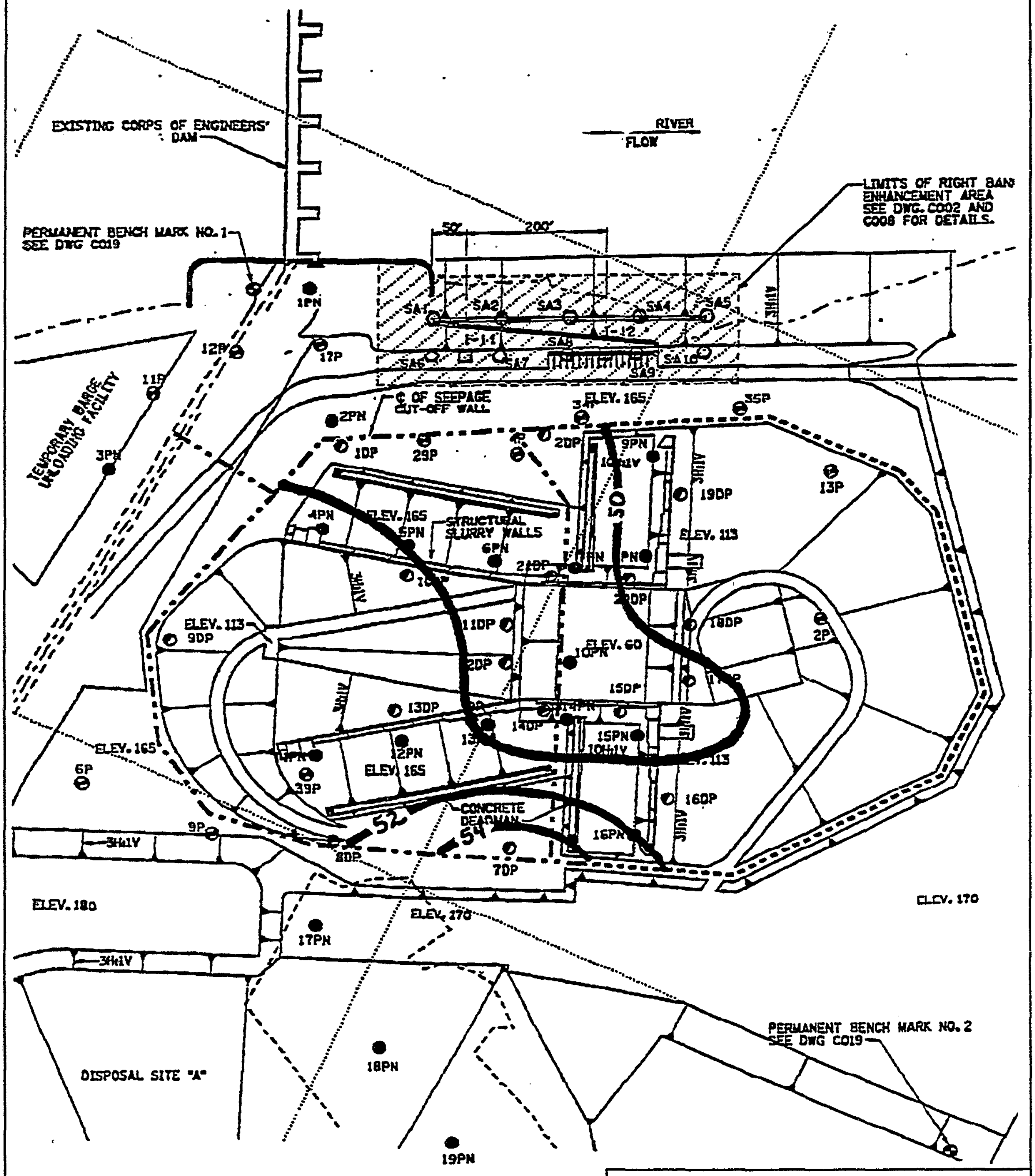
Site 35 contains no contamination. A 150-foot-deep, plastic concrete cutoff wall was required at the site to allow a 90-foot excavation in the immediate vicinity of a large river. The design, CQA/CQC, and monitoring of the cutoff wall were rated better than acceptable. The pumping system inside the excavation employs conventional deep wells. The plastic concrete cutoff wall is subject to a 95-foot head. The mass excavation was completed by January 1996. The dewatering flow rate meets the designed rate, and indicates excellent performance by the cutoff wall.



Site 35

FIGURE 2
PIEZOMETER LAYOUT

Tetra Tech EM Inc.



NOTE: DUE TO THE SMALL AMOUNT OF PIEZOMETER DATA AVAILABLE, THE CENTER SEEPAGE CUT-OFF WALL WAS NOT TAKEN INTO ACCOUNT WHEN DEVELOPING GROUNDWATER CONTOURS.

Site 35

FIGURE 3
GROUNDWATER CONTOURS INSIDE THE PERIMETER SEEPAGE CUT-OFF WALL (4/5/96)

Tetra Tech EM Inc.

Barrier Type	CC
Remedial Objective	Minimize Infiltration of Precipitation
Performance	X

SITE 36

1.0 SITE DESCRIPTION AND HISTORY

Site 36, which is located in the northeastern United States, was evaluated as a"cap only" site. The site is made up of a landfill and landfill expansion areas. The original landfill began operation in 1958 and was initially used for processing and disposal of municipal waste. Industrial wastes were also disposed of in the landfill during the late 1960s and early 1970s. The landfill ceased operation in April 1986. The original landfill has an area of about 65 acres and is unlined. The landfill has an elevation of 240 feet above mean sea level, (msl) and the bottom of the landfill is estimated to be 80 feet above msl. Landfill expansion began in 1977. The landfill expansion areas were lined and provided with leachate collection systems.

In 1977, new state regulations were passed that required the site to implement a program to determine the quality of groundwater below the landfill; this program was later expanded to assess the effect of the landfill on the surrounding area. After contamination was found in the groundwater below the landfill, Site 36 underwent partial capping and installation of a leachate and gas control system was completed. The site was placed on the National Priority List (NPL) in September 1983, and the remedy was implemented in 1992 and 1993.

2.0 GEOLOGIC AND HYDROGEOLOGIC SETTING

The site is located in an area underlain by four hydrogeologic units: the Glacial Formation, Magothy Aquifer, Raritan Clay, and Lloyd Aquifer. These units rest on a bedrock surface that lies about 1,100 feet (ft) below msl at the site and dips to the southeast toward the Atlantic Ocean.

The Glacial Formation occurs from directly below the landfill to about 20 ft below msl at the site. The Glacial Formation is made up of irregular deposits of gravel, sand, sandy clay, and clay. Because they vary in permeability, thickness, and extent, these deposits have great influence on recharge and movement of groundwater. Deposits of clay impede infiltration and percolation of water, thus creating perched water conditions locally, whereas permeable beds of sand and gravel offer little resistance to water.

The upper formation of the Magothy Aquifer ranges from about 200 to more than 120 ft below msl. This formation consists chiefly of interbedded, gray, buff, and white fine-grained sand and clayey sand, and of black, gray, white, buff, and red clay. Gravely zones are common near the bottom of the formation but are rare in the upper part.

The water table occurs in the Glacial Formation at approximately 40 to 70 ft above msl. This water-bearing stratum is commonly referred to as the Upper Glacial Aquifer. Groundwater under the landfill flows to the south-southeast. Water level data collected from walls upgradient of the landfill does not indicate components of groundwater flow north and west of the site.

Key: CC=Composite Cap   Performance Rating: X=Insufficient data to determine if remedial objectives were met

3.0 NATURE AND EXTENT OF CONTAMINATION

Contamination was identified below the original landfill, and an off-site landfill leachate plume extending about 4,000 feet and having a maximum width of 3,000 feet was also identified. The approximate vertical extent of the landfill leachate plume is about 160 feet below msl. The primary contaminants of concern in groundwater on and off site are 1,2-dichloroethene; 1,1-dichloroethane; vinyl chloride; methylene chloride; trichloroethene; and chloroethene.

4.0 CONTAINMENT REMEDY

In 1979, several investigations revealed problems involving volatile organic compounds (VOCs) in groundwater and landfill leachate. The site was placed on the NPL on September 8, 1983. Remedial activities were already underway at the site, including capping of a 29-acre portion of the landfill. A record of decision (ROD) for the site was signed on March 18, 1988. The ROD called for the following measures to be taken at the site:

- Installation of eight diffusion (reinjection) wells for treated groundwater
- Completion of a 35-acre cap consisting of an 18-inch layer of compacted clay and 18 inches of soil cover
- Improvement of the landfill gas collection and leachate control systems
- Installation of five groundwater recovery wells with a design flow of 1.5 million gallons per day and screened to intersect both the shallow and deep
- Installation of an air stripper to treat VOCs in the groundwater.

A landfill gas collection system was installed at the site in 1992, and a leachate control system was installed and has operated since 1993 on 12 acres of the site. The groundwater remediation program involves use of five groundwater recovery wells installed at the leading edge of the VOC plume. The combined flow from all the wells is directed through common transmission piping to an air stripper. Treated groundwater is discharged to eight diffusion wells located in a recharge basin that lies hydraulically upgradient of the landfill at the western perimeter of the site.

5.0 PERFORMANCE EVALUATION

Hydraulic monitoring is conducted quarterly to verify hydraulic containment of the plume by the recovery well system. Water level measurements are required until equilibrium and appropriate drawdown have been established. Groundwater quality monitoring is to be conducted until groundwater quality criteria defined by the consent decree have been met.

Hydraulic monitoring has indicated that the current plume capture zone was developed soon after the startup of the groundwater recovery walls, and that the size and shape of the capture zone have remained relatively stable over 14 operating quarters. Water level data indicates that water levels in the vicinity of the capture zone initially declined about 10 to 12 feet as a result of pumping.

Groundwater quality data indicates no significant change in the VOC plume. However, reductions in total VOC concentrations in some monitoring wells over time indicate that groundwater quality may be improving as a result of the groundwater remediation program.

The on-site treatment plant has displayed an average treatment efficiency of 99.42 percent since its startup. Treated groundwater is discharged to the diffusion wells.
Remedy performance and contributing factors are discussed further in the following subsections.

Localized mounding may be occurring in the vicinity of the recharge basin. This mounding may have a minimal effect on groundwater flow directions.

5.1 Design

The landfill cap design was slightlybetter than acceptablebased on the criteria described in Section 3, Volume I. State regulations require that the capping process include regrading the slopes of the landfill to a slope of 3 horizontal to 1 vertical. The lowest portion of the cap consists of an 18-inch, compacted clay layer. The clay cap was constructed in 6- to 8-inch-thick lifts (after compaction) and had to meet the following specifications:

- Permeability: 1 x 10^{7} cm/sec or less
- Grain size: P200 content of 50 percent by weight or greater
- Liquid limits: 25 percent or greater
- Plasticity index: 10 percent or greater
- Compaction: 90 percent modified proctor density or greater
- Moisture content: varying between optimum and 25 percent of wet optimum

5.2 Construction Quality Assurance and Construction Quality Control

The construction quality assurance (CQA) and construction quality control (CQC) for the cap were rated acceptable relative to industry practices discussed in Section 3, Volume I according to the bid specification for the capping and closure of Site 36. CQA/CQC measures were implemented during construction of the landfill cap.

An independent testing laboratory was used to test the clay seal in place. The parameters tested were permeability, grain size, liquid limits, plasticity index, compaction, and moisture content. In situ compaction was tested using a nuclear densiometer at the intersection points of a 100-foot grid, and the grid was to be offset for each lift of in-place material. One undisturbed sample per acre per lift of clay was collected and analyzed for hydraulic conductivity. One sample for each 500 cubic yards of clay placed was analyzed for grain size distribution, dry density, and moisture content. A qualified soil technician or engineer was present during construction of the cap to provide visual inspection and to direct sampling and testing.

The cover soil (located above the clay seal) was also tested during construction for the following parameters: pH, particle size, liquid limits, plasticity index, moisture content, and unconfined compression strength. The cover soil was placed and compacted to 85 percent of its maximum dry density. Placement was completed in two or more lifts of 6-inch maximum thickness as necessary to achieve the line grade specified.

5.3 Monitoring

A monitoring program was designed and implemented to meet a requirement for ensuring that (1) the off-site leachate plume was being hydraulically controlled and (2) contaminated groundwater was meeting cleanup criteria. Baseline monitoring was conducted from July 30 through August 2, 1991.

The monitoring program is rated acceptable. The cap is inspected quarterly. Quarterly hydraulic monitoring is conducted (1) to verify that equilibrium and appropriate drawdown of the plume is being established to prevent further expansion of the plume and (2) to determine the extent of mounding in the recharge basin area and the effect of that mounding, if any, on local groundwater flow patterns. Review of a third quarter 1995 groundwater sampling report indicates that the current plume capture zone was developed soon after the startup of the groundwater remediation system, and that the size and shape of the capture zone have remained relatively stable over 14 operating quarters. The average flow from the five recovery wells has varied from about 0.90 to 1.44 million gallon per day.

Quarterly monitoring of groundwater quality is being conducted for the leachate plume until the termination criteria are met. Review of quarterly groundwater monitoring results indicates no significant change in the dimensions of the VOC plume. Reductions in total VOC concentrations in some monitoring wells over time indicate that groundwater may be improving as a result of the groundwater remediation program.

Monitoring of the on-site treatment plant influent and effluent is conducted monthly to meet requirements. The treatment plant is also equipped with a gas chromatograph, allowing monitoring of the day-to-day treatment efficiency of the plant. Samples are collected from recovery wells for VOC analysis. The treatment plant is also equipped to monitor water quality parameters for the influent and effluent analysis.

5.4 Operation and Maintenance

A document entitled "Post Closure Operation and Maintenance Manual for the Capping Coverage, Drainage and Roadway Systems" was prepared. This manual presents a protocol for postclosure monitoring and maintenance of the landfill and for corrective measures. The subjects discussed in this manual include the cover system, drainage system, access roads, gabion wall, and materials and equipment required for routine maintenance. No summary reports detailing the results of the operation and maintenance program were available for review.

5.5 Other Considerations

The final costs for the design and construction of the landfill cap are $13,800,000. These costs do not include the costs for the portion of the landfill that was capped in 1983.

5.6 Remedy Performance

The overall performance of the containment remedy appears to be meeting the remedial objectives. The off-site leachate plume appears to have remained relatively stable over 14 operating quarters. Groundwater quality data indicate no significant change in the VOC plume, but reductions in total VOC concentrations have been observed at some monitoring wells. The on-site treatment plant has an average treatment efficiency of 99.42 percent. Localized mounding may be occurring in the vicinity of the upgradient recharge basin.

6.0 SUMMARY

The original landfill at Site 36 began operation in 1958. The landfill initially accepted municipal waste, but industrial wastes were also disposed of in the landfill during the late 1960s and early 1970s. Site 36 was placed on the NPL on September 8, 1983. The landfill ceased operations in April 1986. An investigation of groundwater contamination at and around the landfill begun in 1979 revealed contamination in groundwater below the landfill and in a leachate plume that had migrated about 4,000 feet from the site. The containment remedy consisted of a clay cap, landfill and gas collection and leachate control systems, five groundwater recovery wells, a groundwater treatment plant, and eight diffusion wells for recovered water. The cap design effort was ratedbetter than acceptable, and CQA/CQC of the cap was rated acceptable.