Final
November 29, 1999

COST AND PERFORMANCE REPORT

Groundwater Extraction and
a Permeable Reactive Treatment Cell
at Tacony Warehouse
Philadelphia, Pennsylvania

November 1999

SITE INFORMATION

IDENTIFYING INFORMATION (1)

Site Name: Tacony Warehouse (TW)
Location: Philadelphia, Pennsylvania
Operable Unit: (none)
CERCLIS #: (none)
ROD Date: July 21, 1995
Technology: Permeable Reactive Barriers
Type of Action: Remedial

Figure 1 shows the location of the TW in Pennsylvania, and Figure 2 shows the TW site layout.

TECHNOLOGY APPLICATION

Period of Operation (15):
May 13, 1998 through 2001 (projected)

Quantity of Material Treated During Application (1,2,16,17):
The contaminated aquifer occurs between 8 and 35 feet below ground surface (bgs). The area surrounding monitoring well 9 (MW-9) is contaminated in addition to an area approximately 200 feet downgradient of MW-19. During the first year of treatment operations, a total of approximately 1.8 million gallons of groundwater was extracted from the aquifer beneath the site. Of the 1.8 million gallons of groundwater, 393,165 gallons were treated in situ using iron filings.

In addition to contaminated groundwater, several other areas of concern at the site are being remediated. The six areas of environmental concern at the TW site are (1) asbestos, (2) building surfaces, (3) transformers, (4) underground and aboveground storage tanks, (5) storm drain sediments and groundwater, and (6) surface soils. This report only addresses groundwater remediation at the site.

BACKGROUND

Site Background and History (3):

- The TW site is located on 14.2 acres of land adjacent to the Delaware River in northeast Philadelphia. The majority of the site is covered with pavement or concrete, and when it was in operation, included the following facilities:
  - Warehouses (Buildings 460 and 461);
  - An administration building (Building 462, which accidentally burned down prior to this project);
  - A storage port and vehicle maintenance area (Building 463);
  - A boiler building (Building 464);
  - A steam plant (Building 467);
  - Five underground storage tanks (USTs) and five aboveground storage tanks (ASTs);
  - A spray pond;
  - Two transformer substations; and
  - A pesticides building.

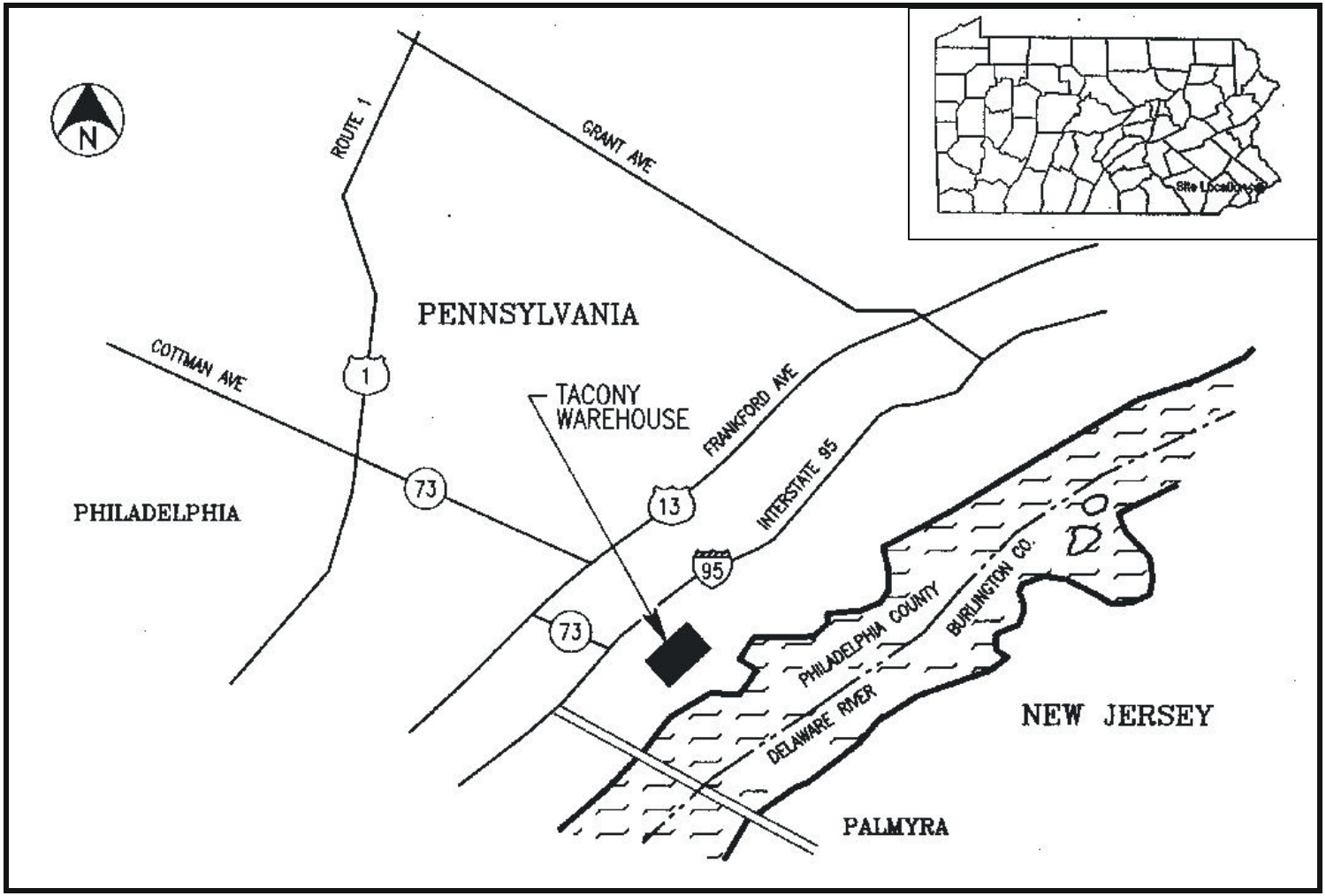

Figure 1. Location of the Tacony Warehouse in Pennsylvania

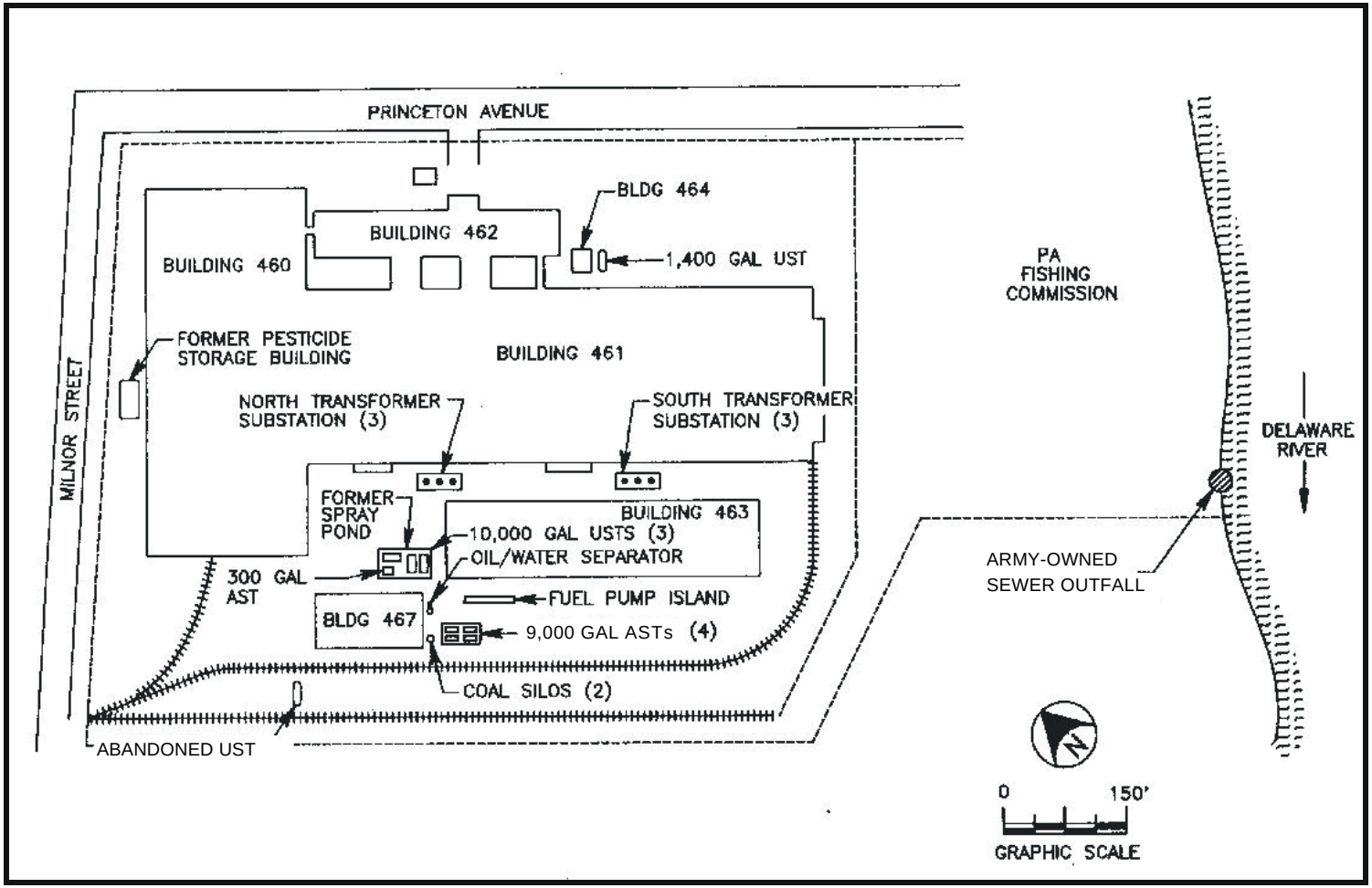

Figure 2. Site Layout for the Tacony Warehouse

- The TW facility was constructed and established as an armor plate assembly facility in 1943. Henry Disston and Sons Co. initially operated the facility, but control was subsequently transferred to the Frankford Arsenal in April 1944. Frankford Arsenal used the property for warehousing operations in the 1950's and 1960's. In 1970, TW was assigned to the Army and Air Force Exchange Service (AAFES). AAFES utilized the facility for warehousing of consumer products including clothing, housewares, and automotive products. In June 1976, responsibility for TW was transferred to Fort Dix. In November 1987, New Cumberland Army Depot entered into an agreement with Fort Dix to warehouse items such as generators, empty drums, office furniture, clothing, and spare parts at TW. The facility was vacated in 1992.

- Due to several periods of inactivity and numerous changes in accountability for the TW, little documentation exists for operations prior to 1970. TW was reportedly a fairly active facility from its founding until approximately 1966. Activity at TW during World War II is believed to have included welding, cutting, and painting. A review of aerial photos showed numerous automobiles and armored military vehicles on the property in the 1950's.

- The TW is included in the Army's Base Realignment and Closure (BRAC) Program, so the site is expected to be closed upon completion of environmental restoration and subsequently offered for government reuse and possible public sale. The most likely future use for the TW site is commercial/industrial, which is similar to current land use in the areas surrounding the site.

SIC Code:

9711A (National Security, Miscellaneous)

Waste Management Practices that Contributed to Contamination (3):

The source of chlorinated solvents in the groundwater at the site is not known. Initially an abandoned UST located west of Building 467 was suspected to be the source. Upon removal, the 500 gallon UST was found to contain oil (without chlorinated solvents), and no evidence of releases was observed.

Site Investigations (1,3,4,16):

- An Enhanced Preliminary Assessment performed by the U.S. Army Environmental Center (AEC) in September 1989 identified a number of physical and operational aspects of the TW site as potential environmental concerns. The assessment was based on a visual site inspection, a review of available records, and interviews with people knowledgeable of the site and its history.

- The AEC conducted an Environmental Investigation at the TW beginning in October 1990. The investigation was designed to identify the types, quantities, and locations of contaminants and to develop ways of addressing the contamination. Samples were collected at the site, including the following media: soil, groundwater, surface water and sediment, building materials, and transformer fluid. Groundwater samples were collected from 14 monitoring wells screened in the upper aquifer between December 1990 and June 1992.

- The U.S. Army Corp of Engineers (USACE) conducted an investigation at the TW site from February 1994 to August 1995. The investigation was designed to determine the relevant hydrogeologic characteristics of the aquifer and provide additional characterization of the nature and extent of groundwater contamination at the site. Five additional monitoring wells were installed, and in May 1994 groundwater samples were collected from the new wells and from 10 of the existing monitoring wells.

- The USACE performed a baseline risk assessment to estimate the health or environmental risks that could result if groundwater contamination at the TW site was not remediated. The risk assessment indicated that if no remedial action was taken, the site might present an unacceptable risk to public health, welfare, or the environment, and limit future site use.

- On May 23, 1997, a sampling event was conducted to locate and delineate the potential contaminant source for the groundwater area of concern around Monitoring Well 9 (MW-9). Soil and groundwater samples were collected from 12 borings located to the north, south and east of MW-9. The data obtained was used to determine the remedial approach for the area of higher concentrations of tetrachloroethene and trichloroethene near MW-9.

Previous Removal Actions (5,15,19):

Early remedial actions conducted at the TW site included removal of ASTs, USTs, associated piping, contaminated soil, a contaminated spray pond, and transformer fluid. The abandoned 500-gallon UST was removed in June 1995, but there were no indications of releases from this tank.

Remedy Selection (1):

Based upon CERCLA requirements and a detailed analysis of the alternatives, the Army determined that pumping groundwater from extraction wells to the local sanitary sewer was the most appropriate remedy for the groundwater contamination at TW. If the selected remedy cannot meet the specified numerical remediation goals at any or all of the monitoring points during implementation, alternate remedies and goals may replace the selected remedy and goals for those portions of the plume.

The main goal of this groundwater remedial action is to protect the environment by significantly reducing the volume of contaminated groundwater, which will prevent contaminant migration and further degradation of the aquifer. It was determined that extracted groundwater would be discharged to the City of Philadelphia's public sanitary wastewater treatment system so that the city system would further reduce contaminant levels to meet the City's effluent discharge limits.

This remedy was selected because it was estimated that it would:

- Achieve the remedial action objectives and is considered protective of human health;
- Comply with chemical-specific ARARs;
- Be effective on a long-term basis;
- Reduce the toxicity of the site by removing the contaminated groundwater; and
- Be less expensive than the other alternatives considered.

SITE LOGISTICS/CONTACTS

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MATRIX AND CONTAMINANT DESCRIPTION

MATRIX IDENTIFICATION

Groundwater (in situ)

SITE GEOLOGY/STRATIGRAPHY (1,3,4,5,6,7)

The site geology is fairly complex in part due to the fluvial processes that deposited and reworked the sediments in the area. The underlying site geology can generally be described as highly interstratified and vertically and horizontally discontinuous.

At the TW, Pliestocene and recent alluvium deposits directly and unconformably overlie the crystalline bedrock. The Pliestocene formations consist mainly of coarse sand and gravel interbedded with clay, silt, and fine sand. The recent floodplain deposits consist of dark gray clay, silt, and sand. Drilling logs for the site revealed an organic layer at approximately 14 feet bgs. The crystalline bedrock consists of fine to coarse-grained banded rock characterized by excess mica. The rocks contain three different lithologies including hornblende gneiss, granite gneiss, and a sequence of alternating micaceous schists and quartzite. The depth to bedrock is approximately 35 feet bgs.

The aquifer is highly stratified with units of varying lithology and, therefore, varying hydraulic conductivity. The aquifer can be described as heterogeneous and anisotropic. Groundwater is encountered between 8 and 16 feet bgs.

Groundwater flow in the eastern portion of the TW site is in an east-southeasterly direction towards a nearby inlet of the Delaware River. Groundwater flow paths in the northwestern portion of the TW site are more complex; some areas are characterized by south-southwesterly flow and some are characterized by northwesterly flow. For the 1993 Environmental Investigation, the direction of groundwater flow in the immediate area of MW-9 was interpreted to be to the west-southwest. November 1996 monitoring data indicated that groundwater flow appeared to be to the northeast from MW-9.

CONTAMINANT CHARACTERIZATION

Primary Contaminant Group: Organic Compounds - Volatiles (Halogenated)

Key Specific Contaminants (1): Tetrachloroethene (PCE)
Trichloroethene (TCE)
cis-1,2- and trans-1,2-Dichloroethene (DCE)
Vinyl Chloride

Table 1 lists selected properties for the key specific contaminants present at the TW.

Table 1. Contaminant Properties (7)

Property	Units	PCE	TCE	1,2-DCE	Vinyl Chloride
Chemical Formula	-	$Cl_2C=CCl_2$	$Cl_2C=CHCl$	$ClHC=CHCl$	$ClHC=CH_2$
Molecular Weight	g/mole	165.83	131.39	96.94	62.50
Specific Gravity (at 20°C)	-	1.62	1.46	1.26	0.91
Vapor Pressure (at 20°C)	mm Hg	14	58	265	2,530
Boiling Point	°C	121	87	48	-13
Octanol-Water Partition Coefficient	log K_{ow}	2.10 – 2.88	2.29 – 3.30	2.09	0.60
Soil-Water Partition Coefficient	log K_{oc}	2.32 – 2.56	1.81 – 2.10	1.77	0.39

Nature and Extent of the Contaminants (3,7,8,11):

Groundwater samples collected during the Environmental Investigation contained VOCs, including PCE and its degradation products: TCE, DCE, and vinyl chloride. Groundwater samples collected from MW-9 had the highest detected concentrations of these contaminants. Table 2 summarizes the VOC results for groundwater samples collected from MW-9. All samples were analyzed using EPA SW-846 Test Method 8260, except the May 1997 sample from MW-9, which was analyzed using a field GC by EPA Method 8010. Figure 3 presents maximum contaminant concentrations observed in MW-9 and downgradient monitoring wells; maximum values were based on sampling events conducted between July 1991 and June 1999.

Table 2. Groundwater VOC Concentrations at MW-9 (mg/L or ppb)

Contaminant	MW-9				
	July 1991	June 1992	May 1994	Nov. 1996	May 1997
PCE	2,530	4,000	1,830	4,100	4,214
TCE	189	200	176	579	229
1,1-DCE	1.88	1.6	2.4	ND(5)	NA
cis-1,2-DCE	200 S	2,000	NR	781	NA
trans-1,2-DCE	NR	NR	64.6	ND(5)	NA
1,1-DCA	80	0.7	1.14	ND(5)	NA
1,2-DCA	LT	LT	NA	ND(5)	NA
Vinyl Chloride	826	2,000	474	ND(5)	NA

LT – Less than the certified reporting limit
ND – Non-Detect (Detection Limit)
NA – Not Analyzed
NR – Not Reported
S – Result based on an internal standard

PCE and TCE were detected in soil samples collected in the vicinity of MW-9, indicating a potential ongoing source of chlorinated solvents to the groundwater. Twelve direct-push soil borings were completed in May 1997 to delineate the contamination around MW-9. Samples were analyzed using a field GC by EPA Method 8010. Contaminant concentrations in the May 1997 soil samples ranged from less than 10 to 1349 ppb for PCE and less than 10 to 45.2 ppb for TCE.

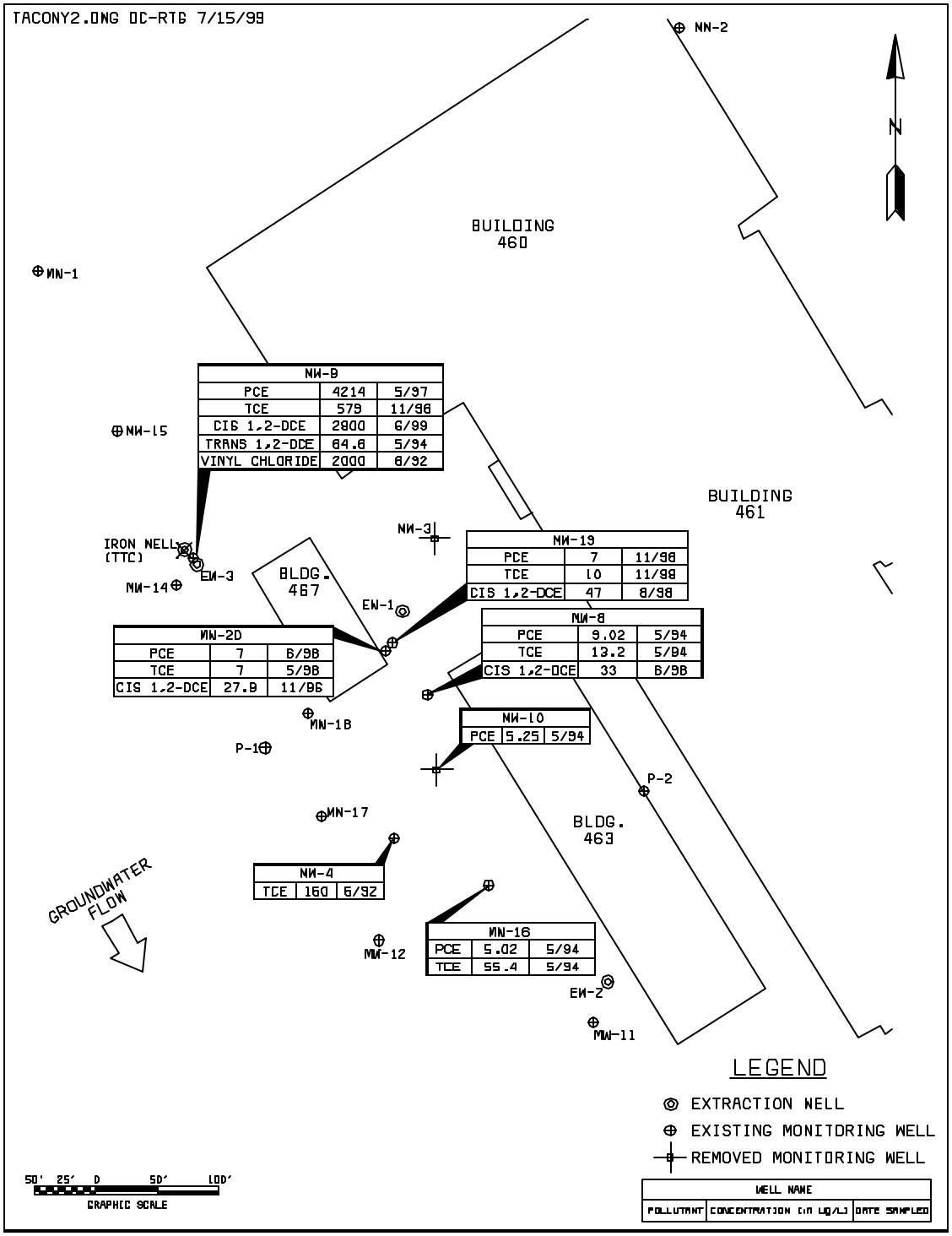


Figure 3. Maximum Groundwater Contaminant Concentrations (for concentrations above the MCLs)

MATRIX CHARACTERISTICS AFFECTING TECHNOLOGY COST OR PERFORMANCE

Table 3 lists selected characteristics of the TW site.

Table 3. Matrix Characteristics

Characteristic	Value	Measurement Procedure
Soil Classification (3)	Range from clays (CL) to gravels (GM); clays (CL) and silts (ML) more prevalent in NW portion of site	Unified Soil Classification System
Clay Content and/or Particle Size Distribution	Information Not Available	Not Applicable
Hydraulic Conductivity (3)	2.3 to 29.4 gal/day/ft^2 (lower at NW portion of site, increases toward river)	Slug Testing, AQTESOLV model
pH (6)	6.4 (MW-9 sample)	Field Measurement
Porosity (3)	33% (effective)	Estimated
Depth and Thickness of Zone of Interest (6)	27 feet (aquifer thickness) 8 to 35 feet bgs	Well installation, water table elevations w/an electronic sounding device
Total Organic Carbon	Information Not Available	Not Applicable
Presence of NAPLs (3)	Not Detected (at MW-14)	Not Available

TECHNOLOGY SYSTEM DESCRIPTION

PRIMARY TECHNOLOGY

Groundwater In-Situ **– Pump and Treat using a Permeable Reactive Treatment Cell**

SYSTEM DESCRIPTION AND OPERATION

System Description (5,10,15)

Groundwater contamination at TW is being remediated by extracting groundwater from the ground and pumping it to the City of Philadelphia sanitary sewer. Three extraction wells are being used to remove the groundwater. They are located near monitoring wells with high contaminant levels and/or located to create a hydraulic capture zone for contaminants in the groundwater. One of the extraction wells, called the Tacony Treatment Cell or TTC, is located approximately 15 feet from MW-9, is four feet in diameter, and is backfilled with zero-valent iron filings around a four-inch diameter extraction well. Figure 4 shows the location of the groundwater extraction system at the site. Figure 5 provides a diagram of the TTC well.

Zero-valent iron has been used at other sites for in situ treatment of groundwater contaminated with chlorinated hydrocarbons. Water is treated by reductive dehalogenation reactions that occur while the water is in contact with the iron filings. The reactions convert chlorinated hydrocarbons to less-chlorinated and non-chlorinated compounds and liberate chloride ions. The degradation pathways for PCE and TCE can result in formation of less-chlorinated daughter compounds in addition to non-chlorinated hydrocarbons (e.g., ethene and ethane).

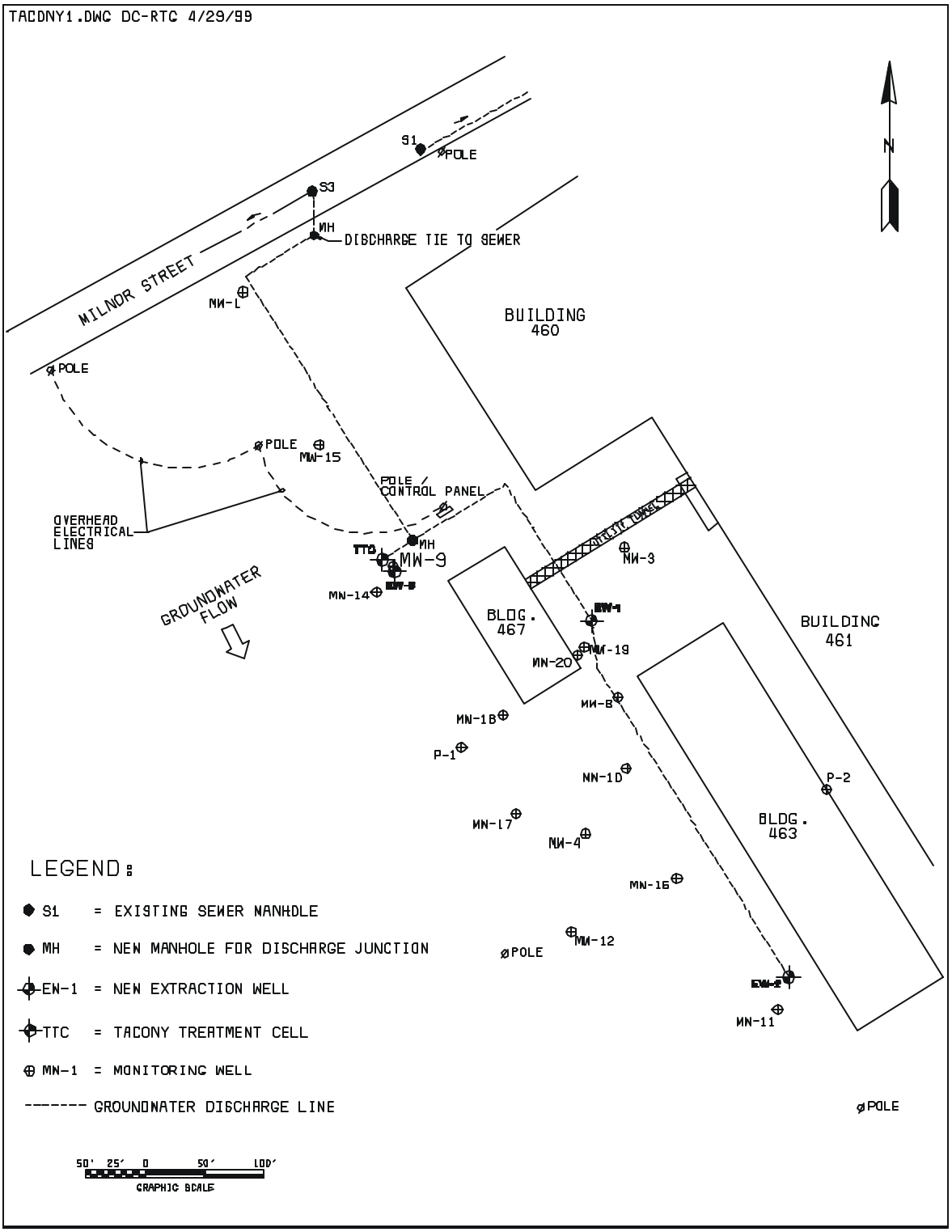
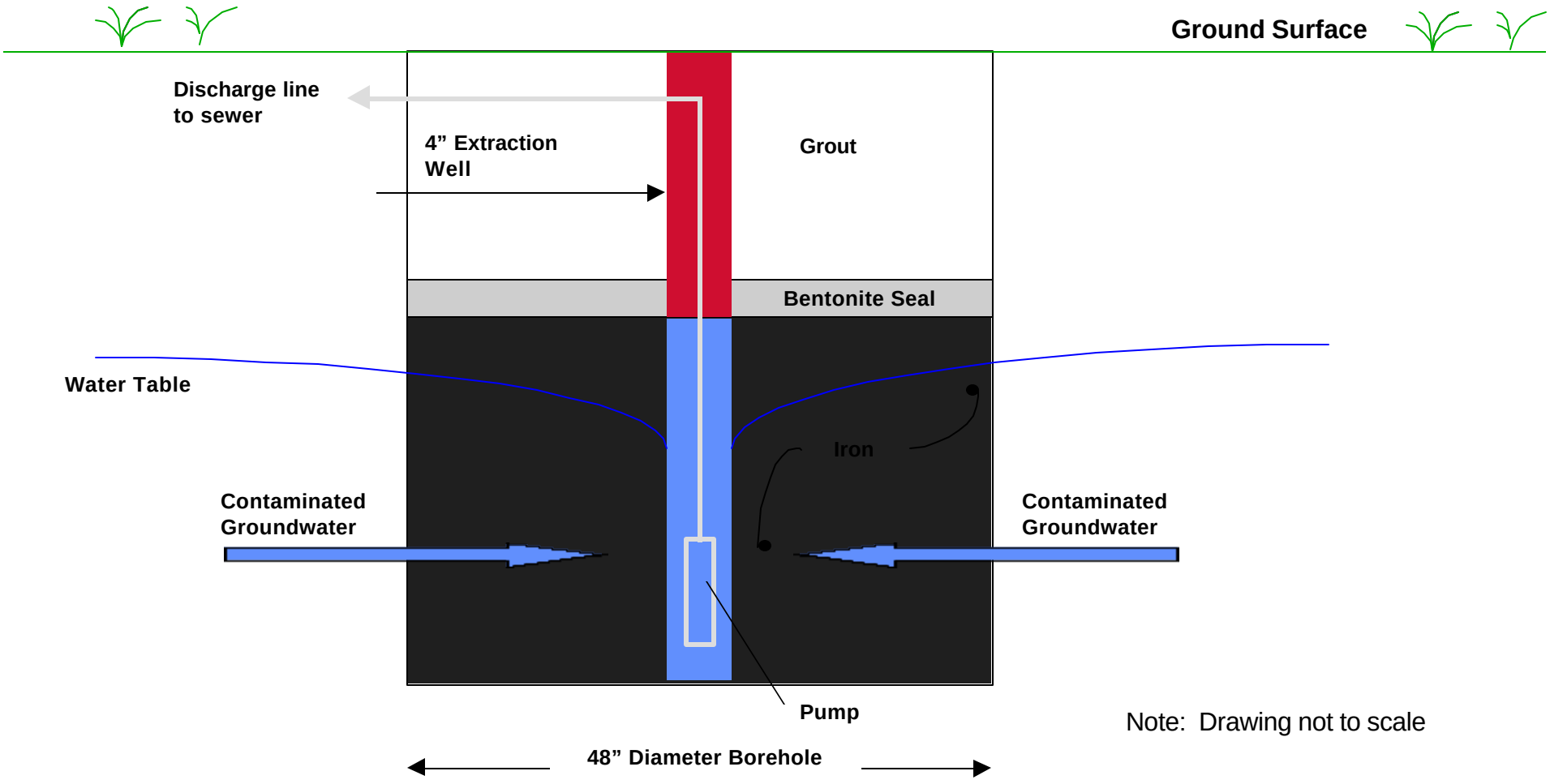


Figure 4. Configuration of the Groundwater Extraction System



Note: Drawing not to scale

Figure 5. Diagram of the TTC

System Operation (1,3,9,13,15,16)

Construction of the extraction and treatment system was conducted in two phases. Phase I included installation and testing of the extraction wells. After installing the first extraction well (EW-1) and prior to drilling the remaining extraction wells, EW-1 was tested using the step-drawdown method. This testing was performed according to the procedures outlined in the American Water Works Association standard, AWWA A100-90. Using the pump test data, modeling software was used to determine the long-term sustainable pump rates and the area of influence at that rate that would minimize the number of wells necessary at the site. The radius of influence for EW-1 was calculated to be 33.6 feet at a pumping rate of 1 gpm.

All extraction wells were installed to the top of bedrock, which ranged from 33 to 45 feet bgs for the three wells. Extraction wells EW-1 and EW-2 were six inches in diameter. The TTC is four feet in diameter and was excavated using a cassion auger. The TTC was backfilled with 22 tons of zero-valent iron filings around a four-inch diameter extraction well located in the center. The thickness of the iron filings layer was calculated to provide at least a 10-hour detention time in the filings based on the expected pumping rates and the porosity of the filings. In addition to the extraction wells, a piezometer (P-3) and a backup extraction well (EW-3) were installed within the TTC.

Phase II of construction of the extraction system included: installation of manhole vaults, electric submersible pumps and well heads at each extraction well; excavation and backfill of trenches for utilities and pipeline connections from the wells to the sewer; and installation of controls and meters.

Upon completion of well construction, all debris and surplus materials generated during the installation were removed from the job site. Purge and decontamination water was stored in four temporary 275-gallon tanks located at the site. Composite samples were collected from the tanks and tested for toxic organic pollutants. The analytical results met the discharge requirements, so the water was discharged to the City of Philadelphia sanitary sewer system.

Long-Term Operation (1,5,17)

Groundwater samples are collected monthly from the six monitoring wells that have historically exceeded ROD cleanup requirements, and from the three active extraction wells. The combined discharge is sampled twice each year in accordance with permit requirements. These activities have been ongoing since May 1998, when the extraction system started operation. The extraction and monitoring wells are analyzed for VOCs (EPA SW-846 Test Method 8260) and the combined discharge is analyzed for toxic organic pollutants (EPA SW-846 Test Methods 8260 and 8270).

Analytical results for these samples are used to determine if the remedial action goals and the discharge permit limits are being met. If the results from a given monitoring well are below the remediation goals during two consecutive quarters, that area of the plume is considered remediated and sampling can be discontinued. The Army will seek approval from the Pennsylvania Department of Environmental Protection (PADEP) before discontinuing monitoring in any areas of the site.

The control system for the extraction system includes a programmable logic controller (PLC) with dial-in and dial-out capabilities to allow for remote control and monitoring of the pumps and discharge. The pumps may be controlled manually on-site or remotely via a modem connection. Flow rate and water level at each pump are monitored once per minute while the system is running. The extraction pumps are run continuously, with pumping rates dependent on preset target rates, water levels and the rate of groundwater recharge at each extraction well.

Personnel Requirements

Long-term O&M involves monthly monitoring, which requires two samplers for one day each month.

Health and Safety Requirements (12)

All contractor and subcontractor personnel who performed work on-site complied with the Site Safety and Health Plan, which was developed in accordance with the requirements set forth in 29 CFR 1910.120 (OSHA's Hazardous Waste Operations and Emergency Response Standard) and 29 CFR 1926.65 (OSHA's Safety and Health Regulations for Construction), the USACE Safety and Health Requirements Manual EM 385-1-1, and the contractor's corporate health and safety program plan. Prior to initiating site activities, all personnel attended site-specific safety training, which covered the site layout, potential hazards, monitoring protocols, safety procedures, and emergency response services. The Site Safety and Health Officer (SSHO) and Site Manager conducted daily safety briefings with site personnel.

Level D personal protective equipment (PPE) was used during activities for delineation of the nature and extent of contamination, installation of the remediation technology, and long-term monitoring. Operations that had potential for splashing of contaminated groundwater or where free product was suspected or encountered required modified Level D. Hearing protection was required for personnel exposed to noise levels in excess of 85 decibels.

Real-time air monitoring (every 15 minutes or at a frequency designated by the SSHO) for VOCs was conducted using an organic vapor meter (OVM) equipped with a photoionization detector. If OVM measurements exceeded 1 ppm VOC in the breathing zone, colorimetric detector tubes were used to test for vinyl chloride. Elevated VOC concentrations or positive vinyl chloride detection in the breathing zone required personnel to upgrade to Level B or C PPE; no upgrades were required during any site activities. Combustible gases in the work area were monitored using a combustible gas indicator (CGI). Operations were only conducted when the CGI response was less than or equal to 20% of the lower explosive limit (LEL).

OPERATING PARAMETERS AFFECTING TECHNOLOGY COST OR PERFORMANCE

Table 4 lists design and actual values for parameters associated with operation of the extraction system at the TW. The parameters were selected for this report based on USACE guidance.

Table 4. Operating Parameters (8,17,19)

System Parameter	Design	Actual
pH	Not Applicable	Not Available
Pumping Rate	0.25 to 2.0 gpm per well	0.25 to 2.0 gpm per well 0.25 to 0.5 gpm at the TTC well
Type of Reactant	Zero-Valent Iron Filings	Zero-Valent Iron Filings
Dissolved Oxygen	0 mg/L (anaerobic)	Not Available
Total VOCs	Not Available	1,440 to 3,780 µg/L

TIMELINE (1,3,8,19)

Date	Activity
December 1989	AEC concludes their Enhanced Preliminary Assessment of the TW site
August 24, 1993	AEC concludes their Environmental Investigation of the TW site
October 25, 1993	Proposed Plan for remedial action at the TW released to public
October 25, 1993 – Nov. 24, 1993	Public comment period on the Proposed Plan

Date	Activity
October 3, 1994	City of Philadelphia approves request to discharge groundwater to the city's sanity sewer system
July 21,1995	ROD finalized
October 6, 1995	PADEP concurrence with the ROD for the TW site
May 23, 1997	Additional borings drilled in order to locate and delineate potential contaminant source near MW-9
February 1998	Mobilization and installation of extraction wells TTC, EW-1, and EW-2; pump test performed on EW-1; installation of extraction system complete
May 1998	System startup and initiation of long-term monthly monitoring
January 2000 (tentative)	Soil removal around MW-9 and installation of replacement monitoring well MW-9a
To Be Determined	System shutdown
To Be Determined	Decontamination and demobilization
To Be Determined	Site restoration complete

TECHNOLOGY SYSTEM PERFORMANCE

CLEANUP GOALS/STANDARDS (1)

The remedial action objective (RAO) for TW is to remediate the site to a level that will permit unlimited future use. The groundwater RAOs listed below were based on the risk assessment:

- To substantially reduce the amount of contamination in the aquifer;
- To prevent ingestion of groundwater estimated to have an excess cancer risk of greater than 10^{-4} or a hazard index of greater than 1.0 by a hypothetical future on-site resident; and
- To restore groundwater to its beneficial use (e.g., a potential drinking water source).

PADEP established the groundwater remediation goal of achieving background levels, which are based on the analytical quantitation limits provided in EPA SW-846 Test Method 8240. These cleanup levels are provided in the following table.

Table 5. Groundwater Cleanup Goals

Contaminant	Remedial Action Goal (µg/L or ppb)
PCE	5
TCE	5
1,1-DCE	5
cis-1,2-DCE	5
trans-1,2-DCE	5
Vinyl Chloride	10
1,1-Dichloroethane (1,1-DCA)	5

The discharge from the groundwater extraction system to the City of Philadelphia sanitary sewer is subject to permit conditions. Specifically, the permit limits the discharge of total toxic organic compounds, including chlorinated solvents, to a concentration limit of 2.13 mg/L. The total quantity of toxic organic compounds is the sum of the results for compounds detected at concentrations greater than 0.01 mg/L.

PERFORMANCE DATA (17)

Table 6 provides the monthly groundwater monitoring data that has been generated since the extraction system began operation. Figure 6 presents this data graphically for the parameters detected in each well. Non-detect (ND) results were represented as zeros in the graphs.

PERFORMANCE DATA ASSESSMENT (16,17)

- Contaminant concentrations at MW-9 were not reduced during the first year of operation of the extraction system. It is assumed that the soil contamination is providing an ongoing source of groundwater contamination.

- The TTC is demonstrating conversion of PCE and TCE to less-chlorinated hydrocarbons when compared to untreated groundwater at MW-9, which is located approximately 15 feet away. PCE and TCE were not detected at the TTC, however, intermediate reaction products (cis-1,2-DCE and vinyl chloride) were observed.

- Because of fluctuations of the groundwater table which influence the TTC pumping rates, flow from MW-9 is not always directed towards the TTC.

- Contaminated concentrations in MW-4, MW-16, and MW-20 have been below the remedial standards. Contaminant concentrations in MW-8 were below the remedial standards in April 1999 but exceeded the standards in June 1999.

- Contaminant concentrations at MW-19 were not reduced during the first year of operation. MW-19 is surrounded by fine soil and is screened at a different depth than EW-1.

- The combined discharge from all extraction wells meets the discharge limits.

PERFORMANCE DATA QUALITY (3,4,6,13,17)

Site activities and sample handling during the Environmental Investigation were performed in accordance with the Quality Assurance Project Plan (QAPP) prepared for the investigation. A Chemical Data Acquisition Plan (CDAP) was prepared to document the procedures required to ensure that all data obtained during sampling activities related to the extraction system at the TW are of acceptable quality.

All on-site and off-site testing was performed by a USACE-approved testing laboratory, where applicable. Groundwater sampling was conducted in accordance with the specifications in the USACE document EM 200-1-3, “Requirements for the Preparation of Sampling and Analysis Plans”, and EPA’s “Technical Guidance Document for RCRA Groundwater Monitoring”. Testing was performed in accordance with recognized standards published by the American Society for Testing and Materials (ASTM) and/or the AWWA. The contractor quality control manager verified that testing procedures and results conformed to contract requirements.

At the time of this report, all long-term monitoring samples were analyzed within allowable holding times. Reported surrogate recoveries were within established control limits, indicating that laboratory quality control was acceptable. Trip blank and field blank results indicated that the field quality control was acceptable. None of the data were qualified; all were accepted as reported.

Table 6. Summary of Monthly Groundwater Monitoring Results (all results are shown in ppb)

Contaminant	5/98	6/98	7/98	8/98	9/98	11/98	12/98	1/99	2/99	3/99	4/99	6/99	Goal
MW-4													
PCE	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	5
TCE	16	6	14	14	24	17	6	15	40	48	36	ND (5)	5
cis-1,2-DCE	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	5
trans-1,2-DCE	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	5
1,1-DCE	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	5
1,1-DCA	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	5
Vinyl Chloride	ND (10)	ND (10)	ND (10)	ND (10)	ND (10)	ND (10)	ND (10)	ND (10)	ND (10)	ND (10)	ND (10)	ND (10)	10
MW-8													
PCE	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	5
TCE	5	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	5
cis-1,2-DCE	22	33	12	31	21	11	11	12	13	9	ND (5)	10	5
trans-1,2-DCE	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	5
1,1-DCE	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	5
1,1-DCA	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	5
Vinyl Chloride	ND (10)	ND (10)	ND (10)	ND (10)	ND (10)	ND (10)	ND (10)	ND (10)	ND (10)	ND (10)	ND (10)	ND (10)	10
MW-9													
PCE	650	670	740	1200	1000	820	710	420	910	870	670	750	5
TCE	190	170	160	250	270	230	180	130	140	170	150	230	5
cis-1,2-DCE	1100	980	1200	1900	1300	1100	960	890	670	840	950	2800	5
trans-1,2-DCE	ND (50)	ND (50)	ND (50)	ND (50)	ND (50)	ND (50)	ND (50)	ND (50)	ND (50)	ND (50)	ND (50)	ND (50)	5
1,1-DCE	ND (50)	ND (50)	ND (50)	ND (50)	ND (50)	ND (50)	ND (50)	ND (50)	ND (50)	ND (50)	ND (50)	ND (50)	5
1,1-DCA	ND (50)	ND (50)	ND (50)	ND (50)	ND (50)	ND (50)	ND (50)	ND (50)	ND (50)	ND (50)	ND (50)	ND (50)	5
Vinyl Chloride	ND(100)	ND(100)	ND(100)	ND(100)	ND(100)	ND(100)	ND(100)	ND(100)	ND(100)	ND(100)	ND(100)	ND(100)	10
MW-16													
PCE	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	5
TCE	19	17	17	20	28	28	25	28	14	9	ND (5)	ND (5)	5
cis-1,2-DCE	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	5
trans-1,2-DCE	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	5
1,1-DCE	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	5
1,1-DCA	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	5

Table 6. Summary of Monthly Groundwater Monitoring Results (all results are shown in ppb) (Continued)

Contaminant	5/98	6/98	7/98	8/98	9/98	11/98	12/98	1/99	2/99	3/99	4/99	6/99	Goal
Vinyl Chloride	ND (10)	ND (10)	ND (10)	ND (10)	ND (10)	ND (10)	ND (10)	ND (10)	ND (10)	ND (10)	ND (10)	ND (10)	10
MW-19													
PCE	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	7	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	5
TCE	9	8	7	5	ND (5)	10	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	5
cis-1,2-DCE	43	38	39	47	45	21	40	33	26	25	28	32	5
trans-1,2-DCE	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	5
1,1-DCE	ND (5)	ND (5)	ND (5)	ND (5)	5	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	5
1,1-DCA	6	ND (5)	ND (5)	5	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	5
Vinyl Chloride	ND (10)	ND (10)	ND (10)	ND (10)	ND (10)	ND (10)	ND (10)	ND (10)	ND (10)	ND (10)	ND (10)	ND (10)	10
MW-20													
PCE	ND (5)	7	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	5
TCE	7	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	5
cis-1,2-DCE	24	23	20	10	8	ND (5)	ND (5)	6	ND (5)	ND (5)	5	ND (5)	5
trans-1,2-DCE	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	5
1,1-DCE	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	5
1,1-DCA	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	5
Vinyl Chloride	ND (10)	ND (10)	ND (10)	ND (10)	ND (10)	ND (10)	ND (10)	ND (10)	ND (10)	ND (10)	ND (10)	ND (10)	10
TTC													
PCE	ND (50)	ND (50)	ND (50)	ND (50)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	NA
TCE	ND (50)	ND (50)	ND (50)	ND (50)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	NA
cis-1,2-DCE	480	340	180	150	78	57	46	41	38	35	42	73	NA
trans-1,2-DCE	ND (50)	ND (50)	ND (50)	ND (25)	ND (25)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	NA
1,1-DCE	ND (25)	ND (25)	ND (25)	ND (25)	ND (25)	ND (25)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	NA
1,1-DCA	ND (25)	ND (25)	ND (25)	ND (25)	ND (25)	ND (25)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	ND (5)	NA
Vinyl Chloride	320	160	25	57	19	30	20	17	22	14	18	ND (10)	NA
Combined Discharge													
Toxic Organic Compounds	NS	NS	NS	NS	NS	0[a]	NS	NS	NS	NS	NS	66	2,130

NA – Not Applicable
NS – Not Sampled
ND – Not Detected (detection limit shown in parenthesis)
[a] Sample analyzed by EPA Method 625.

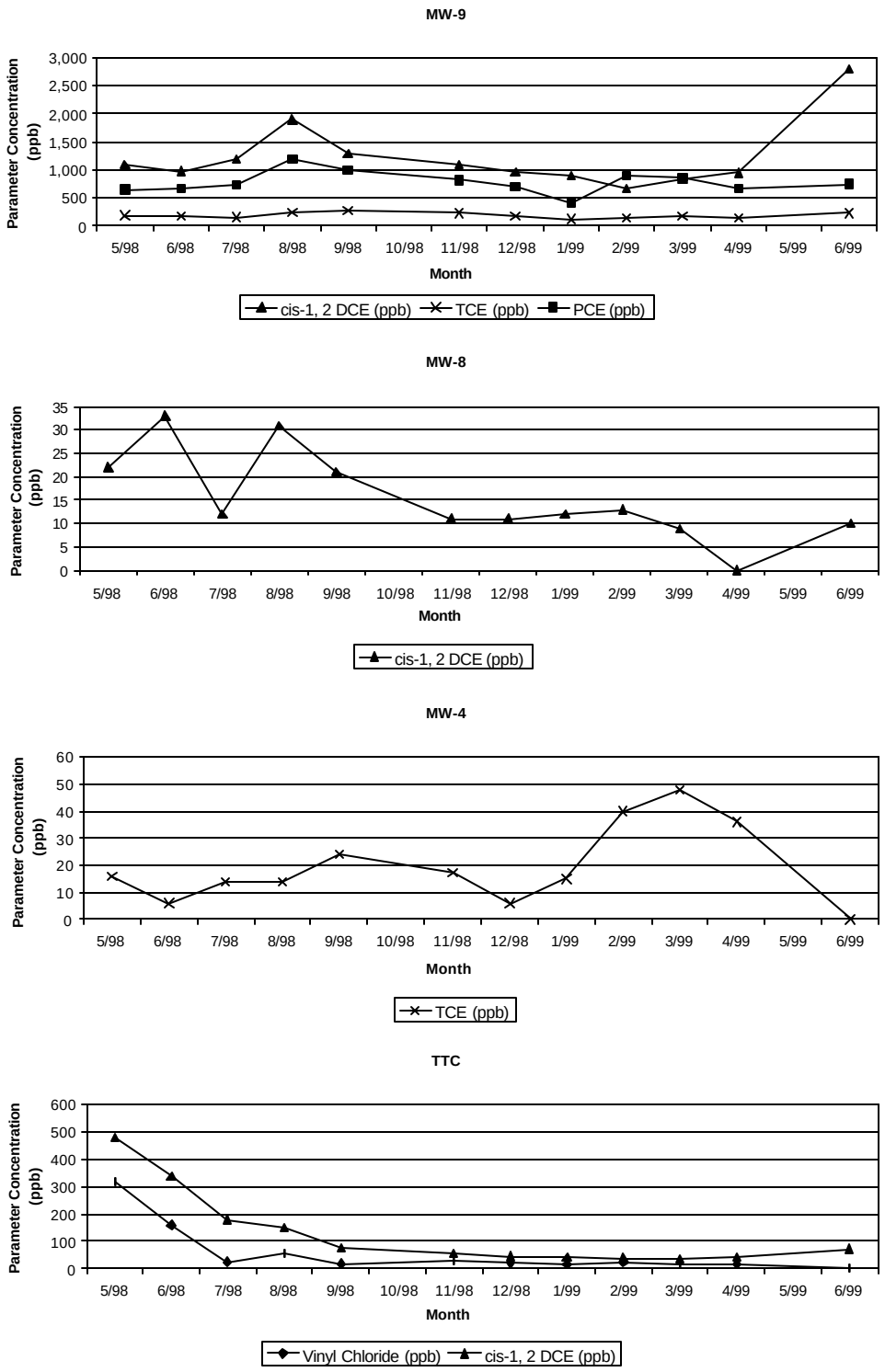
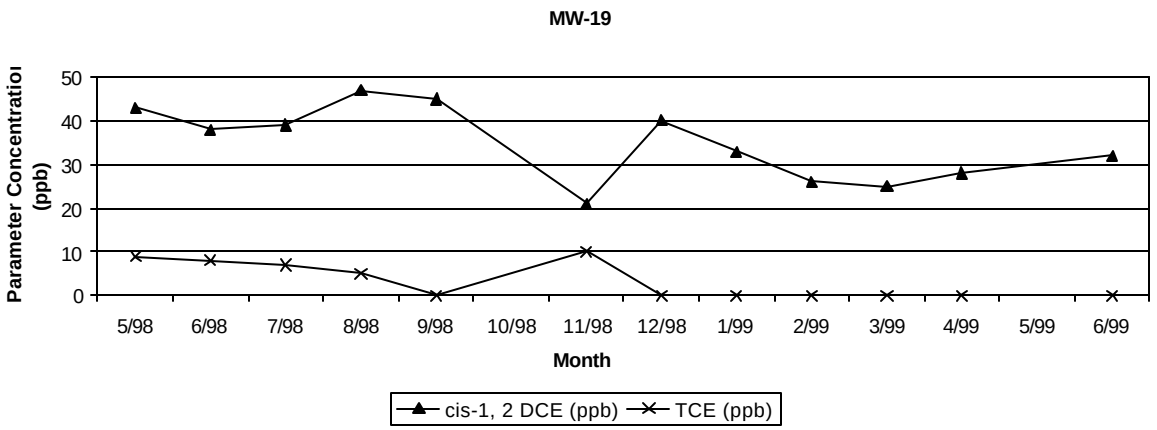
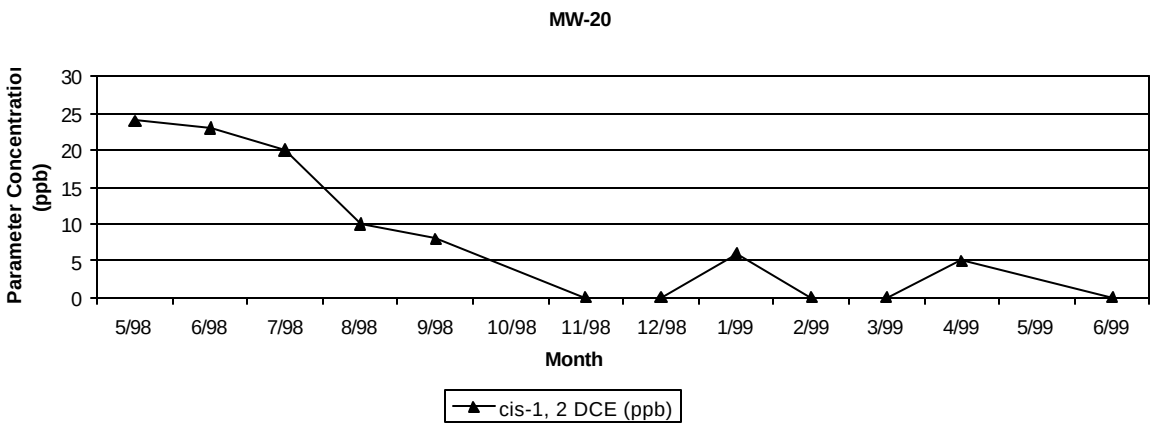


Figure 6. Parameter Concentration Versus Time





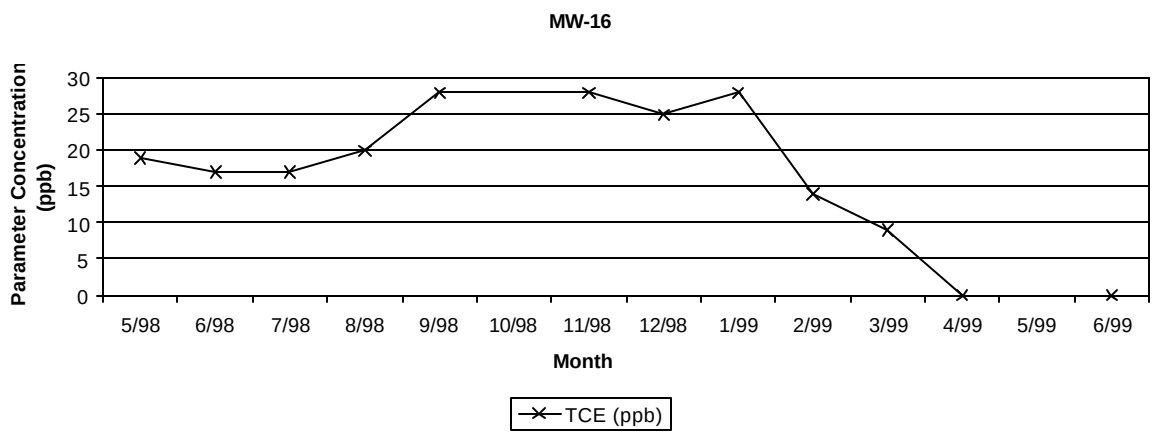


Figure 6. Parameter Concentration Versus Time (Continued)

COST OF THE TECHNOLOGY SYSTEM

PROCUREMENT PROCESS (6,8,16)

USACE awarded Radian International (Radian) the contract to design, construct, and provide long-term O&M services for the groundwater remedial action at TW. This project was not competitively bid but was awarded through a Preplaced Remedial Action Contract (PRAC) that was competitively bid. A PRAC is designed so that contractors can provide non-specific general services to the USACE. A cost- reimbursable delivery order was established for the TW project.

Radian subcontracted with the following companies for this remedial action:

Subcontractor	Tasks
Gascoyne Laboratories	Groundwater sample analysis
BISCO Environmental	Supplier of the control system for the groundwater extraction system

The USACE project manager believes that the PRAC was an appropriate contract vehicle for the remedial work performed at TW because it allowed for flexibility with regard to decision-making. This flexibility was helpful during the design process and during initial operation of the treatment system. In theory, lower costs can be realized if 100% plans and specifications are provided to the contractor, but such projects do not have the flexibility to change the scope of the work.

COST DATA (14,18)

The original budget for the groundwater remediation project was $604,684 and the actual total project cost was $607,336. The total amount of groundwater extracted in the first year of operation was 1,826,966 gallons. (The average extraction rate for the system is 3 gallons per minute.) Therefore, the cost for treatment through April 1999 was $0.33 per gallon of groundwater extracted. Table 7 summarizes the capital costs for design and construction of the extraction system and the costs for one year of operation and maintenance of the system.

Table 7. Technology Costs for the Extraction System at the Tacony Warehouse (14,18)

Cost Category	Cost Element	Total Bid Cost ($)	Total Final Cost ($)
Capital	**Phase I – Confirmational Design**		
	Field Sampling Plan	7,067	3,859
	Site Safety & Health Plan	4,857	2,287
	Pre-Delivery Order Costs	26,390	27,461
	Mobilization & Preparation	4,701	15,646
	Sampling & Analysis	9,186	7,049
	Demobilization	10,858	11,147
	General Requirements (Health & Safety, Administrative)	2,344	9,304
	Phase II – Remediation Site Work		
	Mobilization & Preparation	21,953	12,026
	Engineering, Survey, and QC	2,717	1,936
	Sampling, Analysis & Other Testing	6,755	4,435
	Site Work	72,504	65,933
	Groundwater Treatment System Equipment and Installation	135,381	190,935
	Site Restoration	4,844	244
	Demobilization	11,965	996
	Project Management	54,204	38,618
	General Requirements (Health & Safety, Administrative)	34,951	24,901
	Subtotal	**410,677**	**416,777**
O&M	**Operation & Maintenance (1 year costs)**		
	Labor and Maintenance Materials	14,971	4,908
	POTW Discharge Fees	10,752	20
	Electricity	12,182	6,661
	Project Management	8,754	4,786
	General Requirements (Health & Safety)	923	505
	Subtotal	**47,582**	**16,880**
Other Related	**Sampling & Analysis**	23,928	21,967
	Waste/Soil Management	30,154	29,815
	Closure Report	11,708	0
	Fixed Fee	80,635	80,635
	Subtotal	**146,425**	**132,417**
	Total	**604,684**	**607,336**

REGULATORY/INSTITUTIONAL ISSUES

Because this project was performed under CERCLA regulations, it was not necessary to obtain permits from local regulatory authorities for on-site activities. It was necessary, however, to meet the substantive requirements of potentially applicable regulations. The following permitting, approval and public relations issues were encountered during this project (1,8,16):

- The Proposed Plan for remedial action at the TW was released to the public on October 25, 1993. The public comment period lasted from October 25 to November 24, 1993. A public meeting was offered as an option that could be requested by the public. No public comments were received and, therefore, a meeting was not held.

- On October 3, 1994, the City of Philadelphia granted the Army permission to discharge groundwater from the site into the city's sanitary sewer system. The discharge is subject to the City of Philadelphia Wastewater Control Regulations, including applicable limits.

- The site is not expected to have any limitations on future use based on the use of site cleanup goals that were developed to allow unrestricted use.

- A review of existing patent claims on the use of iron filings was made. None of the existing patented approaches were applicable to the approach used at the TW site. This specific application of the treatment technology is considered to be new and a patent for this approach is pending for the remediation contractor.

OBSERVATIONS AND LESSONS LEARNED

COST OBSERVATIONS AND LESSONS LEARNED (16)

Cost savings can be realized by mixing sand or other media with the iron filings instead of using pure iron filings for treatment. Iron-sand mixtures can also mitigate performance-related problems such as fouling or precipitation on the iron surfaces.

PERFORMANCE OBSERVATIONS AND LESSONS LEARNED (16)

A full engineering design should be performed to properly size iron filings wells if used at other sites. This was not necessary for the TW site because the groundwater already met the sewer discharge requirements. The TTC demonstrated reduction of PCE and TCE, but it did not provide sufficient residence time to allow complete dechlorination of the hydrocarbons. As a result, PCE and TCE were converted to lesser chlorinated species, cis-1,2-DCE and vinyl chloride. Trans-1,2-DCE was not detected and therefore may not be an intermediate reaction product.

Ethene and ethane are the reaction end products, but TCC effluent samples were not analyzed for these parameters. A complete evaluation of the efficiency of iron filings treatment should include analyses of ethene and ethane. Efficiency calculations should also be based on a sample that is more representative of the contaminated zone than a well located 15 feet away from the TTC, that is also screened in a different part of a heterogeneous aquifer.

Contaminant concentrations at MW-9 were not being reduced through use of the extraction system. It was determined that existing soil contamination at the site was acting as a source of contamination, and thereby

maintaining high contaminant levels in the groundwater. The USACE plans to excavate soil around MW-9 to potentially remove the ongoing source of groundwater contamination and promote more

rapid remediation of groundwater at the site. The area to be excavated is expected to be centered on or just southwest of MW-9 and include approximately 100 cubic yards of soil. The excavation is expected to be 10 to 15 feet in diameter and 15 feet deep. Once the excavation is complete, the extraction system would continue operation until groundwater monitoring drop below the remedial action goals. At this point, the extraction system would be shut down and groundwater monitoring would be continued until it was demonstrated that treatment was complete.

The iron filings in the TTC need to be wet to avoid rusting. Exposure of the iron filings to oxygen in the air will rust the filings.

OTHER OBSERVATIONS AND LESSONS LEARNED (16,19)

The extraction system was installed with a control system that can be accessed remotely. Remote access has been a benefit to the project by reducing the labor hours and cost of operating the system. Unfortunately, the system selected has been plagued by electronic and mechanical problems. A more robust system is recommended for future applications.

The iron filings treatment cell would be applicable to any site that would consider the standard passive permeable reactive barrier approach (generally applied to sites contaminated by chlorinated solvents or hexavalent chromium). In particular, this application would be well suited for sites:

- Where pumping is needed to hydraulically control a chlorinated solvent plume that is moving off-site;
- Where installation of an interceptor wall may not be feasible; and
- That cannot have aboveground structures for aesthetic reasons or due to the potential for vandalism.

Factors that may influence the remediation schedule include:

- Obtaining a discharge permit (POTW or NPDES);
- Power availability for running the extraction pumps and monitoring systems; and
- Site geology (e.g., highly stratified aquifers or silts that retain contaminants may slow the remediation process.

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15) Phone conversation between Kristin Andreae and Mark Sylvester of Radian International on April 23, 1999.

16) Phone conversation between Kristin Andreae of Radian International and Russ Marsh of USACE, Baltimore District on April 23, 1999.

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18) Loaded Cost Control Report, Tacony Warehouse, Radian International, April 30, 1999.

19) Phone conversation between Kristin Andreae of Radian International and Russ Marsh of USACE, Baltimore District on November 3, 1999.

ACKNOWLEDGEMENTS

This report was prepared for the U.S. Army Corps of Engineers under USACE Contract No. DACA45-96-D-0016, Delivery Order No. 12.