PARSONS ENGINEERING SCIENCE, INC.

290 Elwood Davis Road, Suite 312 • Liverpool, New York 13088 • (315) 451-9560 • Fax (315) 451-9570

February 25, 1997

Robert W. Schick, P.E.
Section Chief, Remedial Section A
Bureau of Western Remedial Action
Division of Hazardous Waste Remediation
New York State Department of Environmental Conservation
50 Wolf Road
Albany, NY 12233-7010

RE: Feasibility Study
GE Farrell Road Site, Town of Geddes, Onondaga County, New York
NYSDEC Site #734055

Dear Mr. Schick:

Please find enclosed four (4) copies of the final Feasibility Study (FS) prepared by Parsons Engineering Science for the Farrell Road Site. The FS is consistent with Lockheed Martin Corporation's (LMC's) February 19, 1997 response to the January 28, 1997 comments received from the New York State Department of Environmental Conservation (NYSDEC) and the New York State Department of Health (NYSDOH).

If you have any questions, please contact me at (315) 456-3199.

Sincerely,

Patrick D. Salvador

Patrick D. Salvador, P.E.
Principal Engineer

Enclosure

cc: Director, Bureau of Environmental Exposure Investigation - NYSDOH
Sandra Lee Fenske, Esq. - Lockheed Martin
Henriette Hamel - NYSDOH
Michael J. Lesser, Esq. - NYSDEC
Ken Lynch, Acting Director - NYSDEC - Region 7
Virginia C. Robbins, Esq. - Bond, Schoeneck & King, LLP

FEASIBILITY STUDY
FARRELL ROAD PLANT

PREPARED FOR

LOCKHEED MARTIN

Lockheed Martin Corporation
Syracuse, New York

FEBRUARY 1997

PREPARED BY

PARSONS ENGINEERING SCIENCE, INC.
Syracuse, New York

PARSONS

H:\GRAPHICS\730125\LOCKMNCV.DS4

CERTIFICATION STATEMENT

I, Edward C. Glaza, the Parsons Engineering Science, Inc. Project Manager for the Feasibility Study (FS) completed for the Farrell Road Plant, certify that to the best of my knowledge the FS activities were performed in general conformance with Administrative Order on Consent (Index No. A7-0307-93-10) and the New York State Department of Environmental Conservation (NYSDEC) approved Remedial Investigation/Feasibility Study Work Plan dated January 14, 1994.

Edward C Glaza 2/25/97

EDWARD CADWELL GLAZA
070909

Edward C. Glaza, P.E.
Project Manager
NYS License No. 070909

Parsons Engineering Science, Inc.
290 Elwood Davis Road
Liverpool, New York 13088

TABLE OF CONTENTS

PAGE

TABLE OF CONTENTS
(Continued)

TABLE OF CONTENTS
(Continued)

TABLE OF CONTENTS
(Continued)

LIST OF APPENDICES

TABLE OF CONTENTS
(Continued)

PAGE

LIST OF FIGURES

LIST OF TABLES

LIST OF ACRONYMS

ARARs	Applicable or Relevant and Appropriate Requirements
ASTM	American Society for Testing and Materials
BB&L	Blasland, Bouck & Lee, Inc.
BTEX	benzene, toluene, ethylbenzene, xylene
$CaCO_3$	calcium carbonate
CERCLA	Comprehensive Environmental Response, Compensation and Liability Act
cm/s	centimeters per second
COCs	Chemicals of Concern
CFR	Code of Federal Regulations
1,1-DCA	1,1,-dichloroethane
1,2-DCE	1,2-dichloroethene
DNAPL	dense non-aqueous phase liquid
ETI	Envirometal™ Technologies, Inc.
ERM	ERM-Northeast, Inc.
Fe_3CO	siderite
$Fe\ (OH)_2$	ferrous hydroxide
FEMA	Federal Emergency Management Agency
Freon II	trichloromonofluoromethane
FRP	Farrell Road Plant
FS	Feasibility Study
FWIA	Fish and Wildlife Impact Analysis
GAC	granular activated carbon
GE	General Electric

GPM	gallons per minute
IRM	Interim Remedial Measure
LMC	Lockheed Martin Corporation
LNAPL	light non-aqueous phase liquid
MIBK	methyl isobutyl ketone
MMC	Martin Marietta Corporation
MW	monitoring well
NCP	National Oil and Hazardous Substances Pollution Contingency Plan
NOI	Notice of Intent
NYCRR	New York State Codes, Rules, and Regulations
NYSDEC	New York State Department of Environmental Conservation
OSHA	Occupational Safety and Health Administration
O&M	Operational and maintenance costs
Parsons ES	Parsons Engineering Science, Inc.
PCB	polychlorinated biphenyls
POTW	publicly owned treatment works
ppb	parts per billion
PPE	personal protective equipment
ppm	parts per million
RA	risk assessment
RAOs	remedial action objectives
RAP	reclaimed asphalt pavement
RI/FS	Remedial Investigation/Feasibility Study
SARA	Superfund Amendments and Reauthorization Act of 1986
SCGs	Standards, Criteria, and Guidelines

SVE	soil vapor extraction
SVOC	semivolatile organic compound
TAGM	Technical and Administrative Guidance Memorandum
TBC	to be considered
TCE	trichloroethene
1,1,1-TCA	1,1,1-trichloroethane
TCLP	Toxicity Characteristic Leaching Procedure
TPH	total petroleum hydrocarbons
µg/L	micrograms per liter
USEPA	United States Environmental Protection Agency
UST	underground storage tank
UV	ultraviolet
VC	vinyl chloride
VOC	volatile organic compound

SECTION 1

INTRODUCTION

1.1 GENERAL

This Feasibility Study (FS) report supersedes the FS report (BB&L, 1995) submitted to the New York State Department of Environmental Conservation (NYSDEC) in August 1995 for the former General Electric (GE) Farrell Road Plant (FRP) (the site) located on Farrell Road in the Town of Geddes, Onondaga County, New York. The primary purpose of this FS is to develop and evaluate site-wide remediation alternatives consistent with the NYSDEC comments to the 1995 FS and considering investigative data not available during preparation of the 1995 FS.

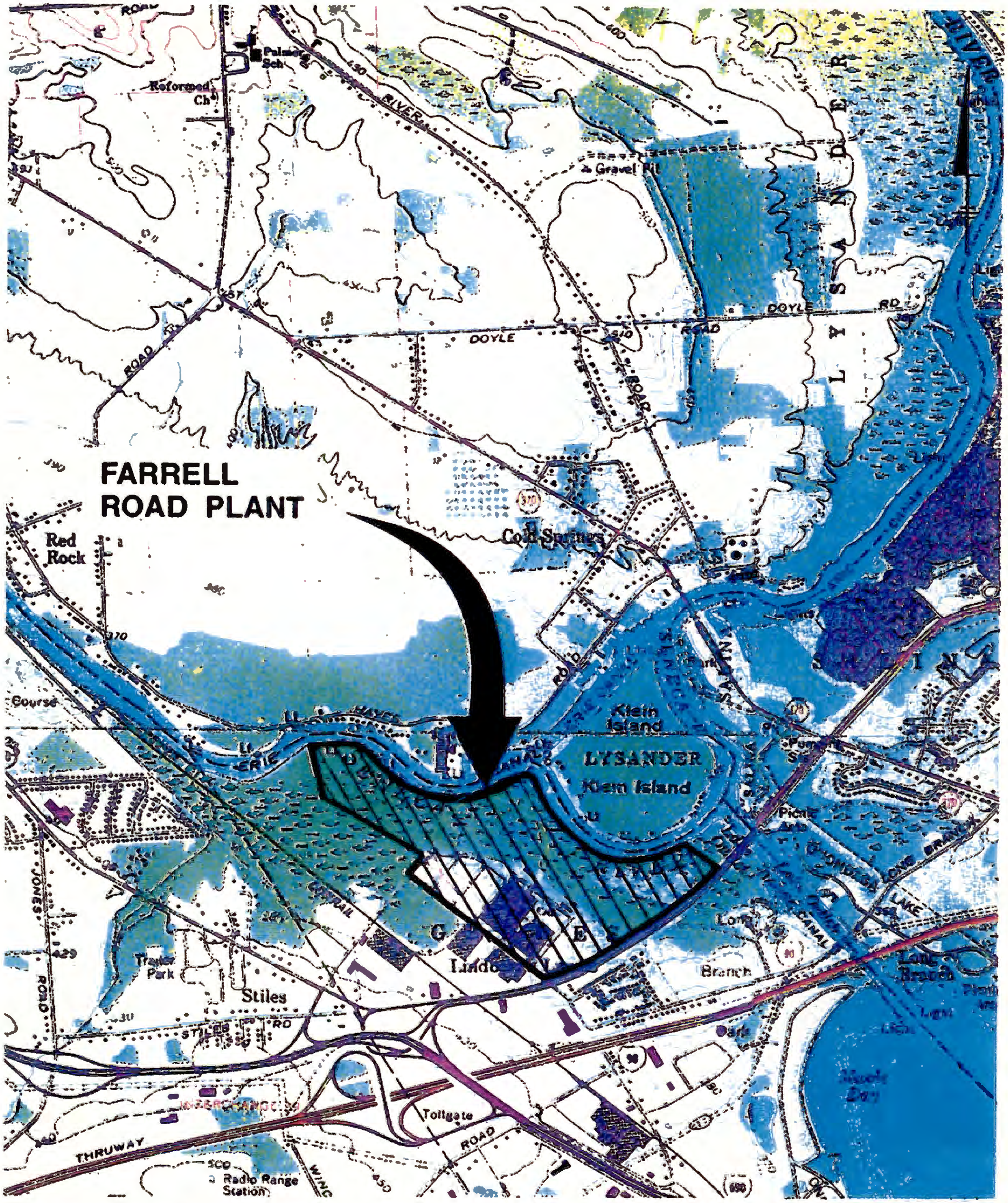
This FS report has been prepared in accordance with the following documents: the NYSDEC-approved Remedial Investigation/Feasibility Study (RI/FS) Work Plan dated January 1994 (ERM, 1994a); the RI/FS Order on Consent (Index No. A7-0307-93-10) entered into between the Martin Marietta Corporation (MMC) and the NYSDEC effective December 15, 1993; the Interim Remedial Measure (IRM) Order on Consent (Index No. A7-0308-93-10) entered into between MMC and the NYSDEC effective March 21, 1994; the United States Environmental Protection Agency (USEPA) guidance document "Guidance for Conducting Remedial Investigations and Feasibility Studies under Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA)"; the "National Oil and Hazardous Substances Pollution Contingency Plan (NCP)" contained in 40 CFR 300; the Superfund Amendments and Reauthorization Act of 1986 (SARA); the NYSDEC guidance document "New York State Applicable or Relevant and Appropriate Requirements (ARARs)"; and the NYSDEC Technical and Administrative Guidance Memorandum (TAGM) 4030, entitled: "Selection of Remedial Actions at Inactive Hazardous Waste Sites". References utilized to develop this FS are presented in Appendix A.

1.2 BACKGROUND INFORMATION

1.2.1 General

The former GE Farrell Road Plant is a 156-acre manufacturing facility located in the Town of Geddes, Onondaga County, New York (Figure 1.1). The site includes four buildings:

- Building No. 1, which was used as a design center;
- Building No. 2, which was used as a manufacturing and assembly plant;
- the Test Building, which was used to test radar products; and
- the Maintenance Garage, which was used to service and house plant support vehicles.



NEW YORK
QUADRANGLE LOCATION

SOURCE: U.S.G.S. 7.5 MINUTE
TOPOGRAPHIC MAPS;
SYRACUSE WEST, 1973 PHOTOREVISED 1978;
BREWERTON, NY, 1973 PHOTOREVISED 1978;
BALDWINSVILLE, NY, 1973, PHOTOREVISED 1978;
CAMILLUS, NY, 1973, PHOTOREVISED 1978

LATITUDE: N 43° 7' 15"
LONGITUDE: W 76° 15' 50"

N

2000' 0 2000'

Approximate Scale in Feet

FIGURE 1.1

FORMER GE
FARRELL ROAD SITE

SITE LOCATION MAP

PARSONS ENGINEERING SCIENCE, INC.

DESIGN • RESEARCH • PLANNING
290 ELWOOD DAVIS ROAD • SUITE 312 • LIVERPOOL, N.Y. 13088 • (315) 451-9560
OFFICES IN PRINCIPAL CITIES

Buildings 1 and 2 each are several acres in size (175,000 square feet and 300,000 square feet, respectively) and dominate the front portion of the developed site. The Maintenance Garage occupies approximately 6,500 square feet and is located at the northwest corner of the fenced area of the site. The Test Building is near the northeast corner of the site and occupies approximately 9,000 square feet (Figure 1.2).

The four buildings are enclosed by a perimeter fence which is bordered by large paved parking areas on the east and west. The site is bordered on the south by Farrell Road, on the north and west by the Seneca River, and on the east by John Glenn Boulevard. The area of the site outside the fence to the north and west, an area of approximately 80 acres, has been classified as a Class I NYSDEC-regulated wetland.

1.2.2 Site History

The Farrell Road property was developed in the early 1960s by GE as a design, manufacturing, and assembly center for radar and sonar equipment. The site was divided into two separate properties; Farrell Road Plant 1 (FRP-1) and Farrell Road Plant 2 (FRP-2). GE owned the FRP-2 property and leased the FRP-1 property. Manufacturing operations continued until December 1992, when GE moved all operations to other locations. In April 1993, GE sold FRP-2, which includes Building No. 2 and the Maintenance Garage, to MMC. At that time, MMC assumed the lease on the adjacent property (FRP-1) which includes Building No. 1 and the Test Building. Ownership of the site was subsequently transferred to Syroco, Inc., in December 1993. Syroco currently operates the facility as a warehouse.

Environmental investigations conducted at the site have determined that soil and groundwater have been impacted by past industrial activities. As a result of these findings, the site was placed on the NYSDEC Registry of Inactive Hazardous Waste Disposal Sites in October 1992 (Site No. 734055). MMC entered into a Consent Order with the NYSDEC to implement a RI/FS for the GE Farrell Road site in December of 1993.

In March 1995, MMC merged with Lockheed Corporation. As a result of that merger, Lockheed Martin Corporation (LMC) was formed as a holding company and MMC became a wholly-owned subsidiary of LMC. Effective January 29, 1996 MMC merged into its parent corporation, LMC. LMC is the successor by merger to MMC and has assumed MMC's obligations under the RI/FS and IRM consent orders.

1.2.3 Summary of Site Investigations

A series of soil and groundwater investigations have been undertaken at the site on behalf of GE and LMC. A preliminary hydrogeologic investigation was conducted in 1991 by ERM-Northeast, Inc. (ERM) to characterize groundwater flow, assess known groundwater impacts associated with a closed underground storage tank (UST), and evaluate potential impacts associated with two site septic tanks/leach field areas. The results of this investigation are presented in the report entitled "Preliminary Hydrogeologic

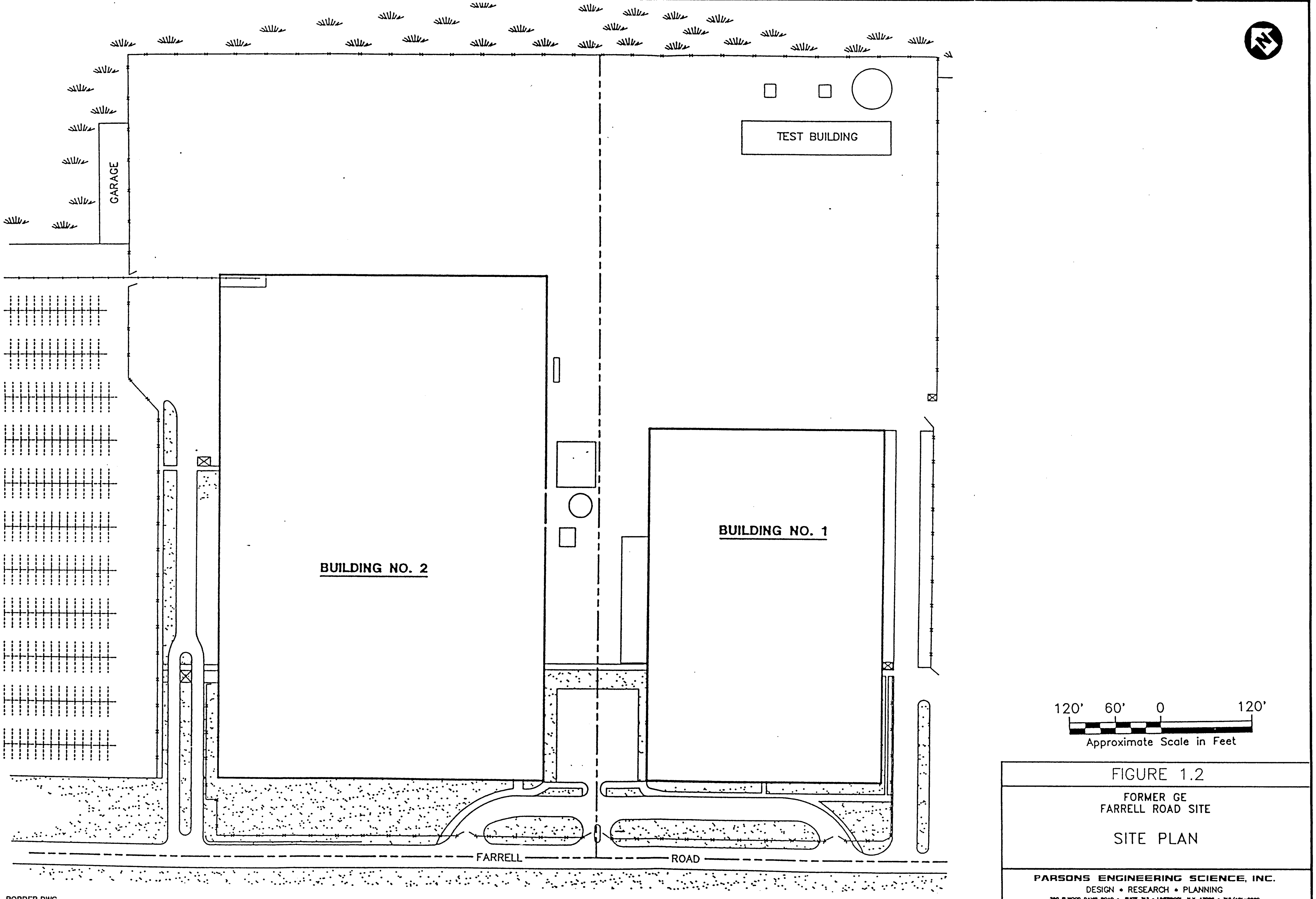


FIGURE 1.2

FORMER GE
FARRELL ROAD SITE

SITE PLAN

PARSONS ENGINEERING SCIENCE, INC.
DESIGN • RESEARCH • PLANNING
290 ELWOOD DAVIS ROAD • SUITE 312 • LIVERPOOL, N.Y. 13088 • 315/451-9000
OFFICES IN PRINCIPAL CITIES

DATE: 12/26/96 (GTC)
H:\CAD\730125\PES1117_BORDER.DWG

H:\CAD\730125\PES1117 Thu Dec 26 09:26:41 1996

Investigation of the GE Aerospace Farrell Road Plant," dated June 27, 1991. As a follow-up to the preliminary hydrogeologic investigation, a Phase II hydrogeologic investigation was conducted by ERM to estimate the extent of oil in the subsurface near former UST T-51 and estimate the extent of volatile organic compounds (VOCs) identified in the groundwater north of the Test Building. The results of this investigation are presented in the report entitled, "Phase II Hydrogeologic Investigation at GE Aerospace Farrell Road Plant," dated November 15, 1991.

In 1992, environmental investigations were conducted by ERM at the site to identify areas of potential environmental concern, characterize the site geology, and estimate the extent of potential environmental impacts. The results of these investigations are presented in the reports entitled "1992 Environmental Investigation, GE Farrell Road Plant Two," and "1992 Environmental Investigation, GE Farrell Road Plant One", dated July 10, 1992 and July 16, 1992, respectively. Two addenda to the 1992 environmental investigations, entitled "Debris Pile Excavation, GE Farrell Road Plant Two" and "Garage Area Investigation, GE Farrell Road Plant Two", were issued on July 29, 1992 and October 14, 1992, respectively. During these two investigations, 16 areas of the site were identified as requiring additional investigation.

ERM also prepared several investigation-related letter reports to document investigations conducted at specific areas of the site, including "PCB Sampling at Farrell Road Plant Two", "Groundwater Sampling North of the Farrell Road Plant", and "MMC Farrell Road Site; 10 Soil Borings at Proposed Loading Dock."

Pursuant to the Order on Consent, ERM conducted an RI of the site during 1993 and 1994. The RI included the sampling and analysis of soils from the previously identified areas of concern (AOCs); sampling and analysis of groundwater and surface water from the wetland north of the site, and sampling and analysis of groundwater from on-site monitoring wells. The results of the RI are presented in the report entitled "1994 Remedial Investigation at the Farrell Road Plant," dated May 1995 (including subsequent addenda and revisions).

Since the completion of the original FS in August 1995, three additional investigations have been conducted at the site. A light non-aqueous phase liquid/dense non-aqueous phase liquid (LNAPL/DNAPL) RI was conducted by Blasland, Bouck & Lee, Inc. (BB&L) at AOC 5 to evaluate the presence, extent, and composition of LNAPL and to assess whether DNAPL is present in the subsurface. Investigative activities were conducted from September to November 1995. The investigation results are presented in the report entitled, "Addendum Remedial Investigation Report Area of Concern 5 LNAPL/DNAPL Investigation" (BB&L, 1996a).

Two additional investigations were completed by ERM adjacent to storm sewer Outfall 003 to define the extent of soil and sediment affected by polychlorinated biphenyls (PCBs). PCBs had been identified in the soils and sediment at the discharge location of storm sewer Outfall 003 during the RI field activities conducted in March 1994. In March 1995, analytical results from seven soil samples from five locations within the storm sewer

Outfall 003 drainage swale indicated that soils adjacent to storm sewer Outfall 003 were impacted by low levels of VOCs and PCBs. In September and October of 1995, 27 surface soil samples (0-0.5 feet deep) were collected adjacent to storm sewer Outfall 003 to define the extent of PCB-affected soil. An areal extent of soil and sediment containing PCBs in excess of one part per million (ppm) was delineated as encompassing approximately 3,550 square feet as a result of the investigation. Results from these investigations are presented in the report entitled, "Addendum Remedial Investigation Report Soil Investigations Adjacent to storm sewer Outfall 003" (BB&L, 1996b).

Finally, a limited groundwater investigation program including the collection of groundwater elevation measurements was conducted by Parsons Engineering Science, Inc. in August 1996 to acquire additional analytical data and to develop a current groundwater contour map of the site. A total of nine monitoring wells were sampled (MW-3D, MW-3S, MW-14, MW-16, MW-17, MW-22, MW-24, MW-26S, and MW-26D) for VOCs and for geochemical indicators of natural contaminant biodegradation. Analytical results are provided in Appendix B. Groundwater elevation measurements were taken at 38 existing groundwater monitoring wells and piezometers at the site. A groundwater contour map based on August 30, 1996 data is also provided in Appendix B.

1.2.4 Site Geology Summary

Previous hydrogeologic investigations of the site indicate that soils near the surface are composed of medium-to-fine sand and silt with traces of clay. This sand/silt overburden is underlain by a dense red clay found at a depth of greater than 40 feet at the northeast corner of the site but at only 9 feet along the west side of Building No. 2. A coarse sand and/or gravel layer separates the sand/silt overburden from the red clay underneath. A clay ridge underneath Building No. 2 extends from west to east across the site.

1.2.5 Site Hydrogeology Summary

Analysis of groundwater movement through the site completed during the 1992 environmental investigations (ERM, 1992a, and ERM, 1992b) and confirmed during the RI (ERM, 1994b) indicate that groundwater flows through a common aquifer in a predominantly northerly direction through the site towards the wetland area. Groundwater elevation monitoring indicates that localized flow-direction changes within the site, such as beneath Building No. 2, are caused by localized mounding of the red clay unit. Despite the localized flow-direction changes, all site-wide groundwater ultimately follows the overall northerly groundwater flow direction.

A grain-size analysis completed during the 1992 Phase II Investigation indicated that the aquifer matrix is composed of approximately 60 percent silt and clay and 40 percent fine sand. The hydraulic conductivity of the saturated overburden has been estimated to range from 4.9×10^{-2} centimeters per second (cm/s), associated with wells completed in the coarse sand and gravel material, to 6.63×10^{-4} cm/s (associated with the fine sand and silt material). Due to its density, fine grain size, and compact nature, the red clay acts as a hydraulic confining unit between the sand/silt and sand/gravel layers, and the underlying bedrock formation. The hydraulic conductivity of the red clay layer has been estimated (via a triaxial permeability test) to be on the order of 1 x 10^{-8} cm/s. The red clay unit is greater than 104 feet thick at the south end of the site and greater than 70 feet thick at the north end of the site. Due to the thickness of the overburden unit (particularly the clay unit), underlying bedrock was not encountered during any environmental investigation; thus, no data has been developed relative to the bedrock groundwater system.

The presence of the red clay layer close to the surface at certain locations of the site, combined with the extensive paving, developed land surface, and the subsequently limited recharge potential, limits the saturated thickness of the overburden throughout most of the site. The saturated thickness of the overburden above the red clay unit varies across the site from approximately one foot on the west side of Building No. 2 to greater than 5 feet on the east side of Building No. 2. The saturated thickness exceeds 20 feet on the north side of the site (i.e., at monitoring well MW-16).

1.2.6 Summary of Potential Areas/Media of Concern

A summary of all media and areas of concern (AOCs) identified during the investigations at FRP-1 and FRP-2 are presented in Table 1.1 and illustrated in Figure 1.3. The 1994 RI report (ERM, 1994b) concluded that the following areas and media of concern should be evaluated further and/or addressed in the FS:

- AOC 2;
- AOC 5;
- AOC 6;
- AOC 7;
- AOC 10;
- AOC 16;
- Storm Sewer Catch Basins;
- Storm Sewer Outfall 003;
- Wetland Sediment; and
- Site-wide Groundwater.

Each of these areas and media of concern are addressed in this FS, as discussed in Section 1.6.

1.2.7 Impacted Groundwater Summary

Analysis of data obtained from 27 permanent overburden monitoring wells and three permanent deep monitoring wells (completed in the glacial till), as well as piezometers and temporary wells, indicates that groundwater in the overburden aquifer at the site contains VOCs and to a lesser extent semivolatile organic compounds (SVOCs), pesticides, PCBs, and inorganic compounds. Many of these constituents are present above New York State groundwater criteria. Based on the results of the RI, even though the presence of the

TABLE 1.1

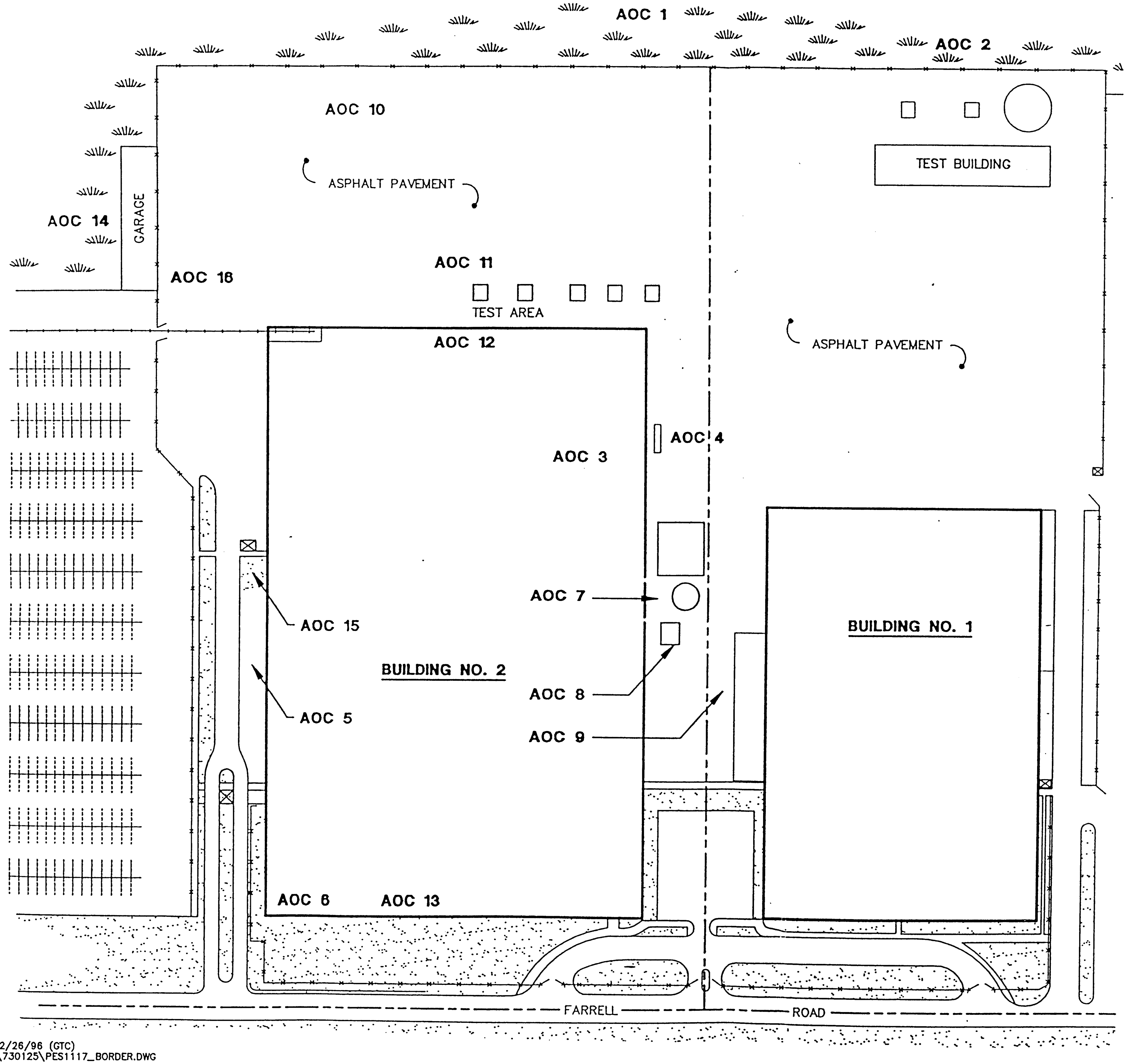
SUMMARY OF AREAS/MEDIA OF CONCERN
FORMER GE FARRELL ROAD PLANT

Area of Concern	Description	To Be Addressed in FS?	Comment
AOC 1	Debris Pile North of FRP-2	No	Impacted soil and fill at AOC 1 was excavated and disposed of as an IRM in 1992. No further action was deemed necessary in the 1994 RI Report (ERM, 1994b).
AOC 2	Septic Leach Field North of Test Building	Yes	Data suggest that asphalt fragments are a source of total petroleum hydrocarbons (TPH) in AOC 2 soils, and that asphalt is not likely to pose a significant threat to future construction workers, or be a significant source of groundwater contamination.
AOC 3	Former Aboveground Solvent Tanks in Northeast Corner of Building No. 2	No	No further action was deemed necessary in the 1994 RI Report (ERM, 1994b).
AOC 4	Removed Aboveground Tanks on East Side of FRP-2	No	No further action was deemed necessary in the 1994 RI Report (ERM, 1994b).
AOC 5	Removed USTs and Drywell on West Side of Building No. 2	Yes	An IRM consisting of NAPL recovery and an SVE system has been installed at AOC 5.
AOC 6	Printed Wire Board Assembly Area	Yes	Data suggest that chromium in AOC 6 soils will not become a significant source of groundwater contamination and that natural attenuation is sufficient as a final remedy.
AOC 7	Removed UST T-51	Yes	A free product recovery system is currently operating as an IRM at AOC 7.
AOC 8	Area of Freon Residuals	No	No further action was deemed necessary in the 1994 RI Report (ERM, 1994b).
AOC 9	Removed UST T-50	No	No further action was deemed necessary in the 1994 RI Report (ERM, 1994b).
AOC 10	Temporary Hazardous Material Storage Area	Yes	Since only low levels of soil contamination have been detected in AOC 10, groundwater contamination immediately downgradient is likely due to upgradient sources.

TABLE 1.1
(Continued)

SUMMARY OF AREAS/MEDIA OF CONCERN
FORMER GE FARRELL ROAD PLANT

Area of Concern	Description	To Be Addressed in FS?	Comment
AOC 11	Radar Test Area	No	No further action was deemed necessary in the 1994 RI Report (ERM, 1994b).
AOC 12	Paint Booth Area	No	No further action was deemed necessary in the 1994 RI Report (ERM, 1994b).
AOC 13	Chemical Laboratory and Associated Underground Septic Tank	No	No further action was deemed necessary in the 1992 Environmental Investigations (ERM, 1992a and 1992b).
AOC 14	Septic and Storm Drainage Headwall West of the Garage	No	No further action was deemed necessary in the 1994 RI Report (ERM, 1994b).
AOC 15	USTs Near Old Metal Finishing Room	No	No further action was deemed necessary in the 1992 Environmental Investigations (ERM, 1992a and 1992b).
AOC 16	Removed Gasoline UST Near the Garage	Yes	A groundwater pump and treat system and an SVE system are currently operating as IRMs at AOC 16. The pump and treat system is capturing groundwater contamination originating at AOC 16.
-	Storm Sewer Catch Basins	Yes	Removal of sediment and vacuuming and pressure washing of catch basins and piping was conducted as an IRM in September 1995. This IRM addressed PCB, pesticide, SVOC, and VOC contamination present in sediments located in catch basins and related storm sewer piping.
-	Storm Sewer Outfall 003	Yes	An IRM completed in August 1996 removed soil contaminated with PCBs from an area of the wetland near storm sewer Outfall 003.
-	Site-wide Groundwater	Yes	Groundwater COCs include chlorinated and non-chlorinated VOCs.
-	Wetland Sediment	Yes	Wetland remediation will only be considered in the context of preventing discharge of impacted groundwater from FRP-2 into the wetland. Any further wetland remedial action would likely result in more harm than benefit to the wetland.



AREAS OF CONCERN (AOC) TABLE	
AOC 1	DEBRIS PILE NORTH OF FRP-2
AOC 2	SEPTIC LEACH FIELD NORTH OF TEST BUILDING
AOC 3	FORMER ABOVE GROUND TANKS IN FRP-2
AOC 4	REMOVED ABOVE GROUND TANKS EAST SIDE OF FRP-2
AOC 5	REMOVED USTs AND DRYWELL WEST SIDE OF FRP-2
AOC 6	PRINTED WIRE BOARD (PWB) ASSEMBLY
AOC 7	REMOVED UST T-51
AOC 8	AREA OF FREON RESIDUALS
AOC 9	REMOVED UST T-50
AOC 10	TEMPORARY HAZARDOUS MATERIAL STORAGE AREA
AOC 11	RADAR TEST AREA
AOC 12	PAINT BOOTH AREA
AOC 13	CHEMICAL LABORATORY AND ASSOCIATED UNDERGROUND SEPTIC TANK
AOC 14	SEPTIC AND STORM DRAINAGE HEADWALL WEST OF THE GARAGE
AOC 15	USTs NEAR OLD METAL FINISHING ROOM
AOC 16	REMOVED GASOLINE UST NEAR THE GARAGE

LEGEND

ѡ ѡ	WETLAND AREA
▨	GRASS AREA

120' 60' 0 120'

Approximate Scale in Feet

FIGURE 1.3

FORMER GE
FARRELL ROAD SITE

AREAS OF CONCERN

PARSONS ENGINEERING SCIENCE, INC.
DESIGN • RESEARCH • PLANNING
290 ELWOOD DAVIS ROAD • SUITE 312 • LIVERPOOL, N.Y. 13088 • 315/451-9560
OFFICES IN PRINCIPAL CITIES

DATE: 12/26/96 (GTC)
H:\CAD\730125\PES1117_BORDER.DWG

H:\CAD\730125\PES1117 Thu Dec 26 09:27:48 1996 various parameters identified in the groundwater is apparently related to soil impacts at several AOCs, groundwater impacts are a site-wide issue. The extent of VOCs in groundwater is shown in Figure 1.4.

The highest groundwater concentrations of chlorinated VOCs, non-chlorinated VOCs, and petroleum hydrocarbons were detected at AOCs 5, 7, and 16. Identified VOCs include trichlorinated ethenes and ethanes, as well as associated degradation products; i.e. trichloroethene (TCE), 1,2-dichloroethene (1,2-DCE), vinyl chloride (VC), 1,1,1-trichloroethane (1,1,1-TCA), 1,1-dichloroethane (1,1-DCA), and 1,1-dichloroethene (1,1-DCE). Pesticides, PCBs, trichloromonofluoromethane (Freon II) and metals (primarily naturally high iron and manganese concentrations in unfiltered water samples and chromium at MW-19) have also been identified in site-wide groundwater, although at lower levels and less frequently than VOCs.

Monitoring wells and piezometers located in the wetland adjacent to the developed portion of the site show VOC concentrations above groundwater standards at MW-8, MW-17, MW-18, P-10S, P-18S, P-18D, P-19S, and P-19D. In addition, one monitoring well (MW-17) in the wetland contained pesticides at a concentration that slightly exceeded groundwater standards. No SVOCs or PCBs were detected at levels that exceed groundwater standards in the wetland (ERM, 1994b).

1.3 SUMMARY OF RISK ASSESSMENT RESULTS

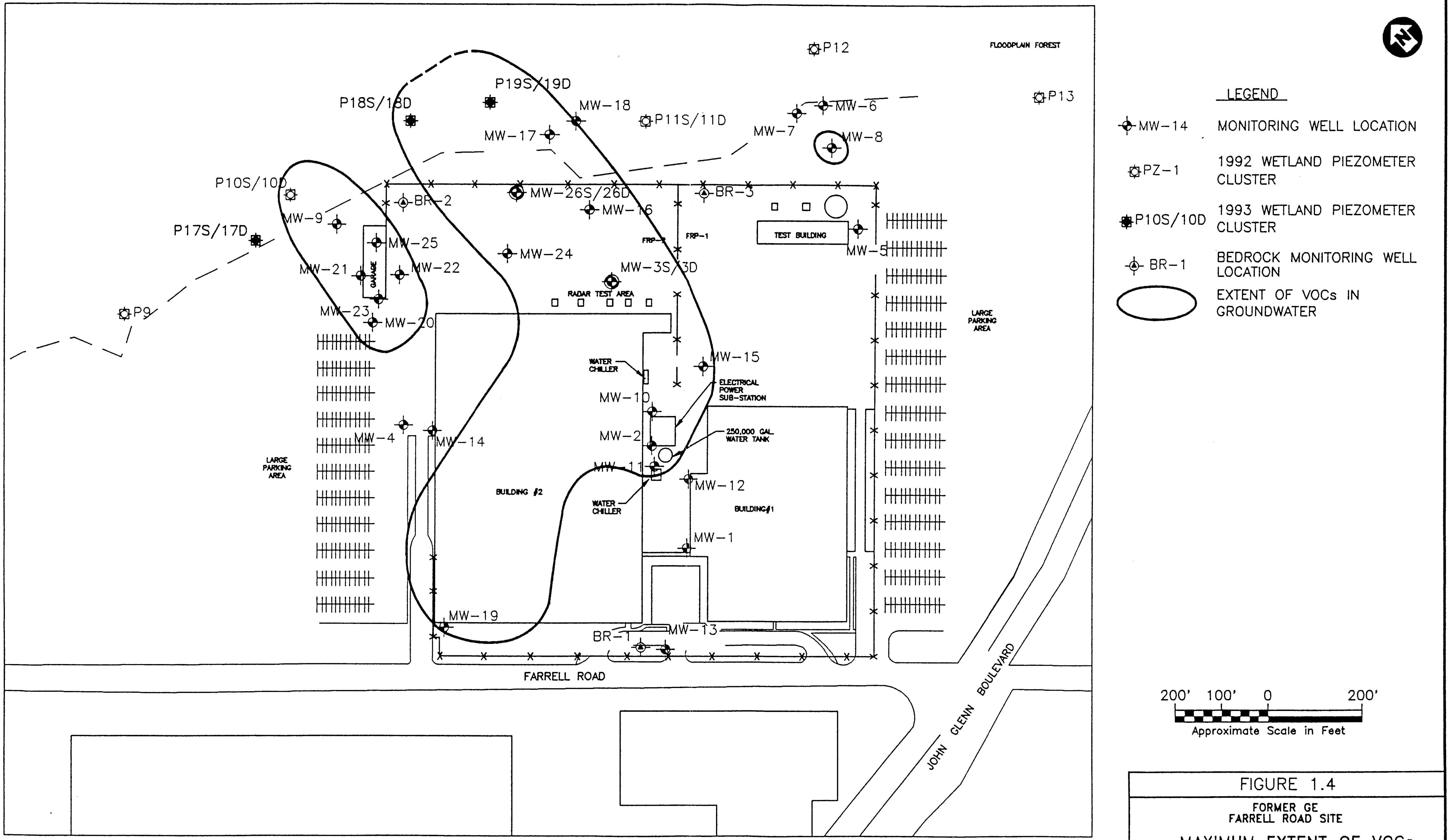
As part of the RI, a Qualitative Public Health Risk Assessment and a Fish and Wildlife Impact Analysis (FWIA) were conducted (ERM, 1994b).

1.3.1 Human Health Risk Assessment

The purpose of the Qualitative Public Health Risk Assessment was to characterize the potential risks to human health resulting from identified areas of impacted soil and groundwater at the site.

The risk assessment did not identify any significant exposure pathways at the site under current conditions. However, several potential exposure pathways were identified associated with: 1) future construction activities at the building portion of the site; and 2) future movement of affected groundwater towards the Seneca River.

The potential exposure pathways during future construction activities include: inhalation of volatile organics and direct contact with impacted site soils. These activities can potentially impact construction workers, site employees, and nearby residents. Nine VOCs and one inorganic analyte (1,1-DCA; 1,1,1-TCA; toluene, ethylbenzene; 4-methyl-2-pentanone; xylene; acetone, TCE; benzene; and cyanide) were identified in the soils of the site above the cleanup objectives of NYSDEC DHWR TAGM #4046. Future construction activities could potentially expose these affected soils.



NOTE: VOC EXTENT BASED ON AVAILABLE GROUNDWATER DATA 1992 THROUGH 1996.

DATE: 1/27/97 (JHG)
H:\CAD\730125\30125G01.DWG (PS = 1/200XP))

FIGURE 1.4

FORMER GE
FARRELL ROAD SITE

MAXIMUM EXTENT OF VOCs
IN GROUNDWATER

PARSONS ENGINEERING SCIENCE, INC.
DESIGN • RESEARCH • PLANNING
290 ELWOOD DAVIS ROAD • SUITE 312 • LIVERPOOL, N.Y. 13088 • 315/451-9560
OFFICES IN PRINCIPAL CITIES

The potential exposure pathways following future movement towards the Seneca River include: inhalation of volatile organics, and direct contact and ingestion of affected fish tissue from the surface water. These exposures can potentially impact nearby residents and recreational river uses. Seven VOCs and two inorganic analytes (1,1,1-TCA; toluene; ethylbenzene; xylene; acetone; TCE; benzene; copper; and manganese) were identified in the groundwater of the wetland above the New York State Department of Health drinking water levels. Sampling done in 1992 indicated that the surface water of the Seneca River has not been affected by site activity.

The above conclusions were based on the Qualitative Public Health Risk Assessment (ERM, 1994b). A quantitative public health risk assessment would be required to determine whether any of these potential exposure pathways present an unacceptable human health risk.

1.3.2 Fish and Wildlife Impact Analysis

The purpose of the FWIA was to identify fish and wildlife resources potentially affected by those site-related contaminants and to determine the impacts of site-related contaminants on those resources. Based on the results of the FWIA, concentrations of certain contaminants have been detected in surface water, shallow groundwater, and sediment in the wetland. There are no guidance values for the three contaminants detected in surface water. An evaluation determined that there appear to be no adverse chronic impacts to aquatic life due to the presence of these three contaminants in surface water. Thirty-seven contaminants were detected in shallow groundwater. Guidance values have been established for twenty-seven of these contaminants. Thirteen of the detected contaminants exceeded the guidance values. Nine of these contaminants (metals) are not related to the site. Nine organic compounds were detected in sediment. There are no guidance values established for four of these compounds. Of the five remaining compounds, the guidance value for one was exceeded.

Considered individually, based on best professional judgment, the presence of these contaminants does not appear to represent a significant environmental risk. However, when considering these contaminants along with the other detected organic compounds for which standards or guidance values do not exist, it is possible that additive and synergistic effects pose potential risk to fish and wildlife resources in the wetland. Although possible risks are presented due to additive and synergistic effects, no evidence of stressed biota or effects of additive or synergistic effects was observed in the wetland by biologists during site inspections completed as part of the FWIA. Provided the remaining source of contaminants to the wetland, that is, the migration of contaminated groundwater, is controlled at the northern edge of FRP-2, contaminant concentrations in the wetland are expected to attenuate, thereby reducing potential risks to ecological receptors.

Further investigation would be necessary to determine if actual impacts to ecological receptors exist as a result of additive and synergistic effects of the contaminants detected. However, because the migration of contaminated groundwater will be controlled at the northern edge of FRP-2, and because remediation of residual contamination in the wetland could itself impact this resource, there is no need for further investigation or remediation of surface water, groundwater or sediment in the wetland.

1.4 SUMMARY OF INTERIM REMEDIAL MEASURES

Prior to and since signing the Consent Order in December 1993, several IRMs have been implemented at the site to address areas of contamination associated with past industrial activities. IRMs are defined by the NYSDEC as short term, effective, and significant actions conducted at inactive hazardous waste sites that minimize potential environmental impacts and human health risks (TAGM HWR-91-4042: Interim Remedial Measures, dated February 12, 1992). The IRMs completed at the site are discussed in more detail in the following paragraphs.

1.4.1 AOC 1

AOC 1 was identified during the 1992 Environmental Investigation as a debris pile located north of FRP-2. Soil in this area was affected by VOCs and metals. An IRM was implemented at this location between May 25 and June 7, 1992. The IRM performed at AOC 1 involved the excavation and disposal of approximately 658 cubic yards of soil and fill material (ERM, 1992c).

1.4.2 AOC 5

AOC 5 was identified during the 1992 Environmental Investigation as the location of nine former underground solvent storage tanks and a drywell on the west side of Building No. 2. The soil and groundwater in the vicinity of AOC 5 was found to have elevated VOC concentrations. An IRM was conducted during the 1992 Environmental Investigation consisting of the excavation and disposal of the abandoned "paint drippings" drywell (ERM, 1992d).

Between October and December 1994, a Soil Vapor Extraction (SVE) system consisting of vapor recovery wells, air injection wells, and a vacuum blower along with associated piping was installed as an IRM to extract the VOCs from the impacted soils located adjacent to and under the building at AOC 5. This system has been operating continuously since November 1995.

During the LNAPL/DNAPL RI at AOC 5 in September and October of 1995, approximately 6 gallons of DNAPL were removed from vapor recovery well (VRW) VRW-203 and 1.7 gallons of LNAPL were removed from VRW-207. The DNAPL thickness observed at VRW-203 decreased from 2.3 feet on September 15, 1995 to 0.4 feet on October 30, 1995. The LNAPL thickness observed at VRW-207 decreased from 1.5 feet on September 15, 1995 to a barely discernible film by October 11, 1995 (BB&L, 1996a). The DNAPL at AOC 5 has been addressed through manual removal via a bottom-loading bailer at VRW-203. LMC began a DNAPL monitoring and recovery program at AOC 5 on a monthly basis in accordance with the August 27, 1996 approval from the NYSDEC. As of November 1996, approximately 7.76 gallons of product have been removed from VRW-203 (Parsons ES, 1996a) and no measurable DNAPL remains. Beginning in November 1996, manual DNAPL recovery efforts were discontinued to allow vapor extraction from VRW-203.

1.4.3 AOC 7

AOC 7 is the former location of an underground fuel oil storage tank, where past leakage resulted in the presence of a floating NAPL on the groundwater. A recovery well and an in-well passive collection device for free product recovery were installed in the area of the NAPL in November 1994. An active product-only recovery system was installed in March 1995, complete with an in-well pump, water and level sensors, and an aboveground recovered product storage drum. As of November 1996, approximately 117 gallons of product have been removed from AOC 7 (Parsons ES, 1996a).

1.4.4 AOC 11

AOC 11 was identified in the vicinity of the radar test area north of Building No. 2 during the 1992 Environmental Investigation. Three test pits were excavated in AOC 11 as part of an IRM conducted on July 29, 1992 (ERM, 1992d) and approximately 15 cubic yards of impacted soil were removed from the site.

1.4.5 AOC 16

AOC 16 is the former location of an underground gasoline storage tank near the former Maintenance Garage. Soil and groundwater contamination is due to gasoline-related VOCs such as benzene, toluene, ethylbenzene, and xylene. The IRM for this location is a combination of an SVE and a Groundwater Collection and Treatment (GCT) system which was completed in December 1994. This system has been operating continuously since December 1995. The SVE system includes vapor extraction wells, passive air injection wells, a vacuum blower, and associated piping and accessories. The objective of the SVE system at AOC 16 is to extract soil gas containing VOCs from impacted soil. The GCT components of the AOC 16 system includes three recovery wells with submersible pumps and level controls, bag filtration units, and a low-profile air stripper for removal of VOCs from impacted groundwater. The GCT system achieves two objectives: it recovers, treats, and discharges impacted groundwater and it also serves to depress the water table which enhances the capability of the AOC 16 SVE system. As of November 1996, the AOC 16 GCT system has treated approximately 568,816 gallons of groundwater (Parsons ES, 1996a).

1.4.6 Storm Sewer Catch Basins

Completed in September 1995, this IRM addressed PCB, pesticide, SVOC, and VOC contamination present in sediments located in catch basins and related storm sewer piping. The IRM consisted of the removal of sediments by manual methods and by vacuuming and pressure washing the catch basins and piping. Sediments and wash water were collected, containerized, characterized, and ultimately sent off-site for disposal.

1.4.7 Storm Sewer Outfall 003

This IRM, completed in August 1996, addressed PCBs and low levels of VOCs in soils adjacent to Storm Sewer Outfall 003. The extent of remediation was defined based on the areal extent of the identified PCB-impacted soil encompassing 3,550 square feet. The impacted soil was removed, transported off-site, and disposed. Site restoration was completed by replacing soil and trees removed during this IRM (Parsons ES, 1996b).

1.5 SUMMARY OF 1995 FS AND NYSDEC COMMENTS

1.5.1 Summary of Previous FS

Based on the results and conclusions of site remedial investigations, the 1995 FS (BB&L, 1995) considered the following areas and media:

- AOC 2 - Septic Leach Field North of Test Building;
- AOC 5 - Removed USTs and Drywell on the West Side of Building No. 2;
- AOC 6 - Printed Wire Board Assembly Area;
- AOC 7 - Removed UST T-51;
- AOC 16 - Removed Gasoline UST Near the Garage;
- Sediment present in specific storm sewer catch basins;
- Sediment in the wetlands near SS-08 and soils adjacent to storm sewer Outfall 003; and
- Site-wide groundwater that migrates toward the wetland.

The FS evaluated a full range of technologies and remedial alternatives for these areas and media to meet the following remedial objectives:

- Prevent off-site migration of affected site-wide groundwater to protect and prevent degradation of surface water quality;
- Prevent off-site migration of affected site-wide groundwater to minimize potential risks to hypothetical future river users;
- Address the AOC soils to reduce and/or eliminate future impacts to groundwater quality; and
- Address the AOC soils to minimize risks to hypothetical future construction workers.

Based on the detailed evaluation of alternatives, the 1995 FS conclusions and recommendations to meet these remedial objectives were:

- No further action is necessary for the storm sewer catch basins and AOC 2, AOC 5, AOC 6, and AOC 16 to achieve the remedial action objectives established for the site;
- The need for remedial action of sediment in the wetlands near SS-08 and soils adjacent to storm sewer Outfall 003 will be evaluated as an addendum to the FS following NYSDEC approval of an RI Report Addendum related to soil and sediment at these locations;
- A bioventing system should be implemented at AOC 7 to address residual soil petroleum hydrocarbon contamination; and
- Natural attenuation will address site-wide groundwater contamination and is the recommended remedial alternative for site-wide groundwater.

1.5.2 Summary of NYSDEC Comments

The NYSDEC provided comments to the 1995 FS via letter correspondence, telephone conversations, and meetings with LMC. Significant NYSDEC comments which necessitated the preparation of this revised FS include:

- The recommended alternative for groundwater contamination, natural attenuation, is not acceptable to the NYSDEC;
- The scope of the FS should include evaluation of measures to prevent migration of impacted groundwater into the wetland;
- Site remedial action objectives must include:
  a) Achievement of groundwater standards, where practical;
  b) Protection of future on-site workers; and
  c) Protection of the Class I wetland.
- The passive treatment wall and hydraulic containment alternatives discussed in the FS should be reconsidered based on a width limited to the area north of FRP-2; and
- It is not appropriate to dismiss further consideration of alternatives to address soils at AOC 5 until the results of the NAPL investigation are available.

These NYSDEC comments, as well as more specific comments on individual sections of the 1995 FS, have been incorporated, where applicable, in this FS.

1.6 AREAS AND MEDIA OF CONCERN ADDRESSED IN THE FS

As summarized in Section 1.2.6, the areas and media of concern which are addressed in this FS are:

- AOC 2;
- AOC 5;
- AOC 6;
- AOC 7;
- AOC 10;
- AOC 16;
- Storm Sewer Catch Basins;
- Storm Sewer Outfall 003;
- Wetland Sediment; and
- Site-wide Groundwater.

Each of these areas of concern are discussed in detail below.

1.6.1 AOC 2 - Septic Leach Field

AOC 2, located north of the Test Building, formerly contained a septic tank and associated leach field, both of which have been removed. During the removal of the septic tank, asphalt and brick fill material were identified.

Total petroleum hydrocarbons (TPH), several pesticide compounds, and one PCB compound were identified in soil samples collected from AOC 2. Pesticide and PCB compounds, however, have not been identified in groundwater samples taken from monitoring wells located either upgradient (MW-5) or downgradient (MW-6, MW-7, and MW-8) of AOC 2 (ERM, 1994b). In addition, due to the low solubility of pesticides and the infrequent detection at low levels of both pesticides and PCB compounds in AOC 2 soils, pesticides and PCBs in AOC 2 soils are not expected to pose a significant risk to human health and/or the environment.

The presence of asphalt fragments, the characterization of sample soils as "fill," and the absence of other activities in the area that could release TPH to the soil indicate that the asphalt fragments are a source of the TPH identified in the soils at AOC 2. Since asphalt is composed primarily of SVOC hydrocarbons, it is likely that the TPH identified in the samples consists of SVOCs.

Asphalt is not considered to be a hazardous substance, nor is its presence considered a threat to groundwater quality. A recent study found virtually no partitioning of asphalt constituents to groundwater (as measured by Toxicity Characteristic Leaching Procedure [TCLP] testing), and concluded that reclaimed asphalt pavement (RAP) is suitable for use as clean fill material (Kriech, 1991). In addition, no SVOCs have been identified in groundwater samples obtained from monitoring wells either upgradient (MW-5) or downgradient (MW-6, MW-7, and MW-8) of AOC 2, as would be expected if the AOC 2 soils were acting as a source of these constituents to site-wide groundwater.

The data suggest that the asphalt fragments, the septic tank and the leach field identified in AOC 2 are a source of the TPH readings detected in AOC 2 soils. Asphalt is not likely to pose a significant threat to future construction workers, or be a significant source of site-wide groundwater contamination. Also, the 1992 Environmental Investigation and 1994 RI indicate that TPH is not migrating into the wetlands, indicating that the source of TPH has been removed. Therefore, no further action is deemed necessary at AOC 2 to address TPH contamination. Several chlorinated VOCs were detected in MW-8 downgradient of AOC 2. However, the 1992 Environmental Investigation concluded that the source of VOCs was a one-time release to the septic system, the release has had a minimal effect on groundwater, and no residual source exists near the septic leach field. Therefore, no further action is deemed necessary at AOC 2 and it will not be considered further in this FS.

1.6.2 AOC 5 - Removed USTs and Drywell

AOC 5, located on the west side of Building No. 2, formerly contained up to nine solvent USTs, as well as a paint drippings drywell. The USTs were removed in 1986 and the dry well was removed in 1992. During subsurface investigations in the vicinity of the former solvent tanks and dry well (ERM, 1992), residual solvents were observed to be present in the soil based on field screening and laboratory analysis. LNAPL was observed at the approximate depth of the water table at borings and test pits installed near the location of the former solvent tanks. Soil sampling and analysis and a soil gas survey indicated elevated VOC concentrations, including chlorinated and aromatic hydrocarbons, in the soil. Groundwater samples obtained upgradient (west) of the former tank locations contained only trace VOC concentrations. However, downgradient of the tanks, beneath the building, a suite of dissolved VOCs was detected similar to those in the vicinity of the former tanks. Geologic characterization based on soil borings indicated a till consisting of dense, red silt, and clay located approximately 7 to 12 feet below grade. The till surface, which dips toward the south, was interpreted as a confining layer. Following the installation of the IRM vapor recovery and air injection wells for the SVE system in October 1994, free phase LNAPL was observed at four of the wells.

To further investigate the nature and extent of NAPL at AOC 5, an LNAPL/DNAPL investigation was completed in November 1995. The areal NAPL extent based on this investigation is shown in Figure 1.5 (BB&L, 1996). Based on three LNAPL samples and one DNAPL sample, the NAPL chemical mole fractions are:

Compound	Average LNAPL Mole Fraction	Average DNAPL Mole Fraction
1,1,1-TCA	10%	35%
Toluene	36%	53%
Ethylbenzene	8%	2%
Xylenes	46%	10%
TCE	ND	0.4%

As detailed in Section 1.4, an IRM SVE system is in operation at AOC 5, and no measurable NAPL remains. The need for remedial action at AOC 5 will be impacted by the remedy selected for site-side groundwater and, therefore, AOC 5 will be addressed further in Section 7 of this FS.

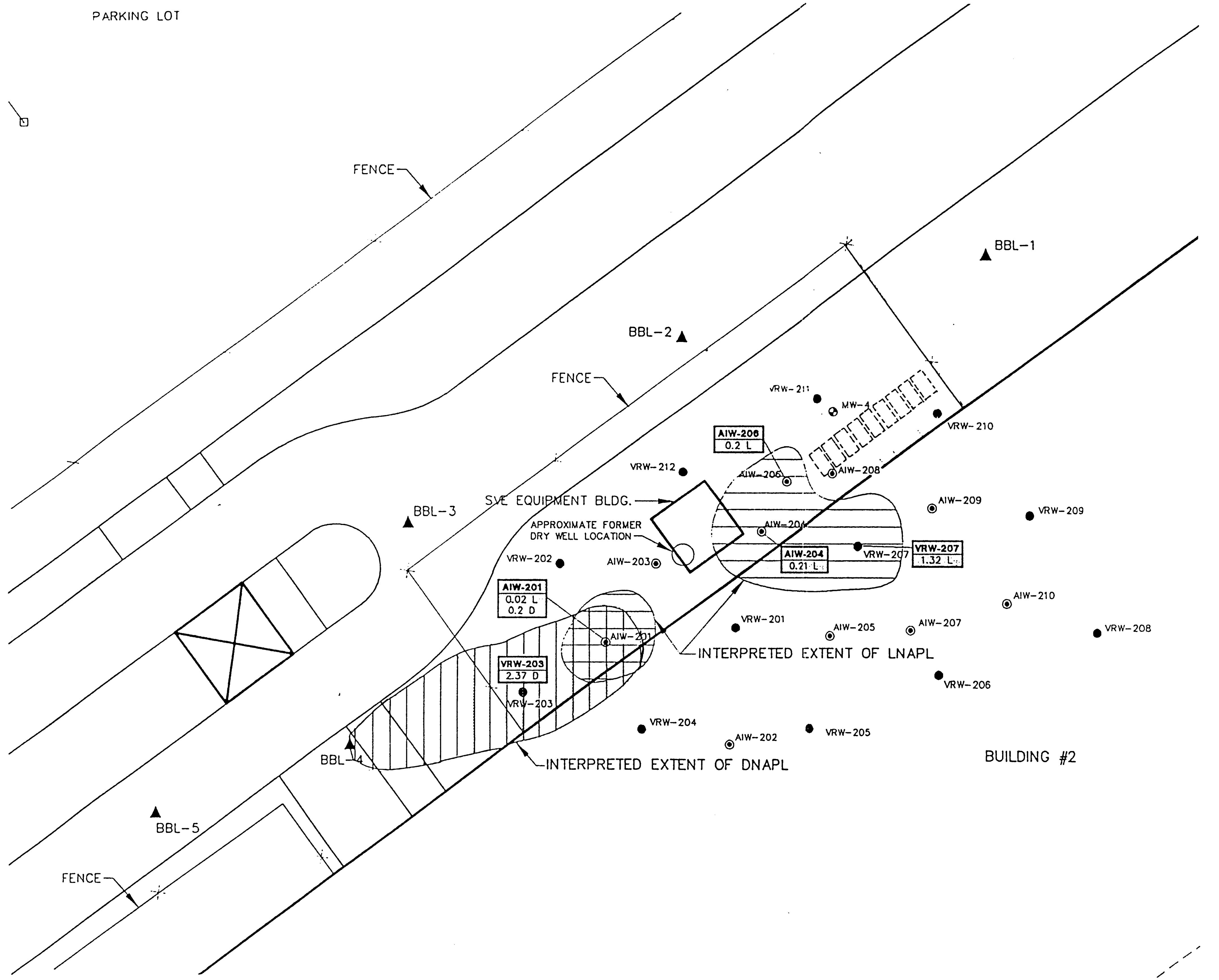
1.6.3 AOC 6 - Printed Wire Board Assembly Area

AOC 6 is located at the southwest corner of Building No. 2. Former plant operations within the building interior near this area included a printed wire board assembly area, a metal plating area, a copper etching bath, and four USTs. Analytical results indicate the presence of elevated levels (in comparison to background concentrations) of chromium in the soil at AOC 6, as well as elevated concentrations of chromium and TCE in the groundwater.

As discussed in the July 14, 1995 correspondence from MMC to the NYSDEC (MMC, 1995), site-specific conditions indicate that chromium in AOC 6 soils will not become a significant source of groundwater contamination, and that existing conditions are therefore sufficient as a final remedy for AOC 6. NYSDEC agreed with this assessment in their response dated August 9, 1995 (NYSDEC, 1995c). Based on the recommendations of this correspondence and the occurrence of natural attenuation at AOC 6, no further action is deemed necessary at AOC 6 and it will not be considered further in this FS.

1.6.4 AOC 7 - Former Underground Storage Tank T-51

AOC 7 is the site of a former 10,000 gallon fuel oil UST located along the east side of Building No. 2. The tank and associated piping were removed in February 1992.



SOURCE REFERENCE: BLASLAND, BOUCK & LEE, INC.
AOC#5 LNAPL/DNAPL INVESTIGATION
38081001/38081B01.DWG

DATE: 12/26/96 (GTC)
H:\CAD\730125\30125G01.DWG (M/P SPACE)

LEGEND

⊘ MONITORING WELL (MW)
◉ AIR INJECTION WELL (AIW)
● VAPOR RECOVERY WELL (VRW)
▲ LNAPL/DNAPL INVESTIGATION SOIL BORING

NAPL THICKNESS (FT):

AIW-201 — WELL NUMBER
0.02 L — LNAPL THICKNESS
0.20 D — DNAPL THICKNESS

NOTES:

1. BASE MAP PREPARED FROM D.W. HANNIG L. S., P.C. SURVEY DRAWING NUMBER J955493, DATED 5/10/95; PHOTOCOPY OF ERM DRAWING NUMBER P-2, DATED 9/93; PHOTOCOPY OF ERM DRAWING ENTITLED "LOCATIONS OF PNEUMATIC OBSERVATION WELLS AND VACUUM EXTRACTION WELL", DATED 10/93 AND MEASUREMENTS BY BBL FIELD PERSONNEL.
2. ALL LOCATIONS ARE APPROXIMATE.
3. TANK INFORMATION FROM HISTORIC GE PLANS (DRAWING PL-1602 DATED 9/28/91 AND PL-2085 DATED 7/17/85).
4. NAPL THICKNESSES PLOTTED REFLECT MAXIMUM THICKNESS OBSERVED 9/25/95. THE OTHER AIW AND VRW WELLS WERE ALSO MONITORED, BUT CONTAINED NO MEASURABLE LNAPL OR DNAPL.

20' 10' 0 20'
Approximate Scale in Feet

FIGURE 1.5

FORMER GE
FARRELL ROAD SITE

NAPL THICKNESS SUMMARY

PARSONS ENGINEERING SCIENCE, INC.
DESIGN • RESEARCH • PLANNING
290 ELWOOD DAVIS ROAD • SUITE 312 • LIVERPOOL, N.Y. 13088 • 315/451-9560
OFFICES IN PRINCIPAL CITIES

H:\CAD\730125\30125G01 Thu Dec 26 10:27:20 1996

Analytical results from soil samples collected during the 1992 and 1994 investigations did not identify significant petroleum contamination, indicating AOC 7 soil contamination is not widespread. However, a limited free-phase floating petroleum layer has been identified at MW-2 and a free product recovery system is currently operating at this well as an IRM. Groundwater analytical results from vicinity monitoring wells MW-2, MW-10, and MW-11 indicate that the free product is serving as a minor source of petroleum hydrocarbon contamination. The need for remedial action at AOC 7 will be impacted by the remedy selected for site-wide groundwater and, therefore, AOC 7 will be addressed further in Section 7 of this FS.

1.6.5 AOC 10 - Temporary Hazardous Materials Storage Area

AOC 10 is an area within the parking lot north of Building No. 2 where GE temporarily stored drums of hazardous materials. Based on elevated readings during the 1992 soil gas survey (ERM, 1992), soil samples were collected at AOC 10 during the 1992 Environmental Investigation and 1994 RI. VOC contamination in soil in excess of NYSDEC criteria designed to be protective of groundwater was detected in only 2 of the 13 samples in this area, as presented in the NYSDEC-approved AOC 10 RI Report Addendum submitted in a July 21, 1995 letter from LMC to the NYSDEC. This RI Report Addendum concluded that ground water in AOC 10 may be affected by more than one upgradient and crossgradient sources and one previously removed proximal source (AOC 1, the debris pile); that there is no source of organic compounds in the shallow soil of AOC 10; and the probable source of organic compounds identified at depth is associated with other releases at other areas of concern. The RI Report Addendum concluded that there are no exceedances of action levels for soil in AOC 10 and no further evaluations or investigations are warranted. Therefore, no further action is deemed necessary with respect to AOC 10 and it will not be considered further in this FS.

1.6.6 AOC 16 - Former UST Near the Maintenance Garage

AOC 16 is the area associated with the former gasoline storage tank near the maintenance garage. In June of 1992, UST T-68 was removed from this area. There was no evidence of release from this tank. However, this tank was installed in 1986 to replace two USTs of unknown integrity.

Previous investigations have demonstrated the presence of elevated levels of petroleum hydrocarbons in both the soil and groundwater in this area. As discussed in Section 1.4, a combined SVE system and groundwater pump-and-treat system is currently in operation at AOC 16 as an IRM. The need for further remediation at AOC 16 will be impacted by the remedy selected for site-wide groundwater and, therefore, AOC 16 will be addressed further in Section 7 of this FS.

1.6.7 Storm Sewer Catch Basins

Sediment samples collected from storm sewer catch basins indicated the presence of VOCs, SVOCs, pesticides, and PCBs. To address this issue, storm sewer catch basin sediments were removed and disposed of off-site and the catch basins and associated piping were pressure washed as an IRM in September 1995. The IRM certification report (dated

December 1995) for this activity was approved by NYSDEC, indicating no further activity is necessary to address the storm sewer catch basins. Therefore, the storm sewer catch basins are not addressed further in this FS.

1.6.8 Storm Sewer Outfall 003

Soil samples collected in the wetland adjacent to storm sewer Outfall 003 were found to be contaminated with PCBs. To address this contamination, an IRM was completed in August 1996 consisting of excavation and off-site disposal of PCB-impacted soils. Following soil removal, the wetland area was revegetated and trees were planted to replace those removed during the excavation. The IRM certification report (dated October 1996) for this activity was approved by NYSDEC, indicating no further activity is necessary to address storm sewer Outfall 003. Therefore, storm sewer Outfall 003 is not addressed further in this FS.

1.6.9 Wetland Sediments

As part of the RI, wetland sediments north of FRP-2 were found to be impacted with low concentrations of VOCs. None of the VOCs were present in excess of the screening criteria developed in the RI to be protective of aquatic life. This contamination is apparently due to the discharge of groundwater into the wetland which has been impacted by upgradient source areas. Therefore, wetland sediments will be addressed further in Section 7 of this FS.

1.6.10 Site-wide Groundwater

As presented in Section 1.2.7, site-wide groundwater has been found to contain contaminant levels in excess of NYSDEC groundwater quality criteria. This includes groundwater underlying FRP-2 and a portion of the wetland north of FRP-2. Therefore, this FS focuses on selecting a remedial alternative for site-wide groundwater. As defined by the NYSDEC in a March 25, 1996 letter to LMC, site-wide groundwater remediation is restricted to the area north of FRP-2. The low levels of groundwater contamination at MW-8 north of FRP-1 do not require further evaluation or remediation as described in detail in Section 1.6.1.

1.6.11 Summary

As discussed above, this FS focuses on selecting a remedial alternative for site-wide groundwater. Following selection of a remedial alternative for site-wide groundwater, the need for remedial action at AOC 5, AOC 7, AOC 16, and in wetland sediments will be addressed. No further action or evaluation is necessary for AOC 2, AOC 6, AOC 10, storm sewer catch basins, and storm sewer Outfall 003.

1.7 FS REPORT ORGANIZATION

This FS is organized into the following seven sections and four appendices:

Section 1 Introduction
Section 2 Development of New York State Standards, Criteria, and Guidelines
Section 3 Remedial Action Objectives

Section 4	Development and Screening of Site-wide Groundwater Remedial Technologies
Section 5	Detailed Evaluation of Remedial Alternatives
Section 6	Comparative Analysis of Remedial Alternatives
Section 7	Impact of Selected Site-wide Groundwater Alternative on AOCs and IRM Operation
Appendix A	References
Appendix B	August 1996 Groundwater Sampling and Analysis Program and Natural Attenuation Evaluation
Appendix C	Groundwater Model Results
Appendix D	Remedial Alternative Cost Estimates

SECTION 2

DEVELOPMENT OF NEW YORK STATE STANDARDS, CRITERIA, AND GUIDELINES

2.1 GENERAL

This FS was conducted in conformance with the guidelines, criteria, and considerations set forth in the NCP, SARA, and the USEPA guidance document entitled "Guidance for Conducting Remedial Investigations and Feasibility Studies under CERCLA" (USEPA, 1988). Consistent with the CERCLA/SARA/NCP framework is the requirement that remedial actions comply with legally Applicable or Relevant and Appropriate Requirements (ARARs). New York State does not use ARARs in its statutes, but instead uses New York State Standards, Criteria, and Guidelines (SCGs) as presented in the NYSDEC Technical and Administrative Guidance Memorandum (TAGM) #HWR-90-4030 (NYSDEC, 1990). This section describes the SCGs that have been identified for site-wide groundwater.

The SCGs considered for the potential site-wide groundwater remedial actions identified in this FS were categorized into the following NYSDEC-recommended classifications:

- Chemical-specific SCGs (e.g., action levels applicable to a given substance);
- Location-specific SCGs (e.g., sitting restrictions due to wetlands, historical sites, and other location-related resources); and
- Action-specific SCGs (e.g., design and performance standards for particular facilities or units).

Each of these SCGs are discussed in more detail in the following sections.

2.2 IDENTIFIED STANDARDS, CRITERIA, AND GUIDELINES

The establishment of SCGs for the evaluation of site-wide groundwater remedial alternatives was a progressive, multi-step process which included evaluating the results of the Qualitative Public Health Risk Assessment (ERM, 1994b). In addition to SCGs, there are "to be considered" items, or TBCs. TBCs include guidance documents, advisory criteria, and guidelines issued by organizations other than federal or state agencies that are not promulgated or binding under federal or state law, and do not have the status of SCGs. However, such guidance may be considered appropriate for protection of human health and the environment, and are evaluated along with SCGs in determining the appropriate cleanup objectives for the site. The SCGs identified for the site are discussed below and presented in Tables 2.1, 2.2, and 2.3 for chemical-specific, location-specific, and action-specific SCGs respectively.

2.2.1 Chemical-Specific SCGs

Chemical-specific SCGs are health-based or risk-based concentration limits, goals, or ranges in various environmental media for specific hazardous substances, pollutants, or contaminants. Chemical-specific SCGs include remediation goals for chemicals of concern in designated media (such as soil or groundwater) which can be used in the development of remedial action objectives for contaminated media at a site.

Statutes and guidance used in the identification of chemical-specific SCGs for the site are listed in Table 2.1.

2.2.2 Location-Specific SCGs

Location-specific SCGs are restrictions placed on the concentration of hazardous substances or the conduct of activities solely because they are in specific locations. Examples of location-specific SCGs include restrictions on land development activities in floodplains, wetlands, coastal zones, and navigable waters of the United States; restrictions to protect critical habitats for endangered or threatened species; restrictions on activities in areas designated as wilderness, wildlife refuges or sole-source aquifers for drinking water; and restrictions to preserve historic structures and properties.

Based on a review of the Federal Emergency Management Agency (FEMA) Floodway Flood Boundary and Floodway Map for the Town of Geddes, Community Panel Number 360579 001 effective February 17, 1982, floodplain regulations need to be considered for the site. Although the developed portion of the site is located outside the regulated 100-year flood boundary, the non-developed portion of the site lies within the 100-year flood plain.

No significant habitat or endangered or threatened species were identified at the site during the RI; therefore, regulations promulgated pursuant to the Endangered Species Act are not considered SCGs for the site. A NYSDEC-regulated Class I freshwater wetland of approximately 80 acres is located in the northern non-developed portion of the site and is designated as a flood control area of the New York State Barge Canal System; therefore, wetland SCGs will be considered for the site. No wild and scenic rivers are located within 2 miles of the site; therefore, regulations promulgated pursuant to the Wild and Scenic Rivers Act are not considered SCGs for the site.

Statutes, regulations, and guidelines used in the identification of location-specific SCGs for the site are listed in Table 2.2.

2.2.3 Action-Specific SCGs

Action-specific SCGs are technology- or activity-based requirements or limitations pertaining to waste remediation. These SCGs are triggered by, and apply to, the implementation of the particular remedial activities that are selected to accomplish the remedy at the site. Statutes, regulations, and guidelines used in the identification of action-specific SCGs for the site are listed in Table 2.3.

TABLE 2.1
STATUTES, REGULATIONS, AND GUIDELINES USED IN THE IDENTIFICATION OF CHEMICAL-SPECIFIC SCGs

REQUIREMENTS	CITATION	DESCRIPTION	SCG or TBC	COMMENT
FEDERAL				
Clean Water Act (CWA)	33 U.S.C. Section 1251-1376			
Ambient Water Quality Criteria Guidelines	40 CFR Part 131	Establishes toxicity-based surface water quality criteria for protection of aquatic organisms and human health.	SCG	Ambient water quality criteria would be potentially applicable in establishing remedial action objectives for surface water.
Soil Screening Guidance: Technical Background Document	EPA/540/R-95/128 May 1996	Provides a methodology to calculate risk-based, site-specific, soil screening levels (SSLs) for contaminants in soil that may be used to identify areas needing further investigation at National Priorities List (NPL) sites.	SCG	SSLs are not national cleanup standards. Where contaminant concentrations exceed SSLs, further study, but not necessarily cleanup, may be warranted.
STATE				
New York State Environmental Conservation Law				
Inactive Hazardous Waste Disposal Sites	Article 27, Title 13	Establishes general cleanup goals for environmental media to levels that will eliminate a significant threat to the environment. This allows the NYSDEC to designate inactive hazardous waste disposal sites.	SCG	Sites are listed based on evidence of a significant threat posed by hazardous waste disposed of at the site. A significant adverse impact on the environment and/or a significantly increased risk to human health would constitute a significant threat.
NYSDEC Determination of Soil Cleanup Objectives and Cleanup Levels	TAGM 4046 January 24, 1994	Provides a basis and procedure (i.e. soil-water partitioning model) to determine soil cleanup levels at Inactive Hazardous Waste Sites. Their objective is to eliminate significant human and/or environmental health threats associated with the Inactive Hazardous Waste Site.	SCG	These cleanup objectives are potentially applicable in establishing remedial action objectives for soil.
NYSDEC Technical Guidance for Screening Contaminated Sediments	Division of Fish and Wildlife Divison of Marine Resources November, 1993	Describes the methodology for establishing sediment criteria for the purpose of identifying contaminated sediment potentially causing harmful impacts to marine and aquatic ecosystems.	SCG	These criteria are potentially applicable in establishing remedial action objectives for sediment.

TABLE 2.1
STATUTES, REGULATIONS, AND GUIDELINES USED IN THE IDENTIFICATION OF CHEMICAL-SPECIFIC SCGs

REQUIREMENTS	CITATION	DESCRIPTION	SCG or TBC	COMMENT
New York State Water Classifications and Quality Standards				
Surface Water Classifications and Standards for Class C Waters	6 NYCRR Parts 701, 702, 704	Defines surface water classifications and ambient water quality standards that are the basis for establishing effluent limitations under the SPDES program.	SCG	These criteria are potentially applicable in establishing remedial action objectives for surface water and defining water body classifications.
Groundwater Quality Standards	6 NYCRR Part 703.5	Establishes quality standards for groundwater and incorporates federal and state MCLs.	SCG	These criteria are potentially applicable in establishing remedial action objectives for groundwater.
NYSDEC Ambient Water Quality Standards and Guidance Values	Division of Water Technical and Operational Guidance Series (TOGS) 1.1.1	Provides a compilation of ambient water quality standards and guidance values for toxic and non-conventional pollutants for use in NYSDEC programs, including the SPDES permit program.	SCG	These standards are applicable in establishing remedial action objectives for surface water and groundwater.
New York State Ambient Air Quality Standards	6 NYCRR Part 257 Air-Guide-1	Establishes state ambient air quality standards and guidelines for evaluating air quality impacts.	SCG	These standards are to be considered in establishing remedial action objectives for air.
NYSDEC Petroleum-Contaminated Soil Guidance Policy	Spill Technology and Remediation Series (STARS) Memo #1 (August 1992)	Provides direction on the handling, disposal and/or reuse of non-hazardous petroleum-contaminated soils. Also constitutes a determination of beneficial use by the NYSDEC as defined in NYCRR Part 360.	SCG	These criteria are potentially applicable in establishing remedial action objectives for petroleum-contaminated soil.
OTHER				
Standard Guide for Risk-Based Corrective Action Applied at Petroleum Release Sites	ASTM E 1739-95 Petroleum Release Sites	Emphasizes the application of risk-based corrective action to petroleum product releases through the use of examples.	TBC	Potentially applicable in evaluation the actual and potential impacts of petroleum releases to environmental receptors.

TABLE 2.2
STATUTES, REGULATIONS, AND GUIDELINES USED IN THE IDENTIFICATION OF LOCATION-SPECIFIC SCGs

LOCATION	REQUIREMENTS	CITATION	DESCRIPTION	SCG or TBC	COMMENT
FEDERAL					
Wetlands	Clean Water Act (CWA) Section 404 Dredge and Fill in Wetlands	33 U.S.C. 1344 33 CFR Parts 320-330 40 CFR Part 230	Discharge of dredge or fill material into wetlands are regulated by permit.	SCG	Potentially applicable to remedial actions resulting in a discharge of fill or dredged material into wetlands.
	Executive Order 11990 Protection of Wetlands	40 CFR Part 6 Subpart A	Executive Order 11990 activities taking place within wetlands must be done to avoid adverse impacts.	SCG	Potentially applicable to remedial actions taking place within wetlands.
Waters of the United States	Clean Water Act (CWA) Section 404 Discharge of Dredge or Fill Materia into Waters of the United States	33 U.S.C. 1344 33 CFR Parts 320-330 40 CFR Part 230	Discharges must be authorized in accordance with Section 404. Activities may qualify for a Nationwide permit authorized by the District Engineer of the USACOE.	SCG	Potentially applicable to remedial activities resulting in a discharge of fill or dredged material into waters of the United States.
Stream or River Area	Fish and Wildlife Coordination Act Modification to Waterways that Affects Fish or Wildlife	16 U.S.C. 661 40 CFR 6.302	Actions must be taken to protect fish or wildlife when diverting channeling, or otherwise modifying a stream or river.	SCG	Potentially applicable to remediation activities that would result in modifications to a stream or river.
	Rivers and Harbors Act 1899 Section 10 Obstruction or Alteration of Naigable Waters of the U.S.	33 U.S.C. Section 403 33 CFR Parts 320-330	Permit required for structures or activities that will affect navigable waters of the United States.	SCG	Potentially applicable to remedial actions that would obstruct or alter navigable waters.
STATE					
Wetlands	New York State Freshwater Wetlands Act New York Freshwater Wetlands Implementation Program	ECL Article 24 and 71 6 NYCRR Parts 662-665	Activities in wetlands areas must be conducted to preserve and protect wetlands. Includes Freshwater Wetlands Permit Requirements Regulations.	SCG	Potentially applicable to remedial actions conducted in or adjacent to a wetlands.
Waters of New York State	Protection of Waters Program	6 NYCRR Part 608	Protection of Waters permit program regulates: (1) any disturbance of the bed or banks of a protected stream or watercourse, (2) construction and maintenance of dams, and (3) excavation or fill in navigable waters of the State.	SCG	Potentially applicable to remediation activities that would result in modifications (temporary or permanent) to a stream or river or to excavation and fill activities in navigable State waters.

TABLE 2.3
STATUTES, REGULATIONS, AND GUIDELINES USED IN THE IDENTIFICATION OF ACTION-SPECIFIC SCGs

ACTION	REQUIREMENTS	CITATION	DESCRIPTION	SCG or TBC	COMMENT
FEDERAL					
Any Site Remediation Activity	Occupational Health and Safety Act	29 U.S.C. Section 651-678			
	Worker Health and Safety	29 CFR 1910.120	Training, personnel protection, medical monitoring, and other health and safety requirements for employers and employees engaged in hazardous waste site operations.	SCG	These regulations are potentially applicable to remedial activities associated with site wastes identified as hazardous and to remedial activities involving construction.
		29 CFR 1926	Standards for general construction.		
Management of Hazardous Waste Generated Offsite	Resource Conservation and Recovery Act (RCRA)	42 U.S.C. Section 6901 et. seq.			
	Standards for Hazardous Waste Generators; Manifesting, Pre-transportation, Reporting Requirements	40 CFR Part 262 Subparts B, C, D	Regulations governing packaging, labeling, reporting, and manifesting of hazardous waste.	SCG	These generator requirements are potentially applicable to remedial activities involving the offsite transport of hazardous waste generated onsite.
Institutional Controls	Resource Conservation and Recovery Act (RCRA)	40 U.S.C. Section 6901 et. seq.			
	Land Disposal Facility Notice in Deed	40 CFR 264/265 116-119(b)(1)	Establishes provisions for a deed notation for closed hazardous waste disposal units, to prevent land disturbance by future owners.	SCG	These regulations are potentially applicable because closed areas may be similar to closed RCRA units but this site is not regulated under RCRA.
Generation, Management, and Treatment of Hazardous Waste	Resource Conservation and Recovery Act (RCRA) Subtitle C - Hazardous Waste Management	40 U.S.C. Section 6901 et. seq.			
	Identification and Listing of Hazardous Wastes	40 CFR Part 261	Outlines criteria for determining if a solid waste is a hazardous waste and is subject to regulation under 40 CFR Parts 260-266.	SCG	These regulations do not set clean-up standards, but are potentially applicable during various remedial actions which generate solid waste.
	Standards for Hazardous Waste Generators	40 CFR Part 262			
	Hazardous Waste Determinations	40 CFR Part 262.11	Generators must characterize their wastes to determine if the waste is hazardous by listing (40 CFR 261, Subpart D), by characteristic (40 CFR 261, Subpart C), or excluded from regulation (40 CFR 261.4).	SCG	These regulations are potentially applicable to wastes generated during remedial activities at the site.
	90-Day Accumulation Rule	40 CFR Part 262.34	Allows generators of hazardous waste to store and treat hazardous waste at the generation site for up to 90 days in tanks, containers, and containment buildings without having to obtain a RCRA hazardous waste permit.	SCG	These regulations are potentially applicable to wastes generated during remedial activities at the site.

TABLE 2.3
STATUTES, REGULATIONS, AND GUIDELINES USED IN THE IDENTIFICATION OF ACTION-SPECIFIC SCGs

ACTION	REQUIREMENTS	CITATION	DESCRIPTION	SCG or TBC	COMMENT
Generation, Management, and Treatment of Hazardous Waste (cont.)	Standards for Owners/Operators of Hazardous Waste Treatment, Storage, Disposal (TSD) Facilities	40 CFR Part 264/265			
	General Facility Standards	Subpart B	General requirements for owners/operators of TSD facilities including general waste analysis and compatability; notices and inspection requirements; location and construction standards; and security.	SCG	These subpart standards are potentially applicable for the construction, operation or closure of a new or currently permitted TSD facility used for management of remediation waste classified as a hazardous waste or for the closure of existing interim-status and new land disposal facilities where hazardous waste will remain in place after completion of closure. These subparts are potentially applicable if existing waste treatment facilities at a site are to be used for the management of hazardous remediation waste.
	Releases from Solid Waste Management Units	Subpart F	Requires the establishment of a detection, compliance, and corrective action monitoring program to ensure protection of the groundwater by assessing the performance of the TSD facility during operatons. The groundwater monitoring program is required to be performed during the post-closure period for land disposal facilities where hazardous wastes remain in place after closure.	SCG	
	Closure and Post-Closure	Subpart G	Establishes closure and post-closure requirements for TSD facilities, including post-closure property uses.	SCG	
	Tank Systems	Subpart J	Tank systems for the treatment or storage of hazardous wastes are to be designed and operated in a manner to prevent releases to the environment.	SCG	Potentially applicable for the tank treatment and/or storage of all remediation waste that is classified as a hazardous waste.
	Corrective Action for Solid Waste Management Units	Subpart S	The EPA or delegated state authority can designate a Corrective Action Management Unit (CAMU) or a Temporary Unit (TU) to allow more flexible management of remediation wastes within these units. Placement or consolidation of remediation waste within these units does not constitute land disposal or creation of a unit subject to minimum technology requirements.	SCG	NYSDEC is authorized to designate CAMUs.
	Miscellaneous Units	Subpart X	New miscellaneous units must be designed, constructed, and operated to meet regulatory performance standards.	SCG	Standards potentially applicable to the construction and operation of new miscellaneous units used to treat remediation waste that is classified, or is sufficiently similar to a hazardous waste. These regulations are potentially applicable to thermal desorption units that are not classified as incinerators or industrial furnaces.

TABLE 2.3
STATUTES, REGULATIONS, AND GUIDELINES USED IN THE IDENTIFICATION OF ACTION-SPECIFIC SCGs

ACTION	REQUIREMENTS	CITATION	DESCRIPTION	SCG or TBC	COMMENT
Water Treatment Discharges	Clean Water Act	33 U.S.C. Section 1251-1376			
	Wastewater Discharge Permits; Effluent Guidelines, Best Available Technology (BAT) and BMPPT	40 CFR Parts 122, 125, 401	Permit requirements for point source discharges to waters of the United States; establishes effluent standards and requirements for preventing toxic releases.	SCG	Potentially applicable for remedial actions involving a direct wastewater discharge to surface waters.
	Discharge to publicly-owned treatment works (POTW)	40 CFR Part 403.5	Discharge must comply with local POTW pretreatment program.	SCG	Requirements potentially applicable to remedial actions involving a discharge to a POTW.
Air Emissions from a Point Source	Clean Air Act (CAA)	40 U.S.C. Section 7401-7642			
	National Ambient Air Quality Standards (NAAQS)	40 CFR Part 50	Establishes ambient air quality standards for protection of public health.	SCG	NAAQS potentially applicable in evaluating whether there are air impacts at the site during remedial activities.
	New Source Review (NSR) and Prevention of Significant Deterioration (PDS) Requirements	40 CFR Part 52	New sources or modifications which emit greater than the defined threshold for listed pollutants must perform ambient impact analysis and install controls which meet best available control technology (BACT).	SCG	These regulations are potentially applicable and would require a comparison of potential emissions from the remedial activity to the emission thresholds for NSR.
	National Emission Standards for Hazardous Air Pollutants (NESHAPs)	40 CFR Part 61 40 CFR Part 63	Source-specific regulations which establish emissions standards for hazardous air pollutants (HAPs).	SCG	NESHAPs are potentially applicable if HAP emissions from remedial activities exceed the thresholds for compliance.
	New Source Performance Standards (NSPS)	40 CFR Part 6	Source-specific regulations with establish testing, control, monitoring and reporting requirements for new emission sources.	SCG	NSPS are potentially applicable if stream-generating equipment, thermal desorption units, or other regulated new sources were to be used onsite.
	Air Emission Standards for Process Vents	40 CFR 264/265	This regulation applies to process vents associated with distillation, fractionation, thin-film evaporation, solvent extraction, or air/stream stripping operations that manage hazardous waste with an organic concentration of at least 10 parts per million by weight (ppmw). Performance standards for closed-vent systems and control devices are specified in this regulation to demonstrate compliance with the above standards.	SCG	This regulation is potentially applicable to the onsite treatment of remediation waste designated as hazardous waste having an organic concentration of at least 10 ppmw.
Land Disposal of Hazardous Waste	RCRA Subtitle C	40 U.S.C. Section 6901 et. seq.			
	Land Disposal Restictions (LDRs)	40 CFR Part 268	Restricts land disposal of hazardous wastes that exceed specific criteria. Establishes Universal Treatment Standards (UTSs) to which hazardous wastes must be treated prior to land disposal.	SCG	These regulations are potentially applicable dependent on the remedial actions.

TABLE 2.3
STATUTES, REGULATIONS, AND GUIDELINES USED IN THE IDENTIFICATION OF ACTION-SPECIFIC SCGs

ACTION	REQUIREMENTS	CITATION	DESCRIPTION	SCG or TBC	COMMENT
STATE					
Generation, Management, and Treatment of Hazardous Waste	NYSDEC Division of Regulatory Affairs Siting of Industrial Hazardous Waste Facilities	6 NYCRR Part 361	Establishes procedures for selecting appropriate sites for hazardous waste facilities.	SCG	These regulations are potentially applicable for remedial activities which would involve the construction of remediation hazardous waste management facilities.
	New York Hazardous Waste Management System (General)	6 NYCRR Part 370	Provides definitions of terms and general instructions for the Part 370 series of hazardous waste management regulations.	SCG	[See RCRA Hazardous Waste Management Regulations, 40 CFR Parts 262 and 264/265 under Federal SCGs listed in this table.]
	NYSDEC Division of Hazardous Substances Regulation Identification and Listing of Hazardous Wastes	6 NYCRR Part 371	Outlines criteria for determining if a solid waste is a hazardous waste and is subject to regulation under 6 NYCRR Parts 372-376.	SCG	These regulations do not set clean-up standards, but are potentially applicable during various remedial actions.
	Hazardous Waste Manifest System and Related Standards for Generators, Transporters, and Facilities	6 NYCRR Part 372	Provides guidelines relating to the use of the manifest system and its recordkeeping requirements.	SCG	These regulations are potentially applicable to any company contracted to transport materials from the site.
	Final Status Standards for Owners and Operators of Hazardous Waste Treatment, Storage and Disposal Facilities	6 NYCRR Part 373	Outlines the requirements for owners and operators of hazardous waste, treatment, storage, and disposal facilities.	SCG	Personnel conducting site activities and personnel at offsite facilities receiving materials from the site will be required to follow these regulations as appropriate.
	New York Regulations for Transportation of Hazardous Waste	6 NYCRR Part 372.3a-d	Outlines procedures for the packaging, labeling, manifesting, and transporting of hazardous waste.	SCG	These requirements are potentially applicable to any company contracted to transport hazardous material from the site.
	New York Regulations for Hazardous Waste Management Facilities	6 NYCRR Part 373-1.1 - 373-1.8	Provides requirements and procedures for obtaining a permit to operate a hazardous waste TSDF. It also lists the contents and conditions of permits.	SCG	Any offsite facility accepting hazardous waste from the site must be properly permitted.
	Corrective Action for Solid Waste Management Units	6 NYCRR Part 373-2.19	The NYSDEC Commissioner can designate a Corrective Action Management Unit (CAMU) or a Temporary Unit (TU) to allow more flexible management of remediation wastes within these units. Placement or consolidation of remediation waste within these units does not constitute land disposal or creation of a unit subject to minimum technology requirements.	SCG	NYSDEC is authorized to designate CAMUs for the purpose of implementing remedial actions under 6 NYCRR Part 373-2.6(1) or RCRA.
	Inactive Hazardous Waste Disposal Site Remedial Program	6 NYCRR Part 375	Establishes purpose, scope, authority, severability, and references for remedial programs and the expenditure of State moneys.	SCG	These requirements are potentially applicable to any remedial program occurring at the site.

TABLE 2.3
STATUTES, REGULATIONS, AND GUIDELINES USED IN THE IDENTIFICATION OF ACTION-SPECIFIC SCGs

ACTION	REQUIREMENTS	CITATION	DESCRIPTION	SCG or TBC	COMMENT
Remedial Actions	Selection of Remedial Actions at Inactive Hazardous Waste Sites	NYSDEC TAGM 4030	Provides guidance during the evaluation and selection of remedial alternatives for all RI/FSs.	SCG	These requirements are potentially applicable to the RI/FS process at the site.
Land Disposal of a Hazardous Waste	Land Disposal Restrictions (LDRs)	6 NYCRR Part 376	Restricts land disposal of hazardous wastes that exceed specific criteria	SCG	The NY State LDR program mirrors the Federal LDR program prior to its adoption of UTSs in September 1994. Therefore, NY State LDRs do not include UTSs or a treatment standard for benzene that fails TCLP. NY plans to adopt federal UTSs in the future.
Water Treatment Discharge	New York State Regulations on the State Pollution Discharge Elimination System (SPDES)	6 NYCRR Parts 750-758	Defines permitting requirements for water treatment discharges including discharges made to a POTW.	SCG	The regulations are potentially applicable for alternatives that include a discharge to surface water or a POTW.
	Groundwater Effluent Standards	6 NYCRR Part 703.6	Establishes effluent standards and/or limitations for discharges to Class GA groundwaters.	SCG	These regulations are potentially applicable for alternatives that include discharges to groundwater.
	Groundwater Effluent Limitations	Technical and Operational Guidance Series (TOGS) 1.1.2	This provides a substance-by-substance list of effluent limitations for substances having an ambient water quality standard or guidance value. It restates the effluent standards in 6 NYCRR Part 703.6 and provides effluent limitations for the substances that have an ambient standard but do not have an effluent standard in Part 703.	SCG	These regulations are potentially applicable for alternatives that include discharges to groundwater.
	NYSDEC Division of Water: Guidance on Groundwater Contamination Strategy	Technical and Operational Guidance Series (TOGS) 2.1.1	Establishes strategies for source control and remediation of groundwater contamination.	SCG	These strategies are potentially applicable guidelines when evaluating groundwater remediation options.
Air Emissions from a Point Source	New York State Air Pollution Control Regulations	6 NYCRR Part 200 Air Guide-1	Establishes emissions standards for new sources of air pollutants, incinerators, and specific contaminants.	SCG	Requirements potentially applicable to alternatives that result in air emissions of regulated substances or equipment.
	New York General Prohibitions	6 NYCRR Part 211	Prohibits air pollution.	SCG	No air pollution, as defined in 6 NYCRR Part 200, shall occur as a result of activities at the site.
	New York Regulations for General Process Emission Sources	6 NYCRR Part 212	Outlines the environmental rating procedure.	SCG	Requirements potentially applicable to alternatives that result in air emissions of regulated substances or equipment.
	New York Air Quality Classification System	6 NYCRR Air Guide-1	Outlines the air quality classification system and gives classifications for different land uses and population densities.	SCG	Requirements potentially applicable to alternatives that result in air emissions of regulated substances or equipment.
	New York State Ambient Air Quality Standards	6 NYCRR Part 257 Air Guide-1	Establishes state ambient air quality standards and guidelines for evaluating air quality impacts.	SCG	Potentially applicable in evaluating air impacts during remedial activities. Establishes short-term action limits for occupational exposure.

SECTION 3

REMEDIAL ACTION OBJECTIVES

3.1 GENERAL

This section presents the remedial action objectives (RAOs) for impacted media at the site. These RAOs were developed to ensure protection of human health and the environment. Specifically, the following information was considered in developing the site RAOs:

- Remedial investigation results;
- Risk assessment conclusions;
- SCGs and TBCs; and
- NYSDEC comments on the 1995 FS.

Following establishment of the RAOs, general response actions are developed to meet the RAOs.

3.2 SITE-WIDE REMEDIAL ACTION OBJECTIVES

The following RAOs were developed for impacted soil and groundwater at the site:

1. Provide protection of the Class I wetland;
2. Provide protection of potential future on-site workers;
3. Achieve groundwater standards, where practicable; and
4. Prevent migration of groundwater into the wetlands from the developed portion of the FRP-2 property.

RAO 1 was developed to address concerns regarding potential impacts to the Class I wetland due to the probable migration of the impacted groundwater from the developed portion of the site to the adjacent Class I wetland.

RAO 2 and RAO 4 were developed based on the results of the Qualitative Public Health Risk Assessment (ERM, 1994b). The Qualitative Public Health Risk Assessment determined that there were no exposure pathways identified for the site under current conditions. However, potential future exposure pathways were identified associated with future construction in the developed portion of the site and with future analyte movement in groundwater towards the Seneca River. RAOs 2 and 4 address these two potential future pathways. In addition, RAO 4 addresses the provisions of 6 NYCRR Part 663 Freshwater Wetlands Permit Requirements Regulations, which was identified as an SCG and which generally prohibits discharge of impacted groundwater into a Class I wetlands.

RAO 3 was developed to address New York State regulations specifying compliance with the groundwater quality standards contained in 6 New York State Codes, Rules, and Regulations (NYCRR) Part 703, which has been identified as an SCG.

3.3 GENERAL RESPONSE ACTIONS

General response actions provide a range of potential actions that may be considered to satisfy the site RAOs. The general response actions developed for the site are:

- No further action;
- Intrinsic remediation;
- Extraction and treatment of impacted groundwater in the contaminated area north of FRP-2; and
- *In situ* treatment of impacted groundwater in the area north of FRP-2.

Remedial technologies and alternatives consistent with these general response actions are developed in Sections 4 and 5, respectively.

The selected alternative for site-wide groundwater will have a direct impact on the need for remediation of impacted soils. Therefore, the need for response actions to address soil contamination to meet the RAOs is evaluated in Section 7, following selection of the site-wide groundwater remedial alternative completed in Section 6.

The general response actions developed above include actions to prevent the migration of impacted groundwater into the wetlands through hydraulic control or *in situ* treatment. They do not include actions to remediate impacted groundwater throughout the entire site due to the impracticability of such an approach. Numerous studies have been completed concluding that, in most cases, achievement of groundwater criteria in a reasonable time frame is not feasible (Doty and Travis, 1989; USEPA, 1989; USEPA, 1992; National Research Council, 1994). The feasibility of achieving groundwater criteria in a reasonable time frame is highly dependent on site-specific considerations. Unfavorable conditions for aquifer restoration typically include heterogeneous aquifers with low hydraulic conductivity and the presence of relatively insoluble contaminants. These conditions exist at the site, as summarized in the RI. In addition, the slow groundwater velocity at the site results in very long down-gradient response times for any source control activities. For example, using the groundwater elevation data in Appendix B and an aquifer permeability of 7×10^{-4} cm/sec (typical for the site fine sand and silt overburden) the groundwater travel time from AOC 5 to the northern edge of the paved area of FRP-2 is approximately 20 years. Therefore, achievement of groundwater standards in a reasonable time frame is not practicable at the site, and hydraulic control rather than groundwater remediation is appropriate.

SECTION 4

DEVELOPMENT AND SCREENING OF SITE-WIDE GROUNDWATER REMEDIAL TECHNOLOGIES

4.1 INTRODUCTION

This section executes the two steps needed to develop and preliminarily screen remedial action alternatives:

- Identification of potentially suitable technologies, including innovative technologies, and/or process options; and
- Preliminary screening of the technologies and process options with respect to implementability, effectiveness, and cost.

The NYSDEC TAGM HWR-90-4030 specifies that individual remedial technologies should be preliminarily screened on their ability to meet media-specific RAOs, their implementability, and their short-term and long-term effectiveness. In addition, the NCP states in 40 Code of Federal Regulations (CFR) Section 300.430 that cost can be used as a criteria to preliminarily screen remedial alternatives. The NCP states that grossly excessive costs, compared to the overall effectiveness of alternatives, may be used as one of several factors to eliminate alternatives. In addition, similar alternatives providing effectiveness and implementability equivalent to that of another alternative, but at a greater cost, may also be eliminated.

Screening for effectiveness considers three aspects: 1) the ability of the process to handle estimated volumes or areas and meet the RAOs; 2) the potential for the process to impact human health and the environment during implementation; and 3) the reliability and record of performance for the process. Implementability encompasses technical feasibility, availability of the technologies, and the administrative feasibility of implementing a technology or process (USEPA, 1988 and NYSDEC, 1990). Technical feasibility includes the availability of the staffing and equipment necessary to implement the alternative, as well as operation, maintenance, replacement, and monitoring of the alternative's components after the remedial action is completed, if necessary. If an alternative requires equipment, specialists, or facilities that are not available within a reasonable period of time, it may be eliminated from further consideration (USEPA, 1993c). Administrative implementability pertains to compliance with SCGs, the ability to obtain approvals from governmental entities, and the availability of treatment, storage, disposal services and capacity, if necessary. Screening based on cost focuses on both the costs of construction and any long-term operation and maintenance costs (USEPA, 1993c).

Based on a review of literature and site hydrogeological and chemical data collected to date, the following list of potential remedial technology alternatives for site-wide groundwater was developed to meet the site's RAOs:

- no further action;
- intrinsic remediation;
- reactive iron wall;
- hydraulic control alternatives consisting of both groundwater recovery and treatment alternatives;
- subsurface barrier wall; and
- *in situ* biological treatment.

The implementability and effectiveness screening rationale for each technology and process option considered are contained in Table 4.1. The "retained" and "not retained" status of each technology is stated in Table 4.1.

4.2 NO FURTHER ACTION

The no further action alternative would consist of the site remaining in its current condition. The following institutional controls and IRM systems have been implemented and are in operation:

- Institutional controls on future site use;
- Site security via fencing;
- SVE system at AOC 5;
- Free-product recovery system at AOC 7; and
- Groundwater pump and treat system and an SVE system at AOC 16.

Since this alternative does not include the implementation of any additional remedial technologies, there would be no short-term environmental impacts or risks to the surrounding area and nearby workers. This alternative allows natural attenuation to occur in addition to the remedial work being performed by the IRM systems. The long-term effectiveness of this alternative is dependent on the natural biodegradation rate of the groundwater contaminants and the continued operation of the IRMs at AOC 5, AOC 7, and AOC 16. As discussed in Appendix B, significant natural biodegradation of site-wide groundwater contaminants is occurring.

This alternative is readily implementable, and also, as discussed in Section 1.3, no unacceptable risks to human health or the environment have been demonstrated to be present at the site. However, this alternative is not likely to be acceptable to the regulatory agencies. This alternative does not prevent the migration of impacted groundwater from FRP-2 into the adjacent wetland, which is contrary to one of the site's RAOs.

TABLE 4.1
SCREENING OF SITE-WIDE GROUNDWATER REMEDIAL TECHNOLOGIES

TECHNOLOGY	EFFECTIVENESS	IMPLEMENTABILITY	RETAINED OR NOT RETAINED FOR FURTHER EVALUATION
No Further Action	Dependent on the natural biodegradation rate of the compounds detected and the continued operation of the IRMs at AOC 5, AOC 7, AOC 16.	Readily implementable.	Retained as a baseline.
Intrinsic Remediation	Significant natural attenuation of site-wide groundwater contaminants is occurring. Not effective in the short-term for protection of the adjacent wetlands from the migration of impacted groundwater.	Readily implementable.	Retained for select areas of the site.
Reactive Iron Wall	No data available (>5 years) on long-term effectiveness of this technology. The need for rehabilitation or replacement of the iron media has not been demonstrated.	Implementation at the site is feasible, provided equipment capable of the necessary depth becomes available in the near future.	Retained.
Groundwater Extraction Wells	Groundwater modeling demonstrates effectiveness in achieving the necessary level of hydraulic containment.	Readily implementable via conventional equipment.	Retained.
Groundwater Interceptor Trench	Groundwater modeling demonstrates the same level of effectiveness as extraction in achieving hydraulic containment, but at a significantly higher cost.	Implementable via a trenching machine or a biopolymer slurry.	Not Retained.
Air Stripping	Performance models indicate that groundwater contaminant removal consistent with the existing discharge limits for the AOC 16 IRM can be achieved.	Readily implementable.	Retained.
UV/Hydrogen Peroxide Oxidation	Preliminary vendor evaluation indicates that groundwater contaminant removal consistent with the existing discharge limits for the AOC 16 IRM can be achieved.	Readily implementable.	Retained.
Ex Situ Biological Degradation	Preliminary evaluation indicates that groundwater contaminant removal consistent with the existing discharge limits for the AOC 16 IRM can be achieved.	Likely to be implementable pending the results of a pre-design treatability evaluation.	Retained.

TABLE 4.1
SCREENING OF SITE-WIDE GROUNDWATER REMEDIAL TECHNOLOGIES

TECHNOLOGY	EFFECTIVENESS	IMPLEMENTABILITY	RETAINED OR NOT RETAINED FOR FURTHER EVALUATION
Ex Situ Reactive Iron Degradation	Preliminary evaluation indicates that this technology cannot achieve groundwater discharge limits consistent with the existing AOC 16 IRM.	Technically feasible. *Ex situ* applications newly developed, few installations.	Not Retained.
Granular Activated Carbon Adsorption	The contaminants present and treatment levels required would likely lead to excessive carbon usage.	Readily implementable.	Not Retained.
Subsurface Barrier Wall	Effective in containing a contaminant plume. Hydraulic controls would need to be implemented in conjunction with wall to maintain the inward hydraulic gradient. Not a permanent remedy. Would not reduce toxicity or volume of impacted groundwater.	Technically feasible. Depth range of walls limited.	Not Retained.
In Situ Biological Treatment	Limited data on full-scale effectiveness on chlorinated organics.	Innovative technology. Not readily commercially available.	Not Retained.

This alternative was retained as a baseline for comparison with the other site-wide groundwater remedial alternatives.

4.3 INTRINSIC REMEDIATION

Intrinsic remediation, also termed natural attenuation, relies on naturally-occurring processes to reduce groundwater contaminant concentrations. Natural attenuation processes include non-destructive processes such as volatilization, adsorption, dilution and dispersion, as well as destructive processes such as biodegradation and hydrolysis. The goal in a typical intrinsic remediation evaluation is to demonstrate that contaminants attenuate to acceptable levels before a potential receptor is impacted. Intrinsic remediation differs from the no further action alternative due to the increased level of modeling and monitoring typically implemented to demonstrate that intrinsic remediation is protective. To provide an increased level of protectiveness over the no action alternative, the intrinsic remediation alternative may include provisions for a contingency action if long-term monitoring indicates that intrinsic remediation will not provide the necessary level of protectiveness within a defined time period. As discussed in Appendix B, significant natural attenuation, and in particular natural biodegradation, of site-wide groundwater contaminants is occurring.

The 1995 FS concluded that intrinsic remediation, in combination with source treatment, was protective of human health and the environment and was the recommended alternative for site-wide groundwater. The NYSDEC rejected this conclusion, primarily due to the potential short-term effects associated with ongoing migration of impacted groundwater from FRP-2 into the adjacent wetlands. Therefore, intrinsic remediation will not be considered as the primary site-wide groundwater alternative. However, as presented in Appendix B, natural attenuation processes will continue to positively impact the long-term distribution and persistence of site-wide groundwater contamination. Therefore, intrinsic remediation will be considered for selected portions of the site and is discussed in Section 6 and 7.

4.4 REACTIVE IRON WALL

Based on technology developed at the Institute for Groundwater Research at the University of Waterloo and implemented through the Canadian-owned company, Envirometal^{TM} Technologies, Inc. (ETI), this alternative consists of placing granular iron in *in situ* permeable zones across the flow path of groundwater containing VOCs. The basis for this technology is the reductive dehalogenation of halogenated VOCs by zero valent iron filings (i.e. hydrogen atoms are substituted for halogen atoms). As the impacted groundwater flows through the permeable wall, the reactive iron metal is corroded by both water and the chlorinated organic compounds. This process is a destructive treatment technology for many contaminants and the end-products are completely dehalogenated and non-toxic. Examples of chlorinated VOC end-products degraded by the reactive iron wall are ethene, ethane, methane, and chloride ions.

At the site, a reactive iron wall would be placed across the northern edge of the paved area of FRP-2 to intercept and treat impacted groundwater from the developed portion of the site prior to its migration into the adjacent wetland.

With the use of suitable personal protective equipment (PPE) by on-site workers during the installation of a reactive iron wall, there should be no short-term environmental impacts or risks to the surrounding area and nearby workers. No air emissions are generated during the ongoing treatment by the reactive iron walls; however, volatilization of both groundwater and soil VOCs may be encountered during the installation of the reactive iron wall.

The long-term effectiveness of this technology has yet to be demonstrated. To date, only seven reactive iron walls have been installed in the United States and all seven have been installed within the last two years. The oldest *in situ* reactive iron wall, installed at the University of Waterloo Borden test site in Canada, has been performing consistently for over five years with no significant precipitates observed. There is no data available on the long-term treatment costs and effectiveness of the technology. The need for rehabilitation or replacement of the reactive iron media has yet to be demonstrated at any of the seven sites in the United States. It has been forecasted that the zero valent iron catalyst may last for decades before needing replacement and the potential exhibited by the passive treatment wall for remediating halogenated VOCs in groundwater is widely accepted (Wilson, 1995).

Implementation of a reactive iron wall at the site would be feasible. A low-permeability layer to key into is available along the northern edge of the paved area of FRP-2. Various sources of granular iron have been identified and tested in recent months for use in this type of reactive iron wall (Focht et al., 1996). Trenching equipment capable of installing the wall to the depths required (i.e. 32 to 37 feet) is currently unavailable. However, one potential vendor has indicated that the necessary equipment will be available by the summer of 1997.

This technology was retained for further evaluation.

4.5 HYDRAULIC CONTROL TECHNOLOGIES

Hydraulic containment would meet the site RAO's through protection of the wetland by intercepting impacted groundwater flow from FRP-2. An hydraulic containment remedial alternative consists of both groundwater extraction technologies and extracted groundwater treatment technologies.

4.5.1 Groundwater Extraction Technologies

The identified groundwater extraction technologies for the purpose of hydraulic containment at the site are extraction wells and an interceptor trench. A preliminary groundwater model was developed in Appendix C to evaluate the effectiveness of groundwater extraction technologies. The groundwater model demonstrates that either of these technologies would be effective in achieving the necessary level of hydraulic containment.

4.5.1.1 Groundwater Recovery Wells

The groundwater model predicts that four recovery wells installed to 35 feet below the ground surface along the northern edge of the paved area of FRP-2 would be effective in providing hydraulic containment at a total pumping rate of less than 10 gallons per minute (GPM).

With the use of PPE by on-site workers installing the recovery wells, there would be no short-term environmental impacts or risks to the surrounding area and nearby workers during the installation of the wells. Captured groundwater would be contained until treatment; thus, no air emissions would be generated during recovery. However, volatilization of both groundwater and soil VOCs may be encountered during the installation of the recovery wells.

Groundwater extraction via recovery wells is an established technology whose long-term effectiveness has been well documented (USEPA, 1995). Extraction permanently removes the contaminated water from the ground and makes it available for *ex situ* treatment.

Implementation of a series of extraction wells at the site is feasible and modeling predicts it will be effective as a form of hydraulic containment. Equipment and materials needed to implement this technology are readily available from more than one vendor.

Groundwater recovery wells, as a form of hydraulic containment, were retained for further evaluation.

4.5.1.2 Groundwater Interceptor Trench

The groundwater model also predicts that an interceptor trench approximately 200 feet long installed to 10 feet below the water table along the northern edge of the paved area of FRP-2 would be effective at providing hydraulic containment with a total pumping rate of less than 10 GPM.

Based on the site geological conditions, two construction methods appear viable for installing the interceptor trench: a trenching machine, or excavation using a biopolymer slurry. Conventional trench excavation is not viable in the area proposed for a trench due to the water table (6 to 9 feet below ground surface), the required depth of the trench (up to 20 feet below ground surface), and the instability of the sands in the saturated zone. With both methods, there is risk for short-term environmental impacts due to impacted soils handling and stockpiling and potential volatilization of groundwater VOCs during installation.

The implementation of a groundwater interceptor trench at the site is feasible via a trenching machine or a biopolymer slurry design. The effectiveness of an interceptor trench is the same as that of extraction wells in providing hydraulic containment. However, the capital costs of installing a trench is significantly greater than the capital costs to install a system of recovery wells. This is due primarily to constructability issues. The mobilization and demobilization of trenching equipment and mixing tanks for a biopolymer slurry is more expensive than mobilizing well construction equipment which is readily available. In addition, the construction of an interceptor trench would involve soil disposal costs that would not be incurred with the installation of the recovery wells.

Since the interceptor trench provides the same effectiveness and implementability as extraction wells but at a significantly greater cost, an interceptor trench was eliminated from further consideration as a groundwater extraction technology.

4.5.2 Groundwater Treatment Technologies

In order to provide hydraulic containment of impacted groundwater by means of groundwater extraction, acceptable methods for disposal of the extracted groundwater must be implemented. The publicly owned treatment works (POTW) responsible for the sanitary sewer that serves the site specifically rejects any water generated from an inactive hazardous waste site (regardless of groundwater pretreatment). Therefore, the treatment of extracted groundwater must achieve discharge criteria comparable to the effluent limitations established for the existing groundwater IRM treatment system at AOC 16.

Several *ex situ* treatment technologies for groundwater were considered for removing the chlorinated and non-chlorinated organic contaminants anticipated in the extracted groundwater at the site. Consideration was given to five different treatment methods: air stripping, ultraviolet (UV)/hydrogen peroxide oxidation, biological degradation, reactive iron degradation and granular activated carbon adsorption. The potential benefits and shortcomings of each method are presented in the following sections.

4.5.2.1 Air Stripping

This technology utilizes the tendency for dissolved VOCs to pass from a liquid solvent (groundwater) to a vapor solvent (ambient air) when the liquid is aerated. A low-profile tray-style air stripper with pre-filtration to reduce the solids loading is typically used for groundwater treatment applications. These units are readily available in skid-mounted packages complete with pumps, blowers, instrumentation and controls. For freeze protection, they are usually located in heated buildings. Contaminants are removed from the groundwater and released to the atmosphere under controlled and regulated conditions. There are no significant short-term impacts during installation of an air stripper system. Air stripping is a proven technology: the operating parameters and controls are well-understood. This approach for groundwater treatment was retained for further evaluation.

4.5.2.2 UV/Hydrogen Peroxide Oxidation

UV/hydrogen peroxide treatment provides photolysis and oxidation of organic contaminants in the extracted groundwater stream by the injection of liquid hydrogen peroxide solution (30%) and exposure to high-intensity UV light. The formation of hydroxyl radicals in the groundwater under these conditions strongly promotes oxidation of dissolved species leading to mineralization (the eventual formation of carbon dioxide and dissolved inorganics). These reactions significantly reduce the toxicity and volume of contaminants. There are no significant short-term impacts during installation of a UV/hydrogen peroxide system. Skid-mounted package units are readily available (after treatability testing) complete with pumps, reactors, UV bulbs, instrumentation and controls. For freeze protection, they are usually located in heated buildings. UV/hydrogen peroxide oxidation is a proven technology: while the mechanisms of hydroxyl radical formation and interaction with UV light and organics are less understood, a broad base of empirical information exists. From an operability standpoint, system mechanical/electrical complexity and the necessity of on-site bulk storage for concentrated hydrogen peroxide result in high maintenance requirements. This approach for groundwater treatment was retained for further evaluation.

4.5.2.3 Biological Degradation

Biological degradation treatment provides dechlorination and degradation of organic contaminants in extracted groundwater by promoting bacterial metabolism using one of two different processes. One process is an aerobic, fluidized bed process, supersaturated with oxygen and with a cometabolite (such as phenol) added to promote the growth of selected bacterial strains (provided by the technology vendor) which can partially degrade chlorinated compounds. Fluidized bed reactors can use granular activated carbon (GAC) as a support media for the bacterial communities. The other process is a series of two fixed film reactors that support anaerobic dechlorination reactions followed by aerobic degradation reactions. Fixed-film reactors use internal plastic media to support the bacterial communities. In both cases, since the concentrations of organic materials and necessary nutrients in the extracted groundwater are not high enough to independently sustain these reactors, organic substrate additions, cometabolites, and/or nutrient supplements must be added.

Biological degradation reduces the toxicity and volume of contaminants. There are no significant short-term impacts during installation of an *ex situ* biological treatment system. Treatability testing is typically performed, followed by the design of a package system complete with reactor tanks, pumps, blowers or other oxygenators, instrumentation, and controls. For temperature control, they are usually located in heated buildings. While *ex situ* biological degradation is a proven technology, the treatment of low flow, low concentration contaminated groundwater with chlorinated organics is relatively uncommon. The results of field studies or performance evaluations of these systems are not readily available. From an operability standpoint, system complexity and the necessity of on-site make-up and bulk storage for nutrient and organic substrate solutions may result in high maintenance requirements. However, since the technology is both proven and widely available, this approach for groundwater treatment was retained for further evaluation.

4.5.2.4 Reactive Iron Degradation

This technology utilizes the capability of reactive iron filings, prepared by a proprietary process, to cause dechlorination and oxidation of organic compounds in aqueous solution. However, reactive iron reactor vessels are newly available on the commercial market and field use has not yet been well-established. In addition, reactive iron cannot degrade the following compounds which may be present in the extracted groundwater: chloroethane, benzene, toluene, ethyl benzene, xylenes, and acetone. These contaminants are more likely to present a problem during *ex situ* treatment than with the *in situ* reactive iron treatment wall. The groundwater extraction system draws contaminated groundwater from a large area, and is thus more likely to extract groundwater with these contaminants, which are less prevalent at the location where the iron reactive wall is proposed. Reactive iron treatment would result in excessively large vessels that would require freeze protection and would not achieve the required level of groundwater treatment for several of the compounds projected to be present in the extracted groundwater. This technology for groundwater treatment was not retained for further evaluation.

4.5.2.5 Activated Carbon Adsorption

This technology utilizes the tendency for some dissolved volatile organic compounds to adsorb on the surface of GAC, thereby leaving the groundwater solution. Liquid-phase GAC reactor vessels are readily available for groundwater treatment use, and are usually located in heated buildings for freeze protection. However, to achieve the necessary level of treatment, the effective GAC loading rates for the following compounds of concern projected to be present in the extracted groundwater are projected to be less than 5 mg/g GAC: 1,1-DCA; 1,1-DCE; 1,2-DCE; 1,1,1-TCA; vinyl chloride, chloroethane, and acetone (USEPA Treatability Manual [EPA-600/2-82-00b]). Thus, GAC treatment would result in the generation of large quantities of poorly-utilized spent GAC that requires off-site disposal and may create long-term liability. This technology for groundwater treatment was not retained for further evaluation.

4.6 SUBSURFACE BARRIER WALL

A subsurface barrier wall surrounding the impacted groundwater plume shown in Figure 1.3, in conjunction with the extensively paved and developed land surface and thus limited recharge potential at the site, would prevent both the migration of site-wide groundwater off-site and the migration of contaminant-free groundwater on-site. Hydraulic controls may need to be implemented with this technology alternative to maintain an inward hydraulic gradient. Collected water would need to be treated prior to disposal.

One of the most common and economical subsurface barrier wall construction methods, a slurry cut-off wall, consists of an excavated trench backfilled with a low permeability slurry. Based on the characteristics of this site, it was assumed that the slurry would consist of soil-bentonite. A soil-bentonite slurry trench is a proven subsurface barrier wall technology capable of achieving permeabilities of less than 1 x 10^{-7} cm/sec. A soil-bentonite slurry trench is constructed by excavating a vertically-walled trench to the desired depth while the trench is filled with a bentonite clay and water slurry. The thick consistency slurry maintains the stability of the trench walls, even in unstable, saturated sand, by applying excess hydrostatic pressure against a filtercake of bentonite clay that forms on the trench walls. The slurry trench operation advances by progressive excavation of the trench with backfilling at the other end with a specifically graded admixture of soil and bentonitic clay. Typically, the excavated soil can be used in the mixing of the backfill; however, compatibility testing would be required to confirm that the required permeability can still be achieved with the on-site soils. The average depth to the site confining layer which may be keyed into is approximately 30 to 40 feet. At that depth, slurry trench barrier walls are typically excavated by hydraulic backhoes.

During the installation of the slurry cut-off wall at the site, workers should wear appropriate PPE to prevent exposure to volatilized chemical constituents present in the site soils and groundwater. A slurry cut-off wall would be effective in containing the contaminant plume in groundwater; however, hydraulic controls would need to be implemented in conjunction with the wall to maintain an inward hydraulic gradient and insure containment. A slurry cut-off wall is not considered a permanent remedy.

Both hydraulic containment and the subsurface barrier wall would be effective in preventing the migration of impacted groundwater from FRP-2 into the wetlands. However, the subsurface barrier wall is significantly more expensive to implement than hydraulic containment. In addition, a barrier wall would isolate the contaminated areas from upgradient sources of electron acceptors, thus limiting the long-term contaminant destruction occurring via natural biodegradation. Naturally-occurring biodegradation would continue to occur with hydraulic containment. Therefore, installation of a subsurface barrier wall was not retained for further evaluation.

4.7 *IN SITU* BIOLOGICAL TREATMENT

Biological treatment utilizes indigenous and/or introduced micro-organisms to biologically degrade groundwater contaminants. This typically involves controlling the subsurface conditions by addition of amendments such as electron acceptors, nutrients, pH adjustments, and primary substrates.

In situ biological treatment of chlorinated organics such as TCE is still in the development phase. "Remediation Technologies Screening Matrix and Reference Guide" (USEPA, July 1993) lists bioremediation of TCE (cometabolism) as being at the pilot-scale level. The technology has continued to advance, but is still an emerging technology and is not readily commercially available. Rigorous bench and pilot testing of this technology would be necessary prior to selecting it for implementation at the site. Due to the unproven status of this technology at full-scale, it was not retained for further evaluation.

4.8 SUMMARY OF RETAINED TECHNOLOGIES

No further action was retained for further evaluation as a baseline. Extraction wells were retained for further evaluation for groundwater recovery. Air stripping, UV/hydrogen peroxide oxidation, and *ex situ* biological degradation were retained for further evaluation for treatment of extracted groundwater. A reactive iron well and intrinsic remediation were retained for further evaluation for *in situ* treatment of impacted groundwater. A summary of the technologies retained for further evaluation is presented in Table 4.2.

TABLE 4.2
SUMMARY OF RETAINED SITE-WIDE GROUNDWATER REMEDIAL TECHNOLOGIES

Institutional Controls	Hydraulic Control	Passive Treatment
- No Further Action	- Groundwater Recovery - Extraction Wells	- Reactive Iron Wall
	- Groundwater Treatment - Air Stripping - UV/Hydrogen Peroxide Oxidation - Ex Situ Biological Degradation	- Intrinsic Remediation

SECTION 5

DETAILED EVALUATION OF REMEDIAL ALTERNATIVES

5.1 INTRODUCTION

Based on the preliminary screening of remedial technologies in Section 4, the remedial alternatives for site-wide groundwater that have been assembled for detailed evaluation are:

- No further action;
- Installation of a reactive iron wall; and
- Hydraulic control.

The no further action alternative is evaluated as a baseline for comparison with other remedial technologies. The reactive iron wall and hydraulic control remedial alternatives are evaluated based on their ability to meet the RAOs defined in Section 3.

Intrinsic remediation is not evaluated as a primary site-wide groundwater alternative. Natural attenuation processes will continue to significantly impact the long-term distribution and persistence of site-wide groundwater contamination for all alternatives. Therefore, the impact of natural attenuation on the selected site alternative is evaluated in Section 6 and 7.

5.2 EVALUATION CRITERIA

The detailed analysis of each alternative presented in this FS uses the evaluation criteria outlined in the NCP (40 CFR Section 300.430), the USEPA feasibility study guidance (USEPA, 1988), as well as the NYSDEC TAGM 4030, "Selection of Remedial Actions at Inactive Hazardous Waste Sites". The detailed evaluation of each remedial alternative consists of a technical description of each alternative and an assessment of each alternative against the following evaluation criteria:

Threshold Criteria

- Overall protection of human health and the environment; and
- Compliance with SCGs.

Primary Balancing Criteria

- Long-term effectiveness and permanence;
- Reduction of toxicity, mobility or volume;
- Short-term effectiveness;
- Implementability; and
- Cost.

Modifying Criteria

- Regulatory acceptance; and
- Community acceptance.

The NCP requires the threshold criteria to be met for an alternative to be eligible for selection. For those alternatives that meet the threshold criteria, the primary balancing criteria are evaluated to provide the best balance of trade-offs among alternatives. In addition, consideration is given to principal threats and practicable remediation [see 40 CFR Section 300.430(a)(1)(iii)]. USEPA defines the term "principal threats" as one of two conditions: (1) toxic concentrations several orders of magnitude above levels for unrestricted use, or (2) wastes that are both highly mobile and unable to be contained (USEPA, 1992). The term "practicable" is a site-specific subjective term. The USEPA has defined practicability for specific sites based on cost effectiveness, impacts, implementability, and the extent of SCG compliance.

In making the final selection of a preferred remedy, the modifying criteria are also considered. The threshold and primary balancing criteria are evaluated in this section for each of the remedial alternatives. The modifying criteria are evaluated in subsequent documents, including the proposed Remedial Action Plan and the Record of Decision.

5.2.1 Overall Protection of Human Health and the Environment

The overall protection of human health and the environment criterion relates to whether, considering the site's characteristics and impacts, risks to human health and the environment are eliminated, reduced, or controlled. This assessment is based on a composite of factors assessed under other evaluation criteria, especially long-term effectiveness and performance, short-term effectiveness, and compliance with SCGs.

5.2.2 Compliance with SCGs

This evaluation criterion is used to determine whether an alternative complies with the federal and state chemical-specific, location-specific, and action-specific SCGs identified in Section 2.

5.2.3 Long-Term Effectiveness and Permanence

The long-term effectiveness and permanence of a remedial action includes consideration of the following:

- Permanence of the remedial alternative;
- Magnitude of the risk remaining after remediation; and
- Adequacy and reliability of controls, if any, used to manage treatment residuals or untreated wastes that remain at the site following remediation.

5.2.4 Reduction of Toxicity, Mobility or Volume

This criterion focuses on the impact of treatment technologies in eliminating any significant threats at a site through destruction of toxic contaminants, reduction of their total mass, or irreversible reduction of the total volume of contaminated media. The reduction of toxicity, mobility or volume criterion includes consideration of the following:

- The amount of hazardous materials that would be destroyed or treated, including how principal threat(s) would be addressed;
- The degree of expected reduction in toxicity, mobility or volume estimate as an approximate percentage of reduction;
- The degree to which treatment would be irreversible;
- The type and quantity of residuals that are present following treatment; and
- Whether the alternative would satisfy the preference for treatment as a principal element.

5.2.5 Short-Term Effectiveness

Short-term effectiveness addresses the effects of an alternative on human health and the environment during the construction and implementation phase until RAOs are met. Short-term effectiveness includes consideration of the following:

- Protection of the community during remedial construction activities;
- Environmental impacts during remedial construction activities;
- Time until remedial response objectives are achieved; and
- Protection of workers during remedial construction activities.

5.2.6 Implementability

Implementability considers the technical and administrative feasibility of implementing an alternative and the availability of the services and materials required during its implementation. The implementability evaluation includes issues related to:

- Construction and operation;
- Reliability of technology;
- Ease of undertaking additional remedial actions;
- Monitoring considerations;
- Activities needed to coordinate with other offices and agencies;
- Availability of adequate off-site treatment, storage capacity and disposal services; and
- Availability of necessary equipment, specialists, skilled operators and provisions to ensure any necessary additional resources.

5.2.7 Cost

The cost evaluation assesses estimated capital costs and annual operation and maintenance (O&M) costs. Capital costs consist of present and future direct and indirect expenses. Direct capital costs include engineering, labor, equipment and material expenses. Indirect capital costs include expenditures for engineering, licenses, permits, contingency allowances, and other services not part of the actual installation costs. O&M costs are the annual costs incurred after the remedial actions are constructed and may include: operating labor, energy chemicals, and sampling and analysis.

In this FS, present worth for each alternative was calculated using a service life of 30 years following remediation and a discount rate of 3.8 percent (based on a 30-year Treasury Bond rate of 6.8 percent (as of October 23, 1996) and an inflation rate of three percent).

Major cost assumptions used in the development of alternatives and individual alternative cost details are provided in Appendix D. The approximate accuracy of these costs is minus 30 to plus 50 percent in accordance with USEPA's "Guidance for Conducting Remedial Investigations and FS under CERCLA".

5.3 DETAILED EVALUATION OF ALTERNATIVES

Each of the alternatives listed in Section 5.1 are evaluated in this section using the specific criteria presented in Section 5.2.

5.3.1 No Further Action

Alternative Description

The no further action alternative is evaluated as a baseline for comparison of the overall effectiveness of each remedial alternative.

The no further action alternative would not utilize any remedial technologies for the treatment of site-wide groundwater. The site would remain in its current condition with the following existing institutional controls and IRM systems in operation:

- Institutional controls on future site use;
- Site security via fencing;
- SVE system at AOC 5;
- Free-product recovery system at AOC 7; and
- Groundwater pump and treat system and an SVE system at AOC 16.

Compliance with SCGs

This alternative, despite the operation of the IRM systems at AOCs 5, 7, and 16, does not prevent discharge of impacted groundwater into the adjacent wetlands.

Overall Protection of Human Health and the Environment

This alternative does not prevent groundwater from FRP-2 from migrating into the adjacent wetland, which is contrary to one of the site's RAOs. However, no unacceptable risks to human health or the environment due to groundwater contamination have been demonstrated to exist for the site. Therefore, the no further action alternative may achieve the required level of protectiveness.

As discussed in Section 1.3.2, contaminants have been detected in wetland sediment and shallow groundwater above guidance values. When considering these contaminants along with other detected organic compounds for which standards or guidance values do not exist, it is possible that additive and synergistic effects pose potential risk to fish and wildlife resources in the wetland. Further investigation would be necessary to determine if actual impacts to ecological receptors exist as a result of additive and synergistic effects of the contaminants detected.

Short-Term Effectiveness

No remedial action would be implemented for site-wide groundwater; therefore, there would be no short-term impacts or risks posed to workers, the community, or environment with this alternative. The time until RAOs are achieved is dependent on the continued operation of the IRM systems at AOCs 5, 7, and 16 and the natural biodegradation rate of the compounds present.

Long-Term Effectiveness and Permanence

This alternative allows natural attenuation to occur in addition to the remedial work being performed by the IRM systems. As such, its effectiveness is dependent on the natural biodegradation rate of the compounds detected and the continued operation of the IRMs at AOC 5, AOC 7, and AOC 16. The continued operation of the IRMs at AOCs 5, 7, and 16 will increase the effectiveness of this alternative but will not be effective in achieving the site RAOs for site-wide groundwater.

Reduction of Toxicity, Mobility, or Volume

The mobility and volume of VOCs in the soils and NAPL in the groundwater will be reduced through the continued operation of the IRMs at AOCs 5, 7, and 16. A reduction in the toxicity, mobility or volume of impacted groundwater would not be achieved.

Implementability

The no further action alternative is technically feasible and would require no implementation of remedial technologies.

Cost

This alternative does not require any actions to be taken; therefore, there are no capital costs associated with this alternative beyond those expenditures which have already occurred for installation of the IRMs. Considerable cost is associated with the long-term O&M of the IRMs currently operating. The present worth of the no further action alternative is $620,000. This is the sum of the present worth O&M costs incurred at the

SVE system at AOC5, the free-product recovery system at AOC7, the SVE system at AOC16, and the groundwater collection and treatment system at AOC16.

5.3.2 Reactive Iron Wall

Alternative Description

This alternative consists of placing a reactive iron wall across the northern edge of the paved area of FRP-2, as shown on Figure 5.1, to intercept and treat impacted groundwater prior to its migration into the adjacent wetland.

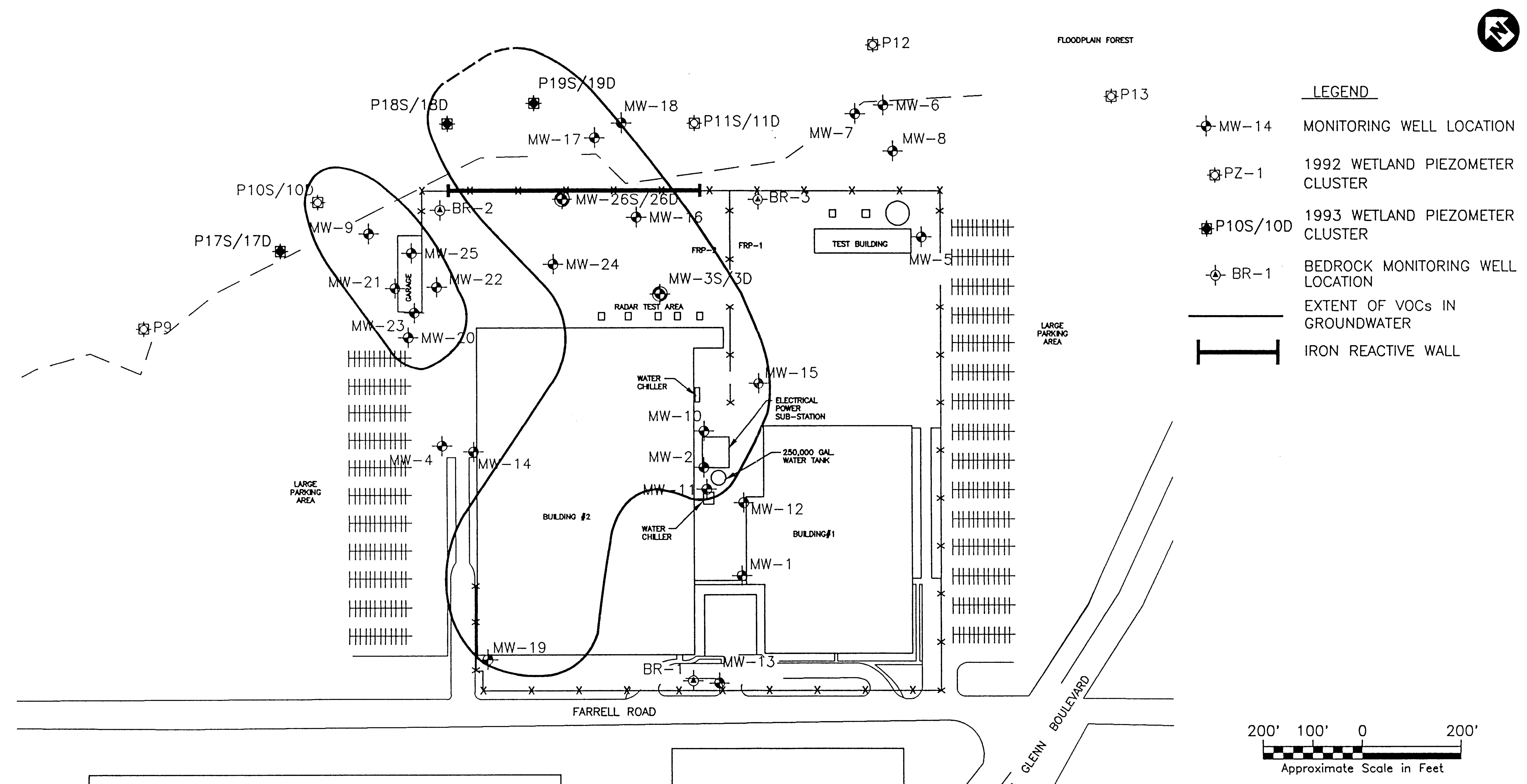
The length of the reactive iron wall needed to capture the impacted groundwater was estimated to be 400 feet based on analytical data and groundwater contours. Based on boring logs, it is estimated that a depth of approximately 32 feet is needed on the western end of the trench and a depth of approximately 37 feet is needed on the eastern end of the trench to tie into a confining layer. Where the saturated zone at this area of the site begins is variable at approximately 6 to 9 feet below ground surface from the eastern to the western end of the trench. Thus, the maximum vertical saturated thickness is 28 feet along the proposed length for the reactive iron wall. The existing horizontal groundwater velocity ranges from approximately 0.1 to 1 foot/day.

The application of the Envirometal™ process to groundwater remediation at the site as described above has been preliminarily evaluated by the vendor for this technology, ETI. ETI asserts that the technology is applicable for the major chlorinated organic contaminants identified in the groundwater at the site (TCE, 1,1-DCA, 1,1,1-TCA, vinyl chloride, 1,1-DCE, 1,2-DCE, and trichlorofluoromethane).

Of the various VOCs identified in the groundwater in the vicinity of the proposed installation, acetone and chloroethane are the only two that will not be degraded by the technology. A predesign investigation may be necessary to provide more data regarding the concentrations of these two contaminants. Acetone and chloroethane are non-carcinogens. Chloroethane was not identified as a chemical of concern during the site's risk assessment. During the 1994 RI, acetone, which has a groundwater standard of 50 parts per billion (ppb), was detected at levels exceeding the groundwater standard in two wells on site and in two wells/piezometers in the adjacent wetland. Detected levels ranged from 34 ppb to 2,300 ppb.

ETI's evaluation of the site concluded the following:

- A reactive iron wall length of 400 feet is adequate to ensure treatment of the groundwater plume;
- A residence time of three days would be needed to treat the maximum levels of VOCs. The residence time is driven by 1,1-DCA which has the slowest degradation rate of the VOCs present in the system; and



NOTE: VOC EXTENT BASED ON AVAILABLE GROUNDWATER DATA 1992 THROUGH 1996.

FIGURE 5.1

FORMER GE
FARRELL ROAD SITE

POTENTIAL LOCATION OF IRON REACTIVE WALL

PARSONS ENGINEERING SCIENCE, INC.
DESIGN • RESEARCH • PLANNING
290 ELWOOD DAVIS ROAD • SUITE 312 • LIVERPOOL, N.Y. 13088 • 315/451-9560
OFFICES IN PRINCIPAL CITIES

DATE: 12/16/96 (GTC)
H:\CAD\730125\30125G01.DWG (M/P SPACE)

H:\CAD\730125\30125G01 Thu Dec 26 13:30:31 1996

- Based on an average velocity of about 0.5 ft/day, a one foot flow-through thickness of iron in a continuous permeable wall was estimated as sufficient to treat the VOCs present along most of the plume, with an increased thickness of 1.5 feet needed in the core of the plume to treat higher concentrations. "Funnel-and-gate" configurations were also investigated; however a continuous wall was preliminarily chosen as the most effective design based on constructability issues.

A pre-installation sampling program consisting of approximately eight groundwater monitoring points would be recommended to ensure the above design is appropriate.

Compliance with SCGs

Chemical-specific SCGs applicable to this alternative include NYS Ambient Water Quality Standards and Guidance Values for VOCs in groundwater and surface water. The reactive wall technology is capable of meeting these SCGs for all VOCs likely present except for possibly acetone and chloroethane, as discussed above.

Location-specific SCGs for this alternative apply to excavation and construction activities expected to occur at the northern edge of the paved area of FRP-2 for the installation of the wall. In accordance with the New York State Freshwater Wetlands Act, remedial actions occurring within 100 feet of a wetland must comply with regulatory standards contained in 6 NYCRR Part 663.

Action-specific SCGs for this alternative apply to the excavation and handling of site soils, monitoring requirements, and Occupational Safety and Health Administration (OSHA) health and safety requirements, (i.e. 29 CFR 1910, 1926, 1904, and 40 CFR 264 and 262). Compliance with these SCGs would be achieved by following a NYSDEC-approved remedial design/remedial action work plan and a site-specific health and safety plan.

Overall Protection of Human Health and the Environment

No unacceptable risks to human health or the environment due to groundwater contamination have been demonstrated to exist for the site. Therefore, implementation of this alternative may not be necessary to achieve the required level of protectiveness. However, this alternative will further reduce any potential risks to human health and the environment by minimizing the discharge of impacted groundwater to the wetland.

As discussed in Section 1.3.2, contaminants have been detected in wetland sediment and shallow groundwater above guidance values. When considering these contaminants along with other detected organic compounds for which standards or guidance values do not exist, it is possible that additive and synergistic effects pose potential risk to fish and wildlife resources in the wetland. Further investigation would be necessary to determine if actual impacts to ecological receptors exist as a result of additive and synergistic effects of the contaminants detected.

Short-Term Effectiveness

No significant short-term impacts from remedial activities are anticipated for remedial workers or residents. Appropriate levels of personal protection and health and safety planning would be required during the excavation and materials handling during the placement of the reactive iron wall. Dust suppression measures for controlling fugitive dust generated during the remedial activities, such as use of water sprays to control dust and modification of soil handling rates ,would be implemented, if necessary. Air-monitoring could also be conducted during implementation of this alternative to ensure that any potential off-site migration of the chemical constituents in the form of dust or vapors is within the pre-defined acceptable limits specified in the site-specific health and safety plan.

Long-Term Effectiveness and Permanence

The reactive iron wall technology is a destructive treatment technology where the end-products are completely dehalogenated and non-toxic. Examples of the end-products that may be expected at this site due to the break-down of the chlorinated VOCs include ethene, ethane, methane, and chloride ions. As such, this alternative would be considered a permanent remedy and effective in the long-term at protecting the wetland from impacted groundwater originating from FRP-2.

To date, there have been limited full-scale applications of this technology. Currently, only seven reactive iron walls have been installed in the United States and all seven have been installed within the last two years. The oldest reactive iron wall, installed at the University of Waterloo Borden test site in Canada, has been performing consistently for five years with no significant precipitates observed. There is no data available on long-term treatment costs and effectiveness of the technology. The need for rehabilitation or replacement of the reactive iron media has yet to be demonstrated at any of the seven sites in the United States. Therefore, the long-term effectiveness of this alternative is uncertain.

Based on the reaction chemistry, precipitates may clog the system and/or coat the surface of the granular iron fillings, thus reducing the treatment effectiveness of the system. The reaction chemistry involves the dissociation of water which causes an increase in the pH of the groundwater. With the increase in pH, conditions are favorable for carbonate minerals in the water such as calcium carbonate ($CaCO_3$) and siderite (Fe_3CO) to precipitate in the reactive material. With further reductions in the groundwater's carbonate buffering capacity and a greater increase in the groundwater's pH, ferrous hydroxides ($Fe(OH)_2$) may also precipitate. Laboratory column results predict porosity losses due to inorganic mineral precipitates from two to fifteen percent per year (Focht et al., 1996).

Reduction of Toxicity, Mobility, or Volume

The mobility, volume, and toxicity of the impacted groundwater from FRP-2 would be reduced. During passage through the reactive iron wall, the toxicity of the chlorinated

VOCs in the groundwater would be reduced by dehalogenated reduction to non-toxic compounds. Mobility of the impacted groundwater would be limited to the perimeter of FRP-2. Impacted groundwater would be treated before it would reach the wetland. The volume of impacted groundwater would also be reduced after passage through the reactive iron wall.

Implementability

From a constructability standpoint, the reactive iron wall could not be built to the required depths with the trenching machinery currently available. Currently, trenching devices are available that are capable of trenching 24 feet deep and two feet wide. The machinery, with benching, can achieve maximum depths of approximately 35 feet below ground surface. A 13-foot bench would be required to construct a trench to the confining layer at the site. However, at this bench depth, excavation would be conducted below the water table, which exists at approximately 6 to 9 feet below grade in the proposed wall region, making this approach impractical.

A trenching machine capable of achieving trench depths of 40 to 45 feet below ground surface without benching will be available in mid-1997. This machinery should be capable of implementing a reactive iron wall at the site without the constructability issues stated above. Provided this equipment becomes available in the near future, this alternative is implementable.

Cost

The total estimated capital cost, annual O&M cost (based on quarterly groundwater sampling only), and 30-year present worth cost to implement the reactive iron wall alternative are:

• Total capital cost:	$ 1,300,000
• Annual O&M cost:	$ 30,000
• Iron Rejuvenation, every 10 years:	$ 100,000
• Present worth of the reactive iron wall alternative:	$ 2,000,000
• Combined present worth of reactive iron wall alternative and continued IRM operation:	$ 2,620,000

The actual O&M costs for a reactive iron wall are uncertain. No wall has been installed for greater than 6 years. ETI recommends considering "rejuvenation" of the reactive material every 5 to 10 years based on potential fouling problems discussed above. ETI is experimenting at the bench and pilot scales with "closed-loop" flushing; a process by which a weak acid is injected through upgradient wells, passed through the iron media causing the dissipation of mineral precipitates, and then extracted in downgradient wells. Other possible O&M procedures for the wall consist of replacing the iron media partially or in full every 5 to 10 years, or per ETI "stirring-up" of the iron media with hollow stem augers, as warranted.

A detailed breakdown of the cost components and assumptions for the cost estimate are included in Appendix D.

5.3.3 Hydraulic Containment Via Groundwater Recovery Wells and Air Stripping

Alternative Description

This alternative consists of installing a groundwater recovery and treatment system at the northern edge of the paved area of FRP-2 in order to intercept the migration of groundwater which would otherwise flow from this area to the adjacent wetland. Hydraulic containment would be accomplished with a series of groundwater recovery wells with automatic pump controls. Groundwater treatment would be achieved by air stripping. Treated groundwater would be discharged in accordance with effluent limitations established for the existing groundwater treatment system at AOC 16.

The capture of groundwater which migrates from FRP-2 would be achieved by the installation of a series of extraction wells. Based on the preliminary results of groundwater modeling (Appendix C), four 4-inch diameter, 35-foot deep recovery wells with 10-foot screened intervals would achieve the necessary zone of capture as shown in Figure 5.2. The wells would be spaced approximately 140 feet apart along the north edge of the pavement adjacent to the wetland. The initial prediction of steady-state average groundwater yield from each well is roughly 1/4 GPM. A pilot-scale pump test may be desirable prior to system design in order to verify the predicted flow rates. Each well would contain pump and level sensors to maintain the appropriate drawdown and control pump cycling. Pump cycling would generate an intermittent flow from each well of approximately 1 to 2 GPM and the resulting total flow rate to the treatment system would vary between 0 and 8 GPM.

For evaluation purposes, it was conservatively assumed that the treatment system would be designed for an average flow of 1 GPM and a maximum flow rate of 8 GPM. Based on existing site-specific analytical data, the contaminants of concern and their maximum detected concentrations in groundwater samples from within the predicted capture zone are:

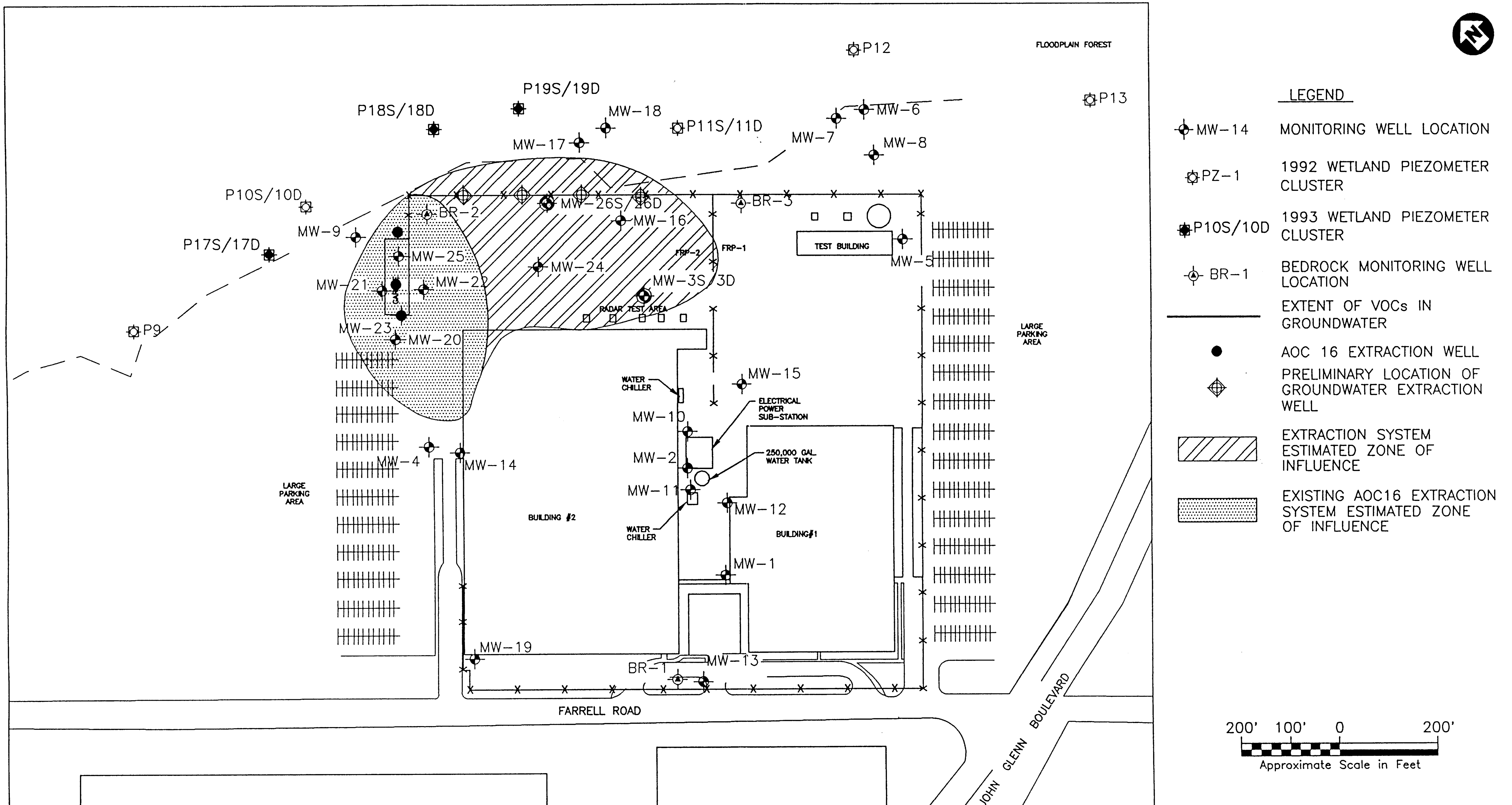


FIGURE 5.2

FORMER GE
FARRELL ROAD SITE

POTENTIAL GROUNDWATER EXTRACTION SYSTEM ESTIMATED ZONE OF INFLUENCE

PARSONS ENGINEERING SCIENCE, INC.
DESIGN • RESEARCH • PLANNING
290 ELWOOD DAVIS ROAD • SUITE 312 • LIVERPOOL, N.Y. 13088 • 315/451-9660
OFFICES IN PRINCIPAL CITIES

NOTE: VOC EXTENT BASED ON AVAILABLE GROUNDWATER DATA 1992 THROUGH 1996.

DATE: 12/16/96 (GTC)
H:\CAD\730125\30125G01.DWG (M/P SPACE)

H:\CAD\730125\30125G01 Thu Dec 26 13:23:54 1996

Compound Name	Maximum Detected Concentration (µg/L)
1,1-DCA	3400
1,1-DCE	270
1,2-DCE (total)	140
1,1,1-TCA	130
TCE	660
Trichlorotrifluoromethane	73
Vinyl Chloride	130
Chloroethane	21
Toluene	60
Ethyl Benzene	960
Xylenes (total)	3900
Acetone	350

These maximum concentrations were used in this FS for technology evaluation purposes. Prior to system design, further evaluation may be required to more accurately predict average influent groundwater concentrations.

The treatment system would likely be enclosed in a small, heated, pre-designed building located along the northern edge of the paved area of FRP-2. The flow would pass through bag filters and into a low-profile tray-style air stripper. Treated water in the air stripper sump would flow by gravity or pumped pressure to a discharge outfall. Based on preliminary evaluations, air emissions from the air stripper is anticipated to be discharged without treatment, consistent with operation of the existing IRM at AOC 16; (i.e. it is assumed air discharge requirements would be met without treatment). The lack of need for off-gas treatment would be verified during detailed design, based on applicable SCGs, including but not limited to 6 NYCRR Part 212, Air Guide-1, Air Guide-20, and Air Guide-29.

Compliance with SCGs

Chemical-specific SCGs applicable to this alternative include New York Ambient Water Quality Standards and Guidance Values for VOCs in groundwater and surface water. Hydraulic containment prevents the migration of groundwater from FRP-2 to the wetland; therefore, all SCGs related to groundwater and discharge to the wetland would be satisfied. Since extracted groundwater would be treated on-site and discharged, the final design of the groundwater treatment technology must achieve the applicable discharge criteria. This treatment system incorporates an air emission source that is subject to New York Air Guide 1 and New York regulations 6 NYCRR 200, 201, and 212. Based on existing site characterization data, the air stripping technology for groundwater treatment is anticipated to meet these regulatory requirements without off-gas treatment.

Location-specific SCGs for this alternative apply to excavation and construction activities expected to occur at the northern edge of the paved area of FRP-2 for the installation of the series of four recovery wells. As per the New York State Freshwaters Wetlands Act, remedial actions occurring within 100 feet of a wetland must comply with regulatory standards contained in 6 NYCRR Part 663.

Action-specific SCGs for this alternative apply to the excavation and handling of site soils during well installation, monitoring requirements, and OSHA health and safety requirements, (i.e. 29 CFR 1910, 1926, 1904, and 40 CFR 264 and 262). Compliance with these SCGs would be achieved by following a NYSDEC-approved remedial design/remedial action work plan and a site-specific health and safety plan.

Overall Protection of Human Health and the Environment

No unacceptable risks to human health or the environment due to groundwater contamination have been demonstrated to exist for the site. Therefore, implementation of this alternative may not be necessary to achieve the required level of protectiveness. However, this alternative would further reduce any potential risks to human health and the environment by minimizing the discharge of impacted groundwater into the wetlands.

As discussed in Section 1.3.2, contaminants have been detected in wetland sediment and shallow groundwater above guidance values. When considering these contaminants along with other detected organic compounds for which standards or guidance values do not exist, it is possible that additive and synergistic effects pose potential risk to fish and wildlife resources in the wetland. Further investigation would be necessary to determine if actual impacts to ecological receptors exist as a result of additive and synergistic effects of the contaminants detected.

Short-Term Effectiveness

No significant short-term impacts from remedial activities are anticipated for remedial workers, site workers, or residents. Appropriate levels of personal protection and health and safety planning and monitoring would be required during the installation of the hydraulic containment and extracted groundwater treatment system to ensure that the required level of protectiveness is maintained.

Long-Term Effectiveness and Permanence

The long-term reliability of this alternative is expected to be high and the generation of treatment residuals will be minimal. The effectiveness of this alternative relies on continuous system O&M of the extraction system until groundwater contaminant concentrations decrease, through natural attenuation processes, to acceptable levels. Therefore, this alternative would achieve long-term effectiveness and permanence.

Reduction of Toxicity, Mobility or Volume

The groundwater extraction system would reduce the volume of impacted groundwater downgradient of the extraction wells. Groundwater treatment by air stripping without off-gas treatment does not reduce the toxicity, mobility or volume of contaminants and increases the mobility of VOCs in the short term by transferring them from water to air. It should be noted, however, that hydraulic containment and treatment of extracted groundwater by air stripping is anticipated to achieve the RAOs without exceeding air emission standards.

Implementability

A hydraulic containment and air stripper treatment system is highly implementable. Construction of groundwater wells is standard practice to achieve groundwater extraction for remediation projects. Air stripping technology is fully developed and there are many operating units throughout the United States. Construction and operation of this treatment system is considered to be readily achievable. Operational monitoring requirements would be established by meeting the substantive requirements of applicable discharge permit and regulatory guidelines.

Cost

The estimated costs to implement hydraulic containment and groundwater treatment via air stripping are:

• Total capital cost	$ 210,000
• Annual O&M cost:	$ 44,000
• Total estimated present worth of the hydraulic containment with groundwater treatment via air stripping alternative:	$ 990,000
• Combined present worth of hydraulic containment with groundwater treatment via air stripping alternative and continued IRM operation:	$1,610,000

In general, most equipment required for a groundwater recovery and air stripping treatment system is commonly available. Therefore, the reliability in projected costs based on vendor quotes, manufacturer's catalogs, standard cost estimating references, and previous engineering experience is relatively high. Variability between projected and actual costs is expected to be due primarily to differences between the initial pre-design assumptions and the requirements of the final design. The projection for annual O&M costs, including a significant contingency for system breakdown and unanticipated reporting requirements, is consistent with actual costs incurred to operate similar systems already in place at the site.

A detailed breakdown of the cost components and assumptions for the cost estimate are included in Appendix D. The approximate accuracy of these costs is minus 30 to plus 50 percent, which are typical accuracies for FS comparative cost estimates.

5.3.4 Hydraulic Containment Via Groundwater Recovery Wells and UV/Hydrogen Peroxide Oxidation

Alternative Description

This alternative consists of installing a groundwater recovery and treatment system at the northern edge of the paved area of FRP-2 in order to intercept the migration of groundwater which would otherwise flow from this area to the adjacent wetland. Groundwater recovery would be achieved by a series of groundwater recovery wells with automatic pump controls as described previously in Section 5.3.3.

Groundwater treatment would be achieved with a UV/hydrogen peroxide oxidation treatment system designed for an average flow of 1 GPM and a maximum flow rate of 8 GPM. The system is anticipated to have a flow equalization tank to improve process control. The contaminants of concern and their anticipated worst-case concentrations in recovered groundwater are as listed in Section 5.3.3. Treated groundwater would be discharged in accordance with effluent limitations established for the existing groundwater treatment system at AOC 16.

The treatment system would likely be enclosed in a small, heated, pre-designed building located along the northern edge of the paved area of FRP-2. It may include a central flow equalization tank with level controls and a discharge pump. The flow would pass through bag filters and into the UV/hydrogen peroxide reactor. A separate treated effluent holding tank may be necessary as a reservoir from which flow could be recirculated through the UV reactor whenever the flow equalization tank was not discharging. The UV system could not be cycled on and off as needed, but must be kept in constant operation. As new batches of influent water were processed, treated water in the effluent holding tank would flow by gravity or pumped to a discharge outfall.

Compliance with SCGs

Chemical-specific SCGs applicable to this alternative include New York Ambient Water Quality Standards and Guidance Values for VOCs in groundwater and surface water. Hydraulic containment prevents the migration of groundwater from FRP-2 into the wetland; therefore, all SGCs related to groundwater and discharge to the wetland surface water would be satisfied. Since extracted groundwater would be treated on-site and discharged, the final design of the groundwater treatment technology must achieve the applicable surface water discharge criteria. Based on existing site characterization data and discharge permitting consistent with the existing groundwater treatment at AOC 16, the UV/hydrogen peroxide oxidation technology for groundwater treatment system is anticipated to meet those requirements.

Location-specific SCGs for this alternative apply to excavation and construction activities expected to occur at the northern perimeter of the paved area of FRP-2 for the installation of a series of four recovery wells. As per the New York State Freshwaters Wetlands Act, remedial actions occurring within 100 feet of a wetland must comply with regulatory standards contained in 6 NYCRR Part 663.

Action-specific SCGs for this alternative apply to the excavation and handling of site soils during well installation, monitoring requirements, and OSHA health and safety requirements, (i.e. 29 CFR 1910, 1926, 1904, and 40 CFR 264 and 262). Compliance with these SCGs would be achieved by following a NYSDEC-approved remedial design/remedial action work plan and a site-specific health and safety plan.

Overall Protection of Human Health and the Environment

No unacceptable risks to human health or the environment due to groundwater contamination have been demonstrated to exist for the site. Therefore, implementation of this alternative may not be necessary to achieve the required level of protectiveness. However, this alternative would further reduce any potential risks to human health and the environment by minimizing the discharge of impacted groundwater into the wetland.

As discussed in Section 1.3.2, contaminants have been detected in wetland sediment and shallow groundwater above guidance values. When considering these contaminants along with other detected organic compounds for which standards or guidance values do not exist, it is possible that additive and synergistic effects pose potential risk to fish and wildlife resources in the wetland. Further investigation would be necessary to determine if actual impacts to ecological receptors exist as a result of additive and synergistic effects of the contaminants detected.

Short-Term Effectiveness

No significant short-term impacts from remedial activities are anticipated for remedial workers, site workers, or residents. Appropriate levels of personal protection and health and safety planning and monitoring would be required during the installation of the hydraulic containment and extracted groundwater treatment system to ensure that the required level of protectiveness is maintained.

However, the system may post a short-term risk to the environment. Bioassay testing has indicated that system effluent may be acutely toxic to freshwater test organisms, even if the influent is not toxic (USEPA, 1993a). The observed toxicity was likely due to high levels of hydrogen peroxide in the system effluent. Due to the proximity of the site to a regulated wetlands, bioassay testing of system may be required before discharge of the effluent.

Long-Term Effectiveness and Permanence

The hydraulic containment via groundwater recovery wells and UV/hydrogen peroxide oxidation alternative provides destruction of the organic contaminants and creation of low-toxicity byproducts. Low volumes of non-hazardous solid waste residuals, in the form of filter solids and iron precipitate sludges, are anticipated to be generated throughout the life of the alternative. System operation is based upon proven technology, but the system complexity may reduce its long-term reliability. The effectiveness of this alternative relies on continuous system O&M of the extraction system until groundwater contaminant concentrations decrease, through natural attenuation processes, to acceptable levels. Therefore, this alternative would achieve long-term effectiveness and permanence.

Reduction of Toxicity, Mobility or Volume

UV/hydrogen peroxide technology provides photolysis and oxidation of organic contaminants that leads to destruction by mineralization (formation of carbon dioxide, water, and other inorganic species). These reactions significantly reduce the toxicity and volume of the contaminants.

Implementability

A hydraulic containment and UV/hydrogen peroxide oxidation system is highly implementable. Construction of groundwater wells is standard practice to achieve groundwater extraction for remediation projects. UV/hydrogen peroxide oxidation technology is fully developed and there are many operating units throughout the United States. Construction and operation of this treatment system is considered to be readily achievable, pending the results of appropriate bench-scale testing as recommended by the UV/hydrogen peroxide treatment system vendor. Operational monitoring requirements would be established by meeting the substantive requirements of applicable discharge permit and regulatory guidelines.

Cost

The estimated costs to implement hydraulic containment and groundwater treatment via UV/hydrogen peroxide oxidation are as follows:

• Total capital cost:	$ 330,000
• Annual O&M cost:	$ 81,000
• Total estimated present worth of the hydraulic containment with groundwater treatment via UV/hydrogen peroxide oxidation alternative:	$ 1,800,000
• Combined present worth of hydraulic containment with groundwater treatment via UV/hydrogen peroxide oxidation alternative and continued IRM operation:	$ 2,420,000

In general, most equipment required for a groundwater recovery and UV/hydrogen peroxide oxidation treatment system is commonly available. Therefore, the reliability in projected costs based on vendor quotes, manufacturer's catalogs, standard cost estimating references, and previous engineering experience is relatively high. Variability between projected and actual costs is expected to be due primarily to differences between the initial pre-design assumptions and the requirements of the final design. Due to the additional system complexity of UV/hydrogen peroxide oxidation treatment, the projection for annual O&M costs is anticipated to be higher than the typical costs incurred to operate the systems already in place at the site. UV lamps are difficult to keep clean with many wastewaters. The high annual cost of electricity consumption, above that required for pumping, controls, and building heat, is high due to the requirements of the UV lamps.

A detailed breakdown of the cost components and assumptions for the cost estimate are included in Appendix D. The approximate accuracy of these costs is minus 30 to plus 50 percent which are typical accuracy's for FS comparative cost estimates.

5.3.5 Hydraulic Containment Via Groundwater Recovery Wells and *Ex Situ* Biological Degradation

Alternative Description

This alternative consists of installing a groundwater recovery and treatment system at the northern edge of the paved area of FRP-2 in order to intercept the migration of groundwater into the adjacent wetland. Groundwater recovery would be achieved by a series of groundwater recovery wells with automatic pump controls as described previously in Section 5.3.3.

Groundwater treatment would be achieved by biological treatment. For evaluation purposes, it was assumed that the aerobic fluidized bed process option would be utilized as discussed in Section 4.5.2.3. The system would be designed for an average flow rate of 1 GPM and a maximum flow rate of 8 GPM and is anticipated to have a flow equalization tank to improve process control. The contaminants of concern and their anticipated worst-case concentrations in recovered groundwater are as listed in Section 5.3.3. Treated groundwater would be discharged in accordance with effluent limitations established for the existing groundwater system at AOC 16.

The treatment system would most likely be enclosed in a small, heated, pre-designed building located along the north edge of the paved area of FRP-2. It may include a central flow equalization tank with level controls and a discharge pump. The flow would be pumped through bag filters, through the oxygenator, and into a fluidized bed reactor loop that would flow at approximately 30 GPM. A treated bleed-off from the loop may then pass through a separator for capturing escaped media and be discharged to the system outfall. Air venting from the aerobic reactor is anticipated to be discharged from the building without treatment, consistent with operation of the existing IRM at AOC 16.

Compliance with SCGs

Chemical-specific SCGs applicable to this alternative include New York Ambient Water Quality Standards and Guidance Values for VOCs in groundwater and surface water. Hydraulic containment prevents the migration of groundwater from FRP-2 to the wetland; therefore, all SGCs related to groundwater and discharge to the wetland surface water are satisfied. Since extracted groundwater is to be treated on-site and discharged, the final design of the groundwater treatment technology must achieve the applicable surface water discharge criteria. Based on existing site characterization data and effluent limitations consistent with the existing groundwater treatment at AOC 16, the *ex situ* biological degradation technology for groundwater treatment is anticipated to meet these regulatory requirements.

Location-specific SCGs for this alternative apply to excavation and construction activities expected to occur at the northern edge of the paved area of FRP-2 during the installation of a series of four recovery wells. As per the New York State Freshwater Wetlands Act, remedial actions occurring within 100 feet of a wetland must comply with regulatory standards contained in 6 NYCRR Part 663.

Action-specific SCGs for this alternative apply to the excavation and handling of site soils during well excavation, monitoring requirements, and OSHA health and safety requirements, i.e. 29 CFR 1910, 1926, 1904, and 40 CFR 264 and 262. Compliance with these SCGs would be achieved by following a NYSDEC-approved remedial design/remedial action work plan and a site-specific health and safety plan.

Overall Protection of Human Health and the Environment

No unacceptable risks to human health or the environment due to groundwater contamination have been demonstrated to exist for the site. Therefore, implementation of this alternative may not be necessary to achieve the required level of protectiveness. However, this alternative would further reduce any potential risks to human health and the environment by minimizing the discharge of contaminated groundwater to downgradient surface waters.

As discussed in Section 1.3.2, contaminants have been detected in wetland sediment and shallow groundwater above guidance values. When considering these contaminants along with other detected organic compounds for which standards or guidance values do not exist, it is possible that additive and synergistic effects pose potential risk to fish and wildlife resources in the wetland. Further investigation would be necessary to determine if actual impacts to ecological receptors exist as a result of additive and synergistic effects of the contaminants detected.

Short-Term Effectiveness

No significant short-term impacts from remedial activities are anticipated for remedial workers, site workers, or residents. Appropriate levels of personal protection and health and safety planning and monitoring would be required during the installation of the hydraulic containment and extracted groundwater treatment system to insure that the required level of protectiveness is maintained.

Long-Term Effectiveness and Permanence

Hydraulic containment via groundwater recovery wells and *ex situ* biological degradation provides destruction of the organic contaminants and creation of low-toxicity byproducts. Small quantities of non-hazardous solid waste residuals, in the form of filter solids, reactor sludges, and iron precipitate sludges, are anticipated to be generated throughout the life of the alternative. The rate of waste solids generation for this alternative is predicted to be similar to the rate for air stripping and for UV/hydrogen peroxide oxidation. System operation is based upon proven technology for wastewater streams with higher flows and organic concentrations but may not be reliable for small volume systems that are more sensitive to changes in parameters such as temperature, pH, and contaminant loading. The effectiveness of this alternative relies on continuous system operation, proper control of all chemical additions, and thorough maintenance of the extraction system. The system would operate until groundwater contaminant concentrations decrease, through natural attenuation processes, to acceptable levels. Therefore, this alternative would achieve long-term effectiveness and permanence.

Reduction of Toxicity, Mobility or Volume

Ex situ biological degradation provides oxidation of organic contaminants via biological respiration reactions which leads to destruction by mineralization (the eventual formation of carbon dioxide, water, and other inorganic species and conversion to biomass). To a lesser degree, assimilation of organic carbon into bacterial cell tissue also occurs. These reactions significantly reduce the toxicity and volume of the contaminants.

Implementability

Hydraulic containment and *ex situ* biological degradation is relatively implementable. Construction of groundwater wells is standard practice to achieve groundwater extraction for remediation projects. *Ex situ* biological degradation technology is fully developed but not typically implemented on groundwater treatment projects with low concentrations of organics and flow rates less than 10 GPM. Construction and operation of this treatment system is considered to be achievable pending the results of appropriate bench-scale testing. Operational monitoring requirements would be established by meeting the substantive requirements of applicable discharge permit and regulatory guidelines.

Cost

The estimated costs to implement hydraulic containment and groundwater treatment via biological degradation are:

• Total capital cost:	$ 390,000

• Annual O&M cost:	$	54,000
• Total estimated present worth of the hydraulic containment with groundwater treatment via air stripping alternative:	$	1,300,000
• Combined present worth of hydraulic containment with groundwater treatment via air stripping alternative and continued IRM operation:	$	1,920,000

In general, most equipment required for a groundwater recovery and *ex situ* biological degradation treatment system is commonly available. Therefore, the reliability in projected costs based on vendor quotes, manufacturer's catalogs, standard cost estimating references, and previous engineering experience is relatively high. Variability between projected and actual costs is expected to be due primarily to differences between the initial pre-design assumptions and the requirements of the final design. It is assumed that air discharge evaluation and permitting will not be required. Due to the additional system complexity of *ex situ* biological treatment, the projection for annual operations and maintenance costs is anticipated to be higher than the typical costs incurred to operate the systems already in place at the site.

A detailed breakdown of the cost components and assumptions for the cost estimate are included in Appendix D. The approximate accuracy of these costs is minus 30 to plus 50 percent which are typical accuracies for FS comparative cost estimates.

SECTION 6

COMPARATIVE ANALYSIS OF REMEDIAL ALTERNATIVES

6.1 INTRODUCTION

Based on the detailed evaluation of each remedial alternative for site-wide groundwater presented in Section 5, a comparative analysis of remedial alternatives is conducted below to select the preferred remedy for site-wide groundwater. The comparative analysis is based on the evaluation criteria identified in Section 5 and compares the relative advantages and disadvantages of each alternative.

6.2 COMPARATIVE ANALYSIS OF SITE-WIDE GROUNDWATER REMEDIAL ALTERNATIVES

The remedial alternatives identified for site-wide groundwater are:

- No further action;
- Installation of a reactive iron wall;
- Hydraulic containment via groundwater recovery wells and air stripping;
- Hydraulic containment via groundwater recovery wells and UV/hydrogen peroxide oxidation; and
- Hydraulic containment via groundwater recovery wells and *ex situ* biological degradation.

The no further action alternative is presented as a baseline for comparison with other remedial technologies.

Compliance with SCGs

All of the remedial alternatives can be designed and implemented to meet all the action-specific and location-specific SCGs. The reactive iron wall would not achieve the chemical-specific SCGs for acetone and chloroethane. Hydraulic containment via groundwater recovery wells would prevent the migration of impacted groundwater into the wetlands, and therefore satisfy SCGs pertaining to groundwater and contaminant discharge to wetlands. Subsequent treatment of extracted groundwater via either air stripping, UV/hydrogen peroxide oxidation, or biological degradation are all expected to meet the effluent limitations established for the existing groundwater treatment system at AOC 16, and thus will meet the chemical-specific SCGs applicable to site groundwater.

Overall Protection of Human Health and the Environment

No unacceptable risks to human health or the environment due to groundwater contamination have been demonstrated to exist for the site. Therefore, the no further action alternative may achieve the required level of protectiveness. However, all alternatives, with the exception of the no further action alternative, would further reduce any potential risks to human health and the environment by minimizing the discharge of contaminated groundwater from the developed portion of the site to downgradient surface waters.

As discussed in Section 1.3.2, contaminants have been detected in wetland sediment and shallow groundwater above guidance values. When considering these contaminants along with other detected organic compounds for which standards or guidance values do not exist, it is possible that additive and synergistic efforts pose potential risk to fish and wildlife resources in the wetland. Further investigation would be necessary to determine if actual impacts to ecological receptors exist as a result of additive and synergistic effects of the contaminants detected.

Short-Term Effectiveness

All of the remedial alternatives, except for the no further action alternative, would involve some degree of excavation of site soils and material handling. However, the soil excavation during well installation would be minor in comparison to the soil excavation during reactive iron wall installation. Soil excavation activities may present potential short-term exposure to on-site workers due to volatilization of VOCs from the contaminated groundwater. Mitigative measures, such as appropriate levels of personal protection and health and safety planning and monitoring would be required during the implementation of any alternative. Dust suppression measures for controlling fugitive dust generated during the remedial activities would be implemented, if necessary. With these measures, no significant short-term risks to site workers and off-site receptors would be presented during the implementation of any of the alternatives. However, the hydraulic containment alternatives may provide slightly lower short-term risks than the reactive iron wall due to the soil excavation necessary during well installation.

Long-Term Effectiveness and Permanence

Continued operation of the IRMs at AOCs 5, 7, and 16 would increase the effectiveness of the no further action alternative, but would not be effective in meeting the RAOs.

As a destructive treatment technology, the reactive iron wall would be considered a permanent remedy for all compounds of concern except for chloroethane and acetone. The reactive iron wall technology has been successful to date; however, it is an innovative technology for which there is limited long-term full-scale data available. There is no data available on the long-term effectiveness of the technology.

The long-term effectiveness of hydraulic containment would rely on continuous system operation and maintenance until site-wide groundwater contaminant concentrations decrease, through natural attenuation processes, to acceptable levels. Therefore, all of the hydraulic containment alternatives would achieve long-term effectiveness and permanence.

Reduction of Toxicity, Mobility, or Volume

All alternatives considered would present some degree of reduction of toxicity, mobility, or volume. Continued operation of the IRMs at AOCs 5, 7, and 16 under the no further action alternative would reduce the contaminant mass loading to site groundwater and thus eventually reduce the toxicity and volume of affected groundwater. The iron reactive wall would destroy most contaminants in groundwater and reduce the volume of impacted groundwater downgradient of the wall installation. The hydraulic control alternatives would also reduce the volume of impacted groundwater downgradient of the extraction system. In addition, the biological treatment and UV/hydrogen peroxide groundwater treatment alternatives would provide destruction of groundwater contaminants.

Implementability

All of the remedial alternatives are technically feasible and could be implemented at the site. Installation of groundwater extraction wells for remedial purposes is standard practice. Air stripping and UV/hydrogen peroxide oxidation treatment technologies are fully developed and currently being used at numerous sites throughout the United States. However, *ex situ* biological degradation technology is not typically implemented on groundwater treatment projects of the size and type required for the site. Therefore, bench-scale and possibly pilot-scale testing would be necessary to verify that it can be successfully implemented for this site. The reactive iron wall, due to its innovative status, has constructability issues that would need to be resolved in the design phase before it can be implemented. The reactive iron wall alternative was developed for this site based on the assumption that a trenching machine capable of achieving the desired depths would be available by the time the chosen alternative would need to be implemented.

Cost

A summary of the capital, annual O&M, and present worth costs of each of the site groundwater remedial alternatives is presented in Table 6.1. Other than no further action, hydraulic control and treatment via air stripping is the least expensive alternative. Installation of a permeable iron reactive wall is the most expensive. A detailed breakdown of the cost components and assumptions for the cost estimate are provided in Appendix D.

6.3 CONCLUSIONS

6.3.1 Selected Remedy for Site-Wide Groundwater

Based on the comparative analysis, hydraulic containment via groundwater recovery wells and extracted groundwater treatment via air stripping was chosen as the recommended alternative for site-wide groundwater. This remedy is protective of public health and the environment. It will satisfy the preference for alternatives which permanently reduce toxicity, mobility, or volume by reducing the volume of impacted

TABLE 6.1

SUMMARY OF SITE-WIDE GROUNDWATER REMEDIAL ALTERNATIVES COST ESTIMATES

Alternative	Estimated Capital Cost	Estimated Annual O&M Cost	Estimated Present Worth of Alternative	Combined Present Worth of Alternative and Continued IRM Operation
No Further Action	$0	$70,000	$620,000	$620,000
Reactive Iron Wall	$1,300,000	$30,000	$2,000,000	$2,620,000
Hydraulic Containment				
Air Stripping	$210,000	$44,000	$990,000	$1,610,000
UV/Hydrogen Peroxide Oxidation	$330,000	$81,000	$1,800,000	$2,420,000
Ex Situ Biological Degradation	$390,000	$54,000	1,300,000	$1,920,000

groundwater and limiting its mobility. It will provide a level of short-term and long-term effectiveness at least as great as the other alternatives evaluated. It will meet all SCGs, which the reactive iron wall can not due to its ineffectiveness on select contaminants. Air stripping is more readily implementable than biological degradation due to its simplistic operation and proven status. Air stripping is also the most economical of the alternatives considered other than no further action. Hydraulic containment and treatment of extracted groundwater via air stripping will meet all site RAOs.

Extracted groundwater will be treated and discharged in accordance with the effluent limitations established for the existing groundwater treatment system at AOC 16. Consistent with the surface water discharge effluent criteria for AOC 16, the effluent criteria for the site-wide groundwater treatment system are shown in Table 6.2. Based on preliminary evaluations, air emissions from the air stripper are anticipated to be discharged without treatment, consistent with the operation of the existing groundwater treatment system at AOC 16. This will be verified during system design based on applicable SCGs, including but not limited to 6NYCRR Part 212, Air Guide-1, Air Guide-20, and Air Guide-29.

Verification of the effectiveness of the hydraulic containment system will be via monitoring of groundwater levels at monitoring wells and piezometers in the vicinity of the extraction system. Installation of additional piezometers during system installation may be required. No sampling of monitoring wells downgradient of the extraction system will be required to verify system effectiveness.

During the system design, various extraction and treatment configurations will be evaluated. This may include consideration of treatment using the existing air stripping system operating at AOC 16.

6.3.2 Role of Intrinsic Remediation in the Selected Remedy

As discussed above, the selected remedy for site-wide groundwater will satisfy the site RAOs without consideration of intrinsic remediation. Nevertheless, natural attenuation processes will continue to reduce site-wide groundwater contamination levels, as presented in detail in Appendix B. In the wetland sediments and groundwater downgradient of the recovery wells, groundwater contaminant levels will continue to decrease through natural attenuation processes following implementation of the hydraulic containment system. No other action will be required to address wetland sediments and groundwater, consistent with the September 13, 1996 letter from NYSDEC to LMC stating "...any remedial action that would occur within the wetland has the potential to cause significantly more harm to the wetland than the no further action alternative."

Groundwater contamination levels upgradient of the recovery wells will also continue to decrease due to natural attenuation processes and source remedial actions already completed.

TABLE 6.2
EFFLUENT LIMITATIONS
SITE-WIDE GROUNDWATER REMEDIAL SYSTEM

Effluent Parameter	Discharge Limitations Daily Avg.	 Daily Max.	Units
Flow	Monitor	Monitor	gpd
pH (Range)	(6.0 - 9.0)		SU
Benzene	Monitor	10	µg/l
Toluene	Monitor	10	µg/l
Ethylbenzene	Monitor	10	µg/l
Xylenes, Total	Monitor	10	µg/l
Chloroethane	Monitor	10	µg/l
1,1-Dichloroethane	Monitor	10	µg/l
1,2-(cis)-Dichloroethene	Monitor	10	µg/l
1,2-(trans)-Dichloroethene	Monitor	10	µg/l
1,1,1-Trichloroethane	Monitor	10	µg/l
Trichloroethene	Monitor	10	µg/l
Chloromethane	Monitor	10	µg/l
Methyl Tertiary-Butyl Ether (MTBE)	Monitor	10	µg/l
4-Methyl-2-pentanone (MIBK)	Monitor	10	µg/l
Iron, Total	Monitor	4	mg/l
Manganese, Total	Monitor	4	mg/l

6.3.3 Yearly Re-evaluation of Selected Remedy

As part of the selected remedy, the need for continued operation of the groundwater extraction system will be re-evaluated on a yearly basis. This will allow the opportunity to evaluate the applicability of innovative technologies as they continue to develop. Also, the site-wide groundwater extraction system is being implemented to satisfy SCGs, and reduce potential risks. The yearly re-evaluation will allow for refinement of the site remedy if SCGs or risk evaluation procedures change. LMC expects that the Remedial Design/Remedial Action Consent Order will include language that the selected remedy may be re-evaluated yearly. Finally, as discussed above, natural attenuation processes will continue to reduce site-wide groundwater contamination levels. The yearly re-evaluation will allow a frequent reassessment of the role of intrinsic remediation in meeting site RAOs.

SECTION 7

IMPACT OF SELECTED SITE-WIDE GROUNDWATER ALTERNATIVE ON AOCs AND IRM OPERATION

7.1 INTRODUCTION

As developed in Section 3, the RAOs for the site are:

1. Provide protection of the Class I wetland;
2. Provide protection of potential future on-site workers;
3. Achieve groundwater standards, where practicable; and
4. Prevent migration of groundwater into the wetlands from the developed portion of the FRP-2 property.

To meet these objectives, the selected alternative for site-wide groundwater is hydraulic containment via groundwater extraction wells along the northern edge of the developed portion of the FRP-2 property. Extracted groundwater will be treated via air stripping, as discussed in Section 6. To verify that this alternative meets the established RAOs, the impact of the selected groundwater alternative on the need for remedial action at AOC 5, AOC 7, and AOC 16, and in wetland sediments is evaluated below. The reasons for focusing on these areas and media of concern are discussed in Section 1. The evaluation includes consideration of the IRMs already completed or currently operating at each AOC. The following section provides a discussion related to the need to remediate site soils to achieve RAO 2 is evaluated on a site-wide basis.

7.2 PROTECTION OF POTENTIAL FUTURE ON-SITE WORKERS

The Qualitative Public Health Risk Assessment (ERM, May 1995) identified a potential future human exposure pathway during future construction activities due to potential human contact with nine VOCs and cyanide in soils in the developed portion of the site. The IRM Work Plans for the AOC 5 and AOC 16 SVE IRM systems specify termination criteria which includes meeting NYSDEC Technical and Administrative Guidance Memorandum (TAGM) 4046 soil cleanup criteria. TAGM 4046 soil cleanup criteria for organic contaminants were developed to be protective of groundwater assuming it will be used as a drinking water source. Soil cleanup criteria based on this pathway are typically significantly lower than soil cleanup criteria based on construction worker exposure pathways. Notwithstanding this position, in order to reduce potential risks during future construction activities, LMC will operate the IRM systems at AOC 5, AOC 7 and AOC 16 consistent with the NYSDEC-approved IRM Work Plans for these areas.

7.3 AOC 5

As summarized in Section 1, a Soil Vapor Extraction (SVE) system consisting of vapor recovery wells, air injection wells, and a vacuum blower along with associated piping was installed as an IRM to extract the VOCs from the impacted soils located adjacent to and under the building at AOC 5. This system has been operating continuously since November 1995.

A summary of the investigative results at AOC 5 from the LNAPL/DNAPL RI and the DNAPL monitoring and recovery program at AOC 5 is contained in Section 1.4.2.

No further remedial action is necessary at AOC 5 to meet site RAOs 1, 3, and 4 listed above. The recommended hydraulic control system will be implemented downgradient of AOC 5 and will capture any groundwater contamination emanating from AOC 5 soils, as demonstrated by the groundwater model presented in Appendix C.

7.4 AOC 7

A free product recovery system is currently operating as an IRM at AOC 7, as summarized in Section 1.

No further remedial action is necessary at AOC 7 to meet site RAOs 1, 3, and 4. The primary contaminants of concern at AOC 7 are petroleum hydrocarbons. Petroleum hydrocarbons have not been detected in downgradient monitoring points located in the wetland (MW-17, MW-18, P-11, P-18, and P-19), indicating that AOC 7 contamination is naturally attenuating before reaching the wetland. In addition, the recommended hydraulic control system will be implemented downgradient of AOC 7 and will capture any groundwater contamination emanating from AOC 7 that does not attenuate, as shown by the groundwater model included in Appendix C.

Although consideration of natural attenuation processes is not necessary at AOC 7 to meet site RAOs, contamination levels within the aquifer are expected to decrease with time via natural attenuation processes, including biodegradation. As presented in the evaluation of natural attenuation in Appendix B, there is ample evidence of natural biodegradation of the petroleum hydrocarbons originating from AOC 7.

In summary, no further remedial action is necessary at AOC 7 to meet site RAOs. Operation of the existing free product recovery system will be continued as specified in the IRM work plan for AOC 7 (ERM, 1994c) to ensure protection of potential future construction workers and to further reduce contaminant loading to site-wide groundwater.

7.5 AOC 16

A groundwater pump and treat system and an SVE system are currently operating as IRMs at AOC 16, as summarized in Section 1.

No further remedial action is necessary at AOC 16 to meet site RAOs 1, 3, and 4 listed above. The AOC 16 pump and treat system is capturing impacted groundwater originating at AOC 16.

7.6 WETLAND SEDIMENTS

As discussed in Section 1.3.2, nine organic compounds were detected in wetland sediment. There are no guidance values established for four of these compounds. Of the five remaining compounds, the guidance value for one (PCBs at Outfall 003, which has since been remediated as an IRM) was exceeded.

Considered individually, based on best professional judgment, the presence of these contaminants does not appear to represent a significant environmental risk. However, when considering these contaminants along with the other detected organic compounds for which standards or guidance values do not exist, it is possible that additive and synergistic effects pose potential risk to fish and wildlife resources in the wetland. Although possible risks are presented due to additive and synergistic effects, no evidence of stressed biota or effects of additive or synergistic effects was observed in the wetland by biologists during site inspections completed as part of the FWIA. Provided the remaining source of contaminants to the wetland, that is, the migration of contaminated groundwater, is controlled at the northern edge of FRP-2, contaminant concentrations in the wetland are expected to attenuate, thereby reducing potential risks to ecological receptors.

Further investigation would be necessary to determine if actual impacts to ecological receptors exist as a result of additive and synergistic effects of the contaminants detected. However, because the migration of contaminated groundwater will be controlled at the northern edge of FRP-2, and because remediation of residual contamination in the wetland could itself impact this resource, there is no need for further investigation or remediation of surface water, groundwater or sediment in the wetland.

7.7 CONCLUSIONS AND SUMMARY

No further action is necessary at AOCs 5, 7, and 16 or in wetland sediments to meet the site RAOs. The groundwater pump and treat system at AOC 16 and the existing free product recovery system at AOC 7 will be operated as specified in their respective IRM work plans (ERM, 1994c; ERM, 1994d).

The SVE IRM systems at AOC 5 and AOC 16 will be operated consistent with the NYSDEC-approved IRM Work Plans for these areas. As discussed in Section 7.2, however, operation of the SVE IRM systems at AOC 5 and AOC 16 until the termination criteria specified in their respective work plans is reached will provide a level of contaminant reduction significantly beyond that required to be protective of potential future site workers and satisfy RAO 2.

In addition, the following changes will be made to the current O&M procedures:

1. System O&M for the AOC 5, AOC 7 and AOC 16 IRMs will be completed monthly rather than bi-weekly, and
2. Regularly scheduled air sample collection and laboratory analysis at the AOC 5 and AOC 16 IRMs will be terminated following the 18-month sampling event provided the 18-month sample does not exceed emission criteria.

The revision to the O&M and air monitoring procedures described above, as well as any future revisions to IRM system O&M procedures or termination criteria (i.e. evaluation of zero slope condition), will be implemented following NYSDEC approval of revisions to the IRM Work Plans.

No further remedial actions beyond the ongoing source control IRMs are needed to address source areas which have been currently identified at the site.

APPENDIX A

REFERENCES

APPENDIX A

REFERENCES

ASTM, 1995. Standard Guide for Risk-Based Corrective Action at Petroleum Release Sites, ASTM E 1739-95. November 1995.

BB&L, 1995. Farrell Road Plant Feasibility Study. Prepared by Blasland, Bouck & Lee, Inc. Prepared for Martin Marietta Corporation. August 1995.

BB&L, 1996a. Addendum Remedial Investigation Report Area of Concern #5 LNAPL/DNAPL Investigation. Prepared by Blasland, Bouck & Lee, Inc. Prepared for Lockheed Martin Corporation. Revised August 1996.

BB&L, 1996b. Addendum Remedial Investigation Report Soil Investigations Adjacent to Storm Sewer Outfall 003. Prepared by Blasland, Bouck & Lee, Inc. Prepared for Lockheed Martin Corporation. August 1996.

Doty, C.B. and Travis, C.C. 1989. The Effectiveness of Groundwater Pumping as a Restoration Technology, Oak Ridge National Laboratory, ORNL/TM-11866.

ERM, 1992a. ERM - Northeast, Inc. 1992 Environmental Investigation GE Farrell Road Plant Two (FRP-2), Syracuse, New York. July 10, 1992.

ERM, 1992b. ERM - Northeast, Inc. 1992 Environmental Investigation GE Farrell Road Plant One (FRP-1), Syracuse, New York. July 16, 1992.

ERM, 1992c. Debris Pile Excavation GE-Farrell Road Plant Two, Addendum to the 1992 Environmental Investigation. July 29, 1994.

ERM, 1992d. Soil Remediation, GE Farrell Road Plant Two. September 15, 1992.

ERM, 1994a. ERM - Northeast, Inc. Martin Marietta Corporation, 1994 RI/FS Work Plan. January 1994.

ERM, 1994b. ERM - Northeast, Inc. Martin Marietta Corporation, 1994 Remedial Investigation at the Farrell Road Plant. May 1995.

ERM, 1994c. ERM - Northeast, Inc. Martin Marietta Corporation, Interim Remedial Measures Work Plan for Area of Concern #7. May 3, 1994.

ERM, 1994d. ERM - Northeast, Inc. Martin Marietta Corporation, Work Plan Document I, Description of Interim Remedial Measure for Area of Concern #16. May 18, 1994.

Focht et al., 1996. Field Application of Reactive Iron Walls for In-Situ Degradation of Volatile Organic Compounds in Groundwater. Remediation, Summer 1996, pp. 81-94.

Kreich, 1991. Kreich, Anthony J. Evaluation of RAP for Use as a Clean Fill. Indianapolis: Heritage Research Group, 1991.

National Research Council, 1994. "Alternatives for Ground Water Clean-up", a report published by the National Academy of Sciences, Commission on Geosciences, Environment and Resources.

NYSDEC, 1990. Selection of Remedial Actions at Inactive Hazardous Waste Sites Technical and Guidance Memorandum HWR-90-4030. Division of Hazardous Waste Remediation. Albany, NY. May 15, 1990.

NYSDEC, 1996. Decision Document, Interim Remedial Measure, GE Farrell Road Inactive Hazardous Waste Site, Town of Geddes, Onondaga County, New York. August 1996.

Parsons ES, 1996a. Lockheed Martin Farrell Road Site, Monthly Progress Report, November 1996.

Parsons ES, 1996b. Certification Report for the Farrell Road Plant Storm Sewer Outfall 003 Interim Remedial Measure, October 1996.

Personal Communication, 1996. Correspondence between Mr. John Vogan of ETI and Ms. Joanne Howard of Parsons ES on November 6, 1996.

USEPA, 1982. Treatability Manual, EPA-600/2-82-001a.

USEPA, 1989. Evaluation of Groundwater Extraction Remedies, Volume 1, Summary Report, EPA/540/2-89/054, Office of Emergency and Remedial Response, Washington, D.C.

USEPA, 1993. Remediation Technologies Screening Matrix and Reference Guide. EPA 542-B-93-005, July 1993.

USEPA, 1993a. United States Environmental Protection Agency. perox-pure™ Chemical Oxidation Technology Peroxidation Systems, Inc. Applications Analysis Report. Washington D.C.: July, 1993. EPA/540/AR-93/501.

USEPA, 1995. Innovative Treatment Technologies: Annual Status Report (Seventh Edition) EPA-542-R-95-008, Revised September 1995.

USEPA, 1996. Soil Screening Guidance: Technical Background Document. May 1996.

Wilson, 1995. Zero-Valent Metals Provide Possible Solution to Groundwater Problems. Chemical & Engineering News, July 3, 1995, p. 19.

APPENDIX B

AUGUST 1996 GROUNDWATER SAMPLING AND ANALYSIS PROGRAM AND NATURAL ATTENUATION EVALUATION

APPENDIX B

TABLE OF CONTENTS

APPENDIX B

TABLE OF CONTENTS
(Continued)

PAGE

LIST OF FIGURES

LIST OF TABLES

LIST OF ATTACHMENTS

Attachment 1 - Analytical Results

Attachment 2 - Redox Information for Important Microbial Processes

SECTION 1.0 INTRODUCTION AND SAMPLING RESULTS

This appendix provides the results from the limited groundwater sampling and analysis program conducted at select monitoring wells on August 29 and 30, 1996. Analytical summary tables from this program are presented in Tables B.1 and B.2. Complete analytical results are included in Attachment 1 to this appendix. The results from the groundwater elevation measurements are presented in Table B.3 and Figure B.1.

The purpose of this sampling and analysis program was to obtain up-to-date groundwater data to be used in evaluating potential remedial technologies for site-wide groundwater and to evaluate the occurrence of on-going natural attenuation processes. The significance of this data in evaluating the occurrence of natural attenuation at the site is discussed below. Natural attenuation of petroleum hydrocarbons, and in particular benzene, toluene, ethylbenzene, and xylene (BTEX) compounds, is discussed in Section 2. Natural attenuation of chlorinated organics is discussed in Section 3.

SECTION 2.0 OPERATIVE MECHANISMS OF BTEX CONTAMINANT ATTENUATION

Understanding the fate of the petroleum hydrocarbons such as BTEX contaminants in environmental media is critical to evaluating and predicting contaminant distribution patterns. There are several physical, chemical, and biological processes that influence how a chemical behaves in soil and groundwater. The following is a brief overview of the major characteristics that define the fate of BTEX compounds in groundwater at the site. These characteristics ultimately determine if the mass of contaminants in the environment can be eliminated or rendered immobile by natural processes. The positive effects of these natural processes on reducing the actual mass of BTEX compounds and/or minimizing the extent of BTEX migration in groundwater has been termed intrinsic remediation or natural attenuation.

2.1 NONDESTRUCTIVE ATTENUATION PROCESSES

Solubility, sorptive, and volatility characteristics are important chemical characteristics to consider in assessing whether hydrocarbon contamination in groundwater at the site may be susceptible to nondestructive attenuation processes. Chemicals characterized by relatively high water solubility and volatility and low sorptive properties, such as the BTEX compounds, can be rapidly introduced into and transported with groundwater.

2.1.1 Solubility

The water solubility of a chemical species defines how that particular chemical could partition (leach) from a contaminant source and dissolve into and migrate with groundwater. BTEX compounds are more water soluble than heavier hydrocarbon compounds, which have a fairly limited water solubility. For example, the water solubilities of benzene, toluene, ethylbenzene, and the various xylene isomers are

TABLE B.1

LIMITED GROUNDWATER SAMPLING AND ANALYSIS PROGRAM
SUMMARY OF GROUNDWATER VOLATILE ORGANIC ANALYTICAL RESULTS
AUGUST 30, 1996

Well ID Screened Interval (feet bgs)	MW-14 19-24	MW-3S 9.8-19.8	MW-3D 19-24	MW-3D (Dup)	MW-16 9-29	MW-17 5-11	MW-22 5-15	MW-24 7.8-17.8	MW-26S 4.5-14.5	MW-26D 23-33	TRIP BLANK
Chloroethane	ND 1	ND 10	12	14	ND 1	ND 50	ND 1	ND 1	21	ND10	ND 1
1,1-Dichloroethane	ND 1	ND 10	ND 10	ND 10	ND 1	ND 50	ND 1	11	13	70	ND 1
1,1-Dichloroethene	ND 1	ND 10	14	ND 10	ND 1	ND 50	ND 1	ND 1	5.6	270	ND 1
cis-1,2-Dichloroethene	ND 1	30	ND 10	ND 10	ND 1	91	ND 1	ND 1	ND 1	16	ND 1
1,1,1-Trichloroethane	ND 1	ND 10	24	34	ND 1	ND 50	ND 1	ND 1	ND 1	52	ND 1
Trichloroethene	ND 1	72	100	86	ND 1	330	ND 1	ND 1	ND 1	16	ND 1
Trichlorofluoromethane	ND 1	ND 10	220	200	ND 1	ND 50	ND 1	ND 1	ND 1	73	ND 1
Benzene	ND 1	ND 1	1.6	1.6	ND 1	ND 1	ND 50	1.1	ND 5	1.2	ND 1
Toluene	1.1	ND 1	ND 1	1	1.1	ND 1	280	ND 1	ND 5	ND 1	ND 1
Ethylbenzene	ND 1	ND 1	ND 1	ND 1	ND 1	ND 1	100	ND 1	10	ND 1	ND 1
Xylene	1	ND 1	ND 1	ND 1	ND 1	ND 1	3900	ND 1	160	ND 1	ND 1

bgs - Below Ground Surface.
ND 1 - Not Detected at specified detection limit.
All results reported in ug/L (parts per billion - ppb).

TABLE B.2

LIMITED GROUNDWATER SAMPLING AND ANALYSIS PROGRAM
SUMMARY OF NATURAL BIODEGRADIATION INDICATOR ANALYTICAL RESULTS
AUGUST 30, 1996

Well ID Screened Interval (feet bgs)	MW-14 19-24	MW-3S 9.8-19.8	MW-3D 19-24	MW-3D (Dup)	MW-16 9-29	MW-17 5-11	MW-22 5-15	MW-24 7.8-17.8	MW-26S 4.5-14.5	MW-26D 23-33
Dissolved Oxygen	5.1	0.2	2.0	NM	0.0	2.5[1]	0.9	0.9	2.0	0.2
pH	7.96	7.59	6.8	NM	6.76	6.85	7.26	6.85	6.85	6.72
Temperature (F°)	77.4	66.9	79	NM	NM	NM	NM	78.2	NM	NM
ORP[2] (mV)	40	50	60	50	50	50	60	-50	50	40
Nitrate	ND 0.1	ND 0.1	1.4	1.5	ND 0.1	0.3	2	ND 0.1	ND 0.1	ND 0.1
Nitrite	ND 0.1	ND 0.1	ND 0.1	ND 0.1	ND 0.1	ND 0.1	0.7	ND 0.1	ND 0.1	ND 0.1
Sulfate	350	ND 25	36	34	ND 50	ND 100	42	ND 5	ND 25	30
Sulfide	0.88	ND 0.5	ND 0.5	ND 0.5	ND 0.5	ND 0.5	ND 0.5	ND 0.5	ND 0.5	ND 0.5
Total Iron	87.8	25.7	0.37	0.42	319	103	34.6	57.5	163	0.56
Dissolved Iron	ND 0.1	2	ND 0.1	ND 0.1	ND0.1	17.2	0.11	8.6	8.9	0.1
Total Manganese	1.7	2.5	0.075	0.055	16.3	3.2	3.2	4.8	8.9	0.21
Dissolved Manganese	0.059	1.8	0.044	0.051	0.087	9	3	3.7	4.9	0.19
Methane	.005	0.58	1.24	.792	6.6	1.02	0.23	0.6	3	.232
Ethane	ND	ND	ND	ND	ND	.0004	ND	.0012	ND	ND
Ethene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Alkalinity	320	320	310	320	590	410	150	660	410	350
Carbon Dioxide	110	318	323	427	690	353	215	887	583	322
Chloride	29	4	320	320	83	320	420	140	62	150
TOC	1	5	3	3	43	8	6	43	19	6

NM - Not measured.

[1] Sample collected via bailer rather than submursable pump due to location restriction, therefore the dissolved oxygen measured may be higher than actual groundwater conditions.

[2] Measurements were made in the laboratory rather than in the field due to field equipment failure. ORP values may change significantly after sample collection, therefore measured ORP values are most likely not indicative of actual groundwater conditions. The lack of valid ORP values does not compromise the significance of the remaining data in evaluating the occurrence of natural occuring biodegradation.

All results reported in mg/l (parts per million - ppm).

TABLE B.3

SUMMARY OF GROUNDWATER ELEVATION MEASUREMENTS
AUGUST 30, 1996

Well ID	Depth of Well[1] (ft)	Well Length[2] (ft)	Screen Length[1] (ft)	Screened Interval[1] (ft)	Well Elevation (ft MSL)	DTW (ft) 3-May-94	Groundwater Elevation (ft. msl) 3-May-94	DTW (ft) 23-Jun-94	Groundwater Elevation (ft msl) 23-Jun-94	DTW (ft) 30-Aug-96	Groundwater Elevation (ft msl) 30-Aug-96
MW-1	18	17.46	10	8.0-18.0	381.66	9.39	372.27	11.52	370.14	12.25	369.41
MW-2	19	22	10	9.0-19.0	383.09	13.81	369.28	14.4	368.69	15.58	367.51
MW-3S	19.8	18.35	10	9.8-19.8	378.38	8.62	369.76	10.06	368.32	NM	NM
MW-3D	21.3(3)	30.1(3)	5	19.0-24.0	377.91	9.02	368.89	9.7	368.21	10.62	367.25
MW-4	10	11.79	5	2.3-7.3(3)	377.29(3)	8.15	371.88	9.28	370.75	7.35	
MW-5	19.5	18.6	10	9.5-19.5	380.07	10.56	369.51	11.65	368.42	12.43	367.64
MW-6	9.8	12.3	4	5.8-9.8	367.98	0	367.98	0.75	367.23	NM	NM
MW-7	11	12.2	6	5.0-11.0	368.3	1.24	367.06	1.37	366.93	1.85	366.45
MW-8	11.5	11.64	10	1.5-11.5	371.2	2.79	368.41	3.79	367.41	4.51	366.69
MW-9	11.5	14.24	10	1.5-11.5	370.24	3.75	366.49	5.93	364.31	6.74	363.5
MW-10	18	18.21	10	8.0-18.0	379.71	10.19	369.52	10.98	368.73	11.4	368.31
MW-11	NR	18.9	NR	NR	379.57	8.68	370.89	10.65	368.92	NM	NM
MW-12	19.6	18.01	10	9.6-19.6	380.72	9.65	371.07	11.52	369.2	11.64	369.08
MW-13	11.6	14.6	10	1.6-11.6	382.07	8.89	373.18	12.33	369.74	13.18	368.89
MW-14	24	23.45	10	19.0-24.0	378.95	8.27	370.68	8.21	370.74	8.55	370.4
MW-15	22	21.1	10	12.0-22.0	380.5	10.89	369.61	11.93	368.57	NM	NM
MW-16	29	28.25	20	9.0-29.0	375.49	6.69	368.8	7.98	367.51	8.25	367.24
MW-17	15	14.2	10	5.0-15.0	367.59	1.21	366.38	2.81	364.78	3.04	364.55
MW-18	17.5	13.9	10	7.5-17.5	367.07	0.57	366.5	2.42	364.65	3.4	363.62
MW-19	15	16.84	10	5.0-15.0	381.01	8.22	372.79	10.77	370.24	11.52	369.49
MW-20	19	17.04	10	9.0-19.0	376.89	7.89	369	9.17	367.72	10.68	366.21
MW-21	19	16.43	10	9.0-19.0	376.98	8.8	368.18	10.8	366.18	12.03	364.95
MW-22	15	14.25	10	5.0-15.0	375.6	7.27	368.33	8.98	366.62	10.21	365.39

Notes:

1 - Distance from grade as reported on construction log.
2 - Measured from top of casing at time of development.
NR - No record.
DTW - Depth to water measured from top of casing.
NM - Not measured.
D - Dry
3 - Well casing elevation has been modified from the originally installed elevation

TABLE B.3
(Continued)

SUMMARY OF GROUNDWATER ELEVATION MEASUREMENTS
AUGUST 30, 1996

Well ID	of Well[1] (ft)	Well Length[2] (ft)	Screen Length[1] (ft)	Screened Interval[1] (ft)	Well Elevation (ft MSL)	DTW (ft) 3-May-94	Groundwater Elevation (ft. msl) 3-May-94	DTW (ft) 23-Jun-94	Groundwater Elevation (ft msl) 23-Jun-94	DTW (ft) 30-Aug-96	Groundwater Elevation (ft msl) 30-Aug-96
MW-23	18	19.9	10	8.0-18.0	379.55	10.79	368.76	12.44	367.11	14	365.55
MW-24	17.8	16.9	10	7.8-17.8	376.58	7.96	368.62	9.01	367.57	10.01	366.57
MW-25	17.8	16.9	10	7.8-17.8	374.85	7.39	367.46	9.36	365.49	10.63	364.22
MW-26S	14.5	14.23	10	4.5-14.5	374.27	NM	NM	7.78	366.49	8.45	365.82
MW-26D	33	29.34	10	23.0-33.0	374.23	NM	NM	7.3	366.93	NM	NM
BR-01	140	NM	10	130-140	378.52	NM	NM	8.23	370.29	10.24	368.28
BR-02	103	101.2	10	90-100	372.06	NM	NM	7.81	364.25	NM	NM
BR-03	103	101.6	10	90-100	377.85	NM	NM	13.44	364.41	13.21	364.64
P-02	11.5	NM	5	6.5-11.5	380.75	NM	NM	10.18	370.57	NM	NM
P-04	11.5	NM	5	6.5-11.5	380.72	NM	NM	10.91	369.81	NM	NM
P-09	3.3	NM	3	0.3-3	366.72	1.84	364.88	NM	NM	NM	NM
P-10S	4	NM	3	1.0-3.0	366.35	1.36	364.99	NM	NM	3.38	362.97
P-10D	12.1	NM	3	9.1-12.1	367.04	1.65	365.39	NM	NM	3.65	363.65
P-11S	3.1	NM	3	0.1-3.1	367.06	0.23	366.83	NM	NM	NM	NM
P-11D	10.4	NM	3	7.4-10.4	365.9	2.19	363.71	NM	NM	NM	NM
P-17S	3.2	NM	2.53	0.67-3.2	366.76	0.66	366.1	NM	NM	D	NM
P-17D	7.5	NM	2	5.5-7.5	367.66	1.8	365.86	NM	NM	4.37	363.29
P-18S	3	NM	2	1.0-3.0	365.96	1.06	364.9	NM	NM	2.79	363.17
P-18D	7.75	NM	2	5.75-7.75	366.19	1.06	365.13	NM	NM	2.6	363.59
P-19S	3.1	NM	2	1.1-3.1	365.74	0.84	364.9	NM	NM	2.79	362.95
P-19D	7.25	NM	2	5.25-7.25	366.71	0.6	366.11	NM	NM	3.41	363.3

Notes:

1 - Distance from grade as reported on construction log.
2 - Measured from top of casing at time of development.
NR - No record.
DTW - Depth to water measured from top of casing.
NM - Not measured.
D - Dry

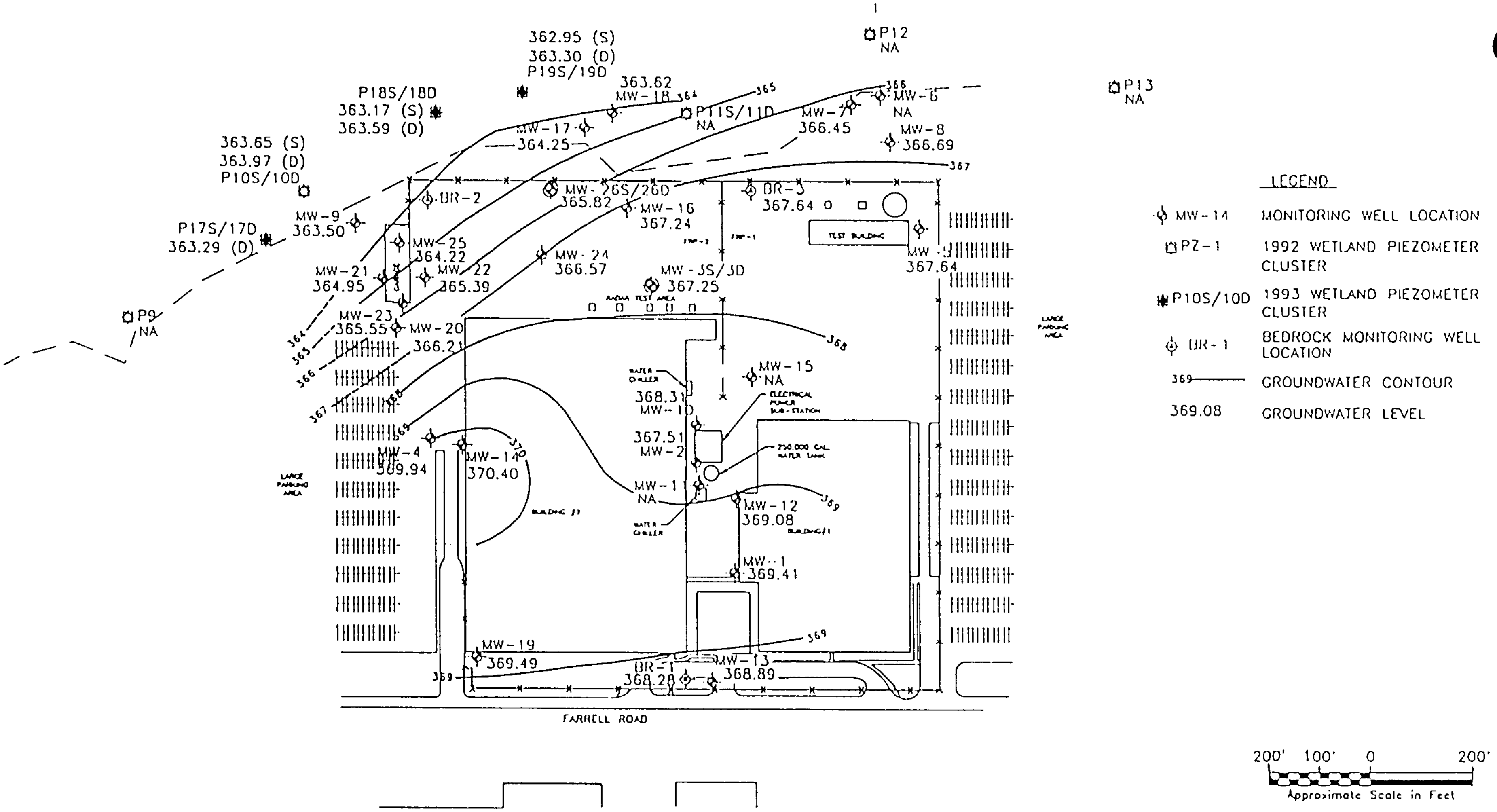


Figure B.1

LOCKHEED MARTIN CORPORATION

GROUNDWATER CONTOUR MAP
AUGUST 30, 1996

PARSONS ENGINEERING SCIENCE, INC.
DESIGN • RESEARCH • PLANNING

DATE: 8/27/98 (GTC)
H:\CAD\730125\30125C01.DWG (M/P SPACE)

approximately 1,700 mg/L, 500 mg/L, 160 mg/L, and 145 to 175 mg/L, respectively (Bohon and Claussen, 1951; Mackay and Shiu, 1981; Verschueren, 1983; Isnard and Lambert, 1988; Howard, 1990). Consequently, even though BTEX compounds may have made up a low mass fraction of the initial source of petroleum contamination, these compounds preferentially leach from soils into groundwater and migrate as dissolved contamination (Lyman *et al.*, 1992).

2.1.2 Sorption

Another chemical characteristic that can govern how a compound is attenuated in soil and groundwater is its sorptive properties. If a contaminant can be strongly sorbed to the aquifer matrix, the compound will be less mobile and less likely to be transported great distances from the source area. The BTEX compounds are less sorptive than other petroleum hydrocarbons. Benzene does not sorb readily to soil and is considered the most mobile of the BTEX compounds. Of all the BTEX compounds, xylenes sorb most strongly to soil, but can still leach from unsaturated soil and dissolve into and migrate slowly in groundwater (Abdul *et al.*, 1987).

The BTEX compounds sorb to that portion of the soil matrix that is composed of organic carbon and to fine clay particles. The organic carbon content of the soil at the site has not been measured. The site soils are primarily fine to medium sand, however, which typically contain only low levels of organic carbon. Therefore, organic carbon in the soil is not likely to significantly retard chemical migration in site groundwater.

2.1.3 Volatility

The volatility of each of the BTEX compounds also can affect how it behaves in the environment. All of the BTEX compounds are classified as volatile chemicals because they have vapor pressures in excess of 0.1 millimeter of mercury (mm Hg). Benzene is the most volatile of the BTEX compounds, with a vapor pressure of about 95 mm Hg, and xylenes are the least volatile with vapor pressures between 6 and 9 mm Hg.

Because of the small surface area of the groundwater flow system exposed to soil gas, volatilization of the BTEX compounds from groundwater is a relatively slow process. In the interest of being conservative, volatilization generally can be neglected when modeling biodegradation. Chiang *et al.* (1989) demonstrated that less than 5 percent of the mass of dissolved BTEX is lost to volatilization in the saturated groundwater environment.

2.1.4 Summary of Nondestructive Processes

The nature and extent of BTEX contamination at the site as defined to date can be explained in part based on the solubility and sorptive properties of each of the BTEX compounds. In summary, BTEX compounds are highly water soluble and do not sorb strongly onto soil. Therefore, these chemicals should preferentially partition from residual soil petroleum contamination and dissolve into and migrate with groundwater.

2.2 DESTRUCTIVE ATTENUATION PROCESSES

Destructive attenuation processes result in the permanent removal of contaminant mass from the environment and may reduce the length of time required to attain cleanup goals. Documenting and distinguishing the effects of destructive attenuation processes, such as biodegradation, from nondestructive attenuation processes is critical to evaluating the potential for intrinsic remediation. The effectiveness of destructive attenuation processes at reducing contaminant mass at a site depends on how amenable the chemical is to biodegradation and whether the site is characterized by physical, chemical, and biological conditions favorable to such processes.

Numerous laboratory and field studies have shown that hydrocarbon-degrading bacteria can participate in the degradation of many of the chemical components of petroleum fuels, including the BTEX compounds, under both aerobic and anaerobic conditions (e.g., Jobson *et al.*, 1972; Perry, 1977; Atlas, 1981, 1984, 1988; Gibson, 1984; Reinhard *et al.*, 1984; Young, 1984; Bartha, 1986; Wilson *et al.*, 1986, 1987, 1990; Baedecker *et al.*, 1988; Lee, 1988; Chiang *et al.*, 1989; Grbic-Galic, 1989, 1990; Leahy and Colwell, 1990; Park *et al.*, 1990; Stieber *et al.*, 1990, 1994; Altenschmidt and Fuchs, 1991; Alvarez and Vogel, 1991; Baedecker and Cozzarelli, 1991; Bauman, 1991; Borden, 1991; Brown and McFarland, 1991; Haag *et al.*, 1991; Hutchins and Wilson, 1991; Beller *et al.*, 1992; Bouwer, 1992; Edwards and Grbic-Galic, 1992; Thierrin *et al.*, 1992; Malone *et al.*, 1993; Davis *et al.*, 1994; ES, 1994a Parsons ES, 1994b, 1994c, 1995). Biodegradation of fuel hydrocarbons will occur when an indigenous population of hydrocarbon-degrading microorganisms is present in the soil and groundwater, and sufficient concentrations of electron acceptors and nutrients, including fuel hydrocarbons, are available to these organisms. Soils and groundwater with a history of exposure to BTEX compounds generally contain microbial populations competent to facilitate biodegradation reactions (Zobell, 1946; Litchfield and Clark, 1973; Borden, 1994; Seech *et al.*, 1994; Simpkin and Giesbrecht, 1994).

The chemical basis for the biodegradation of BTEX compounds is described in more detail in Section 2.3, where geochemical data relevant to documenting biodegradation at the field scale at the site are presented.

2.3 GEOCHEMICAL INDICATORS OF BTEX BIODEGRADATION

A significant line of evidence that can be used to show that BTEX contaminants are biodegrading in saturated soil and groundwater is analytical data concerning potential electron acceptors and related analytes (Salanitro, 1993; McCallister and Chiang, 1994; Wiedemeier *et al.*, 1995; Borden *et al.*, 1995). Reductions in the concentrations of oxidized chemical species that are used by microorganisms to facilitate the oxidation of BTEX compounds within groundwater are an indication that contaminants are biodegrading. This information, along with site-specific biodegradation rates can be used to predict how much and how quickly BTEX compounds can be permanently removed from saturated soils and groundwater at the site by natural processes.

In evaluating geochemical indicators, it is necessary to evaluate analyte levels in the core of the plume to a baseline as measured at a background location, typically upgradient from all site-specific contamination. Monitoring well MW-14 was sampled as the site background well. All remaining wells sampled in the limited groundwater sampling program were within the area of impacted groundwater at the site. Although not all wells sampled showed BTEX contamination, they were all downgradient of AOC-7, which is a source of petroleum hydrocarbons, and/or downgradient of AOC 5, which is a source of TEX contaminants. Geochemical indicators downgradient of groundwater contamination can be used as indicators of upgradient biodegradation.

2.3.1 Oxidizing Potential

2.3.1.1 Background Discussion

Microorganisms obtain energy to replenish enzymatic systems and to reproduce by oxidizing organic matter. Biodegradation of the BTEX compounds is the result of a series of reduction-oxidation (redox) reactions which maintain the charge balance within the natural environment. Microorganisms facilitate the degradation of the BTEX compounds by transferring electrons from the contaminant (electron donor) to available electron acceptors. Electron acceptors are elements or compounds that occur in relatively oxidized states and can participate in redox reactions involving the BTEX compounds. Electron acceptors that may typically be present in saturated soil and groundwater are oxygen, nitrate, manganese, sulfate, ferric iron, and carbon dioxide.

Microorganisms facilitate BTEX biodegradation to produce energy for their use. The amount of energy that can be released when a reaction occurs or is required to drive the reaction to completion is quantified by the free energy of the reaction (Stumm and Morgan, 1981; Bouwer, 1994; Chapelle, 1993; Godsey, 1994; Mueller *et al.*, 1994; Berg *et al.*, 1994). Microorganisms facilitate only those redox reactions that will yield energy. Microorganisms are able to utilize electron transport systems and chemiosmosis to combine energetically favorable and unfavorable reactions to produce energy for life processes. By coupling the oxidation of BTEX compounds, which requires energy, to the reduction of other compounds (e.g., oxygen, nitrate, manganese, ferric iron, sulfate, and carbon dioxide), which yield energy, the overall reaction will yield energy. Detailed information on the redox reactions required to biodegrade each of the BTEX compounds is included in Attachment 2 of this appendix.

In general, reactions yielding more energy tend to take precedence over processes that yield less energy (Stumm and Morgan, 1981; Godsey, 1994; Reinhard, 1994). Oxygen reduction would be expected to occur in an aerobic environment with microorganisms capable of aerobic respiration because oxygen reduction yields significant energy (Bouwer, 1992; Chapelle, 1993). However, once the available oxygen is depleted and anaerobic conditions dominate the interior regions of the contaminant plume, anaerobic microorganisms can utilize other electron acceptors in the following order of preference: nitrate, manganese, ferric iron, sulfate, and finally carbon dioxide. Each successive redox reaction provides less energy to the system, and each step down in redox energy yield would have to be paralleled by an ecological succession of microorganisms capable of facilitating the pertinent redox reactions.

The expected sequence of redox processes is also a function of the oxidizing potential (Eh) of the groundwater. The oxidizing potential measures the relative tendency of a solution or chemical reaction to accept or transfer electrons. The oxidizing potential of the groundwater can be measured in the field. This measurement can be used as a crude indicator of which redox reactions may be operating at a site. This field measurement can then be expressed as pE, which is the hypothetical measure of the electron activity associated with a specific Eh. High pe means that the solution or redox couple has a relatively high oxidizing potential.

Microorganisms can only facilitate the biodegradation (oxidation) of the BTEX compounds using redox couples that have a higher oxidizing potential than the contaminants. Attachment 2 includes tables that show that redox couples including nitrate, oxygen, manganese, ferric iron, sulfate, and carbon dioxide all have higher oxidizing potentials than the redox couples including the BTEX compounds. This is why these electron acceptors can be used to oxidize the BTEX compounds. The reduction of highly oxidized species results in an overall decrease in the oxidizing potential of the groundwater. The reduction of oxygen and nitrate will reduce the oxidizing potential to levels at which manganese and ferric iron (Fe^{3+}) reduction can occur. As each chemical species that can be used to oxidize the contaminants is exhausted, the microorganisms are forced to use other available electron acceptors with lower oxidizing capacity. When sufficiently negative pE levels have been developed as a result of these redox reactions, sulfate reduction and methanogenesis can occur almost simultaneously (Stumm and Morgan, 1981).

2.3.1.2 Site-Specific Evaluation

As explained in the footnote to Table B.2, valid Eh (ORP) data is not available for the site. However, field experience at other sites has shown that the Eh probes used for field measurement are not sensitive to all redox pairs present, and therefore reactions beyond those indicated by Eh measurement alone may be occurring. Therefore, analytical data on oxidized and reduced species as presented in the next sections, are more useful in determining which electron acceptors are actually being used to biodegrade BTEX compounds in saturated soil and groundwater.

2.3.2 Dissolved Oxygen Concentrations

2.3.2.1 Background Discussion

Almost all types of fuel hydrocarbons can be biodegraded under aerobic conditions (Borden, 1994). Mineralization of fuel hydrocarbons to carbon dioxide and water under aerobic conditions involves the use of oxygen as a cosubstrate during the initial stages of metabolism, and as a terminal electron acceptor during the later stages of metabolism for energy production (Higgins and Gilbert, 1978; Gibson and Subramanian, 1984; Young, 1984). The reduction of molecular oxygen during the oxidation of the BTEX compounds yields a significant amount of free energy to the system for use by microorganisms. Reduction in molecular oxygen via microbial respiration also will cause anaerobic conditions and reduce the oxidizing potential of the aquifer, and thus bring about a change in the types of microorganisms that facilitate biodegradation of the contaminants.

2.3.2.2 Site-Specific Evaluation

The DO level for background well MW-14 was 5.1 mg/L, as shown in Table B.2. The DO level for plume wells ranged from 0 to 2.5 mg/L. The low concentrations of DO in contaminated groundwater as compared with background levels indicate that oxygen is functioning as an electron acceptor during microbially-mediated degradation of BTEX compounds.

2.3.3 Dissolved Nitrate Concentrations

2.3.3.1 Background Discussion

Once anaerobic conditions prevail in the groundwater, nitrate can be used as an electron acceptor by facultative anaerobic microorganisms to mineralize BTEX compounds via either denitrification or nitrate reduction processes. Denitrification is the most energetically favorable of the redox reactions likely to be involved in the oxidation of the contaminants. Although the oxidation of the BTEX compounds by nitrate reduction also will yield significant amounts of free energy for microbial use, nitrate reduction is not as energetically favorable as other potential redox reactions. However, nitrate reduction may take precedence over denitrification as the groundwater becomes more reducing. As conditions become more reducing, nitrate is used as an electron acceptor via nitrate reduction. However, nitrate can only function as an electron acceptor in microbially facilitated fuel hydrocarbon degradation reactions if the groundwater system has been depleted of oxygen (i.e., the biologically active zones in soils and groundwater must be functionally anaerobic). Oxygen is toxic to the enzyme systems used for electron transfer and energy production of nitrate-reducing microorganisms (McCarty, 1972). Nitrate reduction results in the formation of nitrite.

2.3.3.2 Site-Specific Evaluation

The nitrate level at background well MW-14 was 0.1 mg/L. The low background nitrate level indicates nitrate reduction is not a significant biological pathway for the site.

2.3.4 Dissolved Manganese Concentration

2.3.4.1 Background Discussion

Manganese also can be used as an electron acceptor to facilitate the oxidation of BTEX compounds under anaerobic and slightly reducing conditions, resulting in the reduction of Mn^{3+} to Mn^{2+}. In fact, manganese reduction can be microbially facilitated in groundwater conditions similar to those required to support denitrification. The reduction of manganese to oxidize BTEX compounds yields essentially as much free energy to the system as aerobic respiration. Under anaerobic and slightly reducing conditions, manganese reduction is the second most energetically favorable redox reaction that can be used to biodegrade BTEX compounds.

2.3.4.2 Site-Specific Evaluation

Total dissolved manganese concentrations were measured at site monitoring wells. Under the pH levels measured in groundwater, the manganese speciation will be almost exclusively Mn^{2+}. Dissolved manganese (i.e., Mn^{2+}) was measured at 1.7 mg/L at background well MW-14. Dissolved manganese was detected at levels up to 9 mg/L for wells within the contaminated area. The elevated dissolved manganese concentration suggests that the manganese-reducing microorganisms are using manganese to oxidize the contaminants.

2.3.5 Dissolved (Ferrous) Iron Concentrations

2.3.5.1 Background Discussion

Although relatively little is known about the anaerobic metabolic pathways involving the reduction of ferric iron (Fe^{3+}, Iron III) to ferrous iron (Fe^{2+}, Iron II), this process has been shown to be a major metabolic pathway for some microorganisms (Lovley and Phillips, 1988; Chapelle, 1993). Elevated concentrations of ferrous iron are often found in anaerobic groundwater systems. Concentrations of dissolved ferrous iron once were attributed to the spontaneous and reversible reduction of ferric oxyhydroxides, which are thermodynamically unstable in the presence of organic compounds such as the BTEX compounds. Recent evidence suggests, however, that the reduction of ferric iron to ferrous iron cannot proceed without microbial mediation (Lovley and Phillips, 1988; Lovley et al., 1991; Chapelle, 1993). None of the common organic compounds found in low-temperature, neutral, reducing groundwater could reduce ferric oxyhydroxides to ferrous iron under sterile laboratory conditions (Lovley *et al.*, 1991). This means that the reduction of ferric iron to ferrous iron requires mediation by microorganisms with the appropriate enzymatic capabilities.

2.3.5.2 Site-Specific Evaluation

Total dissolved iron concentrations were measured at site monitoring wells. Under the pH levels measured in groundwater, the iron speciation will be almost exclusively ferrous iron (Fe^{2+}). Dissolved iron (i.e., ferrous iron) was not detected at MW-14. Dissolved iron was detected at levels up to 17.2 mg/L for wells within the contaminated area. The elevated total dissolved hydrocarbon concentration at MW-8S and elevated ferrous iron concentration suggests that the iron-reducing microorganisms are using ferric iron to oxidize the contaminants. Because the reduction of ferric iron cannot proceed without microbial intervention, the elevated concentrations of ferrous iron that were measured in contaminated groundwater at the site are strong indicators of microbial activity. These geochemical data suggest that iron-reducing microorganisms are present in the groundwater at the site, and that these microorganisms are using ferric iron to energize BTEX metabolism.

2.3.6 Sulfate Concentrations

2.3.6.1 Background Discussion

Sulfate also may be used as an electron acceptor during microbial degradation of fuel hydrocarbons under anaerobic conditions (Grbic-Galic, 1990). This redox reaction is commonly called sulfate reduction. Sulfate is reduced to sulfide during the oxidation of the BTEX compounds. The presence of decreased concentrations of sulfate in an area of elevated contamination relative to background concentrations indicates that sulfate may be participating in redox reactions at a site.

2.3.6.2 Site-Specific Evaluation

Sulfate levels in the contaminated zone ranged as low as non-detect at a detection limit of 5 mg/L. The sulfate level at MW-14 was 350 mg/L. The low concentrations of sulfate in contaminated groundwater as compared with background levels indicate that sulfate is functioning as an electron acceptor during microbially-mediated degradation of BTEX hydrocarbons. Sulfide levels were low at all monitoring wells. The absence of inorganic sulfide does not mean that sulfate reduction is not occurring. Rather, it is an indication that sulfate reduction at this site results in the production of another reduced form such as inorganic sulfur.

2.3.7 Methane Concentrations

2.3.7.1 Background Discussion

The carbon dioxide-methane (CO_2-CH_4) redox couple also can be used to oxidize fuel hydrocarbon compounds to carbon dioxide and water once the groundwater is sufficiently reducing. To attain these reducing levels, other highly oxidizing chemical species such as oxygen, nitrate, and manganese must be reduced. This redox reaction is called methanogenesis or methane fermentation. Methanogensis yields the least free energy to the system in comparison to other chemical species. The presence of methane in groundwater at elevated concentrations relative to background concentrations is a good indicator of methane fermentation.

2.3.7.2 Site-Specific Evaluation

The methane concentration at monitoring well MW-14 was 0.005 mg/l. Methane concentrations at wells within the contaminated area ranged up to 6.6 mg/L. The elevated level of methane in the contaminated zone as compared with background levels indicates BTEX compounds are being biodegraded via methanogenic processes.

2.3.8 Alkalinity Concentrations

2.3.8.1 Background Discussion

In general, as the amount of total dissolved BTEX that is being oxidized increases, the total alkalinity increases. This is expected because the microbially-mediated reactions causing biodegradation of fuel hydrocarbons produce carbon dioxide. Changes in alkalinity are most pronounced during aerobic respiration, denitrification, iron reduction, and sulfate reduction and less pronounced during methanegenisis (Morel and Hering, 1993). In addition, Willey *et al.* (1975) have shown that short-chain aliphatic acid ions which can be produced during biodegradation of fuel hydrocarbons as intermediates can contribute to alkalinity in groundwater.

Carbon dioxide is produced during the respiration of petroleum hydrocarbons. In aquifers that have carbonate minerals as part of the matrix, the carbon dioxide forms carbonic acid which dissolved these minerals, increasing the alkalinity of the groundwater.

An increase in alkalinity (measured as $CaCO_3$) in an area with BTEX concentrations elevated over background conditions can be used to infer the amount of petroleum hydrocarbon destroyed through biological processes.

2.3.8.2 Site-Specific Evaluation

The alkalinity level at background well MW-14 was 320 mg/L. Alkalinity concentrations up to 660 mg/L were measured in the contaminated area. The elevated level of alkalinity in contaminated groundwater in comparison to background levels indicates that BTEX contaminants are being biodegraded.

2.3.9 Carbon Dioxide

2.3.9.1 Background Discussion

Metabolic processes operating during biodegradation of fuel hydrocarbons leads to the production of carbon dioxide (CO_2). Accurate measurement of CO_2 produced during biodegradation is difficult because carbonate in groundwater (measured as alkalinity) serves as both a source of and a sink for free CO_2. If the CO_2 produced during metabolism is not removed by the natural carbonate buffering system of the aquifer, CO_2 concentrations higher than background may be observed.

2.3.9.2. Site Specific Evaluation

The carbon dioxide concentration at background well MW-14 was 110 mg/L. Carbon dioxide levels in the contaminated area were measured up to 887 mg/L. The elevated levels of carbon dioxide in contaminated groundwater indicate biodegradation of BTEX compounds are occurring.

2.3.10 Summary of BTEX Contamination Biodegradation Data

The data presented above indicate that significant biodegradation of BTEX compounds is occurring via aerobic respiration, sulfate reduction, iron reduction, manganese reduction, and methanogenesis. On-going natural attenuation of BTEX contaminants via biodegradation will continue to play a significant role in the fate and distribution of BTEX contaminants at the site.

2.4 THEORETICAL ASSIMILATIVE CAPACITY ESTIMATES

The preceding discussions have been devoted to determining if the BTEX compounds are biodegrading at the site. Analytical data on reduced and oxidized chemical species indicate that indigenous microorganisms are facilitating the oxidation of fuel hydrocarbons, including the BTEX compounds, and the reduction of electron acceptors to generate free energy for cell maintenance and production. The question of how much contaminant mass can be biodegraded must be addressed to assess the full potential for long-term intrinsic remediation of the site.

Mass-balance relationships can be used to determine how much contaminant mass can be degraded by each of the redox reactions that the microorganisms might use to make free energy available for cell maintenance and production. The stoichiometric relationship between the contaminant and the electron acceptor can be used to estimate the assimilative capacity of the groundwater. Now that many of the redox reactions that are operating at the site have been defined, it is possible to estimate how much contaminant mass is being assimilated or oxidized by available electron acceptors.

Attachment 2 presents the coupled redox reactions that represent the biodegradation of each of the BTEX compounds. These tables also present the stoichiometric mass ratio of electron acceptors needed to oxidize each of the BTEX compounds. These stoichiometric mass radios can be used to estimate the assimilative capacity of the groundwater at the site. For example, the stoichiometric relationship for the aerobic degradation of benzene is:

$$C_6H_6 + 7.50_2 \rightarrow 6CO_2(g) + 3\ H_2$$

According to this relationship, 0.33 mg benzene is degraded for every mg of oxygen consumed. Similarly, an average of 0.32 mg of BTEX is degraded for every mg of oxygen consumed. The difference between the DO levels measured at background well MW-14 and representative plume well MW-3S (Table B.1) is 5.1 mg/L - 0.2 mg/L = 4.9 mg/L. Thus, the amount of BTEX biodegraded aerobically at the site is given by 0.32 BTEX/mg oxygen x 4.9 mg oxygen consumed = 1.6 mg/L BTEX consumed.

Thus, the expressed assimilative capacity via aerobic respiration at the site is 1.6 mg/L. Similarly, site-specific data were used to calculate the available or expressed assimilative capacity of each electron acceptor for total BTEX based on the mass stoichiometric relationships presented in detail in Attachment 2. The results of these calculations are presented in Table B.4. As shown by these calculations, there are multiple significant biodegradation pathways contributing to biodegradation at the site. The most significant pathway is sulfate reduction, which accounts for approximately 97 percent of the expressed assimilative capacity.

SECTION 3.0 BIODEGRADATION OF CAHS

3.1 BACKGROUND DISCUSSION

Chlorinated solvents can be transformed, directly or indirectly, by biological processes (e.g. Bouwer *et al.*, 1981; Wilson and Wilson, 1985; Miller and Guengerich, 1982; Nelson *et al* 1986; Bouwer and Wright, 1988; Little *et al.*, 1988; Mayer *et al* 1988; Arciero *et al* 1989; Cline and Delfino, 1989; Freedman and Gossett, 1989; Folsom *et al.*, 1990; Harker and Kim, 1990; Alvarez-Cohen and McCarty, 1991a, 1992b; DeStefano *et al.*, 1991; Henry, 1991; McCarthy *et al.*, 1992; Hartmans and de Bont, 1992; McCarty and Semprini, 1994; Vogel, 1994). Chlorinated aliphatic hydrocarbons (CAHs) such as trichloroethene (TCE) and trichloroethane (TCA) may undergo biodegradation through three different pathways: use as an electron acceptor, use as an electron donor, or cometabolism, which is degradation resulting from exposure to a catalytic enzyme fortuitously produced during an unrelated process. At a given site, one or all of these processes may be operating, although at many sites the use of CAHs as electron acceptors appears to be the most important.

TABLE B.4

EXPRESSED ASSIMILATIVE CAPACITY (EAC)*

PATHWAY	CALCULATION	EAC
Aerobic	$BTEX_{BIO,DO} = 0.32\ (5.1 - 0.2)$	= 1.6 mg/L
Nitrate Reduction	$BTEX_{BIO,DO} = 0.21\ (0.1 - 0.1)$	= 0 mg/L
Manganese Reduction	$BTEX_{MN} = 0.09\ (1.8 - 0.059)$	= 0.16
Iron Reduction	$BTEX_{BIO,DO} = 0.05\ (2.0 - 0.1)$	= 0.1 mg/L
Sulfate Reduction	$BTEX_{BIO,DO} = 0.32\ (350 - 25)$	= 68.3 mg/L
Methanogensis	$BTEX_{BIO,DO} = 1.28\ (0.58 - 0.0005)$	= 0.7 mg/L
Total EAC		70.7 mg/L

*Based on a comparison of MW-14 and MW-3S.

In a pristine aquifer, native organic carbon is utilized as an electron donor and DO is utilized first at the prime electron acceptor. Where anthropogenic carbon (e.g., fuel hydrocarbons or low-molecular-weight CAHs) is present, it also will be utilized as an electron donor. After the DO is consumed, anaerobic microorganisms typically use native electron acceptors (as available) in the following order of preference: nitrate, ferric iron oxyhydroxide, sulfate, and finally carbon dioxide. Evaluation of the distribution of these electron acceptors can provide evidence of where and how CAH biodegradation is occurring.

As with BTEX, the driving force behind redox reactions resulting in CAH degradation is electron transfer. Although thermodynamically favorable, most of the reactions involved in CAH reduction and oxidation cannot proceed abiotically because of the lack of activation energy. Microorganisms are capable of providing the necessary activation energy; however, they will facilitate only those reduction/oxidation (redox) reactions that have a net yield of energy. A more complete description of the main types of biodegradation reactions affecting CAHs is presented in the following subsections.

3.1.1 Electron Acceptor Reactions (Reductive Dehalogenation)

Under anaerobic conditions, biodegradation of chlorinated solvents usually proceeds through a process called reductive dehalogenation. During this process, the halogenated hydrocarbon is used as an electron acceptor, not as a source of carbon, and a halogen atom is removed and replaced with a hydrogen atom. In general, reductive dehalogenation occurs by sequential dehalogenation from perchlorethene (PCE) to TCE to dichloroethene (DCE) to vinyl chloride (VC), and from TCA to dichloroethane (DCA) to chloroethane (CA) to ethane. Depending upon environmental conditions, this sequence may be interrupted, with other processes then acting upon the products.

During reductive dehalogenation, all three isomers of DCE can theoretically be produced; however, Bouwer (1994) reports that under the influence of biodegradation, *cis*-1,2-DCE is a more common intermediate than *trans*-1,2-DCE, and that 1,1-DCE is the least prevalent intermediate of the three DCE isomers. Reductive dehalogenation of chlorinated solvent compounds is associated with the accumulation of daughter products and an increase in chloride.

Reductive dehalogenation affects each of the CAHs differently. For example, PCE is the most susceptible to reductive dehalogenation because it is the most oxidized. Conversely, VC is the least susceptible to reductive dehalogenation because it is the least oxidized of these compounds. The rate of reductive dehalogenation also has been observed to decrease as the degree of chlorination decreases (Vogel and McCarty, 1985; Bouwer, 1994). Murray and Richardson (1993) have postulated that this rate decrease may explain the accumulation of VC in PCE and TCE plumes that are undergoing reductive dehalogenation. Reductive dehalogenation has been demonstrated under anaerobic nitrate- and sulfate-reducing conditions, but the most rapid biodegradation rates, affecting the widest range of CAHs, occur under methanogenic conditions (Bouwer, 1994).

Because CAH compounds are used as electron acceptors, there must be an appropriate source of carbon for microbial growth in order for reductive dehalogenation to occur (Bouwer, 1994). Potential carbon sources can include low-molecular-weight compounds (e.g., lactate, acetate, methanol, or glucose) present in natural organic matter, or fuel hydrocarbons.

3.1.2 Electron Donor Reactions

Under aerobic conditions some CAH compounds can be utilized as the primary substrate (i.e. electron donor) in biologically-mediated redox reactions (McCarty and Semprini, 1994). In this type of reaction, the facilitating microorganism obtains energy and organic carbon from the degraded CAH. In contrast to reactions in which the CAH is used as an electron acceptor, only the least oxidized CAHs can be utilized as electron donors in biologically-mediated redox reactions. McCarthy and Semprini (1994) describe investigations in which VC and 1,2-DCA were shown to serve as primary substrates. These authors also document that dichloromethane has the potential to function as a primary substrate under either aerobic or anaerobic environments. In addition, Bradley and Chapelle (1996) show evidence of mineralization of VC under iron-reducing conditions so long as there is sufficient bioavailable iron (III). Murray and Richardson (1993) write that microorganisms are generally believed to be incapable of growth using TCE and PCE. Aerobic metabolism of VC may be characterized by a loss of VC mass, a decreasing molar ratio of VC to other CAH compounds, and the presence of chloromethane.

3.1.3 Cometabolism

When a CAH is biodegraded through cometabolism, it serves as neither an electron acceptor nor a primary substrate in a biologically mediated redox reaction. Instead, the degradation of the CAH is catalyzed by an enzyme or cofactor that is fortuitously produced by organisms for other purposes. The organism receives no known benefit from the degradation of the CAH; rather the cometabolic degradation of the CAH may in fact be harmful to the microorganism responsible for the production of the enzyme or cofactor (McCarty and Semprini, 1994).

Cometabolism is best documented in aerobic environments, although it potentially could occur under anaerobic conditions. It has been reported that under aerobic conditions chlorinated ethenes, with the exception of PCE, are susceptible to cometabolic degradation (Murray and Richardson, 1993; Vogel, 1994; McCarthy and Semprini, 1994). Vogel (1994) further elaborates that the cometabolism rate increases as the degree of dehalogenation decreases.

In the cometabolic prices, TCE is indirectly transformed by bacteria as they use BTEX or another substrate to meet their energy requirements. Therefore, TCE does not enhance the degradation of BTEX or other carbon sources, nor will its cometabolism interfere with the use of electron acceptors involved in the oxidation of those carbon sources. It is likely that depletion of suitable substrates (BTEX or other organic carbon sources) may limit cometabolism of CAHs.

3.1.4 Behavior of Chlorinated Solvent Plumes

Chlorinated solvent plumes can exhibit three types of behavior depending on the amount of solvent, the amount of organic (native and/or anthropogenic) carbon in the aquifer, the distribution and concentration of natural electron acceptors, and the types of electron acceptors being utilized.

Type 1 behavior occurs where the primary substrate is anthropogenic carbon (e.g. BTEX or landfill leachate), and this anthropogenic carbon drives reductive dehalogenation. Type 2 behavior dominates in areas that are characterized by relatively high native organic carbon concentrations, and this carbon source drives reductive dehalogenation (i.e., the primary substrate for microorganisms growth in native organic carbon).

Type 3 behavior dominates in areas that are characterized by low native and/or anthropogenic carbon concentrations, and DO concentrations that are greater than 1.0 mg/L. Under these conditions the plume is aerobic, and reductive dehalogenation will not occur. Thus there is no reductive dehalogenation of PCE, TCE, and DCE. Biodegradation may proceed via the much slower process of cometabolism, but will be limited by the low concentrations of native or anthropogenic carbon. The most significant natural attenuation mechanisms for these compounds will be advection, dispersion, and sorption. However, VC could be oxidized under these conditions.

A single chlorinated solvent plume can exhibit all three types of behavior in different portions of the plume. This can be beneficial for natural biodegradation of CAH plumes. For example, Wiedemeier *et al.* (1996) describe a plume at Plattsburgh AFB, New York that exhibits type 1 behavior in the source area and type 3 behavior downgradient from the source. The best scenario involves a plume in which TCE and DCE are reductively dehalogenated (type 1 and 2 behavior), then VC is oxidized (type 3 behavior), either aerobically or anaerobically (via iron reduction). VC is oxidized to carbon dioxide in this type of plume and does not accumulate. The following sequence of reactions occurs in this type of plume.

$$\text{TCE} \rightarrow \text{DCE} \rightarrow \text{VC} \rightarrow \text{CO}_2$$

In general, the TCE, DCE, and VC may attenuate at approximately the same rate, and thus these reactions may be confused with simple dilution. Note that no ethene is produced during this reaction. Vinyl chloride is removed from the system much faster under these conditions that it is under VC-reducing conditions.

A less desirable scenario involves a plume in which all CAHs are reductively dehalogenated (type 2 or 3 behavior). VC is reduced to ethene, which is further reduced to ethane. The following sequence of reactions occur in this type of plume.

$$\text{TCE} \rightarrow \text{DCE} \rightarrow \text{VC} \rightarrow \text{Ethene} \rightarrow \text{Ethene}$$

In this type of plume, DCE and VC degrade more slowly than TCE, and thus they tend to accumulate. This type of reductive dehalogenation is described by Freedman and Gossett (1989).

3.2 SITE-SPECIFIC EVALUATION

As discussed above, evidence of natural biodegradation of CAHs includes:

- The presence of a primary carbon source;
- The depletion of electron donors and acceptors; and
- The presence of degradation daughter compounds.

These three conditions are present at the site, as discussed below.

3.2.1 Primary Carbon Source

The primary carbon sources at the site are dissolved toluene, ethylbenzene, and xylenes (TEX) eminating from AOC 5. TEX concentrations in excess of 500 mg/L were measured immediately downgradient of AOC 5 (ERM, 1992). AOC 5 also appears to be the primary source of TCE and TCA. This source of anthropogenic carbon indicates that at least a portion of the CAH plume can be classified as Type 1 behavior, described above, and that reductive dehalogenation of CAHs is occurring. However, the furthest downgradient well (MW-17) consistently shows the presence of CAHs but an absence of anthropogenic carbon (TEX). Therefore, it is likely that the occurrence of reductive dechlorination of CAHs may not be occurring as significantly in the downgradient portion of the plume.

3.2.2 Depletion of Electron Donors and Acceptors

As presented in Section 2, a comparison of background well conditions to plume well conditions indicates electron acceptors such as sulfate and oxygen, are being depleted in the contaminated area of the plume. As a result, groundwater is sufficiently reduced for reductive dehalogenation of CAHs to occur.

Electron donors in the form of TEX compound are also being depleted, as evidenced by the lack of TEX compounds in the downgradient portion of the plume. The degradation of TEX compounds supports the premise that CAHs are being degraded via reductive dehalogenation or cometabolism.

3.2.3 Daughter Degradation Compounds

As CAHs are sequentially dehalogenated, daughter compounds are generated. As discussed in Section 3.1.1, TCE generally degrades to DCE to VC to ethene, while TCA generally degrades to DCA to CA to ethane. DCE, VC, DCA, and CA have been detected in groundwater throughout the site (ERM 1992 and 1994). These compounds, except VC, were also detected in site groundwater during the limited groundwater sampling and analysis program (Table B.1), which also detected ethane (Table B.2). The presence of these daughter compounds indicates that reductive dehalogenation of TCE and TCA are likely occurring in site groundwater. Elevated chloride levels were also measured throughout the plume in comparison to background well MW-14 (Table B.2) further indicating dechlorination is occurring.

SECTION 4.0 REFERENCES

Abdul, S.A., Gibson, T.L., and Rai, D.N., 1987, Statistical correlations for predicting the partition coefficient for nonpolar organic contaminants between aquifer organic carbon and water: Hazardous Waste and Hazardous Materials, vol. 4, no. 3, p. 211-222.

Altenschmidt, U. and Fuchs, G., 1991, Anaerobic degradation of toluene in denitrifying *Pseudomonas* sp.: Indication for toluene methylhydroxylation and benzoyl-CoA as central aromatic intermediate: Arch. Microbial., vol. 156, p. 152.158.

Alvarez, P.J.J., and Vogel, T.M., 1991, Substrate interactions of benzene, toluene, and para-xylene during microbial degradation by pure cultures and mixed culture aquifer slurries: Applied and Environmental Microbiology, vol. 57, p. 2981-2985.

American Society for Testing and Materials (ASTM), 1994, Emergency Standard Guide for Risk-Based Corrective Action Applied at Petroleum Release Sites, ES 38-94.

Atlas, R.M., 1981, Microbial degradation of petroleum hydrocarbons - an environmental perspective: Microbiological Reviews, vol. 45, no. 1, p. 180-209.

Atlas, R.M., 1984, Petroleum Microbiology: Macmillan Publishing Company, New York.

Atlas, R.M., 1988, Microbiology - Fundamentals and Applications: Macmillan Publishing Company, New York.

Baedecker, M.J., Siegel, D.I., Bennett, P.C., Cozzarelli, I.M., 1988, The fate and effects of crude oil in a shallow aquifer: I. The distribution of chemical species and geochemical facies, In: G.E. Mallard, and SE. Ragone, editors, U.S. Geological Survey Toxic Substances Hydrology Program, Proceedings of the Technical Meeting, Phoenix, Arizona, September 26-30, 1988: U.S. Geological Survey Water-Resources Investigations Report 88-42320, p. 29-22.

Baedecker, M.J., and Cozzarelli, I.M., 1991, Geochemical modeling of organic degradation reactions in an Aquifer contaminated with Crude Oil: U.S. Geological Survey Water-Resources Investigations Report 91-4034. Reston, VA. p 627-632.

Bartha, R., 1986, Biotechnology of petroleum pollutant biodegradation: Microbial Ecology, vol. 12, p. 155-172.

Bauman, B, 1991, Biodegradation research of the American Petroleum Institute. Presented at: In Situ Bioreclamation: Application and Investigation for Hydrocarbons and Contaminated Site Remediation. San Diego, CA. March 19-21, 1991.

Bear, J., 1979, Hydraulics of Groundwater. McGraw-Hill, Inc., New York, New York, 569 p.

Beller, H.R. Reinhard, M., and Grbic-Galic, D., 1992, Metabolic byproducts of anaerobic toluene degradation by sulfate-reducing enrichment cultures: Appl. Environ. Microbiol., vol. 58, p. 3192-3195.

Berg, J.D., Neogard, B., Gundersen, R., Lorentsen, A., and Benett, T.E., 1994. Biotreatment of creoste-contaminated soil *in* Bioremediation of Chlorinated and Polycyclic Aromatic Hydrocarbon Compounds. Eds., .E. Hinchee, A. Leeson, L. Simprini, and S.K. Ong. Lewis Publishers, Ann Arbor.

Bohon, R.L., and Claussen, W.F., 1951, The solubility of aromatic hydrocarbons in water: Journal of American Chemical Society, vol. 73, no. 4, p.1571-1578.

Borden, R.C., 1991, Simulation of enhanced in situ biorestoration of petroleum hydrocarbons. In: In Situ bioreclamation: Application and Investigation for Hydrocarbons and contaminated Site Remediation. Eds., R.E. Hinchee and R. F. Olfenbuttel. Butterworth-Heinemann. p. 529-534.

Borden, R.C., 1994, Natural Bioremediation of Hydrocarbon-Contaminated Ground Water: In: Handbook of Bioremediation. Lewis Publishers. Boca Raton, FL. 1994.

Borden, Robert C., Gomez, Carlos A., and Becker, Mark T., 1995, Geochemical indicators of intrinsic bioremediation. Ground Water, vol. 33, no. 2, p. 180-189.

Borden, R.C., and Bedient, P.B., 1986, Transport of dissolved hydrocarbons influenced by oxygen limited biodegradation - theoretical development: Water Resources Research, vol. 22, no. 13, p. 1973-1982.

Bouwer, E.J., 1992, Bioremediation of Subsurface Contaminants, In: Mitchell, R., ed.: Environmental Microbiology. Wiley-Liss, New York, New York.

Buscheck, T.A., and Alcantar, C.M., 1995, Regression techniques and analytical solutions to demonstrate intrinsic remediation, in Proceedings of the Battelle In Situ and On-Site Bioreclamation Symposium, April 1995.

Chapelle, F.H., 1993, Ground-water Microbiology and Geochemistry. John Wiley and Sons, Inc., New York, NY.

Chapelle, F.H., 1994, Assessing the Efficiency of Intrinsic Bioremediation, *in* Proceedings of the Symposium on Intrinsic Bioremediation of Ground Water, August 30 - September 1, 1994: US Environmental Protection Agency, p. 171.

Chiang, C.Y., Salanitro, H.P., Chai, E.Y., Colthart, H.D., and Klein, C.L., 1989, Aerobic biodegradation of benzene, toluene, and xylene in a sandy aquifer - data analysis and computer modeling: Ground Water, vol. 27, no. 6, p. 823-834.

Davis, J.W., Klier, N.J., and Carpenter, 1994, Natural biological attenuation of benzene in ground water beneath a manufacturing facility: Ground Water, vol. 32, no. 2, p. 215-226.

Domenico, P.A., and Schwartz, F.W., 1990, Physical and Chemical Hydrogeology. John Wiley and Sons, New York, New York, 824p.

Edwards, E.A., Wells, L.E., Reinhard, M., and Grbic-Galic, D., 1992, Anaerobic degradation of toluene and xylene by aquifer microorganisms under sulfate-reducing conditions: Appl. Environ. Microbiol., vol. 58, p. 794-800.

Edwards, E.A., and Grbic-Galic, D., 1992, Complete mineralization of benzene by aquifer microorganisms under strictly anaerobic conditions: Appl. Environ. Microbiol., vol. 58, p. 2663-2666.

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

Fusey, P., and Oudot, J., 1984, Relative influence of physical removal and biodegradation in the depuration of petroleum-contaminated seashore sediments. Marine Pollution Bulletin 15: 136-141.

Gibson, D.T., and Subramanian, V., 1984, Microbial degradation of aromatic hydrocarbons, In: Microbial Degradation of Organic Compounds, Ed., D.T. Gibson, Marcel Dekker, Inc., p. 181-252.

Godsy, E.M., 1994, Microbiological and geochemical degradation processes, In: Symposium on Intrinsic Bioremediation in Ground Water. Denver, CO. August 30 - September 1, 1994, p.35-40.

Grbic-Galic, D., 1989, Microbial degradation of homocyclic and heterocyclic aromatic hydrocarbons under conditions: Dev. Ind. Microbiol., vol. 30, p. 237-253.

Grbic'-Galic', D., 1990, Anaerobic microbial transformation of nonoxygenated aromatic and alicyclic compounds in soil, subsurface, and freshwater sediments, In: Bollag, J.M., and Stotzky, G., eds.: Soil Biochemistry: Marcel Dekker, Inc., New York, NY. p. 117-189.

Grbic'-Galic', D., and Vogel, T.M., 1987, Transformation of toluene and benzene by mixed methanogenic cultures: Applied and Environmental Microbiology, vol. 53, p. 254-260.

Haag, F., Reinhard, M., and McCarty, P.L., 1991, Degradation of toluene and p-xylene in an anaerobic microcosms: Evidence for sulfate as a terminal electron acceptor: Environ. Toxicol. Chem., vol. 10, p. 1379-1389.

Heitkamp, M.A., and Cerniglia, C.E., 1989, Polycyclic aromatic hydrocarbon degradation by a *Mycobacterium* sp. in microcosms containing sediment and water from a pristine ecosystem. Applied and Environmental Microbiology, vol. 55, p. 1968-1973.

Higgins, I.J., and Gilbert, P.D., 1978, The biodegradation of hydrocarbons, In: K.W.A. Chator and H.J. Somerville, editors, The Oil Industry and Microbial Ecosystems: Heyden and Sons, London, p. 80-114.

Howard, P.H. 1990. Handbook of Environmental Fate and Exposure Data for Organic Chemicals, Vol. II: Solvents. Lewis Publishers, Inc. Chelsea, Michigan. 546 pp.

Howard, P.H., R.S. Boethling, W.F. Jarvis, W.M. Meylan, and E.M. Michalenko. 1991. Handbook of Environmental Degradation Rates. Lewis Publishers. Chelsea, Michigan.

Hutchins, S.R., 1991, Biodegradation of monoaromatic hydrocarbons by aquifer microorganisms using oxygen, nitrate, or nitrous oxide as the terminal electron acceptor: Appl. Environ. Microbiol., v. 57, p. 2403-2407.

Hutchins, S.R., and Wilson, J.T., 1991, Laboratory and field studies on BTEX biodegradation in a fuel-contaminated aquifer under denitrifying conditions, In: In Situ Bioreclamation, Applications and Investigations for Hydrocarbon and Contaminated Site Remediation. Eds. R.E. Hinchee and R.F. Olfenbuttel. Butterworth-Heinemann. Boston, MA. p. 157-172.

Isnard, S., and Lambert, S., 1988, Estimating bioconcentration factors from octanol-water partition coefficient and aqueous solubility: Chemosphere, vol. 17, no. 1, p. 21-34.

Jobson, A.F., Cook, F.D., and Westlake, D.W., 1972, Microbial utilization of crude oil. Applied and Environmental Microbiology, vol. 23, p. 1082-1089.

LaGrega, M.D., Buckingham, P.L., and Evans, J.C., 1994. Hazardous Waste Management, McGraw-Hill, Inc., 1146 p.

Leahy, J.G., and Colewell, R.R., 1990, Microbial degradation of hydrocarbons in the environment: Microbiolgical Reviews, vol. 53, no. 3, p. 305-315.

Lee, M.D., 1988, Biorestoration of Aquifers Contaminated with Organic Compounds: CRC Critical Reviews in Environmental Control. vol. 18. p. 29-89.

Litchfield, J.H., and Clark, L.C., 1973, Bacterial Activities in Ground Waters Containing Petroleum Products. American Petroleum Institute. Pub. No. 4211.

Lovley, D.R., Baedecker, M.J., Lonergan, D.J., Cozzarelli, I.M., Phillips, E.J.P., and Siegel, D.I., 1989, Oxidation of aromatic contaminants coupled to microbial iron reduction: Nature, vol. 339, p. 297-299.

Lovley, D.R., and Phillips, E.J.P., 1988, Novel mode of microbial energy metabolism: organic carbon oxidation coupled to dissimilatory reduction of iron or manganese. Applied and Environmental Microbiology, vol. 56, no. 6, p. 1472-1480.

Lovley, D.R., Phillips, E.J.P., and Lonergan, D.J., 1991, Enzymatic versus noenzymatic mechanisms for Fe(III) reduction in aquatic sediments. Environmental Science and Technology, vol. 26, no. 6, p. 1062-1067.

Lovley,Derek R., Chapelle, Francis H., and Woodward, Joan C., 1994, Use of dissolved H_2 concentrations to determine distribution of microbially catalyzed redox reactions in anoxic groundwater. Environmental Science and Technology, vol. 28, no. 7, p. 1205-1210.

Lyman, W.J., Reehl, W.F., and Rosenblatt, T.A., 1982, Handbook of Chemical Property Estimation Methods Environmental Behavior of Organic Compounds. McGraw-Hill, Inc., New York, NY.

Mackay, D., and Shiu, W.Y., 1981, A Critical Review of Henry's Law Constants for Chemicals of Environmental Interest: Journal of Physical Chemistry Reference Data, vol. 10, no. 4, p. 1175-1199.

Malone, D.R., Kao, C.M., and Borden, R.C., 1993, Dissolution and biorestoration of nonaqueous phase hydrocarbons - models development and laboratory evaluation: Water Resources Research, vol. 29, no. 7, p. 2003-2213.

McAllister, Paul M., and Chiang, Chen Y., 1994, A practical approach to evaluating natural attenuation of contaminants in ground water. Presented at the USEPA Symposium on Intrinsic Bioremediation of Ground Water, Denver, CO.

McCarty, P.L., 1972, Energetics of organic matter degradation, In. Water Pollution Microbiology, p. 91-118, (ed. R Mitchell). Wiley-Interscience.

McCarty, P.L., Roberts, P.V., Reinhard, M., and Hopkins, G., 1992, Movement and transformations of halogenated aliphatic compounds in natural systems, In: Fate of Pesticides and Chemicals in the Environment. Ed., J.L. Schnoor. John Wiley & Sons, Inc. New York, New York. p. 191-209.

Montgomery, John H. and Welkom, Linda M. 1990. Groundwater Chemicals Desk Reference. Lewis Publishers, Michigan.

Ostendorf, D.W., and Kampbell, D.H., 1989. Vertical profiles and near surface traps for field measurement of volatile pollution in the subsurface environment, Proceedings of the NWWA Conference on New Techniques for Quantifying the Physical and Chemical Properties of Heterogeneous Aquifers, Dallas, Texas.

Park, K.S., Sims, RC, and Dupont, R.R.. 1990. *Transformation of PAHs in Soil Systems*, Journal of Environmental Engineering, Vol. 116, no. 3, pp. 632-640.

Perry, J.J., 1977, Microbial metabolism of cyclic hydrocarbons and related compounds, Critical Reviews in Microbiology, vol., 5, p. 387-412.

Reinhard, M., 1994, In-Situ Bioremediation Technologies for Petroleum-Derived Hydrocarbons Based on Alternate Electron Acceptors (Other Than Molecular Oxygen), In: *Handbook of Bioremediation*. Lewis Publishers, Boca Raton, FL. 1994.

Reinhard, M., Goodman, N.L., and Barker, J.F., 1984, Occurrence and distribution of organic chemicals in two landfill leachate plumes: Environ. Sci. Technol., vol. 18, no. 12, p. 953-961.

Rifai, H.S., Bedient, P.B., Wilson, J.T., Miller, K.M., and Armstrong, J.M., 1988, Biodegredation modeling at aviation fuel spill site: Journal of Environmental Engineering, vol. 114, no. 5, p. 1007-1029.

Salanitro, J.P., 1993, *The role of bioattenuation in the management of aromatic hydrocarbon plumes in aquifers*, Ground Water Monitoring and Remediation, Vol. 13, pp. 150-161.

Stieber, M., K. Böckle, P. Werner, and F.H. Frimmel. 1990. "Biodegradation of Polycyclic Aromatic Hydrocarbons (PAH) in the Subsurface." IN F. Arend, M. Hinseveld, and W. J. Van den Brink (Eds.), *Contaminated Soil 1990*, pp. 473-479. Kluwer Academic Publishers, Netherlands.

Stumm, W. and Morgan, J.J., 1981, Aquatic Chemistry. John Wiley & Sons, New York, NY.

Thierrin, J., Davis, G.B., Barber, C., Patterson, B.M., Pribac, F., Power, T.R., and Lambert, M., 1992, Natural degradation rates of BTEX compounds and napthalene in a sulfate reducing ground water environment, In: In-Situ Bioremediation Symposium "92". Niagara-on-the-Lake, Ontario, Canada. September 20-24, 1992: In Press.

US Environmental Protection Agency. 1987. Compendium of Superfund Field Operations Methods. Office of Emergency and Remedial Response. EPA/540/P-87/001. (OSWER Directive 9355.0-14)

US Environmental Protection Agency. 1989. Risk Assessment Guidance for Superfund, Volume I, Human Health Evaluation Manual (Part A), Interim Final, Publication EPA 540/1-89/002.

Verschueren, K., 1983, Handbook of Environmental Data on Organic Chemicals. Van Nostrand Reinhold Co., New York, New York.

Walker, J.D., Colwell, R.R., and Petrakis, L., 1976, Biodegradation rates of components of petroleum. Canadian Journal of Microbiology, vol. 22, p. 1209-1213.

Weidemeier, T.H., Downey, D.C., Wilson, J.T., Kampbell, D.H., Miller, R.N., and Hansen, J.E. 1995. *Technical Protocol for Implementing the Intrinsic Remediation (Natural Attenuation) with Long-term Monitoring Option for Dissolved-phase Fuel Contamination in Ground Water*. Prepared by the Air Force Center for Environmental Excellence, Brooks Air Force Base, San Antonio, Texas.

Wilson, B.H., Smith, G.B., and Rees, J.F., 1986, Biotransformations of Selected Alkylbenzenes and Halogenated Aliphatic Hydrocarbons in Methanogenic Aquifer Material: A Microcosm Study: Environmental Science and Technology, 20(10):997-1002.

Wilson, B.H., Bledsoe, B., and Kampbell, D., 1987, Biological processes occurring at an aviation gasoline spill site, In: R.C. Averett and D.M. McKnight editors, Chemical Quality of Water and the Hydrologic Cycle. Lewis Publishers, Chelsea, Michigan, p.125-137.

Wilson, B.H., Wilson, J.T., Kampbell, D.H., Bledsoe, B.E., and Armstrong, J.M., 1990, Biotransformation of Monoaromatic and Chlorinated Hydrocarbons at an Aviation Gasoline Spill Site: Geomicrobiology Journal, 8:225-240.

Young, L.Y., 1984, Anaerobic degradation of aromatic compounds, In: Gibson, D.R., ed.: Microbial Degradation of Aromatic Compounds. Marcel-Dekker, New York.

Zobell, C.E., 1946, Action of microorganisms on hydrocarbons: Bacterial. Review. vol. 10, p. 1-49.

ATTACHMENT 1
TO
APPENDIX B

ANALYTICAL RESULTS

SAMPLE SUMMARY

SAMPLE SUMMARY

WO #	LOT-SAMPLE #	SAMPLE IDENTIFICATION	DATE/TIME SAMPLED
C5JJC	A6I030147-001	MW024	08/30/96 13:00
C5JJE	A6I030147-002	MW026D	08/30/96 14:00
C5JJF	A6I030147-003	MW022	08/30/96 13:00
C5JJG	A6I030147-004	MW014	08/30/96 09:30
C5JJH	A6I030147-005	MW003A (MS/MSD)	08/30/96 11:00
C5JJR	A6I030147-006	MW003D	08/30/96 10:10
C5JJX	A6I030147-007	MW003S	08/30/96 11:30
C5JK3	A6I030147-008	MW017	08/30/96 15:30
C5JK4	A6I030147-009	MW016	08/30/96 15:00
C5JK5	A6I030147-010	MW026S	08/30/96 14:30
C5JK6	A6I030147-011	TB-1	08/30/96 16:00

NOTE(S):

- The analytical results of the samples listed above are presented on the following pages.
- All calculations are performed before rounding to avoid round-off errors in calculated results.
- Results noted as "ND" were not detected at or above the stated limit.
- This report must not be reproduced except in full, without the written approval of the laboratory.

GC VOLATILE SAMPLE DATA

8010

PARSONS ENGINEERING SCIENCE, INC.

Lab Name:QUANTERRA

SDG Number:

Matrix: (soil/water) WATER

Lab Sample ID:A6I030147 001

Method: SW846 8010B
Volatile Organics (8010B)

Sample WT/Vol: 5 / mL
Work Order: C5JJC10E
Dilution factor: 1

Date Received: 08/31/96
Date Extracted:09/08/96
Date Analyzed: 09/08/96

QC Batch: 6254169

Client Sample Id: MW024

CAS NO.	COMPOUND	CONCENTRATION UNITS: (ug/L or ug/kg) ug/L	Q
108-86-1	Bromobenzene	1.0	U
75-27-4	Bromodichloromethane	1.0	U
75-25-2	Bromoform	1.0	U
74-83-9	Bromomethane	1.0	U
56-23-5	Carbon tetrachloride	1.0	U
108-90-7	Chlorobenzene	1.0	U
75-00-3	Chloroethane	1.0	U
110-75-8	2-Chloroethyl vinyl ether	5.0	U
67-66-3	Chloroform	1.0	U
74-87-3	Chloromethane	1.0	U
124-48-1	Dibromochloromethane	1.0	U
74-95-3	Dibromomethane	1.0	U
95-50-1	1,2-Dichlorobenzene	1.0	U
541-73-1	1,3-Dichlorobenzene	1.0	U
106-46-7	1,4-Dichlorobenzene	1.0	U
75-71-8	Dichlorodifluoromethane	1.0	U
75-34-3	**1,1-Dichloroethane**	**11**	
107-06-2	1,2-Dichloroethane	1.0	U
75-35-4	1,1-Dichloroethene	1.0	U
156-60-5	trans-1,2-Dichloroethene	1.0	U
75-09-2	Dichloromethane	5.0	U
78-87-5	1,2-Dichloropropane	1.0	U
10061-01-5	cis-1,3-Dichloropropene	1.0	U
10061-02-6	trans-1,3-Dichloropropene	1.0	U
79-34-5	1,1,2,2-Tetrachloroethane	1.0	U
630-20-6	1,1,1,2-Tetrachloroethane	1.0	U
127-18-4	Tetrachloroethene	1.0	U
71-55-6	1,1,1-Trichloroethane	1.0	U
79-00-5	1,1,2-Trichloroethane	1.0	U

PARSONS ENGINEERING SCIENCE, INC.

Lab Name:QUANTERRA

SDG Number:

Matrix: (soil/water) WATER

Lab Sample ID:A6I030147 001

Method: SW846 8010B
Volatile Organics (8010B)

Sample WT/Vol: 5 / mL
Work Order: C5JJC10E
Dilution factor: 1

Date Received: 08/31/96
Date Extracted:09/08/96
Date Analyzed: 09/08/96

QC Batch: 6254169

Client Sample Id: MW024

CAS NO.	COMPOUND	CONCENTRATION UNITS: (ug/L or ug/kg) ug/L	Q
79-01-6	Trichloroethene	1.0	U
75-69-4	Trichlorofluoromethane	1.0	U
96-18-4	1,2,3-Trichloropropane	1.0	U
75-01-4	Vinyl chloride	1.0	U
156-59-2	cis-1,2-Dichloroethene	1.0	U

FORM I

PARSONS ENGINEERING SCIENCE, INC.

Lab Name:QUANTERRA

SDG Number:

Matrix: (soil/water) WATER

Method: SW846 8010B

Volatile Organics (8010B)

Lab Sample ID:A6I030147 002

Sample WT/Vol: 5 / mL

Work Order: C5JJE10E

Dilution factor: 10

Date Received: 08/31/96

Date Extracted:09/09/96

Date Analyzed: 09/09/96

QC Batch: 6254173

Client Sample Id: MW026D

CAS NO.	COMPOUND	CONCENTRATION UNITS: (ug/L or ug/kg) ug/L	Q
108-86-1	Bromobenzene	10	U
75-27-4	Bromodichloromethane	10	U
75-25-2	Bromoform	10	U
74-83-9	Bromomethane	10	U
56-23-5	Carbon tetrachloride	10	U
108-90-7	Chlorobenzene	10	U
75-00-3	Chloroethane	10	U
110-75-8	2-Chloroethyl vinyl ether	50	U
67-66-3	Chloroform	10	U
74-87-3	Chloromethane	10	U
124-48-1	Dibromochloromethane	10	U
74-95-3	Dibromomethane	10	U
95-50-1	1,2-Dichlorobenzene	10	U
541-73-1	1,3-Dichlorobenzene	10	U
106-46-7	1,4-Dichlorobenzene	10	U
75-71-8	Dichlorodifluoromethane	10	U
75-34-3	**1,1-Dichloroethane**	**70**	
107-06-2	1,2-Dichloroethane	10	U
75-35-4	**1,1-Dichloroethene**	**270**	
156-60-5	trans-1,2-Dichloroethene	10	U
75-09-2	Dichloromethane	50	U
78-87-5	1,2-Dichloropropane	10	U
10061-01-5	cis-1,3-Dichloropropene	10	U
10061-02-6	trans-1,3-Dichloropropene	10	U
79-34-5	1,1,2,2-Tetrachloroethane	10	U
630-20-6	1,1,1,2-Tetrachloroethane	10	U
127-18-4	Tetrachloroethene	10	U
71-55-6	**1,1,1-Trichloroethane**	**52**	
79-00-5	1,1,2-Trichloroethane	10	U

FORM I

Lab Name: QUANTERRA	SDG Number:
Matrix: (soil/water) WATER	Lab Sample ID: A6I030147 002
Method: SW846 8010B Volatile Organics (8010B)	
Sample WT/Vol: 5 / mL	Date Received: 08/31/96
Work Order: C5JJE10E	Date Extracted: 09/09/96
Dilution factor: 10	Date Analyzed: 09/09/96
	QC Batch: 6254173
Client Sample Id: MW026D	

CAS NO.	COMPOUND	CONCENTRATION UNITS: (ug/L or ug/kg) ug/L	Q
79-01-6	**Trichloroethene**	16	
75-69-4	**Trichlorofluoromethane**	73	
96-18-4	1,2,3-Trichloropropane	10	U
75-01-4	Vinyl chloride	10	U
156-59-2	**cis-1,2-Dichloroethene**	16	

FORM I

PARSONS ENGINEERING SCIENCE, INC.

Lab Name:QUANTERRA

SDG Number:

Matrix: (soil/water) WATER

Method: SW846 8010B
Volatile Organics (8010B)

Lab Sample ID:A6I030147 003

Sample WT/Vol: 5 / mL
Work Order: C5JJF10E
Dilution factor: 1

Date Received: 08/31/96
Date Extracted:09/09/96
Date Analyzed: 09/09/96

QC Batch: 6254173

Client Sample Id: MW022

CAS NO.	COMPOUND	CONCENTRATION UNITS: (ug/L or ug/kg) ug/L	Q
108-86-1	Bromobenzene	1.0	U
75-27-4	Bromodichloromethane	1.0	U
75-25-2	Bromoform	1.0	U
74-83-9	Bromomethane	1.0	U
56-23-5	Carbon tetrachloride	1.0	U
108-90-7	Chlorobenzene	1.0	U
75-00-3	Chloroethane	1.0	U
110-75-8	2-Chloroethyl vinyl ether	5.0	U
67-66-3	Chloroform	1.0	U
74-87-3	Chloromethane	1.0	U
124-48-1	Dibromochloromethane	1.0	U
74-95-3	Dibromomethane	1.0	U
95-50-1	1,2-Dichlorobenzene	1.0	U
541-73-1	1,3-Dichlorobenzene	1.0	U
106-46-7	1,4-Dichlorobenzene	1.0	U
75-71-8	Dichlorodifluoromethane	1.0	U
75-34-3	1,1-Dichloroethane	1.0	U
107-06-2	1,2-Dichloroethane	1.0	U
75-35-4	1,1-Dichloroethene	1.0	U
156-60-5	trans-1,2-Dichloroethene	1.0	U
75-09-2	Dichloromethane	5.0	U
78-87-5	1,2-Dichloropropane	1.0	U
10061-01-5	cis-1,3-Dichloropropene	1.0	U
10061-02-6	trans-1,3-Dichloropropene	1.0	U
79-34-5	1,1,2,2-Tetrachloroethane	1.0	U
630-20-6	1,1,1,2-Tetrachloroethane	1.0	U
127-18-4	Tetrachloroethene	1.0	U
71-55-6	1,1,1-Trichloroethane	1.0	U
79-00-5	1,1,2-Trichloroethane	1.0	U

FORM I

Lab Name:QUANTERRA

SDG Number:

Matrix: (soil/water) WATER

Method: SW846 8010B
Volatile Organics (8010B)

Lab Sample ID:A6I030147 003

Sample WT/Vol: 5 / mL
Work Order: C5JJF10E
Dilution factor: 1

Date Received: 08/31/96
Date Extracted:09/09/96
Date Analyzed: 09/09/96

QC Batch: 6254173

Client Sample Id: MW022

CAS NO.	COMPOUND	CONCENTRATION UNITS: (ug/L or ug/kg) ug/L	Q
79-01-6	Trichloroethene	1.0	U
75-69-4	Trichlorofluoromethane	1.0	U
96-18-4	1,2,3-Trichloropropane	1.0	U
75-01-4	Vinyl chloride	1.0	U
156-59-2	cis-1,2-Dichloroethene	1.0	U

PARSONS ENGINEERING SCIENCE, INC.

Lab Name:QUANTERRA

SDG Number:

Matrix: (soil/water) WATER

Lab Sample ID:A6I030147 004

Method: SW846 8010B
Volatile Organics (8010B)

Sample WT/Vol: 5 / mL

Work Order: C5JJG10E

Dilution factor: 1

Date Received: 08/31/96

Date Extracted:09/08/96

Date Analyzed: 09/08/96

QC Batch: 6254169

Client Sample Id: MW014

CAS NO.	COMPOUND	CONCENTRATION UNITS: (ug/L or ug/kg) ug/L	Q
108-86-1	Bromobenzene	1.0	U
75-27-4	Bromodichloromethane	1.0	U
75-25-2	Bromoform	1.0	U
74-83-9	Bromomethane	1.0	U
56-23-5	Carbon tetrachloride	1.0	U
108-90-7	Chlorobenzene	1.0	U
75-00-3	Chloroethane	1.0	U
110-75-8	2-Chloroethyl vinyl ether	5.0	U
67-66-3	Chloroform	1.0	U
74-87-3	Chloromethane	1.0	U
124-48-1	Dibromochloromethane	1.0	U
74-95-3	Dibromomethane	1.0	U
95-50-1	1,2-Dichlorobenzene	1.0	U
541-73-1	1,3-Dichlorobenzene	1.0	U
106-46-7	1,4-Dichlorobenzene	1.0	U
75-71-8	Dichlorodifluoromethane	1.0	U
75-34-3	1,1-Dichloroethane	1.0	U
107-06-2	1,2-Dichloroethane	1.0	U
75-35-4	1,1-Dichloroethene	1.0	U
156-60-5	trans-1,2-Dichloroethene	1.0	U
75-09-2	Dichloromethane	5.0	U
78-87-5	1,2-Dichloropropane	1.0	U
10061-01-5	cis-1,3-Dichloropropene	1.0	U
10061-02-6	trans-1,3-Dichloropropene	1.0	U
79-34-5	1,1,2,2-Tetrachloroethane	1.0	U
630-20-6	1,1,1,2-Tetrachloroethane	1.0	U
127-18-4	Tetrachloroethene	1.0	U
71-55-6	1,1,1-Trichloroethane	1.0	U
79-00-5	1,1,2-Trichloroethane	1.0	U

FORM I

PARSONS ENGINEERING SCIENCE, INC.

Lab Name:QUANTERRA

SDG Number:

Matrix: (soil/water) WATER

Method: SW846 8010B

Volatile Organics (8010B)

Lab Sample ID:A6I030147 004

Sample WT/Vol: 5 / mL

Work Order: C5JJG10E

Dilution factor: 1

Date Received: 08/31/96

Date Extracted:09/08/96

Date Analyzed: 09/08/96

QC Batch: 6254169

Client Sample Id: MW014

CAS NO.	COMPOUND	CONCENTRATION UNITS: (ug/L or ug/kg) ug/L	Q
79-01-6	Trichloroethene	1.0	U
75-69-4	Trichlorofluoromethane	1.0	U
96-18-4	1,2,3-Trichloropropane	1.0	U
75-01-4	Vinyl chloride	1.0	U
156-59-2	cis-1,2-Dichloroethene	1.0	U

FORM I

PARSONS ENGINEERING SCIENCE, INC.

Lab Name:QUANTERRA

SDG Number:

Matrix: (soil/water) WATER

Method: SW846 8010B

Volatile Organics (8010B)

Lab Sample ID:A6I030147 005

Sample WT/Vol: 5 / mL

Work Order: C5JJH117

Dilution factor: 10

Date Received: 08/31/96

Date Extracted:09/08/96

Date Analyzed: 09/08/96

QC Batch: 6254169

Client Sample Id: MW003A (MS/MSD)

CAS NO.	COMPOUND	CONCENTRATION UNITS: (ug/L or ug/kg) ug/L	Q
108-86-1	Bromobenzene	10	U
75-27-4	Bromodichloromethane	10	U
75-25-2	Bromoform	10	U
74-83-9	Bromomethane	10	U
56-23-5	Carbon tetrachloride	10	U
108-90-7	Chlorobenzene	10	U
75-00-3	**Chloroethane**	**14**	
110-75-8	2-Chloroethyl vinyl ether	50	U
67-66-3	Chloroform	10	U
74-87-3	Chloromethane	10	U
124-48-1	Dibromochloromethane	10	U
74-95-3	Dibromomethane	10	U
95-50-1	1,2-Dichlorobenzene	10	U
541-73-1	1,3-Dichlorobenzene	10	U
106-46-7	1,4-Dichlorobenzene	10	U
75-71-8	Dichlorodifluoromethane	10	U
75-34-3	1,1-Dichloroethane	10	U
107-06-2	1,2-Dichloroethane	10	U
75-35-4	1,1-Dichloroethene	10	U
156-60-5	trans-1,2-Dichloroethene	10	U
75-09-2	Dichloromethane	50	U
78-87-5	1,2-Dichloropropane	10	U
10061-01-5	cis-1,3-Dichloropropene	10	U
10061-02-6	trans-1,3-Dichloropropene	10	U
79-34-5	1,1,2,2-Tetrachloroethane	10	U
630-20-6	1,1,1,2-Tetrachloroethane	10	U
127-18-4	Tetrachloroethene	10	U
71-55-6	**1,1,1-Trichloroethane**	**34**	
79-00-5	1,1,2-Trichloroethane	10	U

FORM I

PARSONS ENGINEERING SCIENCE, INC.

Lab Name:QUANTERRA

SDG Number:

Matrix: (soil/water) WATER

Lab Sample ID:A6I030147 005

Method: SW846 8010B
Volatile Organics (8010B)

Sample WT/Vol: 5 / mL
Work Order: C5JJH117
Dilution factor: 10

Date Received: 08/31/96
Date Extracted:09/08/96
Date Analyzed: 09/08/96

QC Batch: 6254169

Client Sample Id: MW003A (MS/MSD)

CAS NO.	COMPOUND	CONCENTRATION UNITS: (ug/L or ug/kg) ug/L	Q
79-01-6	**Trichloroethene**	**86**	
75-69-4	**Trichlorofluoromethane**	**200**	
96-18-4	1,2,3-Trichloropropane	10	U
75-01-4	Vinyl chloride	10	U
156-59-2	cis-1,2-Dichloroethene	10	U

FORM I

PARSONS ENGINEERING SCIENCE, INC.

Lab Name: QUANTERRA

SDG Number:

Matrix: (soil/water) WATER

Lab Sample ID: A6I030147 006

Method: SW846 8010B
Volatile Organics (8010B)

Sample WT/Vol: 5 / mL

Work Order: C5JJR10E

Dilution factor: 10

Date Received: 08/31/96

Date Extracted: 09/08/96

Date Analyzed: 09/08/96

QC Batch: 6254169

Client Sample Id: MW003D

CAS NO.	COMPOUND	CONCENTRATION UNITS: (ug/L or ug/kg) ug/L	Q
108-86-1	Bromobenzene	10	U
75-27-4	Bromodichloromethane	10	U
75-25-2	Bromoform	10	U
74-83-9	Bromomethane	10	U
56-23-5	Carbon tetrachloride	10	U
108-90-7	Chlorobenzene	10	U
75-00-3	**Chloroethane**	**12**	
110-75-8	2-Chloroethyl vinyl ether	50	U
67-66-3	Chloroform	10	U
74-87-3	Chloromethane	10	U
124-48-1	Dibromochloromethane	10	U
74-95-3	Dibromomethane	10	U
95-50-1	1,2-Dichlorobenzene	10	U
541-73-1	1,3-Dichlorobenzene	10	U
106-46-7	1,4-Dichlorobenzene	10	U
75-71-8	Dichlorodifluoromethane	10	U
75-34-3	1,1-Dichloroethane	10	U
107-06-2	1,2-Dichloroethane	10	U
75-35-4	**1,1-Dichloroethene**	**14**	
156-60-5	trans-1,2-Dichloroethene	10	U
75-09-2	Dichloromethane	50	U
78-87-5	1,2-Dichloropropane	10	U
10061-01-5	cis-1,3-Dichloropropene	10	U
10061-02-6	trans-1,3-Dichloropropene	10	U
79-34-5	1,1,2,2-Tetrachloroethane	10	U
630-20-6	1,1,1,2-Tetrachloroethane	10	U
127-18-4	Tetrachloroethene	10	U
71-55-6	**1,1,1-Trichloroethane**	**24**	
79-00-5	1,1,2-Trichloroethane	10	U

FORM I

PARSONS ENGINEERING SCIENCE, INC.

Lab Name: QUANTERRA

SDG Number:

Matrix: (soil/water) WATER

Method: SW846 8010B

Volatile Organics (8010B)

Lab Sample ID: A6I030147 006

Sample WT/Vol: 5 / mL

Work Order: C5JJR10E

Dilution factor: 10

Date Received: 08/31/96

Date Extracted: 09/08/96

Date Analyzed: 09/08/96

QC Batch: 6254169

Client Sample Id: MW003D

CAS NO.	COMPOUND	CONCENTRATION UNITS: (ug/L or ug/kg) ug/L	Q
79-01-6	**Trichloroethene**	**100**	
75-69-4	**Trichlorofluoromethane**	**220**	
96-18-4	1,2,3-Trichloropropane	10	U
75-01-4	Vinyl chloride	10	U
156-59-2	cis-1,2-Dichloroethene	10	U

FORM I

PARSONS ENGINEERING SCIENCE, INC.

Lab Name: QUANTERRA

SDG Number:

Matrix: (soil/water) WATER

Lab Sample ID: A6I030147 007

Method: SW846 8010B
Volatile Organics (8010B)

Sample WT/Vol: 5 / mL

Work Order: C5JJX10E

Dilution factor: 10

Date Received: 08/31/96

Date Extracted: 09/08/96

Date Analyzed: 09/08/96

QC Batch: 6254169

Client Sample Id: MW003S

CONCENTRATION UNITS:

CAS NO.	COMPOUND	(ug/L or ug/kg) ug/L	Q
108-86-1	Bromobenzene	10	U
75-27-4	Bromodichloromethane	10	U
75-25-2	Bromoform	10	U
74-83-9	Bromomethane	10	U
56-23-5	Carbon tetrachloride	10	U
108-90-7	Chlorobenzene	10	U
75-00-3	Chloroethane	10	U
110-75-8	2-Chloroethyl vinyl ether	50	U
67-66-3	Chloroform	10	U
74-87-3	Chloromethane	10	U
124-48-1	Dibromochloromethane	10	U
74-95-3	Dibromomethane	10	U
95-50-1	1,2-Dichlorobenzene	10	U
541-73-1	1,3-Dichlorobenzene	10	U
106-46-7	1,4-Dichlorobenzene	10	U
75-71-8	Dichlorodifluoromethane	10	U
75-34-3	1,1-Dichloroethane	10	U
107-06-2	1,2-Dichloroethane	10	U
75-35-4	1,1-Dichloroethene	10	U
156-60-5	trans-1,2-Dichloroethene	10	U
75-09-2	Dichloromethane	50	U
78-87-5	1,2-Dichloropropane	10	U
10061-01-5	cis-1,3-Dichloropropene	10	U
10061-02-6	trans-1,3-Dichloropropene	10	U
79-34-5	1,1,2,2-Tetrachloroethane	10	U
630-20-6	1,1,1,2-Tetrachloroethane	10	U
127-18-4	Tetrachloroethene	10	U
71-55-6	1,1,1-Trichloroethane	10	U
79-00-5	1,1,2-Trichloroethane	10	U

Lab Name:QUANTERRA

SDG Number:

Matrix: (soil/water) WATER

Lab Sample ID:A6I030147 007

Method: SW846 8010B
Volatile Organics (8010B)

Sample WT/Vol: 5 / mL
Work Order: C5JJX10E
Dilution factor: 10

Date Received: 08/31/96
Date Extracted:09/08/96
Date Analyzed: 09/08/96

QC Batch: 6254169

Client Sample Id: MW003S

CAS NO.	COMPOUND	CONCENTRATION UNITS: (ug/L or ug/kg) ug/L	Q
79-01-6	**Trichloroethene**	**72**	
75-69-4	Trichlorofluoromethane	10	U
96-18-4	1,2,3-Trichloropropane	10	U
75-01-4	Vinyl chloride	10	U
156-59-2	**cis-1,2-Dichloroethene**	**30**	

PARSONS ENGINEERING SCIENCE, INC.

Lab Name:QUANTERRA

SDG Number:

Matrix: (soil/water) WATER

Lab Sample ID:A6I030147 008

Method: SW846 8010B
Volatile Organics (8010B)

Sample WT/Vol: 5 / mL
Work Order: C5JK310E
Dilution factor: 50

Date Received: 08/31/96
Date Extracted:09/08/96
Date Analyzed: 09/08/96

QC Batch: 6254169

Client Sample Id: MW017

CAS NO.	COMPOUND	CONCENTRATION UNITS: (ug/L or ug/kg) ug/L	Q
108-86-1	Bromobenzene	50	U
75-27-4	Bromodichloromethane	50	U
75-25-2	Bromoform	50	U
74-83-9	Bromomethane	50	U
56-23-5	Carbon tetrachloride	50	U
108-90-7	Chlorobenzene	50	U
75-00-3	Chloroethane	50	U
110-75-8	2-Chloroethyl vinyl ether	250	U
67-66-3	Chloroform	50	U
74-87-3	Chloromethane	50	U
124-48-1	Dibromochloromethane	50	U
74-95-3	Dibromomethane	50	U
95-50-1	1,2-Dichlorobenzene	50	U
541-73-1	1,3-Dichlorobenzene	50	U
106-46-7	1,4-Dichlorobenzene	50	U
75-71-8	Dichlorodifluoromethane	50	U
75-34-3	1,1-Dichloroethane	50	U
107-06-2	1,2-Dichloroethane	50	U
75-35-4	1,1-Dichloroethene	50	U
156-60-5	trans-1,2-Dichloroethene	50	U
75-09-2	Dichloromethane	250	U
78-87-5	1,2-Dichloropropane	50	U
10061-01-5	cis-1,3-Dichloropropene	50	U
10061-02-6	trans-1,3-Dichloropropene	50	U
79-34-5	1,1,2,2-Tetrachloroethane	50	U
630-20-6	1,1,1,2-Tetrachloroethane	50	U
127-18-4	Tetrachloroethene	50	U
71-55-6	1,1,1-Trichloroethane	50	U
79-00-5	1,1,2-Trichloroethane	50	U

PARSONS ENGINEERING SCIENCE, INC.

Lab Name: QUANTERRA

SDG Number:

Matrix: (soil/water) WATER

Method: SW846 8010B
Volatile Organics (8010B)

Lab Sample ID: A6I030147 008

Sample WT/Vol: 5 / mL
Work Order: C5JK310E
Dilution factor: 50

Date Received: 08/31/96
Date Extracted: 09/08/96
Date Analyzed: 09/08/96

QC Batch: 6254169

Client Sample Id: MW017

CAS NO.	COMPOUND	CONCENTRATION UNITS: (ug/L or ug/kg) ug/L	Q
79-01-6	**Trichloroethene**	**330**	
75-69-4	Trichlorofluoromethane	50	U
96-18-4	1,2,3-Trichloropropane	50	U
75-01-4	Vinyl chloride	50	U
156-59-2	**cis-1,2-Dichloroethene**	**91**	

FORM I

PARSONS ENGINEERING SCIENCE, INC.

Lab Name:QUANTERRA

SDG Number:

Matrix: (soil/water) WATER
Method: SW846 8010B
Volatile Organics (8010B)

Lab Sample ID:A6I030147 009

Sample WT/Vol: 5 / mL
Work Order: C5JK410E
Dilution factor: 1

Date Received: 08/31/96
Date Extracted:09/08/96
Date Analyzed: 09/08/96

QC Batch: 6254169

Client Sample Id: MW016

CAS NO.	COMPOUND	CONCENTRATION UNITS: (ug/L or ug/kg) ug/L	Q
108-86-1	Bromobenzene	1.0	U
75-27-4	Bromodichloromethane	1.0	U
75-25-2	Bromoform	1.0	U
74-83-9	Bromomethane	1.0	U
56-23-5	Carbon tetrachloride	1.0	U
108-90-7	Chlorobenzene	1.0	U
75-00-3	Chloroethane	1.0	U
110-75-8	2-Chloroethyl vinyl ether	5.0	U
67-66-3	Chloroform	1.0	U
74-87-3	Chloromethane	1.0	U
124-48-1	Dibromochloromethane	1.0	U
74-95-3	Dibromomethane	1.0	U
95-50-1	1,2-Dichlorobenzene	1.0	U
541-73-1	1,3-Dichlorobenzene	1.0	U
106-46-7	1,4-Dichlorobenzene	1.0	U
75-71-8	Dichlorodifluoromethane	1.0	U
75-34-3	1,1-Dichloroethane	1.0	U
107-06-2	1,2-Dichloroethane	1.0	U
75-35-4	1,1-Dichloroethene	1.0	U
156-60-5	trans-1,2-Dichloroethene	1.0	U
75-09-2	Dichloromethane	5.0	U
78-87-5	1,2-Dichloropropane	1.0	U
10061-01-5	cis-1,3-Dichloropropene	1.0	U
10061-02-6	trans-1,3-Dichloropropene	1.0	U
79-34-5	1,1,2,2-Tetrachloroethane	1.0	U
630-20-6	1,1,1,2-Tetrachloroethane	1.0	U
127-18-4	Tetrachloroethene	1.0	U
71-55-6	1,1,1-Trichloroethane	1.0	U
79-00-5	1,1,2-Trichloroethane	1.0	U

FORM I

PARSONS ENGINEERING SCIENCE, INC.

Lab Name:QUANTERRA	SDG Number:
Matrix: (soil/water) WATER	Lab Sample ID:A6I030147 009
Method: SW846 8010B Volatile Organics (8010B)	
Sample WT/Vol: 5 / mL	Date Received: 08/31/96
Work Order: C5JK410E	Date Extracted:09/08/96
Dilution factor: 1	Date Analyzed: 09/08/96
	QC Batch: 6254169
Client Sample Id: MW016	

CAS NO.	COMPOUND	CONCENTRATION UNITS: (ug/L or ug/kg) ug/L	Q
79-01-6	Trichloroethene	1.0	U
75-69-4	Trichlorofluoromethane	1.0	U
96-18-4	1,2,3-Trichloropropane	1.0	U
75-01-4	Vinyl chloride	1.0	U
156-59-2	cis-1,2-Dichloroethene	1.0	U

PARSONS ENGINEERING SCIENCE, INC.

Lab Name: QUANTERRA

SDG Number:

Matrix: (soil/water) WATER

Method: SW846 8010B

Volatile Organics (8010B)

Lab Sample ID: A6I030147 010

Sample WT/Vol: 5 / mL

Work Order: C5JK510E

Dilution factor: 1

Date Received: 08/31/96

Date Extracted: 09/09/96

Date Analyzed: 09/09/96

QC Batch: 6254173

Client Sample Id: MW026S

CAS NO.	COMPOUND	CONCENTRATION UNITS: (ug/L or ug/kg) ug/L	Q
108-86-1	Bromobenzene	1.0	U
75-27-4	Bromodichloromethane	1.0	U
75-25-2	Bromoform	1.0	U
74-83-9	Bromomethane	1.0	U
56-23-5	Carbon tetrachloride	1.0	U
108-90-7	Chlorobenzene	1.0	U
75-00-3	**Chloroethane**	**21**	
110-75-8	2-Chloroethyl vinyl ether	5.0	U
67-66-3	Chloroform	1.0	U
74-87-3	Chloromethane	1.0	U
124-48-1	Dibromochloromethane	1.0	U
74-95-3	Dibromomethane	1.0	U
95-50-1	1,2-Dichlorobenzene	1.0	U
541-73-1	1,3-Dichlorobenzene	1.0	U
106-46-7	1,4-Dichlorobenzene	1.0	U
75-71-8	Dichlorodifluoromethane	1.0	U
75-34-3	**1,1-Dichloroethane**	**13**	
107-06-2	1,2-Dichloroethane	1.0	U
75-35-4	**1,1-Dichloroethene**	**5.6**	
156-60-5	trans-1,2-Dichloroethene	1.0	U
75-09-2	Dichloromethane	5.0	U
78-87-5	1,2-Dichloropropane	1.0	U
10061-01-5	cis-1,3-Dichloropropene	1.0	U
10061-02-6	trans-1,3-Dichloropropene	1.0	U
79-34-5	1,1,2,2-Tetrachloroethane	1.0	U
630-20-6	1,1,1,2-Tetrachloroethane	1.0	U
127-18-4	Tetrachloroethene	1.0	U
71-55-6	1,1,1-Trichloroethane	1.0	U
79-00-5	1,1,2-Trichloroethane	1.0	U

PARSONS ENGINEERING SCIENCE, INC.

Lab Name:QUANTERRA

SDG Number:

Matrix: (soil/water) WATER

Lab Sample ID:A6I030147 010

Method: SW846 8010B
Volatile Organics (8010B)

Sample WT/Vol: 5 / mL
Work Order: C5JK510E
Dilution factor: 1

Date Received: 08/31/96
Date Extracted:09/09/96
Date Analyzed: 09/09/96

QC Batch: 6254173

Client Sample Id: MW026S

CAS NO.	COMPOUND	CONCENTRATION UNITS: (ug/L or ug/kg) ug/L	Q
79-01-6	Trichloroethene	1.0	U
75-69-4	Trichlorofluoromethane	1.0	U
96-18-4	1,2,3-Trichloropropane	1.0	U
75-01-4	Vinyl chloride	1.0	U
156-59-2	cis-1,2-Dichloroethene	1.0	U

PARSONS ENGINEERING SCIENCE, INC.

Lab Name: QUANTERRA

Matrix: (soil/water) WATER
Method: SW846 8010B
Volatile Organics (8010B)

Sample WT/Vol: 5 / mL
Work Order: C5JK6101
Dilution factor: 1

Client Sample Id: TB-1

SDG Number:

Lab Sample ID: A6I030147 011

Date Received: 08/31/96
Date Extracted: 09/09/96
Date Analyzed: 09/09/96

QC Batch: 6254173

CAS NO.	COMPOUND	CONCENTRATION UNITS: (ug/L or ug/kg) ug/L	Q
108-86-1	Bromobenzene	1.0	U
75-27-4	Bromodichloromethane	1.0	U
75-25-2	Bromoform	1.0	U
74-83-9	Bromomethane	1.0	U
56-23-5	Carbon tetrachloride	1.0	U
108-90-7	Chlorobenzene	1.0	U
75-00-3	Chloroethane	1.0	U
110-75-8	2-Chloroethyl vinyl ether	5.0	U
67-66-3	Chloroform	1.0	U
74-87-3	Chloromethane	1.0	U
124-48-1	Dibromochloromethane	1.0	U
74-95-3	Dibromomethane	1.0	U
95-50-1	1,2-Dichlorobenzene	1.0	U
541-73-1	1,3-Dichlorobenzene	1.0	U
106-46-7	1,4-Dichlorobenzene	1.0	U
75-71-8	Dichlorodifluoromethane	1.0	U
75-34-3	1,1-Dichloroethane	1.0	U
107-06-2	1,2-Dichloroethane	1.0	U
75-35-4	1,1-Dichloroethene	1.0	U
156-60-5	trans-1,2-Dichloroethene	1.0	U
75-09-2	Dichloromethane	5.0	U
78-87-5	1,2-Dichloropropane	1.0	U
10061-01-5	cis-1,3-Dichloropropene	1.0	U
10061-02-6	trans-1,3-Dichloropropene	1.0	U
79-34-5	1,1,2,2-Tetrachloroethane	1.0	U
630-20-6	1,1,1,2-Tetrachloroethane	1.0	U
127-18-4	Tetrachloroethene	1.0	U
71-55-6	1,1,1-Trichloroethane	1.0	U
79-00-5	1,1,2-Trichloroethane	1.0	U

PARSONS ENGINEERING SCIENCE, INC.

Lab Name:QUANTERRA

SDG Number:

Matrix: (soil/water) WATER
Method: SW846 8010B
Volatile Organics (8010B)

Lab Sample ID:A6I030147 011

Sample WT/Vol: 5 / mL
Work Order: C5JK6101
Dilution factor: 1

Date Received: 08/31/96
Date Extracted:09/09/96
Date Analyzed: 09/09/96

QC Batch: 6254173

Client Sample Id: TB-1

CAS NO.	COMPOUND	CONCENTRATION UNITS: (ug/L or ug/kg) ug/L	Q
79-01-6	Trichloroethene	1.0	U
75-69-4	Trichlorofluoromethane	1.0	U
96-18-4	1,2,3-Trichloropropane	1.0	U
75-01-4	Vinyl chloride	1.0	U
156-59-2	cis-1,2-Dichloroethene	1.0	U

FORM I

GC VOLATILE SAMPLE DATA

8020

PARSONS ENGINEERING SCIENCE, INC.

Lab Name: QUANTERRA

SDG Number:

Matrix: (soil/water) WATER

Lab Sample ID: A6I030147 001

Method: SW846 8020A
Volatile Organics (8020A)

Sample WT/Vol: 5 / mL
Work Order: C5JJC10F
Dilution factor: 1

Date Received: 08/31/96
Date Extracted: 09/10/96
Date Analyzed: 09/10/96

QC Batch: 6255186

Client Sample Id: MW024

CAS NO.	COMPOUND	CONCENTRATION UNITS: (ug/L or ug/kg) ug/L	Q
71-43-2	**Benzene**	**1.1**	
108-90-7	Chlorobenzene	1.0	U
95-50-1	1,2-Dichlorobenzene	1.0	U
541-73-1	1,3-Dichlorobenzene	1.0	U
106-46-7	1,4-Dichlorobenzene	1.0	U
100-41-4	Ethylbenzene	1.0	U
108-88-3	Toluene	1.0	U
1330-20-7	Xylenes (total)	1.0	U

FORM I

PARSONS ENGINEERING SCIENCE, INC.

Lab Name:QUANTERRA

SDG Number:

Matrix: (soil/water) WATER

Lab Sample ID:A6I030147 002

Method: SW846 8020A
Volatile Organics (8020A)

Sample WT/Vol: 5 / mL
Work Order: C5JJE10F
Dilution factor: 1

Date Received: 08/31/96
Date Extracted:09/10/96
Date Analyzed: 09/10/96

QC Batch: 6255186

Client Sample Id: MW026D

CAS NO.	COMPOUND	CONCENTRATION UNITS: (ug/L or ug/kg) ug/L	Q
71-43-2	**Benzene**	**1.2**	
108-90-7	Chlorobenzene	1.0	U
95-50-1	1,2-Dichlorobenzene	1.0	U
541-73-1	1,3-Dichlorobenzene	1.0	U
106-46-7	1,4-Dichlorobenzene	1.0	U
100-41-4	Ethylbenzene	1.0	U
108-88-3	Toluene	1.0	U
1330-20-7	Xylenes (total)	1.0	U

FORM I

PARSONS ENGINEERING SCIENCE, INC.

Lab Name:QUANTERRA	SDG Number:
Matrix: (soil/water) WATER Method: SW846 8020A Volatile Organics (8020A)	Lab Sample ID:A6I030147 003
Sample WT/Vol: 5 / mL Work Order: C5JJF10F Dilution factor: 50	Date Received: 08/31/96 Date Extracted:09/10/96 Date Analyzed: 09/10/96
	QC Batch: 6255186
Client Sample Id: MW022	

CAS NO.	COMPOUND	CONCENTRATION UNITS: (ug/L or ug/kg) ug/L	Q
71-43-2	Benzene	50	U
108-90-7	Chlorobenzene	50	U
95-50-1	1,2-Dichlorobenzene	50	U
541-73-1	1,3-Dichlorobenzene	50	U
106-46-7	1,4-Dichlorobenzene	50	U
100-41-4	**Ethylbenzene**	**280**	
108-88-3	**Toluene**	**100**	
1330-20-7	**Xylenes (total)**	**3900**	

PARSONS ENGINEERING SCIENCE, INC.

Lab Name:QUANTERRA	SDG Number:
Matrix: (soil/water) WATER Method: SW846 8020A Volatile Organics (8020A)	Lab Sample ID:A6I030147 004
Sample WT/Vol: 5 / mL Work Order: C5JJG10F Dilution factor: 1	Date Received: 08/31/96 Date Extracted:09/10/96 Date Analyzed: 09/10/96
Client Sample Id: MW014	QC Batch: 6255186

CAS NO.	COMPOUND	CONCENTRATION UNITS: (ug/L or ug/kg) ug/L	Q
71-43-2	Benzene	1.0	U
108-90-7	Chlorobenzene	1.0	U
95-50-1	1,2-Dichlorobenzene	1.0	U
541-73-1	1,3-Dichlorobenzene	1.0	U
106-46-7	1,4-Dichlorobenzene	1.0	U
100-41-4	Ethylbenzene	1.0	U
108-88-3	**Toluene**	**1.1**	
1330-20-7	**Xylenes (total)**	**1.0**	

FORM I

PARSONS ENGINEERING SCIENCE, INC.

Lab Name:QUANTERRA

SDG Number:

Matrix: (soil/water) WATER
Method: SW846 8020A
Volatile Organics (8020A)

Lab Sample ID:A6I030147 005

Sample WT/Vol: 5 / mL
Work Order: C5JJH11A
Dilution factor: 1

Date Received: 08/31/96
Date Extracted:09/10/96
Date Analyzed: 09/10/96

QC Batch: 6255186

Client Sample Id: MW003A (MS/MSD)

CAS NO.	COMPOUND	CONCENTRATION UNITS: (ug/L or ug/kg) ug/L	Q
71-43-2	**Benzene**	**1.6**	
108-90-7	Chlorobenzene	1.0	U
95-50-1	1,2-Dichlorobenzene	1.0	U
541-73-1	1,3-Dichlorobenzene	1.0	U
106-46-7	1,4-Dichlorobenzene	1.0	U
100-41-4	Ethylbenzene	1.0	U
108-88-3	**Toluene**	**1.0**	
1330-20-7	Xylenes (total)	1.0	U

FORM I

Lab Name: QUANTERRA

SDG Number:

Matrix: (soil/water) WATER
Method: SW846 8020A
Volatile Organics (8020A)

Lab Sample ID: A6I030147 006

Sample WT/Vol: 5 / mL
Work Order: C5JJR10F
Dilution factor: 1

Date Received: 08/31/96
Date Extracted: 09/10/96
Date Analyzed: 09/10/96

QC Batch: 6255186

Client Sample Id: MW003D

CAS NO.	COMPOUND	CONCENTRATION UNITS: (ug/L or ug/kg) ug/L	Q
71-43-2	**Benzene**	**1.6**	
108-90-7	Chlorobenzene	1.0	U
95-50-1	1,2-Dichlorobenzene	1.0	U
541-73-1	1,3-Dichlorobenzene	1.0	U
106-46-7	1,4-Dichlorobenzene	1.0	U
100-41-4	Ethylbenzene	1.0	U
108-88-3	Toluene	1.0	U
1330-20-7	Xylenes (total)	1.0	U

PARSONS ENGINEERING SCIENCE, INC.

Lab Name:QUANTERRA

SDG Number:

Matrix: (soil/water) WATER

Lab Sample ID:A6I030147 007

Method: SW846 8020A
Volatile Organics (8020A)

Sample WT/Vol: 5 / mL
Work Order: C5JJX10F
Dilution factor: 1

Date Received: 08/31/96
Date Extracted:09/10/96
Date Analyzed: 09/10/96

QC Batch: 6255186

Client Sample Id: MW003S

CAS NO.	COMPOUND	CONCENTRATION UNITS: (ug/L or ug/kg) ug/L	Q
71-43-2	Benzene	1.0	U
108-90-7	Chlorobenzene	1.0	U
95-50-1	1,2-Dichlorobenzene	1.0	U
541-73-1	1,3-Dichlorobenzene	1.0	U
106-46-7	1,4-Dichlorobenzene	1.0	U
100-41-4	Ethylbenzene	1.0	U
108-88-3	Toluene	1.0	U
1330-20-7	Xylenes (total)	1.0	U

FORM I

PARSONS ENGINEERING SCIENCE, INC.

Lab Name: QUANTERRA

SDG Number:

Matrix: (soil/water) WATER

Method: SW846 8020A
Volatile Organics (8020A)

Lab Sample ID: A6I030147 008

Sample WT/Vol: 5 / mL

Work Order: C5JK310F

Dilution factor: 1

Date Received: 08/31/96

Date Extracted: 09/10/96

Date Analyzed: 09/10/96

QC Batch: 6255186

Client Sample Id: MW017

CAS NO.	COMPOUND	CONCENTRATION UNITS: (ug/L or ug/kg) ug/L	Q
71-43-2	Benzene	1.0	U
108-90-7	Chlorobenzene	1.0	U
95-50-1	1,2-Dichlorobenzene	1.0	U
541-73-1	1,3-Dichlorobenzene	1.0	U
106-46-7	1,4-Dichlorobenzene	1.0	U
100-41-4	Ethylbenzene	1.0	U
108-88-3	Toluene	1.0	U
1330-20-7	Xylenes (total)	1.0	U

FORM I

PARSONS ENGINEERING SCIENCE, INC.

Lab Name:QUANTERRA

SDG Number:

Matrix: (soil/water) WATER

Method: SW846 8020A

Volatile Organics (8020A)

Lab Sample ID:A6I030147 009

Sample WT/Vol: 5 / mL

Work Order: C5JK410F

Dilution factor: 1

Date Received: 08/31/96

Date Extracted:09/10/96

Date Analyzed: 09/10/96

QC Batch: 6255186

Client Sample Id: MW016

CAS NO.	COMPOUND	CONCENTRATION UNITS: (ug/L or ug/kg) ug/L	Q
71-43-2	Benzene	1.0	U
108-90-7	Chlorobenzene	1.0	U
95-50-1	1,2-Dichlorobenzene	1.0	U
541-73-1	1,3-Dichlorobenzene	1.0	U
106-46-7	1,4-Dichlorobenzene	1.0	U
100-41-4	Ethylbenzene	1.0	U
108-88-3	**Toluene**	**1.1**	
1330-20-7	Xylenes (total)	1.0	U

PARSONS ENGINEERING SCIENCE, INC.

Lab Name: QUANTERRA

SDG Number:

Matrix: (soil/water) WATER

Lab Sample ID: A6I030147 011

Method: SW846 8020A
Volatile Organics (8020A)

Sample WT/Vol: 5 / mL

Work Order: C5JK6102

Dilution factor: 1

Date Received: 08/31/96

Date Extracted: 09/11/96

Date Analyzed: 09/11/96

QC Batch: 6255186

Client Sample Id: TB-1

CAS NO.	COMPOUND	CONCENTRATION UNITS: (ug/L or ug/kg) ug/L	Q
71-43-2	Benzene	1.0	U
108-90-7	Chlorobenzene	1.0	U
95-50-1	1,2-Dichlorobenzene	1.0	U
541-73-1	1,3-Dichlorobenzene	1.0	U
106-46-7	1,4-Dichlorobenzene	1.0	U
100-41-4	Ethylbenzene	1.0	U
108-88-3	Toluene	1.0	U
1330-20-7	Xylenes (total)	1.0	U

INORGANIC SAMPLE DATA

PARSONS ENGINEERING SCIENCE, INC.

Client Sample ID: MW024

DISSOLVED Metals

Lot-Sample #.: A6I030147 - 001 **Work Order #.:** C5JJC **Matrix.......:** WATER
Date Sampled.: 08/30/96 13:00 **Date Received:** 08/31/96

PARAMETER	RESULT	REPORTING LIMIT	UNITS	METHOD	PREPARATION-ANALYSIS DATE	PREP BATCH #
Iron	8.6	0.10	mg/L	SW846 6010A	09/10/96	6254113
		Dilution Fact: 1				
Manganese	3.7	0.015	mg/L	SW846 6010A	09/10/96	6254113
		Dilution Fact: 1				

PARSONS ENGINEERING SCIENCE, INC.

Client Sample ID: MW024

TOTAL Metals

Lot-Sample #.: A6I030147 - 001	**Work Order #.:** C5JJC	**Matrix.......:** WATER
Date Sampled.: 08/30/96 13:00	**Date Received:** 08/31/96	

PARAMETER	RESULT	REPORTING LIMIT	UNITS	METHOD	PREPARATION-ANALYSIS DATE	PREP BATCH #
Iron	**57.5**	0.10	mg/L	SW846 6010A	09/10/96	6254113
		Dilution Fact: 1				
Manganese	**4.8**	0.015	mg/L	SW846 6010A	09/10/96	6254113
		Dilution Fact: 1				

PARSONS ENGINEERING SCIENCE, INC.

Client Sample ID: MW026D

DISSOLVED Metals

Lot-Sample #.: A6I030147 - 002
Date Sampled.: 08/30/96 14:00
Work Order #.: C5JJE
Date Received: 08/31/96
Matrix.......: WATER

PARAMETER	RESULT	REPORTING LIMIT	UNITS	METHOD	PREPARATION-ANALYSIS DATE	PREP BATCH #
Iron	0.10	0.10 Dilution Fact: 1	mg/L	SW846 6010A	09/10/96	6254113
Manganese	0.19	0.015 Dilution Fact: 1	mg/L	SW846 6010A	09/10/96	6254113

Client Sample ID: MW026D

TOTAL Metals

Lot-Sample #.: A6I030147 - 002 **Work Order #.:** C5JJE **Matrix.......:** WATER
Date Sampled.: 08/30/96 14:00 **Date Received:** 08/31/96

PARAMETER	RESULT	REPORTING LIMIT	UNITS	METHOD	PREPARATION-ANALYSIS DATE	PREP BATCH #
Iron	0.56	0.10	mg/L	SW846 6010A	09/10/96	6254113
		Dilution Fact: 1				
Manganese	0.21	0.015	mg/L	SW846 6010A	09/10/96	6254113
		Dilution Fact: 1				

PARSONS ENGINEERING SCIENCE, INC.

Client Sample ID: MW022

DISSOLVED Metals

Lot-Sample #.: A6I030147 - 003
Date Sampled.: 08/30/96 13:00
Work Order #.: C5JJF
Date Received: 08/31/96
Matrix.......: WATER

PARAMETER	RESULT	REPORTING LIMIT	UNITS	METHOD	PREPARATION-ANALYSIS DATE	PREP BATCH #
Iron	0.11	0.10 Dilution Fact: 1	mg/L	SW846 6010A	09/10-09/11/96	6254113
Manganese	3.0	0.015 Dilution Fact: 1	mg/L	SW846 6010A	09/10-09/11/96	6254113

PARSONS ENGINEERING SCIENCE, INC.

Client Sample ID: MW022

TOTAL Metals

Lot-Sample #.:	A6I030147 - 003	**Work Order #.:**	C5JJF	**Matrix.......:**	WATER
Date Sampled.:	08/30/96 13:00	**Date Received:**	08/31/96		

PARAMETER	RESULT	REPORTING LIMIT	UNITS	METHOD	PREPARATION-ANALYSIS DATE	PREP BATCH #
Iron	34.6	0.10	mg/L	SW846 6010A	09/10/96	6254113
		Dilution Fact: 1				
Manganese	3.2	0.015	mg/L	SW846 6010A	09/10/96	6254113
		Dilution Fact: 1				

PARSONS ENGINEERING SCIENCE, INC.

Client Sample ID: MW014

DISSOLVED Metals

Lot-Sample #.: A6I030147 - 004
Work Order #.: C5JJG
Matrix.......: WATER
Date Sampled.: 08/30/96 09:30
Date Received: 08/31/96

PARAMETER	RESULT	REPORTING LIMIT	UNITS	METHOD	PREPARATION-ANALYSIS DATE	PREP BATCH #
Iron	ND	0.10	mg/L	SW846 6010A	09/10-09/11/96	6254113
		Dilution Fact: 1				
Manganese	**0.059**	**0.015**	**mg/L**	**SW846 6010A**	**09/10-09/11/96**	**6254113**
		Dilution Fact: 1				

PARSONS ENGINEERING SCIENCE, INC.

Client Sample ID: MW014

TOTAL Metals

Lot-Sample #.: A6I030147 - 004 **Work Order #.:** C5JJG **Matrix.......:** WATER
Date Sampled.: 08/30/96 09:30 **Date Received:** 08/31/96

PARAMETER	RESULT	REPORTING LIMIT	UNITS	METHOD	PREPARATION-ANALYSIS DATE	PREP BATCH #
Iron	87.8	0.10	mg/L	SW846 6010A	09/10-09/11/96	6254113
		Dilution Fact: 1				
Manganese	1.7	0.015	mg/L	SW846 6010A	09/10-09/11/96	6254113
		Dilution Fact: 1				

PARSONS ENGINEERING SCIENCE, INC.

Client Sample ID: MW003A (MS/MSD)

DISSOLVED Metals

Lot-Sample #.: A6I030147 - 005 **Work Order #.:** C5JJH **Matrix.......:** WATER
Date Sampled.: 08/30/96 11:00 **Date Received:** 08/31/96

PARAMETER	RESULT	REPORTING LIMIT	UNITS	METHOD	PREPARATION-ANALYSIS DATE	PREP BATCH #
Iron	ND	0.10	mg/L	SW846 6010A	09/10-09/11/96	6254113
		Dilution Fact: 1				
Manganese	**0.051**	**0.015**	**mg/L**	**SW846 6010A**	**09/10-09/11/96**	**6254113**
		Dilution Fact: 1				

PARSONS ENGINEERING SCIENCE, INC.

Client Sample ID: MW003A (MS/MSD)

TOTAL Metals

Lot-Sample #.: A6I030147 - 005 **Work Order #.:** C5JJH **Matrix.......:** WATER
Date Sampled.: 08/30/96 11:00 **Date Received:** 08/31/96

PARAMETER	RESULT	REPORTING LIMIT	UNITS	METHOD	PREPARATION-ANALYSIS DATE	PREP BATCH #
Iron	0.42	0.10	mg/L	SW846 6010A	09/10-09/11/96	6254113
		Dilution Fact: 1				
Manganese	0.055	0.015	mg/L	SW846 6010A	09/10-09/11/96	6254113
		Dilution Fact: 1				

PARSONS ENGINEERING SCIENCE, INC.

Client Sample ID: MW003D

DISSOLVED Metals

Lot-Sample #.: A6I030147 - 006　**Work Order #.:** C5JJR　**Matrix.......:** WATER
Date Sampled.: 08/30/96 10:10　**Date Received:** 08/31/96

PARAMETER	RESULT	REPORTING LIMIT	UNITS	METHOD	PREPARATION-ANALYSIS DATE	PREP BATCH #
Iron	ND	0.10	mg/L	SW846 6010A	09/10-09/11/96	6254113
		Dilution Fact: 1				
Manganese	**0.044**	**0.015**	**mg/L**	**SW846 6010A**	**09/10-09/11/96**	**6254113**
		Dilution Fact: 1				

PARSONS ENGINEERING SCIENCE, INC.

Client Sample ID: MW003D

TOTAL Metals

Lot-Sample #.: A6I030147 - 006
Work Order #.: C5JJR
Matrix.......: WATER
Date Sampled.: 08/30/96 10:10
Date Received: 08/31/96

PARAMETER	RESULT	REPORTING LIMIT	UNITS	METHOD	PREPARATION-ANALYSIS DATE	PREP BATCH #
Iron	0.37	0.10 Dilution Fact: 1	mg/L	SW846 6010A	09/10-09/11/96	6254113
Manganese	0.075	0.015 Dilution Fact: 1	mg/L	SW846 6010A	09/10-09/11/96	6254113

PARSONS ENGINEERING SCIENCE, INC.

Client Sample ID: MW003S

DISSOLVED Metals

Lot-Sample #.: A6I030147 - 007
Work Order #.: C5JJX
Matrix.......: WATER
Date Sampled.: 08/30/96 11:30
Date Received: 08/31/96

PARAMETER	RESULT	REPORTING LIMIT	UNITS	METHOD	PREPARATION-ANALYSIS DATE	PREP BATCH #
Iron	2.0	0.10	mg/L	SW846 6010A	09/10-09/11/96	6254113
		Dilution Fact: 1				
Manganese	1.8	0.015	mg/L	SW846 6010A	09/10-09/11/96	6254113
		Dilution Fact: 1				

PARSONS ENGINEERING SCIENCE, INC.

Client Sample ID: MW003S

TOTAL Metals

Lot-Sample #.: A6I030147 - 007
Date Sampled.: 08/30/96 11:30
Work Order #.: C5JJX
Date Received: 08/31/96
Matrix.......: WATER

PARAMETER	RESULT	REPORTING LIMIT	UNITS	METHOD	PREPARATION-ANALYSIS DATE	PREP BATCH #
Iron	25.7	0.10 Dilution Fact: 1	mg/L	SW846 6010A	09/10-09/11/96	6254113
Manganese	2.5	0.015 Dilution Fact: 1	mg/L	SW846 6010A	09/10-09/11/96	6254113

PARSONS ENGINEERING SCIENCE, INC.

Client Sample ID: MW017

DISSOLVED Metals

Lot-Sample #.: A6I030147 - 008
Work Order #.: C5JK3
Matrix.......: WATER
Date Sampled.: 08/30/96 15:30
Date Received: 08/31/96

PARAMETER	RESULT	REPORTING LIMIT	UNITS	METHOD	PREPARATION-ANALYSIS DATE	PREP BATCH #
Iron	17.2	0.10	mg/L	SW846 6010A	09/10-09/11/96	6254113
		Dilution Fact: 1				
Manganese	9.0	0.015	mg/L	SW846 6010A	09/10-09/11/96	6254113
		Dilution Fact: 1				

PARSONS ENGINEERING SCIENCE, INC.

Client Sample ID: MW017

TOTAL Metals

Lot-Sample #.: A6I030147 - 008 **Work Order #.:** C5JK3 **Matrix.......:** WATER
Date Sampled.: 08/30/96 15:30 **Date Received:** 08/31/96

PARAMETER	RESULT	REPORTING LIMIT	UNITS	METHOD	PREPARATION-ANALYSIS DATE	PREP BATCH #
Iron	103	0.10	mg/L	SW846 6010A	09/10-09/11/96	6254113
		Dilution Fact: 1				
Manganese	3.2	0.015	mg/L	SW846 6010A	09/10-09/11/96	6254113
		Dilution Fact: 1				

PARSONS ENGINEERING SCIENCE, INC.

Client Sample ID: MW016

DISSOLVED Metals

Lot-Sample #.: A6I030147 - 009 **Work Order #.:** C5JK4 **Matrix.......:** WATER
Date Sampled.: 08/30/96 15:00 **Date Received:** 08/31/96

PARAMETER	RESULT	REPORTING LIMIT	UNITS	METHOD	PREPARATION-ANALYSIS DATE	PREP BATCH #
Iron	ND	0.10	mg/L	SW846 6010A	09/10-09/11/96	6254113
		Dilution Fact: 1				
Manganese	**0.087**	**0.015**	**mg/L**	**SW846 6010A**	**09/10-09/11/96**	**6254113**
		Dilution Fact: 1				

PARSONS ENGINEERING SCIENCE, INC.

Client Sample ID: MW016

TOTAL Metals

Lot-Sample #.: A6I030147 - 009 **Work Order #.:** C5JK4 **Matrix.......:** WATER
Date Sampled.: 08/30/96 15:00 **Date Received:** 08/31/96

PARAMETER	RESULT	REPORTING LIMIT	UNITS	METHOD	PREPARATION- ANALYSIS DATE	PREP BATCH #
Iron	319	0.10	mg/L	SW846 6010A	09/10-09/11/96	6254113
		Dilution Fact: 1				
Manganese	16.3	0.015	mg/L	SW846 6010A	09/10-09/11/96	6254113
		Dilution Fact: 1				

PARSONS ENGINEERING SCIENCE, INC.

Client Sample ID: MW026S

DISSOLVED Metals

Lot-Sample #.: A6I030147 - 010	**Work Order #.:** C5JK5	**Matrix.......:** WATER
Date Sampled.: 08/30/96 14:30	**Date Received:** 08/31/96	

PARAMETER	RESULT	REPORTING LIMIT	UNITS	METHOD	PREPARATION-ANALYSIS DATE	PREP BATCH #
Iron	8.9	0.10	mg/L	SW846 6010A	09/10-09/11/96	6254113
		Dilution Fact: 1				
Manganese	4.9	0.015	mg/L	SW846 6010A	09/10-09/11/96	6254113
		Dilution Fact: 1				

PARSONS ENGINEERING SCIENCE, INC.

Client Sample ID: MW026S

TOTAL Metals

Lot-Sample #.: A6I030147 - 010 **Work Order #.:** C5JK5 **Matrix.......:** WATER
Date Sampled.: 08/30/96 14:30 **Date Received:** 08/31/96

PARAMETER	RESULT	REPORTING LIMIT	UNITS	METHOD	PREPARATION- ANALYSIS DATE	PREP BATCH #
Iron	163	0.10	mg/L	SW846 6010A	09/10-09/11/96	6254113
		Dilution Fact: 1				
Manganese	8.9	0.015	mg/L	SW846 6010A	09/10-09/11/96	6254113
		Dilution Fact: 1				

WET CHEMISTRY SAMPLE DATA

PARSONS ENGINEERING SCIENCE, INC.

Client Sample ID: MW024

General Chemistry

Lot-Sample #.: A6I030147 - 001 **Work Order #.:** C5JJC **Matrix.......:** WATER
Date Sampled.: 08/30/96 13:00 **Date Received:** 08/31/96

PARAMETER	RESULT	RL	UNITS	METHOD	PREPARATION-ANALYSIS DATE	PREP BATCH #
Chloride - Automated	**140**	**2**	**mg/L**	**MCAWW 325.2**	**09/09/96**	**6253213**
		DIL Factor...: 2				
Nitrate	ND	0.1	mg/L	MCAWW 353.2	08/31/96	6248130
		DIL Factor...: 1				
Nitrite	ND	0.1	mg/L	MCAWW 353.2	08/31/96	6248131
		DIL Factor...: 1				
Total Sulfide	ND	0.50	mg/L	MCAWW 376.1	09/05/96	6249217
		DIL Factor...: 1				
Total Organic Carbon	**43**	**1**	**mg/L**	**MCAWW 415.1**	**09/11/96**	**6255199**
		DIL Factor...: 1				
Oxidation Reduction Potential	**-50**	**--**	**mV**	**ASTM D 1498-93**	**09/11/96**	**6257138**
		DIL Factor...: 1				
Sulfate	ND	5	mg/L	MCAWW 375.4	09/12/96	6256244
		DIL Factor...: 1				
Total Alkalinity	**660**	**5.0**	**mg/L**	**MCAWW 310.1**	**09/12/96**	**6256255**
		DIL Factor...: 1				

PARSONS ENGINEERING SCIENCE, INC.

Client Sample ID: MW026D

General Chemistry

Lot-Sample #.: A6I030147 - 002 **Work Order #.:** C5JJE **Matrix.......:** WATER
Date Sampled.: 08/30/96 14:00 **Date Received:** 08/31/96

PARAMETER	RESULT	RL	UNITS	METHOD	PREPARATION-ANALYSIS DATE	PREP BATCH #
Chloride - Automated	**150**	**2**	**mg/L**	**MCAWW 325.2**	**09/09/96**	**6253213**
		DIL Factor...: 2				
Nitrate	ND	0.1	mg/L	MCAWW 353.2	08/31/96	6248130
		DIL Factor...: 1				
Nitrite	ND	0.1	mg/L	MCAWW 353.2	08/31/96	6248131
		DIL Factor...: 1				
Total Sulfide	ND	0.50	mg/L	MCAWW 376.1	09/05/96	6249217
		DIL Factor...: 1				
Total Organic Carbon	**6**	**1**	**mg/L**	**MCAWW 415.1**	**09/11/96**	**6255199**
		DIL Factor...: 1				
Oxidation Reduction Potential	**40**	**--**	**mV**	**ASTM D 1498-93**	**09/11/96**	**6257138**
		DIL Factor...: 1				
Sulfate	**30**	**20**	**mg/L**	**MCAWW 375.4**	**09/12/96**	**6256244**
		DIL Factor...: 4				
Total Alkalinity	**350**	**5.0**	**mg/L**	**MCAWW 310.1**	**09/12/96**	**6256255**
		DIL Factor...: 1				

PARSONS ENGINEERING SCIENCE, INC.

Client Sample ID: MW022

General Chemistry

Lot-Sample #.: A6I030147 - 003 **Work Order #.:** C5JJF **Matrix.......:** WATER
Date Sampled.: 08/30/96 13:00 **Date Received:** 08/31/96

PARAMETER	RESULT	RL	UNITS	METHOD	PREPARATION-ANALYSIS DATE	PREP BATCH #
Chloride - Automated	**420**	5	**mg/L**	**MCAWW** 325.2	**09/09/96**	**6253230**
		DIL Factor...: 5				
Nitrate	**2.0**	0.2	**mg/L**	**MCAWW** 353.2	**08/31/96**	**6248130**
		DIL Factor...: 2				
Nitrite	**0.7**	0.2	**mg/L**	**MCAWW** 353.2	**08/31/96**	**6248131**
		DIL Factor...: 2				
Total Sulfide	ND	0.50	mg/L	MCAWW 376.1	09/05/96	6249217
		DIL Factor...: 1				
Total Organic Carbon	**6**	1	**mg/L**	**MCAWW 415.1**	**09/11/96**	**6255199**
		DIL Factor...: 1				
Oxidation Reduction Potential	**60**	--	**mV**	**ASTM D 1498-93**	**09/11/96**	**6257138**
		DIL Factor...: 1				
Sulfate	**42**	25	**mg/L**	**MCAWW 375.4**	**09/12/96**	**6256244**
		DIL Factor...: 5				
Total Alkalinity	**150**	5.0	**mg/L**	**MCAWW** 310.1	**09/12/96**	**6256255**
		DIL Factor...: 1				

PARSONS ENGINEERING SCIENCE, INC.

Client Sample ID: MW014

General Chemistry

Lot-Sample #.: A6I030147 - 004 **Work Order #.:** C5JJG **Matrix.......:** WATER
Date Sampled.: 08/30/96 09:30 **Date Received:** 08/31/96

PARAMETER	RESULT	RL	UNITS	METHOD	PREPARATION-ANALYSIS DATE	PREP BATCH #
Chloride - Automated	**29**	**1**	**mg/L**	**MCAWW 325.2**	**09/09/96**	**6253213**
		DIL Factor...: 1				
Nitrate	ND	0.1	mg/L	MCAWW 353.2	08/31/96	6248130
		DIL Factor...: 1				
Nitrite	ND	0.1	mg/L	MCAWW 353.2	08/31/96	6248131
		DIL Factor...: 1				
Total Sulfide	**0.88**	**0.50**	**mg/L**	**MCAWW 376.1**	**09/05/96**	**6249217**
		DIL Factor...: 1				
Total Organic Carbon	**1**	**1**	**mg/L**	**MCAWW 415.1**	**09/11/96**	**6255199**
		DIL Factor...: 1				
Oxidation Reduction Potential	**40**	**--**	**mV**	**ASTM D 1498-93**	**09/11/96**	**6257138**
		DIL Factor...: 1				
Sulfate	**350**	**250**	**mg/L**	**MCAWW 375.4**	**09/12/96**	**6256244**
		DIL Factor...: 50				
Total Alkalinity	**320**	**25**	**mg/L**	**MCAWW 310.1**	**09/12/96**	**6256255**
		DIL Factor...: 5				

PARSONS ENGINEERING SCIENCE, INC.

Client Sample ID: MW003A (MS/MSD)

General Chemistry

Lot-Sample #.: A6I030147 - 005 **Work Order #.:** C5JJH **Matrix.......:** WATER
Date Sampled.: 08/30/96 11:00 **Date Received:** 08/31/96

PARAMETER	RESULT	RL	UNITS	METHOD	PREPARATION-ANALYSIS DATE	PREP BATCH #
Chloride - Automated	**320**	**5**	**mg/L**	**MCAWW 325.2**	**09/09/96**	**6253213**
		DIL Factor...: 5				
Nitrate	**1.5**	**0.2**	**mg/L**	**MCAWW 353.2**	**08/31/96**	**6248130**
		DIL Factor...: 2				
Nitrite	ND	0.1	mg/L	MCAWW 353.2	08/31/96	6248131
		DIL Factor...: 1				
Total Sulfide	ND	0.50	mg/L	MCAWW 376.1	09/05/96	6249217
		DIL Factor...: 1				
Total Organic Carbon	**3**	**1**	**mg/L**	**MCAWW 415.1**	**09/11/96**	**6255199**
		DIL Factor...: 1				
Oxidation Reduction Potential	**50**	--	**mV**	**ASTM D 1498-93**	**09/11/96**	**6257138**
		DIL Factor...: 1				
Sulfate	**34**	**5**	**mg/L**	**MCAWW 375.4**	**09/12/96**	**6256244**
		DIL Factor...: 1				
Total Alkalinity	**320**	**5.0**	**mg/L**	**MCAWW 310.1**	**09/11/96**	**6255241**
		DIL Factor...: 1				

PARSONS ENGINEERING SCIENCE, INC.

Client Sample ID: MW003D

General Chemistry

Lot-Sample #.: A6I030147 - 006 **Work Order #.:** C5JJR **Matrix.......:** WATER
Date Sampled.: 08/30/96 10:10 **Date Received:** 08/31/96

PARAMETER	RESULT	RL	UNITS	METHOD	PREPARATION-ANALYSIS DATE	PREP BATCH #
Chloride - Automated	320	5	mg/L	MCAWW 325.2	09/09/96	6253230
		DIL Factor...: 5				
Nitrate	1.4	0.1	mg/L	MCAWW 353.2	08/31/96	6248130
		DIL Factor...: 1				
Nitrite	ND	0.1	mg/L	MCAWW 353.2	08/31/96	6248131
		DIL Factor...: 1				
Total Sulfide	ND	0.50	mg/L	MCAWW 376.1	09/05/96	6249217
		DIL Factor...: 1				
Total Organic Carbon	3	1	mg/L	MCAWW 415.1	09/11/96	6255199
		DIL Factor...: 1				
Oxidation Reduction Potential	60	--	mV	ASTM D 1498-93	09/11/96	6257138
		DIL Factor...: 1				
Sulfate	36	5	mg/L	MCAWW 375.4	09/12/96	6256244
		DIL Factor...: 1				
Total Alkalinity	310	5.0	mg/L	MCAWW 310.1	09/12/96	6256255
		DIL Factor...: 1				

PARSONS ENGINEERING SCIENCE, INC.

Client Sample ID: MW003S

General Chemistry

Lot-Sample #.: A6I030147 - 007 **Work Order #.:** C5JJX **Matrix.......:** WATER
Date Sampled.: 08/30/96 11:30 **Date Received:** 08/31/96

PARAMETER	RESULT	RL	UNITS	METHOD	PREPARATION-ANALYSIS DATE	PREP BATCH #
Chloride - Automated	**4**	1	**mg/L**	**MCAWW** 325.2	**09/09/96**	**6253213**
		DIL Factor...: 1				
Nitrate	ND	0.1	mg/L	MCAWW 353.2	08/31/96	6248130
		DIL Factor...: 1				
Nitrite	ND	0.1	mg/L	MCAWW 353.2	08/31/96	6248131
		DIL Factor...: 1				
Total Sulfide	ND	0.50	mg/L	MCAWW 376.1	09/05/96	6249217
		DIL Factor...: 1				
Total Organic Carbon	**5**	1	**mg/L**	**MCAWW 415.1**	**09/11/96**	**6255199**
		DIL Factor...: 1				
Oxidation Reduction Potential	**50**	--	**mV**	**ASTM D 1498-93**	**09/11/96**	**6257138**
		DIL Factor...: 1				
Sulfate	ND G	25	mg/L	MCAWW 375.4	09/12/96	6256244
		DIL Factor...: 5				
Total Alkalinity	**320**	25	**mg/L**	**MCAWW** 310.1	**09/12/96**	**6256255**
		DIL Factor...: 5				

NOTE(S):

RL Reporting Limit

G Elevated reporting limit. The reporting limit is elevated due to matrix interference.

PARSONS ENGINEERING SCIENCE, INC.

Client Sample ID: **MW017**

General Chemistry

Lot-Sample #.: A6I030147 - 008 **Work Order #.:** C5JK3 **Matrix.......:** WATER
Date Sampled.: 08/30/96 15:30 **Date Received:** 08/31/96

PARAMETER	RESULT	RL	UNITS	METHOD	PREPARATION-ANALYSIS DATE	PREP BATCH #
Chloride - Automated	**320**	**5**	**mg/L**	**MCAWW 325.2**	**09/09/96**	**6253230**
		DIL Factor...: 5				
Nitrate	**0.3**	**0.1**	**mg/L**	**MCAWW 353.2**	**08/31/96**	**6248130**
		DIL Factor...: 1				
Nitrite	ND	0.1	mg/L	MCAWW 353.2	08/31/96	6248131
		DIL Factor...: 1				
Total Sulfide	ND	0.50	mg/L	MCAWW 376.1	09/05/96	6249217
		DIL Factor...: 1				
Total Organic Carbon	**8**	**1**	**mg/L**	**MCAWW 415.1**	**09/11/96**	**6255199**
		DIL Factor...: 1				
Oxidation Reduction Potential	**50**	--	**mV**	**ASTM D 1498-93**	**09/11/96**	**6257138**
		DIL Factor...: 1				
Sulfate	ND G	100	mg/L	MCAWW 375.4	09/12/96	6256244
		DIL Factor...: 20				
Total Alkalinity	**410**	**25**	**mg/L**	**MCAWW 310.1**	**09/12/96**	**6256255**
		DIL Factor...: 5				

NOTE(S):

RL Reporting Limit

G Elevated reporting limit. The reporting limit is elevated due to matrix interference.

Client Sample ID: MW016

General Chemistry

Lot-Sample #.: A6I030147 - 009	**Work Order #.:** C5JK4	**Matrix.......:** WATER
Date Sampled.: 08/30/96 15:00	**Date Received:** 08/31/96	

PARAMETER	RESULT	RL	UNITS	METHOD	PREPARATION-ANALYSIS DATE	PREP BATCH #
Chloride - Automated	**83**	**1**	**mg/L**	**MCAWW 325.2**	**09/09/96**	**6253213**
		DIL Factor...: 1				
Nitrate	ND	0.1	mg/L	MCAWW 353.2	08/31/96	6248130
		DIL Factor...: 1				
Nitrite	ND	0.1	mg/L	MCAWW 353.2	08/31/96	6248131
		DIL Factor...: 1				
Total Sulfide	ND	0.50	mg/L	MCAWW 376.1	09/05/96	6249217
		DIL Factor...: 1				
Total Organic Carbon	**43**	**1**	**mg/L**	**MCAWW 415.1**	**09/11/96**	**6255199**
		DIL Factor...: 1				
Oxidation Reduction Potential	**50**	**--**	**mV**	**ASTM D 1498-93**	**09/11/96**	**6257138**
		DIL Factor...: 1				
Sulfate	ND G	50	mg/L	MCAWW 375.4	09/12/96	6256244
		DIL Factor...: 10				
Total Alkalinity	**590**	**25**	**mg/L**	**MCAWW 310.1**	**09/12/96**	**6256255**
		DIL Factor...: 5				

NOTE(S):

RL Reporting Limit

G Elevated reporting limit. The reporting limit is elevated due to matrix interference.

PARSONS ENGINEERING SCIENCE, INC.

Client Sample ID: MW026S

General Chemistry

Lot-Sample #.: A6I030147 - 010	**Work Order #.:** C5JK5	**Matrix.......:** WATER
Date Sampled.: 08/30/96 14:30	**Date Received:** 08/31/96	

PARAMETER	RESULT	RL	UNITS	METHOD	PREPARATION-ANALYSIS DATE	PREP BATCH #
Chloride - Automated	**62**	**1**	**mg/L**	**MCAWW 325.2**	**09/09/96**	**6253213**
		DIL Factor...: 1				
Nitrate	ND	0.1	mg/L	MCAWW 353.2	08/31/96	6248130
		DIL Factor...: 1				
Nitrite	ND	0.1	mg/L	MCAWW 353.2	08/31/96	6248131
		DIL Factor...: 1				
Total Sulfide	ND	0.50	mg/L	MCAWW 376.1	09/05/96	6249217
		DIL Factor...: 1				
Total Organic Carbon	**19**	**1**	**mg/L**	**MCAWW 415.1**	**09/11/96**	**6255199**
		DIL Factor...: 1				
Oxidation Reduction Potential	**50**	**--**	**mV**	**ASTM D 1498-93**	**09/11/96**	**6257138**
		DIL Factor...: 1				
Sulfate	ND G	25	mg/L	MCAWW 375.4	09/12/96	6256244
		DIL Factor...: 5				
Total Alkalinity	**410**	**25**	**mg/L**	**MCAWW 310.1**	**09/12/96**	**6256255**
		DIL Factor...: 5				

NOTE(S):

RL Reporting Limit

G Elevated reporting limit. The reporting limit is elevated due to matrix interference.

ATTACHMENT 2
TO
APPENDIX B

REDOX INFORMATION FOR IMPORTANT MICROBIAL PROCESSES

Electron Donor and Electron Acceptor Half Cell Reactions

HALF-CELL REACTIONS	ΔG°$_r$ (kcal/ equiv)*	ΔG°$_r$ (kJ/ equiv)	E° (V)	Eh (V)	pe	Conditions for Eh and pe §
ELECTRON-ACCEPTOR (REDUCTION) HALF CELL REACTIONS						
$5e^- + 6H^+ + NO_3^- \Rightarrow 0.5N_2 + 3H_2O$ *Denitrification*	-28.7	-120.	+1.24	+0.708	+12.0	pH = 7 $\Sigma[N]=10^{-3}$
$4e^- + 4H^+ + O_2 \Rightarrow 2H_2O$ *Aerobic Respiration*	-28.3	-119.	+1.23	+0.805	+13.6	pH = 7 $P_{O_2}=0.21$ atm
$2e^- + 4H^+ + \underline{MnO_2} \Rightarrow Mn^{2+} + 2H_2O$ *Pyrolusite Dissolution/Reduction*	-28.3	-119	+1.23	+0.550	+9.27	pH = 7 $\Sigma[Mn]=10^{-5}$
$CO_2 + e^- + H^+ + \underline{MnOOH} \Rightarrow MnCO_3 + H_2O$ *a Manganite Carbonation/Reduction*	-23.1	-96.8	+1.00	+0.408	+6.90	pH = 8 $P_{CO_2}=10^{-2}$
$e^- + H^+ + MnO_2 \Rightarrow \underline{MnOOH}$ *Pyrolusite Hydrolysis/Reduction*	-22.1	-92.5	+0.959	+0.545	+9.21	pH = 7
$e^- + 3H^+ + \underline{Fe(OH)_{3,amph.}} \Rightarrow Fe^{2+} + 2H_2O$ *Amorphous "Goethite" Dissolution/Reduction*	-21.5	-89.9	+0.932	+0.163	+2.75	pH = 6 $\Sigma[Fe]=10^{-5}$
$8e^- + 10H^+ + NO^-_3 \Rightarrow NH^+_4 + 3H_2O$ *Nitrate Reduction*	-20.3	-84.9	+0.879	+0.362	+6.12	pH = 7
$2e^- + 2H^+ + NO^-_3 \Rightarrow NO^-_2 + H_2O$ *Nitrate Reduction*	-18.9	-78.9	+0.819	+0.404	+6.82	pH = 7
$e^- + 3H^+ + \underline{FeOOH} \Rightarrow Fe^{2+} + 2H_2O$ *"Ferric oxyhydroxide" Dissolution/Reduction*	-15.0	-62.9	+0.652	-0.118	-1.99	pH = 6 $\Sigma\ [Fe]=10^{-5}$
$e^- + 3H^+ + \underline{Fe(OH)_{3,xline.}} \Rightarrow Fe^{2+} + 3H_2O$ *Crystallized "Goethite" Dissolution/Reduction*	-11.8	-49.2	+0.510	-0.259	-4.38	pH = 6 $\Sigma\ [Fe]=10^{-5}$
$e^- + H^+ + CO_{2,g} + \underline{Fe(OH)_{3,amph.}} \Rightarrow \underline{FeCO_3} + 2H_2O$ *Amorphous "Goethite" Carbonation/Reduction*	-11.0	-46.2	+0.479	-0.113	-1.90	pH = 8 $P_{CO_2}=10^{-2}$ atm
$8e^- + 9H^+ + SO^{2-}_4 \Rightarrow HS^- + 4H_2O$ *Sulfate Reduction*	-5.74	-24.0	+0.249	-0.278	-4.70	pH = 8
$8e^- + 10H^+ + SO^{2-}_4 \Rightarrow H_2S^0 + 4H_2O$ *Sulfate Reduction*	-6.93	-28.9	+0.301	-0.143	-2.42	pH = 6
$C_2Cl_4 + H^+ + 2e^- \Rightarrow C_2HCl_3 + Cl^-$ *PCE Reductive Dechlorination*	-14.79	-61.9	+0.642	+0.553	+9.35	pH = 7 $[Cl-]=10^{-4}$
$C_2HCl_3 + H^+ + 2e^- \Rightarrow C_2H_2Cl_2 + Cl^-$ *TCE Reductive Dechlorination*	-14.50	-60.7	+0.629	+0.540	+9.13	pH = 7 $[Cl-]=10^{-4}$
$C_2H_2Cl_2 + H^+ + 2e^- \Rightarrow C_2H_3Cl + Cl^-$ *c-DCE Reductive Dechlorination*	-12.12	-50.7	+0.526	+0.437	+7.39	pH = 7 $[Cl-]=10^{-4}$
$C_2H_3Cl + H^+ + 2e^- \Rightarrow C_2H_4 + Cl^-$ *VC Reductive Dechlorination*	-13.73	-57.4	+0.595	+0.506	+8.55	pH = 7 $[Cl-]=10^{-4}$
$8e^- + 8H^+ + CO_{2,g} \Rightarrow CH_{4,g} + 2H_2O$ *Methanogenesis*	-3.91	-16.4	+0.169	-0.259	-4.39	pH = 7 $P_{CO_2}=10^{-2}$ $P_{CH_4}=10^{0}$

HALF-CELL REACTIONS	ΔG°_r (kcal/ equiv)*	ΔG°_r (kJ/ equiv)*	E° (V)	Eh (V)	pe	Conditions for Eh and pe §
ELECTRON-DONOR (OXIDATION) HALF CELL REACTIONS						
$12H_20 + C_6H_6 \Rightarrow 6CO_2 + 30H^+ + 30e^-$ *Benzene Oxidation*	+2.83	+11.8	-0.122	+0.316	+5.34	pH = 7 $P_{CO_2}=10^{-2}$
$14H_20 + C_6H_5CH_3 \Rightarrow 7CO_2 + 36H^+ + 36e^-$ *Toluene Oxidation*	+2.96	+12.4	-0.128	+0.309	+5.22	pH = 7 $P_{CO_2}=10^{-2}$
$16H_20 + C_6H_5C_2H_5 \Rightarrow 8CO_2 + 42H^+ + 42e^-$ *Ethylbenzene Oxidation*	+2.96	+12.4	-0.128	+0.309	+5.21	pH = 7 $P_{CO_2}=10^{-2}$
$20H_2O + C_{10}H_8 \Rightarrow 10CO_2 + 48H^+ + 48e^-$ *Naphthalene Oxidation*	+2.98	+12.5	-0.130[a]	+0.309	+5.22	pH = 7 $P_{CO_2}=10^{-2}$
$18H_2O + C_6H_3(CH_3)_3 \Rightarrow 9CO_2 + 48H^+ + 48e^-$ *1,3,5-Trimethylbenzene Oxidation*	+3.07	+12.8	-0.133[a]	+0.303	+5.12	pH = 7 $P_{CO_2}=10^{-2}$
$18H_2O + C_6H_3(CH_3)_3 \Rightarrow 9CO_2 + 48H^+ + 48e^-$ *1,2,4-Trimethylbenzene Oxidation*	+3.07	+12.9	-0.134[a]	+0.302	+5.11	pH = 7 $P_{CO_2}=10^{-2}$
$4H_2O + C_2H_3Cl \Rightarrow 2CO_2 + 11H^+ + 10e^- + Cl^-$ *Vinyl Chloride Oxidation*	-0.55	-2.30	+0.024[a]	-0.455	-7.69	pH = 7 $P_{CO_2}=10^{-2}$
$12H_2O + C_6H_5Cl \Rightarrow 6CO_2 + 29H^+ + 28e^- + Cl^-$ *Chlorobenzene Oxidation*	+2.21	+9.26	-0.096[a]	+0.358	+6.05	pH = 7 $P_{CO_2}=10^{-2}$

NOTES:

[*] = ΔG°_r for half cell reaction as shown divided by the number of electrons involved in reaction.

§ = Conditions assumed for the calculation of Eh and pe (pe = Eh/0.05916). Where two dissolved species are involved, other than those mentioned in this column, their activities are taken as equal. Note, this does not affect the free energy values listed.

[a] = E° calculated using the following equation; $E^\circ = \Delta G^\circ_r\,(J/nF) \cdot 1.0365\times10^{-5}$ (VF/J) from Stumm and Morgan, 1981

Coupled Oxidation Reactions

Coupled Benzene Oxidation Reactions	ΔG°r (kcal/mole Benzene)	ΔG°r (kJ/mole Benzene)	Stoichiometric Mass Ratio of Electron Acceptor to Compound
$7.5 O_2 + C_6H_6 \Rightarrow 6 CO_{2,g} + 3 H_2O$ *Benzene oxidation /aerobic respiration*	-765.34	-3202	3.07:1
$6 NO_3^- + 6 H^+ + C_6H_6 \Rightarrow 6 CO_{2,g} + 6 H_2O + 3 N_{2,g}$ *Benzene oxidation / denitrification*	-775.75	-3245	4.77:1
$30 H^+ + 15 \underline{MnO_2} + C_6H_6 \Rightarrow 6 CO_{2,g} + 15 Mn_2^+ + 18 H_2O$ *Benzene oxidation / manganese reduction*	-765.45	-3202	10.56:1
$3.75 NO_3^- + C_6H_6 + 7.5 H^+ + 0.75 H_2O \Rightarrow 6 CO_2 + 3.75 NH_4^+$ *Benzene oxidation / nitrate reduction*	-524.1	-2193	2.98:1
$60 H^+ + 30 \underline{Fe(OH)_{3,a}} + C_6H_6 \Rightarrow 6 CO_2 + 30 Fe_2^+ + 78 H_2O$ *Benzene oxidation / iron reduction*	-560.10	-2343	21.5:1
$7.5 H^+ + 3.75 SO_4^{2-} + C_6H_6 \Rightarrow 6 CO_{2,g} + 3.75 H_2S^o + 3H_2O$ *Benzene oxidation / sulfate reduction*	-122.93	-514.3	4.61:1
$4.5 H_2O + C_6H_6 \Rightarrow 2.25 CO_{2,g} + 3.75 CH_4$ *Benzene oxidation / methanogenesis*	-32.40	-135.6	0.77:1
$15C_2Cl_4 + 12H_2O + C_6H_6 \Rightarrow 15C_2HCl_3 + 6CO_2 + 15H^+ + 15Cl^-$ *Benzene oxidation/ Tetrachloroethylene reductive dehalogenation*	-358.59	-1500	31.8:1
$15C_2HCl_3 + 12H_2O + C_6H_6 \Rightarrow 15C_2H_2Cl_2 + 6CO_2 + 15H^+ + 15Cl^-$ *Benzene oxidation/ Trichloroethylene reductive dehalogenation*	-350.04	-1465	25.2:1
$15C_2H_2Cl_2 + 12H_2O + C_6H_6 \Rightarrow 15C_2H_3Cl + 6CO_2 + 15H^+ + 15Cl^-$ *Benzene oxidation/ cis-Dichloroethylene reductive dehalogenation*	-278.64	-1166	18.6:1
$15C_2H_3Cl + 12H_2O + C_6H_6 \Rightarrow 15C_2H_4 + 6CO_2 + 15H^+ + 15Cl^-$ *Benzene oxidation/ Vinyl chloride reductive dehalogenation*	-327.37	-1370	11.9:1

Coupled Toluene Oxidation Reactions	ΔG°r (kcal/mole Toluene)	ΔG°r (kJ/mole Toluene)	Stoichiometric Mass Ratio of Electron Acceptor to Compound
$9 O_2 + C_6H_5CH_3 \Rightarrow 7 CO_{2,g} + 4 H_2O$ *Toluene oxidation /aerobic respiration*	-913.76	-3823	3.13:1
$7.2 NO_3^- + 7.2 H^+ + C_6H_5CH_3 \Rightarrow 7 CO_{2,g} + 7.6 H_2O + 3.6 N_{2,g}$ *Toluene oxidation / denitrification*	-926.31	-3875	4.85:1
$36 H^+ + 18 \underline{MnO_2} + C_6H_5CH_3 \Rightarrow 7 CO_{2,g} + 18 Mn^{2+} + 22 H_2O$ *Toluene oxidation / manganese reduction*	-913.89	-3824	10.74:1
$72 H^+ + 36 \underline{Fe(OH)_{3,a}} + C_6H_5CH_3 \Rightarrow 7 CO_2 + 36 Fe^{2+} + 94 H_2O$ *Toluene oxidation / iron reduction*	-667.21	-2792	21.86:1
$9 H^+ + 4.5 SO_4^{2-} + C_6H_5CH_3 \Rightarrow 7 CO_{2,g} + 4.5 H_2S^o + 4 H_2O$ *Toluene oxidation / sulfate reduction*	-142.86	-597.7	4.7:1
$5 H_2O + C_6H_5CH_3 \Rightarrow 2.5 CO_{2,g} + 4.5 CH_4$ *Toluene oxidation / methanogenesis*	-34.08	-142.6	0.78:1
$18C_2Cl_4 + 14H_2O + C_6H_5CH_3 \Rightarrow 18C_2HCl_3 + 7CO_2 + 18H^+ + 18Cl^-$ *Toluene oxidation/ Tetrachloroethylene reductive dehalogenation*	-425.66	-1781	32.4:1
$18C_2HCl_3 + 14H_2O + C_6H_5CH_3 \Rightarrow 18C_2H_2Cl_2 + 7CO_2 + 18H^+ + 18Cl^-$ *Toluene oxidation/ Trichloroethylene reductive dehalogenation*	-415.40	-1738	25.7:1
$18C_2H_2Cl_2 + 14H_2O + C_6H_5CH_3 \Rightarrow 18C_2H_3Cl + 7CO_2 + 18H^+ + 18Cl^-$ *Toluene oxidation/ cis-Dichloroethylene reductive dehalogenation*	-329.72	-1380	18.9:1
$18C_2H_3Cl + 14H_2O + C_6H_5CH_3 \Rightarrow 18C_2H_4 + 7CO_2 + 18H^+ + 18Cl^-$ *Toluene oxidation/ Vinyl chloride reductive dehalogenation*	-388.22	-1624	12.1:1

Coupled Ethylbenzene Oxidation reactions	ΔG°_r kcal/mole Ethylbenzene	ΔG°_r kJ/mole Ethylbenzene	Stoichiometric Mass Ratio of Electron Acceptor to Compound
$10.5O_2 + C_6H_5C_2H_5 \Rightarrow 8CO_{2,g} + 5H_2O$ *Ethylbenzene oxidation /aerobic respiration*	-1066.13	-4461	3.17:1
$8.4NO_3^- + 8.4H^+ + C_6H_5C_2H_5 \Rightarrow 8CO_{2,g} + 9.2H_2O + 4.2N_{2,g}$ *Ethylbenzene oxidation / denitrification*	-1080.76	-4522	4.92:1
$46H^+ + 22\underline{MnO_2} + C_6H_5C_2H_5 \Rightarrow 8CO_{2,g} + 22Mn^{2+} + 28H_2O$ *Ethylbenzene oxidation / manganese reduction*	-1066.27	-4461	11.39:1
$84H^+ + 42\underline{Fe(OH)_{3,a}} + C_6H_5C_2H_5 \Rightarrow 8CO_2 + 42Fe^{2+} + 110H_2O$ *Ethylbenzene oxidation / iron reduction*	-778.48	-3257	22.0:1
$10.5H^+ + 5.25SO_4^{2-} + C_6H_5C_2H_5 \Rightarrow 8CO_{2,g} + 5.25H_2S'' + 5H_2O$ *Ethylbenzene* oxidation / sulfate reduction	-166.75	-697.7	4.75:1
$5.5H_2O + C_6H_5C_2H_5 \Rightarrow 2.75CO_{2,g} + 5.25CH_4$ *Ethylbenzene oxidation / methanogenesis*	-39.83	-166.7	0.79:1
$21C_2Cl_4 + 16H_2O + C_6H_5C_2H_5 \Rightarrow 21C_2HCl_3 + 8CO_2 + 21H^+ + 21Cl^-$ *Ethylbenzene oxidation/ Tetrachloroethylene reductive dehalogenation*	-496.67	-2078	32.8:1
$21C_2HCl_3 + 16H_2O + C_6H_5C_2H_5 \Rightarrow 21C_2H_2Cl_2 + 8CO_2 + 21H^+ + 21Cl^-$ *Ethylbenzene oxidation/ Trichloroethylene reductive dehalogenation*	-484.70	-2028	26.0:1
$21C_2H_2Cl_2 + 16H_2O + C_6H_5C_2H_5 \Rightarrow 21C_2H_3Cl + 8CO_2 + 21H^+ + 21Cl^-$ *Ethylbenzene oxidation/ cis-Dichloroethylene reductive dehalogenation*	-384.74	-1610	19.2:1
$21C_2H_3Cl + 16H_2O + C_6H_5C_2H_5 \Rightarrow 21C_2H_4 + 8CO_2 + 21H^+ + 21Cl^-$ *Ethylbenzene oxidation/ Vinyl chloride reductive dehalogenation*	-452.99	-1895	12.3:1

Coupled m-Xylene Oxidation Reactions	ΔG°_r (kcal/mole *m*-xylene)	ΔG°_r (kJ/mole *m*-xylene)	Stoichiometric Mass Ratio of Electron Acceptor to Compound
$10.5O_2 + C_6H_4(CH_3)_2 \Rightarrow 8CO_{2,g} + 5H_2O$ *m-Xylene oxidation /aerobic respiration*	-1063.25	-4448	3.17:1
$8.4NO_3^- + 8.4H^+ + C_6H_4(CH_3)_2 \Rightarrow 8CO_{2,g} + 9.2H_2O + 4.2N_{2,g}$ *m-Xylene oxidation / denitrification*	-1077.81	-4509	4.92:1
$46H^+ + 22\underline{MnO_2} + C_6H_4(CH_3)_2 \Rightarrow 8CO_{2,g} + 22Mn^{2+} + 28H_2O$ *m-Xylene oxidation / manganese reduction*	-1063.39	-4449	11.39:1
$84H^+ + 42\underline{Fe(OH)_{3,a}} + C_6H_4(CH_3)_2 \Rightarrow 8CO_2 + 42Fe^{2+} + 110H_2O$ *m-Xylene oxidation / iron reduction*	-775.61	-3245	22:1
$10.5H^+ + 5.25SO_4^{2-} + C_6H_4(CH_3)_2 \Rightarrow 8CO_{2,g} + 5.25H_2S^o + 5H_2O$ m-Xylene oxidation / sulfate reduction	-163.87	-685.6	4.75:1
$5.5H_2O + C_6H_4(CH_3)_2 \Rightarrow 2.75CO_{2,g} + 5.25CH_4$ *m-Xylene oxidation / methanogenesis*	-36.95	-154.6	0.79:1 [a/]
$21C_2Cl_4 + 16H_2O + C_6H_4(CH_3)_2 \Rightarrow 21C_2HCl_3 + 8CO_2 + 21H^+ + 21Cl^-$ *m-Xylene oxidation/ Tetrachloroethylene reductive dehalogenation*	-493.79	-2066	32.8:1
$21C_2HCl_3 + 16H_2O + C_6H_4(CH_3)_2 \Rightarrow 21C_2H_2Cl_2 + 8CO_2 + 21H^+ + 21Cl^-$ *m-Xylene oxidation/ Trichloroethylene reductive dehalogenation*	-481.82	-2016	26.0:1
$21C_2H_2Cl_2 + 16H_2O + C_6H_4(CH_3)_2 \Rightarrow 21C_2H_3Cl + 8CO_2 + 21H^+ + 21Cl^-$ *m-Xylene oxidation/ cis-Dichloroethylene reductive dehalogenation*	-381.86	-1598	19.2:1
$21C_2H_3Cl + 16H_2O + C_6H_4(CH_3)_2 \Rightarrow 21C_2H_4 + 8CO_2 + 21H^+ + 21Cl^-$ *m-Xylene oxidation/ Vinyl chloride reductive dehalogenation*	-450.11	-1883	12.3:1

Coupled Naphthalene Oxidation Reactions	ΔG°$_r$ (kcal/mole naphthalene)	ΔG°$_r$ (kJ/mole naphthalene)	Stoichiometric Mass Ratio of Electron Acceptor to Compound
$12O_2 + C_{10}H_8 \Rightarrow 10CO_2 + 4H_2O$ *Naphthalene oxidation /aerobic respiration*	-1217.40	-5094	3.00:1
$9.6NO_3^- + 9.6H^+ + C_{10}H_8 \Rightarrow 10CO_2 + 8.8H_2O + 4.8N_{2,g}$ *Naphthalene oxidation / denitrification*	-1234.04	-5163	4.65:1
$24MnO_2 + 48H^+ + C_{10}H_8 \Rightarrow 10CO_2 + 24Mn^{2+} + 28H_2O$ *Naphthalene oxidation / manganese reduction*	-1217.57	-5094	16.31:1
$48Fe(OH)_{3,a} + 96H^+ + C_{10}H_8 \Rightarrow 10CO_2 + 48Fe^{2+} + 124H_2O$ *Naphthalene oxidation / iron reduction*	-932.64	-3902	40.13:1
$6SO_4^{2-} + 12H^+ + C_{10}H_8 \Rightarrow 10CO_2 + 6H_2S^o + 4H_2O$ *Naphthalene oxidation / sulfate reduction*	-196.98	-824.2	4.50:1
$8H_2O + C_{10}H_8 \Rightarrow 4CO_2 + 6CH_4$ *Naphthalene oxidation / methanogenesis*	-44.49	-186.1	1.13:1
$24C_2Cl_4 + 20H_2O + C_{10}H_8 \Rightarrow 24C_2HCl_3 + 10CO_2 + 24H^+ + 24Cl^-$ *Naphthalene oxidation/ Tetrachloroethylene reductive dehalogenation*	-566.59	-2371	31.1:1
$24C_2HCl_3 + 20H_2O + C_{10}H_8 \Rightarrow 24C_2H_2Cl_2 + 10CO_2 + 24H^+ + 24Cl^-$ *Naphthalene oxidation/ Trichloroethylene reductive dehalogenation*	-552.91	-2313	24.6:1
$24C_2H_2Cl_2 + 20H_2O + C_{10}H_8 \Rightarrow 24C_2H_3Cl + 10CO_2 + 24H^+ + 24Cl^-$ *Naphthalene oxidation/ cis-Dichloroethylene reductive dehalogenation*	-438.67	-1835	18.2:1
$24C_2H_3Cl + 20H_2O + C_{10}H_8 \Rightarrow 24C_2H_4 + 10CO_2 + 24H^+ + 24Cl^-$ *Naphthalene oxidation/ Vinyl chloride reductive dehalogenation*	-516.67	-2162	11.6:1

Coupled 1,3,5-Trimethylbenzene Oxidation Reactions	ΔG°$_r$ (kcal/mole 1,3,5-TMB)	ΔG°$_r$ (kJ/mole 1,3,5-TMB)	Stoichiometric Mass Ratio of Electron Acceptor to Compound
$12O_2 + C_6H_3(CH_3)_3 \Rightarrow 9CO_2 + 6H_2O$ *1,3,5-Trimethylbenzene oxidation /aerobic respiration*	-1213.29	-5076	3.20:1
$9.6NO_3^- + 9.6H^+ + C_6H_3(CH_3)_3 \Rightarrow 9CO_2 + 10.8H_2O + 4.8N_{2,g}$ *1,3,5-Trimethylbenzene oxidation / denitrification*	-1229.93	-5146	4.96:1
$24MnO_2 + 48H^+ + C_6H_3(CH_3)_3 \Rightarrow 9CO_2 + 30H_2O + 24Mn^{2+}$ *1,3,5-Trimethylbenzene oxidation / manganese reduction*	-1213.46	-5077	17.40:1
$48Fe(OH)_{3,a} + 96H^+ + C_6H_3(CH_3)_3 \Rightarrow 9CO_2 + 48Fe^{2+} + 126H_2O$ *1,3,5-Trimethylbenzene oxidation / iron reduction*	-928.53	-3885	42.80:1
$6SO_4^{2-} + 12H^+ + C_6H_3(CH_3)_3 \Rightarrow 9CO_2 + 6H_2O + 6H_2S^o$ *1,3,5-Trimethylbenzene oxidation / sulfate reduction*	-192.87	-807.0	4.80:1
$6H_2O + C_6H_3(CH_3)_3 \Rightarrow 3CO_2 + 6CH_4$ *1,3,5-Trimethylbenzene oxidation / methanogenesis*	-40.39	-169.0	0.90:1
$24C_2Cl_4 + 18H_2O + C_6H_3(CH_3)_3 \Rightarrow 24C_2HCl_3 + 9CO_2 + 24H^+ + 24Cl^-$ *1,3,5-Trimethylbenzene oxidation/ Tetrachloroethylene reductive dehalogenation*	-562.48	-2353	33.2:1
$24C_2HCl_3 + 18H_2O + C_6H_3(CH_3)_3 \Rightarrow 24C_2H_2Cl_2 + 9CO_2 + 24H^+ + 24Cl^-$ *1,3,5-Trimethylbenzene oxidation/ Trichloroethylene reductive dehalogenation*	-548.80	-2296	26.3:1
$24C_2H_2Cl_2 + 18H_2O + C_6H_3(CH_3)_3 \Rightarrow 24C_2H_3Cl + 9CO_2 + 24H^+ + 24Cl^-$ *1,3,5-Trimethylbenzene oxidation/ cis-Dichloroethylene reductive dehalogenation*	-434.56	-1818	19.4:1
$24C_2H_3Cl + 18H_2O + C_6H_3(CH_3)_3 \Rightarrow 24C_2H_4 + 9CO_2 + 24H^+ + 24Cl^-$ *1,3,5-Trimethylbenzene oxidation/ Vinyl chloride reductive dehalogenation*	-512.56	-2145	12.4:1

Coupled 1,2,4-Trimethylbenzene Oxidation Reactions	ΔG°$_r$ (kcal/mole 1,2,4-TMB)	ΔG°$_r$ (kJ/mole 1,2,4-TMB)	Stoichiometric Mass Ratio of Electron Acceptor to Compound
$12O_2 + C_6H_3(CH_3)_3 \Rightarrow 9CO_2 + 6H_2O$ *1,2,4-Trimethylbenzene oxidation /aerobic respiration*	-1212.92	-5075	3.20:1
$9.6NO_3^- + 9.6H^+ + C_6H_3(CH_3)_3 \Rightarrow 9CO_2 + 10.8H_2O + 4.8N_{2,g}$ *1,2,4-Trimethylbenzene oxidation / denitrification*	-1229.56	-5144	4.96:1
$24\underline{MnO_2} + 48H^+ + C_6H_3(CH_3)_3 \Rightarrow 9CO_2 + 30H_2O + 24Mn^{2+}$ *1,2,4-Trimethylbenzene oxidation / manganese reduction*	-1213.09	-5076	17.4:1
$48\underline{Fe(OH)}_{3,a} + 96H^+ + C_6H_3(CH_3)_3 \Rightarrow 9CO_2 + 48Fe^{2+} + 126H_2O$ *1,2,4-Trimethylbenzene oxidation / iron reduction*	-928.16	-3883	42.8:1
$6SO_4^{2-} + 12H^+ + C_6H_3(CH_3)_3 \Rightarrow 9CO_2 + 6H_2O + 6H_2S^o$ *1,2,4-Trimethylbenzene* oxidation / sulfate reduction	-192.50	-805.4	4.80:1
$6H_2O + C_6H_3(CH_3)_3 \Rightarrow 3CO_2 + 6CH_4$ *1,2,4-Trimethylbenzene oxidation / methanogenesis*	-40.02	-167.4	0.90:1
$24C_2Cl_4 + 18H_2O + C_6H_3(CH_3)_3 \Rightarrow 24C_2HCl_3 + 9CO_2 + 24H^+ + 24Cl^-$ *1,2,4-Trimethylbenzene oxidation/ Tetrachloroethylene reductive dehalogenation*	-562.11	-2352	33.2:1
$24C_2HCl_3 + 18H_2O + C_6H_3(CH_3)_3 \Rightarrow 24C_2H_2Cl_2 + 9CO_2 + 24H^+ + 24Cl^-$ *1,2,4-Trimethylbenzene oxidation/ Trichloroethylene reductive dehalogenation*	-548.43	-2295	26.3:1
$24C_2H_2Cl_2 + 18H_2O + C_6H_3(CH_3)_3 \Rightarrow 24C_2H_3Cl + 9CO_2 + 24H^+ + 24Cl^-$ *1,2,4-Trimethylbenzene oxidation/ cis-Dichloroethylene reductive dehalogenation*	-434.19	-1817	19.4:1
$24C_2H_3Cl + 18H_2O + C_6H_3(CH_3)_3 \Rightarrow 24C_2H_4 + 9CO_2 + 24H^+ + 24Cl^-$ *1,2,4-Trimethylbenzene oxidation/ Vinyl chloride reductive dehalogenation*	-512.19	-2143	12.4:1

Coupled Chlorobenzene Oxidation Reactions	ΔG°$_r$ (kcal/mole Chlorobenzene)	ΔG°$_r$ (kJ/mole Chlorobenzene)	Stoichiometric Mass Ratio of Electron Acceptor to Compound
$7O_2 + C_6H_5Cl \Rightarrow 6CO_2 + H^+ + 2H_2O + Cl^-$ *Chlorobenzene oxidation /aerobic respiration*	-731.62	-3061	2.00:1
$5.6NO_3^- + 4.6H^+ + C_6H_5Cl \Rightarrow 6CO_2 + 4.8H_2O + 2.8N_{2,g} + Cl^-$ *Chlorobenzene oxidation / denitrification*	-741.33	-3102	3.10:1
$14\underline{MnO_2} + 27H^+ + C_6H_5Cl \Rightarrow 6CO_2 + 16H_2O + 14Mn^{2+} + Cl^-$ *Chlorobenzene oxidation / manganese reduction*	-731.72	-3062	10.9:1
$28\underline{Fe(OH)}_{3,a} + 55H^+ + C_6H_5Cl \Rightarrow 6CO_2 + 72H_2O + 28Fe^{2+} + Cl^-$ *Chlorobenzene oxidation / iron reduction*	-565.51	-2366	26.8:1
$3.5SO_4^{2-} + 6H^+ + C_6H_5Cl \Rightarrow 6CO_2 + 2H_2O + 3.5H_2S^o + Cl^-$ *Chlorobenzene* oxidation / sulfate reduction	-136.38	-570.6	3.00:1
$5H_2O + C_6H_5Cl \Rightarrow 2.5CO_2 + 3.5CH_4 + H^+ + Cl^-$ *Chlorobenzene oxidation / methanogenesis*	-47.43	-198.4	0.80:1
$14C_2Cl_4 + 12H_2O + C_6H_5Cl \Rightarrow 14C_2HCl_3 + 6CO_2 + 15H^+ + 15Cl^-$ *Chlorobenzene oxidation/ Tetrachloroethylene reductive dehalogenation*	-351.99	-1473	20.7:1
$14C_2HCl_3 + 12H_2O + C_6H_5Cl \Rightarrow 14C_2H_2Cl_2 + 6CO_2 + 15H^+ + 15Cl^-$ *Chlorobenzene oxidation/ Trichloroethylene reductive dehalogenation*	-344.01	-1439	16.4:1
$14C_2H_2Cl_2 + 12H_2O + C_6H_5Cl \Rightarrow 14C_2H_3Cl + 6CO_2 + 15H^+ + 15Cl^-$ *Chlorobenzene oxidation/ cis-Dichloroethylene reductive dehalogenation*	-277.37	-1161	12.1:1
$14C_2H_3Cl + 12H_2O + C_6H_5Cl \Rightarrow 14C_2H_4 + 6CO_2 + 15H^+ + 15Cl^-$ *Chlorobenzene oxidation/ Vinyl chloride reductive dehalogenation*	-322.87	-1351	7.75:1

Coupled Vinyl Chloride Oxidation Reactions	ΔG°_r (kcal/mole vinyl chloride)	ΔG°_r (kJ/mole vinyl chloride)	Stoichiometric Mass Ratio of Electron Acceptor to Compound
$2.5O_2 + C_2H_3Cl \Rightarrow 2CO_2 + H_2O + H^+ + Cl^-$ *Vinyl Chloride oxidation /aerobic respiration*	-288.98	-1209	1.29:1
$2NO_3^- + H^+ C_2H_3Cl \Rightarrow 2CO_2 + 2H_2O + Cl^- + N_{2,g}$ *Vinyl Chloride oxidation / denitrification*	-292.44	-1224	2.00:1
$5\underline{MnO_2} + 9H^+ + C_2H_3Cl \Rightarrow 2CO_2 + 6H_2O + 5Mn^{2+} + Cl^-$ *Vinyl Chloride oxidation / manganese reduction*	-289.01	-1209	7.02:1
$10\underline{Fe(OH)}_{3,a} + 19H^+ + C_6H_3(CH_3)_3 \Rightarrow 2CO_2 + 10Fe^{2+} + 26H_2O + Cl^-$ *Vinyl Chloride oxidation / iron reduction*	-229.65	-960.9	17.3:1
$1.25SO_4^{2-} + 1.5H^+ + C_2H_3Cl \Rightarrow 2CO_2 + H_2O + 1.25H_2S^0 + Cl^-$ *Vinyl Chloride* oxidation / sulfate reduction	-76.40	-319.7	1.94:1
$1.5H_2O + C_2H_3Cl \Rightarrow .75CO_2 + 1.25CH_4 + H^+ + Cl^-$ *Vinyl Chloride oxidation / methanogenesis*	-44.62	-186.7	0.44:1
$5C_2Cl_4 + 4H_2O + C_2H_3Cl \Rightarrow 5C_2HCl_3 + 2CO_2 + 6H^+ + 6Cl^-$ *Vinyl Chloride oxidation/ Tetrachloroethylene reductive dehalogenation*	-153.39	-641.8	13.4:1
$5C_2HCl_3 + 4H_2O + C_2H_3Cl \Rightarrow 5C_2H_2Cl_2 + 2CO_2 + 6H^+ + 6Cl^-$ *Vinyl Chloride oxidation/ Trichloroethylene reductive dehalogenation*	-150.54	-629.9	10.6:1
$5C_2H_2Cl_2 + 4H_2O + C_2H_3Cl \Rightarrow 5C_2H_3Cl + 2CO_2 + 6H^+ + 6Cl^-$ *Vinyl Chloride oxidation/ cis-Dichloroethylene reductive dehalogenation*	-126.74	-530.3	7.82:1

I:\sh\gibbs.doc

Gibbs Free Energy of Formation for Species used in Half-Cell reactions and Coupled Oxidation-Reduction Reactions

Species	State	$\Delta G^{o}_{f,298.15}$ (kcal/mole)	Source
e^-	i	0	std
H^+	i	0	std
O_2	g	0	std
H_2O	l	-56.687	Dean (1972)
Carbon Species			
CO_2	g	-94.26	Dean (1972)
CH_2O, formalydehyde	aq	-31.02	Dean (1972)
C_6H_6, benzene	l	+29.72	Dean (1972)
CH_4, methane	g	-12.15	Dean (1972)
$C_6H_5CH_3$, toluene	l	+27.19	Dean (1972)
$C_6H_5C_2H_5$, ethylbenzene	l	+28.61	Dean (1972)
$C_6H_4(CH_3)_2$, o-xylene	l	+26.37	Dean (1972)
$C_6H_4(CH_3)_2$, m-xylene	l	+25.73	Dean (1972)
$C_6H_4(CH_3)_2$, p-xylene	l	+26.31	Dean (1972)
C_2Cl_4, PCE	l	+1.1	CRC Handbook (1990)
C_2HCl_3, TCE	l	+2.9	CRC Handbook (1990)
$C_2H_2Cl_2$, c-DCE	l	+5.27	CRC Handbook (1990)
C_2H_4, ethene	g	+16.28	CRC Handbook (1990)
$C_{10}H_8$, naphthalene	l	+48.05	Dean (1972)
$C_6H_3(CH_3)_3$, 1,3,5-TMB	1	+24.83	Dean (1972)
$C_6H_3(CH_3)_3$, 1,2,4-TMB	1	+24.46	Dean (1972)
C_2H_3Cl, vinyl chloride	g	+12.4	Dean (1972)
C_6H_5Cl, chlorobenzene	1	+21.32	Dean (1972)
$C_{14}H_{10}$, phenanthrene	l	+64.12	Dean (1972)
Nitrogen Species			
NO_3^-	i	-26.61	Dean (1972)
N_2	g	0	std
NO_2^-	i	-7.7	Dean (1972)
NH_4^+	aq	-18.97	Dean (1972)
Sulfur Species			
SO_4^{2-}	i	-177.97	Dean (1972)
H_2S	aq	-6.66	Dean (1972)
H_2S	g	-7.9	Dean (1972)
HS^-	i	+2.88	Dean (1972)
Iron Species			
Fe^{2+}	i	-18.85	Dean (1972)
Fe^{3+}	i	-1.1	Dean (1972)
Fe_2O_3, hematite	c	-177.4	Dean (1972)
FeOOH, ferric oxyhydroxide	c	-117.2	Naumov *et al.* (1974)
$Fe(OH)_3$, goethite	a	-167.416	Langmuir and Whittemore (1971)
$Fe(OH)_3$, goethite	c	-177.148	Langmuir and Whittemore (1971)
$FeCO_3$, siderite	c	-159.35	Dean (1972)
Manganese Species			
Mn^{2+}	i	-54.5	Dean (1972)
MnO_2, pyrolusite	c	-111.18	Stumm and Morgan (1981)
MnOOH, manganite	c	-133.29	Stumm and Morgan (1981)
$MnCO_3$, rhodochrosite	p	-194	Dean (1972)
Chloride Species			
Cl^-	aq	-31.37	Dean (1972)

NOTES:

c = crystallized solid
a = amorphous solid (may be partially crystallized - dependent on methods of preparation)
p = freshly precipitated solid
i = dissociated, aqueous ionic species (concentration = 1 m)
aq = undissociated aqueous species
g = gaseous
l = liquid
std = accepted by convention
Wherever possible multiple sources were consulted to eliminate the possibility of typographical error.

APPENDIX C

GROUNDWATER MODEL RESULTS

APPENDIX C

TABLE OF CONTENTS

PAGE

LIST OF FIGURES

LIST OF TABLES

APPENDIX C

GROUNDWATER MODEL RESULTS

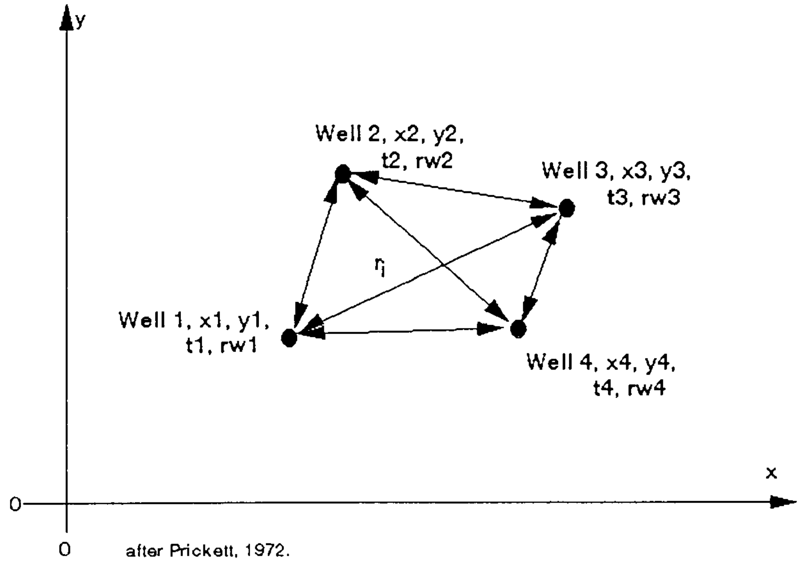
C.1 INTRODUCTION

A preliminary groundwater model of the site was developed to assist with the design of a multiple well, hydrogeologic control system. The extraction-well pumping rates were calculated using the Theis equation and a conceptual model of a single layer aquifer. These evaluations were then included in a simple, analytic-element model to calculate the radius of influence and capture zone of the system. It was found that four extraction wells, pumping at a combined rate of less than 2 gallons per minute (GPM), would be sufficient to sustain a capture zone over 500 feet wide along the northern edge of the paved area of FRP-2.

C.2 ANALYTICAL APPROACH AND PARAMETERS

If closely spaced wells pump from the same aquifer, the cones of depression will overlap. The wells will then interfere with each other and for a given drawdown, the pumping rate of each well will be smaller than if it were pumping alone As a result, the pumping rates of the wells can be over estimated if the interference effects are ignored. The solution is to specify a drawdown for each well and then calculate the pumping rates. This approach is reasonable, since most extraction wells are operated at a constant drawdown.

Figure C.1 shows a plan view of a typical problem.



after Prickett, 1972.

Figure C.1 Multiple well pumping system

The Theis non-equilibrium equation for the drawdown distribution about each point shown above is (Prickett, 1972):

$$s_i = \frac{Q_i}{4\pi T_i} W(u_i) \qquad \textit{(Equation 1)}$$

Where:

$W(u_i) =_{u_i} \int^{\infty} \frac{e^{-ui}}{i_i} du$ (the Theis well function)

$u_i = \frac{r_i^2 S}{4\,Tt_i}$ (the Theis well function argument)

Q_i = the pumping rate to be calculated for well ***i***
s_i = the drawdown (negative for injection) due to well ***i***
T = the aquifer transmissivity
S = the aquifer storage coefficient
r_i = the radial distance from well ***i*** to any other well
r_{wi} = the radius of well ***i***
t_i = the time since well ***i*** started pumping.

The solution of equation (1) requires the solution of ***i*** equations with ***i*** unknowns. These were solved using a computer program derived from calculator codes developed by Prickett (1972) and a program developed by Rugg and Feldman (1980).

The operational history of the existing groundwater control and treatment (GCT) system at Area of Concern (AOC) 16 was used to derive aquifer parameters (see Table C.1 and Figure C.2). The average hydraulic conductivity of the fine sand and silt unit was estimated from slug tests to range from 4.9 x 10^{-2} cm/sec (140 ft/day) to 6.6 x 10^{-7} cm/sec (1.9 ft/day) (ERM, 1992). Using a hydraulic conductivity of 2 ft/day (considered more representative of the silty sands, ERM, 1992) and an approximate aquifer thickness of 35 feet at the location of the existing and proposed groundwater extraction systems, an initial transmissivity of 70 ft^2/day was used in the model. The initial storage value was assumed to be 0.1 (for unconfined aquifers). The aquifer parameters in the model were then adjusted until a reasonable match against the operational history of the GCT system at AOC 16 was made (see Table C.1 and Figure C.2). The final aquifer parameters used to evaluate the site-wide groundwater control system were 50 ft^2/day for transmissivity and 0.001 for storage coefficient.

TABLE C.1
MODEL CALIBRATION AGAINST AOC 16 GCT SYSTEM

		AOC 16 GCT			MODEL		
Date	ELAPSED DAYS	Gallons Since Last Read	Cumulative Gallons	Avg. GPM Since Last Read	GPM	Gallons	Cumulative Gallons
01/03/96	19	11,020	35,787	1.3	1.42	38,851	38,851
01/10/96	26	7,721	43,508	0.8	1.38	13,910	52,762
01/17/96	33	10,069	53,577	1.0	1.38	13,910	66,672
01/24/96	40	14,108	67,685	1.4	1.34	13,507	80,179
01/31/96	47	13,858	81,543	1.4	1.32	13,306	93,485
02/07/96	54	7,436	88,979	0.7	1.30	13,104	106,589
02/14/96	61	9,010	97,989	0.9	1.30	13,104	119,693
02/21/96	68	11,220	109,209	1.1	1.28	12,902	132,595
02/28/96	75	12,816	122,025	1.3	1.28	12,902	145,498
03/06/96	82	12,492	134,517	1.2	1.26	12,701	158,198
03/13/96	89	12,326	146,843	1.2	1.26	12,701	170,899
03/20/96	96	15,732	162,575	1.6	1.24	12,499	183,398
03/27/96	103	14,758	177,333	1.5	1.24	12,499	195,898
04/03/96	110	10,660	187,993	1.1	1.24	12,499	208,397
04/10/96	117	13,358	201,351	1.3	1.24	12,499	220,896
04/17/96	124	15,159	216,510	1.5	1.22	12,298	233,194
04/23/96	130	8,629	225,139	1.0	1.22	10,541	243,734
05/01/96	138	12,437	237,576	1.1	1.22	14,054	257,789
05/08/96	145	16,035	253,611	1.6	1.22	12,298	270,086
05/22/96	159	38,376	291,987	1.9	1.20	24,192	294,278
06/05/96	173	35,363	327,350	1.8	1.20	24,192	318,470
06/19/96	187	27,990	355,340	1.4	1.18	23,789	342,259
07/03/96	201	28,810	384,150	1.4	1.18	23,789	366,048
07/17/96	215	27,461	411,611	1.4	1.18	23,789	389,837
07/31/96	229	29,543	441,154	1.5	1.18	23,789	413,626
08/14/96	243	23,896	465,050	1.2	1.18	23,789	437,414
08/28/96	257	22,021	487,071	1.1	1.16	23,386	460,800
09/11/96	271	18,921	505,992	0.9	1.16	23,386	484,186
09/25/96	285	15,350	521,342	0.8	1.16	23,386	507,571
10/08/96	298	17,174	538,516	0.9	1.14	21,341	528,912

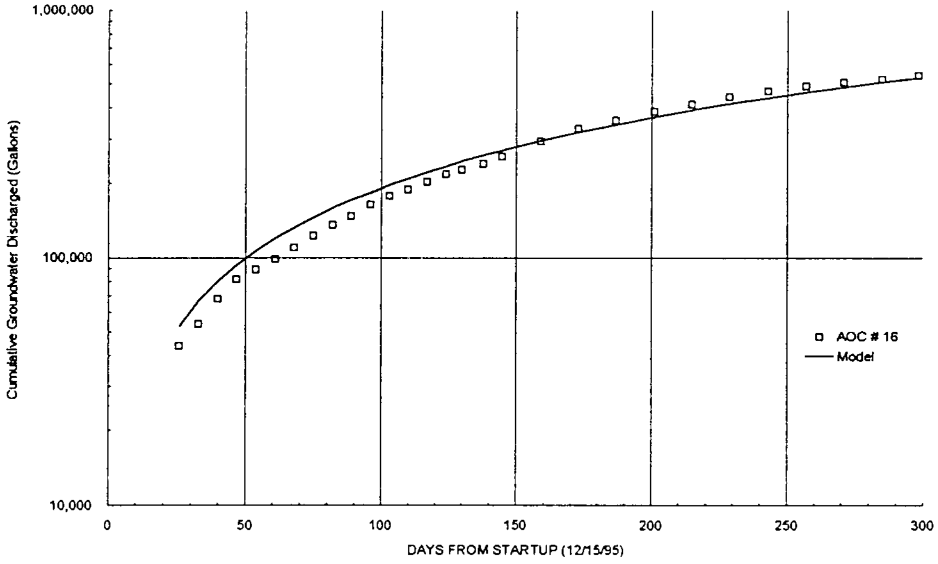


Figure C.2 Model calibration against AOC 16 GCT system.

The number and location of new extraction wells were evaluated by adding wells to the model, calculating pumping rates assuming that the existing AOC 16 GCT wells were in operation, and plotting the capture zones. This process was repeated until overlapping capture zones across the northern portion of the site were achieved. In the final configuration, four "new" extrtraction wells for site-wide groundwater control were added to the existing AOC 16 GCT wells in the model. The drawdowns for the new site-wide groundwater control wells were specified as 5 feet, which is consistent with the drawdowns maintained in the three existing AOC 16 extraction wells.

The drawdowns and capture zones of the site-wide groundwater control system were calculated and plotted using the analytic-element method of Strack (1989) as implemented in the computer program *Quickflow*™ (Rumbaugh, 1991).

In the *Quickflow*™ model, a grid is placed over the area of interest and the discharge potential is computed at each node. The discharge potential at each node is the sum (principle of superposition) of the discharge potential of the uniform flow field and the various elements (wells, drains, ponds, etc.) in the model. The discharge potential is a vector quantity. The magnitude of the discharge potential equals the volume of water flowing through a cross-section of unit width. The vector of the of the discharge potential points in the direction of groundwater flow. Finally the head at the node is calculated from the discharge potential at each node. The analytic-element model used the following assumptions:

- The aquifer is unconfined;
- The aquifer is homogeneous, isotropic, and uniform thickness;
- The pre-pumping water table is nearly horizontal;

- Water is released instantly from storage with increasing drawdown;
- The wells are screened across the full saturated thickness of the aquifer;
- The wells are pumped at a constant rate; and
- There are no well storage effects.

The capture zone of a well is the area of the aquifer where all water enters the well (Keely & Tsang. 1983). It is calculated by computing the net groundwater velocity vector from the velocity vectors generated by each pumping well, and the natural groundwater velocity vector. The velocity vector for each pumping well is computed from the drawdown distribution around the well.

Capture zones for the extraction wells were delineated by reverse-particle tracking. Particles were placed in a circle around each extraction well and allowed to move opposite the hydraulic gradient, that is, upgradient. The pumping rates and locations for the site-wide groundwater control wells were then adjusted until overlapping capture zones were achieved.

The capture zone for a 200-foot long trench was also modeled in *Quickflow*™ using a constant-head drain placed 10 feet below the water table.

C.3 RESULTS

The calculated pumping rates for the site-wide groundwater control wells are listed on Table C.2 and plotted on Figure C.3. The capture zones for the wells are plotted on Figure C.4

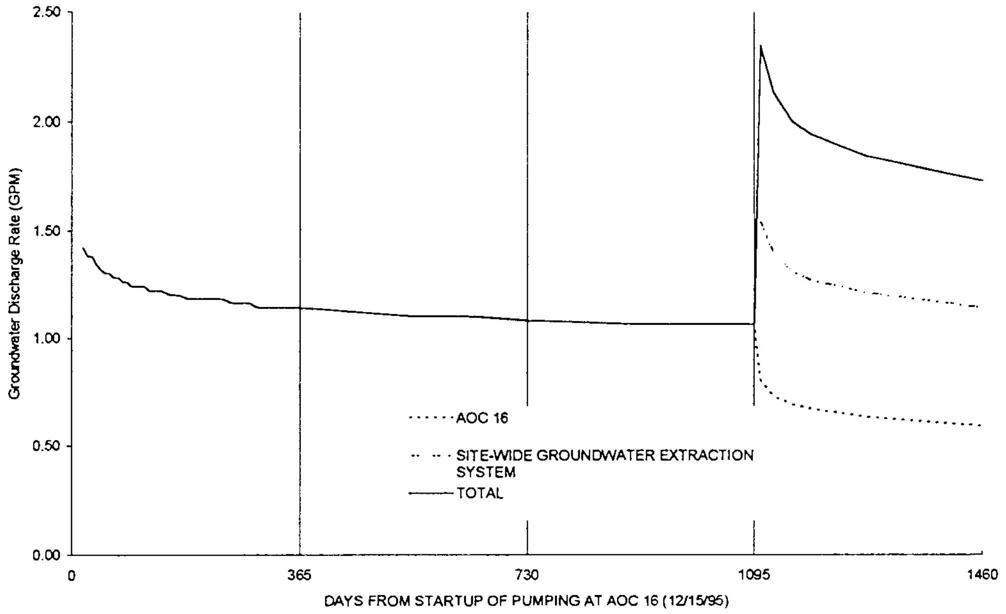


Figure C.3 Estimated pumping rates for site-wide groundwater control system.

TABLE C.2
ESTIMATED PUMPING RATES FOR SITE-WIDE GROUNDWATER CONTROL SYSTEM

Date	Elapsed Days	Model AOC16 GPM	Model GW CONTROL GPM	Model TOTAL GPM
01/03/96	19	1.42		1.42
01/10/96	26	1.38		1.38
01/17/96	33	1.38		1.38
01/24/96	40	1.34		1.34
01/31/96	47	1.32		1.32
02/07/96	54	1.30		1.30
02/14/96	61	1.30		1.30
02/21/96	68	1.28		1.28
02/28/96	75	1.28		1.28
03/06/96	82	1.26		1.26
03/13/96	89	1.26		1.26
03/20/96	96	1.24		1.24
03/27/96	103	1.24		1.24
04/03/96	110	1.24		1.24
04/10/96	117	1.24		1.24
04/17/96	124	1.22		1.22
04/23/96	130	1.22		1.22
05/01/96	138	1.22		1.22
05/08/96	145	1.22		1.22
05/22/96	159	1.20		1.20
06/05/96	173	1.20		1.20
06/19/96	187	1.18		1.18
07/03/96	201	1.18		1.18
07/17/96	215	1.18		1.18
07/31/96	229	1.18		1.18
08/14/96	243	1.18		1.18
08/28/96	257	1.16		1.16
09/11/96	271	1.16		1.16
09/25/96	285	1.16		1.16
10/08/96	298	1.14		1.14
1/97(1)	365	1.14		1.14
6/97(1)	548	1.10		1.10
9/97(1)	639	1.10		1.10
12/97(1)	731	1.08		1.08
6/98(1)	913	1.06		1.06
12/98(1)	1096	1.06		1.06
12/98(1)	1106	0.80	1.54	2.34
1/99(1)	1126	0.73	1.40	2.13
2/99(1)	1156	0.69	1.31	2.00
3/99(1)	1186	0.67	1.27	1.94
6/99(1)	1276	0.63	1.21	1.84
12/99(1)	1461	0.59	1.14	1.73

(1) Projected data

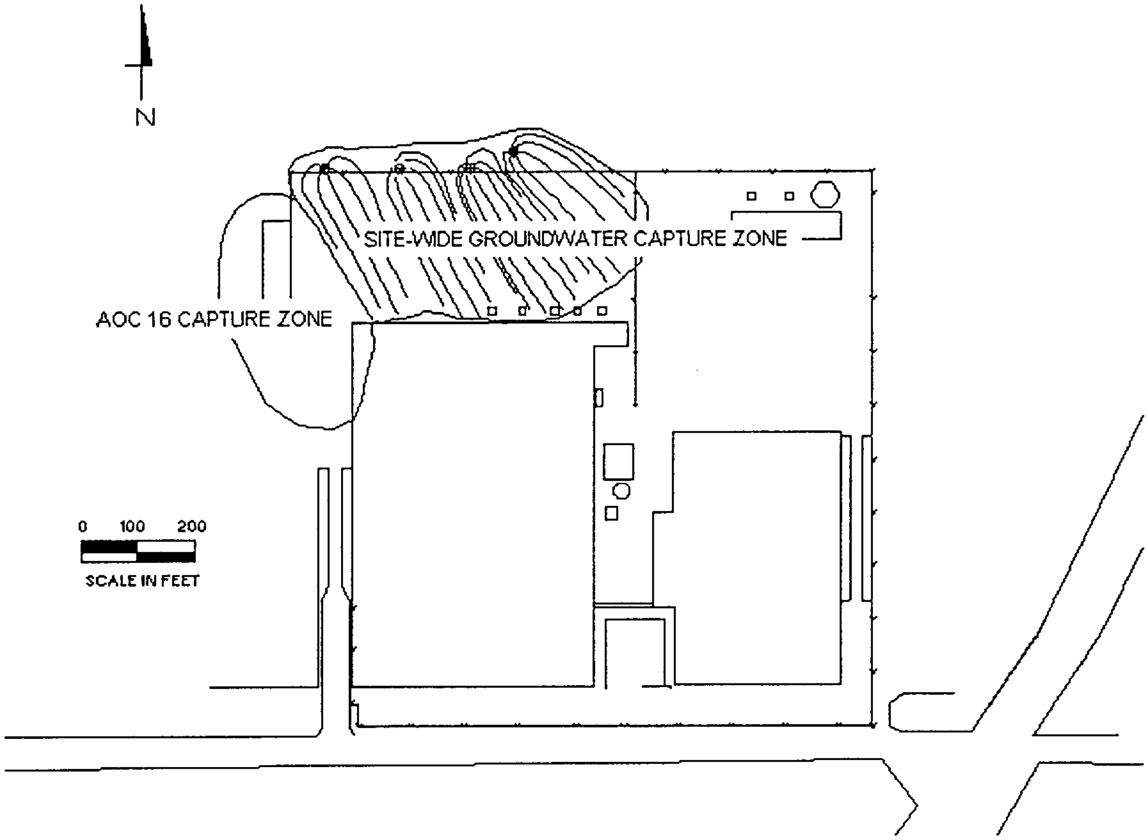


Figure C.4 Capture zone for site-wide groundwater control system.

The discharge rates for the site-wide groundwater control system were calculated to decline from an initial value of approximately 1.5 GPM, to a value of approximately 1.1 GPM. As indicated in Figure C.3, the discharge rates of the existing AOC 16 GCT system are expected to decline due to interference from the new site-wide groundwater control system. However, as indicated in Figure C.4 above, AOC 16 system will continue to maintain control over the AOC 16 area while the proposed groundwater control system will effectively capture groundwater flow across the northern edge of the paved area of FRP-2. The calculated pumping rate for a trench in this same area was 1.4 GPM, similar to that calculated for the groundwater extraction wells. The extent of the capture zone of the trench/drain was also similar to that calculated for the extraction wells.

C.4 REFERENCES

J.F. Keely and C.F. Tsang. 1983. "Velocity Plots and Capture Zones of Pumping Centers for Ground-Water Investigations". *Ground Water* v. 21, no. 6, pp. 701 - 714.

T.A. Prickett. (1972). "Study of Steady-State Flow to Finite Line Sources or Sinks with Drawdown as the Given". *Selected Hand-Held Calculator Codes for the Evaluation of Cumulative Strip-Mining Impacts on Groundwater Resources.* Prepared for the Office of Surface Mining, Region V, Denver Co. by Thomas A. Prickett & Associates, Urbana, Ill.

T. Rugg and P. Feldman. 1980. "SIMEQN.BAS, A Program to Solve a Set of Simultaneous Linear Algebraic Equations". *32 BASIC Programs for the TRS-80 (Level II) Computer.* dilithium Press, Forest Grove, Oregon

J. O. Rumbaugh III, 1991. *Quickflow Analytical 2D Ground-Water Flow Model.* Geraghty & Miller, Inc. Reston, Virginia.

Otto D.L. Strack, 1989. *Groundwater Mechanics.* Prentice-Hall, Inc. Englewood Cliffs, New Jersey.

APPENDIX D

REMEDIAL ALTERNATIVE COST ESTIMATES

TABLE D.1
NO FURTHER ACTION
COST ESTIMATE

CAPITAL COST

Item	Unit	Quantity	Unit Cost	Total Cost	Cost Reference
1. TOTAL CAPITAL COSTS (AOC 5, AOC 7, AOC 16)				$0	

ANNUAL OPERATING AND MAINTENANCE COSTS

Item	Unit	Quantity	Unit Cost	Total Cost	Cost Reference
1. AOC5 SVE System O&M and Air Emission Monitoring					
a. Monthly System Inspection & Maintenance	HRS/YR	68	$50	$3,400	Engineer's Estimate
b. Replacement Parts, Supplies, Materials	LS	1	$1,500	$1,500	Engineer's Estimate
c. Equipment for System Monitoring and Repair	LS	1	$1,800	$1,800	Engineer's Estimate
d. Electricity and Phone Service	LS	1	$2,620	$2,600	Engineer's Estimate
e. Monthly Reporting, Evaluation	HRS/YR	50	$70	$3,500	Engineer's Estimate
f. Disposal of Collected Condensate	GAL	50	$2.00	$100	Engineer's Estimate
Item 1 Subtotal				$12,900	
2. AOC5 SVE O&M Contingency (35%)				$4,500	Engineer's Estimate
3. AOC5 SVE Annual O&M Total				$17,000	
4. **Present Worth of AOC5 SVE O&M** (2 years at 3.8% Discount Rate) [PW = 1.89 * Annual O&M + Capital Cost($0)]				$32,000	
5. AOC7 Free Product Recovery System O&M					
a. System Inspection & Maintenance	HRS/YR	28	$50	$1,400	Engineer's Estimate
b. Replacement Parts, Supplies, Materials	LS	1	$1,000	$1,000	Engineer's Estimate
c. Equipment for System Monitoring and Repair	LS	1	$1,000	$1,000	Engineer's Estimate
d. Electricity	LS	1	$500	$500	Engineer's Estimate
e. Monthly Reporting, Evaluation	HRS/YR	24	$70	$1,700	Engineer's Estimate
f. Disposal of Recovered Product	GAL	100	$2.00	$200	Engineer's Estimate
Item 5 Subtotal				$5,800	
6. AOC7 Free Product Recovery O&M Contingency (35%)				$2,000	Engineer's Estimate
7. AOC7 Free Product Recovery O&M Total				$8,000	
8. **Present Worth of AOC7 Free Product Recovery O&M** (2 years at 3.8% Discount Rate) [PW = 1.89 * Annual O&M + Capital Cost($0)]				$15,000	

TABLE D.1 (CON'T)
NO FURTHER ACTION
COST ESTIMATE

ANNUAL OPERATING AND MAINTENANCE COSTS (CON'T)

Item	Unit	Quantity	Unit Cost	Total Cost	Cost Reference
9. AOC16 SVE System O&M and Air Emission Monitoring					
a. System Inspection & Maintenance	HRS/YR	54	$50	$2,700	Engineer's Estimate
b. Replacement Parts, Supplies, Materials	LS	1	$1,000	$1,000	Engineer's Estimate
c. Equipment for System Monitoring and Repair	LS	1	$1,800	$1,800	Engineer's Estimate
d. Electricity	LS	1	$1,700	$1,700	Engineer's Estimate
e. Monthly Reporting, Evaluation	HRS/YR	50	$70	$3,500	Engineer's Estimate
Item 9 Subtotal				$10,700	
10. AOC16 SVE O&M Contingency (35%)				$3,700	Engineer's Estimate
11. AOC16 SVE Annual O&M Total				$14,000	
12. Present Worth of AOC16 SVE O&M (2 years at 3.8% Discount Rate) [PW = 1.89 * Annual O&M + Capital Cost($0)]				$26,000	
13. AOC16 Groundwater Collection and Treatment System O&M, Influent / Effluent Groundwater Monitoring, and Air Emission Monitoring					
a. System Inspection & Maintenance	HRS/YR	66	$50	$3,300	Engineer's Estimate
b. Replacement Parts, Supplies, Materials	LS	1	$1,000	$1,000	Engineer's Estimate
c. Equipment for System Monitoring and Repair	LS	1	$750	$800	Engineer's Estimate
d. Monthly Influent and Effluent Water Sample Analyses	TEST	24	$250	$6,000	Vendor Quote
e. Electricity and Phone Service	LS	1	$4,820	$4,800	Engineer's Estimate
f. Monthly Reporting, Evaluation	HRS/YR	42	$70	$2,900	Engineer's Estimate
g. Redevelopment of Recovery Wells Every 2 Years	LS/YR	1	$4,000	$4,000	Engineer's Estimate
h. Disposal of Filter Elements, Central Sump Sludge, Stripper Sludge	GAL	100	$2.00	$200	Engineer's Estimate
Item 13 Subtotal				$23,000	
14. AOC16 Groundwater Collection and Treatment System O&M Contingency (35%)				$8,100	Engineer's Estimate
15. AOC16 Groundwater Collection and Treatment System Annual O&M Total				$31,000	
16. Present Worth of AOC16 Groundwater Collection and Treatment System O&M (30 years at 3.8% Discount Rate) [PW = 17.63 * Annual O&M + Capital Cost($0)]				$547,000	
17. TOTAL PRESENT WORTH OF THE NO FURTHER ACTION ALTERNATIVE (Total of Items 4, 8, 12, and 16)				$620,000	

Note: O&M costs for continued operation of existing IRMs at AOC 5, AOC 7, and AOC 16 based on historical cost information from one year of operation.

ASSUMPTIONS FOR NO FURTHER ACTION COST ESTIMATE

GENERAL

1. Three interim remedial measures are included in the No Further Action baseline: the free product recovery system currently operating at Area of Concern (AOC) 7, the soil vapor extraction (SVE) system currently operating at AOC 5, and the combined SVE and groundwater collection and treatment (GCT) system operating at AOC 16. Since these systems are already in place, this cost estimate includes only operating and maintenance (O&M) expenses. The present worth cost was estimated assuming a project life of 30 years and a 3.8% discount rate as per the NYSDEC TAGM 4030 unless otherwise noted. The calculation for the discount rate is attached to this appendix. In the development of operating cost estimates, historical cost information from these systems was utilized and adjusted to reflect the assumptions for future operation as presented below.
2. Values are rounded where appropriate.

ANNUAL O&M COSTS

Item 1 - AOC 5 SVE System O&M and Air Emission Monitoring

System O&M and monitoring includes monthly visits by a technician to perform maintenance and adjustment of the system, engineering oversight and occasional direct involvement in system operation, and the on-site measurement of VOCs in air emissions by PID to assess system operating status. Monthly progress reports to the NYSDEC regarding system operation are included in the estimate. For future operations of this IRM, it is assumed that system O&M and air monitoring will be completed monthly rather than bi-weekly and also that air sample collection and laboratory analysis will be terminated following the 18-month sampling event.

Item 2 - AOC 5 SVE O&M Contingency

As experienced through actual O&M activities for similar treatment systems, it is typical to encounter periodic systems errors and breakdowns related to the unexpected failure of electrical controls, fouling of sensors and instruments, fouling of valves, power outages, and other unforeseen causes. The resolution of this type of problem often requires development of documentation for NYSDEC submittal and coordination with subcontractors. Therefore, the O&M contingency is a significant percentage of the total anticipated O&M cost.

Item 4 - Present Worth of AOC 5 SVE O&M

It is anticipated that a "zero slope condition" of VOCs in the off-gas will be reached for each vapor extraction well within the next two years, and the system operation will be terminated once that condition is reached.

Item 5 - AOC 7 Free Product Recovery System O&M

System O&M and monitoring includes monthly visits by a technician to perform maintenance and adjustment of the system, engineering oversight and occasional direct involvement in system operation, and the off-site disposal of collected free product. Monthly progress reports to the NYSDEC regarding the collected volume are included in the estimate.

Item 6 - AOC 7 Free Product Recovery O&M Contingency

As experienced through actual O&M activities for similar treatment systems, it is typical to encounter periodic systems errors and breakdowns related to the unexpected failure of electrical controls, fouling of sensors and instruments, fouling of valves, power outages, and other unforeseen causes. The resolution of this type of problem often requires development of documentation for NYSDEC submittal and coordination with subcontractors. Therefore, the O&M contingency is a significant percentage of the total anticipated O&M cost.

Item 8 - Present Worth of AOC 7 Free Product Recovery O&M

It is anticipated that free product from AOC 7 will be recovered to the extent specified in the IRM work plan within the next two years and the system operation will be terminated once that condition is reached.

Item 9 - AOC 16 SVE System O&M and Air Emission Monitoring

System O&M and monitoring includes periodic visits by a technician to perform maintenance and adjustment of the system, engineering oversight and occasional direct involvement in system operation, and the on-site measurement of VOCs in air emissions by PID to assess system operating status. Monthly progress reports to the NYSDEC regarding system operation are included in the estimate. For future operations of this IRM, it is assumed that system O&M and air monitoring will be completed monthly rather than bi-weekly and also that air sample collection and laboratory analysis will be terminated following the 18-month sampling event.

Item 10 - AOC 16 SVE O&M Contingency

As experienced through actual O&M activities for similar treatment systems, it is typical to encounter periodic systems errors and breakdowns related to the unexpected failure of electrical controls, fouling of sensors and instruments, fouling of valves, power outages, and other unforeseen causes. The resolution of this type of problem often requires development of documentation for NYSDEC submittal and coordination with subcontractors. Therefore, the O&M contingency is a significant percentage of the total anticipated O&M cost.

Item 12 - Present Worth of AOC 16 SVE O&M

It is anticipated that a "zero slope condition" of VOCs in the off-gas will be reached for each vapor extraction well within the next two years, and the system operation will be terminated once that condition is reached.

Item 13 - AOC 16 Groundwater Collection and Treatment System O&M, Influent / Effluent Monitoring, and Air Emission Monitoring

System O&M and monitoring includes periodic visits by a technician to perform maintenance and adjustment of the system, engineering oversight and occasional direct involvement in system operation, the on-site measurement of VOCs in air emissions by PID to assess system operating status, and the collection and off-site laboratory analysis of influent and effluent groundwater samples for volatile organic compounds (by method EPA 8240), iron, and manganese. Monthly progress reports to the NYSDEC regarding system operation, treated groundwater discharge volume, and treated groundwater effluent quality are included in the estimate. For future operations of this IRM, it is assumed that system O&M and air monitoring will be completed monthly rather than bi-weekly, treated groundwater sampling and analysis will continue to be completed monthly, and air sample collection and laboratory analysis will be terminated following the 18-month sampling event.

Item 14 - AOC 16 Groundwater Collection and Treatment System O&M Contingency

As experienced through actual O&M activities for similar treatment systems, it is typical to encounter periodic systems errors and breakdowns related to the unexpected failure of electrical controls, fouling of sensors and instruments, fouling of valves, power outages, and other unforeseen causes. The resolution of this type of problem often requires development of documentation for NYSDEC submittal and coordination with subcontractors. Therefore, the O&M contingency is a significant percentage of the total anticipated O&M cost.

Item 16 - Present Worth of AOC 16 Groundwater Collection and Treatment System O&M

A 30 year project life and a 3.8% discount rate are assumed as per the NYSDEC TAGM 4030.

TABLE D.2
REACTIVE IRON WALL
REMEDIAL ALTERNATIVE COST ESTIMATE

CAPITAL COST

Item	Unit	Quantity	Unit Cost	Total Cost	Cost Reference
1. Pre-Design Investigation	LS	1	$8,700	$8,700	Engineer's Estimate
2. Site Preparation					
a. Removal of Site Fencing in Area of Wall Placement	LF	650	$2	$1,300	Means
b. Asphalt Pavement Removal in Area of Wall Placement	SY	182	$6.60	$1,200	Means
c. H&S Equipment	LS	1	$2,000	$2,000	Engineer's Estimate
d. H&S Monitoring	LS	1	$3,000	$3,000	Engineer's Estimate
Item 2 Subtotal				$7,500	
3. ETI Data Review, Site Visit, and Laboratory Column Test	LS	1	$31,000	$31,000	Vendor Quote
4. Groundwater Modeling	LS	1	$7,500	$7,500	Engineer's Estimate
5. Installation of Wall					
a. Mobilization of Trenching Equipment	LS	1	$40,000	$40,000	Vendor Quote
b. Construct Trench 2' Wide and 32-37' Deep	LF	400	$500	$200,000	Vendor Quote
c. Installation of Iron Filings/Sand	LF	400	$30	$12,000	Vendor Quote
d. Iron Filings	TONS	1,094	$400	$440,000	Vendor Quote
e. Sand	CY	350	$22.50	$7,900	Means, Engineer's Estimate
f. Backfilling of Excavated Soil in Unsaturated Zone	LF	400	$6	$2,400	Engineer's Estimate
g. Demobilization of Trenching Equipment	LS	1	$20,000	$20,000	Vendor Quote
Item 5 Subtotal				$720,000	
6. Disposal of Unused Excavated Soil	TONS	1,200	$70	$84,000	Engineer's Estimate
7. ETI Involvement During Design and Installation	LS	1	$15,000	$15,000	Engineer's Estimate
8. Site Restoration					
a. Replacement of Asphalt Pavement	SY	182	$6.45	$1,200	Means
b. Fence Replacement	LF	650	$14.40	$9,400	Means
c. Installation of Post-Remediation Monitoring Wells	EA	3	$2,500	$7,500	Engineer's Estimate
Item 8 Subtotal				$18,000	
9. Subtotal Capital Costs				$890,000	
10. Engineering, Design, and Construction Oversight (10%)				$89,000	Engineer's Estimate
11. Contingencies (20%)				$180,000	Engineer's Estimate
12. ETI Licensing Fee (15% of Item 5 Subtotal)				$110,000	Vendor Quote
13. TOTAL CAPITAL COSTS				**$1,300,000**	

TABLE D.2 (CON'T)
REACTIVE IRON WALL
REMEDIAL ALTERNATIVE COST ESTIMATE

ANNUAL OPERATING AND MAINTENANCE COSTS

Item	Unit	Quantity	Unit Cost	Total Cost	Cost Reference
1. Quarterly Groundwater Monitoring					
a. Field Effort (labor, equipment, expenses)	HRS	128	$50	$6,400	Engineer's Estimate
b. Sample Analyses	TEST	24	$500	$12,000	Vendor Quote
c. Data Analysis/Reporting (once yearly)	HRS	80	$80	$6,400	Engineer's Estimate
Item 1 Subtotal				$25,000	
2. O&M Contingency (20%)				$5,000	Engineer's Estimate
3. Annual O&M Total				$30,000	
4. Iron Rejuvenation (Assume $100,000 every 10 years)					Vendor Quote
Present Worth of $100,000 in Year 10 (0.6860 Factor)				$69,000	
Present Worth of $100,000 in Year 20 (0.4707 Factor)				$47,000	
Present Worth of $100,000 in Year 30 (0.3229 Factor)				$32,000	
Iron Rejuvenation Present Worth Total				$150,000	
TOTAL PRESENT WORTH OF THE REACTIVE IRON WALL ALTERNATIVE (30 years at a 3.8% Discount Rate) [PW=17.63*Annual O&M + Capital Cost]				**$2,000,000**	
TOTAL PRESENT WORTH OF CONTINUED IRM OPERATION AT AOC 5, 7, AND 16 [Refer to Table D.1]				$620,000	
COMBINED PRESENT WORTH OF ALTERNATIVE AND CONTINUED IRM OPERATION				**$2,620,000**	

ASSUMPTIONS FOR REACTIVE IRON WALL ALTERNATIVE COST ESTIMATE

GENERAL

1. This cost estimate includes both capital and operating and maintenance (O&M) expenses. The present worth cost was estimated assuming a project life of 30 years and a 3.8% discount rate in accordance with NYSDEC TAGM 4030. The calculation for the discount rate is attached to this appendix. In the development of construction cost estimates, unit costs were obtained from vendor quotations (ETI, Horizontal Technologies, etc.), standard cost estimating documents (Means 1996 Heavy Construction Cost Data, 10th Annual Edition), and from Parsons ES experience with similar projects.
2. Values are rounded where appropriate.

CAPITAL COSTS

Item 1 - Pre-Design Investigation

It was assumed that the following information would need to be collected prior to the design of this alternative:

1) A more detailed definition of VOC concentrations in groundwater at the northern edge of the paved area of FRP-2. This information would be obtained via screen point or piezometer groundwater sampling at approximately 100-foot intervals.
2) Definition of the vertical distribution of VOC concentrations in groundwater. This information would be obtained through collection and analyses of groundwater at two depths during the screen point or piezometer sampling.
3) Inorganic Groundwater Data. This information would be obtained through groundwater analyses.

Based on recent quotations from drillers for similar work, the drilling cost to collect 6 groundwater samples from three different locations at two varying depths was estimated at $2,600 using a Geoprobe and screen point or piezometer sampling. The groundwater VOC and inorganic analytical cost for 8 samples (six piezometers plus two existing wells), based on recent analytical work conducted on groundwater samples from the site, was estimated at $6,100.

Item 2 - Site Preparation

a. It was assumed that 650 linear feet of the existing fence would need to be removed to provide clearance for construction of the reactive iron wall.

b. It was assumed that an area of pavement 4 feet wide and 410 feet long would need to be removed before trenching. An asphalt thickness of 4 inches was assumed.

c. and d. Assumptions regarding health and safety equipment and monitoring costs are based on work for similar projects.

Item 3 - ETI Data Review, Site Visit, and Laboratory Column Test

Vendor quote provided by Envirometal Technologies, Inc. (ETI).

Item 4 - Groundwater Modeling

ETI recommends groundwater flow modeling to determine the most effective wall configuration. It was assumed that the model would be done by Parsons ES at a lump sum of $7,500. This assumes one week of labor to develop the model and additional time to rerun the model based on various design configurations and review comments.

Item 5 - Installation of Wall

a, b, c, g. Vendor quote from Horizontal Technologies, Inc. (HTI) in Florida. HTI will be the only owners of a trenching machine capable of obtaining depths of 37 feet below ground surface without trenching by June of 1997.

d. Vendor quote from ETI. ETI estimates iron filings are available in the cost range of $400 to $450 per ton. During a recent installation of a wall in North Carolina by Parsons ES, iron filings were obtained at $350 a ton. $400 a ton was assumed.

e. It was assumed that the iron required for the needed degradation residence times would be mixed with an inert material (sand) to occupy the 2 foot trench. It was assumed that the sand was screened and washed. The unit cost represents the material cost only based on Means data and is representative of recent Parsons ES experience.

f. Engineer's estimate. It was assumed that backfilling of excavated soil over the iron/sand media to the ground surface and grading to the surface would cost one fifth the cost of the installation of the iron/sand media.

Volume Estimates:

Total excavated volume: (400'L x 2'W x 35'D(avg.))=28,000 CF

Total volume of sand/iron needed:
(400'L x 2'W x 27'D(saturated zone only))=21,600 CF

Total volume of iron needed:
(100'L x 1.5'W x 27'D) + (300'L x 1'W x 27'D) = 12,150 CF.

This assumes a one foot flow-through thickness of iron in a continuous permeable wall would be sufficient to treat the VOCs, with an increased thickness of 1.5 feet needed in the core of the plume to treat higher concentrations. The point at which this thickness would need to be increased would be confirmed by collecting water samples along the line of installation. With an assumed bulk density of 0.09 tons per CF, the volume of iron filings is:

12,150 CF x 0.09 tons per CF = 1094 tons.

Volume of sand needed: 21,600 CF - 12,150 CF = 9,450 CF

Volume of excavated material to backfill: 28,000 CF - 21,600 CF = 6,400 CF

Volume of material to dispose of: 28,000 CF - 6,400 CF = 21,600 CF.
Assuming a bulk density of 1.5 tons per CY, the volume of material to dispose of is 21,600 CF x 1.5 tons per CF x 1 CY per 27 CF = 1,200 tons.

Item 6 - Soil Disposal

Assumed disposal of unused excavated soil would be at a non-hazardous landfill at $70/ton.

Item 7 - ETI Involvement

ETI requires on-site representation during the installation of the reactive iron wall. ETI's staff is also available to assist as a design consultant on a time and materials basis. It was assumed that over the course of the project, ETI's involvement would total $15,000. ETI estimates that for other projects this cost has ranged from $5,000 to $30,000 based on their level of involvement. ETI estimates for this size project, their involvement fee would be approximately $15,000.

Item 8 - Site Restoration

a. It was assumed that the pavement would be repaired where removed for construction. Assumed it would consist of cold laid pavement, spread and compacted.

b. It was assumed that the fence would be replaced with a new chain-link, industrial, 6' high, 9 ga. wire, aluminized steel fence. This would include replacing the northwest corner fence post.

c. It was assumed that post-remediation monitoring wells would be installed, one upgradient and two downgradient. This assumes that the existing wells MW-26S, MW-16, and MW-17 would be sampled during the post-construction monitoring period.

Item 12 - ETI Licensing Fee

An ETI licensing fee of 15% of construction labor and materials is required on all projects that utilize the Envirometal™ technology.

ANNUAL O&M COSTS

Item 1 - Quarterly Groundwater Monitoring

Post-remedial groundwater monitoring for sites with reactive iron walls at other sites is typically conducted on a quarterly basis. The frequency would be established by the regulatory agency. After certain treatment levels are obtained, monitoring at some sites is planned to be reduced to semi-annual sampling. For conservativeness, quarterly groundwater monitoring was assumed for 30 years at this site.

It was assumed that laboratory analyses costs would be $500 per sample for target parameters.

Assumed a total of 6 monitoring points; 3 upgradient and 3 downgradient.

(6 points) (4 samples a year) = 24 samples

Assumed it would take 2 people 2 days at $50 per hour to sample.

(2 people) (2 days) (8 hours a day) (4 times a year) = 128 hours

Assumed data analysis/reporting would require a total of 80 hours per year to complete.

Item 4 - Iron Rejuvenation

Per ETI, "rejuvenation" of the reactive material will be required every 5 to 10 years although no O&M data is available to date on existing walls. This is due to the fact that no wall has been installed at full-scale in the field for longer than six years. ETI is experimenting at the bench and pilot scales with "closed-loop" flushing; a process by which a weak acid is injected through upgradient wells, passed through the iron media causing the dissipation of mineral precipitates, and then extracted in downgradient wells. Other possible O&M procedures for the wall consist of replacing the iron media partially or in full every 5 to 10 years, as warranted, or per ETI "stirring-up" of the iron media with hollow stem augers as warranted. Spent iron filings can be resold as scrap metal when removed.

Due to the uncertainty of the "rejuvenation" costs of the iron filings, an O&M lump sum of $100,000 every 10 years was factored into the cost estimate. This lump sum and cost interval were recommended by the vendor.

TABLE D.3
HYDRAULIC CONTAINMENT WITH GROUNDWATER TREATMENT VIA AIR STRIPPING REMEDIAL ALTERNATIVE COST ESTIMATE

CAPITAL COST

Item	Unit	Quantity	Unit Cost	Total Cost	Cost Reference
1. Pre-Design Investigation	LS	1	$8,700	$8,700	Engineer's Estimate
2. Site Preparation					
a. Placement of Stone for System Discharge	LS	1	$1,000	$1,000	Engineer's Estimate
b. Pavement Removal for Treatment Building Concrete Pad	SY	35	$6.60	$230	Means
c. Project H&S Equipment	LS	1	$2,000	$2,000	Engineer's Estimate
d. Project H&S Monitoring	LS	1	$3,000	$3,000	Engineer's Estimate
Item 2 Subtotal				$6,200	
3. Installation of Four Recovery Wells and Four Piezometers					
a. Mobilization / Demobilization of Drilling Equipment	LS	1	$400	$400	Vendor Quote
b. Construct & Remove Temporary Decon Pad	LS	1	$200	$200	Vendor Quote
c. Four 4" S.S. Wells, complete	LS	1	$12,400	$12,000	Vendor Quote
d. Four 2" Piezometer Wells, complete	LS	1	$4,500	$4,500	Vendor Quote
e. Decontamination Activities, Staging Drums Per Well	EA	4	$300	$1,200	Vendor Quote
Item 3 Subtotal				$18,000	
4. Installation of Groundwater Collection and Transfer System					
a. Submersible Electric Pump with Level Controls	EA	4	$1,200	$4,800	Engineer's Estimate
b. Process Piping, Supports, Insulation, Heat Cable	LS	1	$17,600	$18,000	Means/Engineer's Estimate
c. Central Sump, Pump, Float Control, Bag Filter, Meter	LS	1	$4,200	$4,200	Engineer's Estimate
d. Electrical Service Connection, Conduits, Control Panel	LS	1	$21,200	$21,000	Means/Engineer's Estimate
e. Mobilization / Demobilization & Miscellaneous	LS	1	$5,000	$5,000	Engineer's Estimate
Item 4 Subtotal				$53,000	
5. Installation of Groundwater Treatment System - Air Stripping					
a. Concrete Pad for Pre-Designed Building, CIP, Reinforced	SF	256	$6.12	$1,600	Means
b. Treatment Building (15' x 15') with Expl.-Proof Heat	LS	1	$15,000	$15,000	Engineer's Estimate
c. Skid-Mounted Low-Profile Air Stripper System	LS	1	$29,800	$30,000	Vendor Quote
d. Air Emission Stack, Security Fence with Gates	LS	1	$3,700	$3,700	Means/Engineer's Estimate
e. Mobilization / Demobilization & Miscellaneous	LS	1	$5,000	$5,000	Engineer's Estimate
Item 5 Subtotal				$55,000	
6. Construction, Materials, and Equipment Subtotal				$140,000	
7. Estimated System Start-Up Labor Costs				$6,000	Engineer's Estimate
8. Engineering, Design, and Construction Oversight (25%)				$35,000	Engineer's Estimate
9. Contingencies (20%)				$28,000	Engineer's Estimate
10. TOTAL CAPITAL COSTS				**$210,000**	

TABLE D.3 (CON'T)
HYDRAULIC CONTAINMENT WITH GROUNDWATER TREATMENT VIA AIR STRIPPING REMEDIAL ALTERNATIVE COST ESTIMATE

ANNUAL OPERATING AND MAINTENANCE COSTS

Item	Unit	Quantity	Unit Cost	Total Cost	Cost Reference
1. System O&M and Influent / Effluent Monitoring					
a. System Inspection & Maintenance	HRS/YR	156	$50	$7,800	Engineer's Estimate
b. Replacement Parts, Supplies, Materials	LS	1	$1,500	$1,500	Engineer's Estimate
c. Equipment for System Monitoring and Repair	LS	1	$4,000	$4,000	Engineer's Estimate
d. Monthly Influent and Effluent Water Sample Analyses	TEST	24	$250	$6,000	Vendor Quote
e. Electricity and Phone Service	LS	1	$5,820	$5,800	Engineer's Estimate
f. Monthly Reporting, Evaluation	HRS/YR	48	$70	$3,400	Engineer's Estimate
g. Redevelopment of Recovery Wells Every 2 Years	LS/YR	1	$4,000	$4,000	Engineer's Estimate
h. Disposal of Filter Elements, Central Sump Sludge, Stripper Sludge	GAL	100	$3.00	$300	Engineer's Estimate
Item 1 Subtotal				$32,800	
2. O&M Contingency (35%)				$11,500	Engineer's Estimate
3. Annual O&M Total				$44,000	
TOTAL PRESENT WORTH OF THE HYDRAULIC CONTAINMENT WITH GROUNDWATER TREATMENT VIA AIR STRIPPING ALTERNATIVE (30 years at a 3.8% Discount Rate) [PW=17.63*Annual O&M + Capital Cost]				**$990,000**	
TOTAL PRESENT WORTH OF CONTINUED IRM OPERATION AT AOC 5, 7, AND 16 [Refer to Table D.1]				$620,000	
COMBINED PRESENT WORTH OF ALTERNATIVE AND CONTINUED IRM OPERATION				**$1,610,000**	

ASSUMPTIONS FOR HYDRAULIC CONTAINMENT WITH GROUNDWATER TREATMENT VIA AIR STRIPPING ALTERNATIVE COST ESTIMATE

GENERAL

1. This cost estimate includes both capital and operating and maintenance (O&M) expenses. The present worth cost was estimated assuming a project life of 30 years and a 3.8% discount rate as per the NYSDEC TAGM 4030. The calculation for the discount rate is attached to this appendix. In the development of construction cost estimates, unit costs were obtained from vendor quotations, standard cost estimating documents (Means 1996 Cost Data), and from Parsons ES experience with similar projects.
2. Values are rounded where appropriate.

CAPITAL COSTS

Item 1 - Pre-Design Investigation

It was assumed that the following information would need to be collected prior to the design of any remedial alternative:

1) A more detailed definition of VOC concentration in groundwater at the northern edge of the paved area of the FRP-2 paved area. This information would be obtained via screen point or piezometer groundwater sampling at approximately every 50 feet.
2) Inorganic Groundwater Data. This information would be obtained through groundwater analyses.

Based on recent quotations from drillers for similar work, the drilling cost to collect 6 groundwater samples from three different locations at two varying depths was estimated at $2,600 using a Geoprobe and screen point or piezometer sampling. The groundwater VOC and inorganic analytical cost for 8 samples (six piezometers plus two existing wells), based on recent analytical work conducted on groundwater samples from the site, was estimated at $6,100.

Item 2 - Site Preparation

Site preparation includes site grading and stone placement for a new treated water discharge outfall and the removal of a 17' x 17' area of asphalt in order to install a 16' x 16' concrete pad for a 15' x 15' treatment building.

Item 3 - Installation of Four Recovery Wells and Four Piezometers

Installation of recovery wells and piezometers includes all labor, materials (casing, screen, sand, bentonite, and finishing materials, etc.), and construction equipment use

(drill rig, personal protective equipment, decontamination equipment, etc.) necessary for the on-site installation of four recovery wells. Recovery wells are assumed to be 35 foot deep, 4 inch diameter stainless steel. Piezometer wells are assumed to be 35 foot deep, 2 inch diameter PVC.

Item 4 - Installation of Groundwater Collection and Transfer System

Installation of the groundwater collection and transfer system includes all labor, materials and construction equipment use necessary to provide the following:

- well pumps with level controls;
- piping from four recovery wells to the treatment building and from the treatment building to a nearby discharge outfall (including supports, insulation, and heat tracing for all outdoor piping);
- electrical service with an assumed origin at the north end of the former maintenance building which includes two poles, a main power conductor cable, entrance cap, conduit, meter socket, transformer, and circuit breaker load center;
- electrical system controls in a weatherproof control panel which includes motor starters, fault relays, indicator lights, and hand switches; and
- mobilization/demobilization and miscellaneous charges incurred from the mechanical contractor.

Item 5 - Installation of Groundwater Treatment System - Air Stripping

Installation of the groundwater treatment system includes all labor, materials, and construction equipment use necessary for the construction of a 15' x 15' pre-designed treatment building (with explosion-proof heating, explosion-proof lighting, and security fencing); the subsequent installation of a packaged low-profile, tray-style air stripper (ShallowTray Model 3641) with discharge pump, controls, and instrumentation; the installation of an air emissions stack; and mobilization/demobilization and miscellaneous charges incurred from the mechanical contractor.

Item 7 - Estimated System Start-up Labor Costs

Estimated system start-up costs provide for five days of a technician's time and four days of an engineer's time to troubleshoot and closely monitor the initial operation of the newly installed system.

ANNUAL O&M COSTS

Item 1 - System O&M and Influent / Effluent Monitoring

System O&M and monitoring includes periodic visits by a technician to perform maintenance and adjustment of the system, engineering oversight and occasional direct involvement in system operation, and the collection and off-site laboratory analysis of influent and effluent groundwater samples for volatile organic compounds (by method EPA 8240) and iron. Monthly progress reports to the NYSDEC regarding system discharge volume and effluent quality are included in the estimate.

Item 3 - O&M Contingency

As experienced through actual O&M activities for similar treatment systems, it is typical to encounter periodic systems errors and breakdowns related to the unexpected failure of electrical controls, fouling of sensors and instruments, fouling of valves, power outages, and other unforeseen causes. The resolution of this type of problem often requires development of documentation for NYSDEC submittal and coordination with subcontractors. Therefore, the O&M contingency is a significant percentage of the total anticipated O&M cost.

TABLE D.4
HYDRAULIC CONTAINMENT
WITH GROUNDWATER TREATMENT VIA UV / HYDROGEN PEROXIDE OXIDATION
REMEDIAL ALTERNATIVE COST ESTIMATE

CAPITAL COST

Item	Unit	Quantity	Unit Cost	Total Cost	Cost Reference
1. Pre-Design Investigation	LS	1	$8,700	$8,700	Engineer's Estimate
2. Site Preparation					
a. Placement of Stone for System Discharge	LS	1	$1,000	$1,000	Engineer's Estimate
b. Asphalt Pavement Removal for Treatment Building	SY	60	$6.60	$400	Means
c. Project H&S Equipment	LS	1	$2,000	$2,000	Engineer's Estimate
d. Project H&S Monitoring	LS	1	$3,000	$3,000	Engineer's Estimate
Item 2 Subtotal				$6,400	
3. Installation of Four Recovery Wells and Four Piezometers					
a. Mobilization / Demobilization of Drilling Equipment	LS	1	$400	$400	Vendor Quote
b. Construct & Remove Temporary Decon Pad	LS	1	$200	$200	Vendor Quote
c. Four 4" S.S. Wells, complete	LS	1	$12,400	$12,000	Vendor Quote
d. Four 2" Piezometer Wells, complete	LS	1	$4,500	$4,500	Vendor Quote
e. Decontamination Activities, Staging Drums Per Well	EA	4	$300	$1,200	Vendor Quote
Item 3 Subtotal				$18,000	
4. Installation of Groundwater Collection and Transfer System					
a. Submersible Electric Pump with Level Controls	EA	4	$1,200	$4,800	Engineer's Estimate
b. Process Piping, Supports, Insulation, Heat Cable	LS	1	$17,600	$18,000	Means/Engineer's Estimate
c. Central Sump, Pump, Float Control, Bag Filter, Meter	LS	1	$4,200	$4,200	Engineer's Estimate
d. Electrical Service Connection, Conduits, Control Panel	LS	1	$21,200	$21,000	Means/Engineer's Estimate
e. Mobilization / Demobilization & Miscellaneous	LS	1	$5,000	$5,000	Engineer's Estimate
Item 4 Subtotal				$53,000	
5. Installation of Groundwater Treatment System - UV / Peroxide Oxidation					
a. Treatability Testing (up to $4000)	LS	1	$4,000	$4,000	Vendor Quote
b. Concrete Pad for Pre-Designed Building, CIP, Reinforced	SF	480	$6.12	$2,900	Means
c. Treatment Building (20' x 20') with Expl.-Proof Heat	LS	1	$20,000	$20,000	Engineer's Estimate
d. Skid-Mounted UV / Peroxide Reactor	LS	1	$100,000	$100,000	Vendor Quote
e. Security Fence (3 sides, 40'x60' area)	LS	1	$1,700	$1,700	Means
Item 5 Subtotal				$130,000	
6. Construction, Materials, and Equipment Subtotal				$220,000	
7. Estimated System Start-Up Labor Costs				$10,000	Engineer's Estimate
8. Engineering, Design, and Construction Oversight (25%)				$55,000	Engineer's Estimate
9. Contingencies (20%)				$44,000	Engineer's Estimate
10. TOTAL CAPITAL COSTS				**$330,000**	

TABLE D.4 (CON'T)
HYDRAULIC CONTAINMENT
WITH GROUNDWATER TREATMENT VIA UV / HYDROGEN PEROXIDE OXIDATION
REMEDIAL ALTERNATIVE COST ESTIMATE

ANNUAL OPERATING AND MAINTENANCE COSTS

Item	Unit	Quantity	Unit Cost	Total Cost	Cost Reference
1. System O&M and Influent / Effluent Monitoring					
a. System Inspection & Maintenance Each Two Weeks	HRS/YR	208	$50	$10,000	Engineer's Estimate
b. Replacement Parts, Supplies, Materials	LS	1	$1,500	$1,500	Engineer's Estimate
c. Equipment for System Monitoring and Repair	LS	1	$4,000	$4,000	Engineer's Estimate
d. Annual 50% Hydrogen Peroxide Solution Purchase	LB	2400	$0.50	$1,200	Vendor/Engineer's Estimate
e. UV Lamp Replacement	LS	1	$8,000	$8,000	Vendor/Engineer's Estimate
f. Electricity and Phone Service	LS	1	$23,900	$23,900	Engineer's Estimate
g. Monthly Influent and Effluent Water Sample Analyses	TEST	24	$250	$6,000	Engineer's Estimate
h. Monthly Reporting, Evaluation	HRS/YR	48	$70	$3,400	Engineer's Estimate
i. Redevelopment of Recovery Wells Every 2 Years	LS/YR	1	$4,000	$4,000	Engineer's Estimate
j. Disposal of Filter Elements, Sump Sludge, Reactor Sludge	GAL	100	$3.00	$300	Engineer's Estimate
Item 1 Subtotal				$62,000	
2. O&M Contingency (50% of non-electric costs) (Non-electric costs = Item 1 Subtotal - Line Item 1.f)				$19,000	
3. Annual O&M Total				$81,000	
TOTAL PRESENT WORTH OF THE HYDRAULIC CONTAINMENT WITH GROUNDWATER TREATMENT VIA UV / HYDROGEN PEROXIDE OXIDATION ALTERNATIVE (30 years at a 3.8% Discount Rate) [PW=17.63*Annual O&M + Capital Cost]				**$1,800,000**	
TOTAL PRESENT WORTH OF CONTINUED IRM OPERATION AT AOC 5, 7, AND 16 [Refer to Table D.1]				$620,000	
COMBINED PRESENT WORTH OF ALTERNATIVE AND CONTINUED IRM OPERATION				**$2,420,000**	

ASSUMPTIONS FOR HYDRAULIC CONTAINMENT WITH GROUNDWATER TREATMENT VIA UV/HYDROGEN PEROXIDE OXIDATION COST ESTIMATE

GENERAL

1. This cost estimate includes both capital and operating and maintenance (O&M) expenses. The present worth cost was estimated assuming a project life of 30 years and a 3.8% discount rate as per the NYSDEC TAGM 4030. The calculation for the discount rate is attached to this appendix. In the development of construction cost estimates, unit costs were obtained from vendor quotations, standard cost estimating documents (Means 1996 Cost Data), and from Parsons ES experience with similar projects.
2. Values are rounded where appropriate.

CAPITAL COSTS

Item 1 - Pre-Design Investigation

It was assumed that the following information would need to be collected prior to the design of any remedial alternative:

1) A more detailed definition of VOC groundwater at the northern edge of the paved area of the FRP-2 paved area. This information would be obtained via screen point or piezometer groundwater sampling at approximately every 50 feet.
2) Inorganic Groundwater Data. This information would be obtained through groundwater analyses.

Based on recent quotations from drillers for similar work, the drilling cost to collect 6 groundwater samples from three different locations at two varying depths was estimated at $2,600 using a Geoprobe and screen point or piezometer sampling. The groundwater VOC and inorganic analytical cost for 8 samples (six piezometers plus two existing wells), based on recent analytical work conducted on groundwater samples from the site, was estimated at $6,100.

Item 2 - Site Preparation

Site preparation includes site grading and stone placement for a new treated water discharge outfall and the removal of a 22' x 22' area of asphalt in order to install a 21' x 21' concrete pad for a 20' x 20' treatment building.

Item 3 - Installation of Four Recovery Wells and Four Piezometers

Installation of recovery wells and piezometers includes all labor, materials (casing, screen, sand, bentonite, and finishing materials, etc.), and construction equipment use

(drill rig, personal protective equipment, decontamination equipment, etc.) necessary for the on-site installation of four recovery wells. Recovery wells are assumed to be 35 foot deep, 4 inch diameter stainless steel. Piezometer wells are assumed to be 35 foot deep, 2 inch diameter PVC.

Item 4 - Installation of Groundwater Collection and Transfer System

Installation of the groundwater collection and transfer system includes all labor, materials and construction equipment use necessary to provide the following:

- well pumps with level controls;
- piping from four recovery wells to the treatment building and from the treatment building to a nearby discharge outfall (including supports, insulation, and heat tracing for all outdoor piping);
- electrical service with an assumed origin at the north end of the former maintenance building which includes two poles, a main power conductor cable, entrance cap, conduit, meter socket, transformer, and circuit breaker load center;
- electrical system controls in a weatherproof control panel which includes motor starters, fault relays, indicator lights, and hand switches; and
- mobilization/demobilization and miscellaneous charges incurred from the mechanical contractor.

Item 5 - Installation of Groundwater Treatment System - UV/Hydrogen Peroxide Oxidation

Installation of the groundwater treatment system includes all labor, materials, and construction equipment use necessary for the construction of a 20' x 20' pre-designed treatment building (with explosion-proof heating, explosion-proof lighting, and security fencing); the subsequent installation of a packaged high-intensity UV/hydrogen peroxide reactor system (Rayox Model 30-1 30 kW reactor) with power supply, controls, instrumentation, and hydrogen peroxide feed; and mobilization/demobilization and miscellaneous charges incurred from the mechanical contractor.

Item 7 - Estimated System Start-up Labor Costs

Estimated system start-up costs provide for eight days of a technician's time and six days of an engineer's time to troubleshoot and closely monitor the initial operation of the newly installed system.

ANNUAL O&M COSTS

Item 1 - System O&M and Influent / Effluent Monitoring

System O&M and monitoring includes periodic visits by a technician to perform maintenance and adjustment of the system, engineering oversight and occasional direct involvement in system operation, and the collection and off-site laboratory analysis of influent and effluent groundwater samples for volatile organic compounds (by method

EPA 8240) and iron. Monthly progress reports to the NYSDEC regarding system discharge volume and effluent quality are included in the estimate.

Item 3 - O&M Contingency

As experienced through actual O&M activities for treatment systems of similar size and purpose, it is typical to encounter periodic systems errors and breakdowns related to the unexpected failure of electrical controls, fouling of sensors and instruments, fouling of valves, power outages, and other unforeseen causes. The resolution of this type of problem often requires development of documentation for NYSDEC submittal and coordination with subcontractors. Therefore, the O&M contingency is significant percentage of the total anticipated O&M cost. The O&M contingency is higher for UV/hydrogen peroxide oxidation than for air stripping due to greater system complexity.

TABLE D.5
HYDRAULIC CONTAINMENT WITH GROUNDWATER TREATMENT VIA EX SITU BIOLOGICAL DEGRADATION REMEDIAL ALTERNATIVE COST ESTIMATE

CAPITAL COST

Item	Unit	Quantity	Unit Cost	Total Cost	Cost Reference
1. Pre-Design Investigation	LS	1	$8,700	$8,700	Engineer's Estimate
2. Site Preparation					
a. Placement of Stone for System Discharge	LS	1	$1,000	$1,000	Engineer's Estimate
b. Asphalt Removal for Treatment Building Concrete Pad	SY	60	$6.60	$400	Means
c. Project H&S Equipment	LS	1	$2,000	$2,000	Engineer's Estimate
d. Project H&S Monitoring	LS	1	$3,000	$3,000	Engineer's Estimate
Item 2 Subtotal				$6,400	
3. Installation of Four Recovery Wells and Four Piezometers					
a. Mobilization / Demobilization of Drilling Equipment	LS	1	$400	$400	Vendor Quote
b. Construct & Remove Temporary Decon Pad	LS	1	$200	$200	Vendor Quote
c. Four 4" S.S. Wells, complete	LS	1	$12,400	$12,000	Vendor Quote
d. Four 2" Piezometer Wells, complete	LS	1	$4,500	$4,500	Vendor Quote
e. Decontamination Activities, Staging Drums Per Well	EA	4	$300	$1,200	Vendor Quote
Item 3 Subtotal				$18,000	
4. Installation of Groundwater Collection and Transfer System					
a. Submersible Electric Pump with Level Controls	EA	4	$1,200	$4,800	Engineer's Estimate
b. Process Piping, Supports, Insulation, Heat Cable	LS	1	$17,600	$18,000	Means/Engineer's Estimate
c. Central Sump, Pump, Float Control, Bag Filter, Meter	LS	1	$4,200	$4,200	Engineer's Estimate
d. Electrical Service Connection, Conduits, Control Panel	LS	1	$21,200	$21,000	Means/Engineer's Estimate
e. Mobilization / Demobilization & Miscellaneous	LS	1	$5,000	$5,000	Engineer's Estimate
Item 4 Subtotal				$53,000	
5. Installation of Groundwater Treatment System - Biological Fixed-Film Reactors					
a. Treatability Testing	LS	1	$3,000	$3,000	Engineer's Estimate
b. Concrete Pad for Pre-Designed Building, CIP, Reinforced	SF	480	$6.12	$2,900	Means
c. Treatment Building (20'x20'x16'H) with Expl.-Proof Heat	LS	1	$30,000	$30,000	Engineer's Estimate
d. Fluidized Bed Aerobic Reactor System, Complete	LS	1	$125,000	$130,000	Vendor Quote
e. Security Fence with Gates (3 sides, 40'x60' area)	LS	1	$1,700	$1,700	Means
Item 5 Subtotal				$170,000	
6. Construction, Materials, and Equipment Subtotal				$260,000	
7. Estimated System Start-Up Labor Costs				$10,000	Engineer's Estimate
8. Engineering, Design, and Construction Oversight (25%)				$65,000	Engineer's Estimate
9. Contingencies (20%)				$52,000	Engineer's Estimate
10. TOTAL CAPITAL COSTS				**$390,000**	

TABLE D.5 (CON'T)
HYDRAULIC CONTAINMENT
WITH GROUNDWATER TREATMENT VIA EX SITU BIOLOGICAL DEGRADATION
REMEDIAL ALTERNATIVE COST ESTIMATE

ANNUAL OPERATING AND MAINTENANCE COSTS

Item	Unit	Quantity	Unit Cost	Total Cost	Cost Reference
1. System O&M and Influent / Effluent Monitoring					
a. System Inspection & Maintenance Each Two Weeks	HRS/YR	208	$50	$10,000	Engineer's Estimate
b. Replacement Parts, Supplies, Materials	LS	1	$1,500	$1,500	Engineer's Estimate
c. Equipment for System Monitoring and Repair	LS	1	$4,000	$4,000	Engineer's Estimate
d. Annual Bulk Nutrient Purchase	LB	300	$1.00	$300	Vendor/Engineer's Estimate
e. Annual Bulk Organic Co-substrate Purchase	LB	400	$0.75	$300	Vendor/Engineer's Estimate
f. Monthly Influent and Effluent Water Sample Analyses	TEST	24	$250	$6,000	Engineer's Estimate
g. Electricity and Phone Service	LS	1	$5,820	$5,800	Engineer's Estimate
h. Monthly Reporting, Evaluation	HRS/YR	48	$70	$3,400	Engineer's Estimate
i. Redevelopment of Recovery Wells Every 2 Years	LS/YR	1	$4,000	$4,000	Engineer's Estimate
j. Disposal of Filter Elements, Sump and Reactor Sludge	GAL	100	$3.00	$300	Engineer's Estimate
Item 1 Subtotal				$36,000	
2. O&M Contingency (50%)				$18,000	
3. Annual O&M Total				$54,000	
TOTAL PRESENT WORTH OF THE HYDRAULIC CONTAINMENT WITH GROUNDWATER TREATMENT VIA AIR STRIPPING ALTERNATIVE (30 years at a 3.8% Discount Rate) [PW=17.63*Annual O&M + Capital Cost]				**$1,300,000**	
TOTAL PRESENT WORTH OF CONTINUED IRM OPERATION AT AOC 5, 7, AND 16 [Refer to Table D.1]				$620,000	
COMBINED PRESENT WORTH OF ALTERNATIVE AND CONTINUED IRM OPERATION				**$1,920,000**	

ASSUMPTIONS FOR HYDRAULIC CONTAINMENT WITH GROUNDWATER TREATMENT VIA *EX SITU* BIOLOGICAL DEGRADATION COST ESTIMATE

GENERAL

1. This cost estimate includes both capital and operating and maintenance (O&M) expenses. The present worth cost was estimated assuming a project life of 30 years and a 3.8% discount rate as per the NYSDEC TAGM 4030. The calculation for the discount rate is attached to this appendix. In the development of construction cost estimates, unit costs were obtained from vendor quotations, standard cost estimating documents (Means 1996 Cost Data), and from Parsons ES experience with similar projects.
2. Values are rounded where appropriate.

CAPITAL COSTS

Item 1 - Pre-Design Investigation

It was assumed that the following information would need to be collected prior to the design of any remedial alternative:

1) A more detailed definition of VOC concentration in groundwater at the northern edge of the paved area of the FRP-2 paved area. This information would be obtained via screen point or piezometer groundwater sampling at approximately every 50 feet.

2) Inorganic Groundwater Data. This information would be obtained through groundwater analyses.

Based on recent quotations from drillers for similar work, the drilling cost to collect 6 groundwater samples from three different locations at two varying depths was estimated at $2,600 using a Geoprobe and screen point or piezometer sampling. The groundwater VOC and inorganic analytical cost for 8 samples (six piezometers plus two existing wells), based on recent analytical work conducted on groundwater samples from the site, was estimated at $6,100.

Item 2 - Site Preparation

Site preparation includes site grading and stone placement for a new treated water discharge outfall and the removal of a 22' x 22' area of asphalt in order to install a 21' x 21' concrete pad for a 20' x 20' treatment building.

Item 3 - Installation of Four Recovery Wells and Four Piezometers

Installation of recovery wells and piezometers includes all labor, materials (casing, screen, sand, bentonite, and finishing materials, etc.), and construction equipment use

(drill rig, personal protective equipment, decontamination equipment, etc.) necessary for the on-site installation of four recovery wells. Recovery wells are assumed to be 35 foot deep, 4 inch diameter stainless steel. Piezometer wells are assumed to be 35 foot deep, 2 inch diameter PVC.

Item 4 - Installation of Groundwater Collection and Transfer System

Installation of the groundwater collection and transfer system includes all labor, materials and construction equipment use necessary to provide the following:

- well pumps with level controls;
- piping from four recovery wells to the treatment building and from the treatment building to a nearby discharge outfall (including supports, insulation, and heat tracing for all outdoor piping);
- electrical service with an assumed origin at the north end of the former maintenance building which includes two poles, a main power conductor cable, entrance cap, conduit, meter socket, transformer, and circuit breaker load center;
- electrical system controls in a weatherproof control panel which includes motor starters, fault relays, indicator lights, and hand switches; and
- mobilization/demobilization and miscellaneous charges incurred from the mechanical contractor.

Item 5 - Installation of Groundwater Treatment System - *Ex Situ* Biological Degradation

Installation of the groundwater treatment system includes all labor, materials, and construction equipment use necessary for the construction of a 20' x 20' pre-designed treatment building (with 16' interior ceiling, explosion-proof heating, explosion-proof lighting, and security fencing); the subsequent installation of a packaged, 2-foot diameter fluidized bed upflow biological reactor (by Envirogen, Inc.) with controls, instrumentation, day tank and feed systems for cometabolite and nutrient solutions; and mobilization/demobilization and miscellaneous charges incurred from the mechanical contractor.

Item 7 - Estimated System Start-up Labor Costs

Estimated system start-up costs provide for eight days of a technician's time and six days of an engineer's time to troubleshoot and closely monitor the initial operation of the newly installed system.

ANNUAL O&M COSTS

Item 1 - System O&M and Influent / Effluent Monitoring

System O&M and monitoring includes periodic visits by a technician to perform maintenance and adjustment of the system, engineering oversight and occasional direct involvement in system operation, and the collection and off-site laboratory analysis of influent and effluent groundwater samples for volatile organic compounds (by method

EPA 8240) and iron. Monthly progress reports to the NYSDEC regarding system discharge volume and effluent quality are included in the estimate.

Item 3 - O&M Contingency

As experienced through actual O&M activities for treatment systems of similar size and purpose, it is typical to encounter periodic systems errors and breakdowns related to the unexpected failure of electrical controls, fouling of sensors and instruments, fouling of valves, power outages, and other unforeseen causes. The resolution of this type of problem often requires development of documentation for NYSDEC submittal and coordination with subcontractors. Therefore, the O&M contingency is significant percentage of the total anticipated O&M cost. The O&M contingency is higher for *ex situ* biological degradation than for air stripping due to greater system complexity.

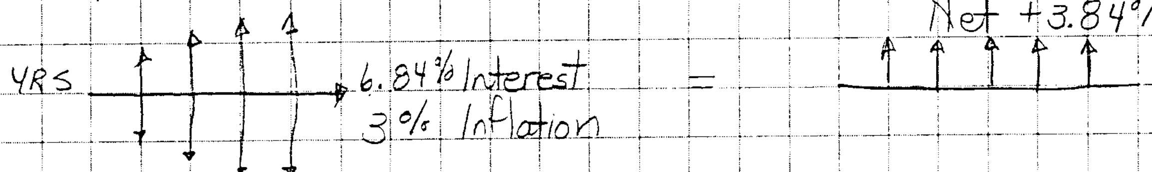
PARSONS ENGINEERING SCIENCE, INC.

Client LMC
Subject Farrell Road FS
Discount Rate Calculation
Job No.
By JMH
Checked
Sheet 1 of
Date 11/1/96
Rev.

In accordance with NYSDEC TAGM 4030, a discount rate equivalent to the 30-year U.S. Treasury bond rate before taxes and after inflation should be used in determining the present worth of an alternative.

- As of 10/23/96: 30-Year Treasury Bond = 6.84% (Wall Street Journal, 10/23/96)
  Inflation ≈ 3.00%
  Discount Rate 3.84%

The discount rate is equal to the Treasury Bond rate (6.84%) minus the inflation rate (3%). A cash flow diagram of this situation is presented below:



According to page 2-3 of the Civil Engineering Reference Manual, 1989, the formula for equal series present worth is:

$$PW = \frac{(1+i)^n - 1}{i(1+i)^n} = \frac{(1+0.0384)^{30} - 1}{(0.0384)(1+0.0384)^{30}} = 17.63$$

where i = net interest
n = years

Therefore, the formula for Present Worth will be:

$$P_W = P_C + 17.63 P_{O\&M}$$

where: P_W = Present Worth
P_C = Capital Costs
$P_{O\&M}$ = Operation and Maintenance Costs

The Wall Street Journal, Wednesday, October 23, 1996

TREASURY BONDS, NOTES & BILLS

NOTICE TO READERS

The Federal Reserve Bank of New York City no longer provides quotations for Treasury issues. The new source for Bond, Note and Bill quotes is Dow Jones Telerate/Cantor Fitzgerald.

Tuesday, October 22, 1996

Representative and Indicative Over-the-Counter quotations based on $1 million or more.

Treasury bond, note and bill quotes are as of mid-afternoon. Colons in bond and note bid-and-asked quotes represent 32nds; 101:01 means 101 1/32. Net changes in 32nds. Treasury bill quotes in hundredths, quoted in terms of a rate discount. Days to maturity calculated from settlement date. All yields are based on a one-day settlement and calculated on the offer quote. Current 13-week and 26-week bills are boldfaced. For bonds callable prior to maturity, yields are computed to the earliest call date for issues quoted above par and to the maturity date for issues quoted below par. n-Treasury note. wi-When Issued; daily change is expressed in basis points.

Source: Dow Jones Telerate/Cantor Fitzgerald.

U.S. Treasury strips as of 3 p.m. Eastern time, also based on transactions of $1 million or more. Colons in bid-and-asked quotes represent 32nds; 99:01 means 99 1/32. Net changes in 32nds. Yields calculated on the asked quotation. ci-stripped coupon interest. bp-Treasury bond, stripped principal. np-Treasury note, stripped principal. For bonds callable prior to maturity, yields are computed to the earliest call date for issues quoted above par and to the maturity date for issues below par.

Source: Bear, Stearns & Co. via Street Software Technology Inc.

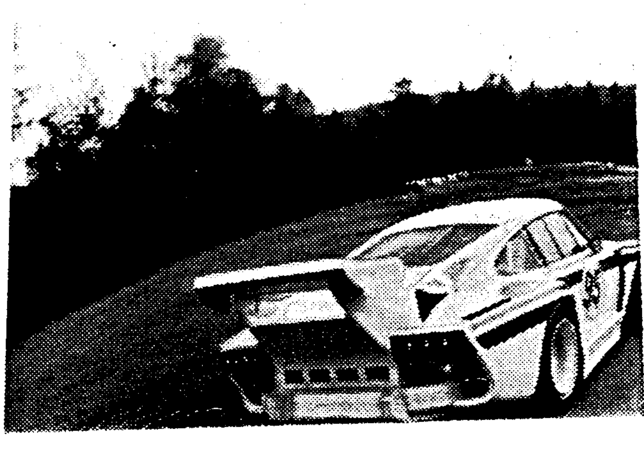
GOVT. BONDS & NOTES

Rate	Maturity Mo/Yr	Bid	Asked	Chg.	Ask Yld.
6 7/8	Oct 96n	100:00	100:02	....	3.87
4 3/8	Nov 96n	99:29	99:31	....	4.78
7 1/4	Nov 96n	100:03	100:05	....	4.60
6 1/2	Nov 96n	100:03	100:05	....	4.86
7 1/4	Nov 96n	100:05	100:07	....	4.99
6 1/8	Dec 96n	100:06	100:08	+ 1	4.69
7 1/2	Dec 96n	100:12	100:14	– 1	5.03
8	Jan 97n	100:18	100:20	– 1	5.12
6 1/4	Jan 97n	100:07	100:09	....	5.13
7 1/2	Jan 97n	100:17	100:19	– 1	5.20
4 3/4	Feb 97n	99:24	99:26	....	5.31
6 3/4	Feb 97n	100:15	100:17	....	5.17
6 7/8	Feb 97n	100:16	100:18	....	5.20
6 5/8	Mar 97n	100:16	100:18	....	5.29
6 7/8	Mar 97n	100:19	100:21	....	5.31
8 1/2	Apr 97n	101:13	101:15	....	5.34
6 1/2	Apr 97n	100:16	100:18	....	5.39
6 7/8	Apr 97n	100:22	100:24	....	5.39
6 1/2	May 97n	100:17	100:19	....	5.41
8 1/2	May 97n	101:20	101:22	....	5.40
6 1/8	May 97n	100:09	100:11	– 1	5.53
6 3/4	May 97n	100:21	100:23	– 1	5.51
5 5/8	Jun 97n	100:01	100:03	– 1	5.47
6 3/8	Jun 97n	100:17	100:19	– 1	5.47
8 1/2	Jul 97n	102:01	102:03	– 1	5.51
5 1/2	Jul 97n	99:30	100:00	....	5.49
5 7/8	Jul 97n	100:06	100:08	– 1	5.53
6 1/2	Aug 97n	100:21	100:23	– 1	5.57
8 5/8	Aug 97n	102:11	102:13	– 1	5.54
5 5/8	Aug 97n	99:31	100:01	....	5.58
6	Aug 97n	100:08	100:10	– 1	5.61
5 1/2	Sep 97n	99:28	99:30	– 1	5.56
5 3/4	Sep 97n	100:03	100:05	....	5.57
8 3/4	Oct 97n	102:28	102:30	– 1	5.62
5 5/8	Oct 97n	99:30	100:00	– 1	5.62
5 3/4	Oct 97n	100:02	100:04	– 1	5.62
7 3/8	Nov 97n	101:21	101:23	– 1	5.68
8 7/8	Nov 97n	103:06	103:08	– 1	5.67
5 3/8	Nov 97n	99:20	99:22	....	5.67
6	Nov 97n	100:09	100:11	– 1	5.67
5 1/4	Dec 97n	99:14	99:16	– 1	5.68
6	Dec 97n	100:10	100:12	– 1	5.66
7 7/8	Jan 98n	102:14	102:16	– 2	5.73
5	Jan 98n	99:01	99:03	– 1	5.74
5 5/8	Jan 98n	99:25	99:27	– 1	5.75
7 1/4	Feb 98n	101:24	101:26	– 1	5.79
8 1/8	Feb 98n	102:28	102:30	– 1	5.76
5 1/8	Feb 98n	99:03	99:05	– 1	5.78
5 1/8	Mar 98n	99:02	99:04	– 1	5.77
6 1/8	Mar 98n	100:13	100:15	– 1	5.78
7 7/8	Apr 98n	102:26	102:28	– 2	5.82
5 1/8	Apr 98n	98:30	99:00	– 1	5.82
5 7/8	Apr 98n	100:01	100:03	– 1	5.81
6 1/8	May 98n	100:13	100:14	– 1	5.82
9	May 98n	104:19	104:21	– 2	5.83
5 3/8	May 98n	99:07	99:09	– 1	5.85
6	May 98n	100:06	100:07	– 1	5.85
5 1/8	Jun 98n	98:25	98:27	– 1	5.85
6 1/4	Jun 98n	100:19	100:20	– 1	5.85
8 1/4	Jul 98n	103:24	103:26	– 2	5.89
5 1/4	Jul 98n	98:28	98:30	– 1	5.88
6 1/4	Jul 98n	100:18	100:19	– 1	5.89
5 7/8	Aug 98n	99:27	99:29	– 2	5.92
9 1/4	Aug 98n	105:18	105:20	– 2	5.92
4 3/4	Aug 98n	97:29	97:31	– 2	5.92
6 1/8	Aug 98n	100:11	100:12	– 2	5.90
4 3/4	Sep 98n	97:28	97:30	– 1	5.89
6	Sep 98n	100:03	100:04	– 2	5.93
7 1/8	Oct 98n	102:04	102:06	– 2	5.94
	Oct 98wi	5:90	5:89	....	....
4 3/4	Oct 98n	97:22	97:24	– 2	5.95
3 1/2	Nov 98	98:20	99:20	– 2	3.69
5 1/2	Nov 98n	99:01	99:03	– 2	5.97
8 7/8	Nov 98n	105:16	105:18	– 2	5.96
5 1/8	Nov 98n	98:10	98:12	– 2	5.95
5 1/8	Dec 98n	98:08	98:10	– 2	5.95
6 3/8	Jan 99n	100:24	100:26	– 3	5.97
5	Jan 99n	97:27	97:29	– 3	5.99
5	Feb 99n	97:27	97:28	– 2	5.99
8 7/8	Feb 99n	106:01	106:03	– 3	6.01
5 1/2	Feb 99n	98:28	98:30	– 2	5.99
5 7/8	Mar 99n	99:21	99:23	– 3	6.00
7	Apr 99n	102:05	102:07	– 3	6.02
6 1/2	Apr 99n	101:01	101:03	– 3	6.03
6 3/8	May 99n	100:23	100:24	– 3	6.05
9 1/8	May 99n	107:03	107:05	– 3	6.06
6 3/4	May 99n	101:18	101:20	– 3	6.06
6 3/4	Jun 99n	101:20	101:22	– 3	6.06
6 3/8	Jul 99n	100:24	100:26	– 3	6.04
6 7/8	Jul 99n	101:28	101:30	– 3	6.10
6	Aug 99n	99:24	99:25	– 3	6.08
8	Aug 99n	104:24	104:26	– 3	6.11
6 7/8	Aug 99n	101:31	102:00	– 4	6.10
7 1/8	Sep 99n	102:21	102:23	– 3	6.10
6	Oct 99n	99:24	99:26	– 3	6.07
7 1/2	Oct 99n	103:22	103:24	– 3	6.12
7 7/8	Nov 99n	104:24	104:26	– 4	6.13
7 3/4	Nov 99n	104:14	104:16	– 4	6.13
7 3/4	Dec 99n	104:17	104:19	– 3	6.14
6 3/8	Jan 00n	100:20	100:22	– 4	6.13
7 3/4	Jan 00n	104:18	104:20	– 4	6.16
8 1/2	Feb 00n	106:27	106:29	– 3	6.16
7 1/8	Feb 00n	102:25	102:27	– 4	6.17
6 7/8	Mar 00n	102:02	102:04	– 4	6.18
5 1/2	Apr 00n	97:27	97:29	– 4	6.18
6 3/4	Apr 00n	101:22	101:24	– 3	6.19
8 7/8	May 00n	108:14	108:16	– 4	6.18
6 1/4	May 00n	100:04	100:06	– 3	6.19
5 7/8	Jun 00n	98:28	98:30	– 4	6.20
6 1/8	Jul 00n	99:21	99:23	– 4	6.21
8 3/4	Aug 00n	108:13	108:15	– 4	6.22
6 1/4	Aug 00n	100:01	100:03	– 4	6.22
6 1/8	Sep 00n	99:19	99:21	– 3	6.22
5 3/4	Oct 00n	98:07	98:09	– 5	6.24
8 1/2	Nov 00n	107:30	108:00	– 5	6.24
5 5/8	Nov 00n	97:23	97:25	– 4	6.24
5 1/2	Dec 00n	97:06	97:08	– 4	6.25
5 1/4	Jan 01n	96:16	96:18	– 4	6.18
7 3/4	Feb 01n	105:15	105:17	– 5	6.26
11 3/4	Feb 01	120:14	120:20	– 5	6.22
5 5/8	Feb 01n	97:18	97:20	– 4	6.25
6 3/8	Mar 01n	100:12	100:13	– 4	6.27
6 1/4	Apr 01n	99:27	99:29	– 4	6.27
8	May 01n	106:23	106:25	– 4	6.27
13 1/8	May 01	126:23	126:29	– 6	6.25
6 1/2	May 01n	100:26	100:27	– 4	6.28
6 5/8	Jun 01n	101:09	101:10	– 5	6.29
6 5/8	Jul 01n	101:09	101:11	– 5	6.29
7 7/8	Aug 01n	106:13	106:15	– 5	6.29
13 3/8	Aug 01	128:30	129:04	– 6	6.27
6 1/2	Aug 01n	100:25	100:26	– 4	6.30
6 3/8	Sep 01n	100:09	100:10	– 5	6.30
	Oct 01wi	6:24	6:23	....	....

Mat.	Type	Bid	Asked	Chg.	Ask Yld.
7 1/2	Nov 01n	105:01	105:03	– 5	6.31
15 3/4	Nov 01	140:12	140:18	– 7	6.27
14 1/4	Feb 02	135:10	135:16	– 7	6.28
7 1/2	May 02n	105:14	105:16	– 5	6.31
6 3/8	Aug 02n	100:03	100:05	– 5	6.34
11 5/8	Nov 02	126:01	126:07	– 6	6.35
6 1/4	Feb 03n	99:06	99:08	– 5	6.39
10 3/4	Feb 03	122:03	122:09	– 5	6.40
10 3/4	May 03	122:22	122:28	– 5	6.42
5 3/4	Aug 03n	96:08	96:10	– 6	6.42
11 1/8	Aug 03	125:10	125:16	– 6	6.44
11 7/8	Nov 03	130:04	130:10	– 7	6.46
5 7/8	Feb 04n	96:17	96:19	– 6	6.46
7 1/4	May 04n	104:16	104:18	– 6	6.48
12 3/8	May 04	134:17	134:23	– 7	6.49
7 1/4	Aug 04n	104:16	104:18	– 6	6.49
13 3/4	Aug 04	143:20	143:26	– 8	6.51
7 7/8	Nov 04n	108:12	108:14	– 7	6.51
11 5/8	Nov 04	131:16	131:22	– 8	6.51
7 1/2	Feb 05n	106:06	106:07	– 6	6.52
6 1/2	May 05n	99:26	99:28	– 6	6.52
8 1/4	May 00-05	105:12	105:14	– 3	6.51
12	May 05	135:06	135:12	– 9	6.54
6 1/2	Aug 05n	99:21	99:23	– 8	6.54
10 3/4	Aug 05	127:18	127:24	– 9	6.55
5 7/8	Nov 05n	95:14	95:16	– 7	6.54
5 5/8	Feb 06n	93:26	93:28	– 8	6.51
9 3/8	Feb 06	119:14	119:18	– 11	6.54
6 7/8	May 06n	102:06	102:07	– 9	6.56
7	Jul 06n	103:01	103:02	– 9	6.57
6 1/2	Oct 06n	99:19	99:20	– 9	6.55
7 5/8	Feb 02-07	104:14	104:16	– 1	6.60
7 7/8	Nov 02-07	107:02	107:04	– 5	6.44
8 3/8	Aug 03-08	110:05	110:09	– 7	6.48
8 3/4	Nov 03-08	111:24	111:28	– 6	6.62
9 1/8	May 04-09	114:18	114:22	– 8	6.62
10 3/8	Nov 04-09	122:30	123:04	– 9	6.63
11 3/4	Feb 05-10	132:08	132:14	– 9	6.61
10	May 05-10	121:18	121:24	– 9	6.63
12 3/4	Nov 05-10	140:30	141:04	– 10	6.64
13 7/8	May 06-11	150:11	150:17	– 10	6.65
14	Nov 06-11	153:02	153:08	– 12	6.65
10 3/8	Nov 07-12	127:21	127:27	– 10	6.76
12	Aug 08-13	141:29	142:03	– 11	6.77
13 1/4	May 09-14	153:28	154:02	– 13	6.79
12 1/2	Aug 09-14	148:06	148:12	– 13	6.79
11 3/4	Nov 09-14	142:17	142:23	– 13	6.77
11 1/4	Feb 15	145:08	145:14	– 15	6.86
10 5/8	Aug 15	139:00	139:06	– 15	6.88
9 7/8	Nov 15	131:06	131:12	– 15	6.89
9 1/4	Feb 16	124:22	124:28	– 14	6.90
7 1/4	May 16	103:16	103:18	– 12	6.91
7 1/2	Nov 16	106:04	106:06	– 12	6.92
8 3/4	May 17	119:21	119:27	– 14	6.93
8 7/8	Aug 17	121:03	121:09	– 14	6.93
9 1/8	May 18	124:05	124:11	– 15	6.93
9	Nov 18	122:30	123:04	– 15	6.94
8 7/8	Feb 19	121:19	121:25	– 14	6.94
8 1/8	Aug 19	113:07	113:11	– 13	6.95
8 1/2	Feb 20	117:20	117:24	– 14	6.95
8 3/4	May 20	120:17	120:23	– 15	6.95
8 3/4	Aug 20	120:19	120:25	– 15	6.95
7 7/8	Feb 21	110:19	110:23	– 13	6.95
8 1/8	May 21	113:18	113:22	– 14	6.95
8 1/8	Aug 21	113:19	113:23	– 14	6.96
8	Nov 21	112:06	112:10	– 14	6.95
7 1/4	Aug 22	103:15	103:17	– 14	6.95
7 5/8	Nov 22	108:00	108:02	– 13	6.95
7 1/8	Feb 23	102:01	102:03	– 13	6.95
6 1/4	Aug 23	91:19	91:21	– 12	6.94
7 1/2	Nov 24	107:01	107:03	– 14	6.92
7 5/8	Feb 25	108:23	108:25	– 14	6.91
6 7/8	Aug 25	99:25	99:28	– 12	6.88
6	Feb 26	89:03	89:05	– 12	6.86
6 3/4	Aug 26	98:26	98:27	– 14	6.84

U.S. TREASURY STRIPS

Mat.	Type	Bid	Asked	Chg.	Ask Yld.
Nov 96	ci	99:22	99:23	....	4.95
Nov 96	np	99:22	99:22	....	5.03
Feb 97	ci	98:12	98:12	....	5.32
May 97	ci	97:02	97:03	....	5.36
May 97	np	97:01	97:01	....	5.45
Aug 97	ci	95:24	95:24	....	5.42
Aug 97	np	95:21	95:22	....	5.53
Nov 97	ci	94:08	94:08	– 1	5.65
Nov 97	np	94:08	94:09	– 1	5.64
Jan 98	ci	93:07	93:08	– 1	5.77
Feb 98	ci	92:24	92:25	– 1	5.79
Feb 98	np	92:25	92:26	– 1	5.76
May 98	ci	91:13	91:14	– 1	5.82
May 98	np	91:13	91:14	– 1	5.81
Aug 98	ci	90:01	90:03	– 1	5.85
Aug 98	np	89:30	90:00	– 1	5.91
Nov 98	ci	88:19	88:21	– 1	5.93
Nov 98	np	88:18	88:20	– 1	5.95
Feb 99	ci	87:06	87:08	– 2	5.99
Feb 99	np	87:06	87:08	– 2	6.00
May 99	ci	85:26	85:28	– 2	6.04
May 99	np	85:25	85:27	– 3	6.06
Aug 99	ci	84:14	84:17	– 2	6.08
Aug 99	np	84:12	84:15	– 4	6.10
Nov 99	ci	83:03	83:05	– 3	6.12
Nov 99	np	83:02	83:05	– 3	6.12
Feb 00	ci	81:25	81:28	– 2	6.14
Feb 00	np	81:23	81:25	– 4	6.17
May 00	ci	80:16	80:19	– 2	6.15
May 00	np	80:14	80:17	– 4	6.17
Jul 00	ci	79:18	79:21	– 3	6.20
Aug 00	ci	79:06	79:09	– 3	6.19
Aug 00	np	79:03	79:05	– 4	6.23
Nov 00	ci	77:30	78:01	– 3	6.21
Nov 00	np	77:26	77:29	– 4	6.24
Jan 01	ci	77:02	77:05	– 3	6.23
Feb 01	ci	76:22	76:25	– 4	6.23
Feb 01	np	76:17	76:20	– 5	6.27
May 01	ci	75:14	75:17	– 4	6.25
May 01	np	75:10	75:13	– 4	6.29
Jul 01	ci	74:18	74:21	– 4	6.28
Aug 01	ci	74:06	74:10	– 4	6.27
Aug 01	np	74:02	74:06	– 5	6.31
Nov 01	ci	73:00	73:03	– 4	6.29
Nov 01	np	72:27	72:30	– 5	6.33
Jan 02	ci	72:06	72:09	– 4	6.31
Feb 02	ci	71:27	71:30	– 4	6.30
May 02	ci	70:21	70:25	– 5	6.32
May 02	np	70:19	70:23	– 6	6.33
Jul 02	ci	69:26	69:30	– 4	6.34
Aug 02	ci	69:16	69:20	– 5	6.33
Aug 02	np	69:13	69:17	– 6	6.35
Nov 02	ci	68:10	68:14	– 5	6.36
Jan 03	ci•	67:15	67:18	– 5	6.39
Feb 03	ci	67:01	67:05	– 5	6.41
Feb 03	np	67:00	67:04	– 6	6.42
May 03	ci	65:28	66:00	– 5	6.44
Jul 03	ci	65:06	65:10	– 6	6.43
Aug 03	ci	64:24	64:29	– 6	6.45
Aug 03	np	64:23	64:27	– 7	6.46
Nov 03	ci	63:21	63:25	– 6	6.47
Jan 04	ci	62:27	62:31	– 5	6.51
Feb 04	ci	62:14	62:18	– 5	6.52
Feb 04	np	62:16	62:20	– 5	6.51
May 04	ci	61:09	61:14	– 5	6.55
May 04	np	61:13	61:17	– 5	6.53
Jul 04	ci	60:20	60:24	– 6	6.55
Aug 04	ci	60:08	60:12	– 6	6.57
Aug 04	np	60:11	60:15	– 5	6.55
Nov 04	ci	59:04	59:09	– 6	6.59
Nov 04	bp	59:01	59:06	– 6	6.61
Nov 04	np	59:09	59:13	– 6	6.57
Jan 05	ci	58:14	58:18	– 6	6.61
Feb 05	ci	58:03	58:07	– 6	6.61
Feb 05	np	58:09	58:13	– 6	6.58
May 05	ci	57:02	57:06	– 6	6.63
May 05	bp	56:31	57:04	– 6	6.65
May 05	np	57:12	57:17	– 7	6.57
Jul 05	ci	56:13	56:18	– 6	6.64
Aug 05	ci	56:03	56:08	– 6	6.64
Aug 05	bp	56:01	56:05	– 6	6.66
Aug 05	np	56:12	56:17	– 6	6.58
Nov 05	ci	55:03	55:07	– 6	6.66
Nov 05	bp	55:15	55:20	– 6	6.58
Jan 06	ci	54:13	54:17	– 6	
Feb 06	ci	54:02	54:07	– 6	
Feb 06	bp	54:15	54:20	– 4	
May 06	ci	53:04	53:08	– 6	
Jul 06	ci	52:16	52:21	– 6	
Aug 06	ci	52:06	52:11	– 6	
Nov 06	ci	51:08	51:13	– 6	
Feb 07	ci	50:09	50:14	– 6	
May 07	ci	49:12	49:17	– 6	
Aug 07	ci	48:17	48:22	– 6	
Nov 07	ci	47:21	47:26	– 6	
Feb 08	ci	46:25	46:30	– 6	
May 08	ci	45:29	46:02	– 6	
Aug 08	ci	45:03	45:08	– 6	
Nov 08	ci	44:09	44:14	– 6	
Feb 09	ci	43:14	43:19	– 8	
May 09	ci	42:20	42:25	– 7	
Aug 09	ci	41:28	42:01	– 7	
Nov 09	ci	41:04	41:09	– 6	
Nov 09	bp	40:20	40:25	– 6	
Feb 10	ci	40:11	40:16	– 6	
May 10	ci	39:18	39:23	– 7	
Aug 10	ci	38:27	39:00	– 7	
Nov 10	ci	38:04	38:09	– 7	
Feb 11	ci	37:14	37:19	– 6	
May 11	ci	36:23	36:28	– 7	
Aug 11	ci	36:02	36:07	– 7	
Nov 11	ci	35:12	35:17	– 7	
Feb 12	ci	34:23	34:28	– 7	
May 12	ci	34:03	34:08	– 7	
Aug 12	ci	33:14	33:19	– 7	
Nov 12	ci	32:26	32:31	– 6	7.03
Feb 13	ci	32:06	32:11	– 7	7.04
May 13	ci	31:19	31:24	– 7	7.05
Aug 13	ci	31:01	31:06	– 7	7.05
Nov 13	ci	30:14	30:19	– 7	7.06
Feb 14	ci	29:28	30:01	– 7	7.07
May 14	ci	29:10	29:15	– 7	7.08
Aug 14	ci	28:25	28:30	– 7	7.09
Nov 14	ci	28:08	28:12	– 7	7.09
Feb 15	ci	27:23	27:28	– 6	7.10
Feb 15	bp	27:31	28:03	– 7	7.05
May 15	ci	27:07	27:12	– 6	7.11
Aug 15	ci	26:23	26:28	– 6	7.11
Aug 15	bp	26:27	26:31	– 7	7.09
Nov 15	ci	26:08	26:12	– 6	7.11
Nov 15	bp	26:10	26:15	– 7	7.10
Feb 16	ci	25:24	25:29	– 6	7.12
Feb 16	bp	25:26	25:31	– 6	7.11
May 16	ci	25:09	25:14	– 6	7.13
May 16	bp	25:17	25:22	– 6	7.07
Aug 16	ci	24:26	24:31	– 6	7.13
Nov 16	ci	24:12	24:16	– 6	7.14
Nov 16	bp	24:18	24:22	– 6	7.09
Feb 17	ci	23:30	24:02	– 5	7.14
May 17	ci	23:16	23:20	– 5	7.14
May 17	bp	23:17	23:21	– 6	7.13
Aug 17	ci	23:02	23:07	– 6	7.14
Aug 17	bp	23:03	23:08	– 6	7.14
Nov 17	ci	22:21	22:26	– 5	7.14
Feb 18	ci	22:08	22:12	– 5	7.15
May 18	ci	21:27	22:00	– 5	7.15
May 18	bp	21:28	22:00	– 5	7.14
Aug 18	ci	21:15	21:19	– 5	7.15
Nov 18	ci	21:03	21:07	– 5	7.15
Nov 18	bp	21:03	21:08	– 6	7.15
Feb 19	ci	20:23	20:27	– 5	7.16
Feb 19	bp	20:23	20:28	– 5	7.15
May 19	ci	20:11	20:15	– 5	7.16
Aug 19	ci	20:01	20:05	– 5	7.15
Aug 19	bp	20:02	20:06	– 5	7.14
Nov 19	ci	19:21	19:26	– 5	7.15
Feb 20	ci	19:10	19:14	– 5	7.15
Feb 20	bp	19:10	19:14	– 5	7.15
May 20	ci	18:31	19:03	– 5	7.15



GOVERNMENT AGENCY & SIMILAR ISSUES

FNMA Issues

Rate	Mat.	Bid	Asked	Yld.
5	11-96	100:00	100:02	4.02
5	12-96	100:00	100:02	4.77
7	12-96	100:09	100:11	4.85
8	12-96	100:14	100:16	4.99
5.30	12-96	99:31	100:01	5.03

Tuesday, October 22, 1996

Over-the-Counter mid-afternoon quotations based on large transactions, usually $1 million or more. Colons in bid-and-asked quotes represent 32nds; 101:01 means 101 1/32.

All yields are calculated to maturity, and based on the asked quote. • – Callable issue, maturity date shown. For is-

D-28

Federal ank

Rate	M			Yld.
5.45	11-96	100:00	100:02	2.21
5.33	11-96	100:00	100:02	2.06
5.60	11-96	100:00	100:02	2.32