FEASIBILITY STUDY REPORT

OPERABLE UNIT II
123 POST AVENUE
WESTBURY, NASSAU COUNTY, NEW YORK
(SITE N0. 1-30-088)

WORK ASSIGNMENT NO. D003600-23

Prepared For

New York State Department of Environmental Conservation

APRIL 2004

DVIRKA AND BARTILUCCI
CONSULTING ENGINEERS
A DIVISION OF WILLIAM F. COSULICH ASSOCIATES, P.C.

RLA/OPER1B60(01/12/04)

FEASIBILITY STUDY REPORT

123 POST AVENUE SITE - OPERABLE UNIT 2
WESTBURY, NEW YORK

SITE REGISTRY NO. 1-30-088

Prepared For

**NEW YORK STATE DEPARTMENT
OF ENVIRONMENTAL CONSERVATION**

By

**DVIRKA AND BARTILUCCI CONSULTING ENGINEERS
WOODBURY, NEW YORK**

APRIL 2004

THOMAS F. MAHER
No. 054488
LICENSED PROFESSIONAL ENGINEER

FEASIBILITY STUDY REPORT
123 POST AVENUE SITE - OPERABLE UNIT 2
WESTBURY, NEW YORK

TABLE OF CONTENTS

Section Title Page

1.0 INTRODUCTION 1-1

1.1 Purpose 1-1
1.2 Site Background 1-2
1.2.1 Summary of Previous On-site Investigations 1-2
1.2.2 Summary of Off-site Investigations 1-4
1.3 Remedial Investigation Results 1-5
1.4 Exposure Assessment Results 1-13
1.5 Remedial Action Objectives 1-14
1.6 Feasibility Study Description 1-19
1.7 Feasibility Study Approach 1-23

2.0 IDENTIFICATION AND SCREENING OF REMEDIAL TECHNOLOGIES 2-1

2.1 Introduction 2-1
2.2 No Action 2-1
2.3 Institutional Controls 2-2
2.4 Groundwater Remediation Technologies 2-2
2.4.1 Extraction and Treatment 2-2
2.4.2 In-situ Treatment 2-4
2.4.2.1 Air Sparging 2-4
2.4.2.2 In-well Air Stripping 2-5
2.4.2.3 Bioremediation 2-6
2.4.2.4 Chemical Oxidation 2-7
2.4.2.5 Ozone-enhanced Air Sparging 2-9
2.4.2.6 Reactive Walls 2-10
2.4.2.7 Chemical Reduction 2-10
2.4.2.8 Funnel and Gate 2-11
2.4.2.9 Natural Attenuation 2-12
2.5 Summary Evaluation of Remediation Technologies 2-13

3.0 TREATABILITY STUDY 3-1

TABLE OF CONTENTS (continued)

Section Title Page

4.0 DEVELOPMENT AND PRELIMINARY EVALUATION OF ALTERNATIVES 4-1

4.1 Description of Remedial Alternatives 4-1
4.1.1 Alternative 1 – No Action with Long-term Groundwater Monitoring 4-1
4.1.2 Alternative 2 – In-situ Chemical Oxidation with Long-term Groundwater Monitoring 4-2
4.1.3 Alternative 3 – In-situ Bioremediation with Long-term Groundwater Monitoring 4-4
3.1.4 Alternative 4 – Ozone-enhanced Air Sparging with Long-term Groundwater Monitoring 4-6
4.2 Preliminary Evaluation of Remedial Alternatives 4-9
4.2.1 Alternative 1 4-9
4.2.2 Alternative 2 4-10
4.2.3 Alternative 3 4-11
4.2.4 Alternative 4 4-12
4.3 Summary Evaluation of Alternatives 4-12

5.0 DETAILED ANALYSIS OF ALTERNATIVES 5-1

5.1 Protection of Human Health and the Environment 5-2
5.2 Compliance with Standards, Criteria and Guidelines/ARARs 5-3
5.3 Short-term Impacts and Effectiveness 5-4
5.4 Long-term Effectiveness and Permanence 5-6
5.5 Reduction of Toxicity, Mobility or Volume Through Treatment 5-8
5.6 Implementability 5-9
5.7 Cost 5-10
5.8 Community Acceptance 5-12

List of Appendices

Chemical Oxidation Bench Scale Test Report .... A

Detailed Cost Estimate .... B

TABLE OF CONTENTS (continued)

List of Figures

1-1 Site Location Map 1-3
1-2 Locations of Subsurface Data Points 1-7
1-3 Horizontal Extent of PCE, TCE and 1,2-DCE in Groundwater 1-10
1-4 Vertical Distribution of PCE, TCE and 1,2-DCE in Groundwater 1-11

List of Tables

1-1 Potentially Applicable Chemical Specific ARARs/TBCs 1-15
1-2 Potentially Applicable Location Specific ARARs/TBCs 1-16
1-3 Potentially Applicable Action Specific ARARs/TBCs 1-17

2-1 Initial Screening of Remediation Technologies 2-14

4-1 Summary of Preliminary Evaluation of Remedial Alternatives 4-14

5-1 Alternatives Cost Summary 5-11
5-1 Summary of Remedial Alternative Comparative Analysis 5-13

Section 1

1.0 INTRODUCTION

This section presents the purpose of the feasibility study for the 123 Post Avenue Site - Operable Unit 2 (OU2), a description of the site, summary of the remedial investigation results and risk assessment, definition of the remedial action objectives and approach to the feasibility study.

1.1 Purpose

As part of New York State's program to investigate and remediate hazardous waste sites, the New York State Department of Environmental Conservation (NYSDEC) issued a Work Assignment to Dvirka and Bartilucci Consulting Engineers (D&B) of Woodbury, New York, under its Superfund Standby Contract with NYSDEC, to conduct a remedial investigation (RI) and feasibility study (FS) to evaluate groundwater quality downgradient of an active dry cleaning facility located at 123 Post Avenue in the Village of Westbury, Nassau County, New York . The off-site groundwater evaluation is being conducted as Operable Unit 2 (OU2) of the site RI/FS with funds allocated under the New York State Superfund Program. Investigation and remediation of soil and groundwater contamination on the 123 Post Avenue Site is being conducted by the property owner as Operable Unit 1.

The objectives of the OU2 RI/FS are to evaluate and characterize groundwater quality downgradient of the 123 Post Avenue Site; determine the extent of off-site contamination; evaluate potential impacts to human health and the environment; determine the need for corrective action; identify and evaluate remedial alternatives; and select a long-term, cost-effective remediation plan.

This feasibility study has been prepared based on the results of the remedial investigation and in accordance with the federal Comprehensive Emergency Response, Compensation and Liability Act (CERCLA), Superfund Amendments and Reauthorization Act (SARA), and the New York State Superfund Program, including the NYSDEC Technical and Administrative

Guidance Memorandum (TAGM HWR-90-4030) for "Selection of Remedial Actions at Inactive Hazardous Waste Sites."

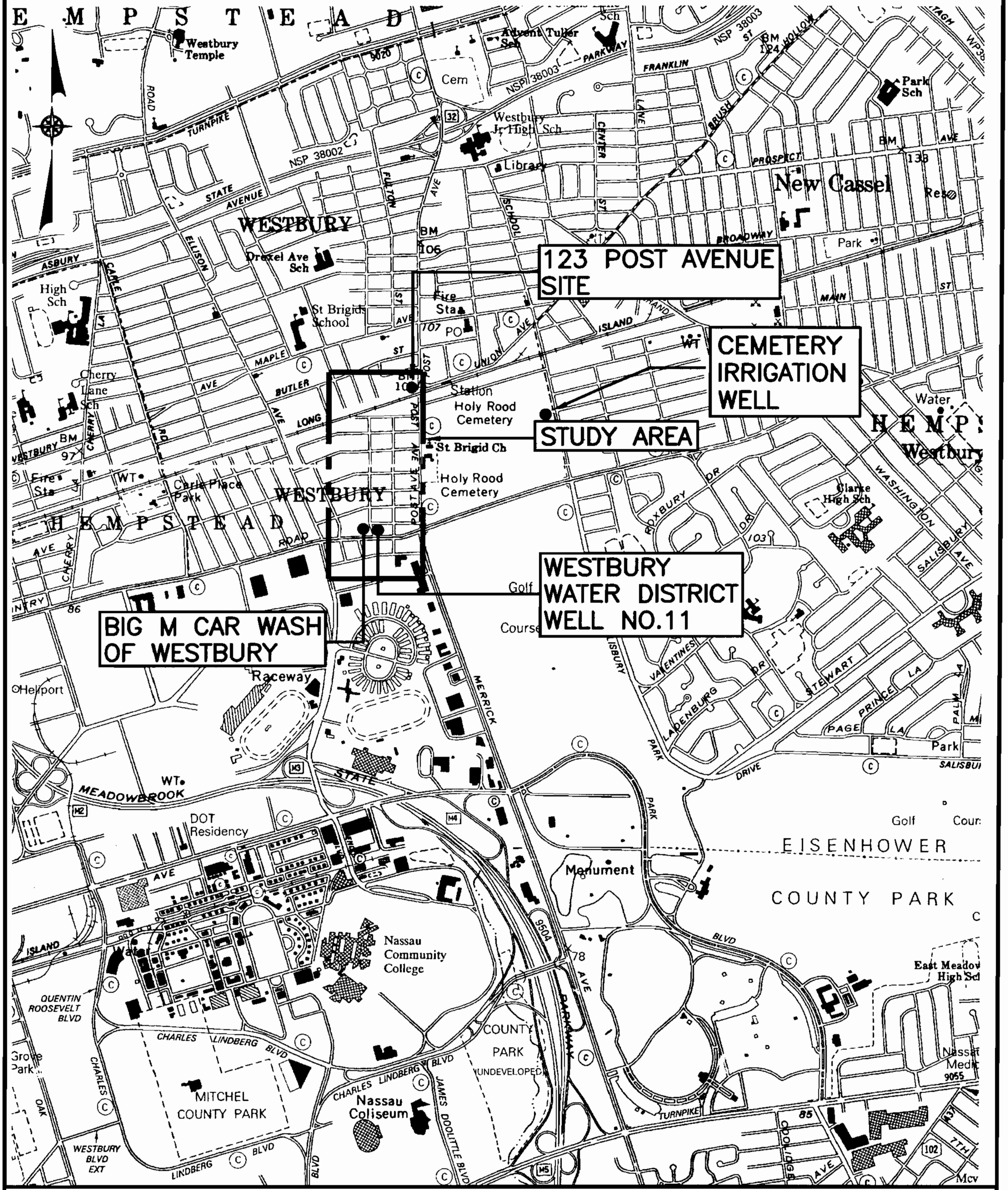
1.2 Site Background

The site is an active dry cleaning facility (Westbury Valet Dry Cleaners) located at 123 Post Avenue in the Village of Westbury, Nassau County, New York. The site location and study area are shown on Figure 1-1. The dry cleaner property is approximately 0.2 acres in size and is bounded by a small shopping center to the north, the Long Island Railroad (LIRR) elevated tracks to the south, Post Avenue to the east and an apartment complex to the west. As shown on Figure 1-1, the study area for OU2 extends from north of the site to just south of Old Country Road approximately 2,200 feet downgradient from the dry cleaner property. This portion of the study area south of the LIRR tracks and north of Old Country Road is primarily residential. Commercial businesses, an assisted living facility, offices and a parking lot occupy the western side of Post Avenue within the study area, and a LIRR station, cemeteries and a church occupy the eastern side of Post Avenue. Commercial businesses occupy the area along and south of Old Country Road.

The study area is served by municipal public water, sanitary and storm water sewer systems. The surrounding residential and commercial/industrial area is also served by public water and municipal sewer systems. Storm water flows from catch basins in the streets into a recharge basin located several miles south of the study area.

1.2.1 Summary of Previous On-site Investigations

The building at the site was constructed in 1949 with at least one expansion in 1957. The building has been occupied by a dry cleaner since at least 1957. The building was connected to the municipal sanitary sewer system in 1979 or 1980. Prior to this time, wastewater generated on-site was apparently discharged to an on-site sanitary system.



123 POST AVENUE FEASIBILITY STUDY–OPERABLE UNIT 2
WESTBURY, NEW YORK

SITE LOCATION MAP

Dvirka and Bartilucci
CONSULTING ENGINEERS
A DIVISION OF WILLIAM F. COSULICH ASSOCIATES, P.C.

FIGURE 1–1

F:\1860\1860-1A.dwg, 01/15/04 08:15:43 AM, LGlubiak

An inspection performed by the Nassau County Department of Health (NCDH) in July 1995 revealed the presence of two floor drains in the western portion of the building. Soil samples were collected from the floor drains and the results of the analysis indicated the presence of tetrachloroethene (PCE) at concentrations up to 5,800 mg/kg and trichloroethene (TCE) at concentrations up to 40 mg/kg.

Contaminated soil was excavated from beneath each of the floor drains and clean endpoint samples were collected from one of the floor drains, however, since additional soil removal could not be conducted at the second floor drain due to concerns about undermining the building foundation, soil vapor extraction was recommended for remediation of the remaining soil contamination. Ten drums (7,000 pounds) of PCE-contaminated soil from the floor drains were transported for off-site disposal as hazardous waste. Based on these results, the site was placed on the New York State Registry of Inactive Hazardous Waste Sites.

Subsequent investigations at the site included installation of one upgradient and two downgradient wells to evaluate groundwater quality, and construction of soil borings inside and outside the building to further investigate soil contamination. A 4-well soil vapor extraction system has been operating at the site since May 2001. Recent sampling of the on-site groundwater wells has indicated low to non-detectable levels of volatile organics in the groundwater. Based on this recent sampling and the effective operation of the on-site soil vapor extraction system, the remediation of the on-site source is essentially complete.

1.2.2 Summary of Previous Off-site Investigations

During a property transfer investigation conducted at 117 Post Avenue, immediately south of the LIRR tracks that form the southern boundary of the site, seven monitoring wells were installed and elevated levels of PCE were detected in each of the seven wells.

In May 1998, TCE was detected in Westbury Water District Well No. 11 south of the site at a concentration of 1.0 ug/l. Since then, TCE consistently has been detected in Well No. 11 at levels below the New York State drinking water standard of 5 ug/l. Trace concentrations of

1,2-dichloroethene (1,2-DCE) also have been sporadically detected in Well No. 11. There is currently no treatment on Well No. 11.

In October 2000, a groundwater sample was collected by the NCDH from the water supply well at the Big M Car Wash of Westbury located south of the site. PCE, chloroform and methyl tert-butyl ether were found at detectable levels.

Periodic sampling of ambient indoor air has been performed by the NCDH and NYSDEC at locations surrounding the site since 2000. PCE concentrations above the New York State Department of Health (NYSDOH) exposure limit for residential properties were detected in samples collected from the basement of the shopping center immediately north of the site and from an apartment on the first floor of the apartment building immediately west of the site. Since the impacted off-site properties are located outside the area of highly contaminated groundwater in the upgradient and sidegradient directions, the detected PCE is likely attributable to migration through the unsaturated zone, rather than volatilization from the groundwater. Air filtration units were installed by the NCDH and NYSDEC in the basement of the adjacent shopping center and the impacted apartment for several months until PCE concentrations were less than the NYSDOH exposure limit. It is likely that operation of the on-site SVE system has reduced the migration of vapors to off-site buildings.

1.3 Remedial Investigation Results

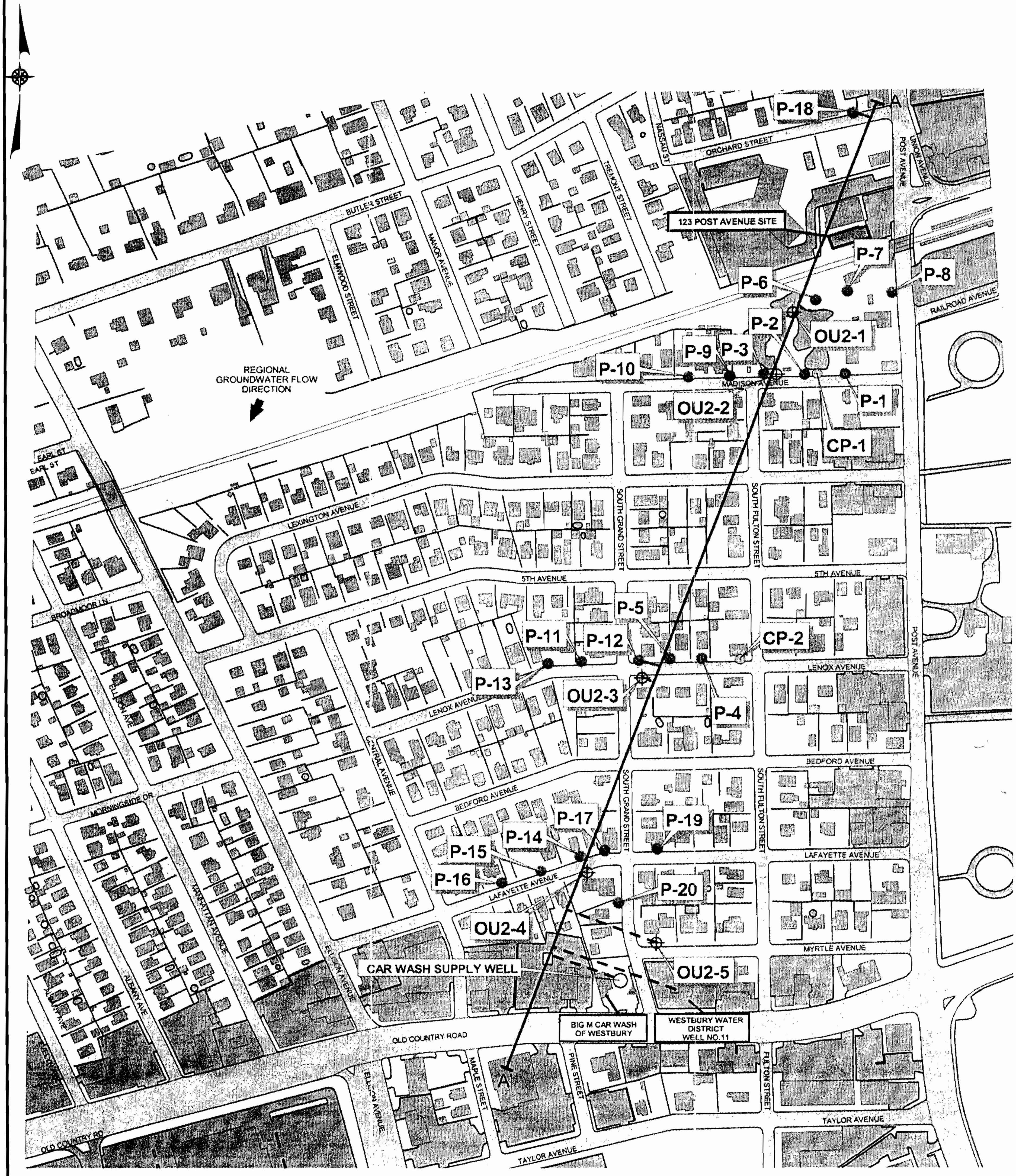
The following is a summary of the findings and conclusions resulting from the remedial investigation and risk assessment conducted for the 123 Post Avenue Site - OU2 as a function of the media investigated. These findings and conclusions are based on comparison of the investigation results to standards, criteria and guidelines (SCGs) selected for the site. The results of the investigation are described in detail in the Remedial Investigation Report, dated July 2002.

Site Geology

In the vicinity of the study area, the Lloyd Magothy and Upper Glacial sediments form the major aquifers, while the Raritan confining unit separates the Lloyd and Magothy aquifers, and limits flow into and out of the Lloyd aquifer. The Lloyd aquifer is approximately 250 feet thick and consists of gravel, sand, sandy clay and clay. The Raritan confining unit is approximately 100 feet thick and is comprised of clay and silty clay. The Magothy aquifer is approximately 550 feet thick and consists of gravel, sand and sandy to solid clay. Gravel layers are common at the base of the Magothy aquifer. The Upper Glacial sediments are approximately 100 feet thick and are comprised of glacial outwash deposits, including fine to coarse sands and gravels with local layers of clay.

The Upper Glacial sediments found during the RI within the study area generally consist of fine to coarse sand with varying amounts of silt and gravel. The primary unit observed during field activities was fine-to-medium grained sand. Soil conductivity performed during the RI show that the upper 115 feet of glacial sediments in the study area consist of sand with little variation.

A clay layer was identified below the glacial sediments in the central and southern portions of the study area. The clay layer was encountered at approximately 115 feet below ground surface in the borings for permanent wells OU2-3 and OU2-4, located approximately 1,200 and 1,700 feet south-southwest of the site, respectively (see Figure 1-2). Clay was not identified in the boring for well OU2-5 to a depth of 130 feet below ground surface. The driller's log for the Big M Car Wash supply well shows fine-to-medium sand to 65 feet below ground surface and a gray clay from 66 to 120 feet below ground surface, which was the bottom of the borehole. The log for Westbury Water District Well No. 11 shows a unit consisting of sand, brown clay and iron oxide from 82 to 136 feet below ground surface, and four clay layers, ranging from 4 to 31 feet thick, between depths of 136 and 260 feet below ground surface. These logs indicate that the clay layers are not continuous in the southern portion of the study area. As such, the clay would possibly limit, but not prevent, vertical migration of contaminants.



BASEMAP COPYRIGHT, 1993, COUNTY OF NASSAU, NY.

LEGEND

CP–1 ● SOIL CONDUCTIVITY PROBE HOLE LOCATION AND DESIGNATION

P–1 ● GROUNDWATER PROBE HOLE SAMPLE LOCATION AND DESIGNATION

OU2–1 ⊕ GROUNDWATER MONITORING WELL LOCATION AND DESIGNATION

A├──┤A' LINE OF GEOLOGIC CROSS SECTION

0 200' 400'

HORIZONTAL SCALE: 1"=200'

F:\1860\1860-7.dwg, 01/16/04 12:18:52 PM, LGlubiak

Dvirka
and
Bartilucci
CONSULTING ENGINEERS
A DIVISION OF WILLIAM F. COSULICH ASSOCIATES, P.C.

123 POST AVENUE FEASIBILITY STUDY-OPERABLE UNIT 2
WESTBURY, NEW YORK

LOCATIONS OF SUBSURFACE DATA POINTS

FIGURE 1-2

Site Hydrogeology

During the RI, the water table in the study area was encountered at depths ranging from 39.4 to 45.6 feet below ground surface. The groundwater elevations measured in the five monitoring wells constructed during the RI (OU2-1 through OU2-5) were highest in the northernmost well OU2-1 (62.30 feet) and lowest in the southernmost well OU2-5 (59.7 feet), indicating a southerly direction of groundwater flow. Since the permanent well locations were selected based on the direct push groundwater sample results, the wells were installed in a nearly linear configuration. As a result, a groundwater elevation contour map could not be prepared. However, based on the VOC results from the direct push groundwater sample locations discussed below, which define a narrow contaminant plume and regional groundwater flow direction, groundwater flow within the study area is toward the south-southwest.

Groundwater Quality

Based on previous investigations conducted at the 123 Post Avenue Site and the groundwater sample results from RI, three chlorinated compounds typically associated with dry cleaner sites, PCE, TCE and 1,2-DCE, have been identified as contaminants of concern. PCE is used as a dry cleaning solvent, and TCE and 1,2-DCE are breakdown products of PCE.

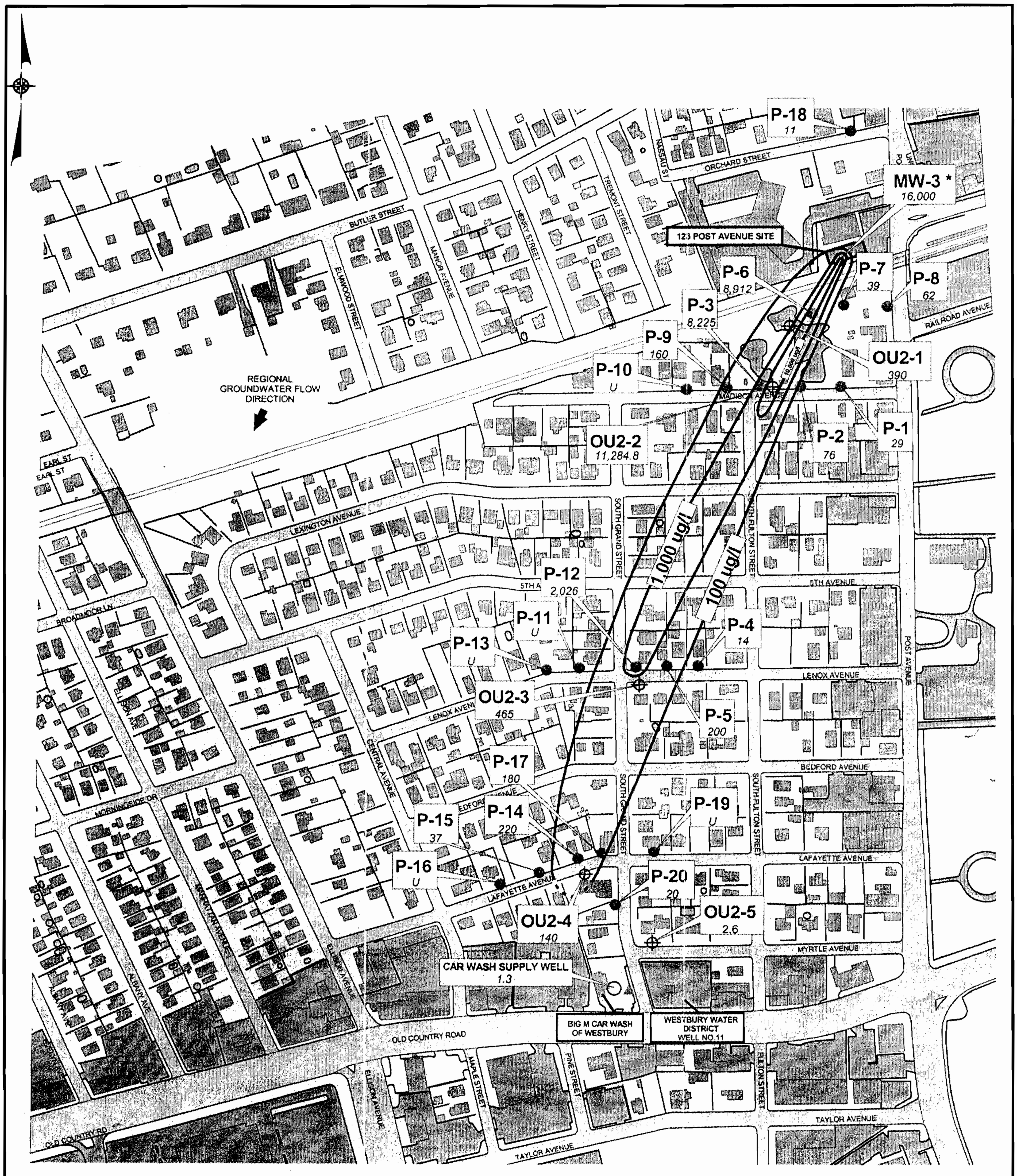
For most direct push samples, the VOCs detected were PCE, TCE and/or 1,2-DCE. The only other VOCs detected in any of the direct push samples were 1,1,2-trichloroethane (1,1,2-TCA) in three samples, chloroform in one sample and methyl tert-butyl ether (MTBE) in six samples. The detections of 1,1,2-TCA were in the three samples containing the highest total VOC concentrations, suggesting that the 1,1,2-TCA may also be associated with the 123 Post Avenue Site. MTBE was detected in upgradient and in the southern portion of the study area, and is attributable to a gasoline release upgradient of the site.

Thirteen compounds other than PCE, TCE or 1,2-DCE were detected in samples collected from the monitoring wells. However, only two of these compounds were detected at concentrations exceeding NYSDEC Class GA groundwater standards or guidance values. These were methacrylonitrile detected in well OU2-2 at 9 ug/l (compared to the standard of 5 ug/l), and acetone detected in well OU2-2 at 670 ug/l and in well OU2-4 at 130 ug/l. Since acetone is a common laboratory contaminant and was not detected in any of the direct push groundwater samples, the detection of acetone is not considered to be related to the site.

The concentrations of total targeted VOCs (PCE, TCE and 1,2-DCE) in direct push and monitoring well samples range from non-detect to 11,294.8 ug/l. The greatest concentrations of targeted VOCs were detected nearest the site at the 117 Post Avenue property (P-6) and immediately south on Madison Avenue (P-3 and OU2-2). Concentrations of total targeted VOCs decrease to the south-southwest, downgradient of the site. In addition, the depth of the zone most highly impacted by the targeted VOCs increases to the south-southwest.

The approximate horizontal extent of total targeted VOCs detected in probe holes and monitoring wells in the study area is shown on Figure 1-3. For each probe hole, the maximum concentration of total targeted VOCs is shown. The chlorinated VOC plume is depicted by total targeted VOC contours of 100 ug/l, 1,000 ug/l and 10,000 ug/l, and extends from the 123 Post Avenue Site in a south-southwest direction. The plume is fairly narrow (as delineated by 100 ug/l contour), with approximate dimensions of 200 feet wide by at least 1,800 feet long (extending to south of Lafayette Avenue). At probe hole P-18, upgradient of the site, the total maximum targeted VOC concentration was 11 ug/l.

The vertical distribution of PCE, TCE and 1,2-DCE in groundwater within the study area is depicted in cross-sectional view on Figure 1-4. The cross-section is oriented along the center axis of the identified plume parallel to groundwater flow. The cross section shown on Figure 1-4 indicates that the plume emanates from the vicinity of the 123 Post Avenue Site and gradually sinks within the aquifer toward the south-southwest. Based on the detected VOC concentrations, the plume appears to be sinking at a rate of approximately 1 vertical foot per 10 horizontal feet. The maximum thickness of the plume (total targeted VOCs greater than 100 ug/l) is approximately 60 feet. The thickness of the more concentrated plume (total VOCs greater than 1,000 ug/l) is approximately 35 to 40 feet.



BASEMAP COPYRIGHT, 1993, COUNTY OF NASSAU, NY.

LEGEND

● GROUNDWATER PROBE HOLE LOCATION

⊕ PERMANENT MONITORING WELL LOCATION AND DESIGNATION

P-4 *14*	PROBE HOLE DESIGNATION MAXIMUM TOTAL PCE, TCE AND 1,2-DCE CONCENTRATION (ug/l)
U	UNDETECTED
*	ON-SITE WELL SAMPLED BY OTHERS ON OCTOBER 3, 2000

0 200' 400'

HORIZONTAL SCALE: 1"=200'

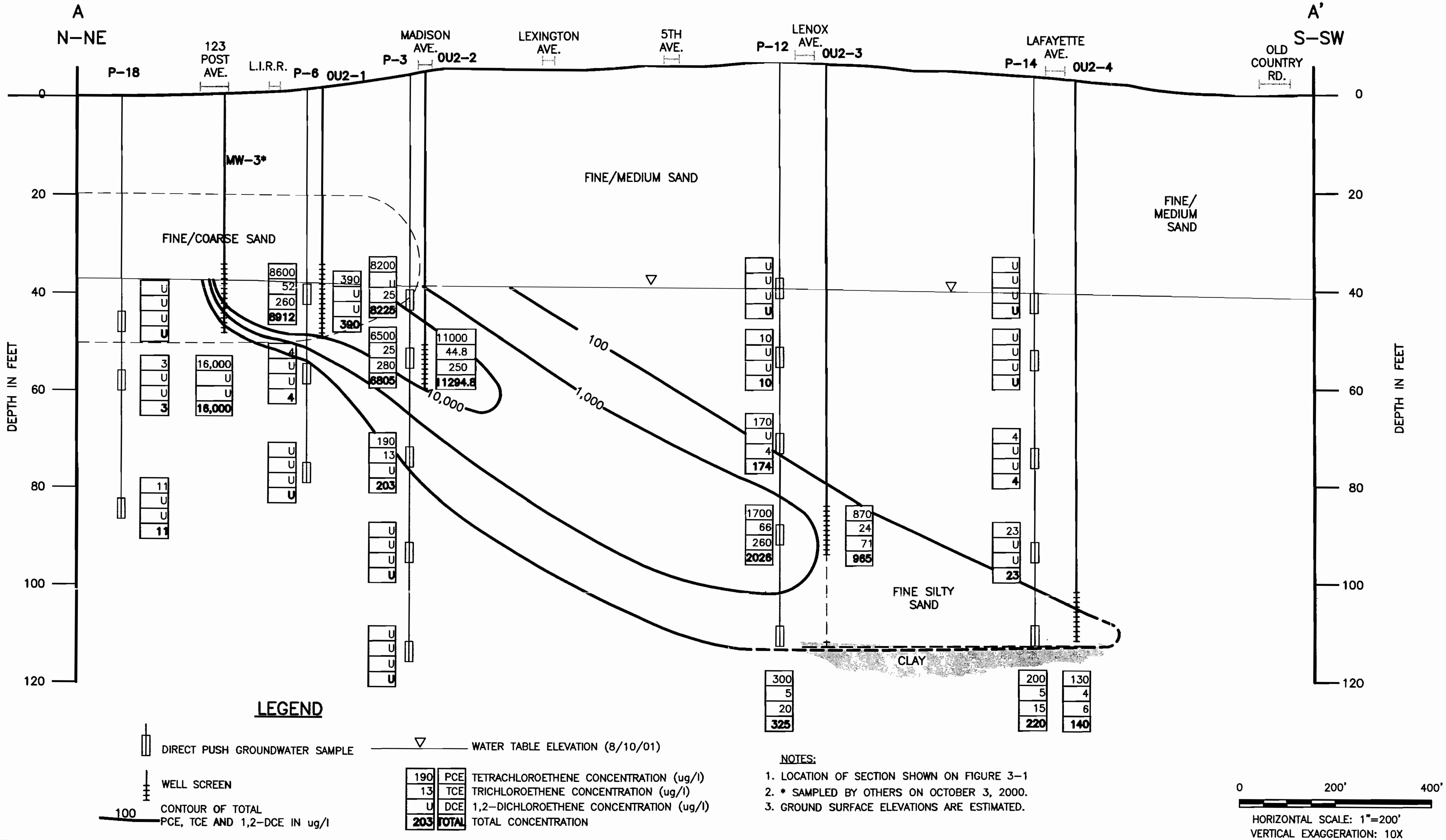
Dvirka
and
Bartilucci
CONSULTING ENGINEERS
A DIVISION OF WILLIAM F. COSULICH ASSOCIATES, P.C.

123 POST AVENUE FEASIBILITY STUDY-OPERABLE UNIT 2
WESTBURY, NEW YORK

HORIZONTAL EXTENT OF PCE, TCE AND 1,2 DCE IN GROUNDWATER

FIGURE 1-3

F:\1860\1860-6.dwg, 01/16/04 12:10:43 PM, LGlubiak



NOTES:

1. LOCATION OF SECTION SHOWN ON FIGURE 3–1
2. * SAMPLED BY OTHERS ON OCTOBER 3, 2000.
3. GROUND SURFACE ELEVATIONS ARE ESTIMATED.

123 POST AVENUE FEASIBILITY STUDY–OPERABLE UNIT 2
WESTBURY, NEW YORK

DISTRIBUTION OF PCE, TCE AND 1,2 DCE IN GROUNDWATER

Dvirka and Bartilucci
Consulting Engineers
A Division of William F. Cosulich Associates, P.C.

FIGURE 1–4

A feature which apparently mitigates the vertical migration and extent of the plume is the clay layer observed at approximately 115 feet below ground surface in the southern portion of the study area at monitoring wells OU2-3 and OU2-4. Although significant clay was not noted at well OU2-5 to a depth of 130 feet below ground surface, the driller's log for Westbury Water District Well No. 11 shows sand, brown clay and iron oxide from 82 to 136 feet below ground surface, and four clay layers from 4 to 31 feet thick between 136 and 260 feet below ground surface. In addition, the driller's log of the Big M Car Wash supply well shows clay from approximately 65 feet to the bottom of the well borehole at 120 feet below ground surface.

One groundwater sample was also collected for analysis of iron and manganese. This sample was collected from well OU2-3 located near the center of the plume. OU2-3 is screened from 90 to 100 feet below ground surface. The iron and manganese concentrations from the unfiltered sample were 450 and 760 ug/l, respectively. Although these concentrations are above the NYSDEC Class GA groundwater standard of 300 ug/l, the results are typical for groundwater within the Upper Glacial aquifer on Long Island.

Recent Groundwater Sampling Results

In October 2002, samples were collected from groundwater monitoring wells OU2-2, OU2-3, OU2-4 and OU2-5, and analyzed for volatile organic compounds. OU2-1 could not be located at this time and was not monitored. The concentrations of total targeted VOCs from this round of sampling ranged from nondetect to 4,770 ug/l. The highest concentration of VOCs was detected in OU2-2. In November 2003, groundwater samples were again collected from each of the five permanent monitoring wells. The results of the analysis indicated total targeted VOCs at concentrations of 1 ug/l in OU2-5 and 5,710 ug/l in OU2-2. Although the results of the recent groundwater sampling indicate lower concentrations of total targeted compounds in individual wells compared to earlier results, the extent of the plume remains essentially the same.

1.4 Exposure Assessment Results

The human health exposure assessment evaluated the potential human health exposures to the chemical contamination detected in groundwater downgradient of the 123 Post Avenue Site. Potential exposures were evaluated on the basis of the environmental setting of the study area, and information on the nature and extent of contamination as described in the RI report. Relevant environmental information is discussed in the context of current and potential human contact with contaminants of concern at potential locations where human exposure could occur without any remedial measures implemented to mitigate exposure to contaminants. The human health exposure assessment is included in the Remedial Investigation Report.

Based on the results of the human health exposure assessment, there are three current potentially complete pathways associated with the groundwater contamination detected downgradient of the 123 Post Avenue Site. The first of these pathways is volatilization from groundwater into buildings within the study area. This potential exposure is greatest in the northern portion of the study area where the VOC concentrations are greatest and the groundwater is closest to the ground surface. Based on air sample results at the 117 Post Avenue property (located across the LIRR tracks from the site), which are well below NYSDOH guidelines, the potential exposure associated with this pathway is not considered significant at this property. Based on the experience of the NYSDOH at similar sites, the potential exposure for occupants of nearby buildings due to volatilization from groundwater is also currently not considered significant.

The two remaining potentially complete exposure pathways associated with groundwater contamination are for employees of the Big M Car Wash of Westbury, and include dermal exposure to impacted groundwater utilized for car washing and inhalation exposure due to volatilization of contaminants from groundwater during car washing. While these exposure pathways are currently complete, the low VOC concentrations detected in the car wash supply well water indicate that these exposures currently are not significant.

An additional potential pathway for exposure to impacted groundwater could be completed if a water supply well is constructed without treatment within the plume area in the future, or if the plume migrates to existing water supply wells. However, it is considered unlikely that any new wells will be constructed in this area and existing wells do not appear to be currently impacted by this plume.

1.5 Remedial Action Objectives

Remedial action objectives are goals developed for the protection of human health and the environment. Definition of these objectives requires an assessment of the contaminants and media of concern, migration pathways, exposure routes and potential receptors. Typically, remediation goals are established based on standards, criteria and guidelines to protect human health and the environment. SCGs for the 123 Post Avenue Site, which were developed as part of the remedial investigation, include NYSDEC Technical and Operational Guidance Series (TOGS) (1.1.1), *Ambient Water Quality Standards And Guidance Values and Groundwater Effluent Limitations (1998).* Based on these SCGs and the results of the RI, the remedial action objectives developed for OU2 are the following:

1. Protection of human health and the environment; and
2. Reduction of contaminant levels in groundwater to standards to the extent practicable to prevent further migration of contaminated groundwater.

In addition to consideration of SCGs to meet the remedial action objectives, Applicable or Relevant and Appropriate Requirements (ARARs) are to be considered when formulating, screening and evaluating remedial alternatives, and selecting a remedial action. ARARs may be categorized as contaminant-specific, location-specific or action-specific. Federal statutes, regulations and programs may apply to the site where state or local standards do not exist. Potentially applicable contaminant-specific, location-specific and action-specific ARARs for the 123 Post Avenue Site, along with guidance, advisories, criteria, memoranda and other information issued by regulatory agencies to be considered (TBC), are presented in Tables 1-1, 1-2 and 1-3. As a

Table 1-1

POTENTIALLY APPLICABLE CHEMICAL SPECIFIC ARARs/TBCs
123 POST AVENUE SITE - OPERABLE UNIT 2

Citation/ Reference	Title	Applicable Media	Potential ARAR/TBC	Regulatory Agency
6 NYCRR 212	General Process Emission Sources	Air	ARAR	NYSDEC
6 NYCRR 257	Air Quality Standards	Air	ARAR	NYSDEC
6 NYCRR 371	Identification and Listing of Hazardous Waste	Hazardous Waste	ARAR	NYSDEC
6 NYCRR 376	Land Disposal Restrictions	Hazardous Waste	ARAR	NYSDEC
6 NYCRR 700-705	Surface Water and Groundwater Classifications and Standards	Groundwater	ARAR	NYSDEC
State Sanitary Code - Part 5	Drinking Water Supply	Water Supply	ARAR	NYSDOH
TOGS 1.1.1	Ambient Water Quality Standards and Guidance Values	Groundwater	TBC	NYSDEC
Air Guide No. 1	Guideline for the Control of Toxic Ambient Air Contaminants	Air	TBC	NYSDEC
TAGM HWR-4046	Determination of Soil Cleanup Objectives and Cleanup Levels	Soil	TBC	NYSDEC

Table 1-2

POTENTIALLY APPLICABLE LOCATION SPECIFIC ARARs/TBCs
123 POST AVENUE SITE - OPERABLE UNIT 2

Citation/ Reference	Title	Applicable Media	Potential ARAR/TBC	Regulatory Agency
6 NYCRR 256	Air Quality Classification System	Air	ARAR	NYSDEC
N/A	Fish and Wildlife Impact Analysis for Inactive Hazardous Waste Sites	Hazardous Waste Sites	TBC	NYSDEC

Table 1-3

POTENTIALLY APPLICABLE ACTION SPECIFIC ARARs/TBCs
123 POST AVENUE SITE - OPERABLE UNIT 2

Citation/ Reference	Title	Applicable Media	Potential ARAR/TBC	Regulatory Agency
6 NYCRR 200	General Provision	Air	ARAR	NYSDEC
6 NYCRR 201	Permits and Registrations	Air	ARAR	NYSDEC
6 NYCRR 211	General Prohibitions	Air	ARAR	NYSDEC
6 NYCRR 212	General Process Emission Sources	Air	ARAR	NYSDEC
6 NYCRR 364	Waste Transporter Permits	Solid/Hazardous Waste	ARAR	NYSDEC
6 NYCRR 370	Hazardous Waste Management System – General	Hazardous Waste	ARAR	NYSDEC
6 NYCRR 372	Hazardous Waste Manifest System and Related Standards for Generators, Transporters and Facilities	Hazardous Waste	ARAR	NYSDEC
6 NYCRR 373	Hazardous Waste Management Facilities	Hazardous Waste	ARAR	NYSDEC
6 NYCRR 375	Inactive Hazardous Waste Disposal Site Remedial Program	Hazardous Waste	ARAR	NYSDEC
6 NYCRR 376	Land Disposal Restrictions	Hazardous Waste	ARAR	NYSDEC
6 NYCRR 617 and 618	State Environmental Quality Review	All Media	ARAR	NYSDEC
6 NYCRR 621	Uniform Procedures	All Media	ARAR	NYSDEC
6 NYCRR 624	Permit Hearing Procedures	All Media	ARAR	NYSDEC
6 NYCRR 650	Qualifications of Operators of Wastewater Treatment Plants	NA	ARAR	NYSDEC
6 NYCRR 700-705	Classifications and Standards of Quality and Purity	Groundwater	ARAR	NYSDEC
6 NYCRR 750-758	State Pollutant Discharge Elimination System	Groundwater	ARAR	NYSDEC
Air Guide No. 1	Guideline for the Control of Toxic Ambient Air Contaminants	Air	TBC	NYSDEC

Table 1-3 (continued)

POTENTIALLY APPLICABLE ACTION SPECIFIC ARARs/TBCs
123 POST AVENUE SITE - OPERABLE UNIT 2

Citation/ Reference	Title	Applicable Media	Potential ARAR/TBC	Regulatory Agency
Air Guide No. 29	Technical Guidance for Regulating and Permitting Air Emissions from Air Strippers, Soil Vapor Extraction Systems and Cold-Mix Asphalt Units	Air	TBC	NYSDEC
TAGM HWR-4030	Selection of Remedial Actions at Inactive Hazardous Waste Disposal Sites	Hazardous Waste	TBC	NYSDEC
TAGM HWR-4031	Fugitive Dust Suppression and Particulate Monitoring Programs at Inactive Hazardous Waste Sites	Air	TBC	NYSDEC
TAGM HWR-4046	Determination of Soil Cleanup Objectives and Cleanup Levels	Soil	TBC	NYSDEC
N/A	Analytical Services Protocol	All Media	TBC	NYSDEC
TOGS 2.1.2	UIR at Groundwater Remediation Sites	Groundwater	TBC	NYSDEC
TOGS 2.1.3	Primary & Principal Aquifer Determinations	Groundwater	TBC	NYSDEC
29 CFR 1910.120	Hazardous Waste Operations and Emergency Response	NA	ARAR	USDOL

note, many of the NYSDEC ARARs include federal requirements which have been delegated to New York State. Generally, federal ARARs are referenced when State requirements do not exist.

1.6 Feasibility Study Description

The Technical and Administrative Guidance Memorandum (TAGM) prepared by NYSDEC entitled, "Selection of Remedial Actions at Inactive Hazardous Waste Sites," describes the feasibility study as a process to identify and screen potentially applicable remedial technologies, combine technologies into alternatives and evaluate appropriate alternatives in detail, and select an appropriate remedial action plan. The objective of this feasibility study is to meet the goal of this guidance document, as well as USEPA guidance in a focused, concise manner.

The approach of a feasibility study is to initially develop remedial action objectives for medium-specific or operable unit-specific goals to protect human health and the environment. The goals consider the contaminants and contaminant concentrations as determined by the remedial investigation, the exposure routes and potential receptors as determined by the human health exposure assessment, and the acceptable contaminant or risk levels or range of levels.

In the initial phase of the feasibility study, identified remedial technologies which are not technically applicable to contamination found, or are unproven and/or are not commercially available, will be eliminated from further consideration. The technologies remaining after initial screening will be assembled into remedial alternatives for evaluation. Preliminary evaluation of alternatives will consider effectiveness, implementability and relative costs.

Effectiveness evaluation includes consideration of the following:

- The potential effectiveness of process options in handling the estimated areas or volumes of contaminated media, and meeting the remediation goals identified by the remedial action objectives;
- The potential impacts to human health and the environment during the construction and implementation phase; and

- The proven effectiveness and reliability of the process with respect to the contaminants and conditions at the site.

Implementability includes both the technical and administrative feasibility of utilizing the technology or alternative. Administrative feasibility considers institutional factors, such as the ability to obtain necessary permits for on-site or off-site actions, and the ability to restrict land use based on specific remediation measures. Technical feasibility considers such aspects as the ability to comply with SCGs, availability and capacity of treatment, storage and disposal facilities, the availability of equipment and skilled labor to implement the technology, the ability to design, construct and operate the alternative, and acceptability to the regulatory agencies and the public.

Preliminary costs are considered at this stage of the feasibility study process for the purpose of relative cost comparison among the alternatives.

The results of the preliminary evaluation includes potentially viable technologies or combinations of technologies/alternatives for the site which will be carried forward for detailed evaluation.

The guidance requires that a feasibility study provide a detailed analysis of the potential remedial alternatives based on consideration of the following evaluation criteria for each alternative.

- Threshold Criteria
    - Compliance with standards, criteria and guidelines/ARARs
    - Protection of human health and the environment
- Balancing Criteria
    - Short-term impacts and effectiveness
    - Long-term effectiveness and permanence
    - Reduction in toxicity, mobility and/or volume of contamination
    - Implementability
    - Cost

In addition to the above listed Threshold and Balancing Criteria, the guidance also provides the following modifying criteria:

- Modifying criteria
  - Regulatory agency acceptance
  - Community acceptance

Provided below is a description of each of the feasibility study criteria.

Compliance with applicable regulatory standards, criteria and guidelines applies the federal and New York State ARARs/SCGs identified for the 123 Post Avenue Site to provide both action-specific guidelines for remedial work at the site and contaminant-specific cleanup standards for the alternatives under evaluation. In addition to action-specific and contaminant-specific guidelines, there are also location-specific guidelines that pertain to such issues as restrictions on actions at historic sites.

Protection of human health and the environment is evaluated on the basis of estimated reductions in both human and environmental exposure to contaminants for each remedial action alternative. The evaluation focuses on whether a specific alternative achieves adequate protection, and how site risks are eliminated, reduced or controlled through treatment, engineering or institutional controls. An integral part of this evaluation is an assessment of long-term residual risks to be expected after remediation has been completed. Evaluation of the human health and environmental protection factor is generally based, in part, on the findings of an exposure assessment. The exposure assessment performed for this site incorporates the qualitative estimation of the risk posed by contaminants detected during the remedial investigation.

Evaluation of short-term impacts and effectiveness of each alternative examines health and environmental risks likely to exist during the implementation of a particular remedial action. Principal factors for consideration include the expediency with which a particular alternative can be completed, potential impacts on the nearby community and on-site workers, and mitigation measures for short-term risks required by a given alternative during the necessary implementation period.

Examination of long-term impacts and effectiveness for each alternative requires an estimation of the degree of permanence afforded by each alternative. To this end, the anticipated service life of each alternative must be estimated, together with the estimated quantity and characterization of residual contamination remaining on-site at the end of this service life. The magnitude of residual risks must also be considered in terms of the amount and concentrations of contaminants remaining following implementation of a remedial action, considering the persistence, toxicity and mobility of these contaminants, and their propensity to bioaccumulate.

Reduction in toxicity, mobility and volume of contaminants is evaluated on the basis of the estimated quantity of contamination treated or destroyed, together with the estimated quantity of waste materials produced by the treatment process itself. Furthermore, this evaluation considers whether a particular alternative will achieve the irreversible destruction of contaminants, treatment of the contaminants or merely removal of contaminants for disposal elsewhere.

Evaluation of implementability examines the difficulty associated with the installation and/or operation of each alternative on-site and the proven or perceived reliability with which an alternative can achieve system performance goals (primarily the SCGs discussed above). The evaluation examines the potential need for future remedial action, the level of oversight required by regulatory agencies, the availability of certain technology resources required by each alternative and community acceptance of the alternative.

Cost evaluations presented in this document estimate the capital, and operation and maintenance (O&M) costs, including monitoring, associated with each remedial action alternative. From these estimates, a total present worth for each option is determined.

Regulatory agency and community acceptance evaluates the technical and administrative issues and concerns which the agencies or the community may have regarding each of the alternatives.

1.7 Approach to Feasibility Study

As discussed previously in this section, the focus of the OU2 RI/FS is the contaminated groundwater downgradient of an active dry cleaning facility located at 123 Post Avenue, Westbury, New York. The technologies identified and evaluated in the next sections are technologies that are applicable to remediation of groundwater contaminated with volatile organic compounds. For the purposes of preparation of this feasibility study, it is assumed that the source of the contamination, the 123 Post Avenue Site, has been remediated and the focus of the feasibility study is to evaluate appropriate alternatives for remediation of the remaining off-site contaminant plume. Plume remediation will focus on remediation of the area of highly contaminated groundwater which has been defined as the area with concentrations of total volatile organic compounds greater than 1,000 ug/l.

The contaminated groundwater at this site is overlain by a densely populated area, which is primarily residential. Consequently, the approach to this feasibility study will be to identify and evaluate technologies and alternatives which will be able to meet the remedial action objectives developed for the site, while at the same time meet the restrictive aboveground space limitations dictated by the study area. As discussed in the following sections, installation of any alternative will need to be completed within the right-of-ways of public roadways. Access to parking areas, particularly the parking area of the assisted living facility located on Madison Avenue and Post Avenue, may not be obtainable. Therefore, preference may be given to technologies and alternatives that can be implemented given the aboveground constraints on space.

Section 2

2.0 IDENTIFICATION AND SCREENING OF REMEDIAL TECHNOLOGIES

2.1 Introduction

In general, response actions which satisfy remedial objectives for a site include institutional, isolation, containment, removal or treatment actions. In addition, United States Environmental Protection Agency guidance under the Comprehensive Emergency Response, Compensation and Liability Act requires the evaluation and comparison of a no-action alternative to the action alternatives. Each response action for each medium of interest must satisfy the remedial action objectives for the site or the specific area of concern. Technologies and process options, which are available commercially and have been demonstrated successfully, are identified in this feasibility study along with selected emerging technologies. The screening of process options or technology types is performed by evaluating the ability of each technology to meet specific remedial action objectives, technical implementability, and short-term and long-term effectiveness. A discussion of selected response actions and their applicability to the 123 Post Avenue Site - Operable Unit 2 is provided below. Preliminary evaluation/screening of the response action and remedial technologies will be based on technical effectiveness as it relates to the specific physical and chemical characteristics of the site. However, where appropriate, consideration will also be given to implementability and cost.

2.2 No Action

The no-action alternative will be considered, and as described above, will serve as a baseline to compare and evaluate the effectiveness of other actions. Under the no-action scenario, limited remedial response actions may be considered, including monitoring. Monitoring would consist of periodic groundwater sampling to evaluate changes over time in conditions at the site, and to ascertain the level of any natural attenuation which may occur or any increase in contamination which may necessitate further remedial action. Natural attenuation (under the no action alternative), as opposed to active remediation, relies on naturally occurring physical, chemical and biological processes (dilution, dispersion and degradation) to reduce contaminant concentrations.

2.3 Institutional Controls

Institutional controls potentially applicable to this site may include resource restrictions such as groundwater use restrictions to ensure that groundwater is not utilized for potable, irrigation or industrial uses.

2.4 Groundwater Remediation Technologies

Treatment, collection and containment technologies, which could be applicable to remediation of groundwater contaminated with volatile organic compounds, such as those found at the 123 Post Avenue Site, are identified and evaluated below.

2.4.1 Extraction and Treatment

Extraction and treatment, or "pump and treat" technologies, are widely used for groundwater remediation and/or containment. Extraction is a remedial technology generally used in combination with aboveground treatment technologies to control and remove contaminants in groundwater. Two types of extraction technologies are pumping wells and interceptor trenches.

The use of wells to pump contaminated groundwater to the surface for treatment is widely used as a remedial technology. With this technology, contaminated groundwater can be extracted for treatment and disposal. Groundwater modeling and/or pump tests are generally utilized to determine optimal pumping rates and well locations.

As opposed to wells, which can extract shallow and deep contaminated groundwater, interceptor trenches have been successfully used to extract groundwater in situations where the depth to groundwater is shallow, contamination is limited to the upper portion of the aquifer, and soils can be excavated without causing major disruption and structural damage and interfering with underground utilities.

Once extracted, contaminated groundwater must be treated to meet discharge standards. As discussed in Section 1.0, groundwater at the 123 Post Avenue Site has been defined as being contaminated with significantly elevated levels of volatile organic compounds (VOCs), primarily tetrachloroethene, trichloroethene and cis-1,2-dichloroethene. In addition to the VOCs, iron and manganese exceeded groundwater standards in the one sample for which these metals were analyzed.

Groundwater treatment technologies include biological, chemical and physical processes. Many of these processes can be combined to form an overall treatment system for groundwater. Groundwater treatment for metals, primarily iron and manganese, may be required prior to removal of VOCs in order to reduce operational difficulties, such as precipitation of iron and/or formation of iron bacteria during treatment which would clog the stripping media. Groundwater extraction and treatment systems will generate a treated wastewater requiring proper management and disposal. Disposal options include discharge to a publicly owned treatment works (POTW), surface water or recharge/reinjection to groundwater. In addition, many of the treatment processes produce residuals that will require proper disposal.

Initial Screening Results: Although groundwater extraction and treatment is applicable to the contaminants of concern, there are several implementability issues that make this technology not applicable to the site. The groundwater treatment equipment requires significant aboveground space, which is not available at or in the vicinity of the site. Extraction of the groundwater would require installation of a piping network to convey contaminated water from the extraction wells to the treatment system. In addition, the treated water would require reinjection, since approval from the POTW for disposal of the treated water would not be able to be obtained and there are no surface waters or recharge basins in the vicinity of the site that would be able to accept the treated water. Therefore, due to the significant difficulties with implementing this technology, extraction and treatment will not be considered further.

2.4.2 In-Situ Treatment

In-situ treatment technologies for remediation of groundwater involve both proven and "emerging" or developing techniques as described below.

2.4.2.1 - Air Sparging

Technology Description: Air sparging involves injecting air through wells into a saturated matrix to create an underground VOC stripping mechanism that removes contaminants cause volatilization. It is a widely used, proven and commercially available technology for the treatment of VOCs. The technology is designed to operate at sufficient air flow rates in order to cause volatilization. At lower air flow rates, the system is used to increase groundwater oxygen concentrations to stimulate biodegradation. Generally, air sparging must operate in conjunction with a soil vapor extraction (SVE) system that captures volatile contaminants in the unsaturated zone as they are stripped from the saturated zone. Air extracted from the SVE wells are treated aboveground and released to the atmosphere. Aboveground equipment can include an air sparge blower, vacuum blower, instrumentation, controls and a granular activated carbon system. Equipment can be housed in a temporary building and underground piping may be necessary for connection of the wells to the equipment.

Air stripping wells must be appropriately placed to overlap the radius of influence for each well and effectively remediate the contaminated zone. Well screens are typically placed 5 feet below the contamination in order to ensure treatment through the contamination zone. Sparging and collection of vapors from deep contamination (over 60 feet) may be difficult.

Initial Screening Results: Although this technology would be applicable to the contaminants of concern at the site, as discussed above, space for the installation of aboveground treatment equipment is not available. In addition, because of the substantial depth to groundwater and contamination at the site (40-60 feet and deeper), it is difficult to ensure that volatile contaminants are effectively collected from the unsaturated zone and do not impact residences in the area of the site. Therefore, this technology will not be retained for further consideration.

2.4.2.2 - In-Well Air Stripping

Technology Description: In-well air stripping is a process by which air is injected into a well, lifting contaminated groundwater in the well and allowing additional groundwater flow into the well. Once inside the well, the volatile organic compounds in the contaminated groundwater are transferred from the water to air bubbles which rise and are collected at the top of the well by vapor extraction. Extracted vapors are collected in a vacuum system and treated through treatment processes, such as carbon adsorption, and released to the atmosphere. The partially treated groundwater is not brought to the surface, but rather, it is discharged into the saturated or unsaturated zone, and the process is repeated. As groundwater circulates through the treatment system, contaminant concentrations are reduced. The flow rate and well spacing may be varied in order to achieve the desired radius of influence and capture zone. If air stripping wells are not properly designed or constructed, the plume may be spread beyond the radius of influence of the stripping well. Hydrogeologic investigation and/or pilot testing would be required to evaluate the radius of influence and capture zone of the wells.

Impacts potentially impacting the effectiveness of in-well air stripping include subsurface anomalies, such as low permeability units and subsurface utilities, which could short circuit the system. Elevated levels of metals, such as levels of iron greater than 0.5 ppm, could cause problems with clogging of the well screens due to precipitation of iron and/or formation of iron bacteria. Iron was detected at 0.45 ppm in the one sample collected from the site. Acid injection into the well may be required to control precipitation of the metals. In addition, in-well air stripping is an emerging technology, and there are not many vendors currently implementing these systems.

Initial Screening Results: Due to the concern regarding clogging of the screens with iron and iron bacteria as a result of elevated levels of iron detected at the site, the potential for spreading of the plume, and the lack of vendors currently marketing this technology, this technology will not be retained for further consideration.

2.4.2.3 - Bioremediation

Technology Description: In-situ bioremediation of chlorinated hydrocarbons can be completed through an anaerobic reductive dechlorination process. Anaerobic conditions can be created in the subsurface through the addition of a readily biodegradable organic compound to exhaust all of the oxygen present and create reducing conditions to stimulate anaerobic bacteria. Liquid delivery of lactate, molasses or vegetable oils is one of the most common applications of engineered in-situ bioremediation to remediate sites contaminated with chlorinated solvents. Hydrogen Release Compound (HRC) is a proprietary polyacetate ester manufactured by Regenesis and is one of several products marketed to remediate chlorinated VOC contaminated groundwater. When HRC is delivered to the subsurface, the lactate is slowly released and metabolized by naturally occurring microorganisms resulting in the creation of anaerobic aquifer conditions and the production of hydrogen. Naturally occurring microorganisms capable of reductive dechlorination then use the hydrogen to progressively remove chlorine atoms from the chlorinated hydrocarbon contaminants. HRC is manufactured as a viscous gel that can be injected into the saturated zone through direct push methods or drilling with hollow stem augers.

Complete degradation of the chlorinated compounds requires close monitoring of the groundwater plume. In order to ensure complete dechlorination and not the production of more toxic compounds such as vinyl chloride, some sites may also need to be augmented with a microbial culture capable of degrading the contaminants along with substrate and/or nutrient injection. Aerobic bioremediation can be used to complete biodegradation of the partially dechlorinated compounds, such as vinyl chloride.

For best results, factors that must be considered for bioremediation include redox conditions, saturation rates, presence of nutrient trace elements, pH, temperature and permeability of the subsurface materials. If nutrients, such as nitrogen and phosphorous, are not present in sufficient amount, they can be added to the subsurface. Similar to the other in-situ remedial technologies discussed in this section, subsurface anomalies, such as low permeability zones, can impact the effective distribution of required materials in the subsurface. In-situ bioremediation is a full-scale commercially available technology.

Initial Screening Results: Due to the potential applicability of this technology to the contaminants of concern at the site and the ability to implement this technology in-situ with limited aboveground disturbance and no aboveground space requirements, this technology will be retained for further consideration.

2.4.2.4 – Chemical Oxidation

Technology Description: Chemical oxidation involves the use of an oxidant to treat or destroy organic contaminants in groundwater. Various types of oxidants have been used including hydrogen peroxide and permanganate. The following provides a brief description of each oxidant and its use.

Hydrogen peroxide typically is used in conjunction with ferrous iron to produce hydroxyl radicals which can break the carbon-hydrogen bonds of organic molecules allowing this reaction to degrade chlorinated solvents, polyaromatic hydrocarbons and petroleum products. Since it is a destruction process, there is no potential for intermediate chlorinated, potentially more toxic compounds to be produced as in the bioremediation process discussed in Section 2.4.2.3. Some of the disadvantages of the use of hydrogen peroxide is the hazardous nature of handling hydrogen peroxide, the potential for reduction of permeability of the saturated zone due to formation of metal oxide precipitates during the reaction and difficulties with delivery of the hydrogen peroxide to the contaminated zone, since it can easily breakdown to water vapor and oxygen. The reaction is typically exothermic and can cause the mobilization of nonaqueous phase liquid, if present, to the dissolved state in groundwater and the release of off-gases. The use of various catalysts and mobility control agents has been shown to better control the increase in temperature and mobility of contaminants.

Sodium or potassium permanganate can react with organic compounds to produce manganese dioxide and carbon dioxide. Permanganate has been shown to oxidize chlorinated volatile organic compounds, as well as alkenes, aromatics, polycyclic aromatic hydrocarbons (PAHs), phenols, pesticides and organic acids. Permanganate is more stable than hydrogen peroxide and is easier to handle; however, there is a potential for permeability reduction due to the formation of metal oxide precipitates during the reaction.

A primary concern with the use of strong oxidants is the corrosive and potentially explosive (i.e., hydrogen peroxide) characteristics of the oxidant. Design and operation of the chemical oxidation system must take into account the potential hazards of the chemicals used to ensure protection of health and safety of operational personnel and residents in the vicinity of the remediation system.

Several vendors are currently utilizing various forms of the above processes to treat contaminated groundwater. Although developing as a technology, it has full-scale application and is commercially available.

Factors associated with the effective implementation of this process include detailed understanding of the nature and extent of contamination in order to effectively place the chemical oxidant. Subsurface anomalies can potentially short circuit the system if not adequately considered. The oxidants are also nonselective to both organic contaminants and natural organic matter. The presence of high natural organic matter content in the soils could consume a large portion of the oxidants making treatment less economically feasible. However, total organic carbon samples collected as part of a treatability study performed for the site did not indicate elevated levels of organic carbon that would make this treatment less economically feasible.

Initial Screening Results: Due to its potential ability to treat the groundwater contaminants of concern at the 123 Post Avenue Site, limited disruption to the surface and no aboveground space requirements, this technology, utilizing permanganate, will be considered further. Due to concerns regarding the use of hydrogen peroxide in the residential areas of the study area, the use of this oxidant will not be considered further. In order to evaluate the potential applicability of permanganate chemical oxidation to this site, a bench scale treatability study is being performed.

2.4.2.5 – Ozone-enhanced Air Sparging

Technology Description: Ozone-enhanced air sparging involves the injection of an air/ozone gas mixture into a saturated matrix to create an in-situ VOC stripping and oxidative decomposition mechanism to remove contaminants in a single process. The air/ozone gas mixture is injected into the saturated zone through sparge wells. Within each sparge well, more than one sparge point can be installed to treat particular zones or depths of contamination.

During air sparging, dissolved VOC transfer from the liquid phase to gas phase is in accordance with Henry's Law. When ozone gas is added to the air sparging system, ozone will react with VOCs in either the gas phase, or dissolve in to the aqueous phase and then react with the dissolved VOCs before reaching the unsaturated zone. Whether VOCs are destroyed in the gas phase or aqueous phase is primarily dependent upon the rate of reaction of each VOC with ozone. To maximize VOC mass transfer, "microbubble" sparge-points are used. Microbubbles will create a very high surface area to volume ratio.

Sparge wells and associated piping for these systems can be installed underground and the ozone generation equipment requires minimal aboveground space. Typically, equipment can be placed in panels, which can be installed on telephone poles or in grass medians between the sidewalk and roadway.

Several pilot-test studies have verified the ability to adjust air/ozone concentrations to eliminate volatilization of VOCs into the unsaturated zone.

Air sparging is a widely used and proven technology for the treatment of chlorinated VOCs and ozonation is a proven technology used in waste water treatment facilities; however, ozone-enhanced air sparging is an emerging technology and not widely used in full-scale applications. There are some vendors currently utilizing various forms of these processes to treat contaminated groundwater and soil; however, the number of vendors is limited.

Initial Screening: Based on review of the results of several pilot-studies in similar situations indicating the effectiveness of ozone-enhanced air sparging for treating VOCs in groundwater and the ability to implement this technology in-situ with limited aboveground disturbance and minimal space requirements, this technology will be retained for further consideration. However, since the site is located in a densely populated residential area, soil vapor extraction would likely be necessary as a precautionary measure to capture vapors in the unsaturated zone.

2.4.2.6 - Reactive Walls

Technology Description: The use of reactive walls involves installing a permeable wall across the flow path of a contaminant plume, which allows the plume to passively move through the wall. Typically, the contaminants are degraded by reactions with a mixture of porous media and a metal catalyst. The use of passive treatment walls is an emerging technology which is applicable only in relatively shallow aquifers. In order to effectively install the reactive wall, the trench must be constructed to the depth of the contamination. Passive treatment walls are often only effective for a short period of time because they lose their reactive capacity, requiring replacement of the reactive medium.

Initial Screening Results: Due to potential difficulties with construction of a trench to approximately 40 to 80 feet in a densely developed area and substantial disruption at the surface during installation, this technology will not be considered further.

2.4.2.7 - Chemical Reduction

Technology Description: Injection of zero-valent colloidal iron into the subsurface through injection wells is developing as an alternative to installation of a passive treatment wall for the remediation of contaminated groundwater. Iron powder in a liquid slurry form is injected under pressure along with a nitrogen gas stream. When the iron comes in contact with water, hydrogen gas, hydroxyl ions and ferrous iron are formed. The hydrogen gas then combines with the organic compound which is then dehalogenated. End products of the reaction are ferrous iron, chloride ions and the dehalogenated compounds. Injection wells can be installed much deeper than walls and can, through the use of nanometer colloids, generate a larger reactive surface area and thus more efficient use of the reactive material.

Factors impacting the effectiveness of the process include appropriate placement of the iron and placement of sufficient amount of iron to react with contaminants of concern. Large quantities of injected iron can reduce the permeability of the soils and contact with the contaminants. Low permeable zones created by the injected iron can cause groundwater flow around the injected area instead of through the area reducing the effectiveness of the system.

Initial Screening Results: Due to the potential for the creation of lower permeability zones and the potential for groundwater flow around the area of injection, this technology will not be considered further.

2.4.2.8 - Funnel and Gate

Technology Description: Another emerging passive groundwater remediation technology, that is very similar to and incorporates the treatment/reactive wall technology, is the funnel-and-gate system. Like treatment walls, the funnel-and-gate system includes the installation of a permeable wall containing a mixture of porous media and treatment media which degrade the contaminants in groundwater and allow the treated water to passively move through the wall. The primary difference between the two technologies is that the funnel-and-gate system includes the installation of low permeability cut-off walls (or “funnels”), such as slurry or sheet pile walls, in the path of the contaminated groundwater which directs or “funnels” the contaminated groundwater to a treatment/reactive wall (or “gate”). The “gate” allows passage of the contaminated groundwater through the treatment wall, which then remediates the groundwater.

Advantages, disadvantages and limitations of the funnel-and-gate technology are similar to those of reactive walls. However, slurry walls, sheet piling and other materials that are used to form the funnel having a greater impact on altering groundwater flow compared to the continuous treatment wall. For both technologies, it is necessary to keep the reactive zone permeability equal to or greater than the permeability of the aquifer to avoid mounding of water behind the wall, and diversion of flow under and around the wall. Accurately modeling the hydraulic characteristics of the aquifer to appropriately design the funnel and gate system to avoid the problems described above is often difficult.

Initial Screening Results: The funnel and gate system would be difficult to install to the depth of contamination (40 to 80 feet) and would cause significant disruption to the surface in the vicinity of the site. Therefore, this technology will not be considered further.

2.4.2.9 - Natural Attenuation

Technology Description: Natural attenuation is an alternative whereby natural processes, such as dilution, dispersion, volatilization, biodegradation, adsorption and chemical reactions with subsurface materials, are allowed to reduce contaminant concentrations to acceptable levels. Consideration of this option requires evaluation of contaminant degradation rates to determine the feasibility and special regulatory approvals may be needed. In addition, groundwater sampling and analysis must be conducted throughout the process to confirm that attenuation is proceeding at a rate consistent with meeting cleanup objectives and that any potential receptors will not be impacted. Several disadvantages of natural attenuation include: generation of intermediate degradation products that may be more mobile and more toxic than the original contaminant; it should be considered only where there are no potential impacts on receptors; contaminants may migrate before they are degraded; regulatory agency acceptability is generally not favorable; and community acceptability is generally poor, in particular, where it is the only remediation measure proposed.

Initial Screening Results: Data collected during the remedial investigation did not indicate that significant natural attenuation is occurring at the 123 Post Avenue Site. Therefore, this alternative, in and of itself, will not be retained for further consideration. However, it may be considered in combination with other technologies, such as for the remediation of residual contamination after physical, chemical or biological treatment.

A summary of the identification and screening of the technologies discussed above is presented in Table 2-1.

2.5 Summary Evaluation of Remediation Technologies

Based on the screening of remedial technologies, provided below is summary of the technologies that are retained for further consideration, either as remedial alternatives in and of themselves, or in combination with other technologies to form alternatives. In addition to the below listed technologies, no action will also be evaluated further.

- Bioremediation
- Ozone-enhanced air sparging
- Chemical oxidation (permanganate)

Table 2-1

INITIAL SCREENING OF REMEDIATION TECHNOLOGIES
123 POST AVENUE SITE - OPERABLE UNIT 2

General Response Action	Remedial Technology	Description	Summary of Initial Screening Results
Ex-situ Treatment	Groundwater Extraction and Treatment	Extraction wells or trenches are constructed and contaminated groundwater is pumped to the surface for treatment.	Due to significant amount of aboveground space required for a groundwater treatment system, and difficulties with installation of a piping network or a collection trench and reinjection of treated water, this technology will not be retained for further consideration.
In-situ Treatment Technologies	Air Sparging	Air is injected into groundwater to strip volatile contaminants, which are recovered by a vapor extraction system in the unsaturated zone and treated at the surface.	Although this technology would be applicable to the contaminants of concern at the site, space for aboveground treatment is not available. In addition, it may be difficult to effectively collect the contaminated vapor from the unsaturated zone. Therefore, this technology will not be retained for further consideration.
	In-Well Air Stripping	Air is injected into a well, displacing contaminated groundwater and stripping VOCs, which are collected and treated in the gas phase at the surface.	Due to the potential for clogging of the screens with iron and iron bacteria, the potential for spreading the plume and the lack of commercial availability, this technology is not retained for further construction.
	Bioremediation	Anaerobic conditions are created in the subsurface through the injection of readily biodegradable organic compounds and the VOCs are degraded through anaerobic decomposition.	Retained for further consideration due to the technology's potential applicability to the contaminants of concern, limited disruption to surface and no aboveground space requirements.

Table 2-1 (continued)

INITIAL SCREENING OF REMEDIATION TECHNOLOGIES
123 POST AVENUE SITE - OPERABLE UNIT 2

General Response Action	Remedial Technology	Description	Summary of Initial Screening Results
In-situ Treatment Technologies (continued)	Chemical Oxidation	Oxidants are injected into the groundwater to treat organic contaminants.	Retained for further consideration due to the technology's potential applicability to the contaminants of concern, limited disruption to surface and no aboveground space requirements.
	Ozone-enhanced Air Sparging	Air and ozone are simultaneously injected into saturated zone to create an in-situ VOC stripping and oxidative decomposition mechanism to remove contaminants in a single process.	Retained for further consideration due to its applicability to contaminants of concern, limited disruption to surface and limited aboveground space requirements. However, the need for soil vapor extraction will be evaluated with this technology to address concerns regarding release of vapors into the unsaturated zone.
	Reactive Walls	A permeable reactive wall is installed across flow path of plume to treat organic contaminants.	Not retained for further consideration due to the difficulties in construction of a wall to the depth of contaminated groundwater (40 to 80 feet) and disruption to the surface in a densely developed area.
	Chemical Reduction	Injection of zero-valent iron to the subsurface through injection wells to treat organic contaminants.	Due to the potential for the creation of lower permeability zones causing groundwater to flow around the iron, this technology will not be considered further.
	Funnel and Gate	Cut-off walls are installed to direct groundwater flow to a permeable wall with treatment media which degrades the contaminants.	Due to the difficulties in construction of a wall to the depth of contaminated groundwater and disruption to the surface in a densely developed area, this technology will not be retained for further consideration.

Table 2-1 (continued)

INITIAL SCREENING OF REMEDIATION TECHNOLOGIES
123 POST AVENUE SITE - OPERABLE UNIT 2

General Response Action	Remedial Technology	Description	Summary of Initial Screening Results
In-situ Treatment Technologies (continued)	Natural Attenuation	Natural subsurface degradation processes reduce contaminant concentrations.	Data from the remedial investigation did not indicate that significant natural attenuation was occurring. Therefore, this technology will not be retained for further consideration in and of itself.

Section 3

3.0 TREATABILITY STUDY

In order to evaluate the effectiveness of chemical oxidation utilizing sodium permanganate for in-situ remediation of volatile organic compounds (VOCs) in groundwater downgradient of the 123 Post Avenue Site, a bench scale treatability study was performed by Geo-Cleanse International, Inc. (GCI). The results of the treatability study are summarized below and the treatability study report is provided in Appendix A.

Soil and groundwater samples collected by D&B from the vicinity of monitoring well OU2-2 were provided to GCI for use in the treatability study. Analytical results from these samples were used by GCI to develop oxidant doses to be utilized during the treatability test program.

Based on these calculations, three different soil to sodium permanganate ratios were utilized to determine the optimal oxidant application rate for remediation of the groundwater in the OU2 study area. A control sample with no oxidant added was also prepared. The amount of oxidant that was added to each reactor was determined based on the initial/baseline VOC concentrations in the soil/groundwater mixture samples and the estimated natural oxidant demand (NOD) of the soil/groundwater system. The NOD for the test was empirically estimated using published literature values.

The results of the treatability study show that sodium permanganate appears to effectively oxidize the chlorinated VOCs detected in the groundwater within the OU2 study area. The concentrations of VOCs were reduced to nondetectable levels in the soil/groundwater mixture samples. The difference in sodium permanganate concentration between the pre-test and post-test samples indicates that virtually no sodium permanganate was consumed by NOD. The total oxidant demand was determined to be a maximum of approximately 4.3 mg of sodium permanganate per 1 gram of soil. GCI recommends that this value be verified in a field scale test.

Section 4

4.0 DEVELOPMENT AND PRELIMINARY EVALUATION OF ALTERNATIVES

Based on the screening of remedial technologies in Section 2.0, the next phase of the feasibility study process is to develop remedial alternatives for preliminary evaluation based on effectiveness, implementability and relative cost. These alternatives can comprise either a single technology, if only one medium at a site is of concern and/or only one treatment process is required, or a combination of technologies.

As described previously, the media of concern at the 123 Post Avenue Site - Operable Unit 2 is groundwater contaminated with total volatile organic compounds (VOCs) greater than 1,000 ug/l downgradient of the source area. Soil and groundwater contamination in the source area has been addressed under the remedial action for Operable Unit 1. The following alternatives focus on remediation of the off-site contaminant plume.

4.1 Description of Remedial Alternatives

4.1.1 Alternative 1 - No Action with Long-term Groundwater Monitoring

The no-action alternative will be considered and serve as a baseline to compare and evaluate the effectiveness of other actions. Under the no-action scenario, limited remedial response actions may be considered, including monitoring. Monitoring would consist of periodic sampling to evaluate changes in groundwater quality over time, and to ascertain the level of any natural attenuation that may occur or any increase in contamination that may necessitate further remedial action. Natural attenuation (under the no-action alternative), as opposed to active remediation, relies on naturally occurring physical, chemical and biological processes (dilution, dispersion and degradation) to reduce contaminant concentrations.

Long-term groundwater monitoring will involve quarterly sampling of one upgradient well located on the 123 Post Avenue property, and three downgradient wells (OU2-2, OU2-3 and OU2-4) for the first 10 years, semiannually for the next 10 years, and annually for the following 10 years. Analysis of the groundwater samples will be for VOCs only.

4.1.2 Alternative 2 - In-situ Chemical Oxidation with Long-term Groundwater Monitoring

As discussed in Section 2.0, in-situ chemical oxidation is a potentially viable alternative for the reduction of VOCs in groundwater at the site. Sodium permanganate is injected into the contaminated groundwater causing a reaction which produces manganese dioxide and carbon dioxide. The effectiveness of the technology is dependent upon delivery of the oxidant to the contaminated groundwater. In order to optimize the remediation of groundwater using this technology, it is assumed that this alternative will be conducted in two phases. The first phase will be performed in Zone 1, which is defined as contaminated groundwater between monitoring wells OU2-1 and OU2-2 (see Figure 1-4). The second phase will involve remediation of Zone 2, which is defined as contaminated groundwater between monitoring wells OU2-2 and OU2-3. Remediation of Zone 2 will be performed when the remediation of Zone 1 has been completed. Information on the radius of influence of injection points and the duration permanganate will remain active in the subsurface, as well as the overall reduction of VOCs during remediation of Zone 1, will be used to design the remediation of Zone 2.

Remediation of Zone 1 will include installation of 14 injection points in the vicinity of groundwater monitoring wells OU2-1 and OU2-2. It is assumed that the injection points will have a 50-foot horizontal radius of influence and a 10- to 20-foot vertical radius of influence. It is also assumed that the injection points will be installed in the right-of-way along Madison Avenue and in the parking area of the assisted living facility. Each injection point will be constructed using hollow stem augers and will comprise permanent well points that can be reused for additional injections. Injection points will be constructed using 2-inch diameter PVC casing and screens and will be accessible by flush-mount lockable manholes. Approximately 1,500 pounds of 40% sodium permanganate will be injected into the groundwater during the initial injection. A second partial injection is assumed to be necessary to reduce the contaminants to below groundwater standards. This second injection will include injection of approximately 450 pounds of 40% sodium permanganate. Each point is assumed to have a 50-foot radius of influence and a 10- to 20-foot vertical radius of influence. In areas where the vertical thickness of the plume is greater than 20 feet, injection points will be nested to address the entire thickness of the plume.

As discussed above, the remediation of Zone 2 will be designed based on the results of Zone 1 remediation. Of primary concern regarding the placement of injection points within Zone 2 is the potential impact that residual permanganate will have on the existing Big M car wash well located on Old Country Road, approximately 850 feet downgradient of Zone 2. Injection of permanganate into groundwater will change the color of the groundwater to purple and will also create manganese dioxide particulates that appear as particles of rust in the groundwater. If permanganate is injected too close to the car wash well, the color of the groundwater in this well may change. Zone 1 remediation will dictate the design parameters so that the second phase can be designed such that the car wash well will not be impacted by residual permanganate. At this time, it appears that the zone of contaminated groundwater in the vicinity of the car wash well is deeper than the car wash well. Therefore, the potential for impacts to the car wash well can likely be mitigated through careful monitoring of the volume and depths that permanganate is injected in Zone 2. However, this may impede the ability of this alternative to remediate the entire 1,000 ug/l VOC plume.

Zone 2 remediation is assumed to require the installation of 19 additional injection points. Injection points will be installed in the right-of-way along Lexington Avenue, 5th Avenue and Lenox Avenue. As discussed above, the exact locations of the points will be determined based on the results of Zone 1 remediation. Each point will be a permanent injection point that can be reused if additional injections are necessary. Approximately 800 pounds of 40% sodium permanganate will be injected into the groundwater in Zone 2. Each point is assumed to have a 50-foot radius of influence and 10- to 20-foot vertical radius of influence. In areas where the vertical thickness of the plume is greater than 20 feet, injection points will be nested to address the entire thickness of the plume.

Since all work will be performed in-situ, there will be no aboveground treatment equipment required. Sampling of the groundwater within the treatment zones during the remediation process will be required in order to evaluate the effectiveness of the alternative. It is assumed that five additional groundwater monitoring wells will be installed within the study area to monitor the effectiveness of this alternative. Samples will be collected from four of the existing monitoring wells and the newly installed monitoring wells in the study area. Samples will be analyzed for VOCs, manganese, chloride, permanganate concentration, color, temperature and pH, one week and one month after each injection for both Zone 1 and Zone 2.

Since chemical oxidation is essentially an instantaneous process, remediation will be completed once the installation, injection and monitoring is completed. Installation, injection and monitoring of this alternative is anticipated to be completed within 1 year of mobilization to the site.

Following treatment, further groundwater monitoring will be required to evaluate the effectiveness of the alternative over the long term. Long-term groundwater monitoring will involve the sampling of one upgradient well and three downgradient wells as described for Alternative 1. During the active remediation period, which is the first year, the wells will be sampled four times. For the next nine years, sampling will be performed on an annual basis. Groundwater samples will be analyzed for VOCs.

4.1.3 Alternative 3 - In-situ Bioremediation with Long-term Groundwater Monitoring

In-situ bioremediation of the contaminated groundwater downgradient of the 123 Post Avenue Site will require the creation of anaerobic conditions within the contaminated zone. Creation of anaerobic conditions will require the addition of a product such as lactate. Lactate can be delivered to the subsurface in the form of a proprietary Hydrogen Release Compound (HRC) as marketed by Regenesis, Inc. For the purpose of this project, based on information obtained from Regenesis, it is assumed that a new product HRC-X, which is an extended release formula of HRC, is appropriate for remediation of the contaminated groundwater at the site.

HRC-X will be injected into the subsurface in a network of permeable treatment barriers placed in the groundwater plume and perpendicular to flow. Similar to the approach used for in-situ chemical oxidation, two zones have been defined for the remedial approach. Zone 1 is the highly contaminated groundwater between monitoring wells OU2-1 and OU2-2 (see Figure 1-4). Zone 2 is the contaminated groundwater between Zone 1 and groundwater monitoring well OU2-3. The proposed design is intended to complete reductive dechlorination of all chlorinated compounds. Where the initial injection radii do not intersect, the lactate/hydrogen from the HRC-X will spread in the subsurface by groundwater flow and diffuse between the rows and injection points.

Three rows of 10 injection points will be constructed within Zones 1 and 2. Each row will be located approximately 150 to 200 feet apart in Zone 1 and 280 feet apart in Zone 2. Each row is considered a permeable barrier and will be approximately 100 feet long. The HRC-X is normally applied to the subsurface using direct push methods. Drive rods are pushed to the bottom of the contaminated saturated zone and then the HRC-X is injected as the rods are withdrawn. HRC-X can also be applied to the subsurface using hollow stem augers where direct push is not feasible. HRC-X is preheated to approximately 95 to 110°F before it is injected.

For the purposes of this feasibility study, it is assumed that only one injection will be required; however, additional injections in limited areas may be necessary based on the results of the groundwater monitoring discussed below. In addition, as discussed in Section 2.0, the treatment of chlorinated solvent contamination sometimes results in slow or incomplete degradation of the intermediate compounds. Formation of intermediate compounds, such as trichloroethene, dichloroethene and vinyl chloride during the remediation process, is likely.

Groundwater monitoring will be performed during the remedial phase to evaluate the effectiveness of the bioremediation. Four existing and five newly installed groundwater monitoring wells will be sampled for the following parameters: VOCs, pH, dissolved oxygen (DO), oxidation/reduction potential (ORP), temperature, total organic carbon, metabolic acids (including lactic, pyruvic, acetic, propionic, and butyric), total and dissolved iron and manganese, nitrate, sulfate, sulfide, carbon dioxide, methane, ethane and ethane. One baseline round of samples will be collected. Following HRC-X injection, DO, ORP, temperature, pH, dissolved and total iron and manganese, dissolved acids and dissolved gases will be analyzed every month for the first year. The remaining parameters will be sampled four times a year for the first year. After the first year, the trends will be evaluated and all sampling can be decreased to semiannual with the exception of VOCs, which will continue to be sampled quarterly. It is assumed that remediation will take approximately eight years to complete and semiannual and quarterly sampling will be required during the entire remediation period.

Long-term groundwater monitoring to be conducted after the first eight years will involve sampling semiannually for the next 10 years and annually for the following 10 years.

4.1.4 Alternative 4 – Ozone-Enhanced Air Sparging with Long-term Groundwater Monitoring

Ozone-enhanced air sparging is a potentially viable alternative for the reduction of VOCs in groundwater at the site through chemical destruction (oxidation). As discussed in Section 2.0, this technology utilizes the injection of ozone at low pressures into the saturated zone through sparge points. The ozone reacts with the chlorinated compounds to form byproducts, such as dilute hydrochloric acid and carbon dioxide.

The effectiveness of this technology depends on the ability to control the chemical reaction between the ozone and the contaminants. The reaction is in part controlled by the efficiency of the delivery system. In order to optimize these factors, it is assumed that remediation will be conducted in a phased approach. This approach has been developed based on discussions with vendors currently marketing this technology.

As discussed for Alternatives 2 and 3, the first phase would be performed within Zone 1. Approximately five ozone delivery locations will be established. Three wells will be installed as a barrier fence to intersect the plume and the two remaining wells will be positioned to address areas of highest contamination. Each location will consist of one borehole or sparge well containing two sparge points. Each sparge point will have a 30- to 50-foot horizontal radius of influence and a 20-foot vertical radius of influence. One sparge point will address upper 20 feet of the plume and the second point will address the lower 20 feet of the plume.

Although, based on the low-pressure injection, it is unlikely that either ozone or contaminant vapors will migrate from the saturated zone into the vadose zone, for this phase of the work, it is assumed that a soil vapor extraction system will be installed because of the densely developed nature of the area, to ensure that any vapors that may migrate to the vadose zone will be collected. The depth of the vapor extraction system will be based on collection of any vapors before they would reach the bottom of nearby structures.

All piping for this system, including sparging and vapor extraction, will be installed below grade. The treatment unit will be placed on a pallet and, therefore, some aboveground space will be needed during the remediation of Zone 1. It is anticipated that five new wells will be installed in this area to monitor ozone levels in groundwater, as well as reduction of VOCs. Samples will be collected from the five new wells and the two existing wells in this area. Sample analysis will include the following parameters: VOCs, pH, DO, ORP, sulfate, nitrate and temperature. Samples will be collected at a minimum of once per week during this phase of remediation.

At this time, it is assumed that Zone 1 will require treatment for approximately three to four months in order to achieve the remediation goals; however, the sparge wells will remain in place and the effectiveness of the treatment will be evaluated. If concentrations of VOCs in groundwater begin to increase, additional treatment can be performed.

Zone 2 will be remediated through the use of four transects to be constructed along each of the four streets that run perpendicular to the plume within this zone (Madison Avenue, Lexington Avenue, Fifth Avenue and Lenox Avenue). Each transect will comprise three sparge wells. It is assumed that each sparge point will have a 30- to 50-foot horizontal radius of influence and a 20- to 30-foot vertical radius of influence. The thickness of the plume ranges between 40 and 100 feet below ground surface in this area. Each sparge well will have a minimum of two points. One sparge point will address the upper 20 to 30 feet of the plume and the second sparge point will address the lower 20 to 30 feet of the plume. The depths and screened zones of the sparge points will be modified in order to address the entire thickness of the plume and, therefore, the wells will be installed to deeper depths at the southerly edge of the plume. All network piping will be installed below grade and connected to the ozone/air sparging control units. Each transect will be equipped with ozone/air sparging control unit and operated independently. Pressurized air will be supplied to the injection wells by a compressor, and ozone will be generated on-site and injected in the gas stream. These units, typically the size of electrical boxes, will be installed on telephone poles or in the grass median between a sidewalk and roadway. Sparge well locations will be accessible by flush mount, lockable manholes. Each unit will be equipped with an auto alarm monitor to check and report pressure failure, power outage and other system failures. Ozone monitoring equipment will be furnished to check for ozone leaks.

It is assumed that a soil vapor extraction system will not be required for remediation of Zone 2. The assumption is based on the low-pressure of air/ozone injection, the increased depth of the contaminant plume, lower levels of VOCs and the expectation that no volatile organics will be detected in the unsaturated zone during remediation of Zone 1. It is assumed that the Zone 2 remediation can be completed within approximately three years.

Groundwater monitoring will be completed during the Zone 2 remediation in order to evaluate the effectiveness of the ozone-enhanced air sparging system. Two newly installed and two existing groundwater monitoring wells will be sampled quarterly for the following parameters: VOCs, pH, DO, ORP, temperature, nitrate and sulfate. Following initiation of operation of the system, DO, ORP, temperature and pH will be analyzed every month for the first year. After the first year, the trends will evaluated and, if warranted, all sampling can be decreased to semiannual, with the exception of VOCs, which will continue to be sampled quarterly.

In addition to the above sampling to be performed while the system is operating, long-term groundwater monitoring will be conducted to evaluate the effectiveness of the ozone-enhanced air sparging system. One upgradient well and three downgradient wells will be sampled for VOCs annually from the end of system operation for the next seven years.

Provided below is a preliminary evaluation of these alternatives for effectiveness, implementability and relative costs. A description of these criteria is provided in Section 1.6.

4.2 Evaluation of Alternatives

4.2.1 Alternative 1

Effectiveness

Alternative 1, no action with long-term groundwater monitoring, would not meet any of the remedial action objectives established for the 123 Post Avenue Site, as discussed in Section 1.5 of this document, since groundwater standards will not be achieved. This alternative relies solely on natural attenuation of contamination, which is not expected to occur in a significant manner based on existing data and the high oxygen content of the groundwater. Therefore, it would not be protective of human health and the environment due to the continued degradation of a sole source aquifer and the potential contamination of downgradient water supply wells.

Implementability

This alternative is readily implementable physically; however, since no action does not mitigate the migration of contaminated groundwater, it is not implementable from a regulatory perspective.

Cost

The cost associated with this alternative involves long-term groundwater monitoring. The cost for of this alternative is significantly lower than the action alternatives discussed below.

4.2.2 Alternative 2

Effectiveness

In-situ chemical oxidation using sodium permanganate will be effective at reducing the contaminants of concern. Since this technology relies on the ability for permanganate to contact contaminated groundwater, multiple injections over time may be required to reduce contaminant concentrations to below groundwater standards. Due to the concern for potential discoloration of the downgradient car wash well, complete remediation of the contaminant plume within Zone 2 may not be possible. Therefore, contaminated groundwater may continue to migrate downgradient.

Implementability

This alternative is readily implementable. Inability to access the assisted living facility for installation of injection points will be the only impediment to implementation of this alternative. Disruption to the surface of the study area will only occur during installation of the injection points. Continued access to these points will only be required for monitoring or reinjection once the initial injections are complete.

Cost

The relative cost of this alternative would be moderate with the most significant cost being the installation of the injection points. Once the points are installed, cost for injection of the sodium permanganate and cost for additional injections are low.

4.2.3 Alternative 3

Effectiveness

Alternative 3, in-situ bioremediation, may be effective at reducing the contaminants of concern to concentrations below the remedial action objectives. However, it is anticipated that it will take approximately eight years for remediation to be complete. In addition, during the remediation, concentrations of the byproducts of tetrachloroethene (PCE), such as trichloroethene, dichloroethene and vinyl chloride, may increase until further dechlorination can be completed.

Implementability

This alternative can be readily implemented. As discussed for Alternative 2, access to the assisted living facility parking area may be difficult. With the exception of access during injection of the HRC-X, no additional aboveground space and no additional disruption of the surface would be required. Although there are significant groundwater monitoring requirements, this would not be difficult to implement.

Cost

The relative cost for this alternative would likely be low to moderate if only one injection of HRC-X is necessary. However, if additional injections of HRC-X are required, the costs would increase. In discussions with vendors, it is likely that a second phase of injections would be performed at this site (over a smaller area at a lower dose) and, therefore, the overall cost would be moderate.

4.2.4 Alternative 4

Effectiveness

Alternative 4, ozone-enhanced air sparging, would be protective of human health and the environment and would prevent further migration of contaminated groundwater. This alternative is estimated to remediate the plume within three years of operation. Refinement of the design and operation of the system may need to be performed based upon field scale operation results.

Implementability

Installation of the sparge wells and associated piping would be more disruptive to the study area than the above alternatives. There are also aboveground space requirements for placement of the ozone panels in Zone 2 and the pallet-sized system within Zone 1. Although the space required is not considerable, it may be difficult to obtain approval from the assisted living facility in Zone 1, as well as local municipalities for road opening permits and placement of the ozone panels within Zone 2. Difficulties may also be encountered due to concerns regarding placement of active ozone generation equipment in a densely developed area.

Cost

The relative cost for implementation of this alternative would likely be moderate to high. This alternative includes operation and maintenance costs of an active system, which is not necessary for Alternatives 1, 2 or 3.

4.3 Summary of Evaluation of Alternatives

Provided in Table 4-1 is a summary of the preliminary evaluation of the remedial alternatives developed for the 123 Post Avenue Site OU2.

With regard to selection of alternatives to be evaluated further in detail in order to select a remedial plan for the site, all of the remedial alternatives discussed above (Alternatives 2 through 4) are considered viable and will be evaluated in greater detail in Section 5.0, together with the no action alternative (Alternative 1) as required by federal and New York State guidance.

Table 4-1

SUMMARY OF PRELIMINARY EVALUATION OF REMEDIAL ALTERNATIVES
123 POST AVENUE SITE – OPERABLE UNIT 2

Remedial Alternative		Effectiveness	Ease of Implementation	Relative Cost	Retained
Alternative 1	No Action with Long-term Groundwater Monitoring	Low	High (however, will likely not be acceptable to regulatory agencies or the public)	Low	Yes (required by feasibility study guidance)
Alternative 2	In-situ Chemical Oxidation with Long-term Monitoring	Moderate to High	Moderate	Moderate	Yes
Alternative 3	In-situ Bioremediation with Long-term Groundwater Monitoring	Moderate	Moderate	Low to Moderate	Yes
Alternative 4	Ozone-Enhanced Air Sparging with Long-term Groundwater Monitoring	Moderate to High	Low to Moderate (will include more significant disruption of surface due to installation of piping and need for aboveground space for the treatment system)	Moderate to High	Yes

Section 5

5.0 DETAILED ANALYSIS OF ALTERNATIVES

Based on the preliminary evaluation of the remedial alternatives selected for the 123 Post Avenue Site – OU2 in Section 4.0, all of the alternatives developed for the site have been retained for further analysis. The following summarizes the alternatives to be evaluated in detail for remediation of groundwater in this section:

Alternative 1 - No Action with Long-term Groundwater Monitoring

Alternative 2 - In-situ Chemical Oxidation with Long-term Groundwater Monitoring

Alternative 3 - In-situ Bioremediation with Long-term Groundwater Monitoring

Alternative 4 – Ozone-enhanced Air Sparging with Long-term Groundwater Monitoring

Provided below is a detailed evaluation of the alternatives. Based on this evaluation, a remedial plan for the site will be selected for regulatory agency approval and public comment. In accordance with federal (USEPA) and New York State guidance, the following feasibility study evaluation criteria will be addressed in this evaluation.

- Threshold Criteria
  - Protection of human health and the environment
  - Compliance with standards, criteria and guidelines (SCGs)/Applicable or Relevant and Appropriate Requirements (ARARs)
- Balancing Criteria
  - Short-term impacts and effectiveness
  - Long-term effectiveness and permanence
  - Reduction in toxicity, mobility and/or volume of contamination
  - Implementability
  - Cost

- Modifying Criteria
  - Regulatory agency acceptance
  - Community acceptance

A description of each of these criteria is provided in Section 1.6 of this document.

Provided below is a comparative analysis of the remedial alternatives to each of the evaluation criteria presented above.

5.1 Protection of Human Health and the Environment

Alternative 1, no action with long-term groundwater monitoring, will not be protective of human health and the environment, since natural attenuation of the groundwater, without some form of active remediation, will allow continued migration of highly contaminated groundwater.

The effectiveness of Alternative 2, in-situ chemical oxidation, depends upon the ability of the sodium permanganate to reach the contaminants in groundwater. Permanganate readily oxidizes VOCs with no intermediate byproducts. Within the study area, where access to the plume is available, reduction of contaminant levels to below groundwater standards will be accomplished; however, multiple injections may be required. In addition, injection of permanganate in close proximity to the existing car wash well may not be possible due to discoloration of groundwater. Therefore, although in-situ chemical oxidation will be effective at reducing the levels of VOCs in groundwater, it may not be able to address the entire plume and, therefore, a portion of the plume may continue to migrate downgradient untreated.

Alternative 3, in-situ bioremediation, may be effective in reducing the levels of VOC contamination in groundwater and mitigating further downgradient migration of contaminated groundwater. The effectiveness of this alternative and, therefore, overall protection of human health and the environment, is dependent upon the ability of the HRC-X to create anaerobic aquifer conditions and the production of hydrogen, which will lead to the dechlorination of tetrachloroethene (PCE) and its breakdown products. Incomplete dechlorination may create an increase in other VOCs, such as trichloroethene, dichloroethene and vinyl chloride. Close monitoring of the system will be required and multiple injections of HRC-X may be required. In addition, remediation of the plume is expected to take approximately 8 years and, therefore, may allow for continued migration of the contaminant plume.

Alternative 4, ozone-enhanced air sparging, will likely be effective in remediating the contaminants of concern and, therefore, providing protection of human health and the environment. Unlike Alternative 2, ozone-enhanced air sparging is an active system, which will allow ozone to contact the contaminant plume as it migrates downgradient. Once the ozone contacts the contaminants, reduction is essentially instantaneous with no toxic byproducts.

As a result of this comparative analysis, Alternative 4 would be the most protective of human health and the environment, since it is a more active system that provides continuous treatment/ozone to the subsurface. Alternative 2 would be more effective than Alternative 3, since it will not produce any intermediate compounds and will likely have a much shorter remediation time (one year versus 8 years). Alternative 1 would not be protective of human health and the environment, since it will continue to allow for downgradient migration of the contaminant plume.

5.2 Compliance with Standards, Criteria and Guidelines/ARARs

Alternative 1, no action, will not be compliant with any of the SCGs established for the site, since significant natural attenuation of the groundwater is not expected and migration of contaminants will continue.

Alternative 2, in-situ chemical oxidation, will significantly reduce the levels of VOCs in groundwater. However, multiple injections may be required to reduce the contaminant to levels below the groundwater SCGs established for the site. Since this alternative will be performed in-situ without any aboveground treatment equipment after the initial installation, this alternative will meet all other applicable SCGs and ARARs established for the site.

Similarly, Alternative 3, in-situ bioremediation, may reduce the levels of VOCs in groundwater over the long term; however, it may create intermediate byproducts during PCE reduction and allow further migration of contaminated groundwater. Natural attenuation will likely be required for this alternative to achieve groundwater standards.

Alternative 4, ozone-enhanced air sparging, will be compliant with all of the SCGs and ARARs established for the site. According to information provided by vendors, it is anticipated that the levels of contaminants can be reduced to below groundwater standards within 3 years of operation; however, full-scale demonstration of this alternative will define the ability of this technology to meet groundwater standards. This alternative will also have to meet vapor emissions requirements for discharge of treated air and disposal restrictions for disposal of spent carbon from the soil vapor extraction system included in the Zone 1 remediation.

Based on the above comparison, Alternatives 4 and 2 will be the most compliant with the SCGs established for the site, respectively, since Alternative 2 may not be able to treat the entire plume and Alternative 3 may create intermediate byproducts of PCE and may not meet groundwater SCGs during the remedial phase. Alternative 1 will not be compliant with SCGs/ARARs.

5.3 Short-term Impacts and Effectiveness

Implementation of Alternative 1, no action with long-term groundwater monitoring, will have no short-term adverse impacts relative to the surrounding community and can be implemented immediately. However, this alternative will not be effective in the short-term in reducing contaminant levels in groundwater or preventing further downgradient migration of contamination.

Alternative 2, in-situ chemical oxidation, will include the installation of approximately 23 injection points. Each injection point will be installed using hollow stem augers. Approximately 14 points will be installed in Zone 1 and, therefore, will need to be installed in the right-of-way of Madison Avenue and in the parking lot for the assisted living facility. Each point will be installed with a flush-mount cover allowing for future access. The use of hollow stem augers for installation will cause more surficial disruption than direct push methods used in Alternative 3; however, once completed, flush mount covers on the injection points will not impact the parking areas or right-of-way. This alternative is expected to be very effective in the short term since remediation time is approximately one year.

Alternative 3, in-situ bioremediation, will include the installation of 60 injection points. Up to 30 of these points will need to be installed in Zone 1 within the parking area of the assisted living facility and the right-of-way of Madison Avenue. The remaining points will be installed in the right-of-way of the cross streets south of the 123 Post Avenue Site to address the downgradient plume. The points installed in the assisted living facility parking area will likely be able to be installed with the use of direct push techniques thereby reducing the surficial impacts. However, due to potential for depth limitations of approximately 120 feet in this area, some of the deeper points along the downgradient edge of the plume may require installation using hollow stem augers. The use of hollow stem augers for installation will cause greater surface disruption. Once the initial installation is completed, it is not expected that additional applications would be required for 3 to 5 years. The results of the groundwater monitoring will dictate the need for additional applications. Any additional applications will be performed in the same manner as the first application and will cause minimal surficial impacts. Reduction in groundwater contamination may be seen within the first year of the initial application; however, reduction to groundwater standards may take up to 8 years.

Alternative 4, ozone-enhanced air sparging will likely have the most short-term impacts of all of the alternatives. Installation of the 28 sparge wells will be completed using hollow stem augers and the wells will be interconnected with underground piping that will require excavation of shallow trenches. Within Zone 1, trenching would also be required for the placement of horizontal soil vapor extraction wells. In addition, there will be aboveground space requirements for the placement of the ozone generation equipment, soil vapor extraction equipment and carbon treatment system. A pallet-sized treatment system will need to be installed within Zone 1, and panel mounted systems, which could be placed on telephone poles or in the grass median between the sidewalk and the roadway, will be installed on each cross road in Zone 2.

Alternative 4 is expected to be effective at reducing the levels of contaminants in the short term. Contact with contaminated groundwater with the ozone will result in immediate destruction of the contaminants. However, since this alternative is based on groundwater flow to the ozone sparge wells, complete remediation is expected to be performed in approximately 3 years.

Based on this comparative analysis, Alternatives 2 and 3 will not have as significant short-term impacts as Alternative 4. Although Alternative 3 will have minimal short-term impacts, it will not be as effective as Alternatives 2 and 4 in the short term, since remediation of the plume is expected to take approximately 8 years. Alternative 1 will have the least short-term impacts but will not be effective. Therefore, with regard to short-term impacts, Alternative 1 will have the least impact on the study area, followed by Alternatives 3, 2 and 4, respectively. However, with regard to short-term effectiveness, Alternative 2 would be the most effective in the short term, followed by Alternatives 4, 3 and 1, respectively.

5.4 Long-term Effectiveness and Permanence

Alternative 1, no action with long-term groundwater monitoring, will not be effective or permanent in the long term.

Although Alternative 2, in-situ chemical oxidation, is a developing technology, and the long-term effectiveness and permanence of this alternative for this site has not been demonstrated to a large degree, it is expected that this alternative will be effective and permanent in the long term if the sodium permanganate is able to come in contact with the entire contaminant plume. Installation of injection points near the car wash well is not recommended due to the potential for discoloration of water in this well. Therefore, complete remediation of the contaminant plume may not be possible. If the plume cannot be entirely remediated, this alternative will result in a continuing impact in the area of the site.

Placement of the HRC-X in the subsurface in Alternative 3, in-situ bioremediation, will likely aid in the creation of anaerobic aquifer conditions and the production of hydrogen which will lead to the dechlorination of PCE. However, close monitoring of the aquifer for the production of byproducts of PCE dechlorination, such as trichloroethene, dichloroethene and vinyl chloride, will be necessary. The potential for incomplete dechlorination of PCE reduces the long-term effectiveness and permanence of this alternative. If the alternative is implemented appropriately, causing complete dechlorination, this alternative will be effective and permanent in the long term. Similar to Alternative 2, this alternative will not have long-term impacts on the study area.

Ozone-enhanced air sparging, Alternative 4, is a developing technology and, therefore, there is not sufficient information regarding the long-term effectiveness or permanence of this alternative. The effectiveness of this alternative, with regard to its potential to reduce groundwater contamination, is dependent on the delivery of ozone to the contaminated groundwater. Since it is an active system to be completed over a 3-year period, it is likely that it will be able to reduce the contaminants of concern to below groundwater standards and be a permanent alternative in the long term.

Long-term impacts associated with this alternative include the presence of a toxic and dangerous gas in a residential neighborhood for a period of approximately 3 years. Although the ozone will be generated in an enclosure, and the enclosures will have telemetry and automatic shutdown designed into the system, there is still the potential for ozone leaks and possible explosion.

In summary, Alternatives 2 and 4 will likely be the most effective and permanent alternatives in reducing the contaminants of concern in groundwater in the long term. However, Alternative 4 may have long-term impacts associated with the use of ozone system in a densely developed area. Although Alternative 3 may be effective, the potential for incomplete dechlorination and the production of VOC byproducts diminishes the long-term effectiveness and permanence of this alternative. Alternative 1 will not be effective or permanent in the long term.

5.5 Reduction of Toxicity, Mobility or Volume Through Treatment

Alternative 1, no action, will not be effective at reducing the toxicity, mobility or volume of contaminants at the site, since natural attenuation is not expected to be effective in the foreseeable future and contaminants will continue to migrate downgradient.

Alternative 2, in-situ chemical oxidation, will be effective in reducing the levels of volatile organic compounds in groundwater through in-situ chemical destruction, thereby reducing the toxicity, mobility and volume of the contaminants in groundwater. As discussed above, the effectiveness of this alternative is based on contact of the permanganate with contaminated groundwater. Contaminated groundwater that does to come in contact with permanganate will not be treated. Multiple injections may be required to treat the entire plume and to reduce contaminant levels to SCGs. However, a portion of the plume may not be treated due to the potential for discoloration of the water in the downgradient car wash well.

Alternative 3, in-situ bioremediation, may be effective in reducing the levels of VOCs in groundwater and reducing the migration of these contaminants downgradient. As discussed above, the effectiveness of this alternative will need to be closely monitored in order to ensure complete dechlorination. If incomplete dechlorination occurs, the toxicity of the contaminants may increase due to the production of vinyl chloride. The mobility of the plume may increase due to the length of the remediation time, approximately 8 years.

Alternative 4, ozone-enhanced air sparging, will also likely be effective in reducing the levels of volatile organic contamination in the groundwater and reducing the mobility and volume of these contaminants. The effectiveness is based on the ability of the ozone to be in contact with the contaminated groundwater. Gaps in the ozone barriers that may allow for the migration of contamination downgradient will likely be treated in subsequent downgradient barriers. Since it is an active system, the ozone is more likely able to treat the entire plume compared to the permanganate injection system described in Alternative 2.

Based on this comparative analysis, Alternative 4 will be the most effective followed by Alternatives 2 and 3, respectively. Alternative 1 will not be effective at reducing the toxicity, mobility or volume of the contaminant plume.

5.6 Implementability

Alternative 1, no action with long-term groundwater monitoring, can be easily implemented. Although Alternative 2, in-situ chemical oxidation, is a developing technology, all the necessary labor, equipment, materials and supplies for installation of this alternative are readily available and will not cause delays in implementation. Similar to the alternatives discussed below, monitoring the effectiveness of the system includes the collection of groundwater samples from wells upgradient, downgradient and within the plume. Installation of injection points on the assisted living facility property will require authorization from and coordination with the property owner. Completion of the installation of the injection points within Zone 1 is anticipated to take approximately 2 months. Completion of the installation of injection points within Zone 2 is anticipated to take 3 to 4 months.

Alternative 3, in-situ bioremediation, will have similar implementability issues as Alternative 2. However, injection of the HRC-X using direct push methods would cause less disruption of the surface and likely be easier compared to use of hollow stem augers as described in Alternative 2. Although it is a developing technology, all of the necessary labor, equipment, materials and supplies for installation of this alternative are readily available. Injection of the HRC-X is expected to be completed within two to three months.

Implementation of Alternative 4, ozone-enhanced air sparging, will include obtaining authorization from and coordination with the property owner of the assisted living facility for installation of the sparge wells, the soil vapor extraction system and placement of the pallet sized remediation system. Installation of the sparge wells in Zone 1, including the assisted living facility property, will likely take approximately one to two months. Installation of the points in Zone 2 is anticipated to take approximately five to six months. Difficulties may also be encountered in obtaining competitive bids for this technology due to the low number of vendors currently marketing this technology.

All of the alternatives will be readily implementable with the simplest being Alternative 1. Due to the relative complexity of the remediation system required for Alternative 4, it is expected that Alternatives 2 and 3 will be easier to implement. Since complete installation of the injection points for Alternative 2 will be more disruptive to the surface and take a longer period of time, Alternative 3 will be easier to implement as compared to Alternative 2.

5.7 Cost

The estimated capital, long-term operation and maintenance (O&M), and monitoring present worth costs associated with the alternatives are presented in Table 5-1. A detailed breakdown of each estimate is provided in Appendix B.

The following assumptions were utilized in the preparation of the cost estimates:

- Costs are rounded to the nearest thousand dollars.
- Remedial technology costs were obtained from vendors experienced in installation and operation of these systems.

Alternative 1, no action, would have the lowest cost, since there are no capital costs associated with this alternative. Alternative 3, in-situ bioremediation will have the next lowest cost due to the installation of injection points using direct push methods in lieu of hollow stem augers. Although the cost for Alternative 2 is greater than Alternative 3, it is still less costly compared to Alternative 4, which will require operation and maintenance of the active system.

Table 5-1

ALTERNATIVES COST SUMMARY
123 POST AVENUE SITE - OPERABLE UNIT 2

Alternative	Estimated Capital Cost	Estimated Contingency and Engineering Fees	Present Worth of Annual Operating Maintenance and Monitoring Costs	Total Estimated Costs Based on Present Worth
1	$0	$0	$172,000	$172,000
2	$648,000	$227,000	$78,000	$953,000
3	$477,000	$190,000	$198,000	$865,000
4	$1,048,000	$367,000	$541,000	$1,956,000

5.8 Community Acceptance

Due to the continued migration of contaminated groundwater, it is not expected that Alternative 1, no action with long-term groundwater monitoring, will be acceptable of the community.

Since Alternative 2, in-situ chemical oxidation with long-term groundwater monitoring, will be effective in a relatively short time frame and will have limited aboveground disturbances, it is likely this alternative will be acceptable to the community.

Although Alternative 3, in-situ bioremediation with long-term groundwater monitoring, can be implemented with little aboveground disturbances, the longer time frame for remediation and the potential for generation of byproducts of PCE, this alternative may not be as acceptable to the community as Alternative 2.

Finally, Alternative 4, ozone-enhanced air sparging with long-term groundwater monitoring, will have the most significant aboveground impacts and may generate vapors that will require collection and treatment and, therefore, may not be acceptable to the community.

Therefore, Alternative 2 will likely be the most acceptable followed by Alternatives 3, 4 and 1, respectively.

The community will have an opportunity to review and provide written comments on the remedial alternatives and the recommended remedy during the Preferred Remedial Alternative Plan (PRAP) comment period and at the public meeting for the PRAP.

A summary of the comparison of alternatives is provided in Table 5-2.

Table 5-2

SUMMARY OF REMEDIAL ALTERNATIVE COMPARATIVE ANALYSIS
123 POST AVENUE – OPERABLE UNIT 2

Evaluation Criteria	**Alternative 1 – No Action with Long-term Groundwater Monitoring**	**Alternative 2 – In-situ Chemical Oxidation with Long-term Groundwater Monitoring**	**Alternative 3 – In-situ Bioremediation with Long-term Groundwater Monitoring**	**Alternative 4 – Ozone-enhanced Air Sparging with Long-term Groundwater Monitoring**
Protection of Human Health and the Environment	4	2	3	1
Compliance with Standards, Criteria and Guidelines	4	2	3	1
Short-term Impacts and Effectiveness	1	3	2	4
Long-term Effectiveness and Permanence	4	1	3	2
Reduction of Toxicity, Mobility or Volume through Treatment	4	2	3	1
Implementability	1	3	2	4
Cost	1	3	2	4
Community Acceptance	4	1	2	3
Regulatory Agency Acceptance	4	1	3	2
Total	23	17	20	20

Note: Lowest numerical score is highest ranking.

Appendix A

APPENDIX A

CHEMICAL OXIDATION BENCH SCALE TEST REPORT

Geo-Cleanse International, Inc.

FINAL
Bench Scale Test Report

Geo-Cleanse® Treatment Program

123 Post Avenue – Operable Unit 2

Prepared for:

Divirka and Bartilucci Consulting Engineers
330 Crossways Park Drive
Woodbury, New York 11797

February 20, 2004

Geo-Cleanse International, Inc
4 Mark Road, Suite C
Kenilworth, NJ 07033
Tel (908) 206-1250
Fax (908) 206-1251
contact@geocleanse.com
www.geocleanse.com

TABLE OF CONTENTS

Section ***Page***

1. INTRODUCTION 1
2. FUNDAMENTALS OF THE GEO-CLEANSE® PROCESS AND SODIUM PERMANGANATE OXIDATION 2
3. BENCH TEST GOALS 4
4. SCOPE OF WORK 5
  4.1 General Details 5
  4.2 Sample Homogenization and Baseline Sampling 5
  4.3 Bench Testing 5
5. MATERIALS, METHODS AND OBSERVATIONS 7
  5.1. Materials 7
  5.2. Baseline Sample Collection 7
  5.3. Oxidant Loadings 7
  5.4. Slurry Preparation and Monitoring 8
  5.5. Post-Treatment Sample Collection 9
6. RESULTS AND DISCUSSION 10
  6.1. Baseline Soil and Groundwater Results 10
  6.2. Control Sample VOC Results 10
  6.3. VOC Destruction 11
  6.4. Oxidant Demand 11
7. CONCLUSIONS 13
8. FULL-SCALE IMPLEMENTATION 15
9. REFERENCES CITED 16

APPENDICIES

Appendix A: STL Analytical Laboratory Report
Appendix B: Full-Scale Implementation Costing

LIST OF FIGURES

2-1. Permanganate Oxidation Pathway for Chlorinated Ethylenes
6-1. Chlorinated VOC Lab Results
6-2. Acetone and Methylene Chloride Lab Results

LIST OF TABLES

5-1. Lab Analytical Summary Results
5-2. Experimental Conditions
5-3. Experiment Monitoring Results
6-1. Oxidant Demand Calculations

1. INTRODUCTION

Divirka and Bartilucci Consulting Engineers (D&B) contracted Geo-Cleanse International, Inc. (GCI) to perform bench-scale tests of sodium permanganate oxidation on soil and groundwater from the 123 Post Avenue – Operable Unit 2 (OU2) site in Westbury, New York. The overall objective was to determine if the Geo-Cleanse® Process can provide a viable treatment alternative to address volatile organic compound (VOC) contamination at the site. The Geo-Cleanse® Process is an in-situ treatment technology, involving the injection of sodium permanganate to the subsurface to oxidize chlorinated volatile organic compounds (CVOCs) to substiuent carbon dioxide, chloride and water. Experiments were conducted on both soil and groundwater collected from OU2.

Sodium permanganate oxidation of organic compounds in groundwater and soil is well known. The Geo-Cleanse® Process has previously been applied to soil and groundwater for treatment of chlorinated compounds, including the compounds identified at OU2. Prior to field demonstration tests, bench scale treatability tests were requested by D&B to demonstrate that sodium permanganate could effectively oxidize the CVOCs (primarily tetrachloroethene [PCE], trichloroethene [TCE], and 1,2-dichloroethene [DCE]) present in native soil and groundwater from this site. The bench test is also used to evaluate oxidant demand for a potential field application. The purposes of this document are to:

- Describe the fundamental basis of the Geo-Cleanse® Process and sodium permanganate oxidation.
- Describe the objectives, methods, and results of bench scale treatability tests conducted with Geo-Cleanse® reagents on soil and groundwater from OU2.
- Draw conclusions regarding overall applicability of the Geo-Cleanse® Process for OU2.
- Determine the full-scale costing for this site.

2. FUNDAMENTALS OF THE GEO-CLEANSE® PROCESS AND SODIUM PERMANGANATE OXIDATION

Permanganate (MnO_4^-) is widely used for drinking and wastewater treatment, and has been recently evaluated at several sites for in-situ destruction of organic contaminants in soil and groundwater (e.g., U.S. EPA, 1998). Permanganate ion is most frequently used as either the potassium permanganate ($KMnO_4$; solubility approximately 65 grams per liter [g/L] at 20°C) or sodium permanganate ($NaMnO_4$; solubility approximately 400 g/L at 20°C) salts. Permanganate is considered a strong oxidizer ($E° = +1.7$ volts [V]) and readily oxidizes PCE ($Cl_2C{=}CCl_2$), TCE ($Cl_2C{=}CHCl$), and DCE ($HClC{=}CHCl$), the primary CVOCs present at OU2, with the following basic stoichiometric relationships:

$$\text{PCE:}\quad 4MnO_4^- + 3Cl_2C{=}CCl_2 + 4H_2O \rightarrow 6CO_2 + 4MnO_2 + 12Cl^- + 8H^+ \qquad (1)$$

$$\text{TCE:}\quad 2MnO_4^- + Cl_2C{=}CHCl \rightarrow 2CO_2 + 2MnO_2 + 3Cl^- + H^+ \qquad (2)$$

$$\text{DCE:}\quad 8MnO_4^- + 3HClC{=}CHCl \rightarrow 6CO_2 + 8MnO_2 + 6Cl^- + 2OH^- + 2H_2O \qquad (3)$$

where CO_2 is carbon dioxide, MnO_2 is manganese dioxide (which precipitates as an insoluble solid), Cl^- is chloride ion, H^+ is hydronium ion, OH^- is hydroxide ion, and H_2O is water.

The systematics and permanganate oxidation pathway for common CVOCs are known, and TCE is discussed as an example. Huang et al. (1999) found that TCE oxidation was generally complete in 60 to 90 minutes, and reported a rate constant for equation 2 of approximately 0.9 $M^{-1}s^{-1}$. The most detailed studies to date on the oxidation pathway are those of Yan and Schwartz (1999, 2000), who proposed a reaction scheme for oxidation of chlorinated ethylenes (including PCE, TCE and DCE) that generates aldehydes and carboxylic acids as intermediate products (Figure 2-1). Yan and Schwartz (1999, 2000) found that the permanganate reaction rates with chlorinated ethylenes increase with decreasing chlorination, i.e., vinyl chloride reacts more rapidly than PCE. Yan and Schwartz (1999) reported that the reaction was pseudo-first order with respect to both TCE and permanganate, and second-order overall, with a second-order rate constant of 0.66 $M^{-1}s^{-1}$.

Precipitated MnO_2 is also environmentally active. Solid MnO_2 can be reduced and dissolved by certain organic compounds, resulting in oxidation and destruction of the organic compound. For example, Laha and Luthy (1990) report oxidation of aniline and other aromatic amines, catechol, and quinones by colloidal suspensions of solid MnO_2. Manganese dioxide also undergoes ion-exchange reactions with dissolved metals. Metal adsorption is sensitive to pH, but under near-neutral conditions (pH of 5 to 8), MnO_2 is capable of adsorbing heavy metals such as hexavalent chromium, cadmium, and copper (Vella, 1998).

Permanganate also reacts with oxidizable metals and certain natural organic compounds in soil and groundwater. For example, MnO_4^- oxidizes Fe^{+2} to Fe^{+3}:

$$3Fe^{+2} + MnO_4^- + 4H^+ \rightarrow MnO_2 + 3Fe^{+3} + 2H_2O \quad (4)$$

Relatively higher concentrations of oxidizable metals or other compounds, therefore, act to increase oxidant demand and reduce permanganate efficiency. The oxidant demand from natural soil metals and total organic carbon (TOC) is often referred to as the soil oxidant demand or the natural oxidant demand (NOD). The NOD is typically much higher (by an order of magnitude or more) than the oxidant demand for VOC destruction, and is also subject to greater variability. Pre-test estimates of NOD are based upon general trends of oxidant demand based upon soil type and TOC concentration. Bench test evaluations of NOD are, therefore, extremely important components of permanganate treatment design.

Permanganate is not a thermodynamically favorable form of manganese in groundwater systems due to the presence of oxidizable organic and transition metals. Any residual permanganate remaining after VOC destruction is consumed by NOD, thus the potential migration of permanganate solutions is limited.

3. BENCH TEST GOALS

Prior to a field test of the Geo-Cleanse® Process at OU2, bench scale treatability tests were performed to:

- Evaluate the effectiveness of the Geo-Cleanse® Process and sodium permanganate on targeted contaminants identified in soil and groundwater at the site;
- Evaluate NOD requirements for the site;
- Characterize the contaminated soil and groundwater with respect to the properties known to affect chemical oxidation (VOCs, TOC, NOD, etc.);
- Determine the optimal application of oxidant and any associated catalysts for remediation of the soil and groundwater; and
- Evaluate the potential for full-scale remediation at this site, including:
  - The number, locations, and depths of required injection points;
  - The estimated contaminant mass and the time required to achieve cleanup goals;
  - The estimated cost for conducting a full-scale remediation project at the OU2 Site.

A range of oxidant loadings was applied to soil and groundwater slurries in order to evaluate contaminant destruction and oxidant demand.

4. SCOPE OF WORK

4.1 General Details

Experiments were conducted by GCI in their laboratory in Kenilworth, New Jersey. Severn Trent Laboratories (STL), in Newburgh, New York performed the analysis of the baseline samples because of STL Edison's inability to provide a 24-hour turn. Severn Trent Laboratories (STL), in Edison, New Jersey, a State of New York Department of Health certified laboratory performed the analysis on the soil and groundwater from the bench test reactors. Soil and groundwater samples for this bench-scale study were analyzed for CLP volatile organic aromatics via method NYSASP 2001, total organic carbon (TOC) via EPA methods SW846 9060 and SM18 5310C, and chlorides via EPA method SM18, 4500 Cl-B. All work performed was in accordance with the EPA Guide for Conducting Treatability Studies under CERCLA.

4.2 Sample Homogenization and Baseline Sampling

Soil from the site was homogenized by GCI. Homogenization was conducted by manually mixing composited samples, exercising all precautions possible to minimize VOC volatilization. Soil mixing was conducted in large Ziploc-type sealable plastic bags. Homogenized baseline samples were then collected by GCI. Baseline soil samples were collected for CLP volatiles, TOC, and chloride analysis, and baseline groundwater samples were analyzed for CLP volatiles, TOC, and chloride. The samples were shipped under standard protocols to STL for 24-hr turnaround to facilitate the bench test.

4.3 Bench Testing

The following is the bench test protocol that was employed. There were three (3) different tests (each with a different volume of oxidant), plus a zero oxidant control, for a total of four tests (mass ratios were based upon the NOD of the soil):

1. Control Sample (no oxidant)
2. 5:1 Sample (mass ratio of 5 milligrams of sodium permanganate ($NaMnO_4$) per 1 gram of soil)
3. 10:1 Sample (mass ratio of 10 milligrams of $NaMnO_4$ per 1 gram of soil)
4. 20:1 Sample (mass ratio of 20 milligrams of $NaMnO_4$ per 1 gram of soil)

For each individual test, a 50% soil slurry was prepared by transferring approximately 0.65 kg of soil and 0.65 L of groundwater to a 1,000 mL, opaque, high-density polyethylene bottle. Sample volumes and masses were adjusted slightly to ensure minimal headspace in the reactor (less than ~25 mL). Slurries were allowed to equilibrate for 8 to 16 hours prior to oxidant addition. Also prior to addition of oxidant, initial volatile concentration of the headspace from the reactor bottles was measured using a Thermo Electron 580B photoionization detector; solution pH was also recorded from each bottle. Oxidant doses were then added to each bottle except for the control. Samples were gently shaken and allowed to react for 48 hours. Samples were periodically agitated throughout the test with headspace, pH, and temperature from each reactor being recorded.

After 48 hours, the test reactors were opened and the water samples collected, first for CLP volatiles and then for TOC and chloride analysis. Residual water was drained from the reactor and set aside. The treated soils were placed into a 1,000 mL beaker (homogenization is not necessary because the samples are agitated during reaction). Soil samples were collected for CLP volatile, TOC and chloride analysis.Soil and groundwater samples for CLP volatiles, TOC and chloride were shipped by GCI under standard protocols to STL laboratories for analysis.

5. MATERIALS, METHODS AND OBSERVATIONS

5.1. Materials

D&B personnel collected and provided soil and groundwater samples from OU2 to GCI. A total of four, one-gallon cans of soil along with two, one-gallon containers of groundwater were delivered to GCI by courier on November 13, 2003. Both the groundwater and soil samples were taken from the area surrounding OU2.

5.2. Baseline Sample Collection

Baseline soil and groundwater samples were collected by GCI on November 24, 2003 from the OU2 soil and groundwater. The purpose of the baseline sampling was to confirm the presence of the targeted compounds and to provide a baseline to estimate oxidant dosing for the tests. The baseline soil samples were taken from homogenized soil and subsequently analyzed for CLP volatile organic compounds (VOCs), chloride, and total organic carbon (TOC). Groundwater samples were also analyzed for CLP VOCs, chloride, and TOC. Samples were collected, preserved, and shipped via courier, utilizing standard preservation methods (methanol) and chain-of-custody protocols. Baseline samples were submitted to STL in Newburgh, New York for analysis. The baseline analytical results are tabulated in Table 5-1, and the laboratory analytical report is located in Appendix A.

5.3. Oxidant Loadings

The amount of oxidant added to each reactor is a function of the soil mass and TOC. An initial loading (a 1:1 case) was estimated empirically using published values (Siegrist et al., 2001) of NOD for the general soil type and TOC concentration observed at the OU2 site. A NOD is estimated for the soil assuming a ratio of 1 mg $NaMnO_4$ per 1 g of soil (an empirical, average ratio), and an NOD is estimated for the TOC assuming a ratio of 1 mg $NaMnO_4$ per 1 mg of TOC (based upon the measured TOC concentration). The *highest* demand from these two estimates (i.e., the highest NOD from either the NOD from the soil, or the NOD from the TOC) is then taken as the initial NOD for the 1:1 case. It is important to note that the 1:1 case is not used in the experiments conducted, because the ratios utilized for the estimates are taken from the relatively low published values and it is GCI's experience that the experimentally determined NOD is higher.

In the case of OU2, the initial target soil mass per reactor was 500 g soil, and the TOC concentration was 450 mg/kg (Table 5-1). Thus the initial 1:1 loadings were estimated at 500 mg $NaMnO_4$ (from soil mass) and at 225 mg $NaMnO_4$ (from TOC; note that the soil mass for the estimate was 500 g, thus the TOC mass corresponding to a concentration of 450 mg/kg is 225 mg). The higher of these two estimates is the NOD from the soil, at 500 mg $NaMnO_4$ for the 1:1 case (or an oxidant loading of 1 mg $NaMnO_4$ per 1 g of soil). Note that the target ratios used in the test were 5:1, 10:1, and 20:1, and that the soil masses used in the tests were approximately 650 g soil (and thus the $NaMnO_4$ loadings were adjusted accordingly).

5.4. Slurry Preparation and Monitoring

The bench test reactors were set-up on December 2, 2003. Each reactor consisted of a 1,000-mL, opaque, high-density polyethylene bottle with an air-tight cap (glass is not used for safety purposes; however, VOC diffusion through high-density polyethylene is negligible over the course of 2 days of reaction time used in these experiments). Slurries prepared in each reactor consisted of approximately 650 g of soil and 650 mL of groundwater from OU2. The volumes and masses were designed to generate a 50% soil slurry and were adjusted to fill the headspace of the reactor. The exact amounts of soil and groundwater for each test and other experimental conditions are summarized in Table 5-2. A total of five reactors were prepared, consisting of one control (no oxidant) and four with varying oxidant masses (or oxidant : soil ratios). The target oxidant ratios used were 5:1, 10:1, and 20:1 relative to the estimated NOD of 1 mg $NaMnO_4$ per 1 g soil (the 1:1 case). The tests were prepared from the same homogenized soil and groundwater as the baseline samples. It is important to note that a substantial decrease in VOC concentrations is typically observed between the baseline sample and the control slurry. This is described in greater detail in Section 6.2. Volatile loss is considered a negligible issue because the NOD is substantially higher (by an order of magnitude or more) than the oxidant demand for VOC oxidation.

The sequence of tasks to prepare the slurries was as follows. First, approximately 500 g soil and 500 mL of groundwater were added to each reactor. Next, additional soil and groundwater (at the ratio of 1 g soil and 1 mL groundwater) were added to fill most of the space in the reactor (leaving approximately 10 mL volume for oxidant). Next the appropriate mass of oxidant was added. The actual oxidant loadings differed slightly from the target loadings due to variability in dispensing specific soil masses. The actual loadings ranged from zero to approximately 18.1:1 (Table 4-2). The oxidant was weighed for addition, rather than measured by volume, because the oxidant concentration is measured in weight % and thus addition by mass was considered more accurate. Next, the reactors were tightly sealed and then thoroughly mixed. The reactors were then stirred several times each day.

The reactors were monitored for pH, headspace photoionization detector (PID) readings, and temperature before and after the completion of the bench scale treatability study. The laboratory measurements are detailed in Table 5-3. The pH and temperature readings were essentially constant throughout the experiment, and 6.0-6.1 and 59-64°F, respectively. Baseline PID readings ranged from 9.8 to 17.4 ppm and averaged 14.9 ppm. At the conclusion of the bench test, the PID reading in the control sample was 12.8 ppm, while the PID readings in the treated samples was zero.

5.5. Post-Treatment Sample Collection

The experiment was concluded and treated samples collected on December 5, 2003. The sample collection sequence of procedures is summarized as follows. First, the test reactor was opened just enough to insert the PID probe, and the headspace reading was collected. Next the liquid VOC sample was collected. The remaining liquid was then sampled for TOC and then chloride. Residual liquid was then decanted from the bottle and the soil was transferred to a stainless steel bowl. The soil VOC sample was then collected immediately after transferring the soil to the bowl (using methanol preservation techniques). The soil TOC and chloride samples were then collected. All samples for analysis were collected, preserved, and shipped via courier to STL in Edison, New Jersey, utilizing standard preservation methods and chain-of-custody protocols. Treated soil and groundwater samples were analyzed for CLP VOCs, TOC, and chloride.

After collecting and preparing the samples for submittal to STL Edison, the remaining liquid from each test was analyzed for residual permanganate concentration. Permanganate was analyzed using a Hach DR-2010 visible range spectrophotometer using calibrated primary standards.

6. RESULTS AND DISCUSSION

The laboratory analytical results are summarized in Table 5-1, and the full laboratory analytical report is included as Appendix A.

6.1. Baseline Soil and Groundwater Results

The baseline soil and groundwater analytical results indicated the presence of PCE, TCE, and DCE, and acetone in groundwater, and acetone and 2-butanone in soil (Table 5-1). The predominant compound detected was PCE, at 1,500 µg/L. TCE and DCE were present in groundwater at concentrations of 32 µg/L and 330 µg/L, respectively. Acetone was detected at approximately 4.5 µg/L. The chlorinated solvents were not detected in the soil samples, which yielded only acetone and butanone at approximately 6.3 and 1.7 µg/kg, respectively.

The baseline soil and water samples were also analyzed for TOC and chloride concentrations. The groundwater sample yielded a TOC concentration of 4.77 mg/L and a chloride concentration of 18 mg/L (Table 5-1). The soil sample yielded a TOC concentration of 450 mg/kg, and chloride was not detected. As described in Section 5.3, the concentration of TOC in the soil was used to determine the oxidant dosing.

6.2. Control Sample VOC Results

A substantial decrease in VOC concentrations (along with associated VOC mass) is typically observed between the baseline sample (collected prior to preparing the slurries) and the control slurry. This is ascribed to volatile loss experienced during storage, homogenization, and slurry preparation, which is inevitable despite measures to minimize losses (e.g., storage at 4°C, working with samples immediately out of the refrigerator while they are still cold, and working as quickly as possible to minimize volatilization). Furthermore, the control slurry samples are collected after the soil and groundwater have equilibrated, and thus may be different due to physicochemical effects relative to the groundwater and soil samples analyzed in the baseline Therefore, all bench tests include a control sample, which is prepared identically to the treated samples except that no oxidant is added, and is therefore subject to the same handling conditions (and volatile loss) as the tests that receive oxidant. The initial baseline samples are utilized to ensure the soil and groundwater samples are representative, and to provide pre-test estimates of oxidant demand. Only the control sample is used to evaluate VOC oxidation relative to the three treated samples. Volatile loss is considered a negligible issue because the NOD is substantially higher (by an order of magnitude or more) than the oxidant demand for VOC oxidation.

The laboratory analytical data confirm significantly lower VOC concentrations in groundwater between the baseline and control samples. The soil VOC concentrations are more difficult to interpret because the chlorinated solvents were not detected in the baseline soil, but were detected (at estimated concentrations) in the baseline soil. This could represent either partitioning of the VOCs from the groundwater to the soil by adsorbance to TOC, or relatively minor sample heterogeneity. Acetone and 2-butanone were not detected in the control sample.

6.3. VOC Destruction

The analytical results for PCE, TCE, and DCE in soil and groundwater are plotted on Figure 6-1. The chlorinated VOCs in groundwater were essentially destroyed with the smallest $NaMnO_4$ amendment. TCE was detected in the groundwater sample from the 10:1 test, but only at an estimated concentration of 0.7 µg/L. This very low residual TCE concentration most likely represents slow desorption from the soil, because TCE is readily destroyed by permanganate. The increased chloride concentration over the course of treatment indicates chlorinated VOC destruction and not simply volatilization.

6.4. Oxidant Demand

As discussed in Section 2, at most sites the oxidant demand is driven by NOD and not by demand for oxidation of the VOCs. This is the case at OU2, because the VOCs were essentially 100% destroyed in the first $NaMnO_4$ dosage. However, the NOD must be overcome at a site in order to distribute the oxidant away from the point of injection. Thus evaluation of NOD is critical for permanganate in-situ chemical oxidation. Soils essentially have an infinite oxidant demand, and furthermore the NOD scales with permanganate concentration (i.e., other conditions being equal, a higher NOD is associated with higher permanganate concentrations because the MnO_2 can catalyze permanganate degradation). Detailed studies of NOD and of permanganate degradation in soil slurries (e.g., Siegrist et al., 2001) have concluded that the rate of permanganate degradation is asymptotic with time; furthermore, if sufficient permanganate is available, NOD is typically satisfied after 48 hours of reaction time (i.e., the degradation rate reaches the asymptote) and any residual permanganate remaining in a soil slurry can be distributed in an aquifer system. Thus the 48-hr oxidant demand is a valuable measure of the overall NOD at the site.

The oxidant demand calculations are presented in Table 6-1. The baseline $NaMnO_4$ concentrations were based upon measurements of the $NaMnO_4$ mass added to each reactor and the volume of liquid (added groundwater plus soil-sorbed water) present. The post-treatment $NaMnO_4$ concentrations were based upon measurements of the treated water samples. The post-treatment $NaMnO_4$ measurements indicate a slightly higher concentration *after* treatment, than was initially present in the slurries. Although this at first suggests a systematic experimental error, the differences are very small (less than 2%), indicating that although an error is possible, the most likely explanation is that the soil has virtually no oxidant demand. This can happen in very sandy soils, similar to those provided from OU2. This is because the bulk of the NOD from the soil metals is from the fine component (silt and clay), which has substantially higher surface area, available metals, and surface charges. Sand particles have relatively few surface metals or charges, and thus exert a lower demand. In these cases, if the TOC is recalcitrant (not very reactive towards the oxidant), the soil will yield a virtually negligible NOD, as observed at OU2.

The best available pre-test estimates were in excess of the actual NOD, thus the oxidant demand for a field pilot should be conservatively based on these results for the 5:1 sample, at which point the chlorinated VOCs were essentially entirely destroyed. That oxidant demand will be conservatively high, to allow for uncertainties that will be experienced in the field. The oxidant loading in the 5:1 sample was 4.29 mg $NaMnO_4$ per 1 g soil. Because the MnO_4^- ion is the active oxidant, the $NaMnO_4$ oxidant demand can also be expressed as a $KMnO_4$ demand in the event that $KMnO_4$ is used as the oxidant salt in the field. The $KMnO_4$ demand is simply calculated as the ratio of the molecular weights of $KMnO_4$ to $NaMnO_4$ and (158.04 / 141.93 = 1.11) multiplied by the demand (4.29 g $NaMnO_4$ per 1 g soil), which yields a $KMnO_4$ demand of 4.76 mg $KMnO_4$ per 1 g soil.

7. CONCLUSIONS

The goals of this bench test were to determine if permanganate could oxidize the contaminants present in soil and groundwater at the OU2 site, and to evaluate the natural oxidant demand of soil at the site. The conclusions drawn from this bench test are as follows:

(1) The chlorinated VOCs in soil and groundwater at the OU2 site (PCE, TCE, and DCE) are susceptible to oxidation with sodium permanganate. These compounds were reduced to non-detectable levels in soil and groundwater from the site.

(2) Methylene chloride, acetone, and 2-butanone were detected in the untreated and treated soils. These compounds cannot be oxidized by permanganate. Acetone appeared to increase in groundwater over the course of treatment, however there is no known mechanism for acetone formation by permanganate oxidation and thus it is likely this represents desorption or some other process unrelated to permanganate oxidation.

(3) The increase in chloride concentration demonstrates that VOCs in groundwater were significantly reduced and not simply volatilized. The chloride concentration increased in each test reactor representing the breakdown of chlorinated VOCs to chloride ions.

(4) The change in sodium permanganate concentration between the pre- and post-test samples indicates that virtually no sodium permanganate was consumed by natural oxidant demand. This is consistent with very sandy soils. The oxidant demand can therefore be constrained as a maximum of approximately 4.3 mg $NaMnO_4$ (or 4.8 mg $KMnO_4$) per 1 g of soil. The chlorinated VOCs were completely destroyed at this minimum oxidant loading.

The ultimate objective of this bench scale treatability study is "proof of concept" of a treatment technology prior to application in the field (i.e., this technology is capable of treating the contaminants present at the site and that site-specific soil and groundwater conditions [matrix effects] do not significantly interfere with reaction efficiency). Efforts have been made to simulate field treatment conditions and procedures as closely as possible in the lab, however, actual field conditions are difficult to recreate in a laboratory setting. The bench test completed for the OU2 site has demonstrated that sodium permanganate can oxidize the VOCs present in the site-specific soil and groundwater. Based on the results of the laboratory testing; supportive academic literature on the oxidation of chlorinated compounds using sodium permanganate; and the experience of GCI, this site is suitable for chemical oxidation via sodium permanganate.

8. FULL-SCALE IMPLEMENTATION

An estimate for a full-scale implementation of sodium permanganate at the OU2 site was submitted to D&B on January 12, 2004. This estimate includes the cost estimate for three specific treatments, including the treatment of the source area, the cost of a second injection, and the cost of the treatment of the downgradient plume. The costs associated with each of these treatments are displayed in detail in Appendix B along with the contaminant mass calculations for each treatment. The initial design of the each treatment is also included in Appendix B, including the number, locations, and depths of injectors, the estimated cost of treatment, and the estimated length of treatment required to reach cleanup goals. The cost for the treatment of the source area was **$77,904**; the cost for a second injection within the source area was **$20,930**; and the cost to treat the downgradient plume was **$74,544**.

9. REFERENCES CITED

Huang, K.-C., Hoag, G. E., Chheda, P., Woody, B. A., and Dobbs, G. M. 1999. Kinetic study of oxidation of trichloroethylene by potassium permanganate. *Environmental Engineering Science* 16: 265-274.

Laha, S., and Luthy, R. G. 1990. Oxidation of aniline and other primary aromatic amines by manganese dioxide. *Environmental Science and Technology* 24: 363-373.

Siegrist, R.L., Urynowicz, Michael A., West, Olivia R., Crimi, Michelle L, Lowe, Kathryn S. 2001. *Principles and Practices of In Situ Chemical Oxidation Using Permanganate*, p. 53-57.

U.S. EPA. 1998. *Field Applications of In Situ Remediation Technologies: Chemical Oxidation*. EPA 542-R-98-008, 31 pages.

Vella, P. 1998. Permanganate wastewater treatment. Pages 3451-3462 *in* Meyers, R. A., *Encyclopedia of Environmental Analysis and Remediation*. Wiley.

Yan, Y. E., and Schwartz, F. W. 1999. Oxidative degradation and kinetics of chlorinated ethylenes by potassium permanganate. *Journal of Contaminant Hydrology* 37: 343-365.

Yan, Y. E., and Schwartz, F. W. 2000. Kinetics and mechanisms for TCE oxidation by permanganate. *Environmental Science and Technology* 34: 2535-2541.

Appendix B

APPENDIX B

DETAILED COST ESTIMATE

Alternative 1
123 Post Avenue Site - OU2
No Action with Long-term Groundwater Monitoring
Cost Estimate

Item	Quantity	Units	Unit Cost	Total
Capital Costs				
	TOTAL ESTIMATED CAPITAL COST			**$0**
Operation and Maintenance Costs				
Groundwater Monitoring Costs Per Event				
Groundwater sampling	2	Mandays	$600	$1,200
Purge water disposal	4	Drums	$200	$800
Equipment, materials and supplies	-	Lump Sum	$1,000	$1,000
Sample analysis[1]	4	Samples	$100	$400
	Estimated per event monitoring costs			$3,400
	Present worth of annual groundwater monitoring (30 yrs, i=5%)[2]			$172,000
	REMEDIAL ALTERNATIVE 1 TOTAL ESTIMATED COSTS			**$172,000**

[1] Sample analysis includes volatile organic compounds

[2] Sampling frequency includes 4 times per year for the first 10 years, 2 times per year for the next 10 years and 1 time per year for the remaining 10 years.

Alternative 2
123 Post Avenue Site - OU2
In Situ Chemical Oxidation with Long-term Groundwater Monitoring
Cost Estimate

Item	Quantity	Units	Unit Cost	Total
Capital Costs				
Mobilization/demobilization[1]	-	Lump Sum	$50,000	$50,000
Vendor Design	-	Lump Sum	$10,000	$10,000
Zone 1 Injector Installation [2]				
Drilling costs, materials and oversight	14	Injection pts	$12,000	$168,000
Zone 1 Oxidant Injection [2] (includes personnel and material costs for 1 complete and 1 partial injection round)	-	Lump Sum	$55,000	$55,000
Zone 2 Injector Installation [2]				
Drilling costs, materials and oversight	19	Injection pts	$12,000	$228,000
Zone 2 Oxidant Injection [2] (includes personnel and material costs for 1 complete injection round)	-	Lump Sum	$30,000	$30,000
Pre-remediation Monitoring				
Monitoring well installation	5	each	$10,000	$50,000
Groundwater sampling	5	Mandays	$600	$3,000
Purge water disposal	9	Drums	$200	$1,800
Equipment, materials and supplies	-	Lump Sum	$1,000	$1,000
Sample analysis[3]	9	Samples	$100	$900
Vendor Support	-	Lump Sum	$50,000	$50,000
		Estimated Capital Cost		**$648,000**
Contingency and Engineering Fees				
Contingency allowance (15%)				$97,000
Engineering fees (20%)[4]				$130,000
Estimated Contingency and Engineering Fees				$227,000
TOTAL ESTIMATED CAPITAL COST				**$875,000**

Alternative 2
123 Post Avenue Site
In Situ Chemical Oxidation with Long-term Groundwater Monitoring
Cost Estimate (continued)

Item	**Quantity**	**Units**	**Unit Cost**	**Total**
Operation and Maintenance Costs				
Groundwater Monitoring Costs Per Event (all parameters)				
Groundwater sampling	5	Mandays	$600	$3,000
Purge water disposal	9	Drums	$200	$1,800
Equipment, materials and supplies	-	Lump Sum	$1,000	$1,000
Sample analysis[4]	9	Samples	$200	$1,800
	Estimated per event monitoring costs			$7,600
	Six events during remedial phase			**$46,000**
Groundwater Monitoring Costs Per Event (VOCs only)				
Groundwater sampling	2	Mandays	$600	$1,200
Purge water disposal	2	Drums	$200	$400
Equipment, materials and supplies	-	Lump Sum	$1,000	$1,000
Sample analysis[3]	4	Samples	$100	$400
	Estimated per event monitoring costs			$3,000
	Present worth of annual groundwater monitoring (10 yrs, i=5%)[5]			**$32,000**
	REMEDIAL ALTERNATIVE 2 TOTAL ESTIMATED COSTS			**$953,000**

[1] Includes bonds, insurance, temporary facilities, pre-construction submittals and shop drawings

[2] Based on costs provided by GeoCleanse International, Inc.

[3] Sample analysis includes volatile organic compounds, manganese, chloride, permanganate concentration, color, temperature and pH during operation of the system and
volatile organic compounds before and after the system is operating.

[4] Includes design and construction inspection

[5] Sampling frequency includes 4 times per year for the first year and 1 time per year for the next 9 years.

Alternative 3
123 Post Avenue Site - OU2
In-Situ Bioremediation with Long-term Groundwater Monitoring
Cost Estimate

Item	Quantity	Units	Unit Cost	Total
Capital Costs				
Mobilization/demobilization[1]	-	Lump Sum	$50,000	$50,000
Zone 1 System[2]				
Injection point installation (30 injection points)	20	days	$2,000	$40,000
HRC injection costs[3] (30 injection points)	-	Lump Sum	$150,000	$150,000
Zone 2 System[2]				
Injection point installation (30 injection points)	30	days	$2,000	$60,000
HRC injection costs[3] (30 injection points)	-	Lump Sum	$110,000	$110,000
Engineering Support	-	Lump Sum	$10,000	$10,000
Pre Injection Sampling				
Monitoring well installation	5	each	$10,000	$50,000
Groundwater sampling	5	Mandays	$600	$3,000
Purge water disposal	9	Drums	$200	$1,800
Equipment, materials and supplies	-	Lump Sum	$1,000	$1,000
Sample analysis[4]	9	Samples	$100	$900
		Estimated Capital Cost		**$477,000**
Contingency and Engineering Fees				
Contingency allowance (20%)				$95,000
Engineering fees (20%)[5]				$95,000
Estimated Contingency and Engineering Fees				$190,000
TOTAL ESTIMATED CAPITAL COST				**$667,000**

Alternative 3
123 Post Avenue Site - OU2
In-Situ Bioremediation with Long-term Groundwater Monitoring
Cost Estimate (continued)

Item	Quantity	Units	Unit Cost	Total
<u>**Operation and Maintenance Costs**</u>				
Groundwater Monitoring Costs Per Event (all parameters except VOCs)				
Groundwater sampling	5	Mandays	$600	$3,000
Purge water disposal	9	Drums	$200	$1,800
Equipment, materials and supplies	-	Lump Sum	$1,000	$1,000
Sample analysis[4]	9	Samples	$300	$2,700
	Estimated per event monitoring costs			$8,500
	Present worth of annual groundwater monitoring (8 yrs, i=5%)[7]			**$126,000**
Groundwater Monitoring Costs Per Event (VOCs only)				
Groundwater sampling	2	Mandays	$600	$1,200
Purge water disposal	2	Drums	$200	$400
Equipment, materials and supplies	-	Lump Sum	$1,000	$1,000
Sample analysis[6]	4	Samples	$100	$400
	Estimated per event monitoring costs			$2,600
	Present worth of annual groundwater monitoring (30 yrs, i=5%)[8]			**$72,000**
	REMEDIAL ALTERNATIVE 3 TOTAL ESTIMATED COSTS			**$865,000**

[1] Includes bonds, insurance, temporary facilities, pre-construction submittals and shop drawings

[2] Based on costs provided by Regenesis, Inc.

[3] Includes taxes and shipping

[4] Sample analysis includes volatile organic compounds, total organic carbon, metabolic acids, total and dissolved iron and manganese, nitrate, sulfate, sulfide and carbon dioxide, methane, ethane and ethene.

[5] Includes design and construction inspection.

[6] Sample analysis includes volatile organic compounds

[7] Sampling frequency includes 4 times per year for the first year, 2 times per year for the next 7

[8] Sampling frequency includes 4 times per year for the first 8 years, 2 times per year for the next 12 years and 1 time per year for the remaining 10 years.

Alternative 4
123 Post Avenue Site - OU2
Ozone Enhanced Air Sparging with Long-term Groundwater Monitoring
Cost Estimate

Item	Quantity	Units	Unit Cost	Total
Capital Costs				
Mobilization/demobilization[1]	-	Lump Sum	$50,000	$50,000
Vendor Design[2]	-	Lump Sum	$150,000	$150,000
Zone 1 System Construction[2]				
Ozone sparge wells (2 sparge points per location)	5	each	$9,000	$45,000
Perozone panel/misc. appurtenances	-	Lump Sum	$75,000	$75,000
Distribution piping/trenching	1	each	$25,000	$25,000
SVE wells (horizontal)/monitoring wells	-	Lump Sum	$25,000	$25,000
SVE/treatment system (assumes carbon)	-	Lump Sum	$15,000	$15,000
Electrical/power connection	-	Lump Sum	$5,000	$5,000
Engineering support	-	Lump Sum	$17,000	$17,000
Utility and local permits	-	Lump Sum	$18,000	$18,000
Zone 2 System Construction[2]				
Ozone sparge wells (2 sparge points per location) (assume 4 transects - 3 sparge wells each)	12	each	$15,000	$180,000
Ozone panel/misc. appurtenances - installed	4	each	$50,000	$200,000
Distribution piping/trenching	1	each	$15,000	$15,000
Electrical/power connection	4	each	$5,000	$20,000
Engineering support	-	Lump Sum	$23,000	$23,000
Utility and local permits	-	Lump Sum	$14,000	$14,000
Pre-remediation Monitoring				
Monitoring well installation	7	each	$9,000	$63,000
Groundwater sampling	5	Mandays	$600	$3,000
Purge water disposal	12	Drums	$200	$2,400
Equipment, materials and supplies	-	Lump Sum	$1,000	$1,000
Sample analysis[3]	12	Samples	$100	$1,200
Vendor Support	-	Lump Sum	$100,000	$100,000
		Estimated Capital Cost		**$1,048,000**
Contingency and Engineering Fees				
Contingency allowance (15%)				$157,000
Engineering fees (20%)[4]				$210,000
Estimated Contingency and Engineering Fees				$367,000
TOTAL ESTIMATED CAPITAL COST				**$1,415,000**

Alternative 4
123 Post Avenue Site - OU2
Ozone Enhanced Air Sparging with Long-term Groundwater Monitoring
Cost Estimate (continued)

Item	Quantity	Units	Unit Cost	Total
Operation and Maintenance Costs				
Zone 1 1 - 3 Months				
Vapor sample collection and analysis	24	each	$500	$12,000
Groundwater samples [3]	90	each	$130	$11,700
O&M	12	weeks	$1,000	$12,000
SVE carbon changeout	3	each	$2,000	$6,000
Engineering support	12	weeks	$1,500	$18,000
Power	3	months	$500	$1,500
Contingencies	-	Lump Sum	$12,000	$12,000
	Estimated O&M costs for Zone 1			**$73,000**
Zone 2 - Annual costs				
O&M	12	months	$4,500	$54,000
Groundwater samples [3]	48	each	$130	$6,240
Engineering support	1	year	$45,000	$45,000
Power	12	months	$2,000	$24,000
Contingencies	-	Lump Sum	$25,000	$25,000
	Estimated annual O&M costs for Zone 2			$154,240
	Present worth of annual O&M (3 yrs, i=5%)			**$420,000**
Groundwater Monitoring Costs Per Event				
Groundwater sampling	2	Mandays	$600	$1,200
Purge water disposal	2	Drums	$200	$400
Equipment, materials and supplies	-	Lump Sum	$1,000	$1,000
Sample analysis[3]	4	Samples	$100	$400
	Estimated per event monitoring costs			$3,000
	Present worth of annual groundwater monitoring (10 yrs, i=5%)[5]			**$48,000**
	REMEDIAL ALTERNATIVE 4 TOTAL ESTIMATED COSTS			**$1,956,000**

[1] Includes bonds, insurance, temporary facilities, pre-construction submittals and shop drawings

[2] Based on costs provided by O'Brien and Gere Engineers

[3] Sample analysis includes volatile organic compounds, sulfate and nitrate during operation of the system and volatile organic compounds only before after the system is no longer operating.

[4] Includes design and construction inspection

[5] Sampling frequency includes 4 times per year for the first 3 years and 1 times per year for the next 7 years.