US Army Corps of Engineers

FINAL

Feasibility Study
3800 Area PCE Site

Fort Drum Installation Restoration Program
Fort Drum, New York

September 2015

Contract No.: W912DR-12-D-0007
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Prepared For:

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A JOINT VENTURE

Feasibility Study
3800 Area PCE Site

Installation Restoration Program
Fort Drum, New York

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Acronyms and Abbreviations

°F	degrees Fahrenheit
%	percent
amsl	above mean sea level
AS	air sparging
bgs	below ground surface
BTEX	benzene, toluene, ethyl benzene, and xylenes
cDCE	cis-1,2-dichloroethene
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act (1980)
CHP	catalyzed hydrogen peroxide
COC	constituent of concern
CVOC	Chlorinated Volatile Organic Compound
DER	Division of Environmental Remediation
DHC	*Dehalococcoides* spp.
DMP	Data Management Plan
DNAPL	Dense Non-Aqueous Phase Liquid
DO	dissolved oxygen
DPW	Department of Public Works
ECD	electron capture detector
ELAP	Environmental Laboratory Approval Program
ERH	electrical resistance heating
EVO	emulsified vegetable oil
ft	feet

gpm	gallons per minute
GRA	general response action
GWQS	Ground Water Quality Standards (NYSDEC)
HHRA	human health risk assessment
IDW	investigative-derived waste
IRZ	in situ reactive zone
ISCO	In-Situ Chemical Oxidation
ISEB	In Situ Enhanced Bioremediation
JV	Joint Venture
K	hydraulic conductivity
LNAPL	light non-aqueous phase liquid
LTM	long-term monitoring
MAES	Multiple Award Environmental Services
MIP	membrane interface probe
NOD	natural oxidant demand
NYSDEC	New York State Department of Environmental Conservation
NZVI	nano-scale zero-valent iron
ORP	oxidation-reduction potential
OSL	Old Sanitary Landfill
PCE	tetrachloroethene
PID	photoionization detector
POTW	publically-owned treatment works
PRB	permeable reactive barrier

psi	pounds per square inch
PWS	Performance Work Statement
RAO	Remedial Action Objective
RCRA	Resource Conservation and Recovery Act
RI	Remedial Investigation
ROI	radius of influence
SCFM	standard cubic feet per minute
SCG	Standards, Criteria, and Guidance
SEE	steam-enhanced extraction
SLERA	screening-level ecological risk assessment
SVE	soil vapor extraction
SWIM	surface water interface monitoring
TSDF	treatment/storage/disposal facility
TSI	Terra Systems, Inc.
USACE	United States Army Corps of Engineers
USEPA	United States Environmental Protection Agency
UST	underground storage tank
VC	vinyl chloride
VOCs	volatile organic compounds
ZVI	zero-valent iron
cm/s	centimeters per second
g/L	grams per liter
mL	milliliter

µg/kg	micrograms per kilogram
µg/L	micrograms per liter
µg/m^3	micrograms per cubic meter

Executive Summary

ES.1 Introduction

The purpose of this Feasibility Study (FS) is to assemble and evaluate remedial alternatives and to identify a preferred remedial alternative for the 3800 Area Tetrachloroethene (PCE) Site at Fort Drum, New York (the Site). The PIKA - MP Joint Venture (JV), LLC[1] (hereinafter referred to as the JV) has prepared this FS to meet the requirements of the performance work statement (PWS) issued by the United States (US) Army Corps of Engineers (USACE) Baltimore District under the Multiple Award Environmental Services (MAES) contract, Award No. W912DR-12-D-0007, Delivery Order 0003. This FS has been prepared in accordance with New York State Department of Environmental Conservation (NYSDEC) Division of Environmental Remediation (DER) Technical Guidance for Site Investigation and Remediation (DER-10), NYSDEC Program Policy for Green Remediation (DER-31), and Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) guidance.

A Draft Final Remedial Investigation Report (RIR) was completed in February 2013 (PARS, 2013a) and presents the findings of field investigation activities performed between 2010 and 2012 to characterize the extent of PCE and other chlorinated volatile organic compounds (CVOCs) at the Site. A Draft Final addendum to the RIR was prepared in August 2013 (PARS, 2013b) and includes the results of a bench study and an in situ chemical oxidation (ISCO) pilot study performed at the Site. This FS incorporates the results of the RI, bench study, and pilot study.

The 3800 Area PCE Site is located near the eastern end of Oneida Avenue, near the intersection with New York State Route 26. The Site includes Fort Drum Areas 1700, 1800, 1900, and 3800; associated buildings; portions of the Old Sanitary Landfill (OSL); and the streams north and northeast of the OSL.

ES.2 Conceptual Site Model Summary

Information obtained during the RI was used to develop a conceptual site model (CSM), which summarizes the site-specific geology and hydrogeology and the depth

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[1] The PIKA-MP LLC Joint Venture is comprised of PIKA International, Inc. and its mentor ARCADIS-U.S. Inc.

and flow of groundwater that affect the distribution, fate, and migration of CVOCs. The CSM for the 3800 Area PCE Site is summarized as follows:

- Subsurface soils at the Site are composed of deltaic sand and silty sand, which grade to clay, which forms the base of the surficial aquifer and confining unit for the deeper bedrock aquifer.
- Due to the gradational change in geology, aquifer properties change in relation to the depth of the aquifer. The aquifer was sub-divided into three hydrostratigraphic zones: 1) Shallow zone, defined as 20 ft from the base of the water table; 2) Intermediate zone, defined as 20 ft from the base of the shallow zone; and 3) Deep zone, from the base of the intermediate zone to the top of the clay confining unit. The water table occurs at approximately 20 ft bgs.
- Groundwater flow in all three zones is towards the north/northeast, with groundwater ultimately discharging into the unnamed creek between OSL Cells 1 and 2.
- K values in the intermediate portion of the aquifer range from 1.8 to 11.6 ft/day, with a geometric mean of 4.5 ft/day. K values are generally higher at shallower depths; historical data from a series of slug tests, geotechnical sampling, and aquifer pump tests reported K from 23 to 45 ft/day. At a depth of 60 feet bgs, the average K value is approximately 3 ft/day ($1*10^{-3}$ centimeters per second (cm/s)).
- Although horizontal flow is dominant, small downward vertical gradients were measured between the shallow and intermediate hydrostratigraphic zones, and upward vertical gradients were measured from the deep to the intermediate hydrostratigraphic zones.
- CVOCs were not detected in vadose zone soils at the Site.
- The results of the RI indicated that the highest concentrations of PCE in groundwater are located in the shallow and intermediate hydrostratigraphic zones south of Ontario Avenue at a depth of 30 to 45 ft bgs. The greatest horizontal extent of PCE occurs in the intermediate zone; PCE detections extend approximately 2,500 feet down-gradient to the groundwater discharge point at the unnamed creek between OSL Cells 1 and 2.
- Aquifer conditions in all three zones are generally aerobic and oxidative, and thus are not conducive to natural attenuation of PCE via intrinsic biodegradation.
- Sub-slab sampling at Building 1885 indicates the presence of a potential source of PCE beneath the building. Indoor air sampling confirms that no CVOCs are present in indoor air at Building 1885.
- Although a definitive “source” of PCE was not identified in the RI report, the MIP-10 data, the soil gas results, and the sub-slab sampling results are indicative of PCE mass in soil in the vicinity and potentially beneath Building 1885. Additionally, the highest PCE concentration in the intermediate zone (599 µg/L) was observed at PCERI-MW25I (screened at 35 to 45 feet bgs), 10 feet down-gradient of

Building 1885. Building 1885 may have been constructed over a historical PCE spill location as this area was historically used for vehicle storage, maintenance, and refueling purposes according to historical aerial photographs. Several smaller structures were present in the area before Building 1885 was constructed in 2010.

- The HHRA indicated that CVOCs in groundwater at the Site are unlikely to result in any future unacceptable health impacts to the evaluated receptors. The SLERA concluded that, based on conservative screening evaluations, there is a possibility of exposure to benthic organisms and amphibian larvae in contact with water in the sediment pores in a localized area of the unnamed creek between OSL Cells 1 and 2.
- Bench study results indicated that ISCO using permanganate, and application of NZVI were promising technologies. ISEB was also promising, although bioaugmentation with CVOC dechlorinating cultures was required to achieve PCE biodegradation.
- An ISCO pilot study conducted in November 2012 had mixed results, primarily due to difficulties in monitoring for dose-response due to snow accumulation and construction activities in the vicinity of the monitoring wells. Additionally, insufficient volume may have been injected to achieve the desired radius of influence (ROI). Where permanganate was detected, PCE concentrations decreased markedly.

ES.3 Remedial Action Objectives

As defined in Section 4.1 of DER-10, Remedial Action Objectives (RAOs) are media or site-specific objectives for the protection of public health and the environment. These goals are developed based on site- and contaminant-specific Standards, Criteria, and Guidance (SCGs). When establishing RAOs, DER-10 states that the following criteria must be identified and considered:

1. Applicable SCGs that consider the current, intended, and anticipated future use of the site and its surroundings;
2. All contaminants exceeding SCGs;
3. Environmental media impacted by such contaminants;
4. Extent of the impact to the environmental media;
5. Actual or potential human exposures and/or environmental impacts resulting from the contaminants in environmental media identified above; and
6. Any site-specific cleanup levels.

The Army has agreed to a Consent Decree that includes the 3800 Area PCE Site. The Consent Decree specifies the requirements with which the Army must comply for remedial actions at the Site. The 3800 Area PCE Site is subject to the Consent Decree Appendix “C” Standard Clauses for all New York State Superfund Orders which, therefore, are also considered an SCG for the 3800 Area PCE Site.

The contaminants of concern for the 3800 Area PCE Site are CVOCs, primarily PCE and TCE. The down-gradient portion of the PCE plume in the intermediate zone, north of Onedia Avenue, is co-located with a plume of petroleum constituents associated with Area 3805. Petroleum-related contamination that is present within the 3800 Area PCE Site boundary is being addressed separately under Area 3805/1995 remedial activities. The environmental media that are impacted by CVOCs are groundwater, saturated soil, surface water/groundwater interface, and sediment. No CVOCs have been detected in unsaturated soil.

Potential groundwater exposure pathways for human receptors include groundwater consumption (i.e., drinking water), dermal contact, inhalation of CVOCs in indoor air due to vapor intrusion, and (for future residents) inhalation of VOCs while showering. None of these exposure pathways are currently complete, as water from the Site is not used for consumptive purposes, and several rounds of indoor air monitoring indicated that PCE is not present in buildings at the Site. The HHRA concluded that even if exposure pathways were complete, risks to all evaluated receptors would be within or below EPA risk ranges (PARS, 2013a). Potential surface water/groundwater interface and sediment exposure pathways exist for ecological receptors including benthic invertebrate communities, aquatic communities, reptiles, and amphibians residing in the unnamed creek between the two OSL cells. Based on very conservative screening evaluation, there is the possibility for localized effects to the benthic community and amphibian larvae in contact with sediment pore water.

DER-10 identifies generic RAOs for the various media and exposure scenarios that should be considered if applicable based on the contaminants present and media affected at a given site. Generic RAOs considered to be applicable to the 3800 Area PCE Site are presented below.

Public Health Protection:

- Prevent ingestion of groundwater with contaminant levels exceeding drinking water standards.
- Prevent contact with and/or inhalation of volatiles from contaminated groundwater.

Environmental Protection:

- Restore groundwater to pre-disposal/pre-release conditions, to the extent practicable.
- Prevent the discharge of contaminants to surface water.

- Remove the source of ground or surface water contamination.

The proposed site-specific RAOs for groundwater are as follows:

- Remove or treat CVOCs from the presumed source area beneath and in the vicinity of Building 1885 to the extent practicable.
- Achieve groundwater quality standards.

ES.4 Remedial Alternatives

Potential remedial technologies were screened based on the criteria of effectiveness, implementability, and relative cost. The technologies that were retained were used to assemble remedial alternatives for the 3800 Area PCE Site. Each alternative (with the exception of Alternative 1) includes groundwater source area treatment followed by long-term monitored natural attenuation (MNA).

Alternative 1 – No Further Action

The No Further Action alternative is included as a baseline alternative for comparison to the active remedial alternatives in accordance with DER-10. In this case, the No Further Action alternative will require that injection and monitoring wells associated with the 2012 ISCO pilot study and the planned summer 2015 ISCO pilot study be abandoned. The No Further Action alternative does not include groundwater monitoring or maintenance of institutional controls. Because there is no active remediation or institutional controls to be maintained, no technical difficulties are anticipated for implementation of Alternative 1.

Alternative 2 – In Situ Chemical Oxidation with Monitored Natural Attenuation

Alternative 2 utilizes the existing injection well network with optimization, via installation of additional injection wells or refinement to the injection strategy, to inject chemical oxidant (sodium permanganate) in the presumed PCE source area between Building 1885 and Oneida Avenue. The ISCO program will focus treatment on the silty sands in the lower shallow and upper intermediate zones, where the bulk of the PCE mass is located, which is responsible for the majority of PCE mass flux down-gradient. Additional injection wells, if required, would be installed in a grid pattern throughout the presumed PCE source area to ensure adequate distribution of the oxidant and facilitate rapid treatment of CVOCs. Placement of the new injection wells would be determined after completion of the second ISCO pilot test. The injection wells would extend into the interval of the highest PCE detections between 35 and 42 ft bgs. Given the extensive ISCO pilot test work completed previously, and given the planned second ISCO pilot test (anticipated to remove a significant amount of PCE mass), a single injection of sodium permanganate is anticipated to be sufficient to reduce PCE concentrations to levels that support MNA. Alternative 2 would rapidly (i.e., within a period of months) eliminate source concentrations of PCE currently migrating down-gradient and thus allow transition to an MNA program within the shortest timeframe. In addition, Alternative 2 provides the ability to remediate the suspected source area under Building 1885 as the reaction kinetics of the selected oxidant provide months of active treatment allowing the injected solution to migrate down-gradient and remediate CVOCs outside the ROI of the injection well network.

The MNA program will include sample collection from existing monitoring wells in the source area and the down-gradient plume. Approximately 30 monitoring wells will be included in the MNA plan. Samples will be analyzed for only VOCs as there is no evidence of natural attenuation via biological degradation. The duration of the MNA program was calculated based on the number of pore flushes required to reach the cleanup criterion for PCE (5 ug/L). Approximately 16 years of groundwater monitoring will be required. Monitoring will be performed semi-annually for 5 years with subsequent sampling annually.

Alternative 3 – In Situ Enhanced Bioremediation with Bioaugmentation with Monitored Natural Attenuation

Alternative 3 utilizes the existing injection well network with optimization via installation of additional injection wells or refinement to the injection strategy, to inject organic carbon (sodium lactate and emulsified vegetable oil [EVO]) and bacterial dechlorinating cultures in the presumed PCE source area between Building 1885 and Oneida Avenue. The in situ enhanced bioremediation (ISEB) program will focus treatment on the silty sands in the lower shallow and upper intermediate zones, where the bulk of the PCE mass is located, which is responsible for the majority of the down-gradient PCE mass flux. Injection wells utilized during the ISCO pilot studies would be utilized to implement this alternative; however, rather than utilizing injection wells in a grid pattern, select transects of wells will be utilized to establish a set of reactive barriers to degrade the PCE as impacted water migrates through each barrier. Additional injection wells would be installed within a specific barrier to ensure adequate distribution of organic carbon and bacterial cultures to alter the aquifer environment and facilitate degradation of PCE. The injection wells would extend into the interval of the highest PCE detections between 35 and 42 ft bgs. In order to complete the remedial design of Alternative 3, tracer testing would be completed to verify groundwater velocities in the target treatment interval. The groundwater velocity and contaminant velocity would be essential design parameters to size each barrier appropriately. Alternative 3 will effectively prevent migration of PCE down-gradient of the treatment area once the in situ reactive zone (IRZ) in the farthest down-gradient barrier is established. Given the required shift in aquifer geochemistry, it could take up to one year post injection before a fully developed IRZ is established. Alternative 3 would require maintenance injections until the impacted water between each barrier has attenuated to concentrations that will support MNA. It is estimated this will take up to four years of active injections.

The MNA program would be similar to that described for Alternative 2 with the exception that the total monitoring duration is 19 years.

Alternative 4 – Air Sparge/Soil Vapor Extraction with Monitored Natural Attenuation

Alternative 4 involves the installation of new well infrastructure to inject ambient air into the target treatment interval (i.e., via air sparging [AS]) and to recover volatilized CVOCs from the vadose zone soils (i.e., via soil vapor extraction [SVE]). The AS system will inject ambient air into the presumed PCE source area between Building 1885 and Oneida Avenue. The AS/SVE system would focus treatment on the silty sands in the intermediate zone, where the bulk of the PCE mass is located. Each well network (AS and SVE) would be installed in a grid pattern to remediate the presumed PCE source area and reduce down-gradient migration. The AS wells would extend to approximately 60 ft bgs to ensure adequate air distribution in the target treatment interval between 35 and 42 ft bgs.AS wells would have two feet of screen. SVE wells would be installed to the top of the water table, approximately 20 ft bgs. As no soil source of PCE is known, the SVE wells would focus on recovery of volatilized compounds from the groundwater and would therefore have 5 ft screens. AS and SVE pilot tests, as well as a combined AS/SVE test, would be completed to confirm design parameters and appropriately size equipment. The AS pilot test would focus on the pressure required to inject an appropriate amount of air into the formation (~10 standard cubic feet per minute [SCFM]) as well as the ROI of the AS well in the target treatment interval. Existing injection wells could be used to assess the ROI of the AS wells. The SVE pilot test would confirm the ROI of the SVE wells, the required vacuum, as well as anticipated VOC concentrations in the vapor stream. It is assumed that granular activated carbon will be used to treat the SVE effluent air stream.

The AS/SVE system would operate approximately two years to reduce source concentrations sufficiently to support MNA. The AS system would operate in zones (specific subsets of AS wells), while the SVE system would operate continuously. In order to operate year round, all the instrumentation and controls would be located inside an insulated and heated equipment building. This requires individual AS lines be installed so that individual well pressure and flow rates can be monitored. The SVE system would be operated continuously and could be piped via common headers for each zone. Individual headers for each zone are necessary to ensure the SVE system is capturing 125% of the air injected, which is sufficient to prevent fugitive vapors.

The MNA program would be similar to that described for Alternative 2 with the exception that the total monitoring duration is 17 years.

ES.5 Comparative Analysis of Remedial Alternatives

Overall Protection of Human Health and the Environment

Besides Alternative 1, all alternatives achieve the RAOs and provide overall protection of human health and the environment in the long term. Alternatives 2 through 4 include source area treatment via in situ chemical, biological, or physically extractive means at the presumed PCE source area.

Compliance with SCGs

Alternatives 2 through 4 would all be expected to comply with the SCGs within a reasonable timeframe. Active remediation time-frame varies with each alternative but is anticipated between 1 and 4 years. Following active remediation, continued monitoring would be required before the Site meets the SCGs; however, further contribution to the down-gradient dissolved phase plume would be greatly reduced, which would facilitate natural attenuation (primarily via non-biological mechanisms) of the down-gradient plume. Alternative 1 would not comply with the SCGs within a reasonable timeframe.

Long-Term Effectiveness and Permanence

With the exception of Alternative 1, all remaining alternatives provide long term effectiveness and permanence. Alternatives 2, 3, and 4 would result in the removal or destruction of PCE in the source area and would prevent further migration down-gradient.

Reduction of Toxicity, Mobility, and Volume

Alternative 1 provides no reduction in toxicity, mobility or volume.

Alternative 2 immediately (within months) reduces the volume, mobility and toxicity of PCE via the injection of an oxidant. Alternative 2 would provide rapid treatment of PCE and would result in the quickest reduction in PCE concentrations. The longevity of the selected oxidant (sodium permanganate) will provide longer active treatment than other oxidants which will result in more efficient treatment of PCE as it back diffuses to mobile pore spaces due to concentration gradients generated by the oxidant. This would reduce the likelihood of rebound of PCE due to back diffusion from immobile pore spaces. Increased solubility (and mobility) of some metals, such as cadmium, chromium, lead, and arsenic, can be expected within the source zone due to the oxidation and low pH effects resulting from the chemical reactions. These constituents would be expected to precipitate as the pH neutralizes (returns to background) outside the treatment zone.

Alternative 3 provides the slowest reduction in volume, mobility and toxicity as it first requires the development of an active biological population. There is no evidence of natural degradation of the PCE to TCE or other daughter products and the aquifer environment is aerobic and lacking in organic carbon. This alternative would require changing the natural aquifer environment which creates additional challenges, but also requires significantly more time to observe measureable remedial benefit. In addition, Alternative 3 results in intermediate degradation products (trichloroethene [TCE], cis-1,2-dichloroethene and vinyl chloride [VC]) that could result in minor down-gradient impacts of these compounds and potentially increase overall toxicity. Additionally, production of VC, methane, and/or hydrogen sulfide could potentially raise vapor intrusion concerns for Building 1885. Increased solubility (and mobility) of some metals, such as iron, lead, and arsenic, can be expected within the source zone due to the reduced biogeochemical conditions. These constituents would be expected to precipitate as the aquifer becomes aerobic and oxidizing outside the treatment zone.

Alternative 4 would provide immediate recovery of PCE and reduce down-gradient migration, which would reduce the volume, mobility and toxicity of the source area. Because PCE, and to a lesser degree TCE, are not aerobically biodegradable, no remedial benefit is realized with the increased dissolved oxygen present in the source area. AS wells must be installed deeper than the target interval to effectively treat the target interval and would therefore have to be installed deeper than the injection wells in Alternatives 2 and 3. The hydraulic conductivity in the source area appears to decrease with depth, which potentially creates a challenging environment to inject and distribute sufficient air to volatilize dissolved phase CVOCs. Similar to Alternative 2, PCE is also subject to rebound via back diffusion as the air only contacts dissolved phase CVOCs in the mobile pore spaces.

Short-Term Effectiveness

Alternative 1 would involve no activities that present short-term exposure risks to human health or the environment. Implementation of Alternative 2 or 3 would result in minimal exposure risks to the community, workers, and the environment through the installation of monitoring wells and injection of reagents. Alternative 4 would subject the community and the environment to minimal risk through the installation of AS and SVE wells. There are no known impacts to shallow soil; however, the increased number of well installations and complexity of the construction activities (trenching, pipe installation, equipment installation) pose an increased risk to workers for Alternative 4. Alternative 2 meets the remedial response objectives the quickest (within 6 months). The remedial response objective for Alternative 4 should be met within 2 years and Alternative 3 within 4 years.

Implementability

Alternative 1 is not administratively feasible due to the lack of monitoring or protection of human health and the environment. All remaining alternatives are technically and administratively feasible with Alternative 4 being the most difficult to implement both technically and administratively. Alternatives 2 and 3 are more implementable due to the ability to utilize existing infrastructure, minimal installation of new wells, and no permanent above ground or below ground infrastructure (other than the injection wells). Alternatives 2 and 3 are comparable and would not interfere or would minimally interfere with ongoing operations. The air sparge wells for Alternative 4 require installation into a deeper interval that may be less amenable to injection and would either limit treatment, or would require a denser well network to achieve treatment. Installation of the infrastructure associated with Alternative 4 would create the most disruption to the ongoing operations in and around the nearby buildings.

Cost

The costs associated with Alternative 1 include only abandoning the existing injection and monitor well infrastructure. The cost for abandoning the wells is estimated to be $72,600. Of the remaining alternatives, Alternative 2 has the lowest present value cost of $1,511,600 and Alternative 4 has the highest present value cost of $3,111,800. The remedial timeframes for each alternative, excluding Alternative 1, are reasonable.

Green and Sustainable Remediation Analysis

A quantitative sustainability assessment was conducted for Alternatives 2, 3, and 4. The quantitative assessment was performed using the ARCADIS sustainability tool, BalancE3™. The analysis addresses the criteria identified in DER-31 through the evaluation of five commonly accepted metrics: 1) energy usage, 2) air emissions, 3) water consumption and impacts, 4) material consumption and waste generation, and 5) land impacts. The comparative sustainability analysis of Alternatives 2, 3, and 4 indicates that Alternative 2 is the most sustainable of the alternatives considered. Alternative 2 has both the lowest energy use and the lowest air emissions. Alternative 2 also has the lowest material consumption and waste generation of the alternatives considered. Because of the extra three years of injections, Alternative 3 is less sustainable than Alternative 2 in all categories evaluated. Due to the continuous system operations associated with Alternative 4, the only sustainability criterion where Alternative 4 is more sustainable than Alternatives 2 and 3 is the Water Consumption and Impacts criterion. The environmental impacts associated with the alternatives are directly affected by the impacts generated during the remedy implementation, energy requirements for the operation of the remedies, and remedy time frame. Alternative 2 presents the lowest energy, air emission, and waste generation, as a result of the reduced equipment operation and the use of the existing remedy infrastructure.

ES.6 Preferred Alternative

Based on the comparative analysis of alternatives discussed above, Alternative 2 is the preferred alternative because it achieves the RAO for groundwater while balancing short-term effectiveness, implementability, and cost. Alternative 2 would also best meet the intent of the NYSDEC Program Policy for Green Remediation (DER-31), as it treats the groundwater contamination in-situ, minimizes waste generation, and does not require much energy usage.

1. Introduction

1.1 Purpose

The purpose of this Feasibility Study (FS) is to assemble and evaluate remedial alternatives and to identify a preferred remedial alternative for the 3800 Area Tetrachloroethene (PCE) Site at Fort Drum, New York (the Site). The PIKA - MP Joint Venture (JV), LLC[2] (hereinafter referred to as the JV) has prepared this FS to meet the requirements of the performance work statement (PWS) issued by the United States (US) Army Corps of Engineers (USACE) Baltimore District under the Multiple Award Environmental Services (MAES) contract, Award No. W912DR-12-D-0007, Delivery Order 0003. This FS has been prepared in accordance with New York State Department of Environmental Conservation (NYSDEC) Division of Environmental Remediation (DER) Technical Guidance for Site Investigation and Remediation (DER-10), NYSDEC Program Policy for Green Remediation (DER-31), and Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) guidance.

A Draft Final Remedial Investigation Report (RIR) was completed in February 2013 (PARS, 2013a) and presents the findings of field investigation activities performed between 2010 and 2012 to characterize the extent of PCE and other chlorinated volatile organic compounds (CVOCs) at the Site. A Draft Final addendum to the RIR was prepared in August 2013 (PARS, 2013b) and includes the results of a bench study and an in situ chemical oxidation (ISCO) pilot study performed at the Site. This FS incorporates the results of the RI, bench study, and pilot study.

1.2 Regulatory Framework

Work under this task order will be conducted pursuant to regulatory coordination and approval by the NYSDEC and United States Environmental Protection Agency (USEPA) Region 2 under the 12 February 2014 Order on Consent. The Site is regulated by the NYSDEC under the Inactive Hazardous Waste Disposal Site Program (i.e., the State Superfund Program) as Class 2 Inactive Hazardous Waste Site DER Registry #623008.

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1.3 Organization of the Report

This FS report consists of seven sections and four appendices:

- **Section 1 – Introduction**: States the purpose and scope of the FS
- **Section 2 – Site Background and History**: Summarizes the background information for the 3800-PCE Site including site history, physical setting, previous investigations, and pilot studies.
- **Section 3** – **Remedial Investigation Summary**: Summarizes the results of the remedial investigation (RI) performed between 2010 and 2012.
- **Section 4 – Conceptual Site Model**: Provides an overall summary of the Site characteristics (including geology, hydrogeology, geochemistry, and contaminant distribution) in relation to the fate and migration of CVOCs. The CSM is used to facilitate the selection and evaluation of potential remedial alternatives.
- **Section 5 – Development of Remedial Alternatives**: Discusses the remedial action objectives (RAOs). Identifies and screens general response actions, technology groups, and process options.
- **Section 6 – Description of Remedial Alternatives**: Describes the proposed remedial alternatives that are assembled using the process options retained after screening in Section 5.
- **Section 7 – Detailed Evaluation of Remedial Alternatives**: Evaluates the remedial alternatives per the evaluation criteria set forth in Title 6 of the New York Code of Rules and Regulations (NYCRR) Part 375 Section 1.8(f).
- **Section 8 – References**: List of all documents used in the preparation of the FS.
- **Appendix A** – **First Phase ISCO Pilot Study Results at the 3800 Area PCE Site**
- **Appendix B – Select Figures from Remedial Investigation Report (excerpted from PARS, 2013a)**
- **Appendix C** - **Appendices C and D, Ex-Situ Treatment Technologies for Ground Water:** From *Presumptive Response Strategy and Ex-Situ Treatment Technologies for Contaminated Ground Water at CERCLA Sites*. Directive 9283.1-12. EPA 540/R-96/023. October 1996.
- **Appendix D – Green and Sustainable Remediation Analysis of Remedial Alternatives**
- **Appendix E – Remedial Alternatives Cost Estimates**

2. Site Background and History

2.1 Site Description

The Fort Drum Military Installation (Fort Drum), which encompasses approximately 168 square miles, is located approximately 10 miles northeast of Watertown, 80 miles north of Syracuse, and 25 miles southeast of the United States and Canadian border (**Figure 2-1**). While the main installation infrastructure and facilities are present in the Town of LeRay in Jefferson County, New York, training and operational areas of Fort Drum occupy a large portion of northeastern Jefferson County and a portion of western Lewis County.

The 3800 Area PCE Site is located near the eastern end of Oneida Avenue, near the intersection with New York State Route 26. The Site includes Fort Drum Areas 1700, 1800, 1900, and 3800; associated buildings; portions of the Old Sanitary Landfill (OSL); and the streams north and northeast of the OSL **(Figure 2-2**).

The OSL is an approximately 50-acre closed landfill consisting of two cells located on the north side of New York State Route 26. Both cells are capped with synthetic covers. Leachate from the OSL co-mingles with a dissolved-phase fuel constituent plume originating from Area 3805, and discharges to the OSL Creek via seeps in the face of the ravine on the north side of the OSL. The primary constituents in the leachate are benzene, toluene, ethylbenzene, and xylenes (BTEX).

2.2 Site History

Fort Drum was established in 1906 as a National Guard training facility. During World War II, Fort Drum functioned as an operations base and firing range and provided combat skills training facilities for the 45th Infantry Division and the 4th and 5th Armored Divisions. The historical land use of the 3800 Area PCE Site has been predominantly industrial since the installation was established. Historically, the Site was primarily used for vehicle and equipment storage, maintenance, and refueling purposes according to historical aerial photography and records (PARS, 2013a). There was documented historical use and storage of hazardous materials, including chlorinated solvents, south of Oneida Avenue (PARS, 2013a). The OSL operated from 1940 until 1973 and was used for the disposal of general refuse, empty containers from paint, solvents and pesticides, and for oil and lubricant-saturated solid waste. The OSL was capped with a 20-mil polyvinyl chloride (PVC) cap in 1981, and the surface was covered with topsoil and grass (Malcolm Pirnie, Inc., 2005).

In 2010, Buildings 1880 and 1885 (located in the 1800 area) were each constructed on a 5-inch reinforced slab-on-grade foundation. In 2012, the concrete slab was expanded on the majority of the Site as part of a facilities upgrade project. Building 1885 and the new concrete slab area cover areas with the highest chlorinated volatile organic compound (CVOC) detections in groundwater (PARS, 2013a).

2.3 Physical Setting

2.3.1 Physiographic Setting

Fort Drum is situated within the Lake Ontario Lowlands and Tug Hill Plateau (Tug Hill) physiographic region of New York State, near the northernmost extent of the Tug Hill (**Figure 2-3**). The Tug Hill region extends to the south of the site with the Lake Ontario Lowlands extending toward the north and west. The Adirondack Mountain region is present toward the west, beyond the eastern extent of the Ontario Lowlands.

The Lake Ontario Lowlands in the vicinity of Fort Drum consist of rolling plains extending north toward the St. Lawrence Valley, and west toward Lake Ontario. The lithology of this region consists of Grenville basement rocks, overlain uncomformably by Late Silurian carbonate rocks exhibiting karstic features. The majority of surficial deposits throughout the region consist of pro-glacial lake sediments and Holocene alluvium.

The Tug Hill region is characterized by an area of elevated bedrock, approximately elliptical in shape and elongated in a north-northwestern direction. Adjacent terrain along the northern, western, and southwestern boundaries of the Tug Hill averages about 400 feet above mean sea level (amsl). The Tug Hill lithology consists of Grenville basement rocks, overlain uncomformably by Ordovician carbonate and clastic rocks (Wallacha and Rheaultb, 2010). The majority of surficial deposits throughout the region consist of glacial drift and Holocene alluvium.

2.3.2 Topography

The portion of Fort Drum that includes the 3800 Area PCE Site lies within the Ontario Lowlands, commonly known as the “Pine Plains”. It is characterized by a broad expanse of mostly flat, sandy surfaces with small sand plains, drumlin fields, swamps, and disturbed drainage patterns that were formed as a result of the Pleistocene continental glaciations.

The 3800 Area PCE Site is located on a flat sand plain that slopes gently toward the north. Elevations range from approximately 672 feet amsl near Area 1900 to 653 feet amsl on the southern edge of OSL Cell 2 (**Figure 2-4**). The OSL cell caps are slightly elevated (5 to 10 feet) with respect to the surrounding ground surface, but also tend to slope toward the north. The ground surface slopes steeply in the vicinity of the ravine between the OSL cells and along the OSL Creek. Stream surface elevations range from 630 feet amsl east of Cell 1 to 582 feet amsl north of Cell 2 (PARS, 2013a).

2.3.3 Climate

The climate of Fort Drum is classified as humid continental, with annual precipitation averaging approximately 43 inches. Monthly precipitation is relatively consistent throughout the year, peaking in October at 4.6 inches. The driest month on average is February at 2.48 inches. Average annual temperatures are 45 degrees Fahrenheit (°F), with the average daily temperatures ranging from 21 °F in the winter and 68 °F in the summer. January is the coldest month, with an average temperature of 18 °F. Fort Drum has an average annual snowfall of 112 inches, with a high monthly average of 34 inches in January. The combination of cold temperatures and heavy snowfall in the winter months leads to frozen ground and snow accumulation, which affects the ability to perform some aspects of environmental field work (e.g., drilling, excavation) during the months of December through March.

2.4 Remedial Investigation

An RI was conducted between 2010 and 2012 to characterize the extent of PCE and other CVOCs at the Site (PARS, 2013a). Prior to the RI, limited information regarding the nature and extent of PCE in the vicinity of the Site was collected during investigations of petroleum releases in nearby areas (i.e., Area 1995/3805). PCE was detected frequently in shallow, intermediate, and deep wells since 1995 during the investigation of the adjacent 3805 site.

The RI was conducted in seven phases to characterize the extent of CVOCs (in particular PCE) in soil, groundwater, and soil gas near the Site, as well as in the sub-slabs and indoor air of Buildings 1880 and 1885. Detailed results of the RI are provided in the *Remedial Investigation Report for Chlorinated Solvent Contaminants at Fort Drum, New York* (PARS, 2013a). The salient findings of the RI are discussed in Section 3.

2.5 Initial Permanganate ISCO Pilot Study

A permanganate ISCO pilot study was implemented at the Site in November 2012 (PARS, 2013b). The target area for the ISCO pilot study was a 0.5-acre area approximately 200 ft down-gradient of Building 1885 in the shallow zone (i.e., 30 to 40 feet below ground surface [ft bgs]) (**Figure 2-3**). Forty injection wells were installed at variable spacing ranging from 15 to 25 ft with screened intervals at 30 to 40 ft bgs. Five-hundred gallons of 10% sodium permanganate ($NaMnO_4$) solution were injected at each well at flow rates that ranged from 1 to 8 gallons per minute (gpm) at pressures that ranged from 10 to 60 pounds per square inch (psi).

Performance monitoring for the pilot study was conducted at 58, 98, and 124 days after injection was completed. Six wells were selected for performance monitoring: IMW-1 through IMW-4, PCERI-MW19S and PCERI-MW19I. Performance monitoring was hindered by construction activities and snow accumulation that prevented access to a number of the wells. Monitoring well PCERI-MW19S, which exhibited the highest PCE concentration during the RI, was not sampled during the study due to apparent damage. Additionally, only three of the remaining five performance monitoring wells were sampled during the 58-day event, and only two of the five wells were sampled during the 98-day event. An additional round of performance monitoring was performed by the USACE on 24 September 2013, approximately 300 days after completion of permanganate injection (see summary data from all of the pilot monitoring events in Appendix A).

The field parameter dose response data (pH, specific conductivity, color, dissolved oxygen, oxidation reduction potential, temperature, and depth to water) collected during the pilot injection suggest inadequate distribution of permanganate. Following the injection event, manganese (Mn) concentrations were not observed to increase at accessible shallow zone monitoring wells; however, Mn did migrate vertically via density and hydraulic advection into the intermediate zone as evidenced by arrival at MW-19I approximately 124 days after the injection. Given the apparent permeable nature of the lithology at 30 to 40 ft bgs and achieved flow rates of 8 gpm, it is likely that 500 gallons per well was inadequate to achieve uniform oxidant distribution with a well spacing of 15 to 25 ft. The absence of a response within the 30 to 40 ft bgs treated interval approximately 300 days post injection suggests that the true radial extent was less than 13 feet, which was the approximate distance to the closest dose response monitoring well.

The highest baseline PCE concentration was detected at IMW-3 (260 ug/L), suggesting that there was contaminant mass migrating from upgradient of the pilot treatment area (i.e., the pilot treatment area was located down-gradient of the PCE source area). PCE concentrations in samples collected at the 300-day event from down-gradient performance monitoring wells IMW-2 and IMW-3 were similar to baseline concentrations. The PCE concentration at down-gradient monitoring well IMW-4 increased from a baseline measurement of 170 ug/L to 750 ug/L in the 300-day sample, indicating that PCE mass shifted and/or was desorbed as a result of the pilot study. Analytical results from PCERI-MW19I demonstrate PCE reduction from a baseline concentration of 110 µg/L to below laboratory detection limits. Considering the simultaneous rise in total Mn, the reductions in PCE may be associated with the presence of unreacted permanganate in the laboratory samples inherently biasing the PCE results low.

2.6 Planned Second Permanganate ISCO Pilot Study

A second permanganate ISCO pilot study has been planned for implementation in summer 2015 (PIKA-MP JV, 2015). The injection design optimizes the original pilot approach by injecting a larger volume of permanganate solution to improve oxidant distribution. Achieving contact of the oxidant with the PCE is the crucial component of successful ISCO, along with the proper management of ISCO kinetics. To focus resources on volume distribution, the permanganate injection concentration will be reduced from 10% $NaMnO_4$ to 3% $NaMnO_4$, while injecting a larger mass of oxidant at each location than what was applied in the first pilot study. The proposed pilot study expands the treatment footprint to target dissolved phase PCE upgradient of the original pilot test injection wells, including injection upgradient of Building1885 (**Figure 2-4**). The selection of this target treatment area is based on an evaluation of the data collected during the RI, as summarized in Section 3. The expanded injection footprint is meant to target residual source mass that the initial ISCO pilot was not designed to address.

Thirty-five injection wells will be installed in support of the second ISCO pilot study. Given the permeable geology and the importance of achieving distribution, a radius of influence (ROI) of 12.5 ft was selected. Wells will be installed approximately 25 ft on center from each other in a grid pattern, with the exception of one row installed on the south side of Building 1885 (**Figure 2-4**). Approximately 2,800 gallons of oxidant solution will be applied at each injection well. Concentrated NaMnO4 solution will be pumped into a batch tank and mixed with potable water. The concentrated NaMnO4 is delivered as a 40% by weight solution. In order to mix a 2.5% to 3% solution, approximately 5.5 gallons of concentrated solution is needed per 100 gallons of water. The dilute NaMnO4 injection solution will be gravity fed or pumped to the injection well manifold. Three rounds of ISCO performance monitoring will be conducted at approximately 30 days, 75 days, and 120 days after injection, respectively.

3. Remedial Investigation and Risk Assessment Summary

The following investigation activities were completed during the RI of the 3800 Area PCE Site between November 2010 and May 2012 (PARS, 2013a):

- Phases 1, 2, and 3 (November to December 2010): These Phases included the advancement of 53 soil borings and installation of groundwater monitoring wells; soil and groundwater sampling during the drilling program to identify the base locations for each well; drilling into the bedrock to confirm maximum impacted depth; and surface water, sediment, and surface water interface monitoring (SWIM) sampling with the objective of characterizing the CVOC-contaminated groundwater plume discharge to surface water.
- Phase 4 (June to July 2011): This Phase included a source area investigation using Membrane Interface Probe (MIP), soil boring, and soil vapor sampling.
- Phase 5 (April and September 2011): This Phase included two rounds of groundwater sampling and water level monitoring (Spring and Fall 2011) at each RI well and at select Area 1995, Area 3805, and OSL monitoring wells. Also pumping and slug tests were conducted on monitoring wells installed in the intermediate and deep surficial zones.
- Phase 6 (February 2012): This Phase included indoor air and sub-slab vapor sampling at Buildings 1880 and 1885.
- Phase 7 (February to December 2011): This Phase included bench-scale studies to evaluate the potential for biologically mediated enhanced reductive dechlorination and chemical oxidation remediation.

Additionally, a human health risk assessment (HHRA) and a screening-level ecological risk assessment (SLERA) were conducted to evaluate potential risks to receptor exposure to CVOCs at the Site. The RI findings and risk assessment conclusions are summarized in the following sections. The Section 3 and 4 figures from the RI Report are provided in Appendix B to facilitate the RI findings discussion.

3.1 Geology and Hydrogeology

A detailed description of the regional geology is provided in the RI Report (PARS, 2013a). The site-specific geology and hydrogeology descriptions provided below are based on data collected during the RI (PARS, 2013a).

During drilling activities at the Site, the primary geologic materials encountered were the Pine Plains deltaic sands and the underlying Pleistocene-age lacustrine deposits of silt and silty clay. The Pine Plains deltaic sands form a fining downward sequence that grades into the lacustrine silts and clays that form the confining unit at the base of the unconfined surficial aquifer. The depth to clay encountered during the RI drilling program ranged from 56 to 97 ft bgs (PCERI-MW18D and –MW23D, respectively). The thickness of the clay confining unit at the base of the deltaic sands ranged from 12 ft at PCERI-MW19D to 30 ft at PCERI-MW01D where the unit was fully penetrated (see Figures 3-2 and 3-3 in Appendix B; PARS, 2013a). The four major units in stratigraphic order (top to bottom) include the surficial sand and silty sand of the unconfined surficial aquifer, the basal lacustrine clay confining unit, and the calcareous mudstone bedrock unit.

The unconfined surficial aquifer at Fort Drum is comprised of the upper portions of the Pine Plains Delta. The aquifer consists of unconsolidated pro-glacial deltaic deposits characterized by fine- to medium-grained sand. The deltaic sand and silty sand of the aquifer grade to clay, which forms the base of the unconfined surficial aquifer. Groundwater in the unconfined surficial aquifer recharges primarily from infiltration of precipitation and snow melt water. Spring represents the seasonal high water table conditions that correspond to thawing of the frost line and the onset of snow melting. Late summer and early fall represent the seasonal low water table conditions that correspond to low precipitation and high evapotranspiration.

To characterize the hydrogeological framework of the unconfined surficial aquifer during the RI, the surficial aquifer was sub-divided into three hydrostratigraphic units (shallow, intermediate, and deep). Due to the gradational nature of the fining downward sequence of the aquifer and the subsequent absence of a definable boundary between the sand and silty sand, the approximate vertical extent of the sub-units were defined as follows:

- Shallow zone – 20 ft from the base of the water table
- Intermediate zone – 20 ft from the base of the shallow zone
- Deep zone – from the base of the intermediate zone to the top of the clay confining unit

The water table elevations of the three unconfined surficial aquifer sub-units show that the general direction of groundwater flow at the Site is to the north and northeast, toward the stream running between the two OSL cells and along the eastern boundary of the OSL (see Figures 3-4 to 3-9 in Appendix B; PARS, 2013a). Groundwater elevations at co-located well clusters were used to characterize the vertical hydraulic gradient across the 3800 Area PCE Site. The results showed that horizontal flow is dominant and the vertical component of flow in the aquifer is small. Generally, where vertical gradients persist, there is a downward component of flow from the shallow to intermediate portions of the aquifer and, conversely, an upward component of flow from the deep to intermediate portions of the aquifer. The vertical gradients fluctuate in the vicinity of the unnamed and OSL creeks due to localized effects of drainage from the OSL cap and seep flow from the steep ravine bank that bounds the creeks. Water-level elevations measured in wells screened in alluvial and bedrock units indicate that the hydraulic head elevation is higher in the deltaic aquifer than in the underlying bedrock, indicating a downward groundwater flow gradient. However, PCE was not detected in the bedrock unit during the RI (PARS, 2013a). Based on the results of historical aquifer pumping tests conducted in the area, the glacial outwash and underlying bedrock units do not appear to be hydraulically connected, due to the presence of the clay aquitard (PARS, 2012).

Hydraulic conductivity (K) values range from 0.01 feet per day (ft/day) in the silt layer, which forms the regional aquitard at the base of the surficial aquifer, to 21 ft/day in the upper portion of the surficial aquifer specific to the Site. Thirteen slug tests were conducted in the intermediate portion of the aquifer during the RI. Based on the slug test data, the calculated K of the intermediate portion of the unconfined surficial aquifer ranged from 1.8 to 11.6 ft/day, with a geometric mean of 4.5 ft/day. The data were correlated to the mid-point of well screen depths to discern potential trends of K with depth. The correlation showed a general trend of high K values at shallow depths (less than 45 ft bgs) and lower K values at greater depths (deeper than 45 ft bgs). The data support the fining downward sequence of the geologic model for the unconfined aquifer.

3.2 Nature and Extent of CVOCs at the 3800 Area PCE Site

A detailed discussion of sampling results for soil, groundwater, and soil gas collected at the 3800 Area PCE Site, as well as sampling results for the sub-slabs and indoor air of Buildings 1880 and 1885 is provided in the RI Report (PARS, 2013a), illustrated on excerpted figures provided in Appendix B, and summarized below.

3.2.1 Soil

During Phases 1 and 2 of the RI, 279 discrete soil samples were collected from various depth intervals and analyzed for VOCs. Soil samples were collected from vadose and saturated zones. The VOC soil data from the saturated zone was used to inform decisions for monitoring well screen depths. Vadose zone samples were collected to for site characterization and to locate potential CVOC source areas. PCE and trichloroethene (TCE) were not detected in vadose zone soil samples. The highest PCE concentration in a saturated soil samples was 350 micrograms per kilogram (µg/kg) from a sample collected at PCERI-MW05 at a depth of 63 ft bgs (see Figure 4-1 in Appendix B). All of the detected soil concentrations were at least an order of magnitude less than the unrestricted use soil cleanup objective for PCE of 1,300 µg/kg (6 NYCRR Part 375, Table 375-6.8 (a)).

3.2.2 Groundwater

Groundwater sampling data obtained from 76 monitoring wells in Spring and Fall 2011 were used to characterize dissolved-phase CVOCs in groundwater. Groundwater samples were collected from each of the unconfined surficial aquifer hydrostratigraphic zones as follows:

- 22 samples from the shallow zone
- 26 samples from the intermediate zone
- 26 samples from the deep zone
- 1 sample from the bedrock unit (PCERI-MW01D)

The CVOC analytical data were compared to the NYCRR Part 703.5 Groundwater Quality Standards (GWQS). The only CVOCs detected above the GWQS were PCE and TCE.

In the shallow zone, PCE concentrations are highest in the upgradient portions of the Site. The highest concentration of PCE was detected at PCERI-MW19S (906 µg/L), screened at 30 to 40 ft bgs, during the Fall 2011 sampling event. The lateral extent of dissolved-phase PCE in the shallow zone is confined to the area south of Oneida Avenue (Figures 4-2 and 4-5 in Appendix B). The absence of the PCE dissolved-phase plume in the shallow zone north of Oneida Avenue is attributed to the downward vertical gradients in this portion of the Site.

Similar to the shallow zone, the highest PCE concentrations in the intermediate zone were detected in the upgradient portion of the Site. The highest concentration of PCE was detected at PCERI-MW25I (906 µg/L), screened at 35 to 45 ft bgs, during the Fall 2011 sampling event. The lateral extent of the dissolved-phase PCE plume extends to the groundwater discharge point at the unnamed creek between OSL Cells 1 and 2 (see Figures 4-3 and 4-6 in Appendix B). A cross-section of the PCE plume (Figure 4-8 in Appendix B) shows that the contaminant plume is predominantly located in the intermediate zone across the Site to the discharge point at the OSL Creek. The width of the plume is narrow in proportion to the length. The elongated shape of the plume is attributed to the high K of the intermediate aquifer, resulting in advection as the dominant transport mechanism.

The highest concentration of PCE in the deep zone was detected at PCERI-MW20D (319 µg/L), screened at 62 to 72 ft bgs, during the Spring 2011 sampling event. PCE detections in the deep zone of the surficial aquifer are confined to the upgradient portion of the Site (see Figures 4-4 and 4-7 in Appendix B). The absence of the PCE plume in the deep zone of the aquifer down-gradient of PCERI-MW15D is consistent with the observed upward vertical gradients between the deep and intermediate aquifer zones. During Phase 1 of the RI field activities, a groundwater monitoring well (PCERI-MW01D) was advanced into the bedrock aquifer. CVOCs were not detected in samples collected from this well.

3.2.3 SWIM, Surface Water, and Sediment

SWIM, surface water, and sediment samples were collected twice during the RI: in Fall 2010 from five locations and in Spring 2011 from seven locations. The SWIM sampling points were located at the anticipated discharge point of the groundwater CVOC plume to surface water (see Figure 4-2 in Appendix B).

The highest concentration of PCE was detected at SWIM-04 (129 µg/L) during the Spring 2011 sampling event. The lateral extent of dissolved-phase PCE in the shallow zone was confined to the area between SWIM locations SWIM-03 and SWIM-05 during both sampling events. In addition to PCE and TCE, cis-1,2-dichloroethene (cDCE) and vinyl chloride (VC) were detected above GWQS.

PCE was detected at trace concentrations (i.e., less than 1 µg/L) in surface water samples. This indicates that CVOC concentrations are being attenuated (likely via dilution and volatilization) after discharge to surface water.

The highest concentrations of PCE (151 µg/kg) and TCE (450 µg/kg) in sediment were detected at SWIM-03 during the Spring 2011 sampling event. Consistent with the SWIM sampling results, PCE detections in sediment were confined to the area between SWIM locations SWIM-03 and SWIM-05 during both sampling events. This area appears to be a discharge point for groundwater containing PCE.

3.2.4 Focused Source Area Investigation

A focused source area investigation was performed to locate and characterize PCE source areas. Three investigative methods were used: membrane interface probe (MIP) sampling; advancement of soil borings with soil sample collection; and soil vapor sampling.

Sixteen MIP locations were advanced (see Figure 4-9 in Appendix B). Notable responses on an electron capture detector (ECD) were observed at MIP points MIP-1, -5, -6, -10, -11, -12, -15, and -16 between 30 to 40 ft bgs (see Figure 4-9 in Appendix B). The highest responses were observed at MIP-1 (near monitoring well PCERI-MW19S) and at MIP-10, closer to Building 1885. To substantiate the ECD detections, soil samples were collected for analysis of CVOCs. The highest saturated soil PCE concentrations were from soil borings advanced near MIP-1 (328 micrograms per kilogram [µg/kg] at 39.5 ft bgs) and MIP-10 (184 µg/kg at 39.5 ft bgs). Detected soil concentrations are at least an order of magnitude less than the unrestricted use soil cleanup objective for PCE of 1,300 µg/kg (6 NYCRR Part 375, Table 375-6.8 (a)) and indicate that no significant PCE soil mass or dense non-aqueous phase liquid (DNAPL) remain. However, these concentrations represent sorbed PCE that will continue to impact groundwater.

Eight soil vapor samples were collected from the perimeter of Building 1885 at a depth interval of 3 to 5 ft bgs. The highest concentration of PCE in soil gas was detected near the southeast portion of Building 1885 (SG-8 at 171 micrograms per cubic meter [µg/m^3]) (see Figure 4-9 in Appendix B).

3.2.5 Sub-Slab Vapor and Indoor Air

Since the results of the soil vapor sampling during the source area investigation indicated the presence of low concentration PCE vapors near Building 1885, a vapor intrusion survey was implemented to assess CVOCs in sub-slab vapor and indoor air at both Building 1885 and Building 1880. Co-located pairs of sub-slab vapor and indoor air samples were collected. Two sample pairs were collected from Building 1880 and four sample pairs were collected from Building 1885 (see Figures 4-10 and 4-11 in Appendix B). The highest concentration of PCE beneath the slab of Building 1885 was detected in the eastern portion of the building, beneath the maintenance pit (1885-SS-3 at 151 µg/m^3; see Figure 4-11 in Appendix B). This sample represents the only exceedance of the NYSDEC action limit of 50 µg/m^3, indicating that little residual source material remains. CVOCs were not detected in indoor air samples collected at

Buildings 1880 and 1885, indicating that PCE vapors beneath the buildings are not migrating into indoor air.

3.3 Natural Attenuation Evaluation

Groundwater and SWIM chemistry indicators of natural attenuation via intrinsic biodegradation were measured during the Spring and Fall 2011 sampling events. Generally, low dissolved oxygen (i.e., anaerobic) and reducing conditions, as well as a neutral pH are required to sustain the bacteria species that have been shown to biodegrade CVOCs (typically *Dehalococcoides* spp. [DHC]). The monitoring results showed that conditions in the PCE plume areas in all three hydrostratigraphic zones are generally aerobic and oxidative. This indicates that aquifer conditions are not conducive to sustaining DHC bacterial populations. This is supported by DHC sampling results, which showed that DHC are present in some locations, but at very low concentrations. In general, a DHC concentration of $1X10^4$ cells per milliliter (cells/mL) is required to yield a useful biodegradation rate (Lu et al., 2006); the highest detection of DHC in groundwater was 4.4 cells/mL at PCERI-MW20I, and the highest SWIM detection of DHC was 52.2 cells/mL. No ethene or ethane (end products of complete dechlorination of PCE) was detected in groundwater samples, supporting the indications that aquifer conditions do not support intrinsic biodegradation.

3.4 Flow and Transport Model

A three-dimensional numerical flow and transport model was developed for the RI study area. The MODFLOW numerical program was developed to provide a calibrated flow model and the MT3D numerical program was used to simulate changes in concentrations of dissolved-phase contaminants. The results of the long-term fate and transport simulation (10-year and 20-year scenarios) for the shallow and intermediate surficial aquifer were:

- Slowly decreasing concentrations trends
- Migration of the bulk VOC mass along the advective flow path
- Minimal dispersion

The results of the long-term fate and transport simulation (10-year and 20-year scenarios) for the deep portion of the surficial aquifer were:

- Slowly decreasing concentrations trends
- Little or no migration of the bulk VOC mass

- Migration of the dissolved-phase PCE plume along the advective flow path
- Minimal dispersion

3.5 Bench Studies

As part of the RI, bench studies were conducted to evaluate three remedial technologies:

- In situ enhanced bioremediation (ISEB) of CVOCs using a proprietary bioaugmentation culture (i.e., a culture comprised of DHC) together with an electron donor substrate consisting of a 50/50 blend of molasses and emulsified vegetable oil (EVO). The electron donor substrate was also evaluated as a stand-alone comparison to the bioaugmented microcosm.
- Application of nano-scale zero-valent iron (NZVI) for abiotic reduction of CVOCs
- Chemical oxidation via potassium permanganate

Groundwater samples were extracted from monitoring well PCERI-MW-19S and soil samples were collected from borehole PCERI-SB-1 located approximately 230 feet upgradient of well PCERI-MW-19S. Split samples from both media were couriered to New Jersey Analytical Laboratories to conduct the NZVI and chemical oxidation tests, and to Terra Systems, Inc. (TSI) to conduct the ISEB tests. For the NZVI and permanganate oxidation tests, soil and groundwater samples were homogenized and split into 40-mL to 60-mL vials. Various dosages of NZVI or potassium permanganate were added to the vials. Triplicate analyses were performed on each set of batch bottles. For the ISEB tests, microcosms were prepared in 250-mL bottles with 60 grams of soil. Four treatment conditions were evaluated in triplicate: (1) Sterile control; (2) Intrinsic control; (3) Molasses and EVO; and (4) Molasses, EVO, and bioaugmentation. Aqueous samples were collected from each condition and analyzed at the beginning of the study, as well as after one, two, and three months of incubation.

The bench-scale testing suggested that each of the three technologies have the potential to decrease PCE concentrations in site groundwater (see **Table 3-1** below).

Table 3-1: Bench Scale Testing Results (PARS, 2013a)

Method	Initial PCE Concentration (ug/L)	Final PCE Concentration (ug/L)	Percent Reduction
Bioaugmentation	317	4.8	98.5
Electron Donor Only	200	1080	0
Nano-scale ZVI (0.5 g/L)	940	462	50.9
Nano-scale ZVI (1.0 g/L)	940	10	98.9
Nano-scale ZVI (2.0 g/L)	940	0	100
Potassium Permanganate	1100	0	100

The results indicate that electron donor alone is not effective in biodegrading PCE, which is consistent with the field results that DHC populations are intrinsically low in the unconsolidated aquifer. Bioaugmentation with electron donor addition appears to be capable of reducing PCE concentrations in a laboratory setting within a time span of three months. However, VC concentrations increased to concentrations well above GWQCs as a result of reductive dechlorination of PCE (elevated VC concentrations in groundwater beneath a structure could pose an exposure risk via the vapor intrusion pathway). Ethene concentrations increased significantly, which indicated that the full reductive dechlorination sequence was occurring. Geochemical parameters also indicated that the appropriate reduction-oxidation shifts occurred.

Results from the bench scale tests using NZVI suggest that this particular technology is effective in removing PCE from Site groundwater in a laboratory setting. Near-complete removal (99 percent) of PCE was achieved with a 1.0 g/L solution of the amendment, while 100 percent removal was achieved using a 2.0 g/L solution. At lower NZVI concentrations (0.5 g/L), the PCE reduction observed was not significantly different from that observed in the control (unamended) sample. There was no daughter product generation as a result of PCE degradation; rather the results suggest that the degradation pathway was exclusively abiotic. The implication of these results being that there is a relatively low risk of producing an undesirable amount of secondary regulated by-products such as VC.

The chemical oxidation approach using potassium permanganate produced the most rapid results, with 100% PCE destruction within 48 hours using a 0.5 g/L dose of potassium permanganate.

3.6 Risk Assessment Summary

Based on the results of the HHRA, all of the reasonable maximum exposure cancer risks for the commercial/industrial worker, construction worker, and residential receptors were within or below the USEPA risk range. The non-cancer hazard indices were less than the non-cancer benchmark of 1 for the construction worker and greater than 1 for the commercial/industrial worker, child resident, and adult resident. Since the overall approach to the HHRA tends to overestimate actual risks to a fairly significant degree, it is unlikely that exposure to groundwater within the study area would result in any future unacceptable health impacts to the evaluated receptors (PARS, 2013a).

CVOCs were not detected during the indoor air investigation. For indoor air screening results and the vapor intrusion pathway, VOCs exceeding the regional screening levels and target groundwater concentrations should be evaluated more comprehensively if or when the land above the contaminated groundwater is developed for future use.

The results of the SLERA indicated the potential for risks from exposure to contaminated sediment is low and the potential for risks to organisms inhabiting the groundwater/surface water interface is higher. However, this analysis represents an overly conservative measure of potential risk since the data were obtained at a depth expected to be below the biologically active zone. There is no potential risk from exposure to CVOC-contaminated water because there were no surface water benchmark exceedances. Overall, based on conservative screening evaluations, there is the possibility of localized effects to the benthic community and amphibian larvae in contact with sediment pore water. Since CVOCs do not generally bioaccumulate, direct toxicity to higher-trophic level organisms foraging in this area would not be expected.

4. Conceptual Site Model

Information obtained during the RI (discussed in Section 3) was used to develop a conceptual site model (CSM), which summarizes the site-specific geology and hydrogeology and the depth and flow of groundwater that affect the distribution, fate, and migration of CVOCs. This CSM is used to facilitate the evaluation of possible remedial technologies and provide a summary for data collected during multiple phases of the RI as described in Section 3. The CSM for the 3800 Area PCE Site is summarized as follows:

- Subsurface soils at the Site are composed of deltaic sand and silty sand, which grade to clay, which forms the base of the surficial aquifer and confining unit for the deeper bedrock aquifer.

- Due to the gradational change in geology, aquifer properties change in relation to the depth of the aquifer. The aquifer was sub-divided into three hydrostratigraphic zones: 1) Shallow zone, defined as 20 ft from the base of the water table; 2) Intermediate zone, defined as 20 ft from the base of the shallow zone; and 3) Deep zone, from the base of the intermediate zone to the top of the clay confining unit. The water table occurs at approximately 20 ft bgs.

- Groundwater flow in all three zones is towards the north/northeast, with groundwater ultimately discharging into the unnamed creek between OSL Cells 1 and 2.

- K values in the intermediate portion of the aquifer range from 1.8 to 11.6 ft/day, with a geometric mean of 4.5 ft/day. K values are generally higher at shallower depths; historical data from a series of slug tests, geotechnical sampling, and aquifer pump tests reported K from 23 to 45 ft/day. At a depth of 60 feet bgs, the average K value is approximately 3 ft/day ($1*10^{-3}$ centimeters per second (cm/s)).

- Although horizontal flow is dominant, small downward vertical gradients were measured between the shallow and intermediate hydrostratigraphic zones, and upward vertical gradients were measured from the deep to the intermediate hydrostratigraphic zones.

- CVOCs were not detected in vadose zone soils at the Site.

- The results of the RI indicated that the highest concentrations of PCE in groundwater are located in the shallow and intermediate hydrostratigraphic zones south of Ontario Avenue at a depth of 30 to 45 ft bgs. The greatest horizontal extent of PCE occurs in the intermediate zone; PCE detections extend approximately 2,500 feet down-gradient to the groundwater discharge point at the unnamed creek between OSL Cells 1 and 2.

- Aquifer conditions in all three zones are generally aerobic and oxidative, and thus are not conducive to natural attenuation of PCE via intrinsic biodegradation.

- Sub-slab sampling at Building 1885 indicates the presence of a potential source of PCE beneath the building. Indoor air sampling confirms that no CVOCs are present in indoor air at Building 1885.

- Although a definitive "source" of PCE was not identified in the RI report, the MIP-10 data, the soil gas results, and the sub-slab sampling results are indicative of PCE mass in soil in the vicinity and potentially beneath Building 1885. Additionally, the highest PCE concentration in the intermediate zone (599 µg/L) was observed at PCERI-MW25I (screened at 35 to 45 feet bgs), 10 feet down-gradient of Building 1885. Building 1885 may have been constructed over a historical PCE spill location as this area was historically used for vehicle storage, maintenance, and refueling purposes according to historical aerial photographs. Several smaller structures were present in the area before Building 1885 was constructed in 2010.

- The HHRA indicated that CVOCs in groundwater at the Site are unlikely to result in any future unacceptable health impacts to the evaluated receptors. The SLERA concluded that, based on conservative screening evaluations, there is a possibility of exposure to benthic organisms and amphibian larvae in contact with water in the sediment pores in a localized area of the unnamed creek between OSL Cells 1 and 2.

- Bench study results indicated that ISCO using permanganate, and application of NZVI were promising technologies. ISEB was also promising, although bioaugmentation with CVOC dechlorinating cultures was required to achieve PCE biodegradation.

- An ISCO pilot study conducted in November 2012 had mixed results, primarily due to difficulties in monitoring for dose-response due to snow accumulation and construction activities in the vicinity of the monitoring wells. Additionally, insufficient volume may have been injected to achieve the desired ROI. Where permanganate was detected, PCE concentrations decreased markedly.

5. Development of Remedial Alternatives

5.1 Remedial Action Objectives

As defined in Section 4.1 of DER-10, Remedial Action Objectives (RAOs) are media or site-specific objectives for the protection of public health and the environment. These goals are developed based on site- and contaminant-specific Standards, Criteria, and Guidance (SCGs). When establishing RAOs, DER-10 states that the following criteria must be identified and considered:

1. Applicable SCGs that consider the current, intended, and anticipated future use of the site and its surroundings;
2. All contaminants exceeding SCGs;
3. Environmental media impacted by such contaminants;
4. Extent of the impact to the environmental media;
5. Actual or potential human exposures and/or environmental impacts resulting from the contaminants in environmental media identified above; and
6. Any site-specific cleanup levels.

5.1.1 Standards, Criteria, and Guidance

SCGs considered to be applicable to the 3800 Area PCE Site are listed below.

- NYCRR Part 375 - Environmental Remediation Programs (December 2006)
- NYCRR Part 376 - Land Disposal Restrictions
- NYCRR Part 608 - Use and Protection of Waters
- 6 NYCRR Parts 700-706 - Water Quality Standards (June 1998)
- DER-10 – Technical Guidance for Site Investigation and Remediation (6/18/2010)
- DER-31 – Green Remediation (09/17/2010)
- DER-33 – Institutional Controls: A Guide to Drafting and Recording Institutional Controls (01/14/2011)
- CP-43 - Groundwater Monitoring Well Decommissioning Policy (11/03/2009)
- Presumptive Response Strategy and Ex-Situ Treatment Technologies for Contaminated Ground Water at CERCLA Sites (USEPA, 1996)

In addition, as discussed in Section 1.2, the Army has agreed to a Consent Decree that includes the 3800 Area PCE Site. The Consent Decree specifies the requirements with which the Army must comply for remedial actions at the Site. The 3800 Area PCE

Site is subject to the Consent Decree Appendix “C” Standard Clauses for all New York State Superfund Orders which, therefore, are also considered an SCG for the 3800 Area PCE Site.

5.1.2 Contaminants Exceeding SCGs

The contaminants of concern for the 3800 Area PCE Site are CVOCs, primarily PCE and TCE. The down-gradient portion of the PCE plume in the intermediate zone, north of Onedia Avenue, is co-located with a plume of petroleum constituents associated with Area 3805. Petroleum-related contamination that is present within the 3800 Area PCE Site boundary is being addressed separately under Area 3805/1995 remedial activities.

5.1.3 Impacted Environmental Media

The environmental media that are impacted by CVOCs are groundwater, saturated soil, surface water/groundwater interface, and sediment. No CVOCs have been detected in unsaturated soil.

5.1.4 Exposure Pathways

Potential groundwater exposure pathways for human receptors include groundwater consumption (i.e., drinking water), dermal contact, inhalation of CVOCs in indoor air due to vapor intrusion, and (for future residents) inhalation of VOCs while showering. None of these exposure pathways are currently complete, as water from the Site is not used for consumptive purposes, and several rounds of indoor air monitoring indicated that PCE is not present in buildings at the Site. The HHRA concluded that even if exposure pathways were complete, risks to all evaluated receptors would be within or below EPA risk ranges (PARS, 2013a).

Potential surface water/groundwater interface and sediment exposure pathways exist for ecological receptors including benthic invertebrate communities, aquatic communities, reptiles, and amphibians residing in the unnamed creek between the two OSL cells. Based on very conservative screening evaluation, there is the possibility for localized effects to the benthic community and amphibian larvae in contact with sediment pore water.

5.1.5 Generic Remedial Action Objectives

DER-10 identifies generic RAOs for the various media and exposure scenarios that should be considered if applicable based on the contaminants present and media affected at a given site. Generic RAOs considered to be applicable to the 3800 Area PCE Site are presented below.

Public Health Protection:

- Prevent ingestion of groundwater with contaminant levels exceeding drinking water standards.
- Prevent contact with and/or inhalation of volatiles from contaminated groundwater.

Environmental Protection:

- Restore groundwater to pre-disposal/pre-release conditions, to the extent practicable.
- Prevent the discharge of contaminants to surface water.
- Remove the source of ground or surface water contamination.

5.2 Site-Specific Remedial Action Objectives

The proposed site-specific RAOs for groundwater are as follows:

- Remove or treat CVOCs from the presumed source area beneath and in the vicinity of Building 1885 to the extent practicable.
- Achieve groundwater quality standards.

5.3 General Response Actions

General Response Actions (GRAs) are broad classes of responses or remedies developed to meet the RAOs. The GRAs consider the nature of the contamination (i.e., dissolved PCE and TCE in groundwater), the physical and hydrogeological characteristics of the Site, and existing Site infrastructure. Eight GRAs have been identified for the contaminated media at the 3800 Area PCE Site. The applicable process options are discussed separately in the technology screening step (Section 5.5).

- No Action

- Institutional Controls
- Engineering Controls
- Long-Term Monitoring
- Monitored Natural Attenuation (MNA)
- *In Situ* Treatment
- Extraction / Removal
- *Ex Situ* Treatment
- Recycling / Disposal

No Action

The No Action response serves as a baseline against which the performance of other GRAs may be compared. Under the No Action response, no remedial actions would be performed to reduce the toxicity, mobility, or volume of contaminated groundwater. No institutional controls would be implemented either on-Site or off-Site as part of the No Action GRA.

Institutional Controls

Institutional controls are legal or administrative measures designed to prevent or reduce human exposure to hazardous substances. Institutional controls are often implemented in conjunction with other remedy components. An institutional control may include an environmental easement, a deed restriction, or an environmental notice as per DER-10 (Section 5.6).

Engineering Controls

Engineering controls are physical barriers or methods employed to actively or passively contain, stabilize, or monitor contamination, or eliminate potential exposure pathways to contamination. As per DER-10, engineering controls include pavement, caps, covers, subsurface barriers, vapor barriers, slurry walls, building ventilation systems, fences, access controls, provision of alternative water supplies, and installing filtration devices on private water supplies.

Long-Term Monitoring

Long-term groundwater monitoring is performed to evaluate the effectiveness of the implemented remedy whether active treatment, institutional controls, or a combination of remedies.

Monitored Natural Attenuation

This GRA relies on natural mechanisms including dispersion, dilution, adsorption, diffusion, and biodegradation to reduce contaminant concentrations in groundwater. There is no intervention to manipulate the physical, geochemical, or hydrological regime. Comprehensive monitoring is a required component of this GRA to evaluate and verify the progress of MNA, as is a contingency plan that defines the appropriate response action(s) should MNA not perform as expected.

In Situ Treatment

In situ treatment technologies may be used to reduce contaminant concentrations without removal or containment of soil or groundwater. Many *in situ* treatment options are typically applied only for source areas (e.g., thermal treatment, *in situ* chemical oxidation). Other *in situ* treatment options may also be applied at areas of lower contaminant concentrations (e.g., *in situ* bioremediation).

Extraction / Removal

Extraction / removal GRAs are designed to collect contaminated media for subsequent treatment with the goal of reducing the volume or toxicity of contaminants. Groundwater may be extracted or removed using a variety of technologies.

Ex Situ Treatment

Ex situ treatment GRAs are typically paired with GRAs involving collection and extraction or removal of contaminated media. The goal of *ex situ* treatment is to reduce concentrations of contaminants to levels required for the selected discharge process option. *Ex situ* treatment includes technologies that involve biological and physical/chemical processes, as well as transport for off-Site treatment.

Groundwater Disposal Options

Groundwater disposal GRAs are typically paired with GRAs involving collection of contaminated media. Extracted groundwater could be transported to a permitted Resource Conservation and Recovery Act (RCRA) treatment/storage/disposal facility (TSDF) or discharged to a publicly owned treatment works (POTW) for treatment. Alternatively, the groundwater could be treated on-Site using *ex situ* treatment and then discharged to a POTW, to a nearby surface water body, or injected into the subsurface via deep well injection.

5.4 Source and Methods for Identification of Potentially Applicable Technologies

Several databases, guidance documents, and journal articles addressing remediation of dissolved CVOCs in groundwater were used to identify potentially applicable remedial technologies for the 3800 Area PCE Site. The following sources are of particular note:

- Federal Remediation Technologies Roundtable (FRTR) website (http://www.frtr.gov/matrix2/top_page.html)
- EPA Green Remediation Primer: Incorporating Sustainable Environmental Practices into Remediation of Contaminated Sites (EPA 542-R-08-002, April 2008) http://www.clu-in.org/download/remed/Green-Remediation-Primer.pdf
- Technical Protocol for Evaluating Natural Attenuation of Chlorinated Solvents in Ground Water (EPA/600/R-98/128, September 1998) http://www.epa.gov/osw/hazard/correctiveaction/resources/guidance/rem_eval/protocol.pdf
- Technical and Regulatory Guidance for In Situ Chemical Oxidation of Contaminated Soil and Groundwater, second edition (The Interstate Technology & Regulatory Council, January 2005). http://www.itrcweb.org/Guidance/GetDocument?documentID=45
- Principles and Practices of Enhanced Anaerobic Bioremediation of Chlorinated Solvents (Air Force Center for Environmental Excellence, August, 2004). http://costperformance.org/remediation/pdf/principles_and_practices_bioremediation.pdf

5.5 Technology Identification and Technical Implementability Screening

The following sub-sections describe the technology classes and process options that encompass the means for achieving the GRAs. For example, *in situ* treatment is a GRA that may achieve RAOs using ISCO or biological remediation technologies. Specific process options were identified within each technology class. For instance, ISCO, which is a technology class, includes process options related to the type of oxidant selected, such as permanganate, hydrogen peroxide, or sodium persulfate. Applicable process options were selected based on an understanding of the characteristics of the contaminated media and the technologies that are available to address the media.

The universe of potentially applicable technology types and process options was reduced by screening the technologies and process options with respect to technical feasibility for the 3800 Area PCE Site. This was accomplished by using the information collected during prior investigations, bench studies, and pilot studies regarding the Site geology and contaminant concentrations and distribution as well as performance of various remedial technologies. The major factors that influence the technical feasibility of remedial technologies at the 3800 Area PCE Site are the relatively low dissolved PCE concentrations (i.e., less than 1 mg/L), the presence of potential PCE mass beneath Building 1885, the depth of PCE in the sub-surface (i.e., approximately 45 ft bgs), the depth to the clay confining unit (approximately 70 to 80 ft bgs), the decreasing permeability of Site soils with depth, and the aerobic, oxidative conditions in the unconfined aquifer. **Table 5-1** lists the identified technologies and process options and summarizes the outcome of the technical implementability screening. Results of the preliminary screening of technologies and process options identified for each GRA are also discussed below.

5.5.1 GRA: No Action

Under the No Action response, no remedial actions would be performed to reduce the toxicity, mobility, or volume of contaminated groundwater. No institutional controls would be implemented. Existing remediation infrastructure (i.e., ISCO injection wells and process monitoring wells) would be abandoned. The No Action GRA is carried forward for evaluation because it provides a baseline to which other GRAs and their associated process options can be compared. There are no specific technology types or process options associated with the No Action GRA.

5.5.2 GRA: Institutional Controls

The remedial technology identified under the Institutional Controls GRA consists of administrative restrictions focused on minimizing potential contact with contaminated groundwater. The process option includes groundwater use restrictions that could be accomplished by placing restrictions or prohibitions on the use of well water and/or prohibitions on the installation of water supply wells in the vicinity of the 3800 Area PCE Site. This process option is technically feasible and is retained for further screening.

5.5.3 GRA: Engineering Controls

Engineering controls for groundwater typically include process options that limit the movement of groundwater contaminants (e.g., slurry walls), or eliminate potential exposure pathways by provision of alternate water supplies, building ventilations systems, or other measures. As discussed previously, exposure pathways to human receptors are currently incomplete, as groundwater at the Site is not utilized for consumptive purposes, and indoor air sampling demonstrated that no CVOCs are migrating into buildings. Therefore, there are no applicable engineering control process options identified for groundwater at the 3800 Area PCE Site, and the engineering controls GRA is not retained for further evaluation.

5.5.4 GRA: Long-Term Monitoring

This GRA includes monitoring to assess the nature and extent of groundwater contamination over time. This GRA is generally conducted during or after other active remediation activities to monitor the progress of remediation. This process option is technically feasible and has been retained for further screening.

5.5.5 GRA: Monitored Natural Attenuation

This GRA relies on natural mechanisms including dispersion, dilution, adsorption, diffusion, and biodegradation to reduce contaminant concentrations in groundwater. There is no intervention to manipulate the physical, geochemical, or hydrological regime. The process option associated with MNA consists of long-term monitoring of groundwater quality with existing and/or newly installed wells to verify the progress of MNA. Typically, analyses include biological and chemical parameters to assess biodegradation of the contaminants of concern. At the 3800 Area PCE Site, the aquifer geochemical conditions are not conducive to natural attenuation via biodegradation. Therefore, MNA monitoring would measure natural attenuation due to abiotic mechanisms. This process option is technically feasible and has been retained for further screening, particularly in conjunction with other active remediation process options.

5.5.6 GRA: *In Situ* Treatment

5.5.6.1 Technology Class: Biological Treatment

Bioremediation is a technology in which the physical, chemical, and biological conditions of a contaminated medium are manipulated to accelerate the natural biodegradation and mineralization processes. Biodegradation is the process whereby microorganisms alter the structure of a chemical, while mineralization is the complete biodegradation of a chemical to carbon dioxide, water, and simple inorganic compounds. In nature, both partial biodegradation and complete mineralization take place; the processes, however, are frequently slow. Biostimulation and bioaugmentation are two processes used to enhance the rates of biodegradation and mineralization. Biostimulation involves the addition of amendments such as carbon substrates and nutrients to stimulate biodegradation. Bioaugmentation involves the addition of engineered microbes that are known to degrade the contaminants of interest.

In Situ Enhanced Bioremediation via Biostimulation: Reductive dechlorination is the most important process in the natural biodegradation of chlorinated solvents. For reductive dechlorination to completely degrade chlorinated CVOCs such as PCE and TCE, the geochemical conditions in the subsurface must be ideal and microorganisms that are capable of degrading the CVOCs must be present. As summarized in Section 3.4, during microcosm testing conducted for the RI, biostimulation was not successful in reducing PCE concentrations. This is consistent with the fact that DHC bacteria were detected at very low concentrations in Site groundwater. Therefore, this process option is not technically feasible and is not retained for further evaluation.

In Situ Enhanced Bioremediation via Bioaugmentation: Bioaugmentation involves the addition of non-native organisms known to degrade the contaminants of interest. Bioaugmentation is typically conducted in concert with biostimulation. Bioaugmentation may be used at a site where the presence of an appropriate population of microbes is not present or sufficiently active to stimulate complete degradation. A microcosm study conducted during the RI demonstrated that bioaugmentation in concert with biostimulation reduced PCE concentrations significantly in Site groundwater. Therefore, this process option is technically feasible and will be retained for further evaluation.

5.5.6.2 Technology Class: In Situ Chemical Oxidation

ISCO involves the delivery and distribution of oxidants and other amendments into the subsurface to transform constituents of concern (COCs) into innocuous end products such as carbon dioxide, water, and inorganic compounds. The appropriateness of ISCO technology at a site depends on matching the oxidant and delivery system to the site contaminants and site conditions. For ISCO to be effective, the oxidant must come into direct contact with COCs. The persistence of the oxidant in the subsurface is important since this affects the contact time for advective and diffusive transport, and ultimately the extent to which the oxidant can be delivered to subsurface targeted zones. The most common oxidants utilized for ISCO are permanganate, catalyzed hydrogen peroxide (CHP), and activated persulfate. Each of these oxidants was evaluated as a potentially feasible process option.

ISCO with Permanganate: Permanganate is an oxidizing agent with a unique affinity for oxidizing organic compounds with carbon-carbon double bonds (e.g., PCE, TCE). There are two forms of permanganate that are used for ISCO: potassium permanganate ($KMnO_4$) and sodium permanganate ($NaMnO_4$). Potassium permanganate is available as a dry crystalline material, while sodium permanganate is a liquid. Permanganate turns bright purple when dissolved in water; this purple color acts as a built-in indicator for unreacted chemical. Reacted permanganate is black or brown, indicating the presence of a manganese dioxide (MnO_2) byproduct. Compared to the other commonly used oxidants, permanganate is more stable in the subsurface. Unlike CHP, permanganate does not degrade naturally and can persist in the subsurface indefinitely (i.e., it is only consumed by interaction with contaminants or natural organic material). The persistence of permanganate in the subsurface allows for diffusion of the oxidant into the subsurface matrix – making treatment of less permeable materials (i.e., silty sand) possible over time. ISCO with permanganate will be retained for additional evaluation.

ISCO with CHP: CHP involves the injection of hydrogen peroxide under acidic conditions in the presence of a ferrous iron catalyst to form hydroxyl free radicals. Hydroxyl radicals are very effective and nonspecific oxidizing agents. However, they are unstable and have a fairly short active life (i.e., on the order of hours or a few days). Because ISCO with CHP produces an exothermic reaction, it is well-suited to use at sites where DNAPL is present, or where there is significant sorbed COC mass, as the heat produced by the oxidation reactions promotes mass desorption. CHP is not the best-suited oxidant for the 3800 Area PCE Site where there is no DNAPL and little PCE mass appears to remain in the subsurface. Therefore, ISCO with CHP is not retained for further evaluation.

ISCO with Activated Persulfate: Sodium persulfate dissociates in water to form the persulfate anion ($S_2O_8^{2-}$) which, although a strong oxidant, is kinetically slow in oxidizing many organic contaminants. When catalyzed or 'activated' in the presence of high pH (e.g., via addition of sodium hydroxide [NaOH]), heat (thermal catalyzation), a ferrous salt, or hydrogen peroxide, the persulfate ion is converted to the sulfate free radical ($SO_4^{-\bullet}$). The sulfate free radical is a very potent oxidizing agent that has a greater oxidation potential and can degrade a wider range of environmental contaminants at faster rates than the persulfate anion. Formation of $SO_4^{-\bullet}$ may also initiate the formation of the hydroxyl free radical, another strong oxidizing agent, as well as a series of radical propagation and termination chain reactions whereby organic compounds may be transformed. ISCO with activated persulfate is potentially technically feasible and has been retained for further evaluation.

5.5.6.3 Technology Class: Enhanced Desorption and Treatment

Enhanced desorption refers to approaches to enhance dissolved CVOC mass removal involving the injection and subsequent extraction of chemicals or air.

Air Sparging (AS) with Soil Vapor Extraction (SVE): Air sparging (AS) involves injection of a gas (typically air) under pressure into the saturated zone to volatilize groundwater contaminants. Volatilized vapors migrate into the vadose zone where they are extracted under vacuum, generally by a soil vapor extraction (SVE) system. Air sparging has been used at many sites to treat CVOCs compounds. Successful use of air sparging technology depends on the ability of the system to effectively deliver air to the treatment area and the ability of the subsurface media to transmit the air. AS/SVE is potentially technically feasible at the 3800 PCE Area Site, where the geology consists primarily of sand and silty sand, and will be retained for further evaluation.

5.5.6.4 Technology Class: Thermal Treatment

Steam-Enhanced Extraction: Steam-enhanced extraction (SEE) uses an alternating steam injection and vacuum extraction approach to remove volatile and semi-volatile COCs from the subsurface. The steam injection displaces mobile liquids ahead of the advancing steam zone. Liquids displaced by the injected steam are pumped from extraction wells. The vapors containing the volatilized contaminants are captured by vacuum extraction. Once above ground, extracted groundwater and vapors are cooled and condensed. Liquid hydrocarbons are separated from the aqueous steam for recycling, and process vapors and water are treated before discharge. Of all the thermal treatment technologies, SEE is best suited to the sandy, permeable geology encountered in the shallow and upper intermediate hydrostratigraphic zones at the Site. However, because it is energy intensive compared to the other In Situ Treatment technology classes, SEE is typically used at sites where non-aqueous phase liquids are present, or where very high dissolved phase concentrations of COCs are detected in groundwater. This is not the case at the 3800 Area PCE Site; therefore, SEE is not retained for further evaluation.

Electrical Resistance Heating: Electrical resistance heating (ERH) involves installation of electrodes in the subsurface. Soil and groundwater are heated by the passage of electrical current between the electrodes. It is the resistance to the flow of electrical current that results in increased subsurface temperatures. The maximum achievable temperature with ERH is the boiling point of water. As the subsurface is heated, contaminants are volatilized and soil moisture and groundwater are converted to steam. Above ground treatment involves treating vapors, condensate, and entrained water. Because it is energy intensive compared to the other In Situ Treatment technology classes, ERH is typically used at sites where non-aqueous phase liquids are present, or where very high dissolved phase concentrations of COCs are detected in groundwater. Additionally, ERH is typically used at sites with lower permeability soils (e.g., clays). This is not the case at the 3800 Area PCE Site where the continual flux of cold water into the treatment area would reduce the effectiveness of ERH, and where no significant source mass has been identified. Therefore, ERH is not retained for further evaluation.

5.5.6.5 Technology Class: Permeable Reactive Barriers

Permeable reactive barriers (PRBs) are installed across the flow path of a contaminant plume, allowing the water portion of the plume to passively move through the wall. These barriers allow the passage of water while inhibiting the movement of contaminants by employing such reactive agents as zero-valent metals, chelators (ligands selected for their specificity for a given metal), sorbents, microbes, and other reactive media. The majority of installed PRBs use zero-valent iron (ZVI) as the reactive medium for the treatment of chlorinated ethenes. As the iron is oxidized, a chlorine atom is removed from the chlorinated ethene by one or more reductive dechlorination mechanisms, using electrons supplied by the oxidation of iron. The iron granules are dissolved by the process, but the metal disappears so slowly that the remediation barriers can be expected to remain effective for many years, possibly even decades. PRBs are generally intended for long-term operation to control migration of contaminants in groundwater. Granular ZVI and nano-scale ZVI were evaluated as process options for PRBs at the 3800 Area PCE Site.

PRB using Granular ZVI: The granular iron used in most PRB applications comprises a mixture of ductile and cast iron cuttings obtained from a number of primary industries that use iron in the production of automotive and related industrial parts. A number of these “feedstocks” are mixed together, put through a rotary kiln in the presence of proprietary gas mixtures, cooled, milled, and sorted to a specific grain size range. Higher grain sizes are used for PRBs constructed using excavation methods where the

ZVI is placed directly into a trench. Smaller grain sizes are used for PRBs constructed using injection technologies (e.g., hydraulic fracturing, high-pressure jetting, or liquid atomized injection). It is good practice to key a PRB into a low-permeability layer to ensure complete capture of the contaminant plume and as a safeguard in the event that the permeability of the PRB is eventually reduced. At the 3800 Area PCE site, the depth to the clay confining unit (approximately 70 to 80 ft bgs) precludes installation of a PRB without significant disturbance to the Site and on-going Army operations. Therefore, use of a PRB with granular ZVI will not be retained for further evaluation.

PRB using Nano-Scale ZVI (NZVI): NZVI is composed of sub-micrometer particles of iron metal (typically 10 – 1000 nanometers). NZVI is highly reactive because of its large surface area. Bench studies conducted during the RI suggest that this technology is effective in removing PCE from Site groundwater in a laboratory setting. Near-complete removal (99 percent) of PCE was achieved with a 1.0 g/L solution of the amendment, while 100 percent removal was achieved using a 2.0 g/L solution. At lower NZVI concentrations (0.5 g/L), the PCE reduction observed was not significantly different from that observed in the control (unamended) sample (see Section 3.4). A NZVI PRB would be created via direct injection of NZVI into the subsurface in a barrier configuration. One of the issues associated with the field application of NZVI is that the particles have a tendency to agglomerate and settle out of the transport solution. In addition, the particles are denser than water, which also gives them a tendency to settle in solutions. Due to difficulties and uncertainties associated with the distribution of NZVI, and because the bench study showed that a relatively high solution concentration is required to achieve PCE treatment, use of a PRB with NZVI will not be retained for further evaluation.

5.5.7 GRA: Extraction

5.5.7.1 Technology Class: Groundwater Extraction

Vertical Extraction Wells: Vertical extraction wells are very commonly used in traditional pump-and-treat applications for contaminated groundwater capture and subsequent treatment and discharge. The water that is extracted typically requires treatment and subsequent disposal. Groundwater flow and contaminant transport modeling could be used to evaluate capture and optimal extraction well placement. Process options for *ex situ* groundwater treatment and discharge are discussed in Sections 5.5.8 and 5.5.9, respectively. Extraction wells could be installed near the source area (i.e., between Building 1885 and Oneida Avenue) and/or in down-gradient areas to remove and treat dissolved COCs. If applied down-gradient of the source area, consideration would need to be given to treating petroleum-related COCs related to the Gasoline Alley sites. Vertical extraction wells for groundwater extraction will be retained for further evaluation.

Interceptor Trenches: Interceptor trenches refer to a wide range of lateral groundwater collection systems from tile-drain systems to deep horizontal well installations. Recent technology advances in trench construction methods, such as continuous trenching equipment, use of biodegradable slurries, geotextiles or plastic shoring materials, and other innovations have led to the more frequent use of interceptor trenches. All of these construction methods involve the installation of a horizontal collection system which intersects a large cross-section of an aquifer. Groundwater is directed to the interceptor trench as a result of a hydraulic head drop maintained across the length of the trench. The hydraulic head drop can be a result of gravity drainage (as in a traditional French Drain) or can be induced by pumping from a collection sump attached to the trench system. Interceptor trenches are typically used in shallow groundwater collection applications in unconsolidated media. This technology is not feasible for use at the Site because of the large depth to groundwater containing PCE (over 40 feet bgs). Therefore, interceptor trenches will not be retained for further evaluation.

5.5.8 GRA: Ex Situ Treatment

Ex situ treatment may be required when the selected remedy involves groundwater extraction, and when the groundwater requires on-site treatment prior to discharge. Although the technologies employed for treating extracted groundwater are important aspects of the remedy, they have little influence on reducing contaminant levels or minimizing contaminant migration at the 3800 Area PCE Site. The technologies presented in USEPA's *Presumptive Response Strategy and Ex-Situ Treatment Technologies for Contaminated Ground Water at CERCLA Sites* (1996) are incorporated into this FS by reference. These presumptive *ex situ* treatment technologies are well-understood methods that have been used for many years in the treatment of drinking water, impacted groundwater and/or municipal or industrial wastewater. The presumptive technologies presented below are the technologies retained for the development of remedial alternatives. The presumptive response guidance document serves as the RAS technology screening step (USEPA, 1996) for the *ex situ* treatment component of a remedy.

The presumptive technologies for treatment of extracted groundwater containing dissolved organic contaminants include the following:

- Air stripping
- Granular activated carbon
- Chemical / Ultraviolet (UV) oxidation
- Biological reactors

Appendix C contains an excerpt from the presumptive response guidance document (USEPA, 1996), providing descriptions, advantages, and disadvantages of these technologies. In addition to the presumptive technologies listed in the guidance, other treatment components may be needed prior to (pretreatment) or subsequent to (post-treatment) the presumptive technologies. These could include pH adjustment, methods for separation of oil and/or grease from water, and filtration technologies to remove solid particles (e.g., resulting from chemical precipitation, from oxidation, or other processes). These ancillary components are not addressed in detail in this FS, but may be used to assemble *ex situ* treatment alternatives, as needed.

5.5.9 GRA: Groundwater Disposal

Groundwater discharge or disposal would be required if the remedy for the 3800 Area PCE Site involved groundwater extraction. The primary options for groundwater disposal include on-Site treatment followed by discharge to surface water or a POTW, or transport to an off-Site location (e.g., POTW or RCRA TSDF) for treatment and disposal. These options are described and evaluated below.

5.5.9.1 Technology Class: Off-Site Treatment

Publicly Owned Treatment Works (POTW): This process option involves the direct discharge of untreated extracted groundwater to a local POTW for treatment. Given the high concentrations of PCE in the groundwater at the Site, pre-treatment would be required prior to discharge to POTW. Therefore, discharge of untreated groundwater to a POTW will not be retained as a process option.

RCRA Treatment/Storage/Disposal Facility: This process option involves the transport of extracted groundwater to a licensed RCRA facility for treatment and/or disposal. This process option is not technically feasible based on the volumes of water anticipated to be extracted for a pump-and-treat remedy. Therefore, this process option will not be retained for further evaluation.

5.5.9.2 Technology Class: Discharge of Treated Water

Discharge to POTW: This process option entails the discharge of treated groundwater to the POTW for further treatment and disposal. An *ex situ* treatment system would need to be designed to meet the POTW's discharge limitations. Treated water from existing groundwater treatment systems is currently being discharged to the POTW. Therefore, this process option is technically feasible and will be retained for further evaluation.

Discharge to Surface Water: This process option involves the discharge of treated groundwater to a surface water body. Discharge to surface water would require a State Pollutant Discharge Elimination System (SPDES) permit from NYSDEC. An evaluation would be required to assess the presence of sensitive environmental areas in the vicinity of the discharge. Discharge of treated groundwater to surface water is retained for further evaluation because it may be technically feasible.

Infiltration Basin or Gallery: An infiltration basin allows treated water to seep through the ground surface in a controlled area. An infiltration gallery includes a subsurface network of perforated pipes in trenches that return the treated water below the surface, but above the water table. Given the medium to fine sand in the upper Pine Plains aquifer zone, infiltration basins or galleries may be technically feasible. Infiltration basins and galleries, therefore, have been retained for further evaluation.

Deep Well Injection: Deep well injection is a liquid waste disposal technology. This process option involves the use of injection wells to place treated or untreated liquid waste into geologic formations that have no potential to allow migration of contaminants into potential potable water aquifers. Permitting of deep injection wells is often challenging, and this option is generally expensive given the deep drilling depths. Additionally, there may be permeability limitations at depth. Although this process option is potentially technically feasible, it has not been retained for further evaluation as it is not a viable option for the Site.

5.6 Effectiveness, Implementability, and Cost Screening of Technology Process Options

Technology process options that were retained after the initial technical feasibility screening are subjected to a further screening based on the three criteria of implementability, effectiveness, and relative cost. The three screening criteria are described below.

__Implementability__

Implementability refers to the technical and administrative feasibility of implementing a particular process option. Technologies that are clearly not applicable to the 3800 Area PCE Site were previously screened and rejected (see **Table 5-1**). Therefore, consideration of implementability focuses on the administrative implementability of process options, including the following:

- The constructability of the remedial technology or process option under current facility conditions (Note: for this FS evaluation it has been assumed that future use in the vicinity of the 3800 Area PCE Site is similar to current use);
- The time needed to implement the remedial technology or process option to achieve beneficial results and to satisfy the RAOs; and
- Availability and capacity of off-facility treatment, storage, disposal services.

__Effectiveness__

Determining the effectiveness of a process option involves the following considerations:

- The ability of the process option to effect reductions in the toxicity, mobility, and/or volume of each of the contaminant types of potential concern;
- How well the process option will handle the estimated areas or volumes of groundwater to be remediated;
- The potential impacts to human health and the environment during the construction and implementation phases; and
- How proven and reliable the process is with respect to the types of geological conditions and types of COCs present at the 3800 Area PCE Site.

__Cost__

Process options were screened with respect to relative costs for considering both capital costs and operations and maintenance (O&M) costs. Cost discriminators used for preliminary screening are defined in terms of high, moderate, and low, based on engineering judgment. Cost plays a limited role in the preliminary screening of technologies and process options.

Table 5-2 summarizes the evaluation of the treatment technologies and process options with respect to implementability, effectiveness, and relative cost.

Green Remediation Strategies and Considerations

While "green" remediation considerations were not a criterion for screening the technologies and process options evaluated below, "green" remediation implementation strategies should be considered in accordance with NYSDEC policy described in DER-31, Green Remediation (NYSDEC, 2010). Some of the potential implementation strategies and considerations applicable to the process options screened below include:

- Minimizing materials usage (e.g., well materials, piping, etc.) through selection of reusable or multi-purpose materials and designs, as opposed to disposable components
- Minimizing energy consumption required to operate pumps and other equipment. Optimizing equipment operation by properly maintaining the equipment. Selection of appropriate pump capacities and use of variable frequency drives.
- Optimizing injection or extraction well spacing to minimize the number of wells required for remediation.
- Minimizing waste generation and landfill usage when in situ treatment options may be feasible.
- Offset energy consumption through power purchase agreements using renewable energy sources such as solar, wind, and biomass.

5.6.1 No Action

Implementability. The No Action GRA is easily implementable as it does not involve performing any remedial actions. Monitoring wells and injection wells from previous and planned ISCO pilot study activities would need to be decommissioned.

Effectiveness. The No Action GRA is not effective in reducing groundwater contamination and would not meet RAOs.

Costs. There would be costs associated with decommissioning existing below-ground remedial system infrastructure. However, costs would be low compared to the other GRAs requiring active treatment.

Screening Decision. The No Action GRA is retained to serve as a baseline against which other remedial alternatives may be compared.

5.6.2 Institutional Controls

Implementability. Institutional controls, such as restrictions on installation of groundwater supply wells, are readily implementable.

Effectiveness. The effectiveness of institutional controls in preventing exposure to contaminated groundwater depends on their continued enforcement. Institutional controls do not reduce the mass of contaminants, nor do they prevent further contaminant migration. Institutional controls are commonly implemented in conjunction with other technologies.

Costs. The capital and O&M costs for establishing institutional controls are low.

Screening Decision. Institutional controls are retained for further evaluation.

5.6.3 Groundwater Monitoring

Implementability. A groundwater monitoring program would be required to demonstrate compliance with the RAOs. Groundwater monitoring is readily implementable and involves sampling to measure concentrations of COCs in groundwater over time. The infrastructure required to monitor groundwater is already present at the 3800 Area PCE Site.

Effectiveness. Monitoring is an effective tool to obtain data regarding COCs in groundwater. However, monitoring does not reduce the mass of contaminants, nor does it prevent further contaminant migration. Monitoring is commonly implemented in conjunction with other technologies.

Costs. It is anticipated that the existing monitoring well network would suffice for groundwater monitoring, so capital costs would be very low. However, the O&M costs are moderate because the monitoring network is fairly extensive and the time-period for groundwater monitoring is expected to be prolonged.

Screening Decision. Groundwater monitoring is retained for further evaluation.

5.6.4 Monitored Natural Attenuation

Implementability. MNA monitoring is readily implementable. It is commonly applied at sites with contaminated groundwater, either as a stand-alone technology, or as a polishing step after completion of active treatment. MNA monitoring is typically applied over long periods of time (e.g., decades). The infrastructure required to monitor groundwater is already present at the 3800 Area PCE Site.

Effectiveness. The effectiveness of MNA varies depending on the efficacy of the various attenuation mechanisms (i.e., dilution, adsorption, dispersion, biodegradation). OSWER Directive 9200.4-17P (USEPA, 1999) states the following requirement for MNA:

> *MNA will be an appropriate remediation method only where its use will be protective of human health and the environment and it will be capable of achieving site-specific remediation objectives within a time frame that is reasonable compared to other alternatives.*

At the 3800 Area PCE Site, aquifer conditions do not support intrinsic biodegradation. Therefore, it is unlikely that MNA alone would achieve the RAOs within a reasonable time-frame.

Costs. It is anticipated that the existing groundwater monitoring network would suffice for MNA monitoring, so capital costs would be very low. O&M costs are moderate because the monitoring network is fairly extensive and the time period for MNA is expected to be prolonged.

Screening Decision. MNA monitoring is retained for further evaluation as a secondary or polishing technology applicable to groundwater after source area treatment.

5.6.5 In Situ Biological Treatment

ISEB with bioaugmentation was retained for further evaluation following the initial technical feasibility screening.

In Situ Enhanced Bioremediation via Bioaugmentation

Implementability. Bioaugmentation involves the addition of non-native organisms (typically bacteria) known to degrade the contaminants of interest. Bioaugmentation is typically performed in conjunction with biostimulation (i.e., typically, the addition of carbon substrate). There are several vendors that provide bacterial cultures (typically DHC species) that are known to completely biodegrade chlorinated ethenes. The main obstacle to implementing this technology is achieving uniform distribution of the bacterial cultures and carbon substrate(s) throughout the treatment zone, particularly in low K zones. Several commercial bacterial cultures have been applied successfully at similar Sites. Biostimulation may be achieved by the addition of various types of carbon substrates (electron donors) that may be divided into the general categories of soluble versus viscous or solid substrates. Soluble substrates are applied as a dissolved or "aqueous" phase and may be more easily applied throughout an aquifer matrix as compared to viscous or solid substrates. Molasses and lactate are the most common soluble substrates. Soluble substrates travel with advective groundwater flow, and are typically applied in a continuous or periodic (pulsed) mode. Slow-release, viscous fluid substrates include Hydrogen Release Compound (HRC®) and neat vegetable oils. These substrates are intended to be long-lasting; a single or limited number of applications are typically sufficient for site remediation. They are intended to be relatively immobile in the subsurface, and rely on advection and dispersion of soluble compounds generated via their degradation (e.g., metabolic acids) for effective delivery throughout the aquifer matrix. Vegetable oil emulsions combine the advantages of relatively low viscosity, which aids distribution, and longevity.

Effectiveness. The effectiveness of ISEB with bioaugmentation is dependent on how well the applied bacterial cultures adapt and grow. This depends significantly on subsurface geochemical conditions. The elevated DO, nitrate, and sulfate concentrations, which are typical conditions in the subsurface at the Site, are not amenable to promoting DHC growth. Therefore, a carbon substrate would need to be applied at the 3800 Area PCE Site prior to injection of microbes to "condition" the aquifer geochemically prior to application of dechlorinating bacteria cultures (see discussion above regarding types of carbon substrates). The bench-scale study conducted during the RI demonstrated that ISEB with bioaugmentation could be effective at the Site in combination with adequate carbon substrate addition and maintenance of anaerobic conditions. The bench-scale study showed the production of VC and methane in the bioaugmented microcosms. The potential exists for vapor-phase VC and methane gas to migrate upward and through the vadose zone and possibly cause vapor intrusion issues for structures located at the Site. Air monitoring and engineering controls may be needed to address vapor intrusion concerns.

Costs. Capital costs include installation of injection wells and monitoring wells. Capital costs are moderate compared to other process options. O&M costs include the price of the substrate, price of bacterial culture, labor for injection, and groundwater monitoring labor and expenses. O&M costs depend on the number of injection events required to achieve desired contaminant concentration reductions. O&M costs are moderate relative to other process options.

Screening Decision. The geochemistry at the Site is not naturally amenable to the growth of DHC bacteria. There are uncertainties in the ability to adequately deliver and distribute substrates and bacterial cultures throughout the treatment areas, particularly in deeper portions of the PCE source area, where the proportion of silt to sand increases, and permeability decreases. It is anticipated that several treatments over a number of years would be required to achieve and maintain optimal geochemical conditions. However, since this process option was deemed effective based on bench study results, it will be retained for consideration as a process option for remedial alternative development.

5.6.6 In Situ Chemical Oxidation

ISCO with permanganate and ISCO with activated persulfate were retained after the initial technical feasibility screening.

5.6.6.1 Permanganate

Implementability. ISCO with permanganate is a proven technology that has been used at many sites to remediate chlorinated ethenes. In recent years, sodium permanganate has been applied more commonly than potassium permanganate, because potassium permanganate is regulated under the Chemical Facility Anti-Terrorism Standards. ISCO involves installation of multiple injection wells, and typically requires a series of injection events to reduce contaminant concentrations to desired levels. There are no above-ground structures associated with ISCO (other than temporary drums or tanks used to store the permanganate during the injection events, which typically have a duration of days or weeks).

Effectiveness. A bench-scale study conducted during the RI demonstrated that permanganate was effective at reducing PCE concentrations in groundwater and soil samples collected from the Site. However, the field-scale effectiveness of ISCO depends on the ability to distribute the permanganate such that it physically contacts the chlorinated ethenes in order for the oxidation reactions to occur. Given the generally permeable nature of the sands at the presumed PCE source area, permanganate distribution should be achievable. This was partially demonstrated during the initial ISCO pilot study (see Section 2.5) and will be further evaluated during a planned upcoming ISCO pilot. Permanganate distribution at the Site could be adversely affected by lower permeabilities in deeper portions of the presumed source area. However, given permanganate's longevity (typically on the order of weeks), some degree of diffusion may be achieved in the lower K portions of the presumed source area (i.e., deeper than approximately 45 feet bgs).

Costs. Capital costs include installation of oxidant injection wells and monitoring wells. Capital costs are moderate compared to other process options. O&M costs include the price of the oxidant, labor for injection, and groundwater monitoring labor and expenses. O&M costs depend on the number of injection events required to achieve desired contaminant concentration reductions. O&M costs are moderate relative to other process options.

Screening Decision. PCE is readily amenable to oxidation by permanganate. The bench study and pilot study results support the implementability and effectiveness of ISCO with permanganate at the Site. Therefore, this process option will be retained for consideration during remedial alternative development.

5.6.6.2 Activated Persulfate

Implementability. ISCO with activated persulfate is a proven technology that has been used at many sites to remediate chlorinated ethenes and other organic compounds. Sodium persulfate dissociates in water to form the persulfate anion ($S_2O_8^{2-}$) which, although a strong oxidant, is kinetically slow in oxidizing many organic contaminants. When catalyzed or 'activated' in the presence of high pH (e.g., via addition of sodium hydroxide [NaOH]), heat (thermal catalyzation), a ferrous salt, or hydrogen peroxide, the persulfate ion is converted to the sulfate free radical ($SO_4^{-\bullet}$). Operationally, heat activation is the most complex method to activate persulfate; therefore, high pH and peroxide activation are used most commonly. ISCO with activated persulfate involves installation of multiple injection wells, and typically requires a series of injection events to reduce contaminant concentrations to desired levels. There are no above-ground structures associated with ISCO other than temporary drums or tanks used to store the persulfate and chemical activators during the injection events, which typically have a duration of days or weeks. The application of activated persulfate is somewhat more complex than ISCO with permanganate, which does not require activation.

Effectiveness. The effectiveness of ISCO depends on the ability to distribute the activated persulfate such that it physically contacts the organic contaminants in order for the oxidation reactions to occur. Given the generally permeable nature of the sands at the presumed PCE source area, activated persulfate distribution should be achievable, with the potential exception of the deeper (i.e., approximately 45 feet bgs) portions of the source area with lower K due to the presence of less permeable silty sands. The persulfate anion and the sulfate free radical may persist for days to weeks depending on subsurface conditions.

Costs. Capital costs include installation of oxidant injection wells and monitoring wells. Capital costs are moderate compared to other process options. O&M costs include the price of the oxidant and activator, labor for injection, and groundwater monitoring labor and expenses. O&M costs depend on the number of injection events required to achieve desired contaminant concentration reductions. O&M costs are moderate relative to other process options.

Screening Decision. PCE is readily amenable to oxidation by activated persulfate. The bench study and pilot study results support the implementability and effectiveness of the ISCO technology at the Site. Therefore, this process option will be retained for consideration during remedial alternative development.

5.6.7 Enhanced Desorption and Treatment

Enhanced desorption and treatment via AS/SVE was retained for further evaluation following the initial technical feasibility screening.

Air Sparging with Soil Vapor Extraction

Implementability. Application of AS/SVE is widely recognized by the regulatory community as an effective remedial technology for removing volatile contaminants from groundwater. Implementation is relatively straight-forward because only readily available commercial equipment is utilized (i.e., PVC well casing, compressors, blowers). The equipment is relatively simple to install and causes minimal disturbances to site operations. Because AS increases the rate of contaminant volatilization, it is important to be aware of the potential for migration of VOC-impacted vapor to nearby structures. An SVE system may be used to reduce or eliminate vapor migration. SVE is straight-forward to implement and is one of USEPA's presumptive remedies for the remediation of VOC-contaminated vadose zone soils.

Effectiveness. For AS to be effective, contaminants must be sufficiently volatile to strip out of the groundwater. PCE has a relatively high Henry's constant (1.8×10^{-2} atm-m^3/mol) due to both its high volatility and low aqueous solubility, and is amenable to removal via AS. AS is best suited to sites with sandy soils and groundwater table depths less than 50 ft bgs. Site geological conditions such as stratification, heterogeneity, and anisotropy, prevent uniform airflow through the subsurface, thus reducing AS effectiveness. Air flow-paths formed during AS are sensitive to small changes in soil permeability, so identification of layers of lower permeability material between the water table and the greatest depth of contaminant presence is important. In general, a K of $1X10^{-3}$ cm/second (2.8 ft/day) or higher is optimal. The K values at the presumed PCE source area at the Site are in the optimal range at depths shallower than 45 feet bgs; however, at depths greater than 45 ft bgs, K values decrease below the optimal range. Therefore, for AS to be effective, sparge points may need to be placed in closer proximity.

Costs. Capital costs include the following: pilot-scale testing to assess the radius of influence for AS; system design; system installation including AS and SVE wells, monitoring wells, blowers, compressors, and associated piping; and system decommissioning. Capital costs are moderate to high compared to other process options (higher costs may be incurred if a tighter spacing of AS wells is required). O&M costs include electricity to power blowers/compressors, and groundwater and vapor monitoring costs. O&M costs are moderate to high relative to other process options.

Screening Decision. AS/SVE is a well-proven technology for removal of VOCs, including PCE, from groundwater. The site geology in the shallow and upper intermediate zones at the 3800 Area PCE Site is well-suited to AS/SVE. However, the deeper portions of the intermediate zone, where PCE mass appears to be adsorbed to finer-grained materials, has a lower K, which is not optimal. Application of AS/SVE would require performing an initial pilot-scale study to confirm the effectiveness of AS in the deeper portions of the intermediate aquifer and to assess the appropriate spacing of sparge points. AS/SVE was retained for consideration as a process option for remedial alternative development.

5.6.8 Groundwater Extraction

Groundwater extraction via vertical extraction wells was retained for further evaluation following the initial technical feasibility screening.

Implementability. Groundwater extraction using single or multiple vertical extraction wells has been used at many sites, including sites similar to the 3800 Area PCE Site. The water that is extracted typically requires treatment and subsequent disposal. Process options for *ex situ* groundwater treatment and discharge are discussed in Sections 5.5.8 and 5.5.9. It is likely that groundwater extraction would be necessary for a fairly long period of time because residual PCE sorbed to silty sands or clays can serve as a long-term source of PCE to groundwater. Permanent infrastructure may be required to treat the water that is extracted, and long-term operation of the treatment system would be needed. The treatment components are readily available.

Effectiveness. The effectiveness of groundwater extraction would depend on optimal placement of extraction wells and optimal extraction rates, which may be selected using a groundwater flow model. The efficiency of groundwater extraction of PCE would be affected by the rate of dissolution of PCE from finer-grained aquifer matrix. Additionally, effectiveness would depend on pairing groundwater extraction with an effective PCE treatment technology.

Costs. Capital costs include drilling and installing the extraction wells and installing pumps. Capital costs also include construction of the required *ex situ* treatment components. Typically capital costs are moderate to high, depending on the number of extraction wells required and the complexity of the treatment system. O&M costs, which depend on the complexity of the treatment train and the cost of discharge, are also typically moderate to high.

Screening Decision. Although groundwater extraction would provide the benefit of hydraulic control of the plume, the rate of CVOC mass removal at the 3800 Area PCE Site source area would be limited by PCE dissolution. Permanent above-ground infrastructure would be required to treat groundwater prior to discharge or disposal. Given the long time-frame anticipated for PCE mass removal, and the site disturbance related to construction and maintenance of permanent groundwater treatment infrastructure, groundwater extraction is not retained as a process option for remedial alternative development.

Since groundwater extraction is not retained as a process option, the ancillary ex situ treatment and groundwater discharge/disposal process options are not required and are not further evaluated.

5.7 Summary of Retained Process Options

Based on the effectiveness, implementability, and cost screening described above, the following remedial process options have been retained for consideration in alternatives assembly to achieve RAOs in groundwater at the 3800 Area PCE Site:

- No Action
- Institutional Controls

- Groundwater Monitoring
- Monitored Natural Attenuation
- In Situ Biological Treatment
    - ISEB with bioaugmentation
- In Situ Chemical Oxidation
    - ISCO with permanganate
    - ISCO with activated persulfate
- Enhanced Desorption and Treatment
    - AS with SVE

6. Description of Remedial Alternatives

6.1 Rationale for Assembly of Alternatives

In assembling alternatives, GRAs and the process options chosen to represent the various technology types are combined to form alternatives for the site as a whole. Often, more than one GRA is used in an alternative (e.g., combination of active treatment plus MNA and institutional controls). The GRAs, technologies, and select process options retained from the identification and initial screening process have been assembled into four remedial alternatives. Each alternative (with the exception of Alternative 1) includes a groundwater monitoring component.

- Alternative 1: No Further Action
- Alternative 2: In Situ Chemical Oxidation with Monitored Natural Attenuation
- Alternative 3: In Situ Enhanced Bioremediation with Bioaugmentation and Monitored Natural Attenuation
- Alternative 4: Air Sparge/Soil Vapor Extraction with Monitored Natural Attenuation

In accordance with DER-10, each alternative is described with respect to:

(1) Size and configuration of process options

(2) Time for remediation

(3) Spatial requirements

(4) Options for disposal

(5) Substantive technical permit requirements

(6) Limitations or other factors necessary to evaluate the alternatives

(7) Beneficial and/or adverse impacts on fish and wildlife resources

The following major assumptions have been made in developing all of the remedial alternatives:

- Remedial alternative are assembled based on the results of bench-scale studies and pilot studies. For all of the alternatives, it is assumed that the 2012 ISCO pilot injection wells and the planned 2015 ISCO pilot wells are in place at time of full-scale remedy implementation.

- Various underground utilities are present in the vicinity of Building 1885. Utilities would be avoided and protected during design, installation, and implementation of the selected remedy.

- All of the alternatives incorporate appropriate institutional controls (i.e., restrictions on groundwater use) that will be incorporated into Fort Drum's base management plan.

6.2 Alternative 1 – No Further Action

The No Further Action alternative is included as a baseline alternative for comparison to the active remedial alternatives in accordance with DER-10. In this case, the No Further Action alternative will require that injection and monitoring wells associated with the 2012 ISCO pilot study and the planned summer 2015 ISCO pilot study be abandoned. The No Further Action alternative does not include groundwater monitoring or maintenance of institutional controls. Because there is no active remediation or institutional controls to be maintained, no technical difficulties are anticipated for implementation of Alternative 1.

6.3 Alternative 2 – In Situ Chemical Oxidation with Monitored Natural Attenuation

Alternative 2 utilizes the existing injection well network with optimization, via installation of additional injection wells or refinement to the injection strategy, to inject chemical oxidant in the presumed PCE source area between Building 1885 and Oneida Avenue. Two oxidants were retained as process options for ISCO after the detailed technology screening in Section 5.6.6: activated persulfate and permanganate. Sodium permanganate is selected for evaluation in Alternative 2 because it has been applied previously at the Site and shown to reduce CVOC concentrations (see Section 2.5). In addition, ISCO with persulfate, which requires activation, requires a more complex injection scenario and does not provide any greater benefit for oxidation of CVOCs. Design parameters are based on the data from the RI (PARS, 2013a) and the 2012 pilot test injection discussed in Section 2.5. The conceptual design assumptions for Alternative 2 are presented in **Table 6-1** and **Figure 6-1**. The ISCO program will focus treatment on the silty sands in the lower shallow and upper intermediate zones, where the bulk of the PCE mass is located, which is responsible for the majority of PCE mass flux down-gradient.

Implementation of Alternative 2 would involve the utilization of the existing injection well network plus the installation of additional injection wells to optimize performance of the remedy. The additional injection wells would be installed in a grid pattern throughout the presumed PCE source area to ensure adequate distribution of the oxidant and facilitate rapid treatment of CVOCs. Placement of the new injection wells would be determined after completion of the second ISCO pilot test (see Section 2.6). The injection wells would extend into the interval of the highest PCE detections between 35 and 42 ft bgs. Given the extensive ISCO pilot test work completed previously, and given the planned second ISCO pilot test (anticipated to remove a significant amount of PCE mass), a single injection of sodium permanganate is anticipated to be sufficient to reduce PCE concentrations to levels that support MNA. Alternative 2 would rapidly eliminate source concentrations of PCE currently migrating down-gradient and thus allow transition to an MNA program within the shortest timeframe. In addition, Alternative 2 provides the ability to remediate the suspected source area under Building 1885 as the reaction kinetics of the selected oxidant provide months of active treatment allowing the injected solution to migrate down-gradient and remediate CVOCs outside the ROI of the injection well network.

Approximately 40 injection wells are currently installed at the site. Prior to final remedy selection, an additional 35 injection wells will be installed and a sodium permanganate ISCO injection will be completed as part of an ongoing pilot test. It is anticipated that full-scale application of Alternative 2 would involve these 75 injection wells. Based on pilot study results, up to 15 additional injection wells may be installed to optimize the remedy through improved oxidant distribution. A total of 302,000 gallons of 3% (by weight) sodium permanganate solution will be injected into the 90 well network with an average volume of approximately 3,360 gallons per well (**Table 6-1**). The total mass of sodium permanganate injected will be approximately 75,600 lbs. The sodium permanganate will be delivered in approximately 60 275-gallon totes as a 40% solution (with a specific gravity of 11.44 pounds per gallon), so approximately 189,000 lbs of 40% solution will be utilized. This is a fairly conservative ISCO design and could be adjusted based on the results of the planned ISCO pilot test.

Oxidant injections will be performed using a temporary central mixing and injection (TCMI) system. Therefore, no permanent injection solution mixing and distributing infrastructure will be needed. The injection equipment can be staged at numerous locations around the site and will be placed to minimize disturbance to building and base operations. The injection system will consist of a large mixing tank, injection/mixing pump, injection manifold, and well head assemblies (flow meter and pressure gauge). In consultation with Fort Drum Department of Public Works (DPW), injection water will be obtained from one of the fire hydrants located near the treatment area (**Figure 6-1**). The TCMI system will be used to dilute the delivered solution down to the target solution of approximately 3% (by weight). The injection solution will be distributed via above grade hose/pipe to each injection area. An injection manifold will allow concurrent injection of up to 20 injection wells. Secondary containment will be utilized at the mixing area and at each manifold location. It is assumed that injection activities would be conducted during the spring/summer/fall field season.

Three rounds of ISCO performance monitoring at ten monitoring wells within the injection area will be conducted at approximately 30 days, 75 days, and 120 days after injection. Samples will be analyzed for VOCs, sodium permanganate (via field colorimeter and visual comparison to serial dilution), metals, and field parameters.

The MNA program will include sample collection from existing monitoring wells in the source area and the down-gradient plume. Approximately 30 monitoring wells will be included in the MNA plan. Samples will be analyzed for only VOCs as there is no evidence of natural attenuation via biological degradation. The timeframe for MNA monitoring was estimated based on the number of pore flushes required to reach the 5 ug/L water quality standard for PCE at the location with the maximum measured PCE concentration during the most recent sampling event (3805-PZ2D during Fall 2014 monitoring; Plexus Scientific, 2014), and at the downgradient receptor (OSL stream). A retardation factor was calculated for PCE which was used to calculate the number of pore flushes required to reach the water quality standard. Based on these preliminary calculations, it is anticipated that PCE concentrations at the OSL stream will be below the water quality standard in approximately 11 years. However, the pore flushing calculation assumes clean water is flushing through the selected well. Until source area treatment is complete, contaminated groundwater will continue to migrate through 3805-PZ2D. It is estimated that three to four years will be required for clean water to begin flushing through 3805-PZ2D after completion of ISCO treatment (which will have a duration of approximately 9 months). Therefore, MNA monitoring will be conducted for approximately 16 years (that is, during the approximately 1 year of active ISCO treatment, 4 years of time for flushing through of CVOCs downgradient of the source area, and 11 years of clean water flushing). The pore water flushing calculation is provided in Appendix E. Groundwater monitoring will be performed semi-annually for 5 years with subsequent sampling annually.

6.4 Alternative 3 – In Situ Enhanced Bioremediation with Bioaugmentation with Monitored Natural Attenuation

Alternative 3 utilizes the existing injection well network with optimization via installation of additional injection wells or refinement to the injection strategy, to inject organic carbon and bacterial dechlorinating cultures in the presumed PCE source area between Building 1885 and Oneida Avenue. Design parameters are based on the data from the RI (PARS, 2013a), including bench scale testing results, and the pilot test injection discussed in Section 2.5 relative to injection volume. The conceptual design assumptions for Alternative 3 are presented in **Table 6-1** and **Figure 6-2**.

The ISEB program will focus treatment on the silty sands in the lower shallow and upper intermediate zones, where the bulk of the PCE mass is located, which is responsible for the majority of the down-gradient PCE mass flux. Implementation of Alternative 3 would involve the utilization of the existing injection well network plus the installation of additional injection wells to optimize performance of the remedy. Injection wells utilized during the ISCO pilot studies would be utilized to implement this alternative; however, rather than utilizing injection wells in a grid pattern, select transects of wells will be utilized to establish a set of reactive barriers to degrade the PCE as impacted water migrates through each barrier. Additional injection wells would be installed within a specific barrier to ensure adequate distribution of organic carbon and bacterial cultures to alter the aquifer environment and facilitate degradation of PCE. Final placement of the new injection wells would be determined after completion of the second ISCO pilot test (see Section 2.6). The injection wells would extend into the interval of the highest PCE detections between 35 and 42 ft bgs. In order to complete the remedial design of Alternative 3, tracer testing would be completed to verify groundwater velocities in the target treatment interval. The groundwater velocity and contaminant velocity would be essential design parameters to size each barrier appropriately.

The current aquifer environment is not conducive to biological degradation of PCE; therefore, in order to more rapidly create the appropriate environment, a soluble donor (sodium lactate), will be injected initially at all of the injection wells. Soluble donors are more easily utilized by the native microbes and are capable of quickly altering (conditioning) the geochemistry of the aquifer. Following an initial injection of soluble donor, an insoluble donor (EVO) will be utilized in all injection wells except the wells upgradient of Building 1885, which will continue to receive a soluble substrate. Insoluble donors, such as EVO, provide limited distribution following an injection. Because the presumed source is beneath Building 1885, migration of the organic carbon is preferred to allow the largest possible in situ reactive zone (IRZ) to develop and aid in remediation of the source. The EVO injection in the wells down-gradient of Building 1885 will be conducted within 6 months of completing the initial sodium lactate injection. EVO injections will be completed annually for three additional years. Sodium lactate will be injected semi-annually for 4 years in the injection wells upgradient of Building 1885.

As the aquifer is not naturally conducive to biological degradation of PCE, bioaugmentation will be implemented during the first EVO injection once an appropriate aquifer environment has been established by the initial sodium lactate injection. Alternative 3 will effectively prevent migration of PCE down-gradient of the treatment area once the IRZ in the farthest down-gradient barrier is established. Given the required shift in aquifer geochemistry, it could take up to one year post injection before a fully developed IRZ is established. Alternative 3 would require maintenance injections until the impacted water between each barrier has attenuated to concentrations that will support MNA. It is estimated this will take up to four years of active injections.

The monitoring program will consist of performance monitoring during active remediation followed by MNA monitoring. Performance monitoring will be completed quarterly at 10 monitoring wells. Samples will be analyzed for VOCs, TOC, dissolved gases (ethane, ethene, and methane), anions (sulfate and nitrate), metals (iron and manganese), dechlorinating bacteria (i.e., DHC), and field parameters. Sampling for anions and metals may be completed semi-annually following the first year of performance monitoring. If groundwater sampling results showed elevated concentrations of VC, methane, and/or hydrogen sulfide in the vicinity of Building 1885, then indoor air monitoring and/or installation of a venting system would be considered.

The MNA program will include sample collection from existing monitoring wells in the source area and the down-gradient plume. Approximately 30 monitoring wells will be included in the MNA plan. Samples will be analyzed for only VOCs as there is no evidence of natural attenuation via biological degradation. As discussed above for Alternative 2, the timeframe for MNA monitoring was estimated based on the number of pore flushes required to reach the 5 ug/L water quality standard for PCE at the location with the maximum measured PCE concentration during the most recent sampling event (3805-PZ2D during Fall 2014 monitoring; Plexus Scientific, 2014), and at the downgradient receptor (OSL stream). A retardation factor was calculated for PCE which was used to calculate the number of pore flushes required to reach the water quality standard. Based on these preliminary calculations, it is anticipated that PCE concentrations at the OSL stream will be below the water quality standard in approximately 11 years. However, the pore flushing calculation assumes clean water is flushing through the selected well. Until source area treatment is complete, contaminated groundwater will continue to migrate through 3805-PZ2D. It is estimated that three to four years will be required for clean water to begin flushing through 3805-PZ2D after completion of ISEB treatment (which will have a duration of approximately 4 years). Therefore, MNA monitoring will be conducted for approximately 19 years (that is, during the approximately 4 years of active ISEB treatment, 4 years of time for flushing through of CVOCs downgradient of the source area, and 11 years of clean water flushing). The pore water flushing calculation is provided in Appendix E. Groundwater monitoring will be performed semi-annually for 5 years with subsequent sampling annually.

6.5 Alternative 4 – Air Sparge/Soil Vapor Extraction with Monitored Natural Attenuation

Alternative 4 requires the installation of new well infrastructure to inject ambient air into the target treatment interval (i.e., via AS) and to recover volatilized CVOCs from the vadose zone soils (i.e., via SVE). The AS system will inject ambient air into the presumed PCE source area between Building 1885 and Oneida Avenue. Some design parameters are based on the data from the RI (PARS, 2013a) discussed in Section 3. However, Alternative 4 will require specific pilot testing to confirm the conceptual design parameters. The conceptual design assumptions for Alternative 4 are presented in **Table 6-1** and **Figure 6-3**.

The AS/SVE system would focus treatment on the silty sands in the intermediate zone, where the bulk of the PCE mass is located. Implementation of Alternative 4 would involve the installation of a new well network for both the AS and SVE systems as the existing well network is not designed appropriately for either type of system. However, the existing injection well infrastructure would be used to demonstrate effectiveness of the remedy. Each well network (AS and SVE) would be installed in a grid pattern to remediate the presumed PCE source area and reduce down-gradient migration. The AS wells would extend to approximately 60 ft bgs to ensure adequate air distribution in the target treatment interval between 35 and 42 ft bgs.AS wells would have two feet of screen. SVE wells would be installed to the top of the water table, approximately 20 ft bgs. As no soil source of PCE is known, the SVE wells would focus on recovery of volatilized compounds from the groundwater and would therefore have 5 ft screens. AS and SVE pilot tests, as well as a combined AS/SVE test, would be completed to confirm design parameters and appropriately size equipment. The AS pilot test would focus on the pressure required to inject an appropriate amount of air into the formation

(~10 standard cubic feet per minute [SCFM]) as well as the ROI of the AS well in the target treatment interval. Existing injection wells could be used to assess the ROI of the AS wells. The SVE pilot test would confirm the ROI of the SVE wells, the required vacuum, as well as anticipated VOC concentrations in the vapor stream. Ultimately, the AS/SVE pilot test will be used to finalize the well spacing, well depth, size the AS and SVE equipment appropriately, and evaluate the need for off-gas treatment. Currently, it is assumed that granular activated carbon will be used to treat the SVE effluent air stream.

The AS/SVE system would operate approximately two years to reduce source concentrations enough to support MNA. The AS system would operate in zones (specific subset of AS wells), while the SVE system would operate continuously. The AS system would be pulsed using motorized valves and a programmable logic controller to prevent the creation of preferential flow paths. This allows the AS system to run continuously and reduces the size of the equipment by minimizing the total air flow to the AS well network. The system would need to operate year round to prevent down-gradient migration of PCE. In order to operate year round, all the instrumentation and controls would be located inside an insulated and heated equipment building. This requires individual AS lines be installed so that individual well pressure and flow rates can be monitored. The SVE system would be operated continuously and could be piped via common headers for each zone. Individual headers for each zone are necessary to ensure the SVE system is capturing 125% of the air injected, which is sufficient to prevent fugitive vapors.

The MNA program will include sample collection from existing monitoring wells in the source area and the down-gradient plume. Approximately 30 monitoring wells will be included in the MNA plan. Samples will be analyzed for only VOCs as there is no evidence of natural attenuation via biological degradation. As discussed above for Alternative 2, the timeframe for MNA monitoring was estimated based on the number of pore flushes required to reach the 5 ug/L water quality standard for PCE at the location with the maximum measured PCE concentration during the most recent sampling event (3805-PZ2D during Fall 2014 monitoring; Plexus Scientific, 2014), and at the downgradient receptor (OSL stream). A retardation factor was calculated for PCE which was used to calculate the number of pore flushes required to reach the water quality standard. Based on these preliminary calculations, it is anticipated that PCE concentrations at the OSL stream will be below the water quality standard in approximately 11 years. However, the pore flushing calculation assumes clean water is flushing through the selected well. Until source area treatment is complete, contaminated groundwater will continue to migrate through 3805-PZ2D. It is estimated that three to four years will be required for clean water to begin flushing through 3805-PZ2D after completion of AS/SVE treatment (which will have a duration of approximately 2 years). Therefore, MNA monitoring will be conducted for approximately 17 years (that is, during the approximately 2 years of active AS/SVE treatment, 4 years of time for flushing through of CVOCs downgradient of the source area, and 11 years of clean water flushing). The pore water flushing calculation is provided in Appendix E. Groundwater monitoring will be performed semi-annually for 5 years with subsequent sampling annually.

7. Detailed Evaluation of Remedial Alternatives

The objective of the detailed analysis of alternatives is to provide adequate information for each alternative to facilitate the selection of remedial actions for implementation at the Site. In this section, each of the alternatives developed in Section 6 are assessed under the nine evaluation criteria specified in 6NYCRR Part 375 Section 1.8(f). The detailed analysis consists of the following components:

- A detailed evaluation of each remedial alternative in relation to the nine evaluation criteria. Community Acceptance is considered a “modifying criterion” and is evaluated after receipt of public comments on the Proposed Remedial Action Plan. Therefore, “Community Acceptance” is not considered in this section.
- A comparative analysis to evaluate the relative performance of each alternative in relation to each other and the evaluation criteria.
- A green and sustainable remediation analysis of selected remedial alternatives to quantitatively address the consumption of natural resources and the environmental burden of the remedial alternatives (see Appendix D).

7.1 Evaluation Criteria

Provisions of the 6NYCRR Part 375 Section 1.8(f) require that each alternative be evaluated under nine criteria. The nine evaluation criteria are described below.

Overall Protection of Human Health and the Environment. Evaluation of the overall protectiveness of an alternative focuses on whether the alternative provides adequate protection and describes how risks associated with the potential site-specific exposure pathways are mitigated through treatment, engineering, and /or institutional controls. Overall protection of human health and the environment draws on the assessments of other evaluation criteria, especially long-term effectiveness and permanence, short-term effectiveness, and compliance with SCGs.

Compliance with SCGs. This evaluation criterion is used to assess whether a remedial alternative will satisfy the standards, criteria, and guidance identified in Section 5.1 of this FS.

Long-Term Effectiveness and Permanence. The long-term effectiveness and permanence criterion addresses the results of a remedial action in terms of the risk remaining at the site after response objectives have been met. Consideration should be given to residual risk remaining from treatment of residuals and/or untreated constituents at the conclusion of remedial activities and the requirement of a five-year review. In addition, the evaluation should include an assessment of the adequacy and reliability of remedial controls, if any, that are used to manage treatment of residues or untreated constituents remaining at the Site. Issues for evaluation are type and degree of long-term management and operations and maintenance (O&M) functions.

Reduction in Mobility, Toxicity, or Volume through Treatment. This criterion addresses the statutory preference for selecting remedial actions that employ treatment technologies that permanently and significantly reduce toxicity, mobility, or volume of the hazardous substances.

Short-Term Effectiveness. This criterion addresses the effects of the remedial alternative on human health and the environment during the construction, implementation, and operational phases of remedial action until response objectives have been met. Consideration is given to protection of the community and workers during construction phases and the effectiveness and reliability of available worker protective measures. Other considerations include the potential short-term adverse environmental impacts that may result from the construction and implementation of an alternative and the time required to complete construction, implementation, and O&M activities to achieve remedial objectives. Estimated remedial time-frames are based on modeling data and calculations, the time required to remediate sites with similar COCs and conditions, COC degradation data, and professional judgment.

Implementability. The implementability criterion addresses the technical and administrative feasibility of implementing an alternative. Factors considered in this evaluation include the following:

- Technical feasibility, including the technical difficulties and unknowns associated with the construction and operation of a technology, the reliability of the technology, the ease of undertaking additional remedial actions, and the ability to monitor the effectiveness of the remedy.
- Administrative feasibility, including the activities needed to coordinate with other agencies and the ability and time required to obtain any necessary approvals and permits from the other agencies (e.g., for off-site actions).
- Availability of services and materials, including the availability of adequate off-site treatment, storage capacity, and disposal services; the availability of necessary equipment and specialists, and provisions to ensure any necessary additional resources; the availability of services and materials; and the availability of prospective technologies.

Cost. Capital costs and O&M costs have been estimated for all of the remedial alternatives. Detailed costs are provided in Appendix E and are summarized in **Table 7-1**. To compare costs of the remedial alternatives, the real 30-year discount rate of 1.4 % was applied, as published in Appendix C of the Office of Management and Budget (OMB) Circular A-94, *Guidance and Discount Rates for Benefit-Cost Analysis of Federal Programs* (December, 2014).

Community Acceptance. Issues and concerns the public may have regarding each of the alternatives fall into this criterion. This criterion will be addressed once comments on the Proposed Plan have been received.

Land Use. The current, intended, and reasonably anticipated future land uses of the site and its surroundings may be considered by NYSDEC in the analysis of alternatives. For the 3800 Area PCE Site, the current and future land use is industrial operations. Since the current and intended future land use for the 3800 Area PCE does not vary based on the remedial alternatives, it will not be discussed in detail for each alternative. Land use is addressed in Section 2.2 of the FS.

7.2 Detailed Analysis of Individual Alternatives

7.2.1 Alternative 1: No Further Action

In this alternative, no further groundwater remediation would be performed, and no institutional controls would be implemented. Any improvement in water quality would be through natural attenuation of the contaminants through physical attenuation processes (advection, dispersion, and dilution). The existing ISCO injection wells and process monitoring wells would be abandoned.

7.2.1.1 Overall Protection of Human Health and the Environment

This alternative would not be effective in protecting human health and the environment. It would provide no administrative system to control the use of contaminated groundwater or monitor plume concentrations and configuration. PCE sorbed to aquifer materials in the presumed source area would continue to serve as a long-term source of CVOCs to the groundwater plume.

7.2.1.2 Compliance with SCGs

There would be no means to monitor the extent of the dissolved groundwater plume; therefore, it is unknown whether potential receptors would be protected, and RAOs would not be met.

7.2.1.3 Long-Term Effectiveness and Permanence

This alternative would not achieve long-term effectiveness or permanence. There would be no use restrictions in place to prevent exposure to contaminated groundwater. There would be no monitoring program in place to assess the extent of the dissolved groundwater plume.

7.2.1.4 Reduction of Toxicity, Mobility, and Volume

This evaluation criterion refers to a reduction in toxicity, mobility, or volume through recovery or treatment. There is no treatment, so the statutory preference for treatment is not a component of this alternative. There would be no documented reduction in toxicity, mobility, or volume of contaminants.

7.2.1.5 Short-Term Effectiveness

Existing injection and monitoring well infrastructure would require abandonment. This activity pose low risk to site workers from groundwater removed from each well, however poses no risk to the community or the environment.

7.2.1.6 Implementability

No permits are required, and there are no administrative controls to implement. This alternative requires abandonment of existing well infrastructure, which poses no technical or administrative challenges.

7.2.1.7 Cost

The costs associated with the No Further Action alternative are provided in **Table 7-1**. Alternative 1 costs are primarily related to abandonment of the existing well infrastructure and preparation of a well abandonment report. The total cost is approximately $72,600.

7.2.2 Alternative 2: In-situ Chemical Oxidation with Monitored Natural Attenuation

This alternative utilizes the existing injection well infrastructure and expands the injection well network to facilitate remediation of the PCE source area. Groundwater in the source area would be remediated through the injection of sodium permanganate. Reduction in mass flux from the source area would enhance the natural attenuation of the CVOC plume by removing a continuing source. Institutional controls would be put in place to prevent use of the groundwater within this aquifer. Long term groundwater monitoring would track natural attenuation and plume configuration following source area remediation.

7.2.2.1 Overall Protection of Human Health and the Environment

Implementation of this alternative is not expected to result in exposure risks to the community, workers, or the environment. PCE concentrations in the source area would be reduced via chemical oxidation and natural attenuation processes. Remediation of the continuing source would result in natural attenuation of the CVOC plume. Groundwater monitoring would be used to assess the achievement of SCGs. Alternative 2 would thereby protect against both current and future exposure to groundwater and would be protective of human health and the environment.

7.2.2.2 Compliance with SCGs

Alternative 2 would reduce PCE concentrations in the source area and achieve the SCGs within a reasonable timeframe. MNA monitoring would be implemented to track the extent of the dissolved phase plume, and to confirm the rate of natural attenuation is sufficient to meet the SCGs within a reasonable timeframe, and confirm RAOs have been met.

7.2.2.3 Long Term Effectiveness and Permanence

With good distribution of the oxidant, ISCO would effectively and permanently reduce the PCE mass in the source area. Additionally, removal of the continuing source would result in a permanent reduction of the PCE plume down-gradient of the source area over time.

7.2.2.4 Reduction of Toxicity, Mobility, and Volume

ISCO, along with natural attenuation, would permanently reduce the mobility, toxicity, and volume of PCE in the dissolved phase groundwater via direct destruction of PCE.

7.2.2.5 Short-Term Effectiveness

Implementation of this alternative would result in minimal exposure risks to the community, workers and the environment. Injection wells would be installed as part of the expanded well network within the source area. Injection of a chemical oxidant (sodium permanganate) would result in minimal risk to site workers, the community and environment. Risks would be controlled with engineering controls. Investigative-derived waste (IDW) from well installation, groundwater sampling, and remedial activities would be handled using approved methods. Potential risks are limited to on-site populations. Active groundwater treatment operations would be performed in less than nine months.

7.2.2.6 Implementability

Implementation of this alternative is both technically and administratively feasible and would not interfere with ongoing operations at Fort Drum. Monitoring or injection wells would be installed using standard drilling methods and materials. These services are readily available, as are the services and materials necessary for the collection and analysis of groundwater samples. The materials required to mix the injection solution are commercially available. The site layout will allow for setup of a temporary injection system that will distribute injection solution and not interfere with ongoing operations with proper coordination. Implementation of this alternative would not limit or interfere with the ability to perform future remedial actions. Institutional controls would be easily implemented.

7.2.2.7 Cost

The costs associated with Alternative 2 are provided in **Table 7-1**. Cost assumptions are included in Appendix E. Capital costs include site mobilization, installation of monitoring and injection wells in the treatment area, and institutional controls. O&M costs include the O&M associated with the oxidant injection, ISCO performance monitoring, and institutional controls. Periodic costs include injection well abandonment. The total active remediation duration for Alternative 2 is estimated to be one year. MNA monitoring duration is assumed to be 16 years.

The total capital costs are estimated to be approximately $174,500 for installation of the active remediation system. ISCO injection costs are estimated to be approximately $766,000. Periodic costs are estimated to be $70,300. MNA groundwater monitoring costs for 16 years are estimated to be $500,700. The total present value cost for this alternative is estimated to be $1,480,100.

7.2.3 Alternative 3: In Situ Enhanced Bioremediation with Monitored Natural Attenuation

This alternative utilizes the existing injection well infrastructure and expands the injection well network to facilitate remediation of the presumed PCE source area. Groundwater in the source area will be remediated through the injection of a carbon substrate (e.g. sodium lactate or EVO) and a bacterial culture suitable for reductively dechlorinating CVOCs. Multiple passive barriers would be established to remediate groundwater passing through each barrier. Reduction in PCE flux from the source area would enhance the natural attenuation of the down-gradient plume by removing a continuing source. Institutional controls would be put in place to prevent use of the groundwater within this aquifer. Long term groundwater monitoring would track natural attenuation and plume configuration following source area remediation.

7.2.3.1 Overall Protection of Human Health and the Environment

Implementation of this alternative is not expected to result in exposure risks to the community, workers, or the environment. PCE concentrations in the source area would be reduced via reductive dechlorination and natural attenuation processes. Remediation of the continuing source would result in faster natural attenuation of the down-gradient PCE plume. MNA monitoring would be used to assess the achievement of SCGs. Alternative 3 would thereby protect against both current and future exposure to groundwater and would be protective of human health and the environment.

7.2.3.2 Compliance with SCGs

Alternative 3 would reduce PCE concentrations in the source area and achieve the SCGs within a reasonable timeframe. MNA monitoring would be implemented to track the extent of the dissolved phase plume, confirm the rate of natural attenuation is sufficient to meet the SCGs within a reasonable timeframe, and confirm RAOs have been met.

7.2.3.3 Long Term Effectiveness and Permanence

With good distribution of the carbon substrate and good survival of the bacterial dechlorinating cultures, ISEB would effectively and permanently reduce the PCE mass in the source area. Additionally, removal of the continuing source would result in a permanent reduction of the PCE plume down-gradient of the source area over time.

7.2.3.4 Reduction of Toxicity, Mobility, and Volume

ISEB, along with natural attenuation, would permanently reduce the mobility, toxicity, and volume of PCE in the dissolved phase groundwater via biological destruction of PCE.

7.2.3.5 Short-Term Effectiveness

Implementation of this alternative would result in minimal exposure risks to the community, workers and the environment. Injection wells would be installed as part of the expanded well network within the source area. Injection of a carbon substrate (e.g., sodium lactate or EVO) would result in minimal risk to site workers, the community and environment. IDW from well installation, groundwater sampling, and remedial activities would be handled using approved methods. Potential risks are limited to on-site populations. If elevated VC, methane, or hydrogen sulfide were detected in groundwater samples collected in the vicinity of Building 1885, indoor air monitoring and/or venting measures may be required to prevent exposure due to vapor intrusion. Active groundwater treatment operations would be completed within approximately four years.

7.2.3.6 Implementability

Implementation of this alternative is both technically and administratively feasible and would not interfere with ongoing operations at Ft Drum. Monitoring and injection wells would be installed using standard drilling methods and materials. These services are readily available, as are the services and materials necessary for the collection and analysis of groundwater samples. The materials required to mix the injection solution are commercially available. The site layout would allow for setup of a temporary injection system that would distribute injection solutions and not interfere with ongoing operations with proper coordination. Implementation of this alternative would not limit or interfere with the ability to perform future remedial actions. Institutional controls would be easily implemented.

7.2.3.7 Cost

The costs associated with Alternative 3 are provided in **Table 7-1**. Cost assumptions are included in Appendix E. Capital costs include site mobilization, installation of monitoring and injection wells in the source area, and institutional controls. O&M costs include the O&M of the injection, long term monitoring, and institutional controls. Periodic costs include well abandonment. The total active remediation duration for Alternative 3 is estimated to be four years. MNA monitoring duration is assumed to be 19 years.

The total capital costs are estimated to be approximately $259,500 for the active remediation system. Annual injection costs are estimated to be approximately

$257,300 during year zero and $177,400 annually for three subsequent years. Periodic costs are estimated to be $70,300. MNA groundwater monitoring costs for 19 years are estimated to be $563,500. The total present value cost for this alternative is estimated to be $1,682,900.

7.2.4 Alternative 4: Air Sparge / Soil Vapor Extraction with Monitored Natural Attenuation

Alternative 4 requires the installation of new well infrastructure for both the AS and SVE systems. The existing injection wells can be used as monitoring locations, but not as remediation wells because they are not constructed at the appropriate depths. Groundwater in the source area would be remediated through the injection of ambient air to volatilize the PCE and be recovered by the SVE system. Reduction in mass flux from the source area would enhance the natural attenuation of the down-gradient PCE plume by removing a continuing source. Institutional controls would be put in place to prevent use of the groundwater within this aquifer. Long term groundwater monitoring would track natural attenuation and plume configuration following source area remediation.

7.2.4.1 Overall Protection of Human Health and the Environment

Implementation of this alternative is not expected to result in exposure risks to the community, workers, or the environment. PCE concentrations in the source area would be reduced via volatilization and natural attenuation processes. Remediation of the continuing source would result in natural attenuation of the down-gradient plume. Groundwater monitoring would be used to assess the achievement of SCGs. Alternative 4 would thereby protect against both current and future exposure to groundwater and would be protective of human health and the environment.

7.2.4.2 Compliance with SCGs

Alternative 4 would reduce PCE concentrations in the source area and achieve the SCGs within a reasonable timeframe. MNA monitoring would be implemented to track the extent of the dissolved phase plume, confirm the rate of natural attenuation is sufficient to meet the SCGs within a reasonable timeframe, and confirm RAOs have been met.

7.2.4.3 Long Term Effectiveness and Permanence

With good distribution of sparged air, Alternative 4 would result in the volatilization and subsequent extraction of PCE, effectively and permanently reduce the PCE mass in the source area. Additionally, removal of the continuing source would result in a permanent reduction of the PCE plume down-gradient of the source area over time.

7.2.4.4 Reduction of Toxicity, Mobility, and Volume

AS/SVE, along with natural attenuation, would permanently reduce the mobility, toxicity, and volume of PCE in the dissolved phase groundwater via removal of PCE.

7.2.4.5 Short-Term Effectiveness

Implementation of this alternative would result in minimal exposure risks to the community, workers and the environment. AS and SVE wells would be installed as part of the expanded well network within the source area. Installation of the remediation system poses low to moderate risk to site workers due to the installation of piping below grade as well as noise and equipment hazards associated with the equipment needed to install the conveyance piping. Operation of the remediation system would result in low risk to site workers due to noise hazards, but no risk to the community and environment. IDW from wells installation, groundwater sampling, and remedial activities would be handled using approved methods. Potential risks are limited to on-site populations. Active groundwater treatment operations would be completed within approximately two years.

7.2.4.6 Implementability

Implementation of this alternative is both technically and administratively feasible; however, it could interfere with ongoing operations around the Site buildings. AS and SVE wells would be installed using standard drilling methods and materials. These services are readily available, as are the services and materials necessary for the collection and analysis of groundwater samples. Extensive trenching and pipe installation would be required across the source area. This trenching would impact site operations and require significant lengths of open trench to connect all the remediation wells to the remediation system. The site layout would allow for installation of a permanent equipment building to house the remediation system. Because of the extensive sub-surface piping, implementation of this alternative would limit the ability to perform future remedial actions without first decommissioning the remediation system. Institutional controls would be easily implemented.

7.2.4.7 Cost

The costs associated with Alternative 4 are provided in **Table 7-1**. Cost assumptions are included in Appendix E. Capital costs include site mobilization, installation of AS and SVE wells in the source area, installation of conveyance piping, installation of the remediation system, and institutional controls. O&M costs include the O&M of the AS/SVE system, long term monitoring, and institutional controls. Periodic costs include system and well abandonment. The total active remediation duration for Alternative 4 is estimated to be two years. MNA monitoring duration is assumed to be 17 years.

The total capital costs are estimated to be approximately $2,123,900 for the active remediation systems. Annual O&M costs are estimated to be approximately $174,600. Periodic costs are estimated to be $117,180. MNA groundwater monitoring costs for 17 years are estimated to be $521,600. The total present value cost for this alternative is estimated to be $3,111,800.

7.3 Comparative Analysis of Alternatives

The purpose of the comparative analysis of alternatives is to evaluate the relative performance of each alternative against the evaluation criteria. A summary of the four remedial alternatives relative to the evaluation criteria (with the exception of costs, which are shown on **Table 7-1**) is presented in **Table 7-2**.

7.3.1 Overall Protection of Human Health and the Environment

Besides Alternative 1, all alternatives achieve the RAOs and provide overall protection of human health and the environment in the long term. Alternatives 2 through 4 include source area treatment via in situ chemical, biological, or physically extractive means at the presumed PCE source area.

7.3.2 Compliance with SCGs

Alternatives 2 through 4 would all be expected to comply with the SCGs within a reasonable timeframe. Active remediation time-frame varies with each alternative but is anticipated between 1 and 4 years. Following active remediation, continued monitoring would be required before the Site meets the SCGs; however, further contribution to the down-gradient dissolved phase plume would be greatly reduced, which would facilitate natural attenuation (primarily via non-biological mechanisms) of the down-gradient plume. Alternative 1 would not comply with the SCGs within a reasonable timeframe.

7.3.3 Long-Term Effectiveness and Permanence

With the exception of Alternative 1, all remaining alternatives provide long term effectiveness and permanence. Alternatives 2, 3, and 4 would result in the removal or destruction of PCE in the source area and would prevent further migration down-gradient.

7.3.4 Reduction of Toxicity, Mobility, and Volume

Alternative 1 provides no reduction in toxicity, mobility or volume.

Alternative 2 immediately (within months) reduces the volume, mobility and toxicity of PCE via the injection of an oxidant. Alternative 2 would provide rapid treatment of PCE and would result in the quickest reduction in PCE concentrations. The longevity of the selected oxidant (sodium permanganate) will provide longer active treatment than other oxidants which will result in more efficient treatment of PCE as it back diffuses to mobile pore spaces due to concentration gradients generated by the oxidant. This would reduce the likelihood of rebound of PCE due to back diffusion from immobile pore spaces. Increased solubility (and mobility) of some metals, such as cadmium, chromium, lead, and arsenic, can be expected within the source zone due to the oxidation and low pH effects resulting from the chemical reactions. These constituents would be expected to precipitate as the pH neutralizes (returns to background) outside the treatment zone.

Alternative 3 provides the slowest reduction in volume, mobility and toxicity as it first requires the development of an active biological population. There is no evidence of natural degradation of the PCE to TCE or other daughter products and the aquifer environment is aerobic and lacking in organic carbon. This alternative would require changing the natural aquifer environment which creates additional challenges, but also requires significantly more time to observe measureable remedial benefit. In addition, Alternative 3 results in intermediate degradation products (TCE, cis-DCE and VC) that could result in minor down-gradient impacts of these compounds and potentially increase overall toxicity. Additionally, production of VC, methane, and/or hydrogen sulfide could potentially raise vapor intrusion concerns for Building 1885. Increased solubility (and mobility) of some metals, such as iron, lead, and arsenic, can be expected within the source zone due to the reduced biogeochemical conditions. These constituents would be expected to precipitate as the aquifer becomes aerobic and oxidizing outside the treatment zone.

Alternative 4 would provide immediate recovery of PCE and reduce down-gradient migration, which would reduce the volume, mobility and toxicity of the source area. Because PCE, and to a lesser degree TCE, are not aerobically biodegradable, no remedial benefit is realized with the increased dissolved oxygen present in the source area. AS wells must be installed deeper than the target interval to effectively treat the target interval and would therefore have to be installed deeper than the injection wells in Alternatives 2 and 3. The hydraulic conductivity in the source area appears to decrease with depth, which potentially creates a challenging environment to inject and distribute sufficient air to volatilize dissolved phase CVOCs. Similar to Alternative 2, PCE is also subject to rebound via back diffusion as the air only contacts dissolved phase CVOCs in the mobile pore spaces.

7.3.5 Short-Term Effectiveness

Alternative 1 would involve no activities that present short-term exposure risks to human health or the environment. Implementation of Alternative 2 or 3 would result in minimal exposure risks to the community, workers, and the environment through the installation of monitoring wells and injection of reagents. Alternative 4 would subject the community and the environment to minimal risk through the installation of AS and SVE wells. There are no known impacts to shallow soil; however, the increased number of well installations and complexity of the construction activities (trenching, pipe installation, equipment installation) pose an increased risk to workers. Alternative 2 meets the remedial response objectives the quickest (within 6 months). The remedial response objective for Alternative 4 should be met within 2 years and Alternative 3 within 4 years.

7.3.6 Implementability

Alternative 1 is not administratively feasible due to the lack of monitoring or protection of human health and the environment. All remaining alternatives are technically and administratively feasible with Alternative 4 being the most difficult to implement both technically and administratively. Alternatives 2 and 3 are more implementable due to the ability to utilize existing infrastructure, minimal installation of new wells, and no permanent above ground or below ground infrastructure (other than the injection wells). Alternatives 2 and 3 are comparable and would not interfere or would minimally interfere with ongoing operations. The air sparge wells for Alternative 4 require installation into a deeper interval that may be less amenable to injection and would either limit treatment, or would require a denser well network to achieve treatment. Installation of the infrastructure associated with Alternative 4 would create the most disruption to the ongoing operations in and around the nearby buildings.

7.3.7 Cost

The costs associated with Alternatives 1, 2, 3, and 4 are provided in **Table 7-1**. The costs associated with Alternative 1 include only abandoning the existing injection and monitor well infrastructure. The cost for abandoning the wells is estimated to be $72,600. Of the remaining alternatives, Alternative 2 has the lowest present value cost of $1,511,600 and Alternative 4 has the highest present value cost of $3,111,800. The remedial timeframes for each alternative, excluding Alternative 1, are reasonable.

7.4 Green and Sustainable Remediation Analysis

A quantitative sustainability assessment was conducted for Alternatives 2, 3, and 4. The quantitative assessment was performed using the ARCADIS sustainability tool, BalancE3™. The analysis addresses the criteria identified in DER-31 through the evaluation of five commonly accepted metrics: 1) energy usage, 2) air emissions, 3) water consumption and impacts, 4) material consumption and waste generation, and 5) land impacts. The methodology for the analysis and the detailed calculations and results are provided in Appendix D. In summary, the comparative sustainability analysis of Alternatives 2, 3, and 4 indicates that Alternative 2 is the most sustainable of the alternatives considered. Alternative 2 has both the lowest energy use and the lowest air emissions. Alternative 2 also has the lowest material consumption and waste generation of the alternatives considered. Because of the extra three years of injections, Alternative 3 is less sustainable than Alternative 2 in all categories evaluated. Due to the continuous system operations associated with Alternative 4, the only sustainability criterion where Alternative 4 is more sustainable than Alternatives 2 and 3 is the Water Consumption and Impacts criterion. The environmental impacts associated with the alternatives are directly affected by the impacts generated during the remedy implementation, energy requirements for the operation of the remedies, and remedy time frame. Alternative 2 presents the lowest energy, air emission, and waste generation, as a result of the reduced equipment operation and the use of the existing remedy infrastructure.

7.5 Preferred Alternative

Based on the comparative analysis of alternatives discussed above, Alternative 2 is the preferred alternative because it achieves the RAO for groundwater while balancing short-term effectiveness, implementability, and cost. Alternative 2 would also best meet the intent of the NYSDEC Program Policy for Green Remediation (DER-31), as it treats the groundwater contamination in-situ, minimizes waste generation, and does not require much energy usage.

8. References

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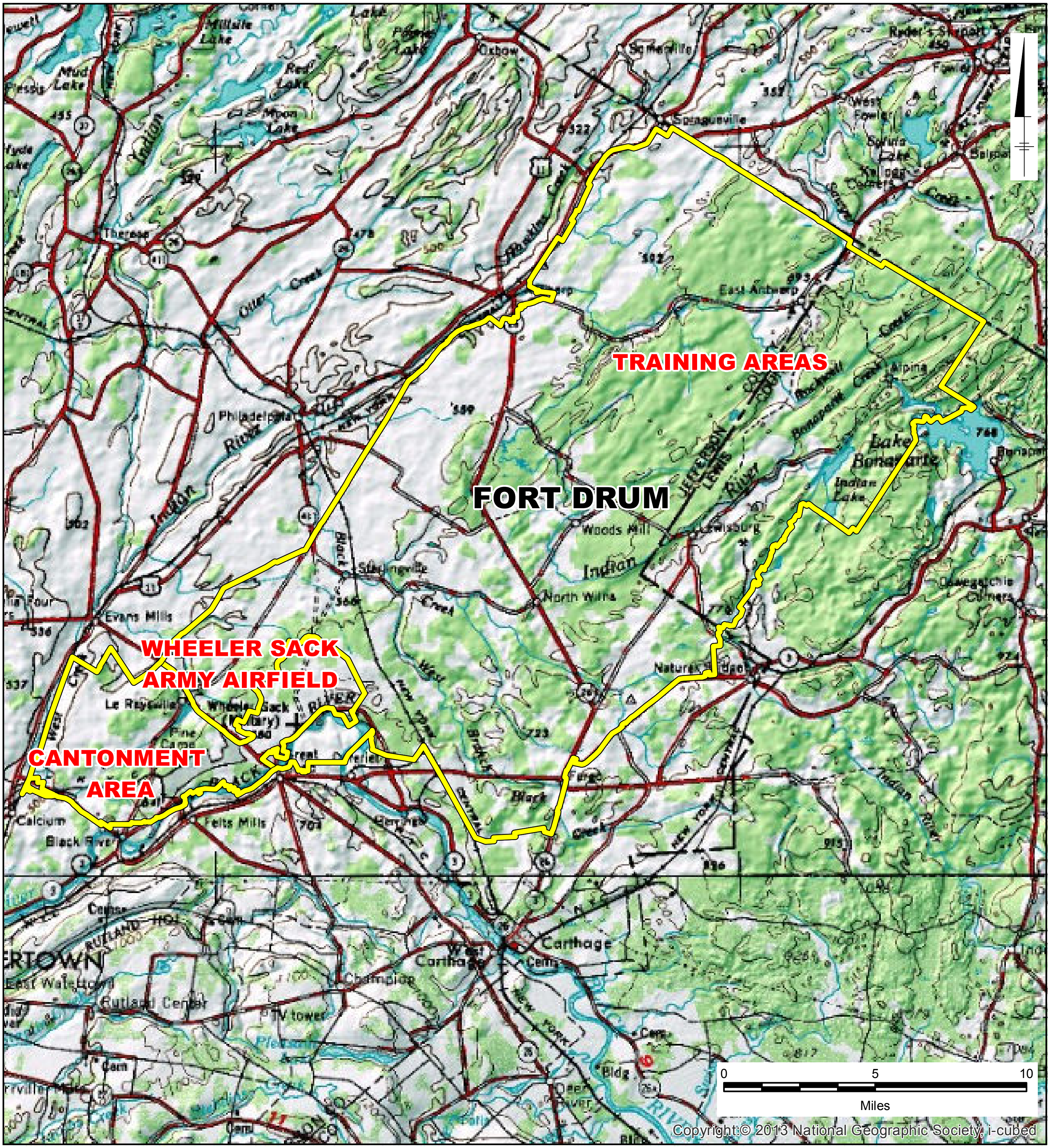
Figures



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FORT DRUM
FORT DRUM, NEW YORK

FEASIBILITY STUDY, 3800 AREA PCE SITE

SITE LOCATION MAP

FIGURE
2-1

CITY: MPLS DIV/GROUP: IM DB: MG LD: CK MADISON-KIPP
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FORT DRUM
FORT DRUM, NEW YORK

FEASIBILITY STUDY, 3800 AREA PCE SITE

3800 AREA PCE SITE AND VICINITY

FIGURE
2-2

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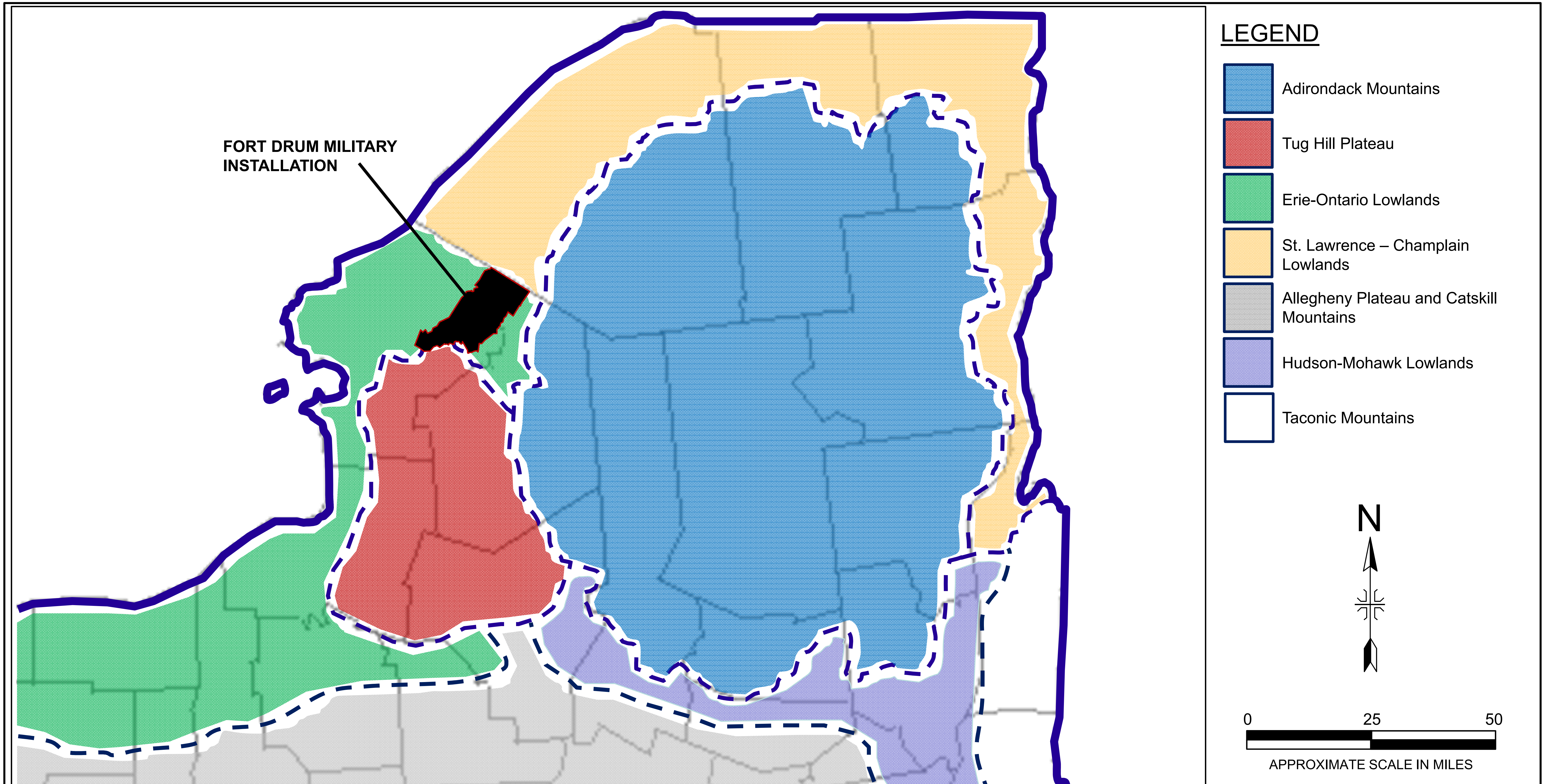
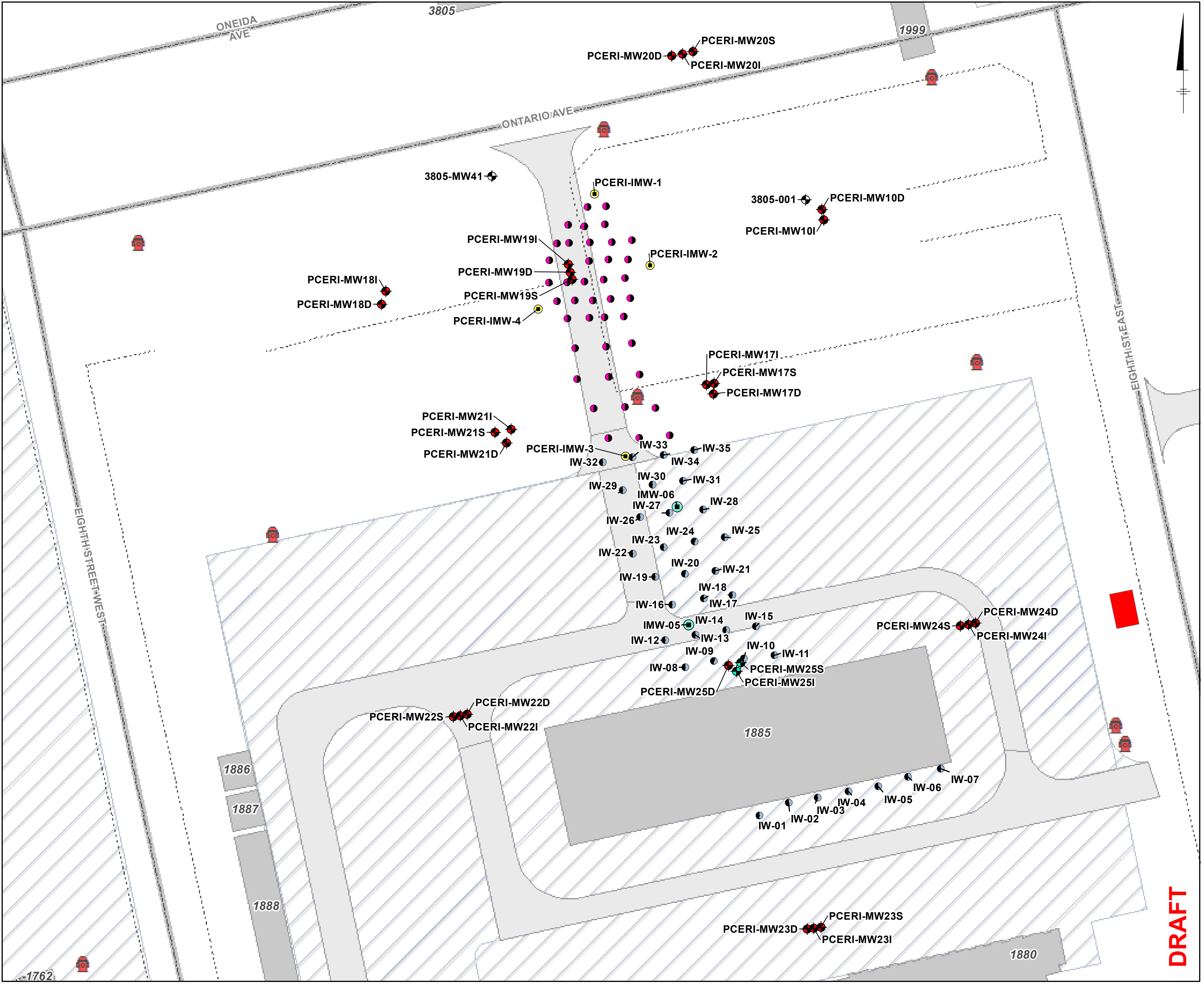


OASIS FUEL POINT - WHEELER SACK ARMY AIRFIELD
FORT DRUM, NEW YORK
Remedial Action Selection Report

Generalized Physiographic Regions of New York State

PIKA International, Inc.
MALCOLM PIRNIE
A JOINT VENTURE

2-3
FIGURE



LEGEND

- ● 2012 ISCO PILOT DOSE-RESPONSE WELLS
- ● 2012 ISCO PILOT INJECTION WELLS
- ● PROPOSED ISCO DOSE-RESPONSE WELLS
- ◐ PROPOSED ISCO INJECTION WELLS
- ⊕ PROPOSED ISCO-DOSE RESPONSE WELLS AND PCE SITE RI MONITORING WELLS
- ⊕ MONITORING WELL
- ⊕ PCE SITE RI MONITORING WELL
- 🟥 PROPOSED INJECTION MIXING EQUIPMENT LOCATION
- HYDRANT
- ----- FENCE LINE
- ROAD CENTERLINE
- ▨ BUILDING
- ▨ PARKING

0 80 160

GRAPHIC SCALE

FORT DRUM
FORT DRUM, NEW YORK

FEASIBILITY STUDY, 3800 AREA PCE SITE

INITIAL AND PLANNED PILOT STUDY LAYOUTS

PIKA INTERNATIONAL, INC. MALCOLM PIRNIE A JOINT VENTURE

FIGURE
2-4

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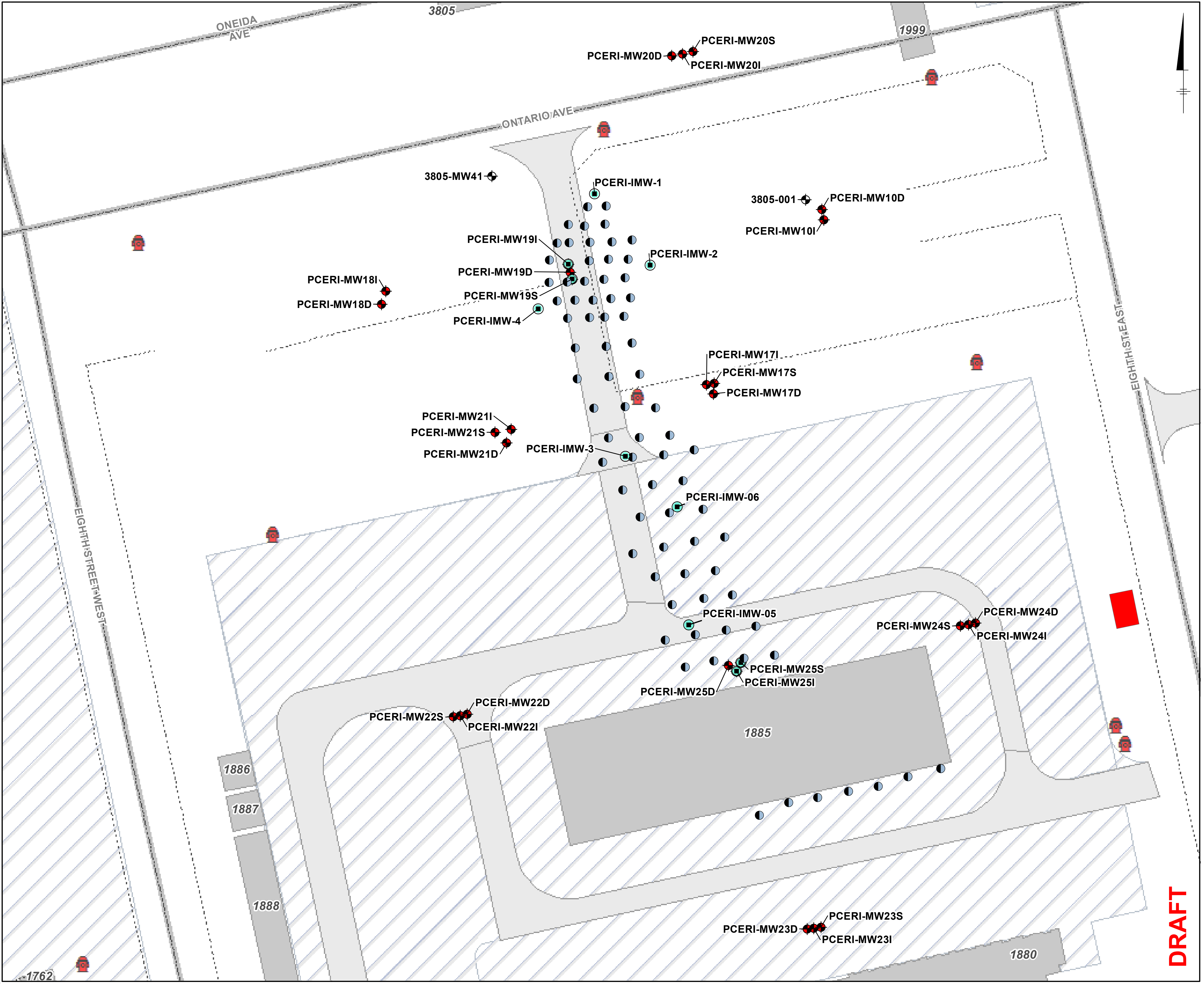

LEGEND

- ● ISCO DOSE-RESPONSE WELLS
- ◐ ISCO INJECTION WELLS
- ⊕ MONITORING WELL
- ⊕ PCE SITE RI MONITORING WELL
- 🟥 PROPOSED INJECTION MIXING EQUIPMENT LOCATION
- HYDRANT
- ------- FENCE LINE
- ROAD CENTERLINE
- ▨ BUILDING
- ▨ PARKING AREA

NOTE:
Up to 15 new ISCO injection wells would be installed to optimize oxidant distribution, if needed, based on the results of the planned ISCO pilot study.

0 80 160
GRAPHIC SCALE

FORT DRUM
FORT DRUM, NEW YORK

FEASIBILITY STUDY, 3800 AREA PCE SITE

ALTERNATIVE 2
ISCO WITH PERMANGANATE

PIKA INTERNATIONAL, INC. | MALCOLM PIRNIE
A JOINT VENTURE

FIGURE
6-1

CITY:(CHARLOTTE) DIV/GROUP:(ENV/GIS) DB: ssutton LD: S.SUTTON PIC: PM: TM: DATE SAVED: 3/4/2015 3:17:45 PM Last Saved By: ssutton
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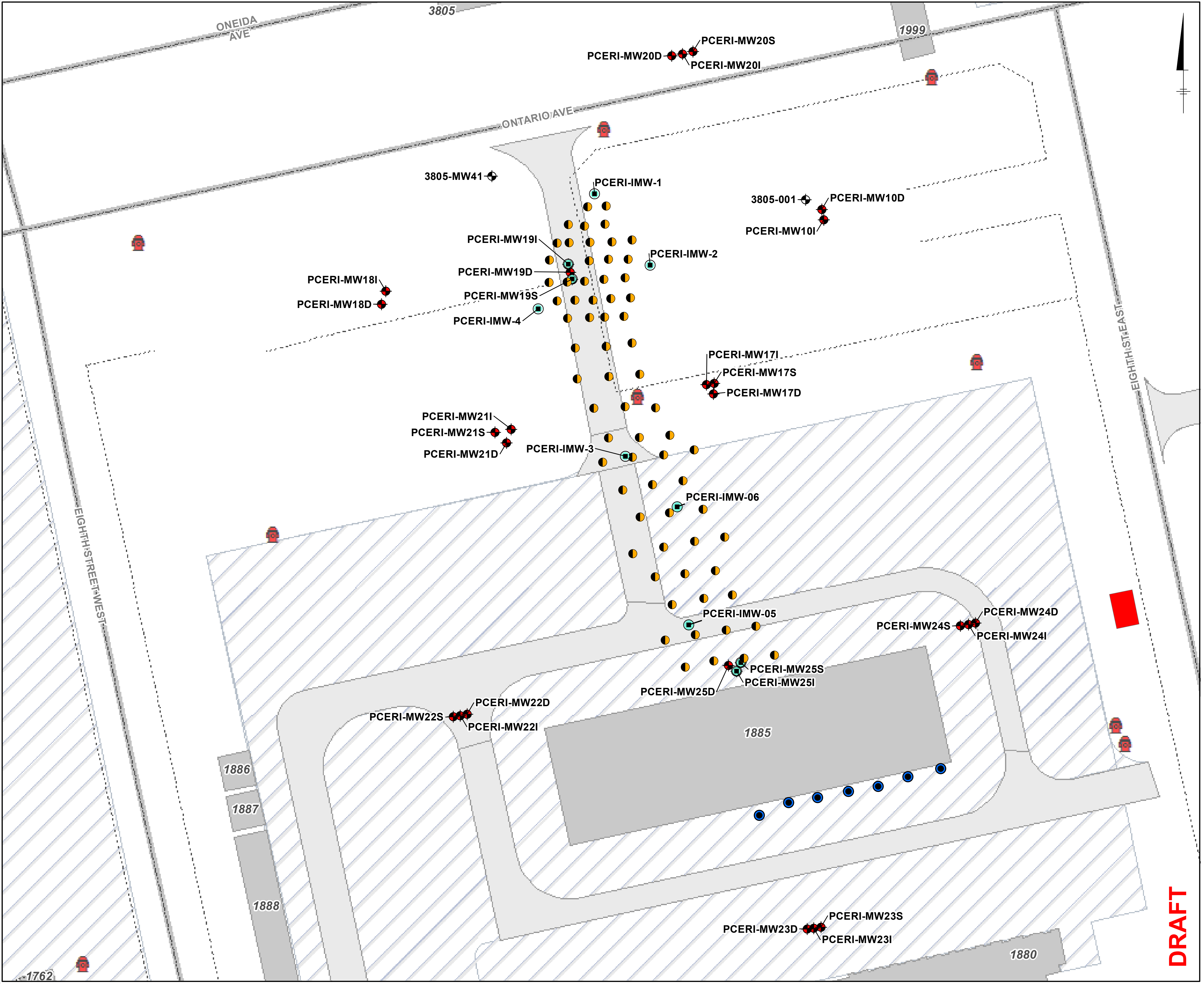

LEGEND

- ● ISEB PERFORMANCE MONITORING WELLS
- ◐ SODIUM LACTATE AND EMULSIFIED VEGETABLE OIL INJECTION POINTS
- ● SODIUM LACTATE INJECTION POINTS
- ⊕ MONITORING WELL
- ⊕ PCE SITE RI MONITORING WELL
- 🟥 PROPOSED INJECTION MIXING EQUIPMENT LOCATION
- HYDRANT
- ----- FENCE LINE
- ROAD CENTERLINE
- ▨ BUILDING
- ▨ PARKING AREA

NOTE:
Up to 15 new ISEB injection wells would be installed during active remedy iplementation, if needed, to optimize carbon substrate distribution.

0 80 160
GRAPHIC SCALE

FORT DRUM
FORT DRUM, NEW YORK

FEASIBILITY STUDY, 3800 AREA PCE SITE

ALTERNATIVE 3
IN SITU ENHANCED BIOREMEDIATION

PIKA INTERNATIONAL, INC.
A JOINT VENTURE
MALCOLM PIRNIE

FIGURE
6-2

CITY:(CHARLOTTE) DIV/GROUP:(ENV/GIS) DB: ssutton LD: S.SUTTON PIC: PM: TM: DATE SAVED: 3/4/2015 4:21:10 PM
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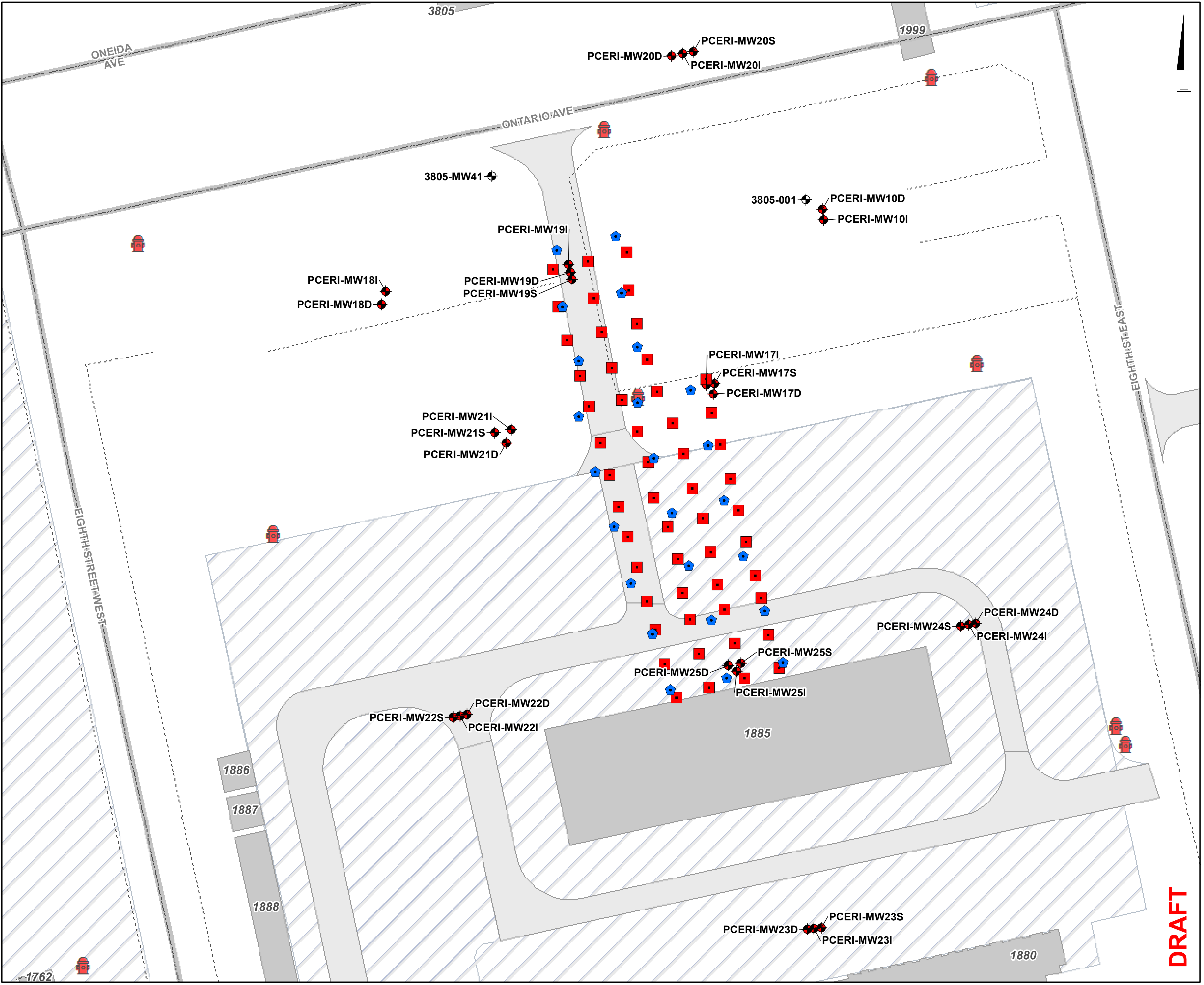


FORT DRUM
FORT DRUM, NEW YORK

FEASIBILITY STUDY, 3800 AREA PCE SITE

ALTERNATIVE 4
AIR SPARGING
WITH SOIL VAPOR EXTRACTION

PIKA INTERNATIONAL, INC.
MALCOLM PIRNIE
A JOINT VENTURE

FIGURE
6-3

Tables

TABLE 5-1
INITIAL TECHNOLOGY SCREENING FOR TECHNICAL IMPLEMENTABILITY
Feasibility Study
3800 Area PCE Site
Fort Drum, New York

General Response Action	Technology Class	Process Option	Brief Description	Screening Action		Screening Comments
				Retain	Reject	
No Further Action	None	Not applicable	No further remedial actions.	X		Retain as a baseline alternative
Institutional Controls and Monitoring	Administrative Restrictions	Groundwater use restrictions and monitoring to verify plume configuration	Restrictions placed on installation of new supply wells and usage of existing groundwater supply wells.	X		Technically feasible. Water supply wells maintained by Fort Drum.
Engineering Controls	Elimination of potential exposure pathways	Provision of alternative water supply	In cases where site water is used for consumptive purposes, provision of an alternative water supply.		X	Not applicable, since Site groundwater is not used for consumptive purposes.
		Building ventilation system	Building ventilation in cases where vapor intrusion is occurring.		X	Not applicable, as indoor air monitoring demonstrated that CVOCs are not present in buildings at the Site.
Monitoring	Groundwater monitoring	Sampling	Sampling to measure concentrations of contaminants of concern in groundwater	X		Monitoring will be a component of each alternative (with the exception of the No Further Action alternative)

TABLE 5-1
INITIAL TECHNOLOGY SCREENING FOR TECHNICAL IMPLEMENTABILITY
Feasibility Study
3800 Area PCE Site
Fort Drum, New York

General Response Action	Technology Class	Process Option	Brief Description	Screening Action		Screening Comments
				Retain	Reject	
Monitored Natural Attenuation	Natural Attenuation via Dilution, Adsorption, Dispersion, Biodegradation	Groundwater monitoring with analysis of biological and chemical indicators of attenuation processes	Establish a monitoring network and monitor contaminant concentrations and indicators of attenuation processes	X		Aquifer geochemical conditions are not conducive to biodegradation processes for CVOCs. However, MNA monitoring is retained to evaluate attenuation via non-biological degradation mechanisms.
In Situ Treatment	Biological Treatment	In Situ Enhanced Bioremediation (biostimulation only)	Injection of carbon substrate to promote anaerobic conditions and foster growth of dechlorinating bacteria.		X	A bench study conducted during the RI demonstrated that biostimulation via addition of a carbon substrate was not sufficient to promote degradation of PCE.
		In Situ Enhanced Bioremediation (biostimulation and bioaugmentation)	Injection of a microbial culture known to perform complete dechlorination of targeted compounds	X		A bench study conducted during the RI demonstrated that biostimulation with bioaugmentation is a promising technology to achieve reduction of PCE concentrations in Site groundwater.
	In Situ Chemical Oxidation	Permanganate	Injection of sodium permanganate or potassium permanganate.	X		A bench study conducted during the RI, as well as a field pilot study, have demonstrated that ISCO with permanganate is a promising technology to achieve reduction of PCE concentrations in Site groundwater.

TABLE 5-1
INITIAL TECHNOLOGY SCREENING FOR TECHNICAL IMPLEMENTABILITY
Feasibility Study
3800 Area PCE Site
Fort Drum, New York

General Response Action	Technology Class	Process Option	Brief Description	Screening Action		Screening Comments
				Retain	Reject	
		Catalyzed hydrogen peroxide (CHP)	Injection of hydrogen peroxide and a catalyst (typically ferrous sulfate) to produce hydroxyl free radicals.		X	CHP is better-suited to sites with DNAPL and/or significant sorbed contaminant mass.
		Activated persulfate	Injection of persulfate into subsurface. The persulfate is activated via addition of a base, addition of a ferrous salt, or addition of heat to produce the sulfate free radical.	X		Potentially technically feasible.
	Enhanced Desorption and Treatment	Air sparging (AS) with soil vapor extraction (SVE)	Inject air into aquifer to gasify volatile contaminants and mobilize gas phase from groundwater to surface. May need additional gas phase treatment at surface.	X		AS/SVE has been used successfully at many sites to treat CVOCs. It is potentially feasible at the 3800 Area PCE Site, where the geology consists primarily of sand and silty sand.

TABLE 5-1
INITIAL TECHNOLOGY SCREENING FOR TECHNICAL IMPLEMENTABILITY
Feasibility Study
3800 Area PCE Site
Fort Drum, New York

General Response Action	Technology Class	Process Option	Brief Description	Screening Action		Screening Comments
				Retain	Reject	
	Thermal treatment	Steam Enhanced Extraction (SEE)	Combination of steam injection and vacuum extraction		X	Of all the thermal treatment technologies, SEE is best suited to the sandy, permeable geology encountered in the shallow and upper intermediate hydrostratigraphic zones at the Site. However, thermal technologies are energy-intensive and are most applicable to Sites where non-aqueous phase liquid and/or significant source mass exists. This is not the case at the 3800 Area PCE Site.
		Electrical Resistance Heating (ERH)	Uses application of 3- or 6-phase electrical power and resistivity of soil particles to heat subsurface		X	ERH is primarily used at Sites with lower permeability geologies (i.e., clays) and where non-aqueous phase liquid and/or significant source mass exists. This is not the case at the 3800 Area PCE Site where the continual flux of cold water into the treatment area would reduce the effectiveness of ERH, and where no significant source mass has been identified.

TABLE 5-1
INITIAL TECHNOLOGY SCREENING FOR TECHNICAL IMPLEMENTABILITY
Feasibility Study
3800 Area PCE Site
Fort Drum, New York

General Response Action	Technology Class	Process Option	Brief Description	Screening Action		Screening Comments
				Retain	Reject	
	Permeable Reactive Barriers	Zero-Valent Iron (ZVI)	Emplace zero-valent iron into the aquifer perpendicular to groundwater flow		X	Not technically feasible. A ZVI barrier would need to be keyed into the clay confining unit, which occurs at 70 to 80 feet bgs. It is not feasible to emplace zero-valent iron to a depth of approximately 70 to 80 feet bgs without significant disruption to site operations.
		Nano-Scale Zero-Valent Iron (NZVI)	Inject NZVI into vertical wells to form a barrier.		X	Not technically feasible. Results of the bench study conducted during the RI indicated that a fairly high dosage of NZVI is needed to successfully treat PCE. Distribution of NZVI via injection, particularly into silty sands, is not technically feasible.
Extraction / Removal	Groundwater extraction	Vertical extraction wells	Single or multiple vertical wells to extract groundwater using pumps. Typically followed by ex-situ treatment and disposal	X		Potentially technically feasible. Technology could be applied in presumed PCE source area or in downgradient plume area to remove and treat dissolved COCs.

TABLE 5-1
INITIAL TECHNOLOGY SCREENING FOR TECHNICAL IMPLEMENTABILITY
Feasibility Study
3800 Area PCE Site
Fort Drum, New York

General Response Action	Technology Class	Process Option	Brief Description	Screening Action		Screening Comments
				Retain	Reject	
		Interceptor trenches	Groundwater collection in a closed, permeable trench from which groundwater is extracted using pumps		X	Not technically feasible due to the depth of groundwater at which PCE is detected (i.e., greater than 40 feet bgs)
Ex Situ Treatment	Biological Treatment	Anaerobic bioreactor	Degradation of organics using microorganisms in an anaerobic environment	X		Potentially technically feasible for the COCs encountered at the PCE Site.
	Physical /Chemical Treatment	Carbon adsorption	Adsorption of contaminants onto activated carbon by passing water through granular activated carbon column	X		Potentially technically feasible. Typically used as a polishing step following other treatment technologies.
		Chemical / UV oxidation	Chemical oxidation with or without enhancement with ultraviolet radiation	X		Technically feasible. Effective on a wide variety of organic compounds including CVOCs.
		Air stripping	Aerate water to induce volatilization of contaminants in a packed column	X		Technically feasible for the VOCs encountered at the PCE Site.

TABLE 5-1
INITIAL TECHNOLOGY SCREENING FOR TECHNICAL IMPLEMENTABILITY
Feasibility Study
3800 Area PCE Site
Fort Drum, New York

General Response Action	Technology Class	Process Option	Brief Description	Screening Action		Screening Comments
				Retain	Reject	
Groundwater Disposal	Off-Site Treatment and Disposal	POTW	Extracted groundwater discharged to local POTW for treatment		X	Not technically feasible, as it is unlikely that a POTW would accept untreated groundwater containing CVOC concentrations encountered in Site groundwater.
		RCRA TSDF	Extracted groundwater transported to licensed RCRA facility for treatment and/or disposal		X	Not technically feasible to transport the high volumes of water likely to be generated over time for an extraction remedy.
	Discharge of water treated on-Site	Discharge to POTW	Treated water discharged to local POTW	X		Technically feasible, as treated water from the existing groundwater treatment systems is currently discharged to a POTW.
		Discharge to surface water	Discharge to nearby surface water body.	X		Potentially technically feasible if meeting discharge criteria (water quality and volume criteria) and obtain a SPDES permit.
		Infiltration Basin or Gallery	Treated water discharged to on-site infiltration basin or gallery	X		Potentially technically feasible to construct a basin or gallery near the 3800 Area PCE Site.
		Deep well injection	Injection of treated water at the site via deep injection wells		X	Not technically feasible, as it is challenging to permit a deep well, and there may be permeability limitations at depth.

TABLE 5-2
EVALUATION OF TECHNOLOGIES AND PROCESS OPTIONS
3800 Area PCE Site
Fort Drum, New York

General Response Action	Technology Class	Process Option	Description/Definition	Effectiveness	Implementability	Relative Cost	Evaluation Action	
							Retain	Reject
No Action	None	None	Not applicable	- Not effective in reducing contamination. - Does not meet RAOs.	- Involves decommissioning and removal of existing injection wells from pilot study activities - Easily implemented.	Low capital. No O&M	X	
Institutional Controls	Administrative Restrictions	Groundwater use restrictions	- Restrictions placed on installation of groundwater supply wells	- Effectiveness depends on continued implementation. - Does not reduce contamination.	- Requires NYSDEC approval. - May be used in conjunction with other technologies.	Low capital No O&M	X	
Long-Term Monitoring	Groundwater monitoring	Sampling	- Sampling to measure concentrations of COCs in groundwater	- Effective in providing data regarding COCs in groundwater to monitor effectiveness of remedies. - Does not reduce contamination	- Easily implemented - Typically used in conjunction with other technologies	Low capital Moderate O&M	X	
Monitored Natural Attenuation	Natural attenuation via dilution, adsorption, dispersion, biodegradation	Groundwater monitoring with analysis of biological and chemical indicators of attenuation processes	- Establish a monitoring network and monitor contaminants concentrations and indicators of attenuation processes	- Most effective in combination with source removal / reduction. - Does not meet the RAO of removing PCE from the presumed source area to the extent practicable. - MNA via biodegradation is not proceeding at an acceptable rate to achieve groundwater RAOs within a reasonable time-frame.	- Easily implemented. - May be used as a stand-alone technology, or applied as a polishing technology after completion of active treatment. - Typically has a long period of performance.	Low capital, Moderate O&M	X (retain as secondary groundwater technology following source removal)	
In Situ Treatment	Biological Treatment	In Situ Enhanced Bioremediation (biostimulation and bioaugmentation)	- Injection of a microbial culture (either non-native, or enriched native culture) known to perform complete dechlorination of targeted compounds - Bioaugmentation may be used at a site when the presence of an appropriate population of microbial dechlorinators is not present, or does not exist in sufficient numbers to achieve remediation criteria in a reasonable time frame - Typically performed in concert with addition of carbon substrate (i.e., biostimulation)	- This technology was proven effective at the bench-scale during the RI. Field-scale effectiveness depends on how well the bacterial cultures adapt and grow. The geochemistry within the areas where bacterial cultures will be applied must first be pre-conditioned, typically via addition of carbon substrate(s), to ensure that conditions are optimal for dechlorinating bacteria. This technology has been shown to be effective at many other sites.	- Implementability is dependent on the ability to achieve optimal geochemistry via distribution of carbon substrate and then on ability to distribute the bacterial cultures. - Adequate flushing must be performed after addition of carbon substrate and bacterial cultures to prevent fouling of injection wells. - There is an additional cost at the outset to develop appropriate site-specific cultures, and the time period for this work is typically 4 to 8 months. However, overall cost increase is typically not	Moderate capital cost Moderate O&M cost	X	

TABLE 5-2
EVALUATION OF TECHNOLOGIES AND PROCESS OPTIONS
3800 Area PCE Site
Fort Drum, New York

General Response Action	Technology Class	Process Option	Description/Definition	Effectiveness	Implementability	Relative Cost	Evaluation Action	
							Retain	Reject
					significant when compared to overall project costs for biostimulation alone. - Typically requires multiple applications, or injection events (e.g., quarterly or semi-annually).			
	In Situ Chemical Oxidation	Permanganate (potassium or sodium)	- Injection of sodium permanganate or potassium permanganate. - Delivery methods include direct injection and oxidant recirculation. - Results in direct oxidation of organic contaminants.	- Bench-scale study during the RI demonstrated that permanganate was effective at reducing PCE concentrations in groundwater and soil samples collected from the Site. - Field-scale effectiveness of ISCO depends on the ability to distribute the permanganate such that it physically contacts the chlorinated ethenes in order for the oxidation reactions to occur. - Given the generally permeable nature of the sands at the presumed PCE source area, permanganate distribution should be achievable. Permanganate distribution at the Site could be adversely affected by lower permeabilities in deeper portions of the presumed source area. - Given permanganate's longevity (typically on the order of weeks), some degree of diffusion may be achieved in the lower K portions of the presumed source area (i.e., deeper than approximately 45 feet bgs).	- ISCO with permanganate is a proven technology that has been used at many sites to remediate chlorinated ethenes. - ISCO involves installation of multiple injection wells, and typically requires a series of injection events to reduce contaminant concentrations to desired levels.	Medium capital cost and medium O&M cost (cost increases when multiple treatments are required)	X	

TABLE 5-2
EVALUATION OF TECHNOLOGIES AND PROCESS OPTIONS
3800 Area PCE Site
Fort Drum, New York

General Response Action	Technology Class	Process Option	Description/Definition	Effectiveness	Implementability	Relative Cost	Evaluation Action	
							Retain	Reject
		Activated persulfate	- Involves injection of persulfate into the subsurface. The persulfate would be activated to produce the sulfate free radicals. Persulfate can be activated via addition of a base, addition of a ferrous salt, or addition of heat. - Results in direct oxidation of organic contaminants - Delivery method is typically direct injection	- The effectiveness of ISCO depends on the ability to distribute the activated persulfate such that it physically contacts the organic contaminants in order for the oxidation reactions to occur. - Given the generally permeable nature of the sands at the presumed PCE source area, activated persulfate distribution should be achievable, with the potential exception of the deeper (i.e., approximately 45 feet bgs) portions of the source area with lower K due to the presence of less permeable silty sands. - The persulfate anion and the sulfate free radical may persist for days to weeks depending on subsurface conditions.	- ISCO with activated persulfate is a proven technology that has been used at many sites to remediate chlorinated ethenes and other organic compounds. - ISCO with activated persulfate involves installation of multiple injection wells, and typically requires a series of injection events to reduce contaminant concentrations to desired levels. - There are no above-ground structures associated with ISCO other than temporary drums or tanks used to store the persulfate and chemical activators during the injection events, which typically have a duration of days or weeks. - The application of activated persulfate is somewhat more complex than ISCO with permanganate, which does not require activation.	Medium capital cost and medium O&M cost (cost increases when multiple treatments are required)	X	

TABLE 5-2
EVALUATION OF TECHNOLOGIES AND PROCESS OPTIONS
3800 Area PCE Site
Fort Drum, New York

General Response Action	Technology Class	Process Option	Description/Definition	Effectiveness	Implementability	Relative Cost	Evaluation Action	
							Retain	Reject
	Enhanced Desorption and Treatment	Air sparging (AS) with soil vapor extraction (SVE)	- Air is injected into groundwater enabling the transfer of dissolved phase VOCs into the vapor phase. Volatilized VOCs are captured by a vapor extraction system for treatment prior to discharge to the atmosphere.	- PCE has a relatively high Henry's constant (1.8 x 10-2 atm-m3/mol) due to both its high volatility and low aqueous solubility, and is amenable to removal via AS. - In general, a K of 1X10-3 cm/second (2.8 ft/day) or higher is optimal. The K values at the presumed PCE source area at the Site are in the optimal range at depths shallower than 45 feet bgs; however, at depths greater than 45 ft bgs, K values decrease below the optimal range. Therefore, for AS to be effective, sparge points may need to be placed in closer proximity.	- Implementation is relatively straight-forward because only readily available commercial equipment is utilized (i.e., PVC well casing, compressors, blowers). - The equipment is relatively simple to install and causes minimal disturbances to site operations. - Because AS increases the rate of contaminant volatilization, it is important to be aware of the potential for migration of VOC-impacted vapor to nearby structures. - An SVE system may be used to reduce or eliminate vapor migration.	Moderate to high capital cost and medium O&M cost (cost increases when AS wells are more closely spaced)	X	
Extraction/ Removal	Groundwater Extraction	Vertical Extraction Wells	- Single or multiple vertical wells to extract groundwater using pumps.	- Most effective for homogenous aquifers with moderate transmissivity and dissolved, mobile compounds. - Effectiveness depends on optimizing extract well placement and groundwater extraction rates. - The efficiency of groundwater extraction of PCE would be affected by the rate of dissolution of PCE from finer-grained aquifer matrix.	- Will need to be implemented in conjunction with a treatment system for the groundwater that is captured. - Long-term operation required.	Moderate to high capital cost (including ex situ treatment components). Moderate to high O&M cost which depends on complexity of treatment train and cost of discharge options.		X
Ex Situ Treatment	Not evaluated, as no groundwater extraction/removal process options have been retained.							
Groundwater Disposal	Not evaluated, as no groundwater extraction/removal process options have been retained.							

N/A – Not Applicable

Table 6-1
SUMMARY OF CONCEPTUAL DESIGN ASSUMPTIONS
3800 Area PCE Site
Fort Drum, New York

Alternative	Active Remediation	MNA Monitoring
Alternative 2 ISCO with MNA	• Single ISCO injection because two pilot injections will have been completed • Installation of up to 15 injection wells (if needed based on second ISCO pilot results) • New 2-inch injection wells installed between 35-42 ft bgs with 10 ft screens • Injection wells network in a grid pattern • Inject into up to 90 wells • Injection volumes between 2,000 and 5,500 gallons per well based on variable screen lengths and variable well spacing • 3% sodium permanganate (by wt) • 189,000 lbs 40% sodium permanganate • Concurrent injection in up to 20 wells • Average injection rate of 1.5 gpm per well • Performance monitoring at 10 source area wells for four event (quarterly for one year) • Samples analyzed for VOCs, metals, manganese and field parameters • Wells to be abandoned in place without overdrilling	• 16 years of groundwater monitoring • 30 monitoring wells • Samples analyzed for VOCs only • Semi-annual sampling for first 5 years • Annual sampling for the following 11 years
Alternative 3 ISEB with MNA	• 4 years ISEB injection • Assumes that aquifer geochemistry can be effectively altered and sustained to allow ISEB. • Injection well network creates ISEB barriers • Aquifer environment requires bioaugmentation • Initial injection of sodium lactate in all wells • Subsequent injection of EVO downgradient of Building 1885 • Continued sodium lactate injection upgradient of Building 1885 • Installation of up to 15 additional injection wells (if needed) • New 2-inch injection wells installed between 35-42 ft bgs with 10 ft screens • Inject into 40 wells • Injection volumes between 2,000 and 5,500 gallons per well based on variable screen length and variable well spacing • 2% sodium lacate or EVO (by wt) • 24,100 lbs sodium lactate (initial injection) • 3,270 lbs sodium lactate (after initial injection) • 20,800 lbs EVO (after initial injection) • Concurrent injection in up to 20 wells • Average injection rate of 1.5 gpm per well • Performance monitoring at 10 wells • Samples analyzed for VOCs, TOC, dissolved gases, DHC, anions and field parameters • Wells to be abandoned in place without overdrilling	• 19 years of groundwater monitoring • 30 monitoring wells • Samples analyzed for VOCs only • Semi-annual sampling for first 5 years • Annual sampling for the following 14 years

Table 6-1
SUMMARY OF CONCEPTUAL DESIGN ASSUMPTIONS
3800 Area PCE Site
Fort Drum, New York

Alternative	Active Remediation	MNA Monitoring
Alternative 4 AS/SVE with MNA	• 2 years of operation • Installation of 51 AS wells and 24 SVE wells • Install 2-inch AS wells to ~60 ft bgs with 2 ft screen sections • AS well ROI of 15 ft • 10 scfm per AS well • 3 AS zones of 17 wells each (170 scfm total air flow) • AS zones cycled every 4-6 hours • Install 4-inch SVE wells to ~20 ft bgs with 5 ft screen sections • SVE well ROI of 25 ft • Recover 25 scfm from each SVE well • 3 SVE zones operated continuously, but piped independently. 600 scfm total air flow • 4,000 lb GAC treatment for one year • Installation of below grade 1-inch piping connecting each AS well • Installation of below grade 4-inch piping connected each SVE zone (3 total) • New equipment and treatment building • Power readily available. Power drop consists of pole and meter installation only • Wells to be abandoned in place without overdrilling	• 17 years of groundwater monitoring • 30 monitoring wells • Samples analyzed for VOCs only • Semi-annual sampling for first 5 years • Annual sampling the following 12 years

Table 7-1: Estimated Remedial Alternatives Costs

Site: 3800 Area PCE Site
Location: Fort Drum, New York
Phase: FS
Base Year: 2015
Date: 5/29/2015

<u>Remedial Alternative</u>	Capital Cost	Total Annual O&M and Periodic Costs	Total MNA Costs	Total Cost	Present Value Total Cost	*Estimated Timeframe of Alternative*[1]
No Action	--	$ 72,600	--	$ 72,600	$ 72,600	--
In-Situ Chemical Oxidation with Monitored Natural Attenuation	$ 174,500	$ 836,400	$ 500,700	$ 1,511,600	$ 1,480,100	1 yr active; 16 yrs MNA
In-Situ Enhanced Bioremediation with Bioaugmentation and with Monitored Natural Attenuation	$ 259,500	$ 859,900	$ 563,500	$ 1,682,900	$ 1,620,100	4 yrs active; 19 yrs MNA
Air Sparge / Soil Vaport Extraction with Monitored Natural Attenuation	$ 2,123,900	$ 466,300	$ 521,600	$ 3,111,800	$ 3,066,000	2 yrs active; 17 yrs MNA

<u>Notes and References:</u>

1: The estimated timeframe of each alternative assumed for costing may not reflect the actual time to cleanup.

United States Environmental Protection Agency. 1988. Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA Interim Final. USEPA Office of Emergency and Remedial Response. October 1988.

TABLE 7-2
COMPARATIVE ANALYSIS OF REMEDIAL ALTERNATIVES
3800 Area PCE Site
Fort Drum, New York

	Alternative 1 **No Further Action**	**Alternative 2** **In Situ Chemical Oxidation with Monitored Natural Attenuation**	**Alternative 3a** **In Situ Enhanced Bioremediation with Bioaugmentation with Monitored Natural Attenuation**	**Alternative 4** **Air Sparge / Soil Vapor Extraction with Monitored Natural Attenuation**
Overall protection of human health and the environment[1]	NO – No actions would be performed. There would be no administrative system to control exposure to contaminated groundwater or to monitor groundwater. The PCE remaining in the sub-surface would continue to serve as a long-term source to the groundwater plume.	YES – PCE concentrations in the source area would be reduced via in situ chemical oxidation. Remediation of the continuing source would result in natural attenuation of the CVOC plume. Groundwater monitoring would be used to assess the achievement of SCGs. Alternative 2 would thereby protect against both current and future exposure to groundwater and would be protective of human health and the environment.	YES – PCE concentrations in the source area would be reduced via reductive dechlorination processes. Remediation of the continuing source would result in faster natural attenuation of the down-gradient PCE plume. MNA monitoring would be used to assess the achievement of SCGs. Alternative 3 would thereby protect against both current and future exposure to groundwater and would be protective of human health and the environment.	YES – PCE concentrations in the source area would be reduced via volatilization and subsequent vapor extraction. Remediation of the continuing source would result in natural attenuation of the down-gradient plume. Groundwater monitoring would be used to assess the achievement of SCGs. Alternative 4 would thereby protect against both current and future exposure to groundwater and would be protective of human health and the environment.
Compliance with SCGs[1]	NO - There would be no means to monitor the extent of the dissolved PCE groundwater plume; therefore, it is unknown whether potential receptors would be protected, and RAOs would not be met.	YES - Alternative 2 would reduce PCE concentrations in the source area and achieve the SCGs within a reasonable timeframe. MNA monitoring would be implemented to track the extent of the dissolved phase plume, and to confirm the rate of natural attenuation is sufficient to meet the SCGs within a reasonable timeframe, and confirm RAOs have been met.	YES - Alternative 3 would reduce PCE concentrations in the source area and achieve the SCGs within a reasonable timeframe. MNA monitoring would be implemented to track the extent of the dissolved phase plume, confirm the rate of natural attenuation is sufficient to meet the SCGs within a reasonable timeframe, and confirm RAOs have been met.	YES - Alternative 4 would reduce PCE concentrations in the source area and achieve the SCGs within a reasonable timeframe. MNA monitoring would be implemented to track the extent of the dissolved phase plume, confirm the rate of natural attenuation is sufficient to meet the SCGs within a reasonable timeframe, and confirm RAOs have been met.
Long-term effectiveness and permanence	This alternative would not achieve long-term effectiveness or permanence. The PCE remaining in the sub-surface would continue to serve as a long-term source to the groundwater plume.	With good distribution of the oxidant, ISCO would effectively and permanently reduce the PCE mass in the source area. Additionally, removal of the continuing source would result in a permanent reduction of the PCE plume down-gradient of the source area over time.	With good distribution of the carbon substrate and good survival of the bacterial dechlorinating cultures, ISEB would effectively and permanently reduce the PCE mass in the source area. Additionally, removal of the continuing source would result in a permanent reduction of the PCE plume down-gradient of the source area over time.	With good distribution of sparged air, Alternative 4 would result in the volatilization and subsequent extraction of PCE, effectively and permanently reduce the PCE mass in the source area. Additionally, removal of the continuing source would result in a permanent reduction of the PCE plume down-gradient of the source area over time.
Reduction of toxicity, mobility, or volume through treatment	There is no treatment, so the statutory preference for treatment is not a component of this alternative. There would be no documented reduction in toxicity, mobility, or volume of contaminants.	ISCO, along with natural attenuation, would permanently reduce the mobility, toxicity, and volume of PCE in the dissolved phase groundwater via direct destruction of PCE.	ISEB, along with natural attenuation, would permanently reduce the mobility, toxicity, and volume of PCE in the dissolved phase groundwater via biological destruction of PCE.	AS/SVE, along with natural attenuation, would permanently reduce the mobility, toxicity, and volume of PCE in the dissolved phase groundwater via removal of PCE.

TABLE 7-2
COMPARATIVE ANALYSIS OF REMEDIAL ALTERNATIVES
3800 Area PCE Site
Fort Drum, New York

	Alternative 1 **No Further Action**	**Alternative 2** **In Situ Chemical Oxidation with Monitored Natural Attenuation**	**Alternative 3a** **In Situ Enhanced Bioremediation with Bioaugmentation with Monitored Natural Attenuation**	**Alternative 4** **Air Sparge / Soil Vapor Extraction with Monitored Natural Attenuation**
Short-term effectiveness	Low risks to site workers during the abandonment of injection and monitoring wells associated with previous pilot studies. Hazards can be controlled using engineering controls such as safe work practices and personal protective equipment. Minimal impact to on-going operations at the Site.	Injection wells would be installed as part of the expanded well network within the source area. Injection of a chemical oxidant (sodium permanganate) would result in minimal risk to site workers, the community and environment. Risks would be controlled with engineering controls. Investigative-derived waste (IDW) from well installation, groundwater sampling, and remedial activities would be handled using approved methods. Potential risks are limited to on-site populations. Active groundwater treatment operations would be performed in less than nine months.	Injection wells would be installed as part of the expanded well network within the source area. Injection of a carbon substrate (e.g., sodium lactate or EVO) would result in minimal risk to site workers, the community and environment. IDW from well installation, groundwater sampling, and remedial activities would be handled using approved methods. Potential risks are limited to on-site populations. If elevated VC, methane, or hydrogen sulfide were detected in groundwater samples collected in the vicinity of Building 1885, indoor air monitoring and/or venting measures may be required to prevent exposure due to vapor intrusion. Active groundwater treatment operations would be completed within approximately four years.	AS and SVE wells would be installed as part of the expanded well network within the source area. Installation of the remediation system poses low to moderate risk to site workers due to the installation of piping below grade as well as noise and equipment hazards associated with the equipment needed to install the conveyance piping. Operation of the remediation system would result in low risk to site workers due to noise hazards, but no risk to the community and environment. IDW from wells installation, groundwater sampling, and remedial activities would be handled using approved methods. Potential risks are limited to on-site populations. Active groundwater treatment operations would be completed within approximately two years.
Implementability	Abandonment of injection and monitoring wells associated with previous pilot studies would be straight-forward to implement.	Implementation of this alternative is both technically and administratively feasible and would not interfere with ongoing operations at Fort Drum. Monitoring or injection wells would be installed using standard drilling methods and materials. These services are readily available, as are the services and materials necessary for the collection and analysis of groundwater samples. The materials required to mix the injection solution are commercially available. Implementation of this alternative would not limit or interfere with the ability to perform future remedial actions. Institutional controls would be easily implemented.	Implementation of this alternative is both technically and administratively feasible and would not interfere with ongoing operations at Fort Drum. Monitoring and injection wells would be installed using standard drilling methods and materials. These services are readily available, as are the services and materials necessary for the collection and analysis of groundwater samples. The materials required to mix the injection solution are commercially available. Implementation of this alternative would not limit or interfere with the ability to perform future remedial actions. Institutional controls would be easily implemented.	Implementation of this alternative is both technically and administratively feasible; however, it could interfere with ongoing operations around the Site buildings. AS and SVE wells would be installed using standard drilling methods and materials. These services are readily available, as are the services and materials necessary for the collection and analysis of groundwater samples. Extensive trenching and pipe installation would be required across the source area. This trenching would impact Site operations and require significant lengths of open trench to connect all the remediation wells to the remediation system. A permanent equipment building would be required to house the remediation system. Because of the extensive sub-surface piping, implementation of this alternative would limit the ability to perform future remedial actions without first decommissioning the remediation system. Institutional controls would be easily implemented.
Costs	Please refer to **Table 7-1** for a summary of the costs for each alternative			

1. To be eligible for selection, an alternative must be protective of human health and the environment and must meet the SCGs. For this reason, each alternative either meets the criterion (i.e., Yes) or does not meet the criterion (i.e., No).

APPENDIX A

First Phase ISCO Pilot Study Results at the 3800 Area PCE Site

TABLE E-1

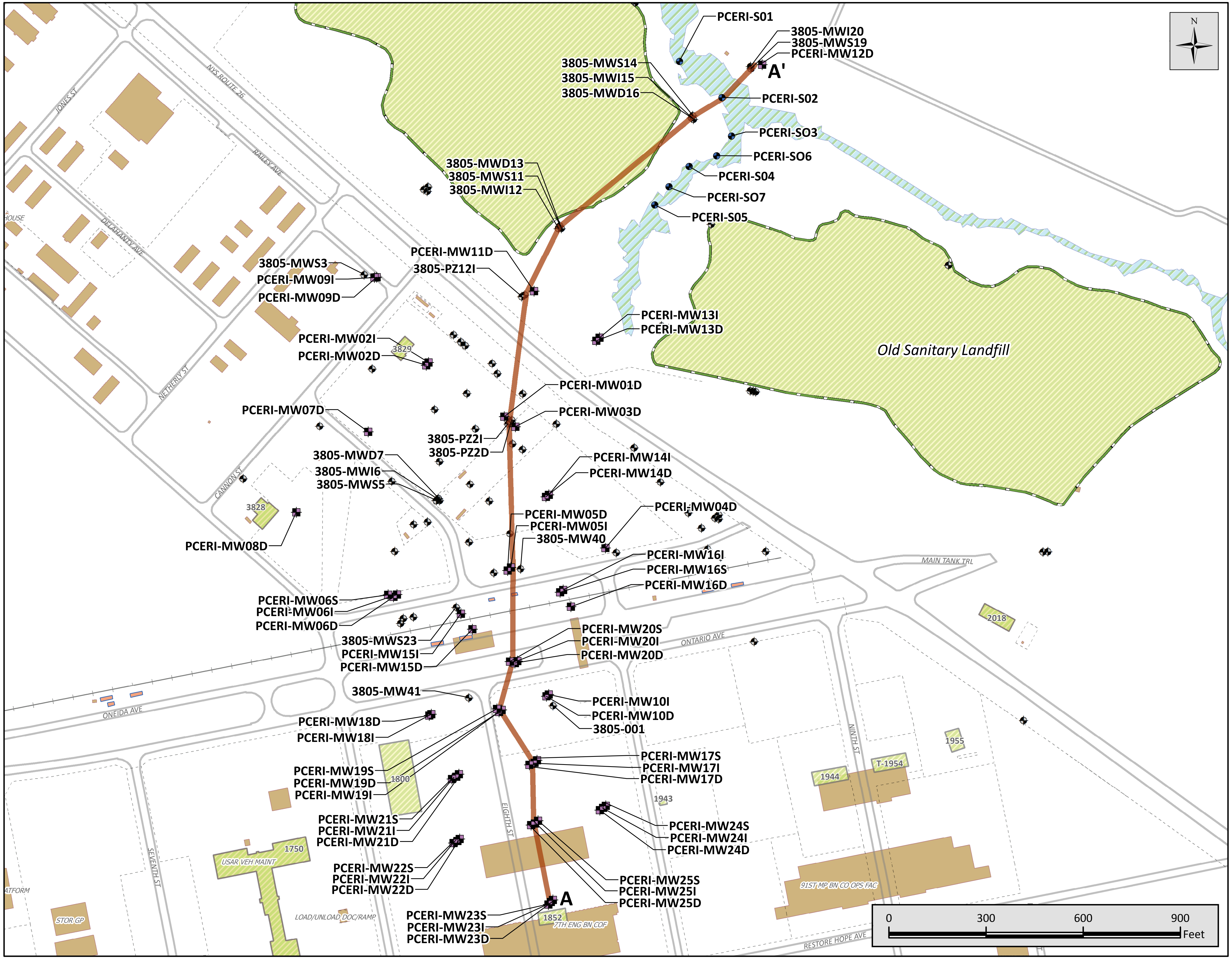
FORT DRUM PCERI - PILOT TESTING ANALYTICAL RESULTS POST-INJECTION SAMPLING EVENT COMPARISON DATA

		11/5/2012					1/18/2013					2/27/2013					3/25/2013					9/24/2013				
ANALYTE	**UNITS**	**MW-19I**	**IMW-1**	**IMW-2**	**IMW-3**	**IMW-4**	**MW-19I**	**IMW-1**	**IMW-2**	**IMW-3**	**IMW-4**	**MW-19I**	**IMW-1**	**IMW-2**	**IMW-3**	**IMW-4**	**MW-19I**	**IMW-1**	**IMW-2**	**IMW-3**	**IMW-4**	**MW-19I**	**IMW-1**	**IMW-2**	**IMW-3**	**IMW-4**
FIELD PARAMETERS	**Units**																									
pH	(su)	8.84	8	7.78	7.38	8	NS	8.57	NS	7.75	8.22	NS	NS	NS			NS	NS	NS			7.6	7.5	7.7	7.5	7.9
Temperature	(°C)	6.67	8.8	8.18	8.08	9	NS	10.98	NS	10.99	10.81	NS	NS	NS			NS	NS	NS			NA	12.7	11.4	10.7	11.3
Specific Conductivity	(ms/cm)	0.701	0.599	0.496	0.631	0.541	NS	0.419	NS	0.496	0.394	NS	NS	NS			NS	NS	NS			2.030	0.614	0.437	0.594	0.472
ORP	(mV)	133	44	92	181	-80	NS	126	NS	136	10	NS	NS	NS			NS	NS	NS			490.4	335.4	310.0	299.5	274.8
DO	(mg/L)	4.8	6.63	7.37	2.97	8.76	NS	2.89	NS	0.66	1.29	NS	NS	NS			NS	NS	NS			0.38	4.61	7.17	4.55	1.08
Turbidity	(NTU)	0	240	311	366	209	NS	23.6	NS	3.1	1.1	NS	NS	NS			NS	NS	NS			8.0	10.0	7.6	3.9	10.0
GENERAL CHEMISTRY																										
Nitrate as N	mg/L	1.8	4.8	2.1	2.4	1.7	NS	2.4	NS	2.8	1.6	NS	NS	NS	3.0	0.20	0.24	0.58	2.2	2.8	0.32	1.3	2.5	1.8	3.0	1.7
Chloride	mg/L	84	81	30	64	58	NS	34	NS	81	52	NS	NS	NS	99	3.8	20	14	46	95	1.9	170	**110**	67	160	86
Sulfate	mg/L	33	42	50	32	37	NS	58	NS	30	36	NS	NS	NS	30	2.3	12	11	46	29	3.3	NA	NA	NA	NA	NA
Alkalinity	mg/L	120	92	130	150	110	NS	140	NS	160	140	NS	NS	NS	150	30	NA*	58	140	140	44	430	130	140	130	130
TDS	mg/L	320	290	260	320	270	NS	270	NS	310	250	NS	NS	NS	320	97	590	110	270	320	60	2800	480	290	310	310
METALS																										
Arsenic, total	µg/L	**0.70**	0.29	0.29	0.29	0.29	NS	0.29	NS	**0.37**	0.29	NS	NS	NS	0.29	0.29	2.2	1.0	2.7	3.5	1.7	NA	NA	NA	NA	NA
Arsenic, dissolved	µg/L	0.29	0.29	0.29	**0.41**	0.29	NS	**0.75**	NS	**0.30**	0.29	NS	NS	NS	0.29	0.29	4.6	4.7	4.9	3.0	5.1	1.3	1.3	1.3	1.3	1.3
Calcium, total	µg/L	84000	46000	62000	51000	54000	NS	92000	NS	50000	58000	NS	NS	NS	54000	2500	27000	12000	62000	48000	2900	NA	NA	NA	NA	NA
Calcium, dissolved	µg/L	52000	49000	65000	54000	56000	NS	80000	NS	54000	59000	NS	NS	NS	55000	1900	34000	12000	62000	49000	3800	NA	NA	NA	NA	NA
Iron, total	µg/L	6600	3300	2500	3300	2300	NS	120	NS	270	130	NS	NS	NS	760	320	430	550	240	270	180	NA	NA	NA	NA	NA
Iron, dissolved	µg/L	61	**47**	**49**	76	53	NS	6.1	NS	6.1	6.1	NS	NS	NS	6.1	**22**	6.1	**36**	6.1	6.1	**9.4**	NA	NA	NA	NA	NA
Potassium, total	µg/L	3600	4200	2900	2600	4400	NS	2900	NS	2000	1800	NS	NS	NS	1900	3800	5600	6000	1600	1900	7300	NA	NA	NA	NA	NA
Potassium, dissolved	µg/L	2800	4500	2800	2600	4900	NS	3000	NS	2100	1800	NS	NS	NS	1700	3800	5900	12000	1600	1900	11000	NA	NA	NA	NA	NA
Magnesium, total	µg/L	6800	12000	5300	3900	6100	NS	5500	NS	2800	4700	NS	NS	NS	2900	210	1600	730	4600	2800	390	NA	NA	NA	NA	NA
Magnesium, dissolved	µg/L	4700	11000	4600	3300	5800	NS	5800	NS	3000	4800	NS	NS	NS	2700	110	2500	780	4800	2900	500	NA	NA	NA	NA	NA
Manganese, total	µg/L	320	230	99	97	300	NS	620	NS	17	60	NS	NS	NS	36	9.2	16000	160	10	17	11	NA	NA	NA	NA	NA
Manganese, dissolved	µg/L	**2.7**	180	48	13	260	NS	15	NS	9.4	58	NS	NS	NS	12	**1.2**	53000	9.0	**2.6**	10	**4.2**	NA	NA	NA	NA	NA
Sodium, total	µg/L	54000	39000	22000	59000	31000	NS	21000	NS	68000	33000	NS	NS	NS	72000	10000	21000	17000	31000	68000	9800	NA	NA	NA	NA	NA
Sodium, dissolved	µg/L	68000	49000	26000	72000	37000	NS	22000	NS	74000	34000	NS	NS	NS	67000	9800	59000	16000	30000	72000	11000	NA	NA	NA	NA	NA
VOCs																										
Acetone	µg/L	5	5	5	5	5	NS	5	NS	13	15	NS	NS	NS	25	5.0	2100	5	5	50	5.0	190	5.0	5.0	25	50
2-Butanone	µg/L	1.1	1.1	1.1	1.1	1.1	NS	1.1	NS	2.7	3.3	NS	NS	NS	5.4	1.1	310	1.1	1.1	11	1.1	**20**	1.0	1.0	10	10
Chloroform	µg/L	**4.2**	**1.3**	1.0	**2.8**	**3.6**	NS	**1.4**	NS	**4.3**	**8.1**	NS	NS	NS	**6.2**	1.0	20	**1.4**	**1.2**	10	1.0	5.9	0.14	1.1	0.70	14
Methylene chloride	µg/L	1.1	1.1	1.1	1.1	1.1	NS	1.1	NS	**3.1**	3.3	NS	NS	NS	5.4	1.1	22	1.1	1.1	11	1.1	5.0	1.0	1.0	5.0	10
Tetrachloroethene	µg/L	110	**2.6**	16	260	170	NS	120	NS	510	290	NS	NS	NS	440	**1.3**	16	5.1	28	310	29	0.75	19	14	250	750
Trichloroethene	µg/L	**4.3**	0.8	**3.0**	9.1	8.7	NS	24	NS	13	18	NS	NS	NS	**14**	0.8	16	**0.93**	**3.7**	8.0	**1.1**	0.65	3.8	1.6	6.6	25
1,2,4-Trichlorobenzene	µg/L	0.38	0.38	0.38	0.38	0.38	NS	0.38	NS	0.94	1.1	NS	0.38	NS	1.9	0.38	7.5	**2.1**	**1.6**	3.8	**0.81**	1.8	0.25	0.25	1.8	2.5

	1.1	Left-justified and shaded cells indicate non-detect (below MDL, indicated)
	4.2	Bold, shaded, right-justified cells indicate analyte detected at estimated trace concentration
	110	Non-shaded cells indicate analyte detected above reporting limit.
Note:	NS	Indicates well was not sampled.
	NA	Indicates analysis not performed for constituent.

APPENDIX B

Select Figures from the Remedial Investigation Report (PARS, 2013a)



Legend

- PCERI Monitoring Wells
- SWIM/SW/Sediment Sample Location
- Cross-section Transect
- Monitoring Well Locations
- Landfill
- Potential Hazardous Waste Sources
- Former UST
- Fence Line
- Rail Road
- Paved Road
- Wetlands
- Building

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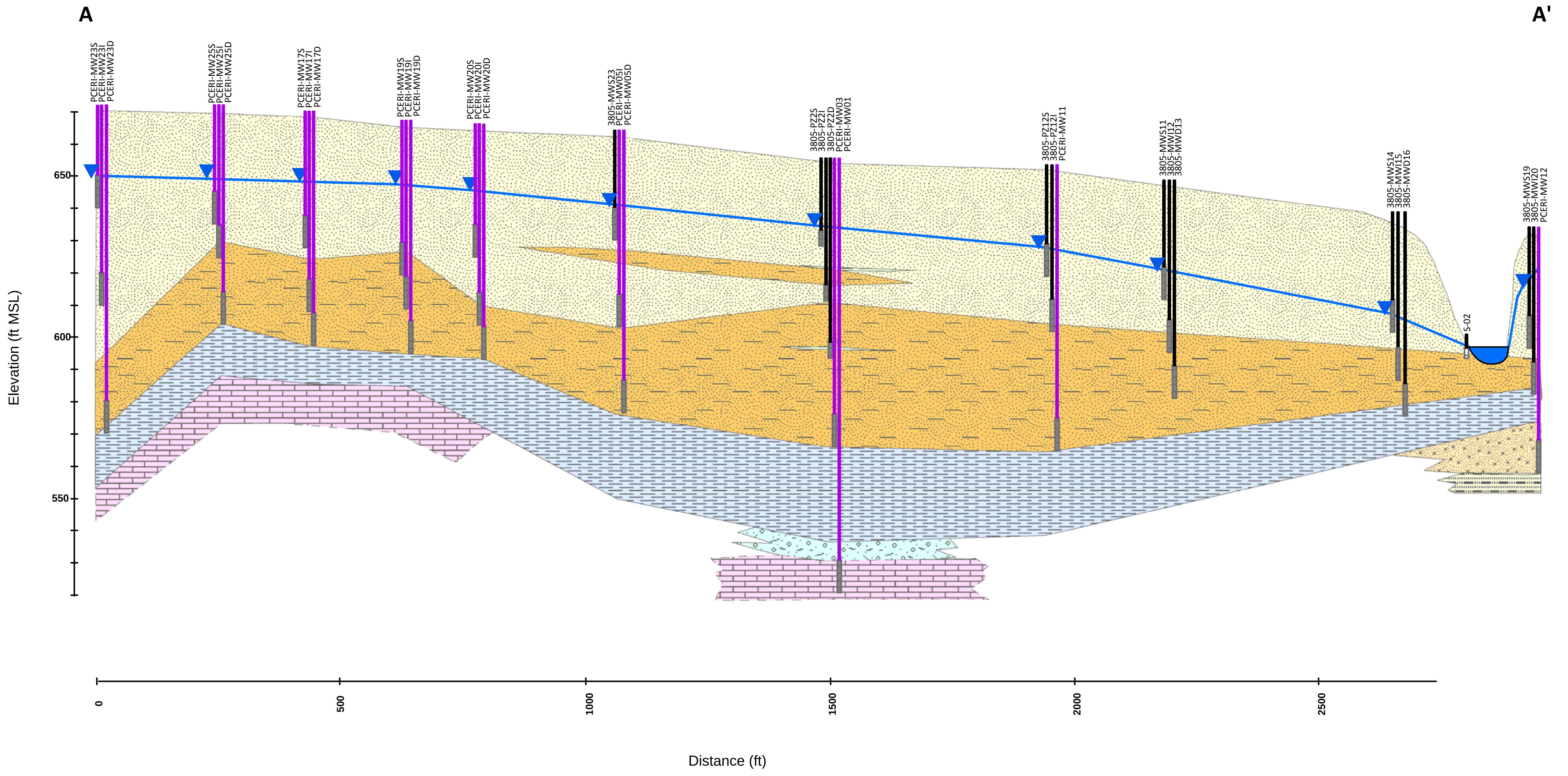
Created By: JRC
Date: May 2012

FIGURE 3-2

Geological Cross-Section Transect Map

Remedial Investigation Report
For Chlorinated Solvent Contaminants
Fort Drum, NY



Lithology

- ▨ Sand
- ▨ Silty Sand
- ▨ Silt
- ▨ Clay
- ▨ Till
- ▨ Gravel
- ▨ Limestone
- ▨ Sandstone

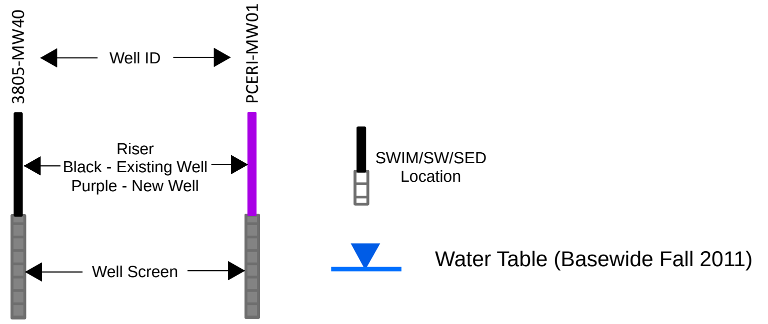


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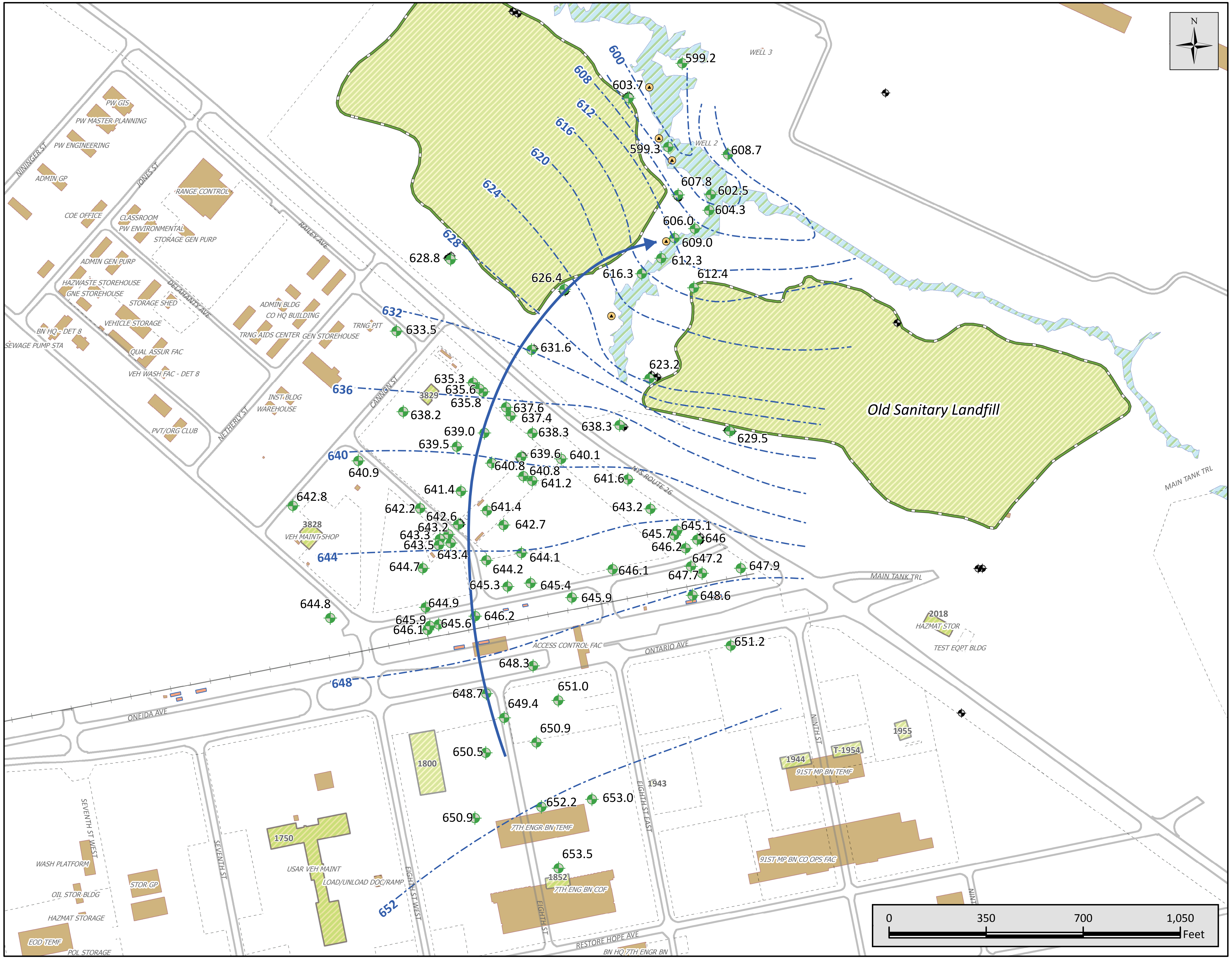
FIGURE 3-3

PCERI Geological Cross-Section

Remedial Investigation Report
For Chlorinated Solvent Contaminants
Fort Drum, NY



Legend

- ➔ Groundwater Flowline
- --- Shallow Contours
- ⊕ Shallow Monitoring Wells
- ◆ Monitoring Well Locations
- ● Seep Sample Location
- ☐ Landfill
- ▨ Potential Hazardous Waste Sources
- 🟧 Former UST
- --- Fence Line
- ┼ Rail Road
- ― Paved Road
- ▨ Wetlands
- 🟫 Building

Groundwater Elevation: Feet Mean Sea Level

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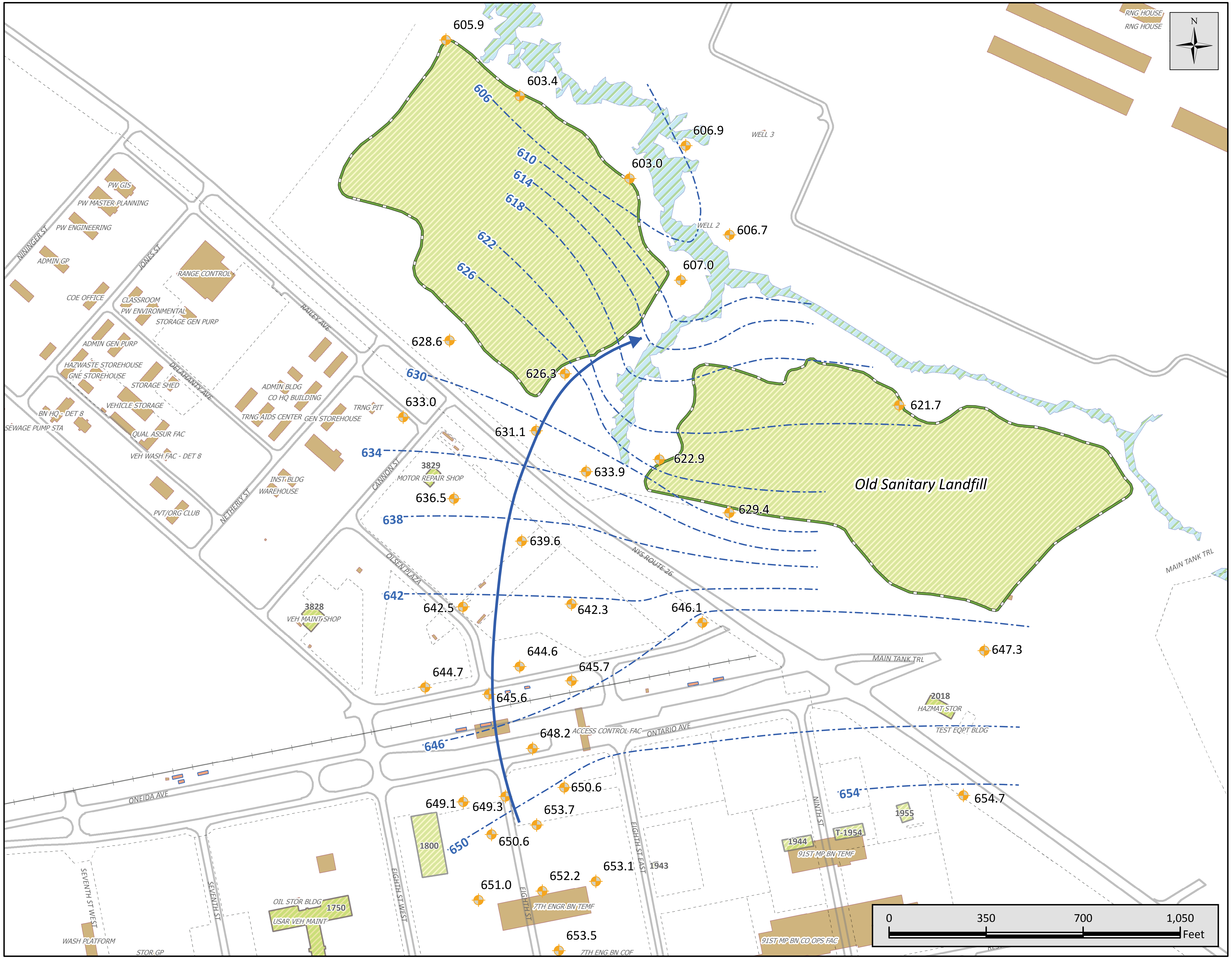
Date: May 2012

FIGURE 3-4

Shallow Aquifer Groundwater Contours, Spring 2011

Remedial Investigation Report
For Chlorinated Solvent Contaminants
Fort Drum, NY



Legend

- Groundwater Flowline
- Intermediate Contours
- Intermediate Monitoring Wells
- Landfill
- Potential Hazardous Waste Sources
- Former UST
- Fence Line
- Rail Road
- Paved Road
- Wetlands
- Building

Groundwater Elevation: Feet Mean Sea Level

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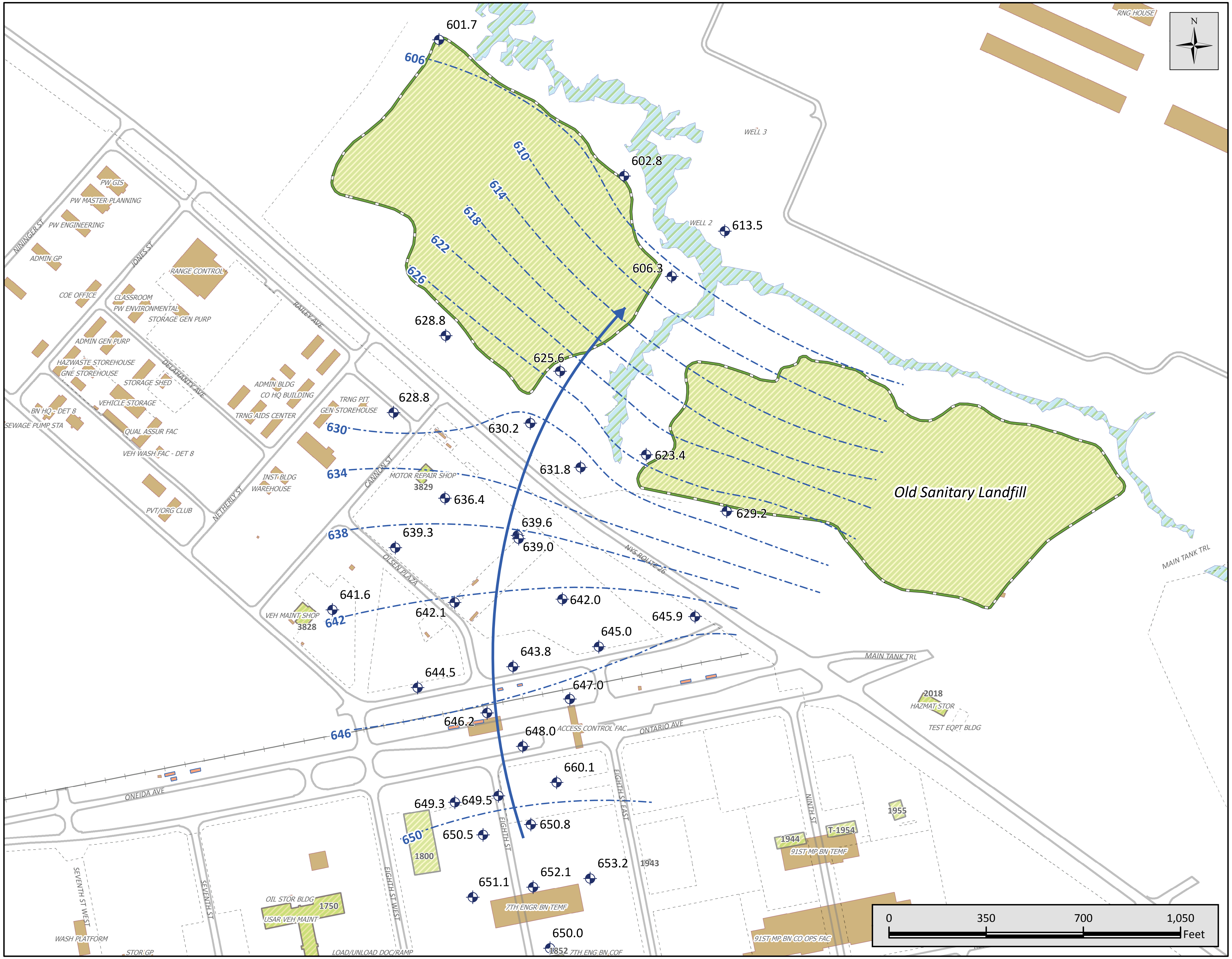
FIGURE 3-5

Intermediate Aquifer Groundwater Contours, Spring 2011

Remedial Investigation Report
For Chlorinated Solvent Contaminants
Fort Drum, NY



Legend

- ➔ Groundwater Flowline
- - - Deep Contours
- ⊕ Deep Monitoring Wells
- ▭ Landfill
- ▨ Potential Hazardous Waste Sources
- 🟧 Former UST
- ┈ Fence Line
- ┼ Rail Road
- ─ Paved Road
- ▨ Wetlands
- 🟫 Building

Groundwater Elevation: Feet Mean Sea Level

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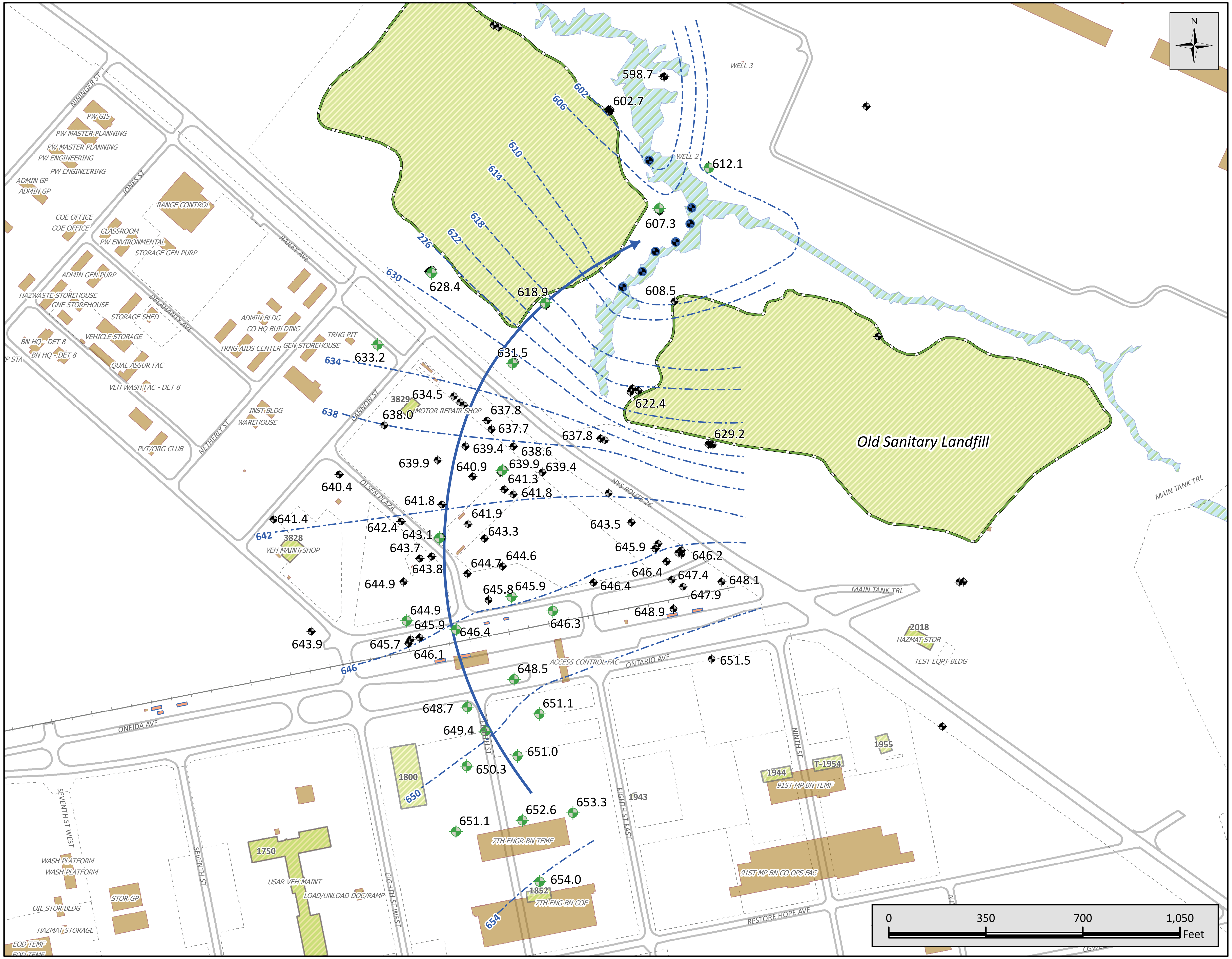
FIGURE 3-6

Deep Aquifer Groundwater Contours, Spring 2011

Remedial Investigation Report
For Chlorinated Solvent Contaminants
Fort Drum, NY



Legend

- ➡ Groundwater Flowline
- - - Shallow Contours
- ⊕ Shallow Monitoring Wells
- ● SWIM/SD/SW Locations
- ◆ Monitoring Well Locations
- ▭ Landfill
- ▨ Potential Hazardous Waste Sources
- 🟧 Former UST
- 🟫 Building
- - - Fence Line
- ┼ Rail Road
- — Paved Road
- ▨ Wetlands

Groundwater Elevation: Feet Mean Sea Level

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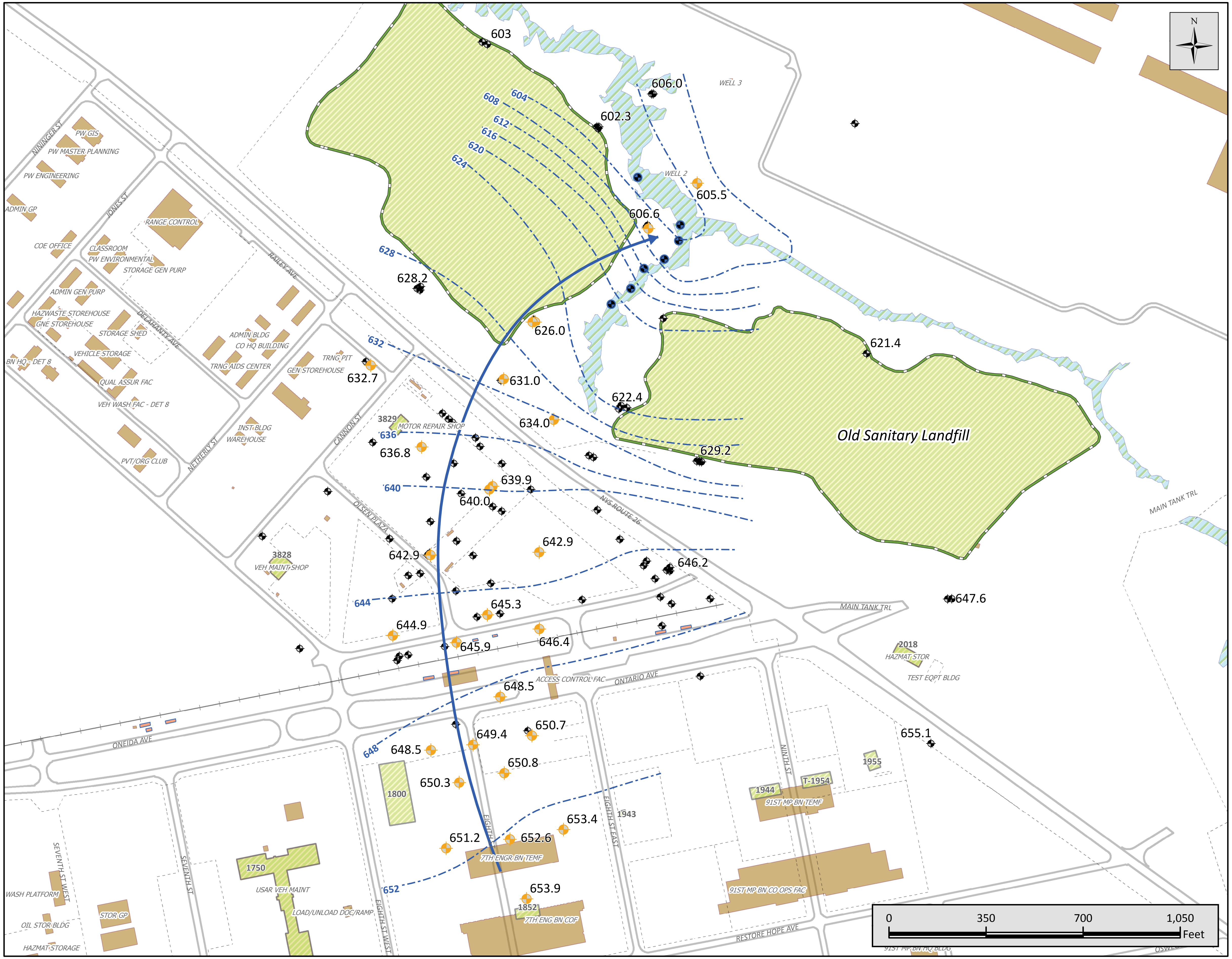
FIGURE 3-7

Shallow Aquifer Groundwater Contours, Fall 2011

Remedial Investigation Report
For Chlorinated Solvent Contaminants
Fort Drum, NY



Legend

- Groundwater Flowline
- Intermediate Contours
- Intermediate Monitoring Wells
- SWIM/SD/SW Locations
- Monitoring Well Locations
- Landfill
- Potential Hazardous Waste Sources
- Former UST
- Fence Line
- Rail Road
- Wetlands
- Building
- Paved Road

Groundwater Elevation: Feet Mean Sea Level

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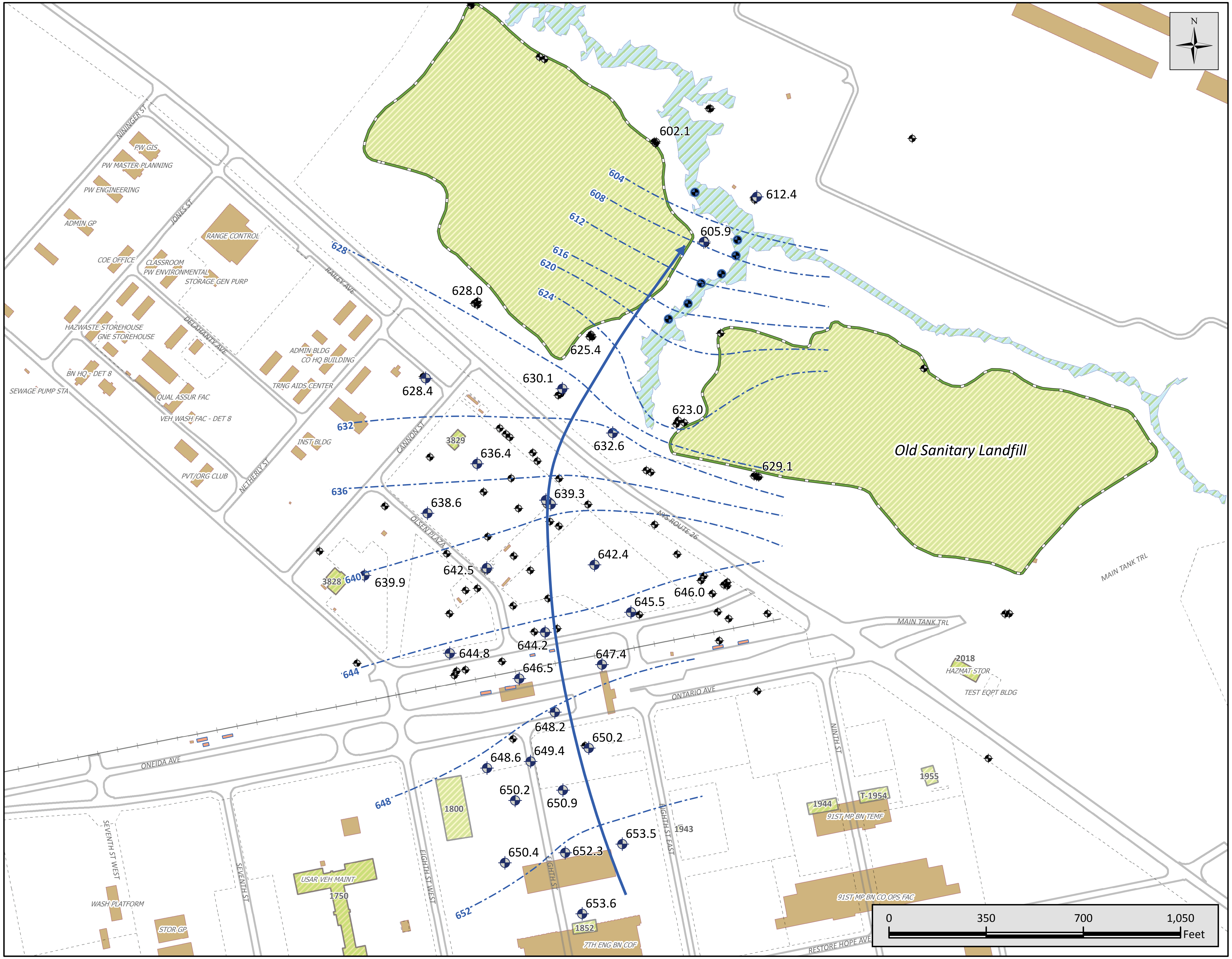
FIGURE 3-8

Intermediate Aquifer Groundwater Contours, Fall 2011

Remedial Investigation Report
For Chlorinated Solvent Contaminants
Fort Drum, NY



Legend

- ➔ Groundwater Flowline
- - - Deep Contours
- ⊕ Deep Monitoring Wells
- ● Swim/SD/SW Locations
- ⊕ Monitoring Well Locations
- ☐ Landfill
- ▨ Potential Hazardous Waste Sources
- 🟧 Former UST
- - - Fence Line
- ┼ Rail Road
- — Paved Road
- ▨ Wetlands
- 🟫 Building

Groundwater Elevation: Feet Mean Sea Level

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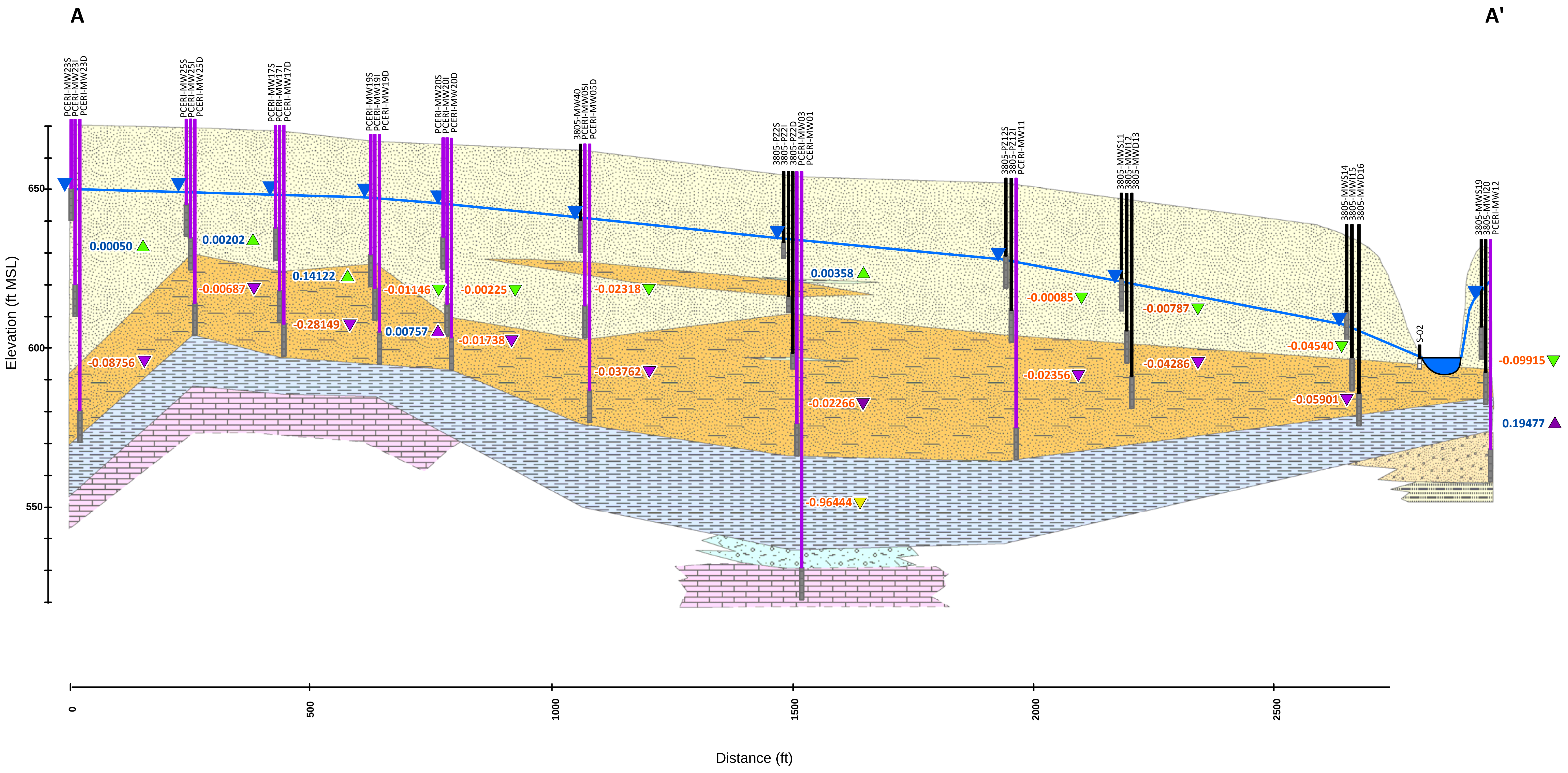
FIGURE 3-9

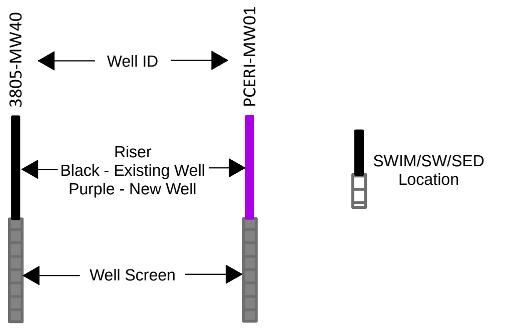
Deep Aquifer Groundwater Contours, Fall 2011

Remedial Investigation Report
For Chlorinated Solvent Contaminants
Fort Drum, NY



Lithology

- ▨ Sand
- ▨ Silty Sand
- ▨ Silt
- ▨ Clay
- ▨ Till
- ▨ Gravel
- ▨ Limestone
- ▨ Sandstone



-0.43403 Red Value Indicates a Downward Vertical Gradient

0.00461 Blue Value Indicates an Upward Vertical Gradient

▲ Gradient Calculated Between the Shallow and Intermediate Wells

▼ Gradient Calculated Between the Intermediate and Deep Wells

▼ Gradient Calculated Between the Deep and Bedrock Wells

▼ Water Table (Basewide Spring 2011)

Gradient data calculated from the spring 2011 well gauging event

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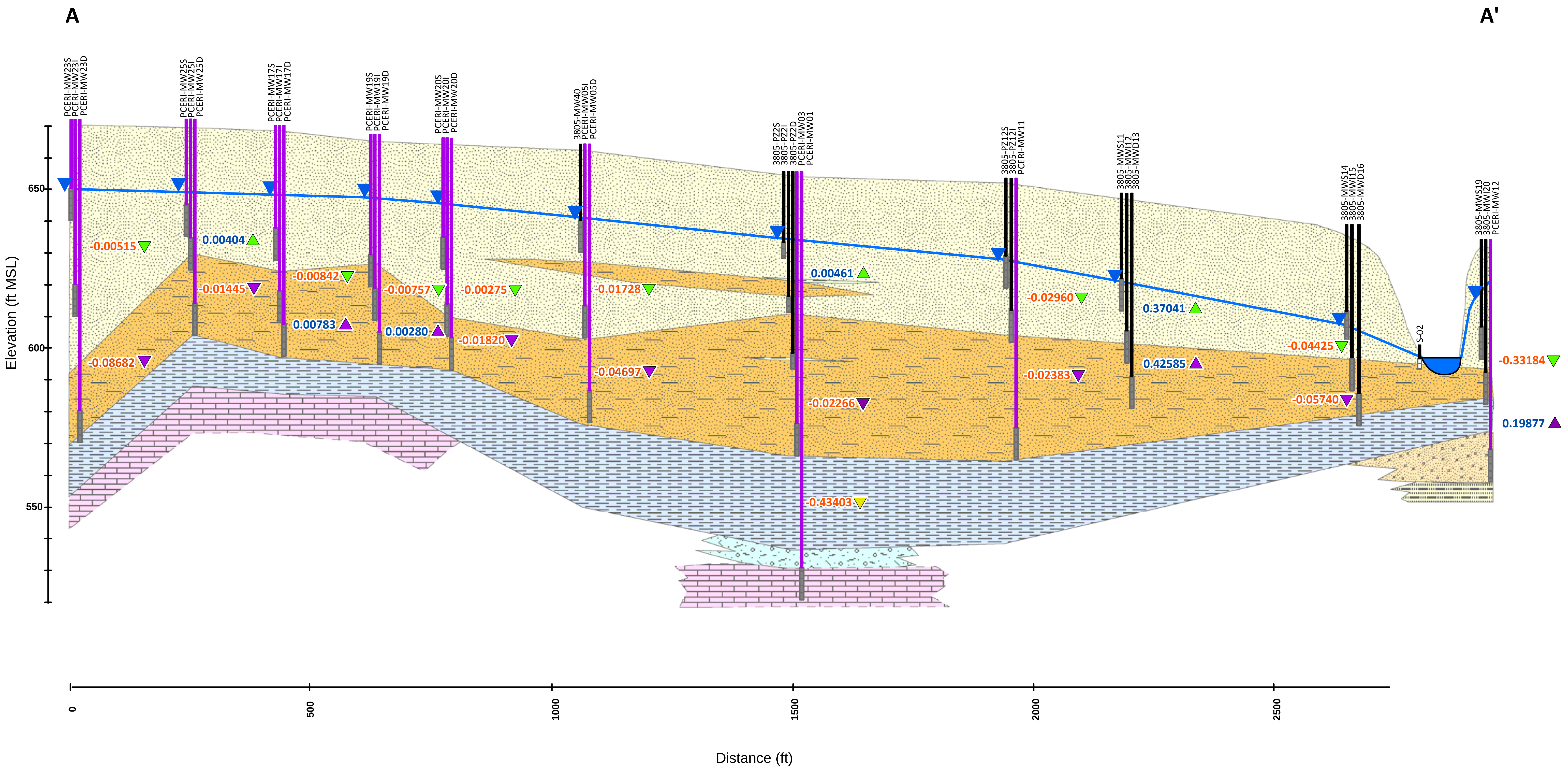
FIGURE 3-10

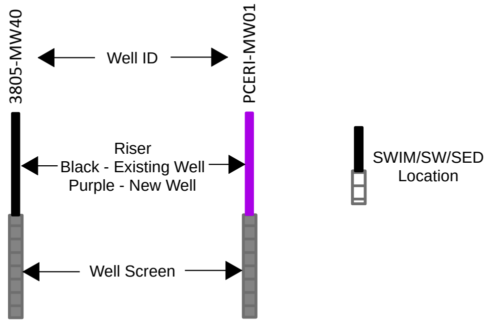
Aquifer Vertical Hydraulic Gradients Spring 2011

Remedial Investigation Report
For Chlorinated Solvent Contaminants
Fort Drum, NY



Lithology

- ▨ Sand
- ▨ Silty Sand
- ▨ Silt
- ▨ Clay
- ▨ Till
- ▨ Gravel
- ▨ Limestone
- ▨ Sandstone



-0.43403	Red Value Indicates a Downward Vertical Gradient
0.00461	Blue Value Indicates an Upward Vertical Gradient
△	Gradient Calculated Between the Shallow and Intermediate Wells
▽	Gradient Calculated Between the Intermediate and Deep Wells
▽	Gradient Calculated Between the Deep and Bedrock Wells
▼	Water Table (Basewide Fall 2011)

Gradient data calculated from the Fall 2011 well gauging event

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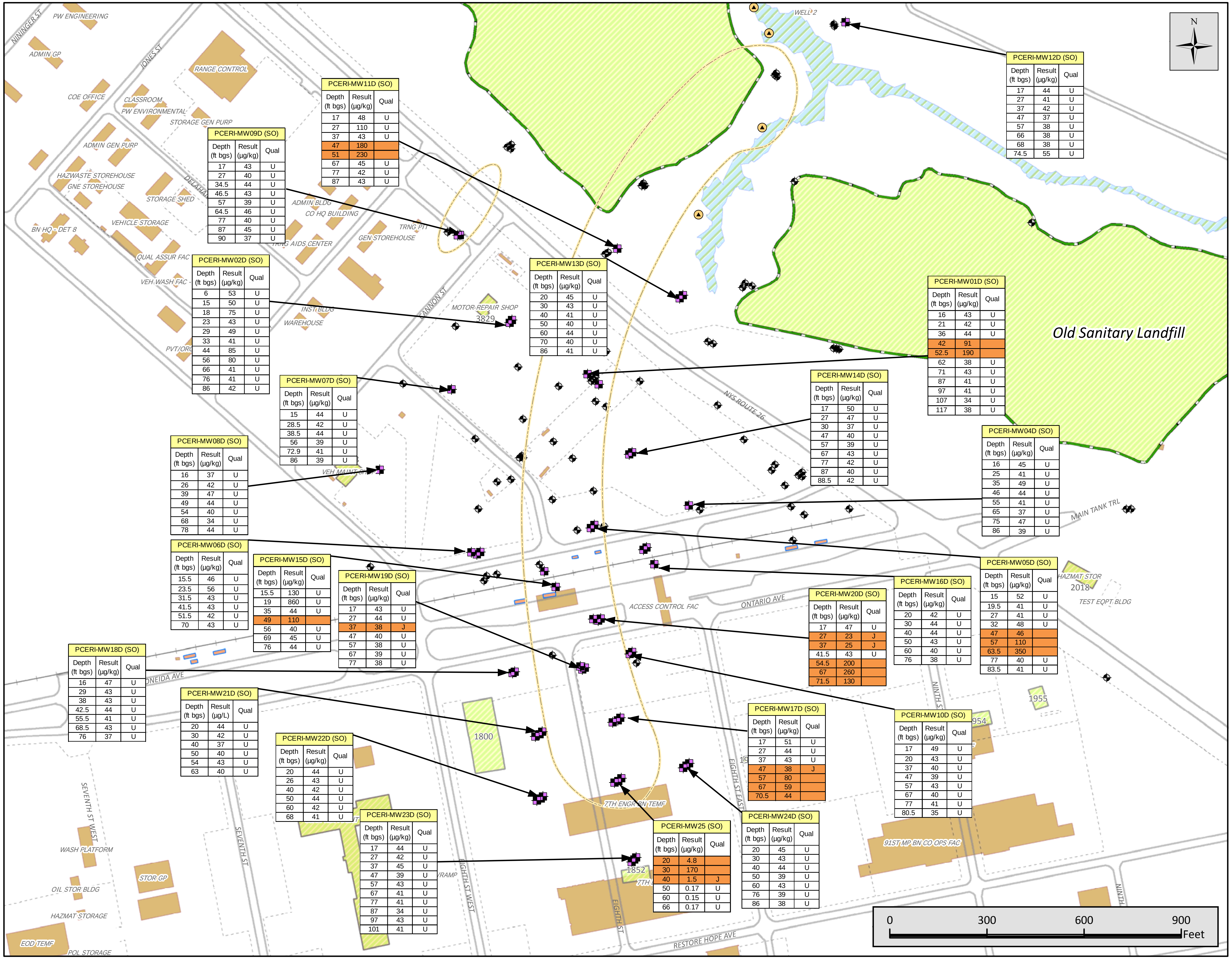
Created By: AES
Date: June 2012

FIGURE 3-11

Aquifer Vertical Hydraulic Gradients Fall 2011

Remedial Investigation Report
For Chlorinated Solvent Contaminants
Fort Drum, NY



PCERI-MW11D (SO)		
Depth (ft bgs)	Result (µg/kg)	Qual
17	48	U
27	110	U
37	43	U
47	180	
51	230	
67	45	U
77	42	U
87	43	U

PCERI-MW09D (SO)		
Depth (ft bgs)	Result (µg/kg)	Qual
17	43	U
27	40	U
34.5	44	U
46.5	43	U
57	39	U
64.5	46	U
77	40	U
87	45	U
90	37	U

PCERI-MW02D (SO)		
Depth (ft bgs)	Result (µg/kg)	Qual
6	53	U
15	50	U
18	75	U
23	43	U
29	49	U
33	41	U
44	85	U
56	80	U
66	41	U
76	41	U
86	42	U

PCERI-MW13D (SO)		
Depth (ft bgs)	Result (µg/kg)	Qual
20	45	U
30	43	U
40	41	U
50	40	U
60	44	U
70	40	U
86	41	U

PCERI-MW12D (SO)		
Depth (ft bgs)	Result (µg/kg)	Qual
17	44	U
27	41	U
37	42	U
47	37	U
57	38	U
66	38	U
68	38	U
74.5	55	U

PCERI-MW01D (SO)		
Depth (ft bgs)	Result (µg/kg)	Qual
16	43	U
21	42	U
36	44	U
42	91	
52.5	190	
62	38	U
71	43	U
87	41	U
97	41	U
107	34	U
117	38	U

PCERI-MW07D (SO)		
Depth (ft bgs)	Result (µg/kg)	Qual
15	44	U
28.5	42	U
38.5	44	U
56	39	U
72.9	41	U
86	39	U

PCERI-MW14D (SO)		
Depth (ft bgs)	Result (µg/kg)	Qual
17	50	U
27	47	U
30	37	U
47	40	U
57	39	U
67	43	U
77	42	U
87	40	U
88.5	42	U

PCERI-MW04D (SO)		
Depth (ft bgs)	Result (µg/kg)	Qual
16	45	U
25	41	U
35	49	U
46	44	U
55	41	U
65	37	U
75	47	U
86	39	U

PCERI-MW08D (SO)		
Depth (ft bgs)	Result (µg/kg)	Qual
16	37	U
26	42	U
39	47	U
49	44	U
54	40	U
68	34	U
78	44	U

PCERI-MW06D (SO)		
Depth (ft bgs)	Result (µg/kg)	Qual
15.5	46	U
23.5	56	U
31.5	43	U
41.5	43	U
51.5	42	U
70	43	U

PCERI-MW15D (SO)		
Depth (ft bgs)	Result (µg/kg)	Qual
15.5	130	U
19	860	U
35	44	U
49	110	
56	40	U
69	45	U
76	44	U

PCERI-MW19D (SO)		
Depth (ft bgs)	Result (µg/kg)	Qual
17	43	U
27	44	U
37	38	J
47	40	U
57	38	U
67	39	U
77	38	U

PCERI-MW05D (SO)		
Depth (ft bgs)	Result (µg/kg)	Qual
15	52	U
19.5	41	U
27	41	U
32	48	U
47	46	
57	110	
63.5	350	
77	40	U
83.5	41	U

PCERI-MW16D (SO)		
Depth (ft bgs)	Result (µg/kg)	Qual
20	42	U
30	44	U
40	44	U
50	43	U
60	40	U
76	38	U

PCERI-MW20D (SO)		
Depth (ft bgs)	Result (µg/kg)	Qual
17	47	U
27	23	J
37	25	J
41.5	43	U
54.5	200	
67	260	
71.5	130	

PCERI-MW18D (SO)		
Depth (ft bgs)	Result (µg/kg)	Qual
16	47	U
29	43	U
38	43	U
42.5	44	U
55.5	41	U
68.5	43	U
76	37	U

PCERI-MW21D (SO)		
Depth (ft bgs)	Result (µg/L)	Qual
20	44	U
30	42	U
40	37	U
50	40	U
54	43	U
63	40	U

PCERI-MW22D (SO)		
Depth (ft bgs)	Result (µg/kg)	Qual
20	44	U
26	43	U
40	42	U
50	44	U
60	42	U
68	41	U

PCERI-MW23D (SO)		
Depth (ft bgs)	Result (µg/kg)	Qual
17	44	U
27	42	U
37	45	U
47	39	U
57	43	U
67	41	U
77	41	U
87	34	U
97	43	U
101	41	U

PCERI-MW17D (SO)		
Depth (ft bgs)	Result (µg/kg)	Qual
17	51	U
27	44	U
37	43	U
47	38	J
57	80	
67	59	
70.5	44	

PCERI-MW10D (SO)		
Depth (ft bgs)	Result (µg/kg)	Qual
17	49	U
20	43	U
37	40	U
47	39	U
57	43	U
67	40	U
77	41	U
80.5	35	U

PCERI-MW25 (SO)		
Depth (ft bgs)	Result (µg/kg)	Qual
20	4.8	
30	170	
40	1.5	J
50	0.17	U
60	0.15	U
66	0.17	U

PCERI-MW24D (SO)		
Depth (ft bgs)	Result (µg/kg)	Qual
20	45	U
30	43	U
40	44	U
50	39	U
60	43	U
76	39	U
86	38	U

Legend

▪	**PCERI Monitoring Wells**
----	**Preliminary PCE Plume Outline**
⌖	**Monitoring Well Locations**
▲	**Seep Sample Location**
▭	**Landfill**
▨	**Potential Hazardous Waste Sources**
🟧	**Former UST**
----	**Fence Line**
—+—	**Rail Road**
—	**Paved Road**
▨	**Wetlands**
■	**Building**

🟧 Highlight indicates a PCE detection

Acronym Key:
UST: Underground Storage Tank
MW: Monitoring Well
ft bgs: Feet Below Ground Surface
µg/L: Microgram per Liter
µg/kg: Microgram per Kilogram

Qualifier Key:
U: Non-detect
J: Result has been estimated
D: Sample has been diluted

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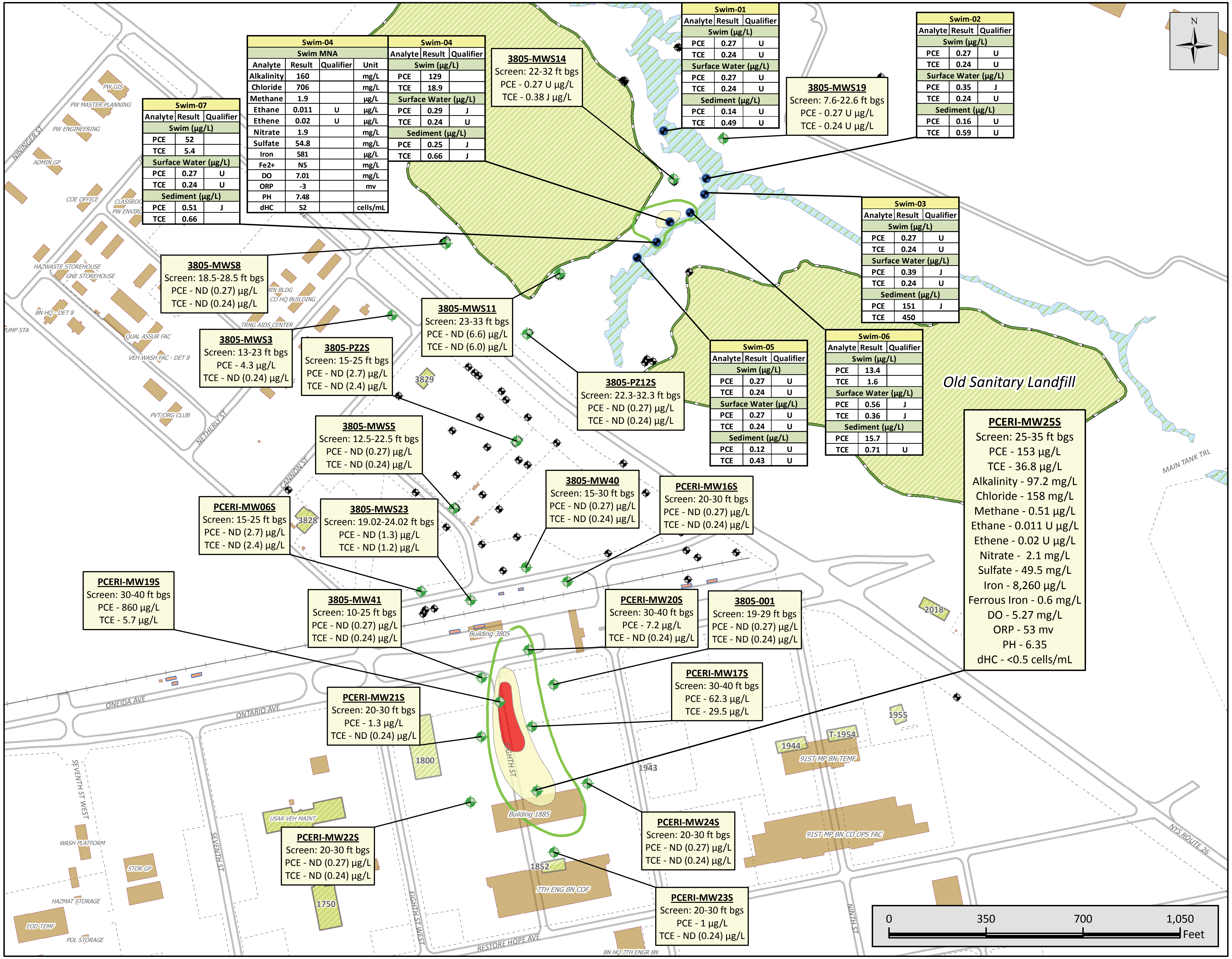
FIGURE 4-1

Soil PCE Results
Fall 2010

Remedial Investigation Report
For Chlorinated Solvent Contaminants
Fort Drum, NY



Swim-07		
Analyte	Result	Qualifier
Swim (µg/L)		
PCE	52	
TCE	5.4	
Surface Water (µg/L)		
PCE	0.27	U
TCE	0.24	U
Sediment (µg/L)		
PCE	0.51	J
TCE	0.66	

Swim-04			
Swim MNA			
Analyte	Result	Qualifier	Unit
Alkalinity	160		mg/L
Chloride	706		mg/L
Methane	1.9		µg/L
Ethane	0.011	U	µg/L
Ethene	0.02	U	µg/L
Nitrate	1.9		mg/L
Sulfate	54.8		mg/L
Iron	581		µg/L
Fe2+	NS		mg/L
DO	7.01		mg/L
ORP	-3		mv
PH	7.48		
dHC	52		cells/mL

Swim-04		
Analyte	Result	Qualifier
Swim (µg/L)		
PCE	129	
TCE	18.9	
Surface Water (µg/L)		
PCE	0.29	J
TCE	0.24	U
Sediment (µg/L)		
PCE	0.25	J
TCE	0.66	J

3805-MWS14
Screen: 22-32 ft bgs
PCE - 0.27 U µg/L
TCE - 0.38 J µg/L

Swim-01		
Analyte	Result	Qualifier
Swim (µg/L)		
PCE	0.27	U
TCE	0.24	U
Surface Water (µg/L)		
PCE	0.27	U
TCE	0.24	U
Sediment (µg/L)		
PCE	0.14	U
TCE	0.49	U

3805-MWS19
Screen: 7.6-22.6 ft bgs
PCE - 0.27 U µg/L
TCE - 0.24 U µg/L

Swim-02		
Analyte	Result	Qualifier
Swim (µg/L)		
PCE	0.27	U
TCE	0.24	U
Surface Water (µg/L)		
PCE	0.35	J
TCE	0.24	U
Sediment (µg/L)		
PCE	0.16	U
TCE	0.59	U

Swim-03		
Analyte	Result	Qualifier
Swim (µg/L)		
PCE	0.27	U
TCE	0.24	U
Surface Water (µg/L)		
PCE	0.39	J
TCE	0.24	U
Sediment (µg/L)		
PCE	151	J
TCE	450	

3805-MWS8
Screen: 18.5-28.5 ft bgs
PCE - ND (0.27) µg/L
TCE - ND (0.24) µg/L

3805-MWS11
Screen: 23-33 ft bgs
PCE - ND (6.6) µg/L
TCE - ND (6.0) µg/L

3805-MWS3
Screen: 13-23 ft bgs
PCE - 4.3 µg/L
TCE - ND (0.24) µg/L

3805-PZ2S
Screen: 15-25 ft bgs
PCE - ND (2.7) µg/L
TCE - ND (2.4) µg/L

3805-PZ12S
Screen: 22.3-32.3 ft bgs
PCE - ND (0.27) µg/L
TCE - ND (0.24) µg/L

Swim-05		
Analyte	Result	Qualifier
Swim (µg/L)		
PCE	0.27	U
TCE	0.24	U
Surface Water (µg/L)		
PCE	0.27	U
TCE	0.24	U
Sediment (µg/L)		
PCE	0.12	U
TCE	0.43	U

Swim-06		
Analyte	Result	Qualifier
Swim (µg/L)		
PCE	13.4	
TCE	1.6	
Surface Water (µg/L)		
PCE	0.56	J
TCE	0.36	J
Sediment (µg/L)		
PCE	15.7	
TCE	0.71	U

PCERI-MW25S
Screen: 25-35 ft bgs
PCE - 153 µg/L
TCE - 36.8 µg/L
Alkalinity - 97.2 mg/L
Chloride - 158 mg/L
Methane - 0.51 µg/L
Ethane - 0.011 U µg/L
Ethene - 0.02 U µg/L
Nitrate - 2.1 mg/L
Sulfate - 49.5 mg/L
Iron - 8,260 µg/L
Ferrous Iron - 0.6 mg/L
DO - 5.27 mg/L
ORP - 53 mv
PH - 6.35
dHC - <0.5 cells/mL

3805-MWS5
Screen: 12.5-22.5 ft bgs
PCE - ND (0.27) µg/L
TCE - ND (0.24) µg/L

3805-MW40
Screen: 15-30 ft bgs
PCE - ND (0.27) µg/L
TCE - ND (0.24) µg/L

PCERI-MW16S
Screen: 20-30 ft bgs
PCE - ND (0.27) µg/L
TCE - ND (0.24) µg/L

PCERI-MW06S
Screen: 15-25 ft bgs
PCE - ND (2.7) µg/L
TCE - ND (2.4) µg/L

3805-MWS23
Screen: 19.02-24.02 ft bgs
PCE - ND (1.3) µg/L
TCE - ND (1.2) µg/L

PCERI-MW19S
Screen: 30-40 ft bgs
PCE - 860 µg/L
TCE - 5.7 µg/L

3805-MW41
Screen: 10-25 ft bgs
PCE - ND (0.27) µg/L
TCE - ND (0.24) µg/L

PCERI-MW20S
Screen: 30-40 ft bgs
PCE - 7.2 µg/L
TCE - ND (0.24) µg/L

3805-001
Screen: 19-29 ft bgs
PCE - ND (0.27) µg/L
TCE - ND (0.24) µg/L

PCERI-MW17S
Screen: 30-40 ft bgs
PCE - 62.3 µg/L
TCE - 29.5 µg/L

PCERI-MW21S
Screen: 20-30 ft bgs
PCE - 1.3 µg/L
TCE - ND (0.24) µg/L

PCERI-MW24S
Screen: 20-30 ft bgs
PCE - ND (0.27) µg/L
TCE - ND (0.24) µg/L

PCERI-MW22S
Screen: 20-30 ft bgs
PCE - ND (0.27) µg/L
TCE - ND (0.24) µg/L

PCERI-MW23S
Screen: 20-30 ft bgs
PCE - 1 µg/L
TCE - ND (0.24) µg/L

Legend

- ⊕ Shallow Monitoring Wells
- ⊕ SWIM/SD/SW Locations
- ⊕ Monitoring Well Locations
- 🟧 Former UST
- ☐ Landfill
- ▨ Potential Hazardous Waste Sources
- - - - Fence Line
- ─┼─ Rail Road
- ── Paved Road
- ▨ Wetlands
- 🟫 Building

Shallow PCE Plume (µg/L)

- 🟩 5-99
- ☐ 100-500
- 🟥 >500

Acornym Key:
PCE - Tetrachloroethene
TCE - Trichloroethene
µg/L - micrograms per Liter
mg/L - miligrams per Liter
NS - Not Sampled
ft bgs - Feet Below Ground Surface
cells/mL - Cells per mililiter
Fe2+ - Ferrous iron
DO - Dissolved Oxygen
ORP - Oxygen-Reduction Potential
dHC - Dehalococcoides
MNA - Monitored Natural Attenuation
SWIM - Surface Water Interface Monitoring

Qualifier Key:
U - Non detect
J - Result has been Estimated
<0.5 cells/mL is a Non-detect

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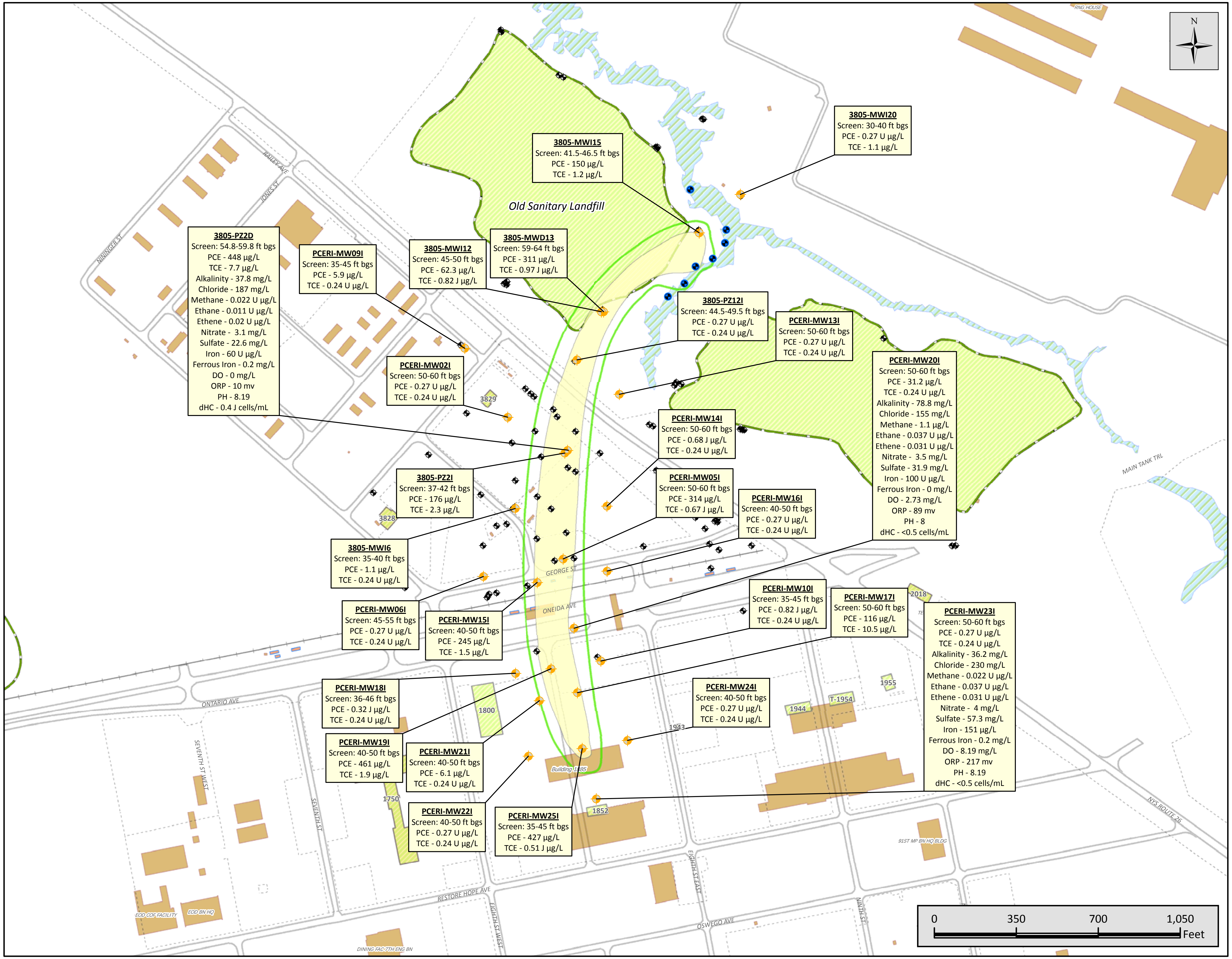
Date: May 2012

FIGURE 4-2

Shallow Aquifer Analytical Results Spring 2011

Remedial Investigation Report For Chlorinated Solvent Contaminants Fort Drum, NY



Legend

- 🟠 Intermediate Monitoring Wells
- 🔵 SWIM/SD/SW Locations
- ⊕ Monitoring Well Locations
- ▭ Landfill
- ▨ Potential Hazardous Waste Sources
- 🟥 Former UST
- ┄ Fence Line
- ┼ Rail Road
- ▨ Wetlands
- 🟫 Building
- ─ Paved Road

Intermediate PCE Plume (µg/L)

- ▭ 5
- ▭ 100-500

Acornym Key:

PCE - Tetrachloroethene
TCE - Trichloroethene
µg/L - micrograms per Liter
mg/L - miligrams per Liter
ft bgs - Feet Below Ground Surface
cells/mL - Cells per mililiter
DO - Dissolved Oxygen
ORP - Oxygen-Reduction Potential
dHC - Dehalococcoides
SWIM: Surface Water Interface Monitoring

Qualifier Key:

U - Non detect
J - Result has been Estimated
<0.5 cells/mL is a Non-detect

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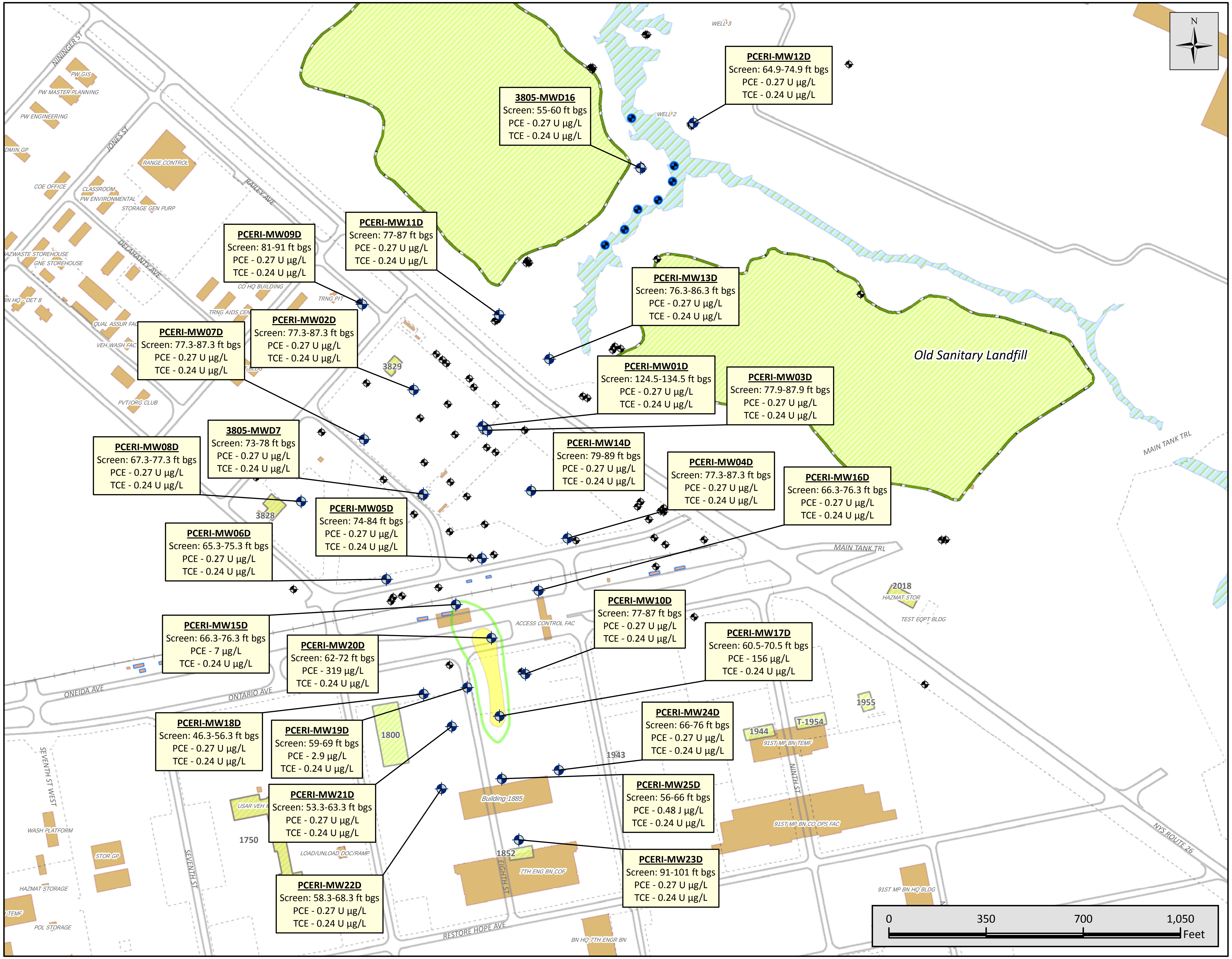
FIGURE 4-3

Intermediate Aquifer Analytical Results, Spring 2011

Remedial Investigation Report
For Chlorinated Solvent Contaminants
Fort Drum, NY



Legend

⊕ Deep Monitoring Wells
● SWIM/SD/SW Locations
◆ Monitoring Well Locations

Deep PCE Plume (µg/L)

▢ 5
🟨 100-500
▢ Landfill
▨ Potential Hazardous Waste Sources
🟧 Former UST
- - - Fence Line
—+— Rail Road
—— Paved Road
▨ Wetlands
🟫 Building

Acornym Key:
PCE - Tetrachloroethene
TCE - Trichloroethene
µg/L - micrograms per Liter
ft bgs - Feet Below Ground Surface
SWIM - Surface Water Interface Monitoring

Qualifier Key:
U - Non detect
J - Result has been Estimated

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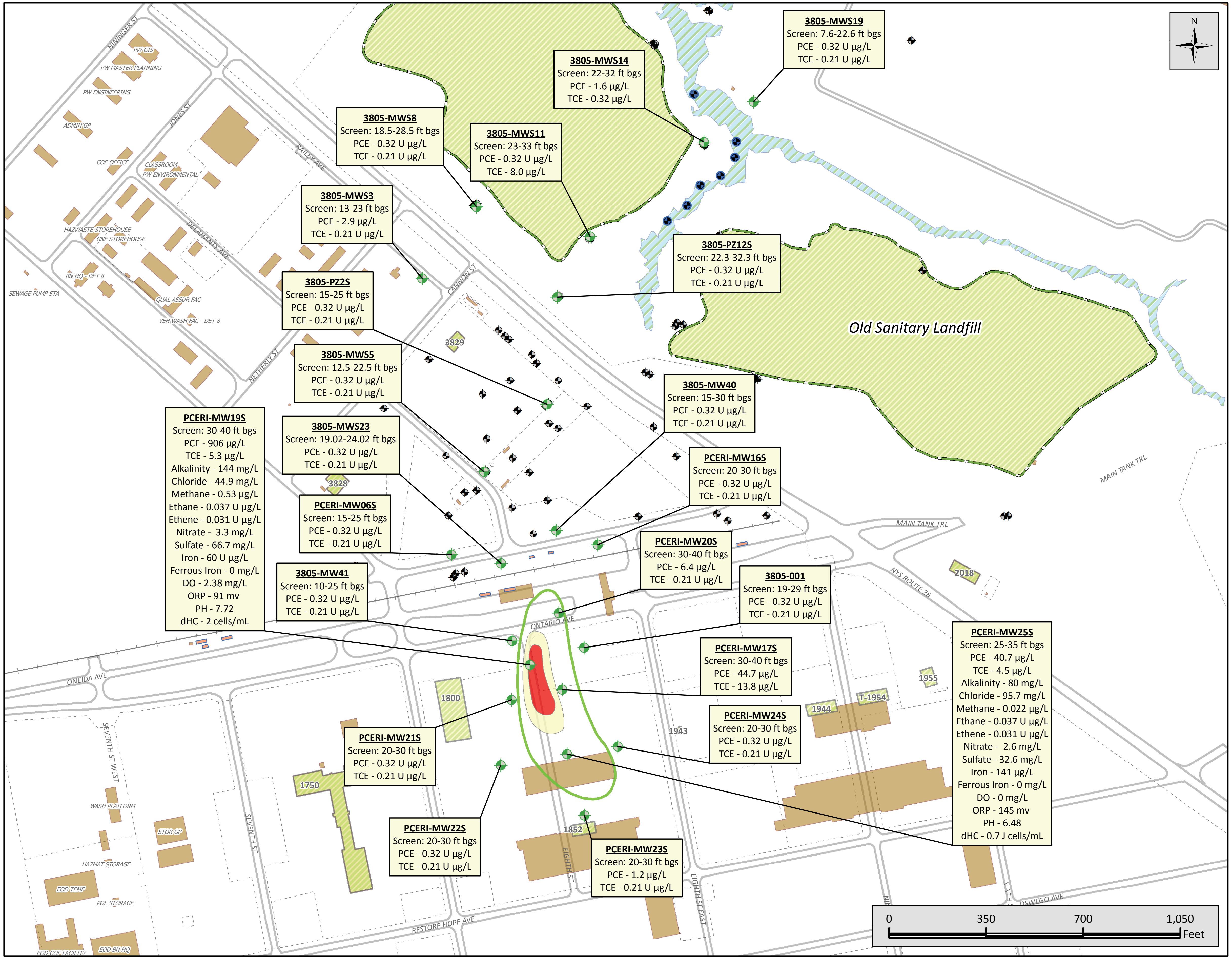
FIGURE 4-4

Deep Aquifer Analytical Results Spring 2011

Remedial Investigation Report
For Chlorinated Solvent Contaminants
Fort Drum, NY



Legend

- Shallow Monitoring Wells
- SWIM/SD/SW Locations
- Monitoring Well Locations
- Landfill
- ▨ Potential Hazardous Waste Sources
- 🟧 Former UST
- Fence Line
- Rail Road
- Paved Road
- ▨ Wetlands
- ■ Building

Shallow PCE Plume (µg/L)

- 🟩 5-99
- ■ 100-500
- 🟥 >500

Acronym Key:
PCE - Tetrachloroethene
TCE - Trichloroethene
µg/L - micrograms per Liter
mg/L - miligrams per Liter
ft bgs - Feet Below Ground Surface
cells/mL - Cells per mililiter
DO - Dissolved Oxygen
ORP - Oxygen-Reduction Potential
dHC - Dehalococcoides
SWIM - Surface Water Interface Monitoring

Qualifier Key:
U - Non detect
J - Result has been Estimated
<0.5 cells/mL is a Non-detect

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FIGURE 4-5

Shallow Aquifer Analytical Results
Fall 2011

**Remedial Investigation Report
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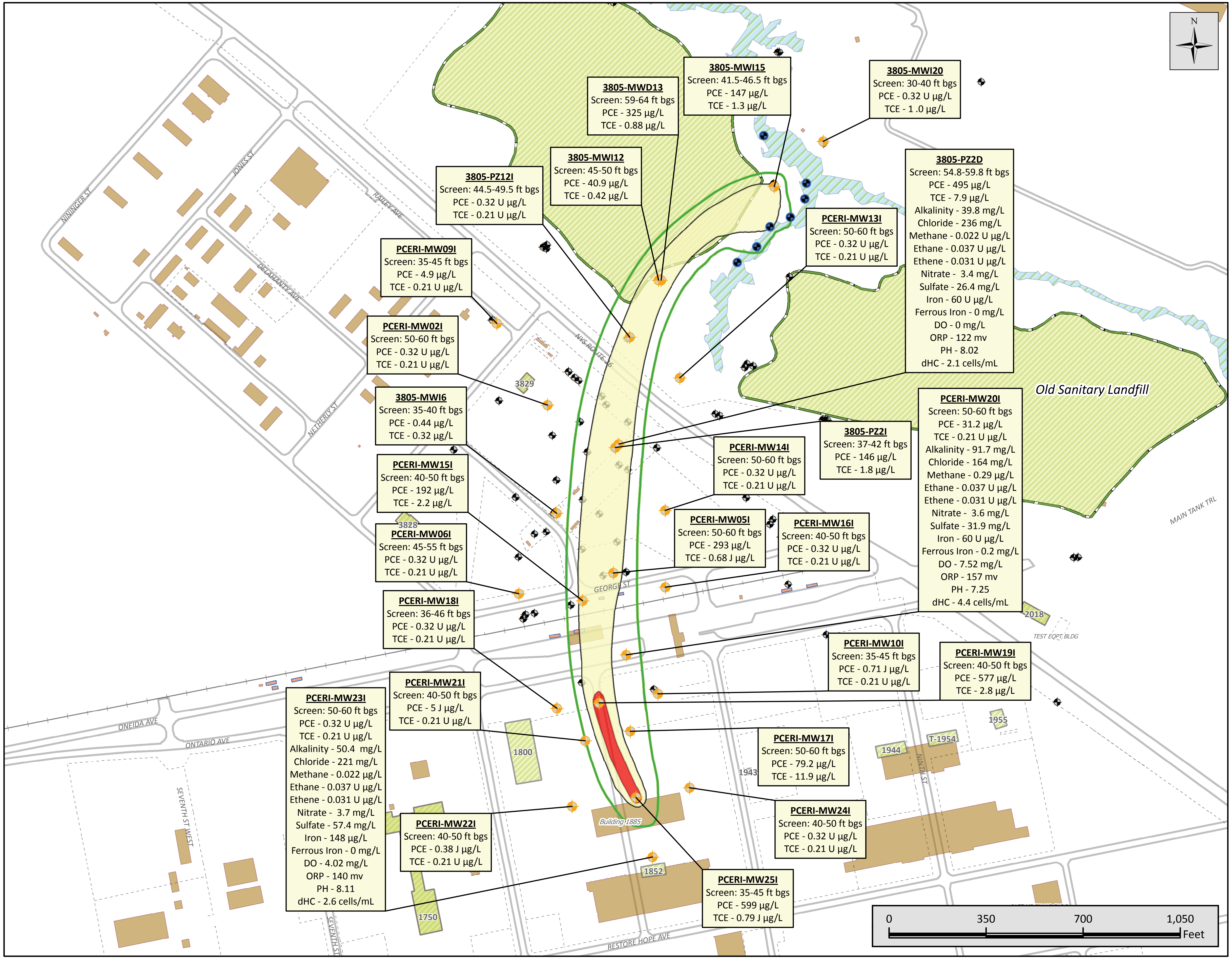
Fort Drum, NY**



3805-MWD13
Screen: 59-64 ft bgs
PCE - 325 µg/L
TCE - 0.88 µg/L

3805-MWI15
Screen: 41.5-46.5 ft bgs
PCE - 147 µg/L
TCE - 1.3 µg/L

3805-MWI20
Screen: 30-40 ft bgs
PCE - 0.32 U µg/L
TCE - 1 .0 µg/L

3805-MWI12
Screen: 45-50 ft bgs
PCE - 40.9 µg/L
TCE - 0.42 µg/L

3805-PZ12I
Screen: 44.5-49.5 ft bgs
PCE - 0.32 U µg/L
TCE - 0.21 U µg/L

3805-PZ2D
Screen: 54.8-59.8 ft bgs
PCE - 495 µg/L
TCE - 7.9 µg/L
Alkalinity - 39.8 mg/L
Chloride - 236 mg/L
Methane - 0.022 U µg/L
Ethane - 0.037 U µg/L
Ethene - 0.031 U µg/L
Nitrate - 3.4 mg/L
Sulfate - 26.4 mg/L
Iron - 60 U µg/L
Ferrous Iron - 0 mg/L
DO - 0 mg/L
ORP - 122 mv
PH - 8.02
dHC - 2.1 cells/mL

PCERI-MW13I
Screen: 50-60 ft bgs
PCE - 0.32 U µg/L
TCE - 0.21 U µg/L

PCERI-MW09I
Screen: 35-45 ft bgs
PCE - 4.9 µg/L
TCE - 0.21 U µg/L

PCERI-MW02I
Screen: 50-60 ft bgs
PCE - 0.32 U µg/L
TCE - 0.21 U µg/L

3805-MWI6
Screen: 35-40 ft bgs
PCE - 0.44 µg/L
TCE - 0.32 µg/L

PCERI-MW20I
Screen: 50-60 ft bgs
PCE - 31.2 µg/L
TCE - 0.21 U µg/L
Alkalinity - 91.7 mg/L
Chloride - 164 mg/L
Methane - 0.29 µg/L
Ethane - 0.037 U µg/L
Ethene - 0.031 U µg/L
Nitrate - 3.6 mg/L
Sulfate - 31.9 mg/L
Iron - 60 U µg/L
Ferrous Iron - 0.2 mg/L
DO - 7.52 mg/L
ORP - 157 mv
PH - 7.25
dHC - 4.4 cells/mL

3805-PZ2I
Screen: 37-42 ft bgs
PCE - 146 µg/L
TCE - 1.8 µg/L

PCERI-MW14I
Screen: 50-60 ft bgs
PCE - 0.32 U µg/L
TCE - 0.21 U µg/L

PCERI-MW15I
Screen: 40-50 ft bgs
PCE - 192 µg/L
TCE - 2.2 µg/L

PCERI-MW05I
Screen: 50-60 ft bgs
PCE - 293 µg/L
TCE - 0.68 J µg/L

PCERI-MW16I
Screen: 40-50 ft bgs
PCE - 0.32 U µg/L
TCE - 0.21 U µg/L

PCERI-MW06I
Screen: 45-55 ft bgs
PCE - 0.32 U µg/L
TCE - 0.21 U µg/L

PCERI-MW18I
Screen: 36-46 ft bgs
PCE - 0.32 U µg/L
TCE - 0.21 U µg/L

PCERI-MW10I
Screen: 35-45 ft bgs
PCE - 0.71 J µg/L
TCE - 0.21 U µg/L

PCERI-MW19I
Screen: 40-50 ft bgs
PCE - 577 µg/L
TCE - 2.8 µg/L

PCERI-MW21I
Screen: 40-50 ft bgs
PCE - 5 J µg/L
TCE - 0.21 U µg/L

PCERI-MW23I
Screen: 50-60 ft bgs
PCE - 0.32 U µg/L
TCE - 0.21 U µg/L
Alkalinity - 50.4 mg/L
Chloride - 221 mg/L
Methane - 0.022 µg/L
Ethane - 0.037 U µg/L
Ethene - 0.031 U µg/L
Nitrate - 3.7 mg/L
Sulfate - 57.4 mg/L
Iron - 148 µg/L
Ferrous Iron - 0 mg/L
DO - 4.02 mg/L
ORP - 140 mv
PH - 8.11
dHC - 2.6 cells/mL

PCERI-MW17I
Screen: 50-60 ft bgs
PCE - 79.2 µg/L
TCE - 11.9 µg/L

PCERI-MW22I
Screen: 40-50 ft bgs
PCE - 0.38 J µg/L
TCE - 0.21 U µg/L

PCERI-MW24I
Screen: 40-50 ft bgs
PCE - 0.32 U µg/L
TCE - 0.21 U µg/L

PCERI-MW25I
Screen: 35-45 ft bgs
PCE - 599 µg/L
TCE - 0.79 J µg/L

Legend

- ⊕ Intermediate Monitoring Wells
- ● SWIM/SD/SW Locations
- ⊕ Monitoring Well Locations

Intermediate PCE Plume (µg/L)

- ☐ 5-99
- 🟨 100-500
- 🟥 >500
- ☐ Landfill
- ▨ Potential Hazardous Waste Sources
- 🟧 Former UST
- - - - Fence Line
- —+— Rail Road
- —— Paved Road
- ▨ Wetlands
- 🟫 Building

Acornym Key:
PCE - Tetrachloroethene
TCE - Trichloroethene
µg/L - micrograms per Liter
mg/L - miligrams per Liter
ft bgs - Feet Below Ground Surface
cells/mL - Cells per mililiter
DO - Dissolved Oxygen
ORP - Oxygen-Reduction Potential
dHC - Dehalococcoides
SWIM - Surface Water Interface Monitoring

Qualifier Key:
U - Non detect
J - Result has been Estimated
<0.5 cells/mL is a Non-detect

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FIGURE 4-6

Intermediate Aquifer Analytical Results, Fall 2011

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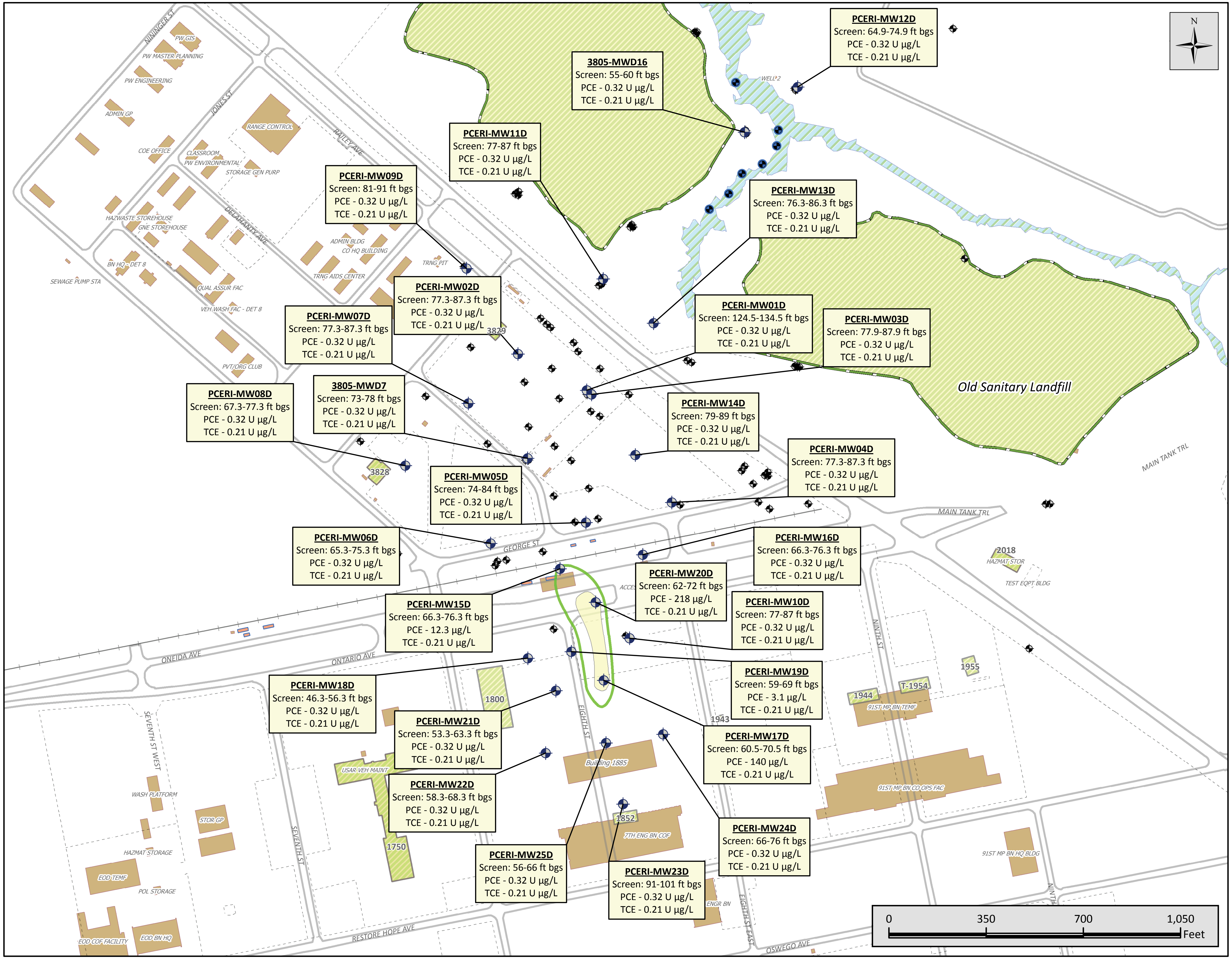
Fort Drum, NY**



Legend

- Deep Monitoring Wells
- SWIM/SD/SW Locations
- Monitoring Well Locations

Deep PCE Plume (µg/L)

- 5-99
- 100-500
- Landfill
- Potential Hazardous Waste Sources
- Former UST
- Fence Line
- Rail Road
- Paved Road
- Wetlands
- Building

Acronym Key:
PCE - Tetrachloroethene
TCE - Trichloroethene
µg/L - micrograms per Liter
ft bgs - Feet Below Ground Surface
SWIM - Surface Water Interface Monitoring

Qualifier Key:
U - Non detect

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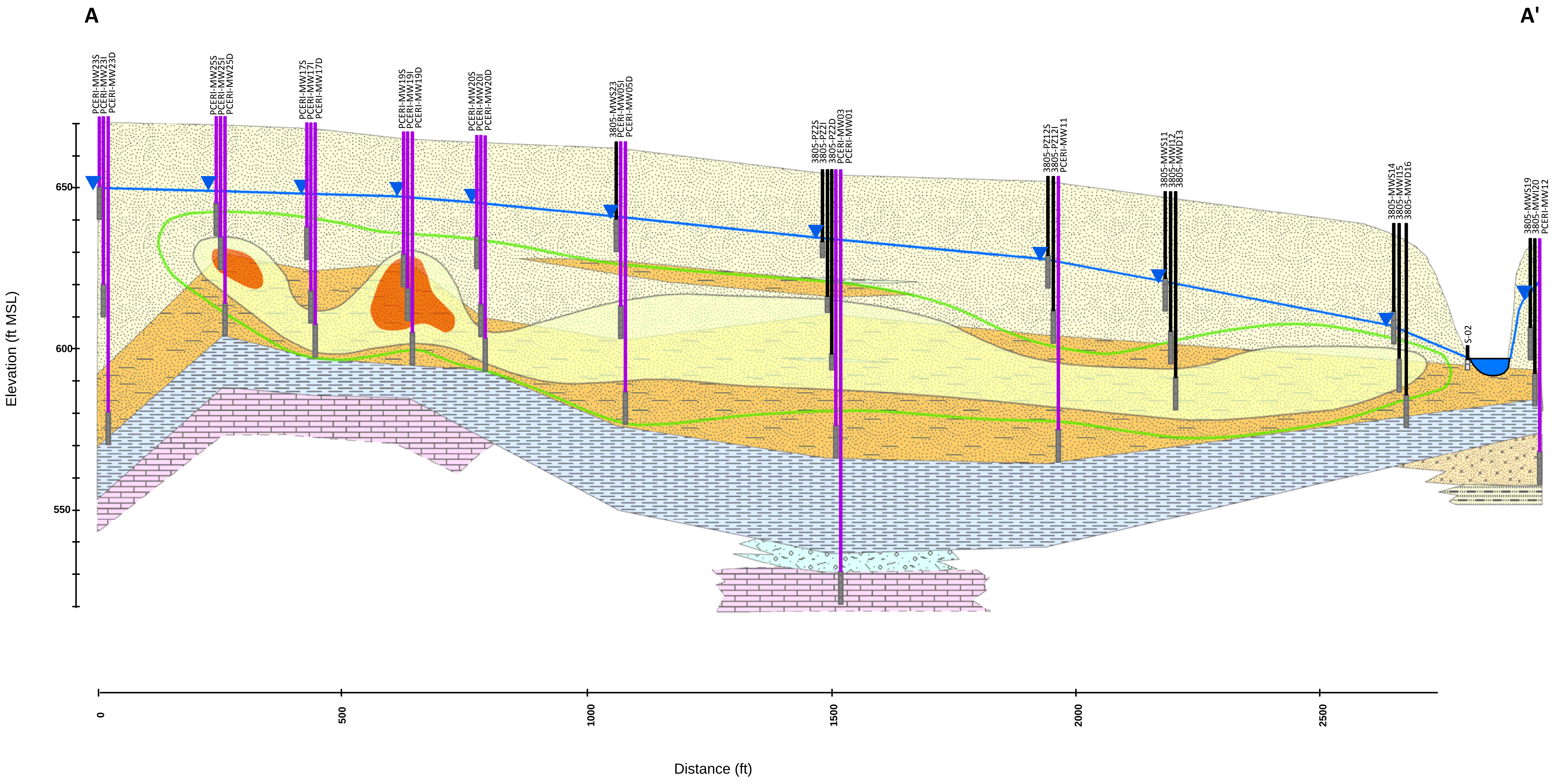
FIGURE 4-7

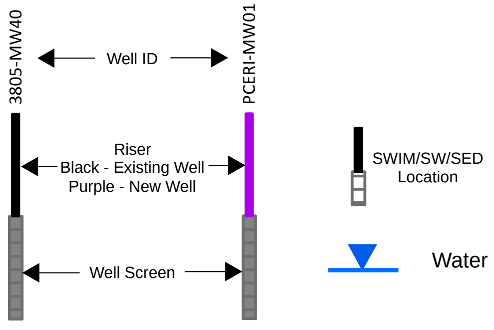
Deep Aquifer Analytical Results
Fall 2011

Remedial Investigation Report
For Chlorinated Solvent Contaminants
Fort Drum, NY



Lithology

- ▨ Sand
- ▨ Silty Sand
- ▨ Silt
- ▨ Clay
- ▨ Till
- ▨ Gravel
- ▨ Limestone
- ▨ Sandstone



PCE Plume Concentrations (µg/L)

- 🟩 5-99
- ▨ 100 - 499
- 🟧 > 500

▼ Water Table (Basewide Fall 2011)

Acronym Key:
µg/L - micrograms per Liter

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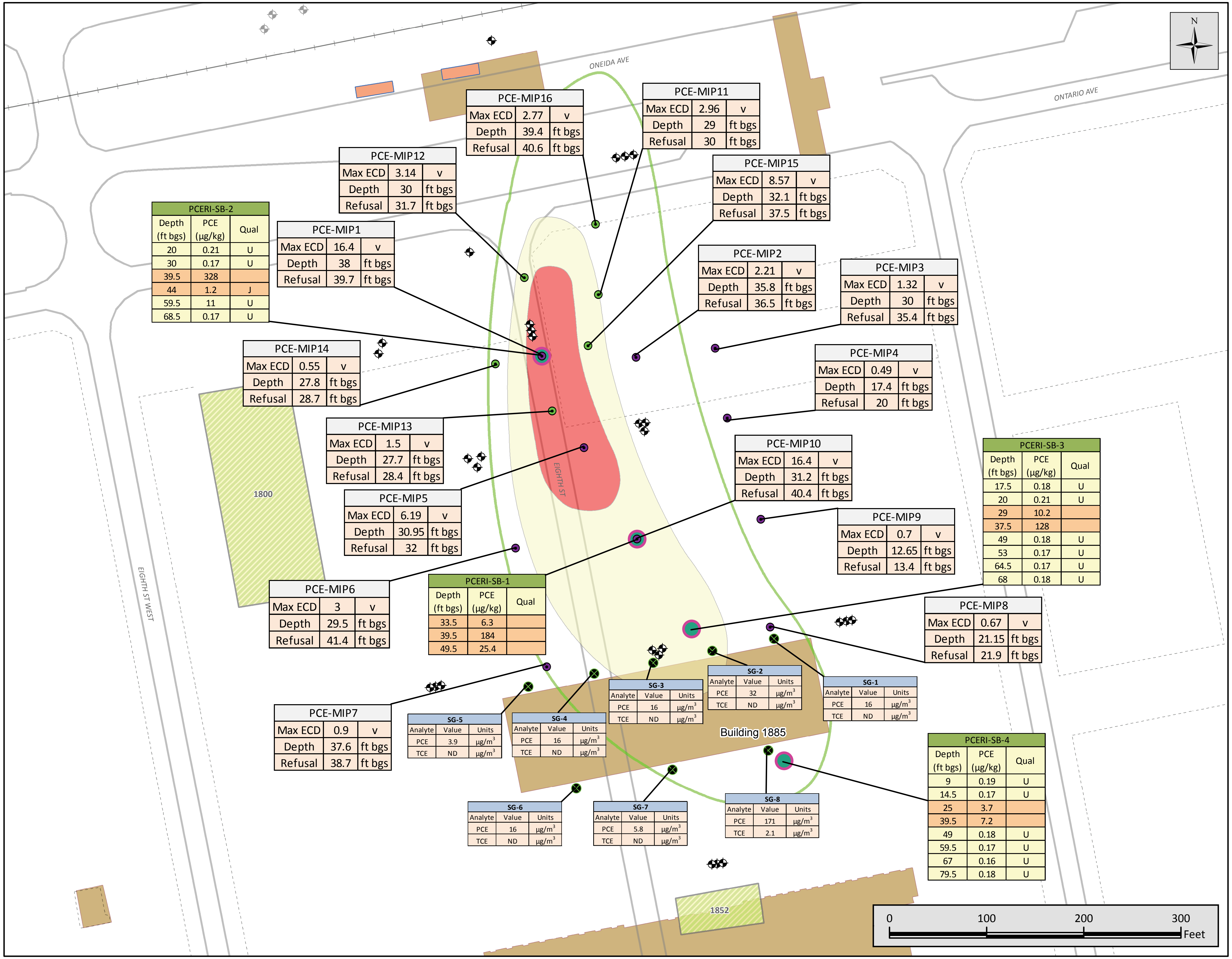
FIGURE 4-8

Cross-Section with
PCE Groundwater Plume
Fall 2011

Remedial Investigation Report
For Chlorinated Solvent Contaminants
Fort Drum, NY



PCE-MIP16		
Max ECD	2.77	v
Depth	39.4	ft bgs
Refusal	40.6	ft bgs

PCE-MIP11		
Max ECD	2.96	v
Depth	29	ft bgs
Refusal	30	ft bgs

PCE-MIP12		
Max ECD	3.14	v
Depth	30	ft bgs
Refusal	31.7	ft bgs

PCE-MIP15		
Max ECD	8.57	v
Depth	32.1	ft bgs
Refusal	37.5	ft bgs

PCERI-SB-2

Depth (ft bgs)	PCE (µg/kg)	Qual
20	0.21	U
30	0.17	U
39.5	328	
44	1.2	J
59.5	11	U
68.5	0.17	U

PCE-MIP1		
Max ECD	16.4	v
Depth	38	ft bgs
Refusal	39.7	ft bgs

PCE-MIP2		
Max ECD	2.21	v
Depth	35.8	ft bgs
Refusal	36.5	ft bgs

PCE-MIP3		
Max ECD	1.32	v
Depth	30	ft bgs
Refusal	35.4	ft bgs

PCE-MIP14		
Max ECD	0.55	v
Depth	27.8	ft bgs
Refusal	28.7	ft bgs

PCE-MIP4		
Max ECD	0.49	v
Depth	17.4	ft bgs
Refusal	20	ft bgs

PCE-MIP13		
Max ECD	1.5	v
Depth	27.7	ft bgs
Refusal	28.4	ft bgs

PCE-MIP10		
Max ECD	16.4	v
Depth	31.2	ft bgs
Refusal	40.4	ft bgs

PCERI-SB-3

Depth (ft bgs)	PCE (µg/kg)	Qual
17.5	0.18	U
20	0.21	U
29	10.2	
37.5	128	
49	0.18	U
53	0.17	U
64.5	0.17	U
68	0.18	U

PCE-MIP5		
Max ECD	6.19	v
Depth	30.95	ft bgs
Refusal	32	ft bgs

PCE-MIP9		
Max ECD	0.7	v
Depth	12.65	ft bgs
Refusal	13.4	ft bgs

PCE-MIP6		
Max ECD	3	v
Depth	29.5	ft bgs
Refusal	41.4	ft bgs

PCERI-SB-1

Depth (ft bgs)	PCE (µg/kg)	Qual
33.5	6.3	
39.5	184	
49.5	25.4	

PCE-MIP8		
Max ECD	0.67	v
Depth	21.15	ft bgs
Refusal	21.9	ft bgs

PCE-MIP7		
Max ECD	0.9	v
Depth	37.6	ft bgs
Refusal	38.7	ft bgs

SG-2

Analyte	Value	Units
PCE	32	µg/m^3
TCE	ND	µg/m^3

SG-3

Analyte	Value	Units
PCE	16	µg/m^3
TCE	ND	µg/m^3

SG-1

Analyte	Value	Units
PCE	16	µg/m^3
TCE	ND	µg/m^3

SG-5

Analyte	Value	Units
PCE	3.9	µg/m^3
TCE	ND	µg/m^3

SG-4

Analyte	Value	Units
PCE	16	µg/m^3
TCE	ND	µg/m^3

PCERI-SB-4

Depth (ft bgs)	PCE (µg/kg)	Qual
9	0.19	U
14.5	0.17	U
25	3.7	
39.5	7.2	
49	0.18	U
59.5	0.17	U
67	0.16	U
79.5	0.18	U

SG-6

Analyte	Value	Units
PCE	16	µg/m^3
TCE	ND	µg/m^3

SG-7

Analyte	Value	Units
PCE	5.8	µg/m^3
TCE	ND	µg/m^3

SG-8

Analyte	Value	Units
PCE	171	µg/m^3
TCE	2.1	µg/m^3

Legend

⊗	Soil Gas Locations
●	Initial MIP Points
●	Step Out MIP Points
●	Soil Borings
⊕	PCE RI Monitoring Wells
⊕	IRP Monitoring Wells

Shallow PCE Plume

(µg/L)

🟩	5
▨	100-500
🟥	>500
▨	Potential Hazardous Waste Sources
🟧	Former UST
- - -	Fence Line
—+—	Rail Road
—	Paved Road
▨	Building

Acronym Key:
MIP - Membrane Interface Probe
ECD - Electron Capture Detector
PID - Photoionization Detector
SG - Soil Gas Location
PCE - Tetrachloroethylene
TCE - Trichloroethylene
ft bgs - feet below ground surface
v - volts
µg/m^3 - micrograms per cubic meter
µg/kg - micrograms per kilogram
µg/L - micrograms per Liter

Qualifier Key:
U - Non detect

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FIGURE 4-9

Source Area Investigation Results

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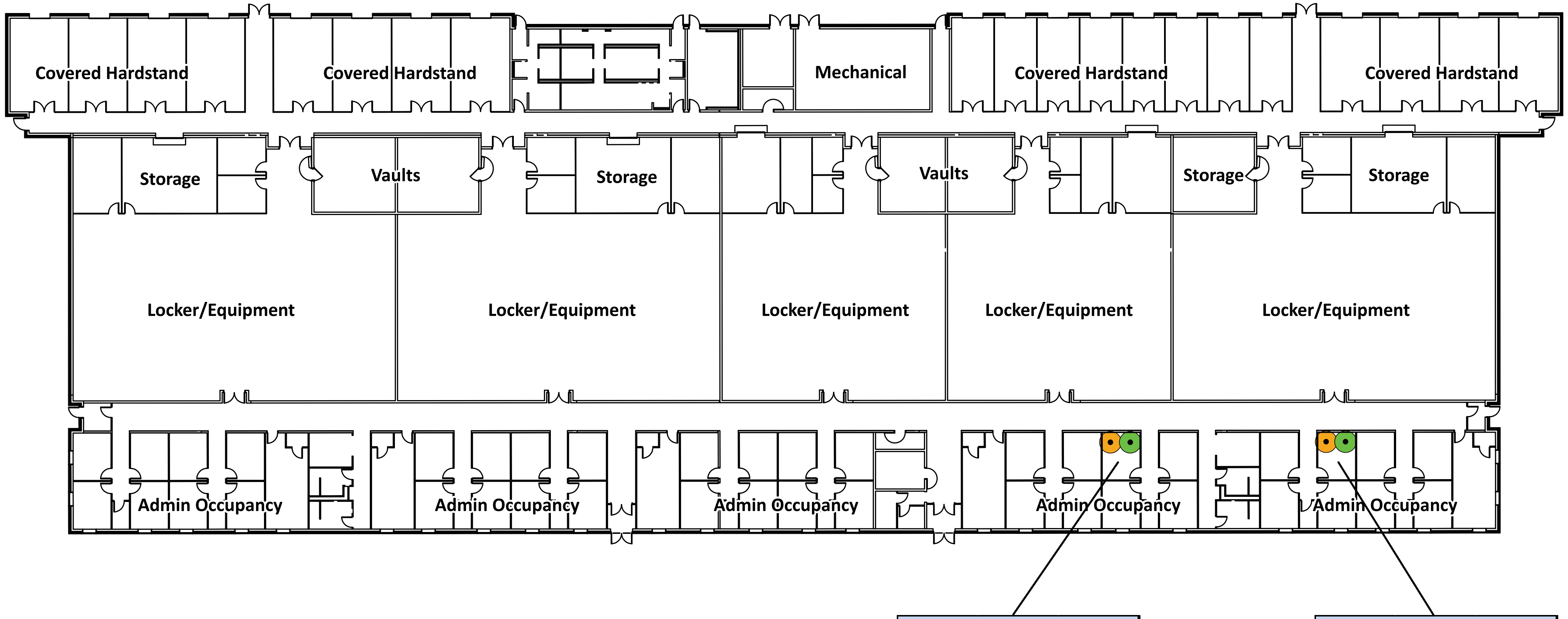

Sample Pair 5		
Sub-Slab Sample		
Analyte	Value	Units
PCE	4.7	µg/m^3
TCE	0.13 U	µg/m^3
Benzene	2.7	µg/m^3
Ambient Air Sample		
Analyte	Value	Units
PCE	0.19 U	µg/m^3
TCE	0.18 U	µg/m^3
Benzene	0.19 J	µg/m^3

Sample Pair 6		
Sub-Slab Sample		
Analyte	Value	Units
PCE	4.7	µg/m^3
TCE	0.13 U	µg/m^3
Benzene	6.1	µg/m^3
Ambient Air Sample		
Analyte	Value	Units
PCE	0.19 U	µg/m^3
TCE	0.18 U	µg/m^3
Benzene	0.70	µg/m^3

Legend

Vapor Intrusion Sample Locations

- 🟢 **Indoor Air Sample Location**
- 🟠 **Sub-Slab Soil Vapor Sample Location**

Acronym Key:
PCE - Tetrachloroethene
TCE - Trichloroethene
µg/m^3 - micrograms per cubic meter

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FIGURE 4-10

Building 1880 Indoor Air Sampling Results February 2012

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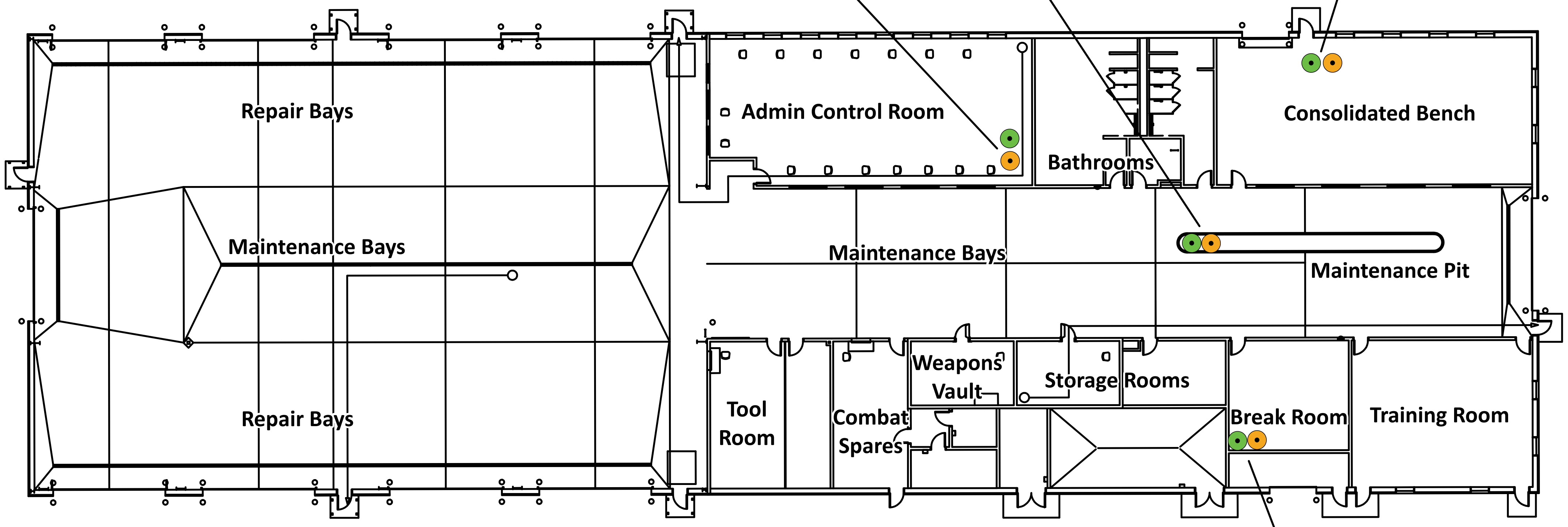
Fort Drum, NY

Sample Pair 1		
Sub-Slab Sample		
Analyte	Value	Units
PCE	9.5	µg/m^3
TCE	0.70 U	µg/m^3
Benzene	26	µg/m^3
Ambient Air Sample		
Analyte	Value	Units
PCE	0.19 U	µg/m^3
TCE	0.18 U	µg/m^3
Benzene	4.2	µg/m^3

Sample Pair 3		
Sub-Slab Sample		
Analyte	Value	Units
PCE	151	µg/m^3
TCE	1.7	µg/m^3
Benzene	2.9	µg/m^3
Ambient Air Sample		
Analyte	Value	Units
PCE	0.19 U	µg/m^3
TCE	0.18 U	µg/m^3
Benzene	8.9	µg/m^3

Sample Pair 2		
Sub-Slab Sample		
Analyte	Value	Units
PCE	8.8	µg/m^3
TCE	0.70 U	µg/m^3
Benzene	3.1	µg/m^3
Ambient Air Sample		
Analyte	Value	Units
PCE	0.19 U	µg/m^3
TCE	0.18 U	µg/m^3
Benzene	5.1	µg/m^3



Sample Pair 4		
Sub-Slab Sample		
Analyte	Value	Units
PCE	8.8	µg/m^3
TCE	1.8	µg/m^3
Benzene	52.1	µg/m^3
Ambient Air Sample		
Analyte	Value	Units
PCE	0.19 U	µg/m^3
TCE	0.18 U	µg/m^3
Benzene	7.3	µg/m^3

N

0 30 60 90 Feet

Legend

— 1885 Floorplan

Vapor Intrusion Sample Locations

● Indoor Air Sample Location

● Sub-Slab Vapor Sample Location

Acronym Key:
PCE - Tetrachloroethene
TCE - Trichloroethene
µg/m^3 - micrograms per cubic meter

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FIGURE 4-11

Building 1885 Indoor Air Sampling Results February 2012

Remedial Investigation Report
For Chlorinated Solvent Contaminants
Fort Drum, NY

APPENDIX C

Appendices C and D, Ex-Situ Treatment Technologies for Groundwater (from Presumptive Response Strategy and Ex-Situ Treatment Technologies for Contaminated Ground Water at CERCLA Sites. Directive 9283.1-12. EPA 540/R-96/023. October 1996.)

APPENDIX C (from USEPA, 1996)

Ex-Situ Treatment Technologies for Ground Water

Appendix C1:	Ex-Situ **Technologies Considered** in Sample of 25 Sites
Appendix C2:	**Other Components** Needed for Treatment Trains
Appendix C3:	**Information Needed** for Selection of Technologies and Design of Treatment Train
Appendix C4:	**Advantages and Limitations** of Presumptive Treatment Technologies

Appendix C1: Ex-Situ Technologies Considered in Sample of 25 Sites

Technologies that were **considered** for treatment of extracted ground in the sample of 25 sites reviewed in detail (EPA, 1996b) are listed below. These technologies were either considered in the feasibility study (FS), or considered and/or selected in the record of decision (ROD) or remedial design. The technologies are listed according to overall process type, and by design style within each type. Those technologies identified as **presumptive technologies** are also indicated. For further information on how presumptive technologies were identified, refer to Section 3.2 of this guidance and EPA, 1996b.

For Treatment of **Organic** Contaminants:

Presumptive Technologies:

Air stripping:

- Packed tower
  - Ambient temperature
  - Higher temperature
- Aeration methods
  - Ambient temperature
  - Higher temperature
- Cascade falls

Granular activated carbon (GAC)

Chemical/UV oxidation:

- Chemical oxidation alone
  - Ozone
  - Hydrogen peroxide
  - Chlorine compounds
  - Potassium permanganate
- Chemical with UV oxidation
  - Ozone
  - Hydrogen peroxide
- UV oxidation alone (photolysis)
- Alkaline chlorination (**for cyanide**)
- Unspecified oxidation methods

Aerobic biological reactors:

- Attached growth
  - Trickling filter
  - Rotating biological contactors
  - Fixed bed
- Suspended growth
  - Activated sludge
  - Sequencing batch reactors
  - Aeration ponds/lagoons
  - Unspecified suspended growth
- Unspecified aerobic reactors

For Treatment of **Metals**:

Chemical precipitation:

- Hydroxide precipitants
  - Sodium hydroxide
  - Lime
  - With prior chemical reduction
- Sulfide precipitants
  - Sulfur dioxide
  - Sodium sulfide
  - Sodium bisulfide/bisulfites
  - With prior chemical reduction
  - Unspecified sulfide precipitant
- Other precipitation methods
  - Ferrous sulfate
  - Potassium permanganate
  - Activated consumable element
  - Unspecified chemical precipitation

Ion exchange/adsorption:

- Fixed bed
  - Impregnated/synthetic resin
  - Activated alumina
- Electrodialysis
- Unspecified ion exchange

Electrochemical methods:

- Electrochemical reduction
- Magnetically activated

Aeration of Background Metals:

- Aeration basin
- Cascade aeration
- Other aeration methods

Appendix C1: Ex-Situ Technologies Considered in Sample of 25 Sites (continued)

For Treatment of **Organic** Contaminants:

Other Technologies Considered:

Chemical treatment:
- Hydrolysis
- Catalytic dehydrochlorination
- Catalytic dechlorination
- Chlorinolysis

Thermal Destruction:
- Incineration
- Calcination
- Wet air oxidation
- Supercritical water oxidation
- Microwave discharge/plasma

High temperature separation:
- Steam stripping
- Distillation

Membrane filtration:
- Reverse osmosis
- Ultrafiltration

Anaerobic biological treatment:
- Anaerobic biological reactor
- Enzymatic degradation

Liquid-liquid extraction:
- Solvent extraction
- Liquid carbon dioxide extraction

Evaporation:
- Evaporation basin

Land treatment:
- Surface spreading
- Spray irrigation

For Treatment of **Metals**:

Granular activated carbon (for metals)

Reverse Osmosis

Biological treatment of metals

Appendix C2: Other Components Needed for Treatment Trains [1]

Solid or Liquid Separation Technologies

- Oil/grease separation[4]
- Filtration[5]
- Coagulation[5] (or flocculation)
- Clarification[5] (or sedimentation)

Effluent Polishing Technologies[2]

- Activated carbon
- Ion exchange
- Neutralization

Vapor Phase Treatment Technologies[3]

- Activated carbon
- Resin adsorption
- Catalytic oxidation
- Thermal incineration
- Acid gas scrubbing
- Condensation

General Sequence of Unit Processes Used in Aqueous Treatment Trains

Sequence	Unit Treatment Process	Treatment Stage
Begin	Equalize inflow	Pretreatment
	Separate solid particles	Pretreatment
	Separate oil/grease (NAPLs)	Pretreatment
	Remove metals	Treatment
	Remove volatile organics	Treatment
	Remove other organics	Treatment
	Polish organics[2]	Post-treatment
	Polish metals	Post-treatment
End	Adjust pH, if required	Post-treatment

NOTES:

[1] In addition to the presumptive technologies listed in the guidance, other treatment components are needed either prior to (pretreatment) or subsequent to (post-treatment) the presumptive technologies. This listing is not intended to be presumptive. Not listed are technologies that may be required for treatment residuals, such as spent carbon.

[2] Effluent polishing technologies are those used for the final stage of treatment prior to discharge, and can include pH adjustment (neutralization) as well as additional removal of aqueous constituents.

[3] Vapor phase contaminants released during water treatment may need to be contained and treated. This includes organic contaminants volatilized during air stripping, from biological treatment, or other gases released from chemical oxidation, reduction or biologic processes (e.g., hydrochloric acid, hydrogen sulfide, methane, etc.).

[4] Methods for separation of oil and/or grease from water include, but are not limited to, gravity separation and dissolved air floatation. These methods can be used to remove NAPLs from the extracted ground water.

[5] These technologies can be used to remove solid particles at the beginning of the treatment train or for removal of other solids resulting from chemical precipitation, chemical/UV oxidation or biological treatment.

Appendix C3: Information Needed for Selection of Technologies and Design of Treatment Train

Information Needed	Purpose of Information
1. Total extraction flow rate: - Total extracted flow - Flow variability - Uncertainty of estimate	**Inflow** to the treatment system is the total flow from all extraction wells. Since this flow must also be discharged, large flows may determine the availability of some discharge options. Flow rate and concentration determines the mass loading (mass per unit water volume) of each contaminant entering the treatment system. The mass loading determines the dimensions and capacities of treatment vessels, and whether continuous flow or batch design are used for each treatment unit. Flow is also a factor for selecting among the presumptive treatment technologies because some are less cost effective for high or low flows. **Variable inflow** rates may require use of flow equalization tanks, batch instead of continuous flow operation or use of modular treatment units that can be added or subtracted from the treatment train. Some technologies can handle variable flow more easily than others. Variable extraction rates may result from short-term operational changes, seasonal changes or phased well installation. **Uncertainty** in the flow estimate can result from natural variability of aquifer properties over the site, and from the method used to measure these properties. Since flow is a critical design parameter, additional characterization may be needed to reduce the level of uncertainty. **Estimates of the total extraction rate should be based on pumping type aquifer tests, since this method provides a much better estimate of average aquifer properties than other methods.**

Appendix C3: Information Needed for Selection of Technologies and Design of Treatment Train (continued)

Information Needed	Purpose of Information
2. Discharge options and effluent requirements: ● Options available ● Target effluent concentrations, each option - Contaminants - Contaminant degradation products - Treatment additives - Natural constituents - Water quality parameters ● Other requirements, each option - Regulatory - Operational ● Community concerns or preferences	Options for discharge of treated ground water could include: discharge to surface waters; discharge to a drinking water system; reuse or recycling for other purposes (e.g., industrial processes); infiltration or reinjection to shallow subsurface or reinjection to the same aquifer; or discharge to POTW. Target effluent concentration levels for both contaminants and naturally occurring constituents may be markedly different for each discharge option. Effluent requirements could include those for chemicals added during treatment, contaminant degradation products, naturally occurring constituents (e.g., arsenic), and water quality parameters (e.g., suspended solids) in addition to maximum concentration levels for chemicals of concern. These requirements will determine the overall level of treatment needed, which in turn determines the type of components needed in the treatment train and is a critical factor in selecting appropriate treatment technologies. Each discharge option may have different water quality requirements for the treated effluent, from both a **regulatory** and **operational** standpoint. For example, reinjection to the subsurface must meet substantive federal and/or state requirements for underground injection (regulatory) as well as minimize chemical and biological clogging of injection wells or infiltration lines (operational). Use of the best available technology (BAT) could also be a regulatory requirement. The **affected community** may also have concerns or preferences regarding the type of discharge. **Target effluent concentrations** determine the overall removal efficiency the treatment train must attain for each constituent. For example, if the target effluent level is 10 mg/L and the inflow concentration is 1000 mg/L, then the treatment train must attain an overall removal efficiency of 99.0 percent (1000 - 0.99(1000) = 10). The treatment train may need to include more than one type of technology, or multiple units of a single technology, in order to attain the required overall removal efficiency.

Appendix C3: Information Needed for Selection of Technologies and Design of Treatment Train (continued)

Information Needed	Purpose of Information
3. Water quality of treatment influent: ● Contaminant types and concentrations: - Inorganic chemicals - Organic chemicals - Concentration changes over time - Nonaqueous phase liquids (NAPLs) ● Naturally occurring constituents: - Major cations (metals) and anions - Organic chemicals - Radionuclides	**Contaminant types and concentrations** must be estimated for the total flow entering the treatment system. Since some technologies are more effective in removing certain contaminant types, this is an important technology selection factor. Inflow concentrations are needed to determine the removal efficiency of the treatment train, as discussed above. **The design should consider the potential for inflow concentrations to change over time.** Contaminant concentrations usually decrease as remediation progresses. Also, short term increases may occur if a "hot spot" of more highly contaminated ground water is captured by the extraction system. Samples obtained from **pumping type aquifer tests provide better estimates of average contaminant concentrations**, because such samples are obtained from a relatively large aquifer volume. If present, subsurface **NAPLs** (refer to Appendix A1) may become entrained in the extracted ground water. These immiscible liquids should be removed in a pretreatment step (process used prior to other treatment methods). Also, a specialized extraction system may be needed to remove free-phase NAPLs from the subsurface. **Naturally occurring** or non-site related constituents may need to be removed to prevent interference with treatment processes and may be a factor in technology selection. **Metals** such as iron, manganese, and calcium can leave mineral deposits (scaling) on air stripper packing and on activated carbon or other treatment media. If not accounted for, these metals can also cause premature exhaustion of ion exchange capacity and increased consumption of reagents in chemical oxidation or precipitation processes. Iron also promotes biological fouling in air strippers. Heavy metals (e.g., lead, mercury) and cyanides can be toxic to microorganisms in biological reactors. Metals can also form deposits on well screens of extraction or reinjection wells (encrustation) or promote biological fouling (clogging) on well screens.

Appendix C3: Information Needed for Selection of Technologies and Design of Treatment Train (continued)

Information Needed	Purpose of Information
3. Water quality of influent (continued): ● Other water quality parameters: - Indicator parameters - Design parameters	Dissolved **organic constituents** (e.g., from decay of organic materials or from landfill leachate) can interfere with adsorption of targeted compounds and can cause premature exhaustion of activated carbon. Metal-organic complexes can interfere with chemical oxidation or precipitation processes. If present, naturally occurring **radionuclides** can accumulate in treatment media or residuals (e.g., activated carbon or chemical sludges) resulting in potential exposure hazards for personnel and additional transportation and disposal considerations. Other water quality parameters are used as effluent quality standards, indicator parameters, or design parameters for treatment processes. **Indicator parameters** are used to indicate the presence of other constituents. For example, total dissolved carbon (TDC) is a measure of the relative level of dissolved organic constituents. Gross alpha and gross beta particle activity are relatively simple measurements that indicate the relative abundance of **naturally occurring radionuclides**. Other indicator parameters include: total dissolved solids (TDS), chemical oxygen demand (COD), biological oxygen demand (BOD) and total suspended solids (TSS). Temperature and pH are **design parameters** for most treatment processes. Also, high levels of total suspended solids (TSS) in extracted ground water may indicate that extraction wells are not properly designed or developed. Most treatment technologies require that suspended solids in excess of certain level be removed during pretreatment, where acceptable levels may differ for each technology.

Appendix C3: Information Needed for Selection of Technologies and Design of Treatment Train (continued)

Information Needed	Purpose of Information
4. Treatability information: ● From technical literature ● Treatability studies - Laboratory screening - Bench-scale testing - Pilot-scale testing ● Modeling predictions ●Projections of effluent quality	Treatability information is needed to select technology types and design styles from among the presumptive technologies; and for selection and design of other components of the treatment train. The particular mix of contaminants and naturally occurring constituents can vary considerably for different sites. Treatability information is available in the **technical literature** for some technologies, including air stripping and granular activated carbon (GAC). **Treatability studies** include 1) laboratory screening, 2) bench-scale testing, or 3) pilot-scale testing. These studies may begin with any tier and skip tiers that are not needed (see Section 3.4 of guidance). **Computer models** for predicting treatment performance are available for some technologies. In general, treatability studies should be performed prior or during the design of any system expected to provide **long-term treatment** of extracted ground water, including systems using presumptive technologies. Treatability studies are needed to accurately predict the effectiveness and cost of a technology for a given site, including construction and operating costs; and the costs of other components of the treatment train. Optimizing the cost effectiveness of the treatment train (i.e., minimizing the total cost per unit volume of water treated) is especially important for systems designed to operate over a long time period. Treatability studies **may reveal unexpected site conditions**, such as the presence of naturally occurring compounds that interfere with the planned treatment process or that metal contaminants can be effectively removed by removing mineral solids. Such studies are also needed to determine pretreatment requirements, and requirements for treating aqueous, vapor and solid waste streams resulting from a particular treatment process. Treatability studies are needed to determine optimum chemical reagents and reagent quantities for pH adjustment; oxidation, reduction or precipitation of contaminants; and parameters for design of biological and other reactors. Treatability studies should be performed on samples obtained from **pumping type aquifer tests** instead of from monitoring wells, because such samples are more representative of contaminated ground water that will enter the treatment system. Samples obtained for treatability studies should be obtained after several hours of pumping.

Appendix C4: Advantages and Limitations of Presumptive Treatment Technologies

Technology	Advantages	Limitations
Treatment Technologies for the Removal of Organic Contaminants		
Air Stripping	• Successfully used in hundreds of groundwater applications • Low operating cost relative to other technologies (e.g., energy usage is relatively low). • Operationally simple system requiring a minimum of operator assistance. • Treatability studies often not required for selection or design, but are recommended. • Trained contractors available to implement the technology.	• Contaminants transferred to air, and treatment of air emissions may be required. • Pretreatment for metals removal and pH control may be needed to reduce fouling and corrosion. • Post-treatment (polishing) may be required. • Large surges in influent concentrations can reduce removal efficiency because the efficiency for an individual compound is fixed regardless of influent concentrations. • Air stripping is not as effective for compounds with low Henry's law constants or high solubilities.[b,c] • Cold weather can reduce efficiency.
Granular Activated Carbon	• Successfully used for contaminated ground water at many Superfund and underground storage tank sites. • Operationally simple system requiring a minimum of operator assistance. • Regularly used as a polishing step following other treatment technologies. • Treatability studies generally not required, but are recommended (information is available from carbon vendors). • Trained contractors available to implement the technology. • Generally a cost-effective alternative as single- step treatment for flows less than about 3 gpm.[d]	• Activated carbon is generally too costly for use as a single-step treatment if ground-water chemistry requires high carbon usage rates. • Contaminants are not destroyed but are transferred to another media (i.e., spent carbon must be regenerated or disposed of properly). • Pretreatment for suspended solids removal is often required. • Pretreatment for metals removal and pH control may be needed to reduce fouling and corrosion. • Organic compounds that have low molecular weight and high polarity are not recommended for activated carbon (e.g., acetone). • Naturally occurring organic compounds may exhaust carbon bed rapidly and may interfere with the adsorption of targeted chemicals.

Appendix C4: Advantages and Limitations of Presumptive Treatment Technologies (continued)

Technology	Advantages	Limitations
Chemical/ UV Oxidation	• Where oxidation is complete, organic contaminants are destroyed and not transferred to other media; minimal residuals generated. • Effective on a wide variety of volatile and semivolatile organics, including chlorinated organics, as well as cyanide and some metals. • Operating costs can be competitive with air stripping and activated carbon.	• Incomplete oxidation will leave original contaminants and possibly toxic oxidation products; activated carbon polishing may be required. • Capital costs may preclude small-scale applications, especially for ozone systems. • Metals may precipitate during oxidation, requiring filtration post-treatment and residuals disposal. • UV light sources are subject to fouling and scaling from solids, iron compounds, carbonates, etc. Pretreatment may be required to remove these substances. • Process must be closely monitored to ensure contaminant destruction and to prevent safety hazards. • Peroxide and other chemical oxidants must be properly stored and handled. • Site-specific treatability studies are necessary (process may require large quantities of oxidizer to destroy target compound(s) if reactive nontarget compounds are present).
Aerobic Biological Reactors	• Organic contaminants degraded, often with minimal cross-media environmental impacts. • Proven effective for many organic compounds. • Some systems (e.g., trickling filters and rotating biological contactors) have minimal energy requirements and generally low capital and operating costs. • Can be designed to require a minimum of operator attention. • Relatively simple, readily available equipment. • Trained contractors available to implement the technology.	• A residual organic sludge is generated that must be disposed of properly. • Some compounds are difficult or impossible to degrade (recalcitrant) or slow to degrade. • Difficulties acclimating microorganisms to contaminants are possible; requires longer startup time than other technologies to achieve effective steady-state performance • Volatile organics may require air emission controls or pretreatment to remove them. • Variations in flow or concentration may require significant operator attention to prevent microorganisms from being killed. • Cold weather can cause operational difficulties. • Treatability studies are needed for selection and design. • Pretreatment may be needed to remove contaminants toxic to the microorganisms, such as heavy metals. • Low organic loading and the potential for supplementary nutrients and food sources must be considered.

Appendix C4: Advantages and Limitations of Presumptive Treatment Technologies (continued)

Technology	Advantages	Limitations
Treatment Technologies for the Removal of Inorganic Contaminants		
Chemical Precipitation	• Most commonly used method for removing soluble heavy metal ions from contaminated water. • Pretreatment for solids and iron generally not required. Hydroxide Precipitation • Reliable method, chemicals relatively easy to handle, and not costly. Carbonate Precipitation • Reliable method, calcium carbonate easy to handle, and not costly. • Effectively removes a variety of soluble metals. Sulfide Precipitation • Reliable method. • High removal efficiency over a broader pH range. • Relatively insensitive to most chelating agents. • Can remove chromates and dichromates without reducing hexavalent chromium to trivalent form if ferrous ions are present or added.	• A residual sludge is generated that must be treated and/or disposed of properly; metals are not usually easy to recover from sludge. • Up to four times stoichiometric chemical additions may be required, especially for sulfide precipitation (see below). Hydroxide Precipitation • Organics or complexing ions may form chelates/complexes instead of insoluble metal hydroxides. • Optimum pH is different for each metal hydroxide, one pH may not effectively treat all soluble metal ions; successive treatments may be required. • pH must be controlled within a narrow range. • Naturally occurring sulfate in ground water may react with lime to form gypsum, which increases sludge, can clog filters, and can coat pipelines (caustic soda addition can reduce this problem but increases costs and dissolved solids [sodium salts] that must be removed from treated ground water). Carbonate Precipitation • Calcium carbonate is not effective for ground water with high alkaline content. • Pretreatment to remove organic, chelating, or oil and grease contaminants may be required. Sulfide Precipitation (Soluble Sulfide) • Excess sulfide ions that are not precipitated remain in solution. They may be removed by using aeration to convert them from ionic to oxide form (sulfate). • pH control between 8 and 9.5 is required to avoid release of hydrogen sulfide gas. • Cost is high compared to hydroxide and carbonate precipitation Sulfide Precipitation (Insoluble Sulfides) • Ferrous sulfide is used in amounts greater than that required by stoichiometric considerations. • Produces more sludge than soluble sulfide or hydroxide processes.

Appendix C4: Advantages and Limitations of Presumptive Treatment Technologies (continued)

Technology	Advantages	Limitations
Treatment Technologies for the Removal of Inorganic Contaminants (continued):		
Ion Exchange/ Adsorption	• High removal efficiencies for heavy metals. • Suitable for use as a polishing step after other technologies. • Technology is reasonably well understood. • On-site backflushing of exchange media allows immediate reuse.	• Resins are usually costly and may not be cost-effective for large treatment loadings. • Generates large volume of backflush solution (approximately 2.5 to 5% of the original ground-water flow rate) that is concentrated in the metals removed and requires treatment or disposal. • Requires bench-scale testing to determine operational requirements and suitability of prospective resins. • Beds can be fouled by particulate matter, oxidizing agents, oils, greases, biological growths, and intra-bed precipitates; therefore, pretreatment may be needed. • Resins may be irreversibly harmed by aromatics and certain other organic compounds; and by iron, manganese, and copper if enough dissolved oxygen is present. Pretreatment may be needed. • Spent resins require treatment before disposal.
Electro-chemical Methods	• High removal efficiencies for certain heavy metals. • Can treat both metals and cyanide simultaneously. • Technology is reasonably well understood. • Requires little floor space due to short residence time for hexavalent chromium reduction. • Requires minimal operator attention. • Low operating costs compared to chemical reduction or precipitation. • Requires no chemical addition.	• Particulate matter, oxidizing agents, oils, greases, biological growths may reduce process efficiency; therefore, pretreatment may be needed. • Hexavalent chromium reduction generates a heavy metal precipitate that must be removed from solution in a subsequent clarification or settling process. • A heavy metal sludge residual may be generated that may require treatment (dewatering and/or fixation) and that will require disposal. • A spent acid rinse solution may be generated that requires treatment or disposal. • Electrodes must be replaced occasionally.

NOTES:

[a] U.S. Environmental Protection Agency. 1991. Engineering Bulletin: *Air Stripping of Aqueous Solutions*. EPA/540/2-91/022. 8 pp.

[b] B. Lamarre. 1993. Selecting an air stripper (what to consider!) *The National Environmental Journal*: 26-29.

[c] G. M. Long. 1993. Clean up hydrocarbon contamination effectively. *Chemical Engineering Progress*: 58-66.

APPENDIX D (from USEPA, 1996)

Descriptions of Presumptive Treatment Technologies

Appendix D1: Air Stripping
Appendix D2: Granular Activated Carbon
Appendix D3: Chemical/UV Oxidation
Appendix D4: Aerobic Biological Reactors
Appendix D5: Chemical Precipitation
Appendix D6: Ion Exchange/Adsorption
Appendix D7: Electrochemical Methods
Appendix D8: Aeration of Background Metals

Appendix D1: Air Stripping

Air stripping uses volatilization to transfer contaminants from ground water to air. In general, water is contacted with an air stream to volatilize dissolved contaminants into the air stream. Stripping of a specific chemical depends on the equilibrium vapor pressure of that chemical as expressed by its Henry's law constant.

Applicability

Air stripping is *applicable* to most of the volatile organic compounds (VOCs) as well as volatile inorganics such as ammonia and hydrogen sulfide. VOCs with high solubility in water (e.g., acetone) are more difficult to air strip. Air stripping is *potentially applicable* to certain halogenated semi-volatile organic compounds (SVOCs). It is *not applicable* to nonhalogenated SVOCs; heavy organics such as PCBs, dioxins/furans and pesticides; or inorganic metal compounds (U.S. EPA, 1991).

Air stripping is most effective for contaminants with a dimensionless (molar volume) Henry's law constant greater than 0.01 (or 2.4×10^{-4} atm-m^3/gmol at 25° C). (Henry's law constants are available in U.S. EPA [1990]). Removal efficiencies greater than 99 percent are difficult to achieve for certain compounds. In general, other treatment technologies will be required for such chemicals when ground-water concentrations are high (e.g., above 10,000 ppm or 1 percent).

Contaminant Fate

Contaminants are not destroyed by air stripping but are physically separated from contaminated ground water and transferred to air. Depending on the level of contaminants in the air discharge, the contaminated air stream may need further treatment. Additional polishing treatment of the aqueous effluent also may be necessary, depending on discharge requirements.

Design

Air strippers are designed for a specific target chemical (either the predominant contaminant or the most difficult-to-strip contaminant) with a desired target removal efficiency. The air stripping process is well understood and the technology is well developed. Air stripping has an extensive track record in a variety of applications.

The most frequently used configuration is a packed tower equipped with an air blower. The ground water is fed into the top of the stripper and the air is introduced at the bottom, creating a countercurrent gas-liquid contact. Random plastic packing is frequently used to improve gas-liquid contact. Structured packing and steel packing may also be used. Packed-tower air stripper design involves specification of stripper column diameter and packing height for a specified ground-water flow rate and air-to-water ratio. Shallow-tray aeration devices provide an alternative gas-liquid contacting system that provides a more compact, lower profile system that is less subject to fouling.

Alternative Techniques/Enhanced Methods

- For high flow rates (over 1,000 gpm), cooling towers (large structures with cascading water primarily used to cool water using countercurrent ambient air flow) may provide a cost-effective alternative to conventional packed towers.
- Shallow tray air strippers or diffused tank aeration units are less susceptible to fouling problems than packed towers and may be preferable where the water to be treated contains high concentrations of certain inorganics (e.g., iron).

Alternative Techniques/Enhanced Methods (continued)

- Because the efficiency of air stripping increases at higher temperatures, increasing the influent ground-water temperature (typically about 55° F) using a heat exchanger can increase the stripper's removal efficiency, especially for less volatile contaminants.
- Steam stripping methods, which use steam rather than air as the stripping medium, can be used to remove highly soluble contaminants and SVOCs not usually amenable to air stripping. However, operation costs for steam stripping can be two to three times greater than air stripping, depending on the cost of steam. In this guidance, these methods are not considered a type of air stripping and are not identified as a presumptive technology for ex-situ treatment of ground water.

Pre/Post-treatment

- Pretreatment to remove iron and other metals and to control hardness may be necessary to reduce fouling and mineral deposition in packed tower air strippers.
- Granular activated carbon is sometimes used to polish the treated water from an air stripper to further reduce organic contaminant levels and meet discharge requirements.
- Contaminants in the air discharge may be reduced by activated carbon adsorption, catalytic oxidation, or incineration to meet air emission requirements.

Selected References

Lamarre, B. 1993. Selecting an air stripper (what to consider!). The National Environmental Journal: 26-29.

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Nyer, E.K. 1993. Practical Techniques for Groundwater and Soil Remediation. CRC Press, Inc., Boca Raton, FL. 214 pp.

Okoniewski, B.A. 1992. Remove VOCs from wastewater by air stripping. Chemical Engineering Progress: 89-93.

U.S. EPA Environmental Protection Agency. 1990. Hazardous Waste Treatment, Storage, and Disposal Facilities (TSDF) - Air Emission Models. EPA/450/3-87-026. Office of Air Quality Planning and Standards, Research Triangle Park, NC. Appendix D.

U.S. Environmental Protection Agency. 1991. Engineering Bulletin: Air Stripping of Aqueous Solutions. EPA/540/2-91/022. Office of Research and Development, Cincinnati, OH. 9 pp.

Appendix D2: Granular Activated Carbon

Activated carbon removes contaminants from ground water by adsorption. The adsorption process takes place in three steps: (1) contaminant migration to the external sorbent surface; (2) diffusion into the sorbent pore structure; and (3) adsorption onto the sorbent surface. The principal form of activated carbon used for ground-water treatment is granular activated carbon (GAC). GAC is an excellent sorbent due to its large surface area, which generally ranges from 500 to 2,000 m^2/g.

Applicability

GAC is *applicable* to a wide variety of contaminants including: halogenated volatile and semivolatile organics, nonhalogenated volatile and semivolatile organics, PCBs, pesticides, dioxins/furans, most organic corrosives, metals, radioactive materials, inorganic cyanides, and certain oxidizers. GAC is *potentially applicable* to certain organic cyanides, and it is *not applicable* to asbestos, inorganic corrosives, and reducers (U.S. EPA, 1991). GAC is sometimes used alone for ground-water treatment. However, GAC is typically used for polishing aqueous effluents or controlling air emissions from other treatment technologies.

The adsorption capacity of activated carbon varies for specific organic compounds and for different types of GAC (based on the origin of coal and the percent binder used in the manufacture of the GAC). Contaminant-specific adsorption isotherms for a given type of GAC are generally available from the carbon manufacturer.

Contaminant Fate

Contaminants are not destroyed by carbon adsorption, but are physically separated from contaminated water and transferred to carbon. After exhaustion, the spent carbon may be reactivated, regenerated, incinerated, or disposed of. Thermal reactivation and incineration destroy most or all adsorbed organic contaminants. Steam or hot gas regeneration is not appropriate for spent GAC from treatment of contaminated ground water but can be used for spent GAC from air emission control devices. GAC used for metals sorption may require disposal. If disposed of, spent GAC may have to be managed as a hazardous waste.

Design

Activated carbon is a well-developed, widely used technology with many successful ground-water treatment applications, especially for secondary polishing of effluents from other treatment technologies. Contaminated ground water is contacted with a fixed GAC bed in a vessel. Flow direction is generally vertically downward, although an upward flow configuration is also possible. Fixed-bed configurations are also used for air emission control.

Adsorber design involves determining total carbon requirements and the number and dimensions of vessels needed to house the carbon. The amount of carbon required for a given application depends on the loading of adsorbable constituents in ground water (or contaminated air stream), the carbon's adsorption capacity for these constituents, and the carbon reactivation (or regeneration) frequency. Depending on the ground-water suspended solids content, it may be necessary to periodically backwash down flow carbon beds to relieve pressure drop associated with solids accumulation.

Alternative Techniques/Enhanced Methods

- Staged bed (multiple beds operated in series) and pulsed bed (carbon beds operated with nearly continuous "pulsed" addition of fresh carbon and withdrawal of spent carbon) designs can be used if higher removal efficiencies are required.

Alternative Techniques/Enhanced Methods (continued)

- Because the adsorption capacity of GAC is much higher for gas phase treatment than for liquid phase treatment, it is often more economical to use an air stripper followed by gas phase GAC to treat the air stripper exhaust than to use GAC alone for ground-water treatment.

- **GAC is not identified as a presumptive technology for removal of metals dissolved extracted ground water. Spent carbon used for metals removal can be difficult to regenerate and may require treatment and/or disposal as a hazardous waste.** Although GAC can remove low concentrations of certain metals, it has not been widely used for this purpose (U.S. EPA, 1991).

Pre/Post-treatment

- Pretreatment may be required to remove natural organic matter, such as fulvic and humic acids, that may interfere with the adsorption of the target contaminants or rapidly exhaust the GAC.
- Naturally occurring **radionuclides**, if present in ground water, can accumulate in the GAC during treatment, **which could result in potential exposure hazards for operating personnel and the spent carbon may require treatment and/or disposal as hazardous waste**.

- Thermal reactivation, using heat alone or steam, is typically used as a post-treatment method for the spent carbon. The carbon is reactivated in a high-temperature reactor under reducing conditions. Most organic contaminants are thermally degraded during the reactivation process.

Selected References

Long, G.M. 1993. Clean up hydrocarbon contamination effectively. *Chemical Engineering Progress*, 89(5):58-67.

Stover, E.L. 1988. Treatment of herbicides in ground water. *Ground Water Monitoring Review*: 54-59.

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U.S. Environmental Protection Agency. 1991. *Engineering Bulletin: Granular Activated Carbon Treatment*. EPA/540/2-91/024. Office of Emergency and Remedial Response, Washington, D.C. 8 pp.

Appendix D3: Chemical/UV Oxidation

Chemical oxidation uses chemical oxidizing agents to destroy toxic organic chemicals and cyanide compounds (CN) in ground water. Commonly used oxidizing agents include: ozone, hydrogen peroxide, hypochlorites, chlorine, and chlorine dioxide. Ozone and hydrogen peroxide are generally preferred for removing organics and CN from ground water because chlorine-based oxidants can produce toxic byproducts (e.g., HCl, chlorinated organics). Ultraviolet light (UV) is often used in conjunction with ozone and/or hydrogen peroxide to promote faster and more complete destruction of organic compounds (reaction rates may be increased by factors of 100 to 1,000).

Applicability

Chemical oxidation is *applicable* to both volatile and semivolatile organic compounds and cyanide compounds. Chemical oxidation is *potentially applicable* to PCBs, dioxins/furans, and metals (oxidation can be used to precipitate metals under certain conditions). Chemical oxidation is *not applicable* to asbestos and radioactive materials (U.S. EPA, 1991).

Chemical oxidation generally is effective for concentrations less than 500 µgL, but has been used for certain compounds at concentrations ranging up to several thousand mg/L. UV can enhance the oxidation of compounds that are resistant to chemical oxidation alone (e.g., PCBs). Iron or copper catalysts may be required for efficient destruction of certain organic compounds (e.g., phenols).

Contaminant Fate

Complete oxidation decomposes hydrocarbons into carbon dioxide and water, although chlorinated organic compounds also yield chloride ions. CN is oxidized to ammonia and bicarbonate by hydrogen peroxide in an alkaline environment. If oxidation is incomplete, toxic constituents may remain, or intermediate degradation products can be formed that may be toxic. These toxic substances may be removed using GAC as a secondary or polishing treatment step.

Design

Chemical oxidation is a proven and effective technology that is carried out in either batch or continuous reactors. Oxidants are generally added to contaminated ground water in a mixing tank prior to introduction into the reaction vessel (reactor). The use of ozone as the oxidizing agent requires an onsite ozone generator and an ozone decomposition unit or other ozone emission control device. The use of hydrogen peroxide as the oxidizing agent requires storage tanks and special handling protocols to ensure operator safety. The use of chlorine as the oxidizing agent may produce HCl gas. If HCl is produced, an acid gas removal system may be necessary.

UV lamps, if used, are typically enclosed in quartz tubes submerged inside the reaction vessel. The tubes are subject to fouling or scaling from compounds such as iron oxide or calcium carbonate and from biological flocs from microorganisms in ground water. If fouling occurs, oxidation rates are drastically reduced.

Site-specific treatability studies are generally recommended for chemical oxidation systems. Extensive pretreatment may be required to condition ground water for effective oxidation. If UV lamps are used, the studies must evaluate the potential for fouling or scaling of the quartz tubes at the ground-water composition, oxidant concentration, and UV intensity conditions anticipated for long-term system operation. If fouling or scaling is likely, pretreatment and/or physical methods for keeping the tubes clean (e.g., wipers) may be required. If metals are to be removed by oxidation, solids should be removed by clarification or filtration prior to UV oxidation. Provisions for removing precipitated metal sludges also may be necessary.

Alternative Techniques/Enhanced Methods

- UV radiation can be used in combination with a chemical oxidizing agent to increase the effectiveness of oxidation, especially for difficult-to-oxidize compounds.
- Metal catalysts, such as iron or copper, can be used in combination with a chemical oxidizing agent to increase the effectiveness of oxidation for certain types of compounds.
- Hydrodynamic cavitation is an innovative technology recently demonstrated under EPA's SITE program that uses forced cavitation of gas to enhance destruction of organics during UV oxidation processes.

Pre/Post-treatment

- Pretreatment may be necessary to remove solids, microorganisms, calcium carbonate, iron oxides, and/or other metals that can interfere with the oxidation process or UV transmission. A pretreatment sequence of precipitation, flocculation, clarification, and/or filtration steps may be necessary.
- Post-treatment of the aqueous effluent with GAC may be necessary if destruction is not complete or if toxic byproducts are formed during oxidation.
- If toxic metals precipitate during the oxidation process, treatment and/or proper disposal of the resulting sludge may be required.

Selected References

U.S. Environmental Protection Agency. 1990. *CERCLA Site Discharges to POTWs Treatability Manual.* EPA/540/2-90/008. Office of Emergency and Remedial Response. PB91-921269/CCE. NTIS. Springfield, VA. pp. 11-7 to 11-17.

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U.S. Environmental Protection Agency. 1993. *Superfund Innovative Technology Evaluation Program. Technology Profiles. Sixth Edition.* EPA/540/R-93/526. Office of Research and Development, Washington, DC.

U.S. Navy. 1993. *UV/Oxidation Treatment of Organics in Ground Water.* NEESA Document Number 20.2-051.7. Navy Energy and Environment Support Activity, Port Hueneme, CA. 11 pp.

Appendix D4: Aerobic Biological Reactors

Biological reactors use microorganisms to degrade organic contaminants in ground water in ex situ reactors. There are two basic types of ex situ biological treatment processes: aerobic reactors and anaerobic reactors. Aerobic reactors use oxygen to promote biodegradation and are widely used. Anaerobic reactors degrade organics in the absence of oxygen. This guidance focuses on aerobic biological treatment because anaerobic treatment processes are not widely used for ground-water treatment.

Applicability

Aerobic biological reactors are *applicable* to a wide variety of halogenated and nonhalogenated volatile and semivolatile organics. Aerobic biological reactors are *potentially applicable* to heavy organics, such as PCBs and certain pesticides, and organic and inorganic cyanides, but are generally not as effective for such recalcitrant compounds. Aerobic processes are *not applicable* to metals, asbestos, radioactive materials, or corrosive or reactive chemicals (U.S. EPA, 1992).

Contaminant Fate

Organic compounds are decomposed to carbon dioxide and water (aerobic processes) or to methane and carbon dioxide (anaerobic processes). Volatile organics are also removed by volatilization as a competing mechanism. Microbial growth produces an excess organic sludge (biomass) that must be disposed of properly. This sludge may concentrate metals and recalcitrant organic compounds that are resistant to degradation. Biodegradation may produce decomposition byproducts that are emitted to the air or dissolved in the effluent, and these decomposition byproducts may require additional treatment.

Design

Ex situ biological treatment of ground water is conducted in bioreactors. The primary factors influencing bioreactor design are the microbial organic utilization rates and the peak organic loading rate (i.e., flow rate times organic concentration). Treatability tests are necessary to determine these and other design parameters. Under most circumstances, bioreactors require a significant startup time to acclimate the microorganisms to the specific contaminants being treated before the bioreactor will operate at optimal degradation rates. There are two general types of bioreactor design:

- In **suspended growth** reactors, microbes are kept suspended in water using mechanical aerators or diffused air systems. These aeration systems also keep the solution well mixed, improving contact between microbes and dissolved contaminants and supplying oxygen to the system. Activated sludge systems are the most common suspended growth bioreactors. Other examples include aerated ponds or lagoons, stabilization ponds (using both algae and bacteria), and sequencing batch reactors.
- In **attached growth** reactors, biomass is attached to a solid substrate, such as sand, rock, plastic, activated carbon, or resin. Reactor design is dependent upon the surface area of substrate media available for biomass growth. Examples include trickling filter, rotating biological contactor, fluidized bed, fixed bed, and roughing filter designs.

Alternative Techniques/Enhanced Methods

- Direct addition of powdered activated carbon (PAC) into suspended growth bioreactors can both improve removal efficiency and reduce the likelihood of process upsets by buffering the concentrations of toxic compounds at levels amenable to biodegradation.

Alternative Techniques/Enhanced Methods (continued)

- Microbial augmentation (the addition of specially cultured microorganisms) may be used to increase the system's removal efficiency for certain difficult-to-degrade contaminants.
- Anaerobic reactors (digesters) may be preferred for the treatment of certain ground-water contaminants (e.g., certain chlorinated organics) that are difficult to degrade aerobically. **However, anaerobic reactors have not been identified as a presumptive technology for the following reasons**: 1) anaerobic processes have not been widely used for ground-water treatment; 2) reaction rates are slower than for aerobic processes, which result in longer startup times (for acclimation) and longer treatment times; and 3) such reactors have a greater sensitivity to process upsets, especially where flow and contaminant concentrations vary over time. These factors generally result in higher operation and maintenance requirements and costs, and lower performance efficiencies than for aerobic processes in ground-water applications.

Pre/Post-treatment

- Chemical precipitation (for metals) or other pretreatment (e.g., PAC addition for organics) may be required to reduce (or buffer) concentrations of compounds that are toxic to microorganisms.
- Carbon adsorption post-treatment may be used to reduce contaminant concentrations in the treated water to meet discharge requirements.
- Because certain aerated bioreactor designs (e.g., mechanically aerated activated sludge systems, aerated ponds and lagoons) present difficulties for direct capture and control of air emissions, an air stripper (with emission controls) may be a cost-effective treatment prior to biodegradation if volatile contaminant emissions need to be controlled. For other bioreactor designs, such as diffused-aeration activated sludge and trickling filter systems, air emissions are more easily captured and can be treated using carbon adsorption, catalytic oxidation, or incineration.

Selected References

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Appendix D5: Chemical Precipitation

Chemical precipitation chemically converts dissolved metal and/or other inorganic ions in ground water into an insoluble form, or precipitate. Metal ions generally precipitate out as hydroxides, sulfides, or carbonates and are removed as solids through clarification and filtration. In this guidance, chemical precipitation is defined to include chemical precipitation of metals by oxidizing or reducing agents, as well as any pH adjustment (neutralization) and solids removal steps required.

Applicability

Chemical precipitation is *applicable* to dissolved metal and other inorganic ions (such as arsenate and phosphate). Chemical precipitation is *not applicable* to volatile or semivolatile organic compounds (U.S. Navy, 1993).

Contaminant Fate

Dissolved metals are converted to insoluble forms, which are subsequently removed by flocculation, clarification, and/or filtration. The solid residue (chemical sludge) containing the metal contaminant then must be treated and/or disposed of properly.

Design

The process generally takes place at ambient temperatures. Batch reactors are generally favored for lower flowrates (e.g., up to about 50,000 gpd), and usually use two tanks operating in parallel. Each tank can act as a flow equalizer, reactor, and settler, thus eliminating separate equipment for these steps. Continuous systems have a chemical feeder, flash mixer, flocculator, settling unit, filtration system (if used), and control system for feed regulation. Site-specific treatability tests are required to determine the optimum type and dosage of precipitation chemicals, necessary pretreatment steps, and post-treatment requirements for aqueous effluent and sludge residuals.

There are three types of precipitation chemicals:

- **Metal hydroxides** are formed by the addition of alkaline reagents (lime or sodium hydroxide). Precipitation is then initiated by adjusting pH to the optimum level for the particular metal ion. Maintaining pH levels within a relatively narrow optimum range is usually necessary to achieve adequate metal precipitation. Pretreatment with oxidizing or reducing chemicals (e.g., hydrogen peroxide, ferrous sulfate) may be necessary to precipitate some metals (e.g., iron, manganese, chromium) in their least soluble form. Natural organic matter can inhibit the formation of insoluble metal hydroxides by forming metal-organic complexes. Metal hydroxide precipitation is typically effective for arsenic, cadmium, chromium (+3), nickel, zinc, manganese, copper (+2), tin (+3), and iron (+3).
- **Metal sulfides** are formed by the addition of either soluble sulfides (e.g., hydrogen sulfide, sodium sulfide, or sodium bisulfide) insoluble sulfides (e.g., ferrous sulfide). Sodium sulfide and sodium bisulfide are most commonly used. Sulfur dioxide and sulfur metabisulfite have also been demonstrated for chromium reduction prior to precipitation. Metal sulfides have lower solubilities than metal hydroxides, and effective metal removal efficiencies can be achieved over a broader pH range. The method is mainly used to remove mercury and lead and may be used to remove arsenic, cadmium, chromium (+3,or +6), silver and others. Sulfide precipitation also can be used to treat filtered ground water after hydroxide precipitation.

Alternative Techniques/Enhanced Methods

- **Metal carbonates** are formed by the addition of calcium carbonate or by adding carbon dioxide to metal hydroxides. Solubilities of metal carbonates are intermediate between the solubilities of metal hydroxides and metal sulfides. Insoluble metal carbonates are easily filtered from treated ground water. The method is particularly good for precipitating lead, cadmium, and antimony.

- Sodium xanthate has shown promise as a precipitation agent similar to sodium sulfide.

Pre/Post-treatment

- Pretreatment to adjust pH is normally required to obtain the lowest precipitate solubility.
- Pretreatment may be necessary to oxidize iron or manganese compounds or reduce hexavalent chromium compounds into forms that can be readily precipitated.
- Depending on discharge requirements, the aqueous effluent may need pH adjustment and/or further polishing. Activated alumina or ion exchange media are regenerable treatment options for effluent polishing for metals. Activated carbon also may be used but spent carbon may require treatment and disposal as a hazardous waste.
- The sludge may require stabilization treatment by addition of lime/fly ash or portland cement to reduce permeability and the leachability of metals prior to disposal. In some cases, metals may be recovered from the residue for reuse, but this is generally not economical.

Selected References

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U.S. Environmental Protection Agency. 1987. *Handbook on Treatment of Hazardous Waste Leachate.* EPA/600/8-87/006. Office of Research and Development, Cincinnati, OH. pp. 44-45.

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U.S. Navy. 1993. *Precipitation of Metals from Ground Water.* NEESA Document Number 20.2-051.6. Navy Energy and Environment Support Activity. Port Hueneme, CA. 11 pp.

Appendix D6: Ion Exchange/Adsorption

Ion exchange removes metal contaminants from water by passing contaminated ground water through a granular solid or other porous material, usually an impregnated resin, that exchanges sorbed ions (e.g., H^+, OH^-, Na^+, Li^+, CO_3^{--}) for contaminants dissolved in ground water. The ion exchange media are selected to have sorptive affinity for the ionic forms (cation or anion) of the contaminants being removed. The ion exchange media can therefore be either cationic, anionic, or a mixture of the two. Because ion exchange is a reversible process, resins can be regenerated by backwashing with a regeneration solution (e.g., brine; strong or weak acids or bases). Conventional ion exchange resins are generally too costly for large-scale ground-water treatment and are predominantly used for polishing of aqueous effluents after other treatment processes.

Applicability

Ion exchange is *applicable* to ionic contaminants such as dissolved metals or nitrates. Ion exchange is *not applicable* to non-ionic contaminants such as most organic compounds.

Contaminant Fate

Contaminants are removed from ground water through sorption onto the exchange media. When most of the exchange sites of the media become filled, the exchange media are regenerated by backflushing with a suitable regeneration solution. The concentrated backflush solution must then be disposed of or stripped of its contaminants. Exchange resins can generally be regenerated many times and have a relatively long useful life.

Design

Various resin types are available to tailor systems to discrete ionic mixes. For example, acid exchangers replace cations in water with hydrogen ions and base exchangers replace anions with hydroxide ions. Weak acid and base exchangers are selective for more easily removed ions while strong acid and base exchangers are less selective, removing most ions in the ground water. Generally, ease of cation and anion removal follows an affinity sequence specific to the ions in question. Synthetic resins are available with unique selectivity sequences. The wide variety of resins and other ion exchange media (e.g., activated alumina, biological materials) that are available make the selection of an appropriate exchange media a critical design step. Information on the applicability of specific resins may be obtained from resin manufacturers. In addition, ion exchange resins generally have an optimum pH range for effective metals removal. pH control may be required to achieve maximum removal efficiency from ground water.

A typical ion exchange installation has two fixed beds of resin. While one is in operation, the other is regenerated. Batch, fixed column, and continuous column bed designs can be used. Downflow column designs are generally preferred. Continuous column systems eliminate the need for backwashing but are not commonly used because of the complexity of the resin removal mechanics.

Flow rates up to 7,000 gpm have been reported for ion exchange systems. However, conventional ion exchange is generally cost-effective for ground-water treatment only at low flow rates or low contaminant concentrations. It is therefore primarily used as a polishing step following chemical precipitation or other treatment.

Alternative Techniques/Enhanced Methods

- Activated alumina is an anionic exchange medium comprised of granulated, dehydrated aluminum hydroxide. Activated alumina is effective for removing fluoride, selenium, chromium (+6), and arsenic ions, which are exchanged for hydroxide ions. Adjustment of pH may be necessary to achieve optimal removal efficiency. The alumina is regenerated with a sodium hydroxide solution.
- Biological materials (e.g., algae, crop residues) have recently shown great promise as an innovative ion exchange media for metals. Biological media are significantly less costly than conventional resins (cents per pound vs. dollars per pound), and may become more commonly used for metals removal from ground water.
- Electrodialysis uses alternately placed cation and anion permeable membranes (made of ion exchange resin) and an electrical potential to separate or concentrate ionic species.
- Activated carbon adsorption can also be used to remove inorganics at low concentrations. **However, activated carbon is not identified as a presumptive technology for removal of metals dissolved extracted ground water.** Spent carbon used for metals removal can be difficult to regenerate and may require treatment and/or disposal as a hazardous waste.

Pre/Post-treatment

- Pretreatment may be required to remove suspended solids at concentrations greater than about 25 mg/L or oil at concentrations greater than about 20 mg/L. Large organic molecules also can clog resin pores and may need to be removed.
- pH adjustment may be necessary to achieve optimal metals removal.
- The backwash regeneration solution must be treated to remove contaminants.
- Post-treatment of spent ion exchange media may be required to recover concentrated contaminants or management as a hazardous waste may be required.

Selected References

Clifford, D., Subramonian, S., and Sorg, T.J., 1986. "Removing Dissolved Inorganic Contaminants from Water," *Environmental Science and Technology*, Vol. 20, No. 11.

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U.S. Environmental Protection Agency. 1990. *CERCLA Site Discharges to POTWs Treatability Manual.* EPA/540/2-90/008. Office of Emergency and Remedial Response. PB91-921269/CCE. NTIS. Springfield, VA. pp. 11-102 to 11-112.

Appendix D7: Electrochemical Methods

Electrochemical processes use direct electrical current applied between two immersed electrodes to drive chemical oxidation-reduction reactions in an aqueous solution. Historically, electrochemical processes have been used to purify crude metals or to recover precious metals from aqueous solutions. Positively charged metal ions are attracted to the negatively charged electrode (the cathode), where they are reduced. The reduced metals typically form a metallic deposit on the cathode. Negatively charged ions are attracted to the positively charged electrode (the anode), where they are oxidized.

For contaminated ground water treatment, electrochemical cells have been used for the reduction (and subsequent precipitation) of hexavalent chromium to trivalent chromium. In this process, consumable iron electrodes are used to produce ferrous ions (Fe^{2+}) at the anode and hydroxide ions (OH^-) at the cathode. An oxidation-reduction reaction then occurs between the ferrous, chromium, and hydroxide ions to produce ferric hydroxide $Fe(OH)_3$ and chromic hydroxide $Cr(OH)_3$, which subsequently precipitate from solution.

Applicability

Electrochemical processes are *applicable* to dissolved metals. It is most commonly used in ground water treatment for the reduction and precipitation of hexavalent chromium. The process also may be applicable to removing other heavy metals including arsenic, cadmium, molybdenum, aluminum, zinc, and copper ions. Electrochemical processes have also been used for the oxidation of cyanide wastes (at concentrations up to 10 percent). Electrochemical processes are *not applicable* to organic compounds or asbestos.

Contaminant Fate

Dissolved metals either deposit on the cathode or precipitate from solution. Precipitates form an inorganic sludge that must be treated and/or disposed of, typically in a landfill. Spent acid solution, which is used to periodically remove deposits formed on the electrodes, will also require proper treatment and disposal. Cyanide ions are hydrolyzed at the anode to produce ammonia, urea, and carbon dioxide.

Design

Electrochemical reactors generally operate at ambient temperatures and neutral pHs. Both batch reactors and continuous flow reactors are commercially available. A typical electrochemical cell for hexavalent chromium reduction consists of a tank, consumable iron electrodes, and a direct current electrical supply system. An acid solution is used to periodically clean the iron electrodes, which need to be replaced when they are significantly consumed. Reactor residence times required for treatment depend on the contaminants present as well as the degree of mixing and current density. Reduction of hexavalent chromium generally requires short residence times (approximately 10 seconds), whereas treatment of cyanide compounds requires longer process times.

Pre/Post-treatment

- Pretreatment may be necessary to remove suspended solids.
- Settling or clarification post-treatment may be necessary to remove the precipitated trivalent chromic and ferric hydroxides formed during hexavalent chromium electrochemical reduction.

Appendix D7: Electrochemical Methods (continued)

Pre/Post-treatment (continued)

- The sludge may require stabilization prior to disposal by addition of lime/fly ash or portland cement to reduce permeability and metal leachability. In some cases, metals may be recovered from the plated electrode or precipitated residue, but this is generally not economical for typical groundwater applications.

Selected References

Englund, H.M. and L. F. Mafrica. 1987. *Treatment Technologies for Hazardous Waste.* APCA Reprint Series RS-13. Air Pollution Control Association, Pittsburgh, PA. pp. 43-44.

U.S. Environmental Protection Agency. 1990. *A Compendium of Technologies Used in the Treatment of Hazardous Wastes.* EPA/625/8-87/014. Office of Research and Development. PB91-90-274093. NTIS. Springfield, VA. p. 23.

Appendix D8: Aeration of Background Metals

Aeration (contact with air) removes some metals from water by promoting chemical oxidation and the formation of insoluble hydroxides that precipitate from the water. Aeration for metals removal differs from air stripping in that precipitation rather than volatilization is the desired effect of the technology.

Applicability

Aeration techniques are useful for the removal of limited number of dissolved cations and soluble metal compounds. This method is well suited for the removal of background metals such as iron and manganese which is necessary as part of a selected remedy such as pretreatment to air stripping. Methods of aeration for metals include aeration tanks, aeration basins, or cascade aeration. Aeration methods are usually not sufficient as an independent technology for iron and manganese, but are utilized as a step in the treatment process. Often, the air-water contact in tank and cascade aeration is not enough to obtain high removal efficiencies. Spray basins are limited by area, wind, and ice particle formation (Nyer, 1985).

Contaminant Fate

Dissolved metals are oxidized to insoluble hydroxides which precipitate from solution, and can then can be subsequently removed by flocculation, sedimentation, and/or filtration.

Design

The three types of aeration systems:

- Aeration tanks bubble compressed air through a tank of water.
- Cascade aeration occurs when air is made by turbulent flow and agitation.
- Spray or aeration basins use an earthen or concrete basin with a piping grid and spray nozzles that spray the water into the air in very fine droplets.

Related methods include aeration used to remove volatile organic contaminants from water are considered to be a type of air stripping, as discussed in Section 2.1.1. The use of aeration to promote aerobic biological treatment processes is considered to be an element of biological treatment as discussed in Section 2.1.4.

Pre/Post Treatment

- Aeration is often a pretreatment for other remediation technologies, such as air stripping, to remove certain metals.
- Aeration can be followed by other treatments such as flocculation, sedimentation, and/or filtration to remove oxidized metals.

Appendix D8: Aeration of Background Metals

Selected References

Betz. 1962. *Betz Handbook of Industrial Water Conditioning.* Trevose, PA. pp.19-22

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Nyer, E.K. 1993. *Practical Techniques for Groundwater and Soil Remediation* . CRC Press, Inc, Boca Raton, FL. 214 pp.

APPENDIX D

Green and Sustainable Remediation – Alternatives Evaluation

Sustainability Analysis For Selected Remedial Alternatives
3800 Area PCE Site, Fort Drum, New York

Remedial alternatives concidered for the 3800 Area PCE Site where evaluated according to 6NYCRR Part 375. Following DER -31 (NYDEC, 2011) a quantitative assessment was conducted of Alternatives 2,3, and 4. Although the final remedy is selected in accordance with the nine remedy selection critieria set forth at 375-1.8(f), the green and sustainable remediation (GSR) criterion was added to the selection process to serve as a differentiator in the evaluation of the selected feasible remedial alternatives (Alternative 2, Alternative 3, and Alternative 4). The sustainability criterion addresses the consumption of natural resources and the environmental burden of each remedial alternative. The primary considerations for this criterion are 1) consumption of natural resources (electricity, fuel, water, materials); 2) production of green house gas (GHG) emissions associated with the extent of construction, decommisioning, earth moving activitiesand travel required to maintain the remedy; and 3) material consumption and waste generation..

The quantitative sustainability assessment for the selected proposed remedial alternatives was performed using the ARCADIS sustainability tool, BalancE3™ Tool. This comprehensive analysis addresses the critieria identified in DER-31 through the evaluation of the following commonly accepted five metrics: energy usage, air emissions, water consumption and impacts, material consumption and waste generation, and land impacts. Metric quantification was completed for all activities conducted on-site (identified as Scope 1) and transportation associated with movement of materials and worker to and from the Site (identified as Scope 2). In addition, the health and safety risks and community impacts associated with each alternative were also considered on a qualitative basis during the evaluation.

A discussion of the metrics that were used to complete the quantitative sustainability assessment of the alternatives follows:

1. **Energy usage** was calculated by quantifying the fuel, electrical energy and machinery power requirements for remedial alternative implementation and operation based on remedy history and fundamental engineering assumptions and manufacturers' specifications for equipment similar to that used in comparable remedial technologies. Energy consumption for each alternative was converted into kilowatt hours (kWh) using standard factors for converting equipment horsepower to kilowatt and energy content of fuels from joules to kilowatts and then multiplying by the time required for the volume of fuel used.

2. **Air emissions** were calculated for each alternative by quantifying the greenhouse gas (GHG) emissions expressed in carbon dioxide (CO_2) equivalent units, measured in tons, for on-site equipment use and transportation of material to and from the site (i.e., Scope 1 and Scope 2 analysis). The GHG emissions inventory and calculation methods were completed using guidance provided by the U.S. EPA Climate Leaders Greenhouse Gas Inventory Protocol (Climate Leaders) (U.S. EPA, 2008). Air emissions were calculated by identifying emission sources of major remedial alternative activities and applying documented emission factors for these activities as provided by Climate Leaders (World Resource Institute [WRI], 2008). For comparison purposes, total air emissions for each scenario were then converted to CO_2 equivalents, the most common unit for expressing carbon footprint.

3. **Water consumption and impacts** were determined for each alternative based on expected on-site activities for each remedial alternative. Examples of water impacts include extraction of groundwater that is not returned to the same aquifer (such as purge water), whereas examples of water consumption include the use of potable water to support components of the remedial alternative (such as reagent preparation, equipment cleaning, and decontamination). Water usage and impacts were calculated in total gallons of water.

4. **Material consumption and waste generation** were quantified by estimating the amount of materials to be consumed and waste created for each remedial alternative during implementation and operation based on fundamental engineering assumptions and material consumption and waste generation expected in comparable remedial technologies. Material volumes were determined using manufacturers' specifications of product dimensions for weights and standard densities per material type. Examples of materials consumed include reagent used for injections and carbon PVC for piping and well casings. Examples of waste generated include soil cuttings and purge water generated during well drilling or soil generated during excavation. For comparison purposes, total material consumption and waste generated were quantified for each alternative and converted into cubic feet of material.

5. **Land impact** was evaluated by estimating the land usage and disturbance associated with on-site activities (e.g., excavation area, well installation, staging, and decontamination) during the implementation of each remedial alternative. Examples of land impacts include change in the land usage required for system installation or disturbance to the natural ecosystem in the land. Additional construction taken place in already disturbed land is not considered. Land impacts are quantified in acres for each remedial alternative.

6. **Health and Safety and Community Impacts** were evaluated for each alternative by identifying both the associated inherent risks, which include risks that are associated with active remedies and site conditions, and risks that are a direct result of the technical approaches within the alternatives.

The result of the overall analysis is a relative comparison of the potential remedial alternatives based on the identified criteria to promote consideration of GSR principles as part of the remedy selection process. A summary of the sustainability assessment results for the selected metrics is included in **Table D-1** and **Figure D-1**. Fundamental engineering assumptions developed for the relative cost evaluation for each proposed remedial alternative were used to quantify sustainability metrics. Minor impacts common to each remedial alternative, such as routine management and reporting, were not included in this sustainability analysis. Impacts derived from the construction of already existing infrastructure (e.g., already installed injection wells) were not considered. Instead a focus was maintained on activities with significant associated impacts that could be used as differentiators during the analysis.

Consistency with Green and Sustainable Remediation Principles

Alternative 1 - No Action

The "no action" alternative was not considered as part of the sustainability analysis because it does not meet the threshold criteria. Non-adherence to the threshold criteria makes Alternative 1 unsustainable.

Alternative 2- In-Situ Chemical Oxidation (ISCO): Use of existing 75 injections wells, installation of 15 additional injection wells, decommissioning (1 year)

Alternative 2 includes the use of a proven in-situ technology to treat VOCs in groundwater while minimizing waste generation and minimizing energy consumption and mobile source air emissions associated with the transportation of materials and waste.

Key components that influence the GSR analysis of Alternative 2 include the reuse of existing infrastructure, the use of on-site potable water for reagent preparation, daily activities that require some energy and fuel consumption during the active remediation phase (injections), mobilization of non-local labor, and implementation of best management practices. Performance monitoring will be required during the period of active remediation and post remediation (long-term monitoring) will be required until the groundwater quality standards (GWQS) are achieved. The time frame of long-term monitoring has been considered as the same for all technologies so the only modification to the life time of the remedy is the active remediation period. Therefore, environmental impacts associated with this alternative are directly affected by the life time of the remedy which is reduced by this technology due to the rapid nature of the chemical reactions. Though the existing infrastructure will be used where practical to achieve reagent distribution, the installation of additional injection wells is required. Use of existing infrastructure will minimize the use of large-scale fuel-powered construction equipment with high energy requirements and elevated air emissions and reduce material consumption and waste generation.

The oxidant used under this alternative may impose an additional environmental footprint due to an associated manufacturing process; however, manufacture was not considered under the scope outlined above. The reduction in the construction time by the use of existing infrastructure and in the remedy lifetime reduces the transportation required for movement of materials and workers and decreases the use of heavy machinery, which also decreases the health and safety risks associated with this alternative and minimizes disturbance to the local community. Land impacts are considered minimal since this alternative will predominantly be using existing infrastructure and site conditions would not change.

Overall, total impacts associated with this remedial alternative are considerably lower than for the other alternatives. **Table D-1** summarizes the sustainability assessment results for Alternative 2. Additional information for the comparative analysis is included in **Figure D-1**.

Alternative 3- In Situ Enhanced Bioremediation (ISEB) : use of existing 25 injections wells, installation of 15 additional injection wells, decommissioning of 90 wells (includes the ISCO pilot inject wells) (4 years)

Alternative 3 includes the use of renewable biological resources to treat groundwater in-situ, minimizing waste generation and minimizing energy consumption and mobile source air emissions associated with the transportation of materials and waste.

Key components that influence the GSR analysis of Alternative 3 include the reuse of existing infrastructure, the use of on-site potable water for reagent preparation, daily activities that require some energy and fuel consumption during the active remediation phase (injections), mobilization of non-local labor, the duration of the active phase of remediation and implementation of best management practices. Environmental impacts associated with this alternative are affected by the increase in the number of injections events and the period of performance monitoring for the active remedy.

This alternative requires the installation of additional injection wells; however, this alternative has been designed to use existing infrastructure; therefore minimizing the use of large-scale fuel-powered construction equipment with high energy requirements and elevated air emissions and reducing the material consumption and waste generation. Land impacts are considered minimum since this alternative will be using predominantly existing infrastructure and site conditions would not change.

The increase in the remedy lifetime increases the transportation required for movement of materials and workers, which increases the health and safety risks associated with this alternative and increases disturbance to the local community.

Overall, total impacts associated with this remedial alternative are considerably lower than for Alternative 4 but higher than for Alternative 2. **Table D-1** summarizes the sustainability assessment results for Alternative 3. Additional information for the comparative analysis is provided in **Figure D-1**.

Alternative 4 - Air Sparge / Soil Vapor Extraction: Installation of 24 SVE and 51 AS wells, decommissioning (2 years)

Key components that influence the GSR analysis of Alternative 4 include reduced water consumption since it is air driven; reduced waste generation since the groundwater is treated in-situ, energy requirements for continuous operation of the system, infrastructure requirements, use of local labor to reduce fuel use associated with travel, and implementation of best management practices. Implementation of this remedy requires the installation of infrastructure (e.g. well installation, trenching and piping) which requires the operation of fuel-powered equipment with high energy requirements and elevated air emissions during the construction phase. The construction phase also requires direct oversight and continuous mobilization of personnel and materials. Additional health and safety risks would be posed by the construction and the use of large-scale construction equipment and it is expected to increase the estimated disturbance in the local community. Land impacts are considered minimum since site conditions would not change.

Overall, total impacts associated with this remedial alternative are higher than for Alternatives 2 and 3. **Table D-1** summarizes the sustainability assessment results for Alternative 4. Additional information for the comparative analysis is provided in **Figure D-1**.

Summary of Consistency with Green and Sustainable Remediation Principles

The results of the overall analysis are a relative comparison of the potential remedial alternatives developed for the Site to promote consideration of GSR principles as part of the remedy selection process. Beyond the standard feasibility criteria, the quantified sustainability assessment adds an additional dimension in the evaluation and selection of a final remedy which incorporates the commonly accepted principles of GSR.

In all instances, the analysis was performed with the fundamental assumption that all remedies must achieve the remedial goals identified for the site to be retained and qualify for further consideration. The comparative sustainability analysis of alternatives 2, 3, and 4 indicates that alternative 2 is the most sustainable of the alternatives considered. The environmental impacts associated with the alternatives are directly affected by the impacts generated during the implementation, energy requirements for the operation of the remedies, and remedy lifetime. Alternative 2 presents the lowest energy, air emission, and waste generation, since it entails lower energy requirements and the use of the existing infrastructure and shorter remedy life.

Summary of Consistency of Preferred Alternative with Green Best Practices Principles

Incorporation of green best practices into the design and operation of a remedial activity can help achieve cleanup objectives by ensuring protectiveness while decreasing the environmental footprint of the cleanup activity itself. Consistent with the Environmental Protection Agency (EPA) Principles for Greener Cleanups, and DER-31, a qualitative analysis of the green best management practices (GBMP) for the preferred remedy was performed. It is recommendable that these practices are incorporated during the implementation of the remedial alternative and should be maintained during the lifetime of the remediation. These practices address the core elements of a green cleanup:

- Reducing total energy use and increasing renewable energy use
- Reducing air pollutants and GHG emissions
- Reducing water use and negative impacts on water resources
- Improving materials management and waste reduction efforts, and
- Enhancing land management and ecosystems protection.

The sustainability evaluation of alternative 2 identified the following sustainable practices included within the remedial alternative which contributed in reducing the overall environmental impact of the remedy; these practices should be maintained through of the life of the project to minimize the impacts of the clean-up efforts.

- Use of existing infrastructure
- Use of local vendors and local workers with shorter travel/shipping distances to reduce the energy usage and mobile source air emissions associated with the transportation of materials, equipment, and workers.
- Optimization of injections to focus on the areas of highest concentration.

Green Best Practices Recommendations for Preferred Alternative

The sustainability evaluation of Alternative 2 identified two components of the remedy as major contributors of the overall environmental impact of the remedy: energy and air emissions associate with continuous mobilization of personnel and materials and water consumption during the active remediation phase. Below is the summary of recommendations for each one of the components to attain further reduction of the impacts by optimizing efficiency of long-term operations, particularly in terms of energy and other natural resource consumption such as the practices listed below:

Mobilization of personnel and materials

- Reduce mobile source air emissions by using alternative fuels such as biodiesel, ultra-low sulfur diesel, electric vehicles, and by reducing transportation miles of workers during the active remediation phase (e.g. carpooling).
- Institute vehicle maintenance plans that assure engine tune-ups and scheduled maintenance in accordance with manufacturer recommendations.
- Avoid rapid acceleration, braking, and excessive speeds, which can lower gas mileage.
- Considering non purge sampling methods to reduce sampling time and minimize energy consumption while producing little IDW and decrease water impacts.
- Retain local laboratories or use an onsite laboratory program if possible to reduce the footprint associated with transportation of samples.
- Request electronic deliverables to minimize materials and fuel consumption associated with hard-copy data reports, which also facilitates data sharing across team members.
- Consolidate field efforts where practical to reduce the number of trips to the site

System Construction & Operation

- Establish an appropriate target zone and thoroughly evaluate and optimize the substrate delivery to provide effective treatment
- Avoid engine idle during construction activities and use machinery with automatic idle-shutdown devices. Idling of fuel-powered vehicles, equipment, and machinery should be kept to a maximum of three minutes whenever possible, except for equipment such as drill rigs which commonly need longer idling times to maintain efficient work flow.
- Use of energy efficient equipment and optimize energy efficiency by maintaining equipment at peak performance. Select of suitably sized and type of machinery and equipment for intended application to use only the amount of energy needed.
- Use cleaner fuels to power machinery and auxiliary equipment. Prepare a diesel emission reduction plan and use heavy equipment efficiently.
- Retrofit engines to accommodate diesel emission controls or replacing obsolete engines; catalysts and filters should be verified by EPA or approved organization.

- Implementation of an erosion control plan to minimize generation and transport of airborne contaminants and dust.

- Minimization of dust generation and H&S risks by limiting speed to 10 miles per hour on site premises.

<u>References</u>

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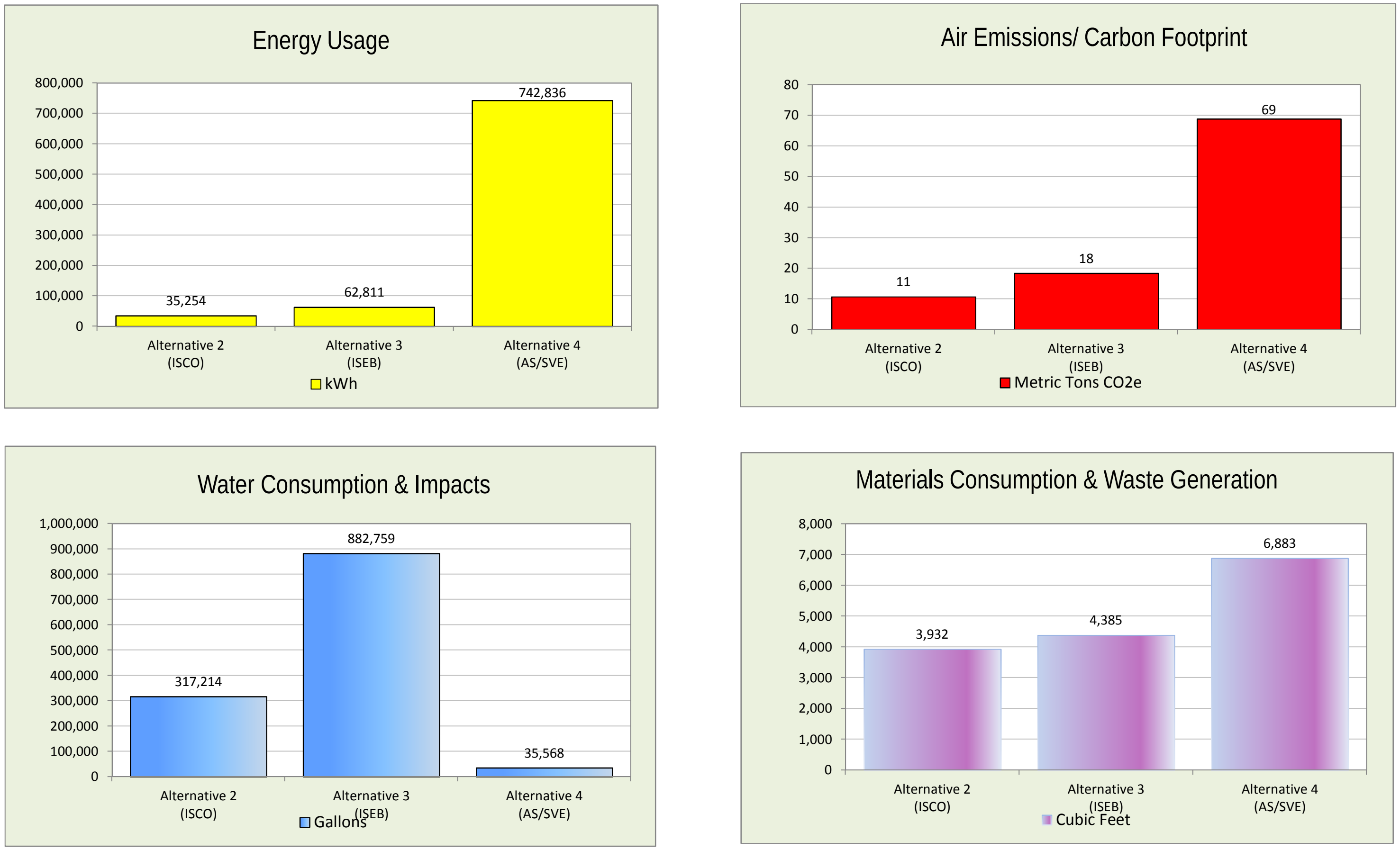
Table D-1. Sustainability Evaluation of Remedial Alternatives for the 3800 Area PCE Site, Fort Drum, New York

Remedial Alternative	Alternative Description	Energy usage		Air Emissions/ Carbon Footprint		Water Consumption and Impacts		Materials Consumption and Waste Generation	
		Usage	Units	Unit Usage	Ass. Units	Usage	Units	Usage	Units
Alternative 2 (ISCO)	In-situ Chemical Oxidation (ISCO): continuation of ISCO pilot injections, installation of 15 additional injection wells, decommissioning (1 year)	35,254	kWh	11	Metric Tons CO2e	317,214	Gallons	3,932	Cubic Feet
Alternative 3 (ISEB)	In Situ Enhanced Bioremediation (ISEB): use of existing 25 injections wells, installation of 15 additional injection wells, decommissioning (4 years)	62,811	kWh	18	Metric Tons CO2e	882,759	Gallons	4,385	Cubic Feet
Alternative 4 (AS/SVE)	Air Sparge / Soil Vapor Extraction (AS/SVE): Instalation of 24 SVE and 51 AS wells, decommissioning (2 years)	742,836	kWh	69	Metric Tons CO2e	35,568	Gallons	6,883	Cubic Feet

The quantitative sustainability assessment was performed using the BalancE3™ Tool
Usage for energy, water, and material and waste are rounded to the nearest 100

Figure D-1. Summary of the Sustainability Evaluation of Alternatives 2, 3, and 4 for the 3800 Area PCE Site, Fort Drum, New York



<u>General Assumptions</u>

Fundamental engineering assumptions developed for the cost evaluation for each proposed remedial alternative were used to quantify sustainability metrics
Area is cleared and accessible. No major site preparation required. Site is already a disturbed area, no additional land disturbance occurs.
Assumptions developed for the cost evaluation for each proposed remedial alternative were used to quantify sustainability metrics
No quantification was performed for the equipment and infrastructure already in place
Minor impacts common to each remedial alternative, such as routine management and reporting, were not included
The long-term monitoring portion of the remdy is common to all alternatives; therefore, it is not considered a differentiator and was not included in the analysis
All purge water is treated and discharged to POTW

APPENDIX E

Remedial Alternatives Cost Estimates

Appendix E: Estimated Remedial Alternatives Costs

Site: 3800 Area PCE Site
Location: Fort Drum, New York
Phase: FS
Base Year: 2015
Date: 5/29/2015

Remedial Alternative	**Capital Cost**	**Total Annual O&M and Periodic Costs**	**Total MNA Costs**	**Total Cost**	**Present Value Total Cost**	***Estimated Timeframe of Alternative*** [1]
No Action	--	$ 72,600	--	$ 72,600	$ 72,600	--
In-Situ Chemical Oxidation with Monitored Natural Attenuation	$ 174,500	$ 836,400	$ 500,700	$ 1,511,600	$ 1,480,100	1 yr active; 16 yrs MNA
In-Situ Enhanced Bioremediation with Bioaugmentation and with Monitored Natural Attenuation	$ 259,500	$ 859,900	$ 563,500	$ 1,682,900	$ 1,620,100	4 yrs active; 19 yrs MNA
Air Sparge / Soil Vaport Extraction with Monitored Natural Attenuation	$ 2,123,900	$ 466,300	$ 521,600	$ 3,111,800	$ 3,066,000	2 yrs active; 17 yrs MNA

Notes and References:

1: The estimated timeframe of each alternative assumed for costing may not reflect the actual time to cleanup.

United States Environmental Protection Agency. 1988. Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA Interim Final. USEPA Office of Emergency and Remedial Response. October 1988.

Alternative 1 - No Action

Site: 3800 PCE Site
Location: Ft Drum, NY
Phase: FS
Base Year: 2015
Date: 4/24/2015

Alternative Description:
No action taken
Abandonment of all wells associated with the site

Capital Costs:

DESCRIPTION	QTY	UNIT$^{(1)(2)}$	UNIT COST	TOTAL	NOTES
TOTAL CAPITAL COST				-	

Annual Operation and Maintenance Costs

DESCRIPTION	QTY	UNIT$^{(1)(2)}$	UNIT COST	TOTAL	NOTES
TOTAL ANNUAL O&M COST				$ -	

Alternative 1 - No Action

Site: 3800 PCE Site
Location: Ft Drum, NY
Phase: FS
Base Year: 2015
Date: 4/24/2015

Periodic Costs:

DESCRIPTION	Year	QTY	UNIT[(1)(2)]	UNIT COST	TOTAL	NOTES
Well Abandonment - 2-inch	0	4935	linear foot	$ 10.00	$ 49,350	
Well Abandonment Surface Restoration	0	53	each	$ 250.00	$ 13,250	
Well Abandonment Report	0	1	each	$ 10,000.00	$ 10,000	
SUBTOTAL					$ 72,600	

Present Value Analysis

Cost Type	Year	Total Cost	Total Cost Per Year	Discount Factor 1.4%	Present Value	Notes
Periodic Cost	0	$ 72,600	$ 72,600	1.00	$ 72,600	
TOTAL PRESENT VALUE OF ALTERNATIVE					$ 72,600	

Notes:

(1) Lump Sum Unit Costs based on ARCADIS project experience of similar size and nature and engineering judgment. Additional costs associated with specific project location and working calendar were accounted for.

(2) Individual Unit (i.e. each, tons, cubic yards) Costs based on executed construction bid documents (for other ARCADIS recent projects), vendor quotes and costing tools (e.g. RS Means).

Alternative 2 - In Situ Chemical Oxidation

Site: 3800 PCE Site
Location: Ft Drum, NY
Phase: FS
Base Year: 2015
Date: 4/24/2015

Alternative Description:

Continuation of ISCO pilot injections
Assumes injection wells installed during first phase of the pilot test do not have to be replaced
Installation of 15 injection points
Sodium permanganate injection into all existing injection wells (90 wells)

Pilot Testing

Field investigation to assess condition of Phase 1 pilot test injection wells
Injection testing on Phase 1 pilot test wells

ISCO Well Installation

15 injection wells
2-inch diameter wells installed to 42' bgs with 5' PVC/WR screen sections
Assumed AS ROI is 12.5'

ISCO Injections

Single injection event following pilot scale injections
3% (by weight) Sodium permanganate Solution
Variable injection volumes based on well details
- 28 existing wells with 10-ft screens spaced at 15 feet = ~2,000 gallons per well for a total of ~56,000 gallons
- 12 existing wells with 10-ft screens spaced at 25 feet = ~5,500 gallons per well for a total of ~66,000 gallons
- 35 Phase 2 wells with 5-ft screens spaced at 25 feet = ~2,800 gallons per well for a total of ~98,000 gallons
- 15 full scale additional wells with 10-ft screens spaced at 25 feet = ~5,500 gallons per well for a total of ~82,500
- 302,500 gallons total

75,600 lbs sodium permanganate
~189,000lbs of 40% sodium permananate solution
Up to 20 wells injected concurrently.
Average injection rates of 1.5 gpm
4 weeks (including setup and breakdown) required to complete injection in Phase 1 wells
6 weeks (including setup and breakdown) required to complete Phase 2 and new injection wells
12 weeks total per injection event

Performance Monitoring

10 monitor wells sampled for VOCs and manganese
4 sample events per year during injections

Alternative 2 - In Situ Chemical Oxidation

Site: 3800 PCE Site
Location: Ft Drum, NY
Phase: FS
Base Year: 2015
Date: 4/24/2015

Capital Costs:

DESCRIPTION	QTY	UNIT(1)(2)	UNIT COST	TOTAL	NOTES
Mobilization/Demobilization					
Construction Crew Mob/Demob	1	each	$ 2,500.00	$ 2,500	
Drill Rig Mob/Demob	1	each	$ 1,250.00	$ 1,250	
SUBTOTAL				$ 3,750	
Pre-Design Investigation, Monitoring, Sampling, Pilot Testing					
Injection Testing	1	LS	$ 15,000.00	$ 15,000	Pilot test wells installed during Phase 1
SUBTOTAL				$ 15,000	
ISCO System					
Drill Rig (2" or 4" well)	8	day	$ 1,950.00	$ 15,600	
2-inch well install	630	Linear Feet	$ 25.30	$ 15,939	
Waste Disposal	8	55-gal	$ 200.00	$ 1,600	Non-Haz, 202 pounds per CY
Remediation Well House w/ Connections	15	each	$ 1,500.00	$ 22,500	
Wellhead Assembly	20	each	$ 450.00	$ 9,000	
Misc valves and fittings	0.5	LS	$ 12,000.00	$ 6,000	
Distribution Hose (1-inch), with cam-lock fittings	1000	Linear Feet	$ 5.00	$ 5,000	
Shipping	1	Lump Sum	$ 0.07	$ 1,400	7% of equipment cost
Tax	1	Lump Sum	$ 0.05	$ 1,000	5% of equipment cost
SUBTOTAL				$ 78,039	
Contingency	25%			$ 24,197	
SUBTOTAL				$ 24,197	
Project Management	10%			$ 12,099	
Remedial Design	15%			$ 18,148	
Construction Management	8%			$ 9,679	
Information/Database Management	3%			$ 3,630	
Institutional Controls					
Institutional Controls Plan	1	each	$ 5,000.00	$ 5,000	
Groundwater Use Restrictions	1	each	$ 5,000.00	$ 5,000	
SUBTOTAL				$ 10,000	
TOTAL CAPITAL COST				$ 174,541	

Alternative 2 - In Situ Chemical Oxidation

Site: 3800 PCE Site
Location: Ft Drum, NY
Phase: FS
Base Year: 2015
Date: 4/24/2015

Annual Operation and Maintenance Costs

DESCRIPTION	QTY	UNIT(1)(2)	UNIT COST	TOTAL	NOTES
Performance Monitoring					
VOCs by 8260	40	each	$ 55.00	$ 2,200	
Metals	40	each	$ 70.00	$ 2,800	
Total Manganese	40	each	$ 20.00	$ 800	
Dissolved Manganese	40	each	$ 20.00	$ 800	
Low Flow Sampling Setup	12	day	$ 300.00	$ 3,600	
Environmental Technician	120	hour	$ 70.00	$ 8,400	
SUBTOTAL				$ 18,600	
ISCO Injection					
Environmental Technician	1000	hour	$ 70.00	$ 70,000	12 weeks, 2 people, 10 hours per day
Remox L (Sodium Permanganate, delivered)	189000	lb	$ 2.42	$ 457,380	
Water	302500	gal	$ 0.00	$ 1,210	
Injection Equipment Rental	10	week	$ 1,500.00	$ 15,000	
O&M Field Expenses	120	day	$ 250.00	$ 30,000	
Well Redevelopment	9	/well	$ 2,500.00	$ 22,500	Assume 10% of well require redevelopment
SUBTOTAL				$ 596,090	
Project Management	10%			$ 61,469	
Technical Support	10%			$ 61,469	
Information/Database Management	3%			$ 18,441	
Annual Reporting				$ 10,000	
TOTAL ANNUAL O&M COST				$ 766,069	

Alternative 2 - In Situ Chemical Oxidation

Site: 3800 PCE Site
Location: Ft Drum, NY
Phase: FS
Base Year: 2015
Date: 4/24/2015

Periodic Costs:

DESCRIPTION	Year	QTY	UNIT(1)(2)	UNIT COST	TOTAL	NOTES
Well Abandonment - 2-inch	5	3780	linear foot	$ 10.00	$ 37,800	
Well Abandonment Surface Restoration	5	90	each	$ 250.00	$ 22,500	
Construction Completion Report	1	1	each	$ 10,000.00	$ 10,000	
SUBTOTAL					$ 70,300	

Present Value Analysis

Cost Type	Year	Total Cost	Total Cost Per Year	Discount Factor 1.4%	Present Value	Notes
Capital Cost	0	$ 174,541	$ 174,541	1.00	$ 174,541	
ISCO Injection	0	$ 766,069	$ 766,069	1.00	$ 766,069	
Construction Completion Report	1	$ 10,000	$ 10,000	0.99	$ 9,862	
Periodic Cost	5	$ 60,300	$ 60,300	0.93	$ 56,251	

TOTAL PRESENT VALUE OF ALTERNATIVE $ 1,006,723

Notes:
(1) Lump Sum Unit Costs based on ARCADIS project experience of similar size and nature and engineering judgment. Additional costs associated with specific project location and
(2) Individual Unit (i.e. each, tons, cubic yards) Costs based on executed construction bid documents (for other ARCADIS recent projects), vendor quotes and costing tools (e.g. RS Means).

Alternative 3 - In Situ Enhanced Bioremediation

Site:	3800 PCE Site
Location:	Ft Drum, NY
Phase:	FS
Base Year:	2015
Date:	4/24/2015

Alternative Description:

Assumes injection wells installed during first phase of the pilot test do not have to be replaced
Installation of 15 injection points
Initial injection of sodium lactate followed by maintenance injections of EVO downgradient of source
Continued injection of sodium lactate upgradient of source
Due to aquifer environment and general lack of natural degradation, bioaugmentation is included following initial sodium lactate injection.

Pilot Testing

Tracer testing to determine GW velocity and barrier width requirement
Field investigation to assess condition of Phase 1 pilot test injection wells
Injection testing on Phase 1 pilot test wells

ERD Well Installation

15 injection wells
2-inch diameter wells installed to 42' bgs with 5' PVC/WR screen sections
Assumed AS ROI is 12.5'

ERD Injections

Initial injection of sodium lactate in all injection wells to condition the aquifer and rapidly generate anaerobic conditions
With the exception of a 7 well transect upgradient of the source, subsequent injection of EVO
Continued injection of sodium lactate in 7 wells upgradient of source
Four years of injections including 1 lactate in all wells, 3 EVO injections, and 5 additional lactate injections upgradient of the source

Variable injection volumes based on well details

- 10 existing wells with 10-ft screens spaced at 15 feet = ~2,000 gallons per well for a total of ~20,000 gallons
- 15 Phase 2 wells with 5-ft screens spaced at 25 feet = ~2,800 gallons per well for a total of ~42,000 gallons
- 15 full scale additional wells with 10-ft screens spaced at 25 feet = ~5,500 gallons per well for a total of ~82,500
- 144,500 gallons total

- Lactate Injections

Initial injection of 2% by weight lactate in all wells

- 24,100 lbs sodium lactate (2,230 gal)
- 5 subsequent injections of 19,600 gallons 2% (by wt) sodium lactate - 3,270 lbs (303 gallons)

- EVO Injections

- 3 Injection events (annually)
- 124,900 gallons of 2% (by wt) EVO - 20,800 lbs EVO (2,537 gallons)

Up to 20 wells injected concurrently; Average injection rates of 1.5 gpm; 4 weeks total per injection event

Performance Monitoring

10 monitor wells sampled for VOCs, TOC, dissolved gases, anions
4 events per year during injections

Alternative 3 - In Situ Enhanced Bioremediation

Site:	3800 PCE Site
Location:	Ft Drum, NY
Phase:	FS
Base Year:	2015
Date:	4/24/2015

Capital Costs:

DESCRIPTION	QTY	UNIT(1)(2)	UNIT COST	TOTAL	NOTES
Mobilization/Demobilization					
Construction Crew Mob/Demob	1	each	$ 2,500.00	$ 2,500	
Drill Rig Mob/Demob	1	each	$ 1,250.00	$ 1,250	
SUBTOTAL				$ 3,750	
Pre-Design Investigation, Monitoring, Sampling, Pilot Testing					
Injection Testing	1	LS	$ 15,000.00	$ 15,000	Pilot test wells installed during Phase 1
Tracer Testing	1	LS	$ 50,000.00	$ 50,000	Tracer Testing
SUBTOTAL				$ 65,000	
ERD System					
Drill Rig (2" or 4" well)	8	day	$ 1,950.00	$ 15,600	
2-inch well install	630	Linear Feet	$ 25.30	$ 15,939	
Waste Disposal	8	55-gal	$ 200.00	$ 1,600	Non-Haz, 202 pounds per CY
Remediation Well House w/ Connections	15	each	$ 1,500.00	$ 22,500	
Wellhead Assembly	20	each	$ 450.00	$ 9,000	
Misc valves and fittings	0.5	LS	$ 12,000.00	$ 6,000	
Distribution Hose (1-inch), with cam-lock fittings	1000	Linear Feet	$ 5.00	$ 5,000	
Shipping	1	Lump Sum	$ 0.07	$ 1,400	7% of equipment cost
Tax	1	Lump Sum	$ 0.05	$ 1,000	5% of equipment cost
SUBTOTAL				$ 78,039	
Contingency	25%			$ 36,697	
SUBTOTAL				$ 36,697	
Project Management	10%			$ 18,349	
Remedial Design	15%			$ 27,523	
Construction Management	8%			$ 14,679	
Information/Database Management	3%			$ 5,505	
Institutional Controls					
Institutional Controls Plan	1	each	$ 5,000.00	$ 5,000	
Groundwater Use Restrictions	1	each	$ 5,000.00	$ 5,000	
SUBTOTAL				$ 10,000	
TOTAL CAPITAL COST				$ 259,541	

Alternative 3 - In Situ Enhanced Bioremediation

Site: 3800 PCE Site
Location: Ft Drum, NY
Phase: FS
Base Year: 2015
Date: 4/24/2015

Annual Operation and Maintenance Costs

DESCRIPTION	QTY	UNIT$^{(1)(2)}$	UNIT COST	TOTAL	NOTES
Performance Monitoring					
VOCs by 8260	40	each	$ 55.00	$ 2,200	
TOC	40	each	$ 20.00	$ 800	
Dissolved Gases	40	each	$ 75.00	$ 3,000	
Anions	40	each	$ 82.00	$ 3,280	
Low Flow Sampling Setup	12	day	$ 300.00	$ 3,600	
Environmental Technician	120	hour	$ 70.00	$ 8,400	
SUBTOTAL				$ 21,280	
Year 0 ERD Injections (1 sodium lactate, 1 EVO/sodium lactate injection)					
Environmental Technician	800	hour	$ 70.00	$ 56,000	4 weeks, 2 people, 10 hours per day
Sodium Lactate	2533	gal	$ 10.00	$ 25,330	
EVO (EOS® 598B42)	2537	lb	$ 1.99	$ 5,049	
Bioaugmentation Culture	40	well	$ 750.00	$ 30,000	
Water	289000	gal	$ 0.00	$ 1,156	
Injection Equipment Rental	10	week	$ 1,500.00	$ 15,000	
O&M Field Expenses	120	day	$ 250.00	$ 30,000	
Well Redevelopment	4	/well	$ 2,500.00	$ 10,000	Assume 10% of well require redevelopment
SUBTOTAL				$ 172,535	
Project Management	10%			$ 19,381	
Technical Support	12%			$ 23,258	
Information/Database Management	3%			$ 5,814	

Alternative 3 - In Situ Enhanced Bioremediation

Site: 3800 PCE Site
Location: Ft Drum, NY
Phase: FS
Base Year: 2015
Date: 4/24/2015

Year 1-3 ERD Injections (2 sodium lactate, 1 EVO injection per year)					
Environmental Technician	500	hour	$ 70.00	$ 35,000	4 weeks full scale event, 1 week lactate ever
Sodium Lactate	606	gal	$ 10.00	$ 6,060	
EVO (EOS® 598B42)	2537	lb	$ 1.99	$ 5,049	
Water	164100	gal	$ 0.00	$ 656	
Injection Equipment Rental	10	week	$ 1,500.00	$ 15,000	
O&M Field Expenses	120	day	$ 250.00	$ 30,000	
Well Redevelopment	8	/well	$ 2,500.00	$ 20,000	Assume 20% of well require redevelopment
SUBTOTAL				$ 111,765	
Project Management	10%			$ 11,758	
Technical Support	12%			$ 14,110	
Information/Database Management	3%			$ 3,527	
Annual Reporting				$ 15,000	
TOTAL ANNUAL O&M COST (Year 0)				$ 257,268	
TOTAL ANNUAL O&M COST (Year 1-3)				$ 177,440	

Periodic Costs:

DESCRIPTION	**Year**	**QTY**	**UNIT**[(1)(2)]	**UNIT COST**	**TOTAL**	**NOTES**
Well Abandonment - 2-inch	5	3780	linear foot	$ 10.00	$ 37,800	
Well Abandonment Surface Restoration	5	90	each	$ 250.00	$ 22,500	
Construction Completion Report	1	1	each	$ 10,000.00	$ 10,000	
SUBTOTAL					$ 70,300	

Alternative 3 - In Situ Enhanced Bioremediation

Site: 3800 PCE Site
Location: Ft Drum, NY
Phase: FS
Base Year: 2015
Date: 4/24/2015

Present Value Analysis

Cost Type	Year	Total Cost	Total Cost Per Year	Discount Factor 1.4%	Present Value	Notes
Capital Cost	0	$ 259,541	$ 259,541	1.00	$ 259,541	
ERD Injection	0	$ 257,268	$ 257,268	1.00	$ 257,268	
Construction Completion Report	1	$ 10,000	$ 10,000	0.99	$ 9,862	
ERD Injection	1-3	$ 532,320	$ 177,440	2.92	$ 517,755	
Periodic Cost	5	$ 60,300	$ 60,300	0.93	$ 56,251	

TOTAL PRESENT VALUE OF ALTERNATIVE $ 1,100,678

Notes:

(1) Lump Sum Unit Costs based on ARCADIS project experience of similar size and nature and engineering judgment. Additional costs associated with specific project location and working calendar were accounted for.

(2) Individual Unit (i.e. each, tons, cubic yards) Costs based on executed construction bid documents (for other ARCADIS recent projects), vendor quotes and costing tools (e.g. RS Means).

Alternative 4 - Air Sparging with Soil Vapor Extraction

Site:	3800 PCE Site
Location:	Fort Drum, New York
Phase:	FS
Base Year:	2015
Date:	4/24/2015

Alternative Description:
Installation of AS system to remediate PCE Source Area

AS System:
51 air sparge wells
2-inch diameter wells installed to 60' bgs with 2' screen sections
Assumed AS ROI is 15'
Dedicated piping to each well
System operation will be pulsed with a maximum air flow of 170 scfm at 20-30 psi
Assume 10 scfm per AS well. System set up to operate in 3 zones of approximately 17 wells each (8 hours per day)
Installation of below grade individual air lines to each well

SVE System:
24 SVE wells
4-inch diameter wells installed to 20' bgs with 5' screen sections
SVE ROI is 25'
System will be operated continuously to ensure capture of volatilized COCs generated by the AS system.
Assume 25 scfm recovered from each SVE well.
4,000 lbs GAC change-out one time. Assume atmosphere discharge following first year of operation
Installation of below grade individual headers to each operating zone (3 zones)

Performance monitoring - 12 monitor wells for VOCs sampled quarterly
Assumed 2 years of operation.
Monthly O&M visits (24 hours per visit)
Quarterly system sampling to include influent and effluent air for VOCs from each zone (6 samples total)

Alternative 4 - Air Sparging with Soil Vapor Extraction

Site: 3800 PCE Site
Location: Fort Drum, New York
Phase: FS
Base Year: 2015
Date: 4/24/2015

Capital Costs:

DESCRIPTION	QTY	UNIT(1)(2)	UNIT COST	TOTAL	NOTES
Mobilization/Demobilization					
Construction Crew Mob/Demob	1	each	$ 2,500.00	$ 2,500	
Drill Rig Mob/Demob	5	each	$ 1,250.00	$ 6,250	
SUBTOTAL				$ 8,750	
Pre-Design Investigation, Monitoring, Sampling, Pilot Testing					
AS/SVE Pilot Test	1	Lump Sum	$ 20,000.00	$ 20,000	
SUBTOTAL				$ 20,000	
AS/SVE System					
Drill Rig (2" or 4" well)	45	day	$ 1,950.00	$ 87,750	
2-inch well install	3060	Linear Feet	$ 25.30	$ 77,418	
4-inch well install	480	Linear Feet	$ 27.50	$ 13,200	
Waste Disposal	60	55-gal	$ 200.00	$ 12,000	202 pounds per CY
Remediation Well House w/ Connections	75	each	$ 1,500.00	$ 112,500	
Regenerative Blower (Rotron EN-979,20 HP, 60 in-H2O, 600 sc	1	each	$ 35,000.00	$ 35,000	
SVE knockout tank	1	each	$ 1,000.00	$ 1,000	
4,000 lb vapor phase carbon vessel	1	each	$ 12,000.00	$ 12,000	
Claw Compressor (Zephyr C-DLR 300, 23 psi, 190 scfm, 24 kW	1	each	$ 20,000.00	$ 20,000	
Manifold (piping; fitting; appurtenant equipment)	3	/zone	$ 15,000.00	$ 45,000	3 AS manifolds, 1 SVE manifold
Treatment Building	750	Square Feet	$ 100.00	$ 75,000	
Piping, 1" HDPE	23100	Linear Feet	$ 5.00	$ 115,500	
Piping, 4" HDPE	4180	Linear Feet	$ 9.00	$ 37,620	
Conveyance Pipe Installation	4180	Linear Feet	$ 75.00	$ 313,500	
SCADA Telemetry	1	each	$ 15,000.00	$ 15,000	
Electrical Controls	20	each	$ 3,500.00	$ 70,000	
Control Panel	1	LS	$ 50,000.00	$ 50,000	
Electrician	10	day	$ 1,800.00	$ 18,000	
Power Drop	0.25	Lump Sum	$ 30,000.00	$ 7,500	Power pole and meter only
Shipping	1	Lump Sum	$ 0.07	$ 55,273	7% of equipment cost
Tax	1	Lump Sum	$ 0.05	$ 39,481	5% of equipment cost

Alternative 4 - Air Sparging with Soil Vapor Extraction

Site: 3800 PCE Site
Location: Fort Drum, New York
Phase: FS
Base Year: 2015
Date: 4/24/2015

	QTY	UNIT	UNIT COST	TOTAL	NOTES
Remediation System Startup Testing	1	Lump Sum	$ 30,000.00	$ 30,000	
SUBTOTAL				$ 1,242,742	
Contingency	25%			$ 317,873	
SUBTOTAL				$ 317,873	
Project Management	10%			$ 158,937	
Remedial Design	12%			$ 190,724	
Construction Management	8%			$ 127,149	
Information/Database Management	3%			$ 47,681	
Institutional Controls					
Institutional Controls Plan	1	each	$ 5,000.00	$ 5,000	
Groundwater Use Restrictions	1	each	$ 5,000.00	$ 5,000	
SUBTOTAL				$ 10,000	
TOTAL CAPITAL COST				$ 2,123,856	

Annual Operation and Maintenance Costs

DESCRIPTION	**QTY**	**UNIT$^{(1)(2)}$**	**UNIT COST**	**TOTAL**	**NOTES**
Performance Monitoring					
VOCs by 8260	48	each	$ 55.00	$ 2,640	
Low Flow Sampling Setup	12	day	$ 300.00	$ 3,600	
Environmental Technician	120	hour	$ 70.00	$ 8,400	
SUBTOTAL				$ 14,640	

Alternative 4 - Air Sparging with Soil Vapor Extraction

Site: 3800 PCE Site
Location: Fort Drum, New York
Phase: FS
Base Year: 2015
Date: 4/24/2015

Remedial System O&M					
Environmental Technician	192	hour	$ 70.00	$ 13,440	
EPA TO-15	24	each	$ 195.00	$ 4,680	
Summa Canister	24	each	$ 60.00	$ 1,440	
Equipment Repair/Replacement	1	Lump Sum	$ 0.05	$ 39,481	
Electricity	280119	KwHr	$ 0.12	$ 33,614	45 total system HP - 95% runtime
Granular Activated Carbon Change out	2000	lb	$ 2.50	$ 5,000	
O&M Field Expenses	36	day	$ 250.00	$ 9,000	
Well Redevelopment	5	/well	$ 2,500.00	$ 12,500	10% of AS wells redeveloped
SUBTOTAL				$ 119,155	
Project Management	10%			$ 13,380	
Technical Support	10%			$ 13,380	
Information/Database Management	3%			$ 4,014	
Annual Reporting				$ 10,000	
TOTAL ANNUAL O&M COST				$ 174,568	

Periodic Costs:

DESCRIPTION	**Year**	**QTY**	**UNIT$^{(1)(2)}$**	**UNIT COST**	**TOTAL**	**NOTES**
Well Abandonment - 2-inch	5	3315	linear foot	$ 10.00	$ 33,150	
Well Abandonment - 4-inch	5	480	linear foot	$ 11.00	$ 5,280	
Well Abandonment Surface Restoration	5	115	each	$ 250.00	$ 28,750	
Construction Completion Report	2	1	each	$ 50,000.00	$ 50,000	
SUBTOTAL					$ 117,180	

Alternative 4 - Air Sparging with Soil Vapor Extraction

Site: 3800 PCE Site
Location: Fort Drum, New York
Phase: FS
Base Year: 2015
Date: 4/24/2015

Present Value Analysis

Cost Type	Year	Total Cost	Total Cost Per Year	Discount Factor 1.4%	Present Value	Notes
Capital Cost	0	$ 2,123,856	$ 2,123,856	1.00	$ 2,123,856	
Annual O&M Cost	1-2	$ 349,136	$ 174,568	1.96	$ 341,939	
Construction Completion Report	2	$ 50,000	$ 50,000	0.97	$ 48,629	
Periodic Cost	5	$ 67,180	$ 67,180	0.93	$ 62,669	

TOTAL PRESENT VALUE OF ALTERNATIVE $ 2,577,093

Notes:

(1) Lump Sum Unit Costs based on ARCADIS project experience of similar size and nature and engineering judgment. Additional costs associated with specific project location and

(2) Individual Unit (i.e. each, tons, cubic yards) Costs based on executed construction bid documents (for other ARCADIS recent projects), vendor quotes and costing tools (e.g. RS Means).

MNA Groundwater Monitoring for Alternatives 2, 3, and 4

Site: 3800 PCE Site
Location: Fort Drum, New York
Phase: FS
Base Year: 2015
Date: 4/24/2015

Alternative Description:
No additional investigation or system enhancements.
Shut down all operating systems

Monitor 30 wells
Assumed 19 years of monitoring (ERD Alternative)
Semi-annual sampling for 5 years
Annual sampling for 14 years
Analyze for VOCs and field parameters

Capital Costs:

DESCRIPTION	QTY	UNIT[(1)(2)]	UNIT COST	TOTAL	NOTES
TOTAL CAPITAL COST				$ -	

Annual Operation and Maintenance Costs

DESCRIPTION	QTY	UNIT[(1)(2)]	UNIT COST	TOTAL	NOTES
Performance Monitoring					
Environmental Technician	160	hour	$ 70.00	$ 11,200	
VOCs by 8260	60	each	$ 55.00	$ 3,300	
Low Flow Sampling Setup	20	day	$ 300.00	$ 6,000	
O&M Field Expenses	20	day	$ 250.00	$ 5,000	
SUBTOTAL				$ 25,500	
Project Management	10%			$ 2,550	
Technical Support	12%			$ 3,060	
Information/Database Management	3%			$ 765	
Annual Reporting				$ 10,000	
TOTAL ANNUAL O&M COST				$ 41,875	

MNA Groundwater Monitoring for Alternatives 2, 3, and 4

Site: 3800 PCE Site
Location: Fort Drum, New York
Phase: FS
Base Year: 2015
Date: 4/24/2015

Periodic Costs:

DESCRIPTION	Year	QTY	UNIT$^{(1)(2)}$	UNIT COST	TOTAL	NOTES
Remedial Design	0	1	each	$ 10,000.00	$ 10,000	
SUBTOTAL					$ 10,000	
5-Year Review	5	1	each	$ 12,000.00	$ 12,000	
Update LUCIP	5	1	each	$ 5,000.00	$ 5,000	
SUBTOTAL					$ 17,000	
5-Year Review	10	1	each	$ 12,000.00	$ 12,000	
Update LUCIP	10	1	each	$ 5,000.00	$ 5,000	
SUBTOTAL					$ 17,000	
5-Year Review	15	1	each	$ 12,000.00	$ 12,000	
Update LUCIP	15	1	each	$ 5,000.00	$ 5,000	
SUBTOTAL					$ 17,000	

MNA Groundwater Monitoring for Alternatives 2, 3, and 4

Site: 3800 PCE Site
Location: Fort Drum, New York
Phase: FS
Base Year: 2015
Date: 4/24/2015

Present Value Analysis

Cost Type	Year	Total Cost	Total Cost Per Year	Discount Factor	Present Value	Notes
				1.4%		
Capital Cost	0	$ -	$ -	1.00	$ -	
Annual O&M C	0-19	$ 502,500	$ 26,447.37	17.58	$ 464,993	
Periodic Cost	0	$ 10,000	$ 10,000	1.00	$ 10,000	
Periodic Cost	5	$ 17,000	$ 17,000	0.93	$ 15,858	
Periodic Cost	10	$ 17,000	$ 17,000	0.87	$ 14,793	
Periodic Cost	15	$ 17,000	$ 17,000	0.81	$ 13,800	

TOTAL PRESENT VALUE OF ALTERNATIVE $ 519,445

Notes:
(1) Lump Sum Unit Costs based on ARCADIS project experience of similar size and nature and engineering judgment. Additional costs associated with specific
(2) Individual Unit (i.e. each, tons, cubic yards) Costs based on executed construction bid documents (for other ARCADIS recent projects), vendor quotes and

Ft Drum 3800 PCE Area Flushing Calculation
Fort Drum, NY

Aquifer and IRZ Parameters	Unit	Values	Notes
Total Porosity (θ_t)	--	0.3	based on previous estimates
Mobile Porosity (θ_m)	--	0.15	based on previous estimates
Bulk Density (ρ_b)	g/cc	1.85	assumed value
Fraction Organic Carbon	--	0.0005	assumed value
Groundwater Velocity (V_{GW})	ft/day	1.08	average unconfined aquifer grounwater velocity in the area with CVOC contamination; Assumed 300 ft/year based on Pilot Test results

Contaminant Parameters		PCE	TCE	c-DCE	Notes
Log Koc	--	2.42	1.81	1.62	look up values
Kd	--	0.13	0.03	0.02	Kd=Koc*foc
Retardation Factor (R)	--	1.81	1.20	1.13	
Contaminant Velocity (V_c)	ft/day	0.60	0.90	0.96	V_c=V_{GW}/R
Maximum Contaminant Concentration (C_{max})[1]	ppb	569	0	0	See Note Below
Cleanup Goal (C_{goal})	ppb	5	5	70	chemcial specific ARARs
# of pore flushes to achieve cleanup	--	8.6			
Distance for pore flushing	ft	500			
Groundwater Travel Time between Barriers	Year	1.3			
Year to Cleanup	Year	**10.9**	**0.0**	**0.0**	based on GW velocity

[1] PCE concentration represents concentration at 3805-PZ2D during Fall 2014 sampling event and assumes source area treatment is successful