IN-SITU BIOREMEDIATION
OPERATION, MAINTENANCE & MONITORING PLAN
for
SITE 5 - FIRE TRAINING AREA
GROUNDWATER (OU 2)

FORMER NAVAL AIR STATION JOINT RESERVE BASE
WILLOW GROVE, PENNSYLVANIA

COMPREHENSIVE LONG-TERM
ENVIRONMENTAL ACTION NAVY (CLEAN) CONTRACT

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ACRONYMS AND ABBREVIATIONS

AFFF Aqueous film-forming foam
ARARs Applicable or Relevant and Appropriate Requirements
BRAC Base Realignment and Closure
CERCLA Comprehensive Environmental Response, Compensation, and Liability Act
CFR Code of Federal Regulations
CLEAN Comprehensive Long-Term Environmental Action Navy
COCs Chemicals of Concern
CVOC Chlorinated Volatile Organic Compound
DO Dissolved Oxygen
DoD Department of Defense
EPA U.S. Environmental Protection Agency
ESTCP Environmental Security Technology Certification Program
FFA Federal Facilities Agreement
FS Feasibility Study
gph gallons per hour
gpm gallons per minute
HASP Health and Safety Plan
HHRA Human Health Risk Assessment
HLRA Horsham Land Redevelopment Authority
IDW Investigation Derived Waste
ISB in-situ bioremediation
LUC Land use control
MBT Molecular Biological Tools
MCL Maximum contaminant level
MNA monitored natural attenuation
MSC Medium-specific concentration
NAS JRB Naval Air Station Joint Reserve Base
NEESA Naval Energy and Environmental Support Activity
NFA No further action
NPL National Priorities List
O&M Operation and Maintenance
OM&M Operation, Maintenance & Monitoring
OPS Operating Properly and Successfully
ORP Oxidation-Reduction Potential
OSHA Occupational Safety and Health Administration
OU Operable Unit
## ACRONYMS AND ABBREVIATIONS (Continued)

<table>
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<tr>
<th>Acronym</th>
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<tr>
<td>PADEP</td>
<td>Pennsylvania Department of Environmental Protection</td>
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<tr>
<td>PAH</td>
<td>polycyclic aromatic hydrocarbon</td>
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<tr>
<td>PCE</td>
<td>Tetrachloroethylene</td>
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<tr>
<td>PCR</td>
<td>Polymerase Chain Reaction</td>
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<tr>
<td>PFOA</td>
<td>Perfluorooctanoic acid</td>
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<tr>
<td>PFOS</td>
<td>Perfluorooctane sulfate</td>
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<tr>
<td>PMO</td>
<td>Program Management Office</td>
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<tr>
<td>psi</td>
<td>pounds per square inch</td>
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<tr>
<td>PVC</td>
<td>polyvinyl chloride</td>
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<tr>
<td>qPCR</td>
<td>quantitative Polymerase Chain Reaction</td>
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<td>Remedial Action</td>
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<tr>
<td>SU</td>
<td>standard units</td>
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<tr>
<td>SVOC</td>
<td>Semivolatile organic compound</td>
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<tr>
<td>TCE</td>
<td>trichloroethylene</td>
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<tr>
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<td>Target Compound List</td>
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<tr>
<td>TOC</td>
<td>Total Organic Carbon</td>
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<tr>
<td>VC</td>
<td>vinyl chloride</td>
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<tr>
<td>VFA</td>
<td>volatile fatty acid</td>
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<tr>
<td>VOC</td>
<td>Volatile organic compound</td>
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1.0 INTRODUCTION

This Operation, Maintenance & Monitoring (OM&M) Plan has been prepared under Contract Task Order No. WE05 of Contract N62470-08-D-1001, Comprehensive Long-Term Environmental Action Navy (CLEAN) between Tetra Tech, Inc. (Tetra Tech) and the U.S. Navy. This Plan identifies the approach and requirements for in-situ anaerobic bioremediation operations, maintenance and long term monitoring activities at the Site 5 - Fire Training Area Groundwater, Operable Unit (OU) 2, located in the former Naval Air Station Joint Reserve Base (NAS JRB) Willow Grove, Horsham Township, Montgomery County, Pennsylvania.

The major components of the Selected Remedy for Site 5 groundwater include in-situ anaerobic bioremediation of contaminated groundwater within the source area, and monitored natural attenuation (MNA) of the groundwater plume downgradient of the source area. This Plan includes details for in-situ bioremediation injection system operations and maintenance; operational procedures and protocols; and the associated sampling and analysis, data evaluation, remedy performance reviews, long term monitoring, and implementation and inspection of Land Use Controls (LUCs).

1.1 SITE DESCRIPTION AND BACKGROUND

The former NAS JRB Willow Grove is located in Horsham Township in Montgomery County, Pennsylvania. NAS JRB Willow Grove occupied approximately 900 acres of the 1,100 acres the Department of Defense (DoD) maintained at the Air Station (Figure 1-1). The primary mission of NAS JRB Willow Grove was to provide support for operations involving aviation training activities and to train Navy reservists. NAS JRB Willow Grove supported other DoD tenants such as the Marine Reserve and the Army Reserve, and shared facilities and services with the Air Force Reserve. NAS JRB was placed on the National Priorities List (NPL) in September 1995. The former NAS JRB Willow Grove was selected in 2005 by the Base Realignment and Closure (BRAC) Commission for closure, and was officially disestablished on March 30, 2011. The base continued to provide services and facilities, on a limited basis, until September 2011, at which time it was transferred to BRAC Program Management Office (PMO) and entered caretaker status. Decisions regarding the future use of the land are coordinated by the Horsham Township Authority for NAS JRB Willow Grove. On March 21, 2012, the Horsham Land Redevelopment Authority (HLRA) officially approved the proposed NAS JRB Willow Grove Redevelopment Plan and Homeless Assistance Submission. The full NAS JRB Willow Grove Redevelopment Plan was submitted to the Navy on April 27, 2012. Concurrently, the Homeless Assistance Submission was submitted to the U.S. Department of Housing and Urban Development. On September 19, 2012, all assets and liabilities of the Horsham Township Authority were transferred to the HLRA.
Site 5 – Fire Training Area was identified as part of the NPL designation. The Fire Training Area is located in the south-central portion of former NAS JRB Willow Grove, approximately midway between Runway 10/28 and State Route 463 (Figure 1-1). The training area was used from 1942 to 1975 for large-scale firefighting exercises, which included the disposal and burning of flammable liquid wastes generated by the Naval Air Station. Wastes (including solvents, paint chemicals, xylenes, toluene, and various petroleum compounds) were consumed at the rate of up to 4,000 or more gallons per year in these firefighting exercises. The area was reportedly used for the drum storage of these flammable materials during the periods between burning exercises.

The Fire Training Area is primarily covered by grasses, with some woody and brushy vegetation present within the southern portion of the area. The burn area consisted of a "burning ring" that was actually a section of a partially buried steel tank, open at the top with an intact bottom below the surrounding grade, which was located in the south-central portion of the site. Site 5 consists of a groundwater plume containing multiple volatile organic compounds (VOCs) that were historically disposed or spilled near the former drum staging area located to the north of monitoring well cluster 05MW01 (see Figure 1-2).

The final Remedial Investigation (RI) report for Site 5 was completed in February 2002 (Tetra Tech, 2002a). The results of the RI indicated that small and isolated areas of VOCs remained in soil at low concentrations, and did not serve as a major source of groundwater contamination. Most of the VOCs that serve as the source of the groundwater plume exist within the matrix and secondary porosity (including fractures) of the shallow bedrock. The principal contaminants associated with Site 5 groundwater are VOCs. Compounds detected at levels of potential concern included: trichloroethylene (TCE); tetrachloroethylene (PCE); benzene; 1,1,1-trichloroethane (1,1,1-TCA); 1,1-dichloroethane (DCA); 1,1-dichloroethene (1,1-DCE); 1,4-dioxane; and 1,2-DCE (total).

A soil removal action for polycyclic aromatic hydrocarbon (PAH)-contaminated soil in the vicinity of the Site 5 burning ring began in December 2005. Initial excavation confirmation samples indicated PAHs remained at some spots at concentrations above cleanup levels. A second round of excavation and confirmation samples [including sampling and analysis for dioxins as requested by the United States Environmental Protection Agency (EPA)] was followed by soil backfill in October 2006. Results from confirmation samples were evaluated for residual risk. The increased carcinogenic risk was 8.6E-05 which falls within EPA's acceptable risk range. On September 21, 2007, a No Further Action (NFA) Record of Decision (ROD) for Site 5 Soil (OU 4) (Tetra Tech, 2007b) was signed by the Navy and EPA with concurrence from the Pennsylvania Department of Environmental Protection (PADEP).
A Technical Memorandum of Risk Assessment Evaluation for Site 5 Groundwater (Tetra Tech, 2007c) included a limited update of the Human Health Risk Assessment (HHRA) for groundwater in response to changes in risk assessment methodology. The revised HHRA estimated unacceptable risk for future child and adult residents and future lifelong residents exposed to untreated groundwater.

The Feasibility Study (FS) for Site 5 Groundwater (OU 2) was finalized in November 2008 (Tetra Tech, 2008b). This FS identified and evaluated five remedial alternatives for Site 5 groundwater to address unacceptable risks identified during the RI. The FS included a remedial alternative of in-situ enhanced biological anaerobic reductive dehalogeneration (bioremediation) and natural attenuation to promote the in-situ remediation of the VOCs in groundwater. Tetra Tech was subsequently assigned to perform a bioremediation pilot test to evaluate the potential efficacy of this remedial alternative. The project plans are documented in the Sampling and Analysis Plan (SAP) for the Bioremediation Pilot Test at Site 5 (Tetra Tech, 2008c).

Preliminary soil sampling and monitoring well installation for the Site 5 groundwater pilot study commenced in May 2008. In April 2009, Tetra Tech began operation of the treatment phase of the bioremediation pilot study to remediate the groundwater of Site 5. The Pilot Test Report for Site 5 Groundwater (OU 2) was finalized in May 2011 (Tetra Tech, 2011a). The test report indicated that bioremediation had proven to be an effective strategy in destroying the Site 5 groundwater contaminants through the anaerobic, reductive dechlorination process; and that the Site 5 groundwater recirculation system was very effective at distributing the biostimulation amendments throughout the remediation cell.

In June 2011, the Proposed Remedial Action Plan for Site 5 Groundwater (OU 2) was finalized (Tetra Tech, 2011b). A public meeting was held to present the Navy’s plan for Site 5 Groundwater on June 22, 2011. The public comment period was set for June 15 through August 1, 2011 to encourage public participation in the decision. In September 2011, at the request of EPA, four monitoring wells were sampled for perfluorooctanoic acid (PFOA) and perfluorooctane sulfate (PFOS). These compounds are components of the aqueous film-forming foam (AFFF) which was used for fire suppression training at the site. EPA has published non-enforceable provisional health advisory concentration levels for drinking water of 0.4 micrograms per liter (μg/L) for PFOA, and 0.2 μg/L for PFOS. Results were above these provisional levels. As a result, these compounds were incorporated into the MNA portion of the remedy. On September 25, 2012, the ROD for Site 5 Groundwater (OU 2) was signed by the Navy and EPA with concurrence from PADEP (Tetra Tech, 2012).

The Remedial Designs (RDs) for the installation of additional injection/monitoring wells in the source area, and for Land Use Controls (LUCs) for Site 5 were finalized in May 2013 (Tetra Tech; 2013a, 2013b). The remedial action (RA) described in the RD was completed in July 2013. Seven injection/monitoring wells
(05MW20 through 05MW26) were installed in the areas with highest levels of groundwater contamination. The draft Remedial Action Completion Report (RACR) was submitted in November 2013 the draft-final RACR was submitted on May 7, 2014, and the final RACR was signed by Navy and EPA in September 2014 (Tetra Tech, 2014).

1.2 IN-SITU BIOREMEDIATION OBJECTIVES

1.2.1 Remedial Action Objectives

The human health risk assessment concluded that under a future residential land use scenario, exposure to VOCs in the groundwater through ingestion, dermal contact, and inhalation, would pose a potential carcinogenic risk exceeding EPA’s target risk range for the future adult and the lifetime (child and adult) resident. To address these risks, these Remedial Action Objectives (RAOs) were established in the ROD for Site 5 groundwater:

- Prevent potential human exposures to contaminated groundwater.
- Restore concentrations of chemicals of concern (COCs) in groundwater to maximum contaminant levels (MCLs).
- Prevent further degradation of groundwater.

Data from the RI and the human health risk assessments and the Applicable or Relevant and Appropriate Requirements (ARARs) were reviewed to identify the Site 5 groundwater COCs that would be used to determine the appropriate remedial goals. The Site 5 groundwater remediation goals (RGs) are presented in Table 1-1, along with the basis for their selection.

1.2.2 Selected Remedy

The selected remedy presented in the ROD for Site 5 groundwater consists of the following major components:

- In-situ anaerobic bioremediation of contaminated groundwater within the source area until VOC concentrations meet established cleanup levels (i.e., remedial goals).
- MNA of the groundwater plume downgradient of the source area.
• Implementation of land use controls (LUCs).

• Long-term groundwater monitoring until the plume has attenuated to concentrations that meet the established cleanup levels.

The Selected Remedy eliminates potential unacceptable human exposure to hazardous substances in and vapors emanating from the contaminated groundwater by reducing VOC concentrations in the groundwater, and by implementing LUCs. The Selected Remedy is expected to achieve substantial long-term risk reduction and allow the property to be used for the reasonably anticipated future land uses; currently, these are open space, recreational, and non-residential (e.g., office space) uses.

1.3 IN-SITU BIOREMEDIATION IMPLEMENTATION STRATEGY

The remedy selected for Site 5 groundwater (OU 2) was implemented in July 2013. The performance standards are based on a future residential site use scenario. Implementation of in-situ bioremediation will largely consist of the continued operation of the successful pilot test treatment system. Periodic biostimulation events consisting of the injection of organic substrate will be performed to maintain the geochemical conditions necessary for efficient bioremediation. In addition, the remediation of the source area will be accelerated by the operation of a shallow injection well system. The in-situ anaerobic bioremediation implementation ensures that a large portion of the site’s most highly impacted groundwater is most efficiently addressed.

1.3.1 Initial Operations

Initial operations will continue to be performed during the first 2 years (approximately) of full-scale in-situ anaerobic bioremediation system operations. The bioremediation recirculation and treatment system will be continually operated as it was during the pilot study. Shallow injection well system operations will be initiated. During this period, various injection strategies will be tested to determine the best operation method for the remediation of contaminated groundwater within the source area. At a minimum, one biostimulation event will be performed yearly. Post-injection monitoring will be performed throughout this operational phase.

The segment of the groundwater plume located downgradient of the source area will not immediately be impacted by bioremediation, and will initially contain contaminants at concentrations exceeding remediation goals. Because bioremediation of the diffuse plume outside of the source area is not practical, this segment of the plume will attenuate under natural physical, chemical, and biological processes as the source of the plume is removed through bioremediation.
1.3.2 Optimization Operations

Optimization operations will comprise the next 2 years (approximately) of full-scale in-situ anaerobic bioremediation operations. During this phase, injection strategies will be selected and used to demonstrate progress toward the restoration of the source area contaminated groundwater. Performance monitoring will be conducted throughout this operational phase.

1.3.3 Long-Term Operations

Long-term operations will be performed to maintain the geochemical conditions necessary for efficient bioremediation until VOC concentrations meet established cleanup levels. The VOCs in the Site 5 source area groundwater will be reduced over time by bioremediation: the toxic halogenated compounds will be destroyed through the process of dechlorination. The lower concentrations of VOCs in the downgradient portion of the dissolved-phase plume will be monitored to establish that contaminant concentrations are naturally attenuating.

1.4 GROUNDWATER MONITORING

Groundwater monitoring will be conducted to: evaluate and maintain the proper geochemical conditions within the source area; assess the effectiveness and rate of bioremediation in the source area; assess the effectiveness and rate of attenuation of VOCs in the source area and the down-gradient segment of the plume; and confirm that remediation is complete when VOC and 1,4-dioxane concentrations throughout the entire extent of the plume are reduced to levels at or below the remediation goals. Groundwater monitoring will also be conducted as part of a separate initiative to evaluate PFOA and PFOS concentrations. PFOA and PFOS are not responsive to anaerobic bioremediation, but will attenuate through dilution and dispersion.

1.5 LAND USE CONTROLS

LUCs will be implemented within the Site 5 LUC boundary to prohibit the use of untreated groundwater, and to require that future buildings be constructed in a way that mitigates the potential for vapor intrusion of VOCs from the subsurface into the buildings. LUCs will also require that systems be installed which mitigate the potential intrusion of VOCs from the subsurface into existing buildings prior to their reuse, or that the buildings be subject to a vapor intrusion investigation to assess whether an unacceptable risk to future occupants is present. The LUCs will be implemented and maintained by the Navy until concentrations of hazardous substances in groundwater are at levels that allow for unrestricted use and unlimited exposure. When the Site 5 property is transferred to a non-federal entity, the LUCs will consist...
of deed restrictions to prohibit the use of untreated groundwater, and requirements for incorporating vapor intrusion mitigation in buildings until contaminants in the groundwater are at levels that allow for unlimited use and unrestricted exposure. The use of treated groundwater must be approved by the Navy, EPA, and PADEP. The Site 5 LUC boundary encompasses the entire extent of the groundwater plume, as shown on Figure 1-3. The LUC implementation actions including monitoring and enforcement requirements were provided in a LUC RD (Tetra Tech, 2013b). The Navy will maintain, monitor, and enforce the LUCs according to the LUC RD. Implementation of this remedy will therefore require annual visual inspections and a five-year review with report preparation. A survey of the LUC boundary was performed and is included in the LUC RD. This was submitted to Horsham Township on April 24, 2014. The annual LUC inspections will be due on the anniversary of submittal of the LUC survey to Horsham Township.
2.0 IN-SITU BIOREMEDIATION SYSTEM

The in-situ anaerobic bioremediation of groundwater at Site 5 is not designed to treat the entire plume, but is targeted to destroy the VOCs in the source area. The in-situ bioremediation (ISB) system consists of a groundwater recirculation and treatment system, and a shallow injection well system. Injection and extraction wells were installed to establish a groundwater recirculation system or bioremediation treatment cell. The treatment system was designed to extract groundwater, add amendments under controlled conditions, and reinject the treated groundwater/amendments.

2.1 RECIRCULATION AND TREATMENT SYSTEM

The recirculation and groundwater treatment system was constructed as part of a groundwater bioremediation pilot study that was conducted from May 2008 to December 2010. The treatment system consists of three open-bedrock test wells (TW-1, TW-2, TW-3) and one converted screened monitoring well (05MW17S) that are plumbed and connected to the treatment system trailer via underground water and electrical lines. Wells TW-1 and TW-3 can be used for both extraction and injection. Electrical connections for a pump are not currently installed at TW-2; therefore, TW-2 can only be used for injection at this time without further retrofitting. The converted monitoring well can also only be used for injection. Groundwater is withdrawn from the extraction wells and sent to the treatment system trailer, where the amendments are fed by metering pumps into the recirculation line, and the water is then directed into the injection wells.

2.1.1 Groundwater Recirculation Cell

A groundwater recirculation cell was constructed by installing four large-diameter wells (TW-1 through TW-4) around the source area to create a zone within which bioremediation testing would occur. One well was installed at each of the test cell’s four corners, with the wells along the northern and southern border of the cell constructed as pairs located directly along bedrock strike. The wells were installed as 8-inch open bedrock boreholes constructed to serve as both injection and extraction wells in order to be able to evaluate multiple recirculation scenario options for the distribution of amendments within the treatment cell. The well construction logs are included in Appendix A.

Based on short-term pumping tests, wells TW-1, TW-2, and TW-3 were determined to be suitable wells for either injection or extraction. Wells TW-1 and TW-2 could either be pumped or injected at any desired rate without causing excessive drawdown or mounding. Because the natural gradient across the site is very low, relatively small changes in hydraulic head result in fairly extensive areas of influence. TW-3 is not quite as good an extraction well as TW-1 or TW-2. TW-3 must be pumped at a rate that avoids
drawing down the water level below the water-bearing fracture at 30 feet; otherwise, the resulting cascading of groundwater entering the well tends to oxygenate the water and work against the goal of anaerobic conditions.

Well TW-4 was determined to be an unsuitable recirculation system well. Although subsequent baseline analytical testing indicated that the VOC concentrations in TW-4 are similar to those in the neighboring wells, the low specific capacity of the well and its limited interconnectedness with the surrounding wells would have made it difficult to adequately distribute the bioremediation amendment materials throughout the southwest corner of the recirculation cell within the timeframe of the pilot test. Adjacent well 05MW17S was chosen to replace TW-4 because of its performance during the initial aquifer pumping test, and because of its observed response to the pumping of the other TW-series wells. Because 05MW17S had already been retrofitted as a 2-inch monitoring well, it could not serve as an extraction well; therefore, it was converted to an injection well only by inserting a drop pipe below the water level in the monitoring well. TW-4 was left as an open borehole, and has been used as a monitoring point located inside of the recirculation system.

Trenches were excavated between wells TW-1, TW-2, TW-3, TW-4, 05MW17S and the treatment trailer location so that water transmission tubing and electrical conduit could be installed (Figure 1-2). Ground surface flush-mount well boxes were placed around wells TW-1, TW-2, TW-3, and TW-4 so that the well opening was inside the well box below the level of the surrounding ground surface. Wells TW-1 and TW-2 were outfitted with pressure flange lids for use during injection operations. Wells TW-3 and TW-4 were fitted with sanitary seals to prevent surface water from entering the wells. Well 05MW17S was converted from a stick-up well to a flush-mount well, and the polyvinyl chloride (PVC) well riser pipe was plumbed so that the water transmission tubing could be connected. Pitless adaptors were installed in wells TW-1, TW 2, and TW-3 to connect transmission tubing to the drop tubing or pump inside each well. TW-4 was not connected to the treatment system; however, transmission tubing and electrical conduit were buried in the trench for possible future use. Electrical conduit and wiring were installed from the treatment trailer to wells TW-1 and TW-3; only conduit is present at TW-2.

2.1.2 Treatment Trailer

The treatment system in the treatment trailer consists of three major components: extraction and injection manifolds and connective plumbing; electrical process control systems; and amendment storage tanks. The treatment system aboveground components are shown in photographs in Appendix B.
2.1.2.1 Extraction and Injection Manifolds

Groundwater from either or both wells TW-1 and TW-3 can be pumped to the extraction manifold in the treatment trailer. TW-2 could be used if a pump was properly installed. Extracted groundwater passes through a bag filter to remove suspended solids before entering the injection loop of the manifold. Amendments (e.g., sodium bicarbonate, LactOil®, etc.) can be added to the recirculation flow through two ports downstream of the bag filter. In this way, filtered/treated groundwater from either extraction well can be directed to the other wells in the recirculation loop via the manifold system in the treatment trailer. The injection wells are TW-1, TW-2, TW-3, and 05MW17S. Flow meters in each leg of the manifold system are used to set and balance desired extraction and reinjection rates to or from each well, and sample taps are provided for collecting samples of the recirculation stream.

2.1.2.2 Electrical Process Control Systems

Electricity for Site 5 is provided by a transformer located approximately 200 feet from the trailer, near the Marine Corps Reserve Compound. The main electrical feed is nominally 220 volts. The two pulsating metering feed pumps and the trailer space heater use 220 volts. Mix tank recirculation pumps and lighting in the treatment trailer use 110 volts, as do the wall outlets which provide power for the power tools and a portable transfer pump. Two control boxes mounted on the wall in the trailer provide electricity for the down-well pumps.

2.1.2.3 Amendment Storage Tanks

Two cylindrical 300-gallon polyethylene mix tanks in the treatment trailer are used to prepare amendment solutions for injection. Amendment solutions are prepared by adding 300 gallons of formation water via a temporary hose from the inlet manifold, to the amendment material (LactOil® or sodium bicarbonate). An approximately 18-inch covered opening at the top of each mix tank is where amendment materials and formation water are added. Each tank has a bottom discharge valve (normally plugged) which is used only for cleaning/draining, and is fitted with a recirculation pump which mixes the amendment material with the formation water to produce the dilute amendment solution for injection.

2.2 SHALLOW INJECTION WELL SYSTEM

The results of the pilot test indicated that bioremediation is an effective strategy for destroying the Site 5 contaminants through the anaerobic, reductive dechlorination process. The test also concluded that the highest concentrations of VOCs occur right at, and just below, the water table, or at a subsurface depth of about 25 feet. During the pilot test, amendments were periodically injected manually into 05MW01S,
which is not plumbed into the site’s recirculation system. The pilot test results indicated that the installation of several additional shallow injection wells would accelerate remediation of the source area by augmenting the existing injection operation, and would ensure that a larger portion of the site’s most highly impacted groundwater is most efficiently addressed. This recommendation was included in the ROD for Site 5 groundwater.

In December 2012, the draft Remedial Design (RD) for Installation of Additional Injection Wells at the Source Area Bioremediation for Site 5 Groundwater (OU 2) was submitted to regulators for review. The Final RD was submitted in May 2013 (Tetra Tech, 2013a). As specified in the RD, seven new injection/monitoring wells (05MW20 through 05MW26) were installed from July 8 to 16, 2013. The wells were constructed using 4-inch diameter PVC well casing and screen. Injections into these wells introduce additional bioremediation amendments to the shallow groundwater in the areas that may be beyond the influence of the injections into monitoring well 05MW01S. The wells are not plumbed into the existing recirculation system. Amendments are added manually to these wells in a manner similar to the current operations at 05MW01S. These wells will also be used for process and performance monitoring. The locations of the shallow injection wells are illustrated on Figure 1-2. Table 2-1 shows the well construction details.

2.3 GROUNDWATER MONITORING WELLS

Groundwater monitoring will be performed to obtain performance and compliance monitoring data to evaluate progress (process and long-term performance monitoring), and to eventually confirm that the in-situ bioremediation RAOs have been achieved (long-term monitoring).

Additional monitoring wells were installed at the source area during the Pilot Study to provide the hydrogeological, chemical, and biological information needed to determine: the optimum location and configuration of the recirculation system treatment cell; and the types and amounts of biostimulation materials required to condition the aquifer.

The following monitoring wells were installed during the pilot Study (see Figure 1-2):

- 05MW16S
- 05MW17S
- 05MW17I
- 05MW18S
- 05MW18I
Table 2-1 provides well construction summary details. Monitoring well 05MW16S was installed as an upgradient monitoring point, because the existing upgradient monitoring wells (clusters at 05MW02, 05MW03, and 05MW12 which are located more than 150 feet away from the source area at cluster 05MW01) were deemed to be too distant to provide useful information during the pilot test. Monitoring well clusters 05MW17 and 05MW18 were installed as near-downgradient monitoring wells, because the existing clusters at 05MW09 and 05MW10 were deemed too distant from (and outside of) the planned recirculation cell to provide timely information on the biological and chemical changes in the aquifer caused by the pilot test. Well clusters 05MW17 and 05MW18 were also installed directly along bedrock strike to evaluate the effects of the bedrock structure on plume migration. Monitoring wells 05MW19S and 05MW19I were installed to monitor the groundwater plume immediately downgradient of the recirculation cell.
3.0 OPERATIONS AND MAINTENANCE

This section identifies the O&M requirements for the in-situ bioremediation system, including operational criteria and a description of the procedures developed to operate and maintain the in-situ bioremediation system. All operations will be performed in accordance with the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA).

3.1 IN-SITU BIOREMEDINATION SYSTEM OPERATIONS

In-situ bioremediation system operations include system checks, groundwater recirculation, amendment injections, waste handling, and maintenance. The actual injection strategies including the amendment used, amendment quantity, solution concentration, and injection location may change based on the groundwater conditions during the initial and optimization phases of operations.

3.1.1 System Checks

Operations will not be started until the system has been completely checked. Each component’s start-up procedures, maintenance requirements and safety/operational warnings will be reviewed with the operations team. The specific components that will be reviewed and checked include the following:

- Extraction Pumps.
- Manifold (including pressure regulators, flow meters, and pressure gauges), additional piping, and valves.
- Bag Filter.
- Mixing Tanks, including recirculation pumps.
- Cycle Timer.
- Pulsating Metering Feed Pumps.
- Trailer Space Heater.
3.1.2 Groundwater Recirculation

Because the horizontal hydraulic gradients throughout the site are very low, amendment delivery that depends on groundwater dispersion and advection is not viable. The groundwater recirculation system increases the flow velocity and delivers and distributes amendments (e.g., substrate, and sodium bicarbonate) throughout the formation to support the in-situ bioremediation process. The size of the recirculation cell is approximately 120 feet long by 60 feet wide by 40 feet thick. The estimated duration of recirculation events is 1 month. This is based on an effective formation porosity of 4 percent, an achievable recirculation rate of 2 gallons per minute (gpm), and based on empirical observations from previous recirculation events.

Groundwater recirculation occurs within a closed loop configuration. Groundwater will be pumped from extraction wells and returned to the subsurface via injection wells. The recirculation system configuration is similar to the biostimulation events of the pilot study: groundwater will be extracted from TW-1 at an average rate of 2 gpm; and groundwater will be injected into 05MW17S, TW-2, and TW-3 at the rate of 0.6 gpm, 1.0 gpm and 0.4 gpm, respectively during the first injection/recirculation. The actual operational flow rates will be determined by a remedial design engineer based on site conditions at that time. Based on the results of the prior event, the pumping and injection configuration may be modified for subsequent injections. If it is determined that extraction of groundwater from TW-2 would be beneficial to system operation, the average extraction rate from TW-2 will be 2 gpm; and the injection rates into 05MW17S, TW-1, and TW-3 will be 0.6 gpm, 1.0 gpm and 0.4 gpm, respectively.

The recirculation system will be operated initially to attain steady-state water level conditions. The steady-state conditions will be determined by routinely measuring the water levels until they have stabilized. The high degree of biofouling that has occurred within the aquifer requires a constant monitoring and adjustment of the withdrawal and injection rates.

During recirculation, readings at the pressure manifolds will be obtained. Pressure should not exceed 20 pounds per square inch (psi) at any manifold (extraction well, injection well, or filter). Pressure may be regulated by adjusting the valves associated with the extraction and injection wells, which in turn, will regulate the pressure at the bag filter.

3.1.3 Biostimulation Injection Operations

Biostimulation injection will be conducted periodically to maintain favorable reducing and anaerobic environmental conditions to support the in-situ bioremediation process. In order to deliver amendments (e.g., substrate, and sodium bicarbonate) to the groundwater recirculation cell, groundwater will be
pumped from extraction wells, and amended water delivered to the injection wells. The actual biostimulation injection strategies (including composition of donor substrate, dosage, injection rates and duration, injection locations, and minimum periodic frequency) will be determined during the initial and optimization phases of operations.

LactOil® has replaced sodium lactate as the donor substrate since April 2011, because the pilot test indicated that the sodium lactate had a very short residence time and was quickly consumed by the microbial population. The main goal of the continued Site 5 groundwater remediation operations is to maintain the conditions favorable for anaerobic degradation of VOCs for an extended period of time. The switch to a slow-release substrate is meant to create such long-term favorable conditions without frequent amendment injection and recirculation.

The results of the baseline sampling event showed that groundwater pH was below the optimal range for active anaerobic reductive dechlorination. *Dehalococcoides* ethenogenes strain 195 (i.e., the only known bacterium capable of complete reductive dechlorination of PCE to ethene) thrives in an environment of pH 6.8 to 7.5 standard units (SU). Likewise, optimal pH ranges for several Desulfitobacterium species (capable of reductive dechlorination of chlorinated ethenes and ethanes) are near neutral. Therefore, it is necessary to increase groundwater pH to improve the performance of the ISB system.

Sodium bicarbonate (NaHCO₃) was selected for pH adjustment during the pilot test and was determined to successfully raise the pH to the required levels. This solution will be prepared during regular site visits. The NaHCO₃ buffering solution will be prepared in the 300-gallon tank. A quantity of 100 pounds of sodium bicarbonate will be mixed into 300 gallons of water, resulting in a 4 percent solution. Based on the results of pilot study, sodium bicarbonate (4 percent solution) will be injected at a dosing rate of approximately 0.42 gallons per hour (gph).

Prior to initiating the addition of amendment or nutrient, the recirculation system will be operated for about 2 days to attain steady-state conditions. Amendment and nutrient will be injected using the mixing tanks and amendment pump and the associated amendment pump manifold.

The dosages, recirculation rates, and duration have been selected based on the following considerations:

- Generally, the proposed substrate dosage should be adequate to maintain the current favorable conditions, and should not be excessive so as to avoid acid formation. The sodium lactate substrate dosages during the previous recirculation events at Site 5 proved to be effective and therefore the LactOil® substrate dosage will be similar to the pilot study recirculation events at the Site.
• Recirculation rates and the injection/extraction wells configuration that were established during the recirculation events of the pilot study proved to be effective in uniformly distributing the injected substrate. Therefore, similar recirculation rates and injection/extraction wells configurations will be used during the recirculation with the LactOil® substrate.

• Recommended recirculation duration is approximately 1 month. This recommended duration is based on previous experience and site conditions.

• Moderate pH buffering using sodium bicarbonate is recommended during the recirculation with the LactOil® substrate.

Table 3-1 presents the recommended LactOil® substrate and buffering agent dosages, the recirculation rates and injection/extraction wells configuration, and other operational parameters for the biostimulation event. The LactOil® nutrient are normally purchased in 5-gallon pails for ease of handling. Sodium bicarbonate is normally received in 50-pound bags. Figure 3-1 shows the LactOil® injection and groundwater recirculation system. The actual biostimulation injection strategies may change during the initial and optimization phases of operations. As previously discussed, extensive biofouling has occurred which has significantly altered the hydraulic characteristics in some areas of the treatment cell; therefore, the extraction and injection rates must be closely monitored, and will likely require adjustments based on current aquifer conditions.

NaHCO₃ Replenishment Procedures

• Transfer 300 gallons of formation water into NaHCO₃ tank by connecting hose to effluent port.
• Add 100 pounds NaHCO₃ to NaHCO₃ tank.
• Mix solution for 30 to 60 minutes using sump pump in tank.
• Unplug sump pump in tank.
• Check to make sure that metering pump has resumed operation.

LactOil® Replenishment Procedures

• Place four 5-gallon pails of LactOil® on the shelf near the metering pump.
• Place pump intake tubing into each pail of LactOil®.
• Restart metering pump.

The above recommended operational schedule will require that the system operator visit at a minimum of once per week. During regular site visits, the system operator will: replenish the substrate and sodium bicarbonate.
bicarbonate quantities, perform routine system parameters monitoring, and make well configuration changes (if deemed necessary) and other adjustments. The system operator will add LactOil® nutrient and sodium bicarbonate (4 percent solution) directly to the shallow injection well system (including monitoring well 05MW01S) during each site visit, as has been established in the past, to directly treat the shallow groundwater near the historical solvent source area. New injection/monitoring wells (05MW20 through 05MW26) may also be used for direct injection of substrate depending on site conditions, and results of post-injection monitoring.

### 3.1.4 Bioaugmentation Injection Operations

Biostimulation of groundwater will produce the neutral, reducing and anaerobic groundwater conditions required by the Dhc and Dhb bacteria. During in-situ anaerobic bioremediation of contaminated groundwater, the bacterial populations will be recounted periodically to determine if the biostimulation alone resulted in the increased target bacterial population levels desired, or if additional bioaugmentation (addition of the target bacteria Dhb and/or Dhc) will be necessary. If the bacterial population is not sufficiently large or of the right genetic composition for the process to efficiently achieve completion, bioaugmentation will introduce large volumes of Dhc and Dhb (which contain the required functional genes) into the aquifer's bacterial population.

Based on the results of the pilot study, SiREM KB-1 Plus dechlorinating culture (containing Dhc and Dhb microbes) will be the inoculating culture product that is used. About 20,000 to 35,000 liters of formation groundwater can be treated with 1 liter of culture. Assuming an effective formation porosity of 4 percent (conservative for bedrock), the size of the recirculation cell as 120 feet long by 60 feet wide by 40 feet thick, and using the more conservative dilution ratio (20,000 to 1), the estimated volume of KB-1 Plus culture is approximately 20 liters.

The bioaugmentation culture will be injected into the formation using the existing recirculation system and shallow injection well system. The actual quantity of KB-1 Plus culture injected into the aquifer may change based on site information collected during post injection monitoring.

The injection process will be performed as follows:

- Prior to the injection of the KB-1 Plus culture, the recirculation system will be operated for several hours to bring formation groundwater into the system, and to assure that the culture will be injected into groundwater that has strongly reducing conditions and essentially no dissolved oxygen (DO).
The injection of the KB-1 Plus culture will be initiated when the DO is essentially absent (0.1 mg/L) and the oxidation reduction potential (ORP) is negative at <-100 millivolts (mV). Such parameters indicate that strongly reducing conditions are present at the point of injection.

The following additional measures will be implemented to assure that reducing conditions are maintained and that no atmospheric oxygen enters the injection loop:

- Continuous monitoring of DO and ORP at the point of the culture injection will be performed during the entire injection period.
- Injection tubes in the injection wells will be submerged at least 15 feet below the static water table.
- The injection wells and the extraction well will be filled with argon prior to the culture injection.
- Ambient air will be purged from the injection line with argon or nitrogen.
- Compressed argon or nitrogen will be used to displace the KB-1 Plus culture from the transportation cylinder into the recirculation system manifold.

The KB-1 Plus will be injected into the recirculation system manifold. The culture injection rate will be adjusted to approximately 0.4 pounds per minute (10 liters per hour) culture, and 70 gallons of formation water.

The KB-1 Plus will also be injected into the shallow injection well system using similar procedures to avoid exposing the culture to oxygen.

After all of the bacterial culture is added to the treatment system, the recirculation system will be turned off, and the injected culture will be left to acclimate under ambient conditions.

After 5 days, the recirculation system will be turned on to assure that the now-acclimated injected culture is distributed throughout the recirculation cell.

### 3.1.5 Post-Injection Recirculation Period Operations

Following the addition of amendment and nutrient, the in-situ bioremediation system will be recirculated. The objective of this post-injection recirculation period is to: distribute the amendment and nutrient throughout the treatment cell; and to increase contact between extracted groundwater and the injected amendment/nutrient at the site. The duration and flows of the treatment system recirculation period will be determined by a remedial design engineer based on site conditions.
3.2 MAINTENANCE

3.2.1 Equipment Inspection and Maintenance

The inspection and maintenance of safety equipment (which includes eye wash bottles, portable fire extinguishers, emergency lights, and a first aid kit) will be conducted periodically.

Routine inspection and maintenance of the ISB process equipment will be performed, as needed. These activities will be based on observations made by the ISB operators during their operational inspections, or at a minimum periodic frequency.

Corrective maintenance primarily consists of unplanned repairs or replacement of system components after degradation has been observed or failure has occurred, and will be performed on a case-by-case basis. Examples of corrective maintenance include repairing or replacing: worn-out pumps, bag filters, leaky pipes, clogged or failed flow meters, and failed electronic equipment. Bag filters will be changed prior to the start of each injection/recirculation event. Any changes in pressure at the filter during operation will result in an inspection of the filter. If fouled, the filter will be changed. Replacement or repair of all other equipment will be done on an as-needed basis. All corrective measures will be documented in the facility logbook. Review of the maintenance logbooks will be performed periodically to see if there are any specific trends or problems that could be corrected with a system modification.

3.2.2 Freeze Protection

The ISB system has been designed to allow operation in the winter months at Site 5. The system is designed in such a way that piping subject to freezing is routed underground, and can be drained enough to prevent piping ruptures subsequent to each injection/recirculation event. Measures will be taken after each injection event to remove all process water from the system components and piping. This will remove the risk of pipes freezing. The treatment trailer is also equipped with a heater. During injection of LactOil® in winter months, the heater should be turned on to maintain the LactOil® at recommended temperatures (between 50° F and 85° F).

3.3 WASTE MANAGEMENT

The In-Situ Bioremediation Remedial Action Work Plan addresses the general requirements for all waste generated during the Site 5 groundwater remedial action, including waste generated during O&M. All waste generated during O&M will be identified, stored, and disposed of in a manner consistent with waste management requirements, and all other applicable requirements. The waste streams expected to be
generated by O&M operations are expected to include only investigation derived wastes (IDW) generated during groundwater sampling. These wastes include sampling purge water, used personal protective equipment, and spent filter bags.

At this time, EPA and PADEP have permitted the discharge of purge water to the ground surface at the area of the well which is being sampled. Used personal protective equipment and spent filter bags will be placed in trash bags for disposal as municipal solid waste.
4.0 MONITORING PROGRAM AND DATA EVALUATION

Periodic biostimulation events consisting of the injection of organic substrate and pH buffering agent will be performed to maintain the geochemical conditions necessary for efficient bioremediation. Post-injection process monitoring will be conducted to evaluate and maintain the proper geochemical conditions within the source area. Performance (long-term) monitoring will assess the effectiveness and rate of bioremediation in the source area; and assess the effectiveness and rate of attenuation of VOCs in the source area and the down-gradient segment of the plume.

A data evaluation process will be implemented for the in-situ bioremediation data. The data evaluation process includes reviewing and interpreting data, evaluating system performance, and recommending operational changes, if necessary.

4.1 POST-INJECTION MONITORING

Following the biostimulation events, groundwater samples and water-level measurements from selected wells will be obtained on a periodic basis. Samples will be collected from the wells for both chemical and physical parameter analyses. The monitoring program will help to determine the effectiveness and rate of bioremediation in the source area. Two types of post-injection monitoring will be performed: process monitoring and performance monitoring.

Process Monitoring: Post-injection process monitoring will be performed, with events occurring approximately quarterly after each biostimulation event. The schedule and monitoring parameters for these events will be adjusted based on the results from the previous process monitoring event. Process monitoring events will involve the use of field instruments (for the water quality parameters of pH, DO, ORP, conductivity, and temperature), and test kits (dissolved oxygen).

Performance Monitoring: Performance monitoring will be performed annually. Process monitoring parameters, as indicated above, will also be measured concurrently with performance monitoring parameters. The schedule for performance monitoring events may need to be adjusted based on previous results. These results will also be used in conjunction with process monitoring results to evaluate the subsequent frequency of biostimulation and/or bioaugmentation events, any necessary modifications to the dosage of amendments, injection volumes/durations, recirculation rates, and other operational parameters.

The performance monitoring program will generate information to evaluate changes in: VOC and degradation/ transformation products and to evaluate if performance standards have been achieved. For
Performance monitoring events, groundwater samples will be collected for laboratory analyses and general chemistry measurements. Groundwater will be analyzed for Target Compound List (TCL) VOCs and 1,4-dioxane. Some samples may also be analyzed for total organic carbon (TOC), and/or dissolved gases, and these field parameters: dissolved oxygen, total alkalinity, ferrous iron, and hydrogen sulfide. Field test kits will be used to measure dissolved oxygen, total alkalinity, and total soluble sulfide levels so that these results can be compared to pre-injection groundwater quality results. Bio-Trap devices will be placed in select injection wells, and analyzed for polymerase chain reaction (PCR) and functional genes (TCE R-Dase, BAV1 VC R-Dase, and VC R-Dase), and phylogenetic groups (eubacteria and methanogens). Bio-Trap samples will not be collected during every biostimulation event. Based on the evidence of biodegradation processes, it will be determined if Bio-Trap samples are necessary in post-injection monitoring.

Twenty wells will be monitored to assess the in-situ bioremediation process. Wells may be used for performance and/or process monitoring, but all wells may not be sampled during all events and all sample parameters may not be collected during every event. Table 4-1 presents the sampling strategy and plan for process and performance monitoring: recommended well locations, field tests, and laboratory analyses.

Groundwater samples will be obtained by the low-flow purging and sampling method following EPA Region 3 guidelines. Groundwater low-flow purging will be done using an adjustable-rate submersible pump equipped with dedicated polyethylene tubing, a water quality meter-YSI, and a flow-through cell. Water level measurements will be recorded using an electronic water level indicator prior to purging/sampling. During the purging operations, the pump speed will be adjusted to achieve minimal stabilized drawdown, to the extent practical. If drawdown cannot be stabilized, the pumping rate will be reduced to the minimum rate the equipment can maintain and continue to pump groundwater.

Low-flow sampling in wells with more than one water bearing fracture present in the open or screened interval will adhere to a purging and sampling method using a low flow submersible-type pump to purge at least one well volume prior to sampling the well with the pump set at the lowest setting.

Groundwater quality indicator parameters will be recorded approximately every 5 minutes during the groundwater purging process. The groundwater quality indicator parameters to be recorded include pH, temperature, specific conductivity, dissolved oxygen, turbidity, and ORP.

The microbial samples will be obtained by following the laboratory’s specifically prescribed sampling technique which is included as Appendix C.
4.2  BIOREMEDIATION PARAMETERS

Biodegradation processes can be measured through several lines of evidence. The first line of evidence that the bioremediation is effective is a trend of decreasing chlorinated volatile organic compound (CVOC) concentrations, and more stable patterns of VOC-contaminant plumes. A secondary line of evidence that the bioremediation is effective includes the use of geochemistry data to indirectly illustrate that biodegradation is occurring. A tertiary line of evidence is the presence and the quantity of the microbiological population.

The operating performance of the ISB system will be evaluated using a number of different parameters. These parameters will be used during initial, optimization, and long-term operations. Historical data for these parameters are presented on trend graphs in Appendix D. Evaluations and trending of these parameters will be used to evaluate the compliance and performance objectives of the different operational phases, and to determine the success of meeting the RAOs. Long-term monitoring will include analysis for these parameters.

4.2.1  Dechlorination Parameters

The first line of evidence that the bioremediation is effective is a trend of decreasing contaminant mass and/or concentration. More specifically, demonstrating a decrease in the concentration of the parent compounds [for example, PCE, TCE], coupled with the generation or increase in concentration of daughter or breakdown products [cis-1,2-DCE, vinyl chloride (VC), ethene, etc.] is useful. It is important to note that because dechlorination occurs sequentially, dechlorination of a parent compound may result in a temporary increase, then decrease, in the concentrations of the various daughter products. The trend graphs in Appendix D show that dechlorination is occurring.

4.2.2  In-Situ Parameters

A secondary line of evidence that the bioremediation is effective includes the use of in-situ parameters including geochemistry data to indirectly illustrate that biodegradation is occurring. Natural attenuation (i.e., geochemical) parameters are generally used to evaluate the suitability of geochemical conditions for biodegradation, and to determine if bioremediation is occurring.

**pH:** pH concentration is an indicator of the amount of free hydrogen available in a solution. *Dehalococcoides* spp., the only genera known to completely degrade PCE to ethene, are inhibited at pH less than 5.5, with complete cessation of biological activity at pH less than 5.0. Optimum conditions for microbial growth are within the pH range of 6.0 to 8. If the aquifer buffering capacity is low, and acids
produced during fermentation cannot be completely neutralized, it may be necessary to limit electron donor loading rates, add buffers, or neutralize the acid with a base (e.g., sodium bicarbonate).

During past operation, pH levels have generally been recorded between 6.0 and 7.0, which is within the acceptable range. Sampling in late 2013 showed a slight decreasing trend in pH, with levels falling below 6.0 in some wells. Injection of sodium bicarbonate solution in early 2014 was successful in restoring pH levels to between 6.0 and 7.0.

**Dissolved Oxygen:** DO acts as a primary substrate or co-substrate during the initial stages of metabolism. For chlorinated hydrocarbon degradation, anaerobic pathways are more efficient. If DO concentrations are greater than 0.5 to 1.0 mg/L, anaerobic bacteria cannot exist and reductive dechlorination will not occur. Historical levels of DO have been in the acceptable range.

**Oxidation-Reduction Potential:** The ORP of groundwater can provide an indication of whether or not anaerobic conditions are present. The range of ORP values representing optimum conditions for reductive dechlorination is typically between -100 to -350 mV. ORP is used in conjunction with other geochemical parameters to determine whether groundwater conditions are optimal for anaerobic biodegradation. Positive ORP values in conjunction with elevated levels of DO and the absence of TOC may indicate that additional substrate is required to promote anaerobic dechlorination.

ORP values have generally been within the acceptable range; however, an increase in ORP in several wells was observed in 2013. Sampling after injection of substrate in 2014 showed a return of ORP values in treatment area wells to acceptable levels. The wells installed in July 2013 also had negative ORP values.

**Temperature:** Temperature affects the metabolic activity of bacteria, as well as the solubility of geochemical species. Microbes are generally more active and efficient in warmer water. Biochemical processes are accelerated at temperatures greater than approximately 20 degrees Celsius. Temperatures recorded during the winter months typically range from 10 to 15 degrees Celsius, but reach optimal conditions during the summer.

**Sulfate/Sulfide:** After dissolved oxygen, nitrate, manganese, and ferric iron have been utilized, anaerobic microbes will utilize sulfate (SO\(_4^{2-}\)) as an electron acceptor, resulting in sulfide and carbon dioxide increases. Sulfate reduction (along with methanogenesis) is one of the most important reduction pathways that indicates that conditions are favorable for biodegradation of chlorinated hydrocarbons. Sulfide can be present in many forms; the three primary forms are the sulfide ion (S\(^2-\)) or dissolved hydrogen sulfide as either H\(_2\)S or HS\(^-\). Sulfide typically precipitates with iron minerals, but elevated levels...
of sulfide may be toxic to dechlorinating microorganisms. Sulfate/Sulfide analysis is included for long-term monitoring, but has not been conducted since 2011 when levels were acceptable.

**Dissolved Methane:** Because methane is not a chemical component of solvents, its presence at concentrations greater than background provides strong evidence of methanogenic fermentation (and carbon dioxide utilization). The measurement of background concentrations of methane are important because some natural sources of methane exist. Methane levels greater than 1.0 mg/L are desirable, but not required for dechlorination to occur. Methane levels less than 1.0 mg/L and the accumulation of cis-1,2-DCE and VC may indicate that additional substrate is required to shift reducing conditions into an environment suitable for reduction of these compounds. Methane levels have historically been greater than 1.0 mg/L in all wells, and typically exceed 10 mg/L.

**Dissolved Ethene/Ethane:** Ethene and possibly ethane signify the final degradation step of chlorinated ethenes. Concentrations of ethene greater than 0.01 mg/L and ethane greater than 0.1 mg/L provide strong evidence of such degradation. If elevated levels of ethene or ethane are not observed, potential accumulation of cis-1,2-DCE or VC should be monitored. Ethane and ethene levels have historically been within acceptable limits.

**Total Organic Carbon:** TOC is an indicator of natural organic carbon present at a site during baseline characterization, and is an indicator of substrate distribution during performance monitoring. TOC concentrations greater than 20 to 50 mg/L are desired in the anaerobic treatment zone. Stable or declining TOC levels less than 20 mg/L in conjunction with elevated levels of VOCs and alternate electron acceptors indicate that additional substrate is required to sustain the anaerobic treatment zone. TOC analysis is included for long-term monitoring, but has not been conducted since 2011 when levels were significantly above the minimal acceptable range.

**Total Alkalinity:** Total alkalinity is an indicator of biodegradation and the buffering capacity of the aquifer (neutralization of weak acids). An increase in alkalinity and stable pH indicate that the buffering capacity of the aquifer is sufficient to neutralize metabolic acids produced by degradation of substrates. In low alkalinity aquifers, the pH may drop to levels outside the acceptable range for microbial activity. Concentrations of alkalinity that remain at or below background in conjunction with pH less than 5 indicate that a buffering agent may be required to sustain high rates of anaerobic dechlorination. Thus, to have optimum conditions for microbial growth, it is essential to have a properly buffered aquifer. pH trends at the site were discussed previously in this section.
4.2.3 Biological Growth and Activity

Molecular biological tools (MBTs) are available to identify *Dehalococcoides* and specific reductases that have differing dechlorinating capacities. Several *Dehalococcoides* 16S rRNA gene sequences have been analyzed to date. The tertiary lines of evidence employed in this plan will use quantitative polymerase chain reaction (qPCR) analysis to quantify specific bacterial populations in the groundwater, and to determine whether the bacterial population is sufficiently large and of the right genetic composition for complete reductive dechlorination. qPCR analysis will be conducted during bioremediation to assess the site and evaluate the potential need for bioaugmentation.

There are consortia of microbes responsible for the various steps of CVOC degradation. However, *Dehalococcoides* spp. is the only bacteria that have been identified which can completely reduce PCE to ethene. Therefore, increasing concentrations of *Dehalococcoides* spp. are a good indication that a complete reductive dechlorination pathway of chlorinated ethenes is present. The *Dehalococcoides* spp. 16S rRNA molecular results can be qualitatively used to determine the performance of a biological anaerobic reductive dechlorination system [Environmental Security Technology Certification Program (ESTCP), 2010]. *Dehalococcoides* spp. 16S rRNA titers less than $10^4$ per liter to $10^6$ per liter, or the requirement for faster remediation time frames, indicate bioaugmentation may be needed.

The assessment of *Dehalococcoides* spp. should also consider CVOC trends and ethene/ethane production. Because the primary line of evidence supporting bioremediation is the CVOC concentration trend, biological activity and the presence of ethene/ethane support a conclusion that complete reductive dechlorination is occurring.

The last critical piece of information to understanding the biological activity in the aquifer is the molecular analysis of functional genes present within the *Dehalococcoides* spp. in the aquifer. Three genes are important to complete reduction of TCE to ethene: *tceA*, *vcrA*, and *bvcA*. These three genes encode for RDase proteins that are necessary to complete the reductive dechlorination pathway. Of these three genes, *vcrA* and *bvcA* (both encoding for VC R-Dase), are the most important because they can efficiently reduce VC to ethene, while still capturing the energy necessary for cellular growth.

In addition to *Dehalococcoides* spp. growth, the growth of methanogens and other bacteria which indicate that anoxic conditions exist are significant indicators that the aquifer is under strongly reducing conditions that are the most favorable for efficient degradation. Molecular analysis of methanogens will typically yield higher copy numbers than *Dehalococcoides* spp. Correlations between the presence of methanogenic growth and pH, organic acid formation, and methane and carbon dioxide generation may prove useful in understanding the biological activity in the aquifer. The metabolic balance between
fermentation and methanogenesis will be indicated by changes in pH, organic acid loading, and methane and carbon dioxide generation. Maintaining a neutral pH, sustaining a methanogen population, and balancing organic acid loading and methane production are all critical factors in promoting reductive dechlorination and encouraging *Dehalococcoides* spp. growth.

4.3 DATA EVALUATION

An annual data evaluation report will be prepared that summarizes the yearly performance monitoring activities. Post-injection process monitoring results and trends will also be discussed in the annual report. Data collected in accordance with this plan will be used to support the data evaluation process for anaerobic reductive dechlorination. The data evaluation will include activities such as creation of graphs, and the review and interpretation of data. Trends in various parameters over time such as amendment distribution, reductive dechlorination, and geochemical and microbiological conditions will be evaluated to determine the performance of in-situ anaerobic bioremediation. The current and historical conditions will be illustrated in the graphs for pH, ORP, DO, alkalinity, ferrous iron, sulfide, and dissolved gases. The continued effectiveness of the bioremediation system will be evaluated by tracking the concentrations of the VOCs and their biodegradation products in the groundwater. The concentrations of chlorinated ethanes and chlorinated ethenes will be illustrated in the graphs. Graphs showing historical data results of the biodegradation processes within the treatment system are included in Appendix D.

The concentrations of individual volatile fatty acids will be used to monitor appropriate amendment utilization in support of the most efficient conditions for anaerobic reductive dechlorination of CVOCs. In order for anaerobic reductive dechlorination of PCE and TCE to be energetically favorable, redox conditions must be methanogenic. For this reason, graphs showing concentrations of iron, sulfide, and methane can be used to assess redox conditions throughout the treatment system, and predict where anaerobic reductive dechlorination is occurring or not occurring.

In order to assess the efficiency of anaerobic reductive dechlorination reactions throughout the treatment system, and to ensure that the ISB system discontinues the flux of VOCs from the source area, the concentrations of these COCs will be plotted for each well: PCE; TCE; cis-1,2-DCE; 1,1,1-TCA; 1,1-DCA; 1,1-DCE; VC; and ethene.

Post-injection monitoring results will be used to predict amendment distribution and trends in other parameters. These results, along with the system monitoring parameters described in Section 4.2, will be used to evaluate possible operational changes in amendment injection and post-injection sampling.
4.4 OPTIMIZATION

If one of the key system operating parameters described in Section 4.2 is not within accepted ranges, then modifications may be required to optimize the treatment system. Results of the data evaluation will be used to develop recommended actions for operational changes, if needed. Figure 4-1 shows the decision-making flow chart for the operation of the in-situ anaerobic bioremediation system. The data will be compiled and summarized and included in the annual performance report for the in-situ anaerobic bioremediation system. An evaluation will be performed to determine if the operational changes can be implemented under the existing work control documentation, and/or if they are within the scope of the current Remedial Action Work Plan. If changes to the Remedial Action Work Plan are required, the proposed changes will be presented to the Navy for approval and implemented only after approval is received and controlling documents are updated, as required.
5.0 LAND USE CONTROLS AND LONG-TERM MONITORING

LUCs are used at sites where contaminants are left in place at levels that do not allow for unlimited use and unrestricted exposure. LUCs will be implemented to protect current and future users from health risks associated with groundwater contamination at Site 5. Long-term groundwater monitoring will be conducted to: evaluate the effectiveness and rate of bioremediation in the source area; assess the effectiveness and rate of attenuation of VOCs in the source area and the down-gradient segment of the plume; and determine when remediation is complete.

5.1 LAND USE CONTROLS

The LUC RD (Tetra Tech, 2013b) for Site 5 was completed in May 2013, and defines the land use controls required by the Site 5 groundwater ROD. LUCs will be established to prevent exposure to COCs in groundwater in accordance with the LUC RD. The LUCs ensure that any remaining contaminants do not pose an unacceptable risk to human health and the environment. LUCs can consist of institutional controls and/or engineering controls. Institutional controls, such as restrictions and notifications, are typically legal documents in the form of deed restrictions, easements, and restrictive covenants. Engineering controls are typically barriers, such as a fence.

Pursuant to the ROD, the Navy is responsible for implementing, inspecting, reporting, and enforcing the institutional controls in accordance with the LUC RD. The Navy will perform all short- and long-term implementation actions at Site 5 per DoD guidance, the Federal Facilities Agreement (FFA), the ROD, and applicable Navy directives. Although the Navy may in the future delegate or transfer authority to conduct these actions to another entity as part of property transfer agreements (i.e., deed), the Navy shall retain ultimate responsibility for remedy integrity.

The ROD selected LUCs, including institutional controls, as components of the final remedy for Site 5 groundwater to control or restrict certain types of property uses. The LUCs included in the selected remedy will be maintained until concentrations of hazardous substances have been reduced to levels that allow for unlimited use and unrestricted exposure. The Site 5 groundwater LUC performance objective as stated in the ROD is:

Prohibit the use of untreated groundwater, and mitigate the potential for vapor intrusion from the subsurface into future structures until contaminants in groundwater are at levels that allow for unlimited use and unrestricted exposure. Require that systems to mitigate the potential intrusion of VOCs from the subsurface into existing buildings be installed, or else conduct a vapor intrusion
investigation to assess whether an unacceptable risk to future occupants is present in those structures. The use of treated groundwater must be approved by the Navy, EPA, and PADEP.

Institutional controls will be implemented to ensure that the LUC performance objective is met. Figure 1-3 presents the area encompassing Site 5 and the groundwater VOC plume, and identifies the LUC boundary.

LUC monitoring will be conducted by the Navy to verify that LUCs are being properly implemented, and that the LUC objective is being met. LUC compliance inspections will be conducted on an annual basis unless the frequency is reduced by agreement with the Navy, EPA Region 3, and PADEP. The LUC monitoring and compliance inspection results will be provided to EPA Region 3 and PADEP as part of an annual report. A checklist to be used during LUC inspections is provided as Appendix E.

5.2 LONG-TERM GROUNDWATER MONITORING

Section 4.0 provides details for the proposed frequency and analytical requirements for long-term monitoring. Long-term groundwater monitoring will be conducted to ensure contaminated groundwater is not migrating beyond the LUC boundary; assess the effectiveness and rate of bioremediation in the source area; assess the effectiveness and rate of MNA of the groundwater plume downgradient of the source area; and confirm that remediation is complete when VOC and 1,4-dioxane concentrations throughout the entire extent of the plume are reduced to levels at or below the remediation goals. Groundwater monitoring to evaluate PFOA and PFOS concentrations will be conducted as part of a separate initiative and is not included in the long-term monitoring of the bioremediation system.

A SAP for long-term monitoring at Site 5 Groundwater will be prepared. Table 4-1 provides the wells included in the long-term (performance) monitoring program.

The long-term groundwater monitoring will be conducted at least annually. The long-term monitoring program may vary from year-to-year based on the following factors:

- The importance of the monitoring wells for defining the plume(s).
- The effectiveness of the monitoring wells in monitoring the overall groundwater remedy.
- The necessity of the monitoring wells for further characterizing the site.
- The importance of the monitoring wells for defining background water quality.
• The distance of the monitoring well from the plume.

• The contaminant concentrations as compared to laboratory detection limits or groundwater clean-up goals.

In addition to these factors, the sampling frequency required to monitor the performance of the groundwater remedy may vary. More frequent sampling than annually may be considered for a well located closer to the source area. Less frequent sampling (i.e., every 5 years) may be considered if a well is located farther from the source area, or if its contaminant concentrations would not be expected to significantly change over time. After data indicate that performance standards have been achieved, final confirmation sampling for site closeout will be performed. The Navy and EPA will determine the frequency of scheduling for confirmation. As part of site closure, a risk assessment calculating residual risk will be performed to assure that there is no unacceptable risk for exposure to Site 5 groundwater.

Modifications to the long-term groundwater monitoring program may be made based on discussions between the Navy and EPA.
6.0 HEALTH AND SAFETY

General safety and health program requirements associated with the O&M of the in-situ bioremediation system are addressed within the current site-specific Health and Safety Plan (HASP). The Health and Safety Plan was prepared to meet the requirements of the Occupational Safety and Health Act standard, 29 Code of Federal Regulations (CFR) 1910.120/1926.65: "Hazardous Waste Operations and Emergency Response." The HASP is specific for operating the groundwater ISB system. The Health and Safety Plan governs all work that is performed by employees of the management and operations contractor, and subcontractors. In general, it is the responsibility of the in-situ bioremediation system operators to ensure that these activities are well-planned and performed safely:

- Injection facility O&M activities
- Groundwater monitoring activities
- Other activities performed within the plume

The facility is equipped with fire extinguishers, eye wash bottles, and an emergency lighting system. Proper signs, markings, and labels have been used to identify items or areas that may pose some safety risk if the operators are unaware of them. Possible hazards within the injection facility include:

- Slip, trip, and fall hazards
- Pressurized water
- Electrical equipment and wiring
- Chemical hazards

Other hazards associated with the post–injection monitoring and field tests include:

- VOC inhalation
- Dissolved gases including methane

All personnel involved in the completion of the activities described in the plan will have received training in accordance with Occupational Safety and Health Administration (OSHA) 1910.120 (including a 40-hour initial Hazardous Waste Site Worker certification), and will maintain the current 8-hour annual refresher training. These personnel will be participants in an approved medial surveillance program.
7.0 RECORDS

Records provide past operational performance to identify trends in equipment operation, performance, and maintenance requirements. Decisions regarding the performance of the system, regulatory compliance, and optimization will be made based on routine and complete record keeping. The records support a continuous record of proof of performance, decision justification, expenditures, and recommendations.

7.1 OPERATIONS AND MAINTENANCE RECORDS

The operating records for the Site 5 groundwater in-situ bioremediation system will be maintained. Record completion and retention is an important aspect of the maintenance program. Record keeping will aid in: identifying recurring problems with equipment, selecting spare parts to be inventoried on site, and developing and designing ongoing preventative maintenance procedures to optimize the operation of the system. The O&M records will include:

- Description of O&M activities performed
- Results of post-injection monitoring
- Summary of the long-term monitoring
- LUC inspections

7.2 ANNUAL PERFORMANCE REPORT

The Annual Performance Report will combine information about these components of the in-situ anaerobic bioremediation system: groundwater monitoring, operations, and performance reviews. The report will be prepared in accordance with the Navy’s Monitoring Report Template.

Groundwater monitoring will be conducted in accordance with the requirements set forth in the SAP. Groundwater monitoring results will be included in the Annual Performance Report, and will discuss groundwater analytical data from the monitoring activities. This information will present a historical perspective and trend analysis of monitoring results.

The operations information included in the Annual Performance Report will be a summary of the ISB system operations, including any abnormal operating situations encountered, modifications made to operational parameters, etc.
An annual performance review will be included in the Annual Performance Report and will include evidence of ISB performance, and compliance with RAOs and land use controls. Operational modifications or optimization activities implemented will also be described.
REFERENCES


Tetra Tech, 2002b. Draft Feasibility Study (FS) Report for (OU 2), (Site 5 - Fire Training Area Groundwater), NAS JRB Willow Grove. February.


REFERENCES (Continued)

Tetra Tech, 2008c. Sampling and Analysis Plan for Pilot Test, Site 5 - Fire Training Area, Groundwater (OU 2), NAS JRB Willow Grove. October.


Tetra Tech, 2013b. Land Use Control Remedial Design for Site 5 - Former Fire Training Area, Former NAS JRB Willow Grove. May.

TABLES
TABLE 1-1
SITE 5 GROUNDWATER REMEDIATION GOALS
IN SITU BIOREMEDIATION OPERATION, MAINTENANCE & MONITORING PLAN
SITE 5 - FIRE TRAINING AREA
FORMER NAS JRB WILLOW GROVE, PENNSYLVANIA

<table>
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<tr>
<th>COC</th>
<th>RANGE OF DETECTED CONCENTRATIONS(^{(1)})</th>
<th>EXCEEDS MCL?</th>
<th>REMEDIAL GOAL(^{(4)}) (µg/L)</th>
<th>RATIONALE FOR REMEDIAL GOAL</th>
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<tr>
<td>1,1,1-Trichloroethane (TCA)</td>
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<td>1,1,2-TCA</td>
<td>10</td>
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<td>MCL</td>
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<td>3 - 350</td>
<td>NC</td>
<td>31</td>
<td>MSC</td>
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<td>1,1-DCE</td>
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<td>c-1,2-DCE</td>
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<td>PCE</td>
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<td>Yes</td>
<td>5</td>
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<td>VC(^{(2)})</td>
<td>ND</td>
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<td>2</td>
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Notes:

- MSC - Medium Specific Concentration for Groundwater, Residential Used Aquifers, PA Code 250, Table 1. (see Appendix A, Table A-1 for rationale for selecting MSC in lieu of EPA Regional Screening Level for Tap Water)
- MCL – Maximum Contaminant Level
- \(^{(1)}\) Summer 2005 results, prior to bioremediation pilot test.
- \(^{(2)}\) Breakdown products of parent compounds 1,1,1-TCA, PCE, and TCE that either currently exist in Site 5 groundwater or are expected to be temporarily created (or increase in concentration) as byproducts of the reductive dechlorination process before they are in turn reduced through the same bioremediation process.
- \(^{(3)}\) September 2011 results
- \(^{(4)}\) Residual risk will be calculated when cleanup goals are thought to be achieved

ND – Not detected
NC – No MCL
µg/L – micrograms per liter
## TABLE 2-1

**WELL CONSTRUCTION SUMMARY**

**IN-SITU BIOREMEDIATION OPERATION, MAINTENANCE & MONITORING PLAN**

**SITE 5 - FIRE TRAINING AREA**

**FORMER NAS JRB WILLOW GROVE, PENNSYLVANIA**

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<th>Open (O)</th>
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<td>05MW01I</td>
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<td>32 - 47 S</td>
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<td>*03MW8D</td>
<td>163 - 173 S</td>
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**Notes:**

Monitored interval is measured as feet below ground surface.

* = Wells were installed as part of the Site 3 Remedial Investigation, but are also relevant to Site 5.
**TABLE 3-1**

**BIOSTIMULATION INJECTION OPERATIONS**

**IN-SITU BIOREMEDIATION OPERATION, MAINTENANCE & MONITORING PLAN**

**SITE 5 - FIRE TRAINING AREA**

**FORMER NAS JRB WILLOW GROVE, PENNSYLVANIA**

<table>
<thead>
<tr>
<th>Parameter</th>
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<td>Vegetable oil desired concentration in formation</td>
<td>200 mg/L</td>
</tr>
<tr>
<td>Recirculation rate</td>
<td>2 gallons per minute</td>
</tr>
<tr>
<td>LactOil™ substrate concentration (as product)</td>
<td>444 mg/L</td>
</tr>
<tr>
<td>Concentration of ethyl lactate in formation</td>
<td>156 mg/L</td>
</tr>
<tr>
<td>LactOil™ substrate daily dosage (as product, metering pump setting)</td>
<td>1.3 gallons per day</td>
</tr>
<tr>
<td>LactOil™ substrate monthly dosage (as product)</td>
<td>38 gallons per month</td>
</tr>
<tr>
<td>Sodium bicarbonate desired weekly dosage (as solid)</td>
<td>50 lbs. per week(1)</td>
</tr>
<tr>
<td>Sodium bicarbonate dosage (as solution in 300-gal tank, metering pump setting)</td>
<td>0.42 gallons per hour</td>
</tr>
<tr>
<td>1st month recirculation injection/extraction wells configuration</td>
<td>TW-1 extraction well, 05MW17S, TW-1, and TW-3 - injection wells</td>
</tr>
<tr>
<td>2nd month recirculation injection/extraction wells configuration (if needed)</td>
<td>TW-1 or TW-2 (if outfitted) extraction well, 05MW17S, TW-2 or TW-1, and TW-3 - injection wells</td>
</tr>
</tbody>
</table>

**Notes:**

The input values are in bold, and the calculated values are normal font.
mg/L – milligrams per liter

(1) mix 200 lbs. sodium bicarbonate solid with 300 gallons water for 30-day duration
<table>
<thead>
<tr>
<th>Sample Location</th>
<th>Fixed Base Laboratory (Performance Monitoring)</th>
<th>Process Monitoring Test</th>
<th>Field Test Kit</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>TCL VOCs and 1,4-Dioxane</td>
<td>Dissolved Gases&lt;sup&gt;(1)&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>TOC</td>
<td>Sulfide/Sulfate</td>
<td></td>
</tr>
<tr>
<td></td>
<td>qPCR and genes&lt;sup&gt;(2)&lt;/sup&gt;</td>
<td>Water Level/Turbidity&lt;sup&gt;(3)&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Temperature</td>
<td>pH</td>
<td></td>
</tr>
<tr>
<td></td>
<td>pH</td>
<td>Specific Conductivity</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Specific Conductivity</td>
<td>Oxidation/Reduction Potential</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Dissolved Oxygen</td>
<td>DO</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Alkalinity as CaCO₃</td>
<td>Hydrogen Sulfide</td>
<td></td>
</tr>
<tr>
<td>05MW01S</td>
<td>•</td>
<td>•</td>
<td>•</td>
</tr>
<tr>
<td>05MW01SI</td>
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</tr>
<tr>
<td>05MW10I</td>
<td>•</td>
<td>•</td>
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</tr>
<tr>
<td>05MW16S</td>
<td>•</td>
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<tr>
<td>05MW17I</td>
<td>•</td>
<td>•</td>
<td>•</td>
</tr>
<tr>
<td>05MW18S</td>
<td>•</td>
<td>•</td>
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</tr>
<tr>
<td>05MW18I</td>
<td>•</td>
<td>•</td>
<td>•</td>
</tr>
<tr>
<td>05MW19S</td>
<td>•</td>
<td>•</td>
<td>•</td>
</tr>
<tr>
<td>05MW19I</td>
<td>•</td>
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<td>•</td>
</tr>
<tr>
<td>05MW20</td>
<td>•</td>
<td>•</td>
<td>•</td>
</tr>
<tr>
<td>05MW21</td>
<td>•</td>
<td>•</td>
<td>•</td>
</tr>
<tr>
<td>05MW22</td>
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<td>•</td>
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</tr>
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<td>05MW23</td>
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</tr>
<tr>
<td>05MW24</td>
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<td>05MW26</td>
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<td>05TW01</td>
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<td>05TW02</td>
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<tr>
<td>05TW03</td>
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</tr>
<tr>
<td>05TW04</td>
<td>•</td>
<td>•</td>
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</tr>
</tbody>
</table>

**Notes:**

1. Dissolved gases include ethane, ethene, methane, and acetylene.
2. qPCR includes dechlorinating bacteria, and functional genes, and phylogenetic groups.
3. Although not considered process or performance monitoring parameters, water level and turbidity measurements should be acquired during each sampling event.
FIGURES
SITE 5 - LOCATION MAP
NAS JRB WILLOW GROVE
WILLOW GROVE, PENNSYLVANIA

AERIAL BASE MAP PROVIDED BY THE PAMAP PROGRAM, PA DEPARTMENT OF CONSERVATION
AND NATURAL RESOURCES, BUREAU OF TOPOGRAPHIC AND GEOLIC SURVEY
MONITORING WELL LOCATION
INJECTION/EXTRACTION WELL LOCATION
WATER TABLE INJECTION WELLS INSTALLED JULY 2013
UNDERGROUND ELECTRIC AND WATER LINE
UNDERGROUND ELECTRIC LINE

TREATMENT TRAILER
FORMER BURN RING
MONITORING WELL LOCATION
INJECTION/EXTRACTION WELL
WATER TABLE INJECTION WELLS
INSTALLED JULY 2013
UNDERGROUND ELECTRIC AND WATER LINE
UNDERGROUND ELECTRIC LINE

TETRA TECH
SITE LAYOUT
SITE 5 – FIRE TRAINING AREA
NAS JRB WILLOW GROVE
WILLOW GROVE, PENNSYLVANIA

FIGURE 1-2
SCALE IN FEET
0 30 60
SCALE OUTLINE
MEASUREMENTS
0 09/17/13
DATE
REV
FIGURE NUMBER
AS NOTED
SCALE
FIGURE 3-1
LACTOIL INJECTION SCHEMATIC
SITE 5 - FIRE TRAINING AREA
FORMER NAS JRB WILLOW GROVE,
Pennsylvania
FIGURE 4-1
DECISION MAKING FLOW CHART
IN SITU BIOREMEDIATION OPERATION, MAINTENANCE & MONITORING PLAN
SITE 5 - FIRE TRAINING AREA
FORMER NAS JRB WILLOW GROVE, PENNSYLVANIA

Full-scale ISB system construction

Full-scale ISB system operation
Biostimulation injection

Post-Injection monitoring,
Key system operating parameters

Are system variables within accepted range?
No
Yes

Implement operational changes

Are remediation goals achieved?
No
Yes

Continue operation

Implement bioaugmentation
Yes
No

Need additional bioaugmentation?

Remedy complete
APPENDIX A

WELL CONSTRUCTION LOGS
**Tetra Tech NUS, Inc.**

**BEDROCK MONITORING WELL SHEET**
**OPEN HOLE WELL**

<table>
<thead>
<tr>
<th>PROJECT</th>
<th>NAS JP8 Willow Grove</th>
</tr>
</thead>
<tbody>
<tr>
<td>LOCATION</td>
<td>SITE 5</td>
</tr>
<tr>
<td>PROJECT NO.</td>
<td>BORING</td>
</tr>
<tr>
<td>DATE BEGUN</td>
<td>11/12/08</td>
</tr>
<tr>
<td>DATE COMPLETED</td>
<td>11/14/08</td>
</tr>
<tr>
<td>FIELD GEOLOGIST</td>
<td>Vince Shickora/Chuck Meyer</td>
</tr>
<tr>
<td>GROUND ELEVATION</td>
<td>DATUM</td>
</tr>
</tbody>
</table>

**DRILLER** TALON  
**DRILLING METHOD**  Air Rotary  
**DEVELOPMENT METHOD**

---

**ELEVATION/HEIGHT OF TOP OF SURFACE CASING:**  
**TYPE OF SURFACE SEAL:** Concrete  
**Flush-Mount Vault**  
**I.D. OF CASING:** 8"  
**TYPE OF CASING:** STEEL  
**TEMP./PERM.:** Permanent  
**DIAMETER OF HOLE:** 12"  
**TYPE OF CASING SEAL:** Bentonite/Cement Grout  
**DEPTH TO TOP OF ROCK:** 14.5'  
**DEPTH TO BOTTOM CASING:** 20'  
**DIAMETER OF HOLE IN BEDROCK:** 8"  
**DESCRIBE IF CORE/REAMED WITH BIT:**

---

**DESCRIBE JOINTS IN BEDROCK AND DEPTH:**

---

**ELEVATION/DEPTH OF HOLE:** 176'
# BEDROCK MONITORING WELL SHEET
## OPEN HOLE WELL

**Tetra Tech NUS, Inc.**

<table>
<thead>
<tr>
<th>Field</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>PROJECT</strong></td>
<td>NASJRB Willow Grove</td>
</tr>
<tr>
<td><strong>LOCATION</strong></td>
<td>SITE 5</td>
</tr>
<tr>
<td><strong>PROJECT NO.</strong></td>
<td>BORING</td>
</tr>
<tr>
<td><strong>DATE BEGUN</strong></td>
<td>11/13/08</td>
</tr>
<tr>
<td><strong>DATE COMPLETED</strong></td>
<td>11/17/08</td>
</tr>
<tr>
<td><strong>FIELD GEOLOGIST</strong></td>
<td>Vince Shickora</td>
</tr>
<tr>
<td><strong>GROUND ELEVATION</strong></td>
<td>Datum</td>
</tr>
<tr>
<td><strong>DRILLER</strong></td>
<td>Talon</td>
</tr>
<tr>
<td><strong>DRILLING METHOD</strong></td>
<td>Air Rotary</td>
</tr>
<tr>
<td><strong>DEVELOPMENT METHOD</strong></td>
<td></td>
</tr>
</tbody>
</table>

| **ELEVATION/HEIGHT OF TOP OF SURFACE CASING:** | |
| **TYPE OF SURFACE SEAL:** | Concrete | Flush-Mount Vault |
| **I.D. OF CASING:** | 8" |
| **TYPE OF CASING:** | Steel |
| **TEMP./PERM.:** | Permanent |
| **DIAMETER OF HOLE:** | 12" |
| **TYPE OF CASING SEAL:** | Bentonite/Cement Grout |
| **DEPTH TO TOP OF ROCK:** | 14' |
| **DEPTH TO BOTTOM CASING:** | 20' |
| **DIAMETER OF HOLE IN BEDROCK:** | 6" |
| **DESCRIBE IF CORE/REAMED WITH BIT:** | |
| **DESCRIBE JOINTS IN BEDROCK AND DEPTH:** | |
| **ELEVATION/DEPTH OF HOLE:** | 90' |
**Bedrock Monitoring Well Sheet**

**Open Hole Well**

**Project Name:** Willow Grove Site 5  
**Location:** Site 5  
**Project No.:** Boring

**Date Begun:** 11/13/08  
**Date Completed:** 11/14/08  
**Field Geologist:** Vince Shickora  
**Ground Elevation Datum:**

<table>
<thead>
<tr>
<th>Field</th>
<th>Value</th>
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</thead>
<tbody>
<tr>
<td>Driller</td>
<td>Talon</td>
</tr>
<tr>
<td>Drilling Method</td>
<td>Air Rotary</td>
</tr>
<tr>
<td>Development Method</td>
<td></td>
</tr>
</tbody>
</table>

**Elevation/Height of Top of Surface Casing:**

**Type of Surface Seal:** Concrete, Flush Mount Vault

**I.D. of Casing:** 8"

**Type of Casing:** Steel

**Temp./Perm.:** Permanent

**Diameter of Hole:** 12"

**Type of Casing Seal:** Bentonite/Cement Grout

**Depth to Top of Rock:** 14.5'  
**Depth to Bottom Casing:** 20'

**Diameter of Hole in Bedrock:** 8"

**Describe if Core/Reamed with Bit:**

---

**Describe Joints in Bedrock and Depth:**

---

**Elevation/Depth of Hole:** 111'
**BEDROCK MONITORING WELL SHEET**
**WELL INSTALLED IN BEDROCK**

<table>
<thead>
<tr>
<th>PROJECT</th>
<th>LOCATION</th>
<th>DRILLER</th>
<th>DRILLING METHOD</th>
<th>DEVELOPMENT METHOD</th>
</tr>
</thead>
<tbody>
<tr>
<td>NASSREA Willow Grove</td>
<td>Site 5 (FFTH)</td>
<td>Joe Deihorn</td>
<td>Air Rotary</td>
<td>Method</td>
</tr>
<tr>
<td>PROJECT NO.</td>
<td>BORING</td>
<td>DATE BEGUN</td>
<td>DATE COMPLETED</td>
<td>GROUND ELEVATION</td>
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<tr>
<td>1120Co.0910</td>
<td>C5MW-16</td>
<td>6-12-08</td>
<td>6-13-08</td>
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</table>

**FIELD GEOLOGIST:** Veer Shikara

**GROUND ELEVATION**

<table>
<thead>
<tr>
<th>ELEVATION/HEIGHT OF TOP OF SURFACE CASING:</th>
<th>0.0'</th>
</tr>
</thead>
<tbody>
<tr>
<td>ELEVATION/HEIGHT TOP OF RISER:</td>
<td>0.0'</td>
</tr>
<tr>
<td>TYPE OF SURFACE SEAL:</td>
<td>Concrete Apron</td>
</tr>
<tr>
<td>I.D. OF SURFACE CASING:</td>
<td>6 inch (Steel)</td>
</tr>
<tr>
<td>DIAMETER OF HOLE:</td>
<td>18 inch</td>
</tr>
<tr>
<td>RISER PIPE I.D.:</td>
<td>2 inch</td>
</tr>
<tr>
<td>TYPE OF RISER PIPE:</td>
<td>Schedule 40 PVC</td>
</tr>
<tr>
<td>TYPE OF BACKFILL:</td>
<td>Grout from 19.5' to surface</td>
</tr>
<tr>
<td>ELEVATION/DEPTH TOP OF SEAL:</td>
<td>19.5'</td>
</tr>
<tr>
<td>ELEVATION/DEPTH TOP OF BEDROCK:</td>
<td></td>
</tr>
<tr>
<td>TYPE OF SEAL:</td>
<td>Bentonite Hsealplug to 19.5'065</td>
</tr>
<tr>
<td>ELEVATION/DEPTH TOP OF SAND:</td>
<td>33.6'</td>
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<tr>
<td>ELEVATION/DEPTH TOP OF SCREEN:</td>
<td>38.6'</td>
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<tr>
<td>TYPE OF SCREEN:</td>
<td>Schedule 40 PVC</td>
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<tr>
<td>SLOT SIZE x LENGTH:</td>
<td>0.02&quot; x 10'</td>
</tr>
<tr>
<td>I.D. SCREEN:</td>
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</tr>
<tr>
<td>TYPE OF SAND PACK:</td>
<td>2 Silica Quartz</td>
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<tr>
<td>DIAMETER OF HOLE IN BEDROCK:</td>
<td>6 inch</td>
</tr>
<tr>
<td>CORE/REAM:</td>
<td></td>
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<tr>
<td>ELEVATION/DEPTH BOTTOM SCREEN:</td>
<td>48.6'</td>
</tr>
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<td>ELEVATION/DEPTH BOTTOM OF SAND:</td>
<td>53.4'</td>
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<tr>
<td>ELEVATION/DEPTH BOTTOM OF HOLE:</td>
<td>71.6'</td>
</tr>
<tr>
<td>BACKFILL MATERIAL BELOW SAND:</td>
<td>Bentonite Hsealplug</td>
</tr>
</tbody>
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**BEDROCK MONITORING WELL SHEET**

**WELL INSTALLED IN BEDROCK**

**PROJECT:** NASA JRB Willow Grove  
**LOCATION:** Site 5 (FETA)  
**DATE BEGUN:** 6-12-08  
**DATE COMPLETED:** 6-13-08  
**DRILLER:** Joe Doehn  
**DRILLING METHOD:** Air Rotary  
**FIELD GEOLOGIST:** Vince Shickora  
**GROUND ELEVATION:** DATUM

---

**ELEVATION/HEIGHT OF TOP OF SURFACE CASING:** 2.5'  
**ELEVATION/HEIGHT TOP OF RISER:** 2.0'  
**TYPE OF SURFACE SEAL:** Concrete Apron  
**I.D. OF SURFACE CASING:** 6 inch steel  
**DIAMETER OF HOLE:** 10 inch  
**RISER PIPE I.D.:** 2 inch  
**TYPE OF RISER PIPE:** schedule 40 pvc  
**TYPE OF BACKFILL:** Concrete/Bentonite  
**ELEVATION/DEPTH TOP OF SEAL:** 19.5'  
**ELEVATION/DEPTH TOP OF BEDROCK:** 45.0'  
**TYPE OF SEAL:** Bentonite Holeplug  
**ELEVATION/DEPTH TOP OF SAND:** 50.0'  
**ELEVATION/DEPTH TOP OF SCREEN:** 50.0'  
**TYPE OF SCREEN:** schedule 40 pvc  
**SLOT SIZE X LENGTH:** .02" X 20'  
**I.D. SCREEN:** 2 inch  
**TYPE OF SAND PACK:** #2 Silica Quartz  
**DIAMETER OF HOLE IN BEDROCK:** 6 inch  
**CORE/REAM:**  
**ELEVATION/DEPTH BOTTOM SCREEN:** 78.5'  
**ELEVATION/DEPTH BOTTOM OF SAND:** 71.5'  
**ELEVATION/DEPTH BOTTOM OF HOE:** 71.5'  
**BACKFILL MATERIAL BELOW SAND:** None
# Bedrock Monitoring Well Sheet

**Project:** Nastro Willow Grove  
**Location:** Site 5 (FFTA)  
**Date Begun:** 6-12-08  
**Date Completed:** 6-13-08  
**Field Geologist:** Vince Shickora

**Driller:** Joe Deithorn  
**Drilling Method:** Air Rotary  
**Development Method:**

---

**Elevation/Height of Top of Surface Casing:** 2.5'  
**Elevation/Height of Riser:** 2.0'  
**Type of Surface Seal:** Concrete Grout  
**I.D. of Surface Casing:** 6 inch steel  
**Diameter of Hole:** 10 inch  
**Riser Pipe I.D.:** 2 inch  
**Type of Riser Pipe:** Schedule 40 PVC  
**Type of Backfill:** Grout/Bentonite great from 24.5' to surface  
**Elevation/Depth Top of Seal:**  
**Elevation/Depth Top of Bedrock:**  
**Type of Seal:** Bentonite Holeplug  
**Elevation/Depth of Sand:** 86.0'  
**Elevation/Depth Top of Screen:** 84.0'  
**Type of Screen:** Schedule 40 PVC  
**Slot Size x Length:** 0.62'' x 20'  
**I.D. Screen:** 2 inch  
**Type of Sand Pack:** #2 Silica Quartz  
**Diameter of Hole in Bedrock:** 6 inch  
**Core/Ream:**  
**Elevation/Depth Bottom Screen:** 104.0'  
**Elevation/Depth Bottom of Sand:** 110.0'  
**Elevation/Depth Bottom of Hole:** 150.3'  
**Backfill Material Below Sand:** Bentonite Holeplug
**BEDROCK MONITORING WELL SHEET**
**WELL INSTALLED IN BEDROCK**

**Tetra Tech NUS, Inc.**

**PROJECT** NassJRB Willow Grove  
**LOCATION** Site 5  (FEMA)  
**PROJECT NO.** 11260910  
**BORENG** 05MW-18$  
**DATE BEGUN** 6-12-09  
**DATE COMPLETED** 6-13-09  
**FIELD GEOLOGIST** Vince Shickora  
**GROUND ELEVATION DATUM**

---

**ELEVATION/HEIGHT OF TOP OF SURFACE CASING:** 2.5'

**ELEVATION/HEIGHT TOP OF RISER:** 20'

**TYPE OF SURFACE SEAL:** Concrete Apron

**I.D. OF SURFACE CASING:** 6inch Steel

**DIAMETER OF HOLE:** 10 inch

**RISER PIPE I.D.:** 2 inch

**TYPE OF RISER PIPE:** Schedule 40 PVC

**TYPE OF BACKFILL:** Cement/Bentonite

**ELEVATION/DEPTH TOP OF SEAL:**

**ELEVATION/DEPTH TOP OF BEDROCK:**

**TYPE OF SEAL:** Bentonite Helopley

**ELEVATION/DEPTH TOP OF SAND:** 45.0'

**ELEVATION/DEPTH TOP OF SCREEN:** 50.0'

**TYPE OF SCREEN:** Schedule 40 PVC

**SLOT SIZE x LENGTH:** 0.02" x 20'

**I.D. SCREEN:** 2 inch

**TYPE OF SAND PACK:** #2 Silica Quartz

**DIAMETER OF HOLE IN BEDROCK:** 6 inch

**CORE/REAM:**

**ELEVATION/DEPTH BOTTOM SCREEN:** 70.0'

**ELEVATION/DEPTH BOTTOM OF SAND:** 71.0'

**ELEVATION/DEPTH BOTTOM OF HOLE:** 71.0'

**BACKFILL MATERIAL BELOW SAND:** None
**BEDROCK**
**MONITORING WELL SHEET**
**WELL INSTALLED IN BEDROCK**

**PROJECT:** NassRb Willow Grove Location Site 5 (FFTA)
**PROJECT NO.:** 112-G0-0910
**BORING:** 05MW-18T
**DATE BEGUN:** 6-12-08
**DATE COMPLETED:** 6-13-08

**WELL NO.:** 05MW-18T

**FIELD GEOLOGIST:** Vince Shickora

**DRILLER:** Joe Deithera
**DRILLING METHOD:** Air Rotary
**DEVELOPMENT METHOD:**

---

**ELEVATION/HEIGHT OF TOP OF SURFACE CASING:** 25'
**ELEVATION/HEIGHT OF RISER:** 20'

**TYPE OF SURFACE SEAL:** Concrete Apron
**I.D. OF SURFACE CASING:** 6 inch Steel
**DIAMETER OF HOLE:** 10 inch

**RISER PIPE I.D.:** 2 inch
**TYPE OF RISER PIPE:** Schedule 40 PVC

**TYPE OF BACKFILL:** Cement/Bentonite grout from 19.5' to surface

**ELEVATION/DEPTH TOP OF SEAL:**
**ELEVATION/DEPTH TOP OF BEDROCK:**

**TYPE OF SEAL:** Bentonite Holeplug
**To ~ 19.5'86.5

**ELEVATION/DEPTH TOP OF SAND:** 30.0'
**ELEVATION/DEPTH TOP OF SCREEN:**
**TYPE OF SCREEN:** Schedule 40 PVC
**SLOT SIZE x LENGTH:** 0.02" x 20'
**I.D. SCREEN:** 2 inch

**TYPE OF SAND PACK:** #2 Silica Quartz

**DIAMETER OF HOLE IN BEDROCk:** 6 inch
**CORE/REAM:**

**ELEVATION/DEPTH BOTTOM SCREEN:**
**ELEVATION/DEPTH BOTTOM OF SAND:**
**ELEVATION/DEPTH BOTTOM OF HOLE:** 108.0'

**BACKFILL MATERIAL BELOW SAND:** Bentonite Holeplug
**ELEVATION/DEPTH BOTTOM OF HOLE:** 123.67'
**ELEVATION/DEPTH BOTTOM OF HOLE:** 151.27'
Project: NASTRA Willow Grove  Location: Site 5  

Driller: Tony Petris  Drilling Method: Air Rotary  Development Method: Submersible Pump  

Date Begun: 12-27-08  Date Completed: 12-22-08  

Field Geologist: Vince Shuckara  Ground Elevation Datum:  

Elevation/Height of Top of Surface Casing: 1.2'  
Elevation/Height of Riser:  
Type of Surface Seal: Concrete Apron  
I.D. of Surface Casing: 6 inch  
Diameter of Hole: 10 inch  
Riser Pipe I.D.: 2 inch  
Type of Riser Pipe: Schedule 40 PVC  
Type of Backfill: Cement/Bentonite  Grout (Grout from 16' to Surface only)  
Elevation/Depth of Seal: 16'  
Elevation/Depth of Bedrock: 164'  
Type of Seal: 3/8" Bentonite: Holeplug (Holeplug from 64' to 164' bgs)  
Elevation/Depth of Sand: 168'  
Elevation/Depth of Screen:  
Type of Screen: Schedule 40 PVC  
Slot Size x Length: 0.02" x 10'  
I.D. Screen: 2 inch  
Type of Sand Pack: *2 Silica Quartz Sand  
Diameter of Hole in Bedrock: 6 inch  
Core/Ream:  
Elevation/Depth Bottom Screen: 78'  
Elevation/Depth Bottom of Sand: 78'  
Elevation/Depth Bottom of Hole: 78'  
Backfill Material Below Sand: None
**BEDROCK**

**MONITORING WELL SHEET**

**WELL INSTALLED IN BEDROCK**

<table>
<thead>
<tr>
<th>PROJECT NO.</th>
<th>LOCATION</th>
<th>DRILLER</th>
<th>DRILLING METHOD</th>
<th>DEVELOPMENT METHOD</th>
</tr>
</thead>
<tbody>
<tr>
<td>112600910</td>
<td>Site 5</td>
<td>Tony Pirylosi</td>
<td>Air Rotary</td>
<td>Submersible Pump</td>
</tr>
<tr>
<td>BORING C5-MW19I</td>
<td>DATE BEGUN: 12-22-05</td>
<td>DATE COMPLETED: 12-22-08</td>
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<tr>
<td>FIELD GEOLOGIST</td>
<td>GROUND ELEVATION</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vince Shickora</td>
<td>ELEVATION/HEIGHT OF TOP OF SURFACE CASING: 1-2.5'</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**ELEVATION/HEIGHT OF TOP OF RISER:**

**TYPE OF SURFACE SEAL:** Concrete Apron

**I.D. OF SURFACE CASING:** 6 inch

**DIAMETER OF HOLE:** 10 inch

**RISER PIPE I.D.:** 2 inch

**TYPE OF RISER PIPE:** Schedule 40 PVC

**TYPE OF BACKFILL:** Cement/Bentonite Grout

**ELEVATION/DEPTH TOP OF SEAL:** 1/16'

**ELEVATION/DEPTH TOP OF BEDROCK:**

**TYPE OF SEAL:** 3/4 Bentonite Holeplug

**ELEVATION/DEPTH TOP OF SAND:** 197'

**ELEVATION/DEPTH TOP OF SCREEN:**

**TYPE OF SCREEN:** Schedule 40 PVC

**SLOT SIZE x LENGTH:** 0.02" x 20'

**I.D. SCREEN:** 2 inch

**TYPE OF SAND PACK:** #2 Silica Quartz Sand

**DIAMETER OF HOLE IN BEDROCK:** 6 inch

**CORE/REAM:**

**ELEVATION/DEPTH BOTTOM SCREEN:** 1102'

**ELEVATION/DEPTH BOTTOM OF SAND:**

**ELEVATION/DEPTH BOTTOM OF HOLE:**

**BACKFILL MATERIAL BELOW SAND:** None - Natural Formation
**PROJECT** WILLAM GAGE
**LOCATION** S17T-5
**PROJECT NO.** 112G02014
**BORING** OS MW 20
**DATE BEGUN** 7/10/13
**DATE COMPLETED** 7/10/13
**FIELD GEOLOGIST** JS Tom/AVAC
**GROUND ELEVATION** DATUM

---

**DRILLER** TALON
**DRILLING METHOD** AIR ROTARY
**DEVELOPMENT METHOD** PUMPING

---

**ELEVATION/HEIGHT OF TOP OF SURFACE CASING:**

**ELEVATION/HEIGHT TOP OF RISER:**

**TYPE OF SURFACE SEAL:** CONCRETE

**I.D. OF SURFACE CASING:** 6-1/2

**DIAMETER OF HOLE:** 14-1/2

**RISER PIPE I.D.:** 4-1/2
**TYPE OF RISER PIPE:** PVC

**TYPE OF BACKFILL:** CEMENT BENTONITE

**ELEVATION/DEPTH TOP OF SEAL:** 126

**ELEVATION/DEPTH TOP OF BEDROCK:** 14

**TYPE OF SEAL:** BENTONITE CHIPS

**ELEVATION/DEPTH TOP OF SAND:** 127

**ELEVATION/DEPTH TOP OF SCREEN:** 137
**TYPE OF SCREEN:** PVC
**SLOT SIZE x LENGTH:** 1/10 x 15 FT
**I.D. SCREEN:** 4-1/2
**TYPE OF SAND PACK:** #2 FILTER SAND

**DIAMETER OF HOLE IN BEDROCK:** 14-1/2
**CORE/REAM:** NA

**ELEVATION/DEPTH BOTTOM SCREEN:** 152
**ELEVATION/DEPTH BOTTOM OF SAND:** 152
**ELEVATION/DEPTH BOTTOM OF HOLE:**
**BACKFILL MATERIAL BELOW SAND:** NA
**BEDROCK MONITORING WELL SHEET**

**WELL INSTALLED IN BEDROCK**

- **PROJECT:** WASJBR Willow Grove
- **LOCATION:** SITE F
- **PROJECT NO.:** 11/3-22014
- **BORING:** 0SMW21
- **DATE BEGUN:** 7/1/13
- **DATE COMPLETED:** 7/1/13
- **FIELD GEOLOGIST:** TS Tomahawk
- **GROUND ELEVATION DATUM:**

---

### Elevations/Heights

- **ELEVATION/HEIGHT OF TOP OF SURFACE CASING:**
- **ELEVATION/HEIGHT TOP OF RISER:**

### Dimensions

- **TYPE OF SURFACE SEAL:** CONCRETE
- **I.D. OF SURFACE CASING:** 6-1/2
- **DIAMETER OF HOLE:** 14-1/2
- **RISER PIPE I.D.:** 4-1/2
- **TYPE OF RISER PIPE:** PVC
- **TYPE OF BACKFILL:** CEMENT/REINFORCED CEMENT SLURRY
- **ELEVATION/DEPTH TOP OF SEAL:** 128.3
- **ELEVATION/DEPTH TOP OF BEDROCK:** 14
- **ELEVATION/DEPTH TOP OF SAND:** 130
- **ELEVATION/DEPTH TOP OF SCREEN:** 132
  - **TYPE OF SCREEN:** PVC
  - **SLOT SIZE x LENGTH:** #10 X LEFT
  - **I.D. SCREEN:** 4-1/2
  - **TYPE OF SAND PACK:** #2 FILTER SAND
- **DIAMETER OF HOLE IN BEDROCK:** 14-1/2
- **CORE/REAM:** NA
- **ELEVATION/DEPTH BOTTOM SCREEN:** 147
- **ELEVATION/DEPTH BOTTOM OF SAND:** 147
- **ELEVATION/DEPTH BOTTOM OF HOLE:** 147
- **BACKFILL MATERIAL BELOW SAND:** NA
Tetra Tech

MONITORING WELL SHEET
WELL INSTALLED IN BEDROCK

PROJECT: NASJRB WILLOW CREEK
PROJECT NO.: 112G02014
Boring: OSW02
DATE BEGUN: 7/19/18
DATE COMPLETED: 7/14/18
FIELD GEOLOGIST: JS TO MANHATTEN
GROUND ELEVATION: ___

DRILLER: THYOM
DRILLING METHOD: BLUE BUCKET
DEVELOPMENT METHOD: PUMPING

ELEVATION TOP OF RISER: ___

TYPE OF SURFACE SEAL: CONCRETE

TYPE OF PROTECTIVE CASING: STEEL FLUSH MOUNT

I.D. OF PROTECTIVE CASING: ___

DIAMETER OF HOLE: 14-IN.

TYPE OF RISER PIPE: PVC

RISER PIPE I.D.: 4-IN.

TYPE OF BACKFILL/SEAL: BENTONITE CHIPS

ELEVATION DEPTH TOP OF BEDROCK: 114

ELEVATION DEPTH TOP OF SAND: 127.5

ELEVATION DEPTH TOP OF SCREEN: 130

TYPE OF SCREEN: PVC

SLOT SIZE X LENGTH: #10 X 15 1/2

TYPE OF SAND PACK: #2 FILTER SAND

DIAMETER OF HOLE IN BEDROCK: 14-IN

CORE/REAM: NA

ELEVATION DEPTH BOTTOM OF SCREEN: 145

ELEVATION DEPTH BOTTOM OF SAND: 145

ELEVATION DEPTH BOTTOM OF HOLE: 145

BACKFILL MATERIAL BELOW SAND: NA

Diagram showing well installation details with labeled measurements and materials used.
Tetra Tech

BEDROCK MONITORING WELL SHEET
WELL INSTALLED IN BEDROCK

PROJECT: NA/STB WILLOW GROVE LOCATION
PROJECT NO.: 117-602014 BORING
DATE BEGUN: 7/1/13 DATE COMPLETED: 7/16/13
FIELD GEOLOGIST: S. Tomalavage
GROUND ELEVATION: _______ DATUM: _______

DRILLER: _______ DRILLING METHOD: AIR ROTARY
DEVELOPMENT METHOD: PUMPING

ELEVATION/HEIGHT OF TOP OF SURFACE CASING: _______
ELEVATION/HEIGHT TOP OF RISER: _______
TYPE OF SURFACE SEAL: CONCRETE
I.D. OF SURFACE CASING: 6-1N
DIAMETER OF HOLE: 14-1N
RISER PIPE I.D.: 4-1N
TYPE OF RISER PIPE: PVC
TYPE OF BACKFILL: CEMENT BENTONITE
SLURRY
ELEVATION/DEPTH TOP OF SEAL: 126.5
ELEVATION/DEPTH TOP OF BEDROCK: 20
ELEVATION/DEPTH TOP OF SAND: 129
ELEVATION/DEPTH TOP OF SCREEN: 135
TYPE OF SCREEN: PVC
SLOT SIZE x LENGTH: #10 X 1 FT
I.D. SCREEN: 4-1N
TYPE OF SAND PACK: #2 FILTER SAND
DIAMETER OF HOLE IN BEDROCK: 14-1N
CORE/REAM: NA
ELEVATION/DEPTH BOTTOM SCREEN: 135
ELEVATION/DEPTH BOTTOM OF SAND: 152
ELEVATION/DEPTH BOTTOM OF HOLE: 147
BACKFILL MATERIAL BELOW SAND: NA
**BEDROCK MONITORING WELL SHEET**

**WELL INSTALLED IN BEDROCK**

**PROJECT** NAS JRB Willow Grove

**LOCATION** SITE J

**BORE NO.** W-19

**DATE BEGUN** 7/9/13

**DATE COMPLETED** 7/9/13

**FIELD GEOLOGIST** AS TO MATERIAL

**GROUND ELEVATION** DATUM

---

**ELEVATION/HEIGHT OF TOP OF SURFACE CASING:**

**ELEVATION/HEIGHT TOP OF RISER:**

**TYPE OF SURFACE SEAL:** CONCRETE

**I.D. OF SURFACE CASING:** 6-IN

**DIAMETER OF HOLE:** 14-IN

**RISER PIPE I.D.:** 4-IN

**TYPE OF RISER PIPE:** PVC

**TYPE OF BACKFILL:** CEMENT - BENTONITE SLURRY

**ELEVATION/DEPTH TOP OF SEAL:** 130.5

**ELEVATION/DEPTH TOP OF BEDROCK:** 18

**TYPE OF SEAL:** BENTONITE CHIPS

**ELEVATION/DEPTH TOP OF SAND:** 131.6

**ELEVATION/DEPTH TOP OF SCREEN:** 133.5

**TYPE OF SCREEN:** PVC

**SLOT SIZE x LENGTH:** #10 x 15 FT

**I.D. SCREEN:** 4-IN

**TYPE OF SAND PACK:** #2 FILTER SAND

**DIAMETER OF HOLE IN BEDROCK:** 14-IN

**CORE/REAM:** NA

**ELEVATION/DEPTH BOTTOM SCREEN:** 146.5

**ELEVATION/DEPTH BOTTOM OF SAND:** 148.5

**ELEVATION/DEPTH BOTTOM OF HOLE:** 148.5

**BACKFILL MATERIAL BELOW SAND:** NA
**BEDROCK MONITORING WELL SHEET**

**WELL NO.: C5 MW 26**

### WELL INSTALLED IN BEDROCK

<table>
<thead>
<tr>
<th><strong>PROJECT</strong></th>
<th>NAS JRB WILLOW CREEK</th>
<th><strong>LOCATION</strong></th>
<th>SITE J</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>PROJECT NO.</strong></td>
<td>112502014</td>
<td><strong>BORING</strong></td>
<td>C5 MW 26</td>
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<tr>
<td><strong>DATE BEGUN</strong></td>
<td>7/10/13</td>
<td><strong>DATE COMPLETED</strong></td>
<td>7/10/13</td>
</tr>
<tr>
<td><strong>FIELD GEOLOGIST</strong></td>
<td>J. T. R. TAN</td>
<td><strong>GROUND ELEVATION</strong></td>
<td><strong>DATUM</strong></td>
</tr>
</tbody>
</table>

| **ELEVATION/HEIGHT OF TOP OF SURFACE CASING:** | 1 |
| **ELEVATION/HEIGHT TOP OF RISER:** | 1 |
| **TYPE OF SURFACE SEAL:** | CONCRETE |
| **I.D. OF SURFACE CASING:** | 6-1/2 |
| **DIAMETER OF HOLE:** | 14-1/2 |
| **RISER PIPE I.D.:** | 4-1/2 |
| **TYPE OF RISER PIPE:** | PVC |
| **TYPE OF BACKFILL:** | CEMENT PENTONITE SLURRY |
| **ELEVATION/DEPTH TOP OF SEAL:** | 130 |
| **ELEVATION/DEPTH TOP OF BEDROCK:** | 14 |
| **TYPE OF SEAL:** | PENTONITE CHIPS |
| **ELEVATION/DEPTH TOP OF SAND:** | 131.6 |
| **ELEVATION/DEPTH TOP OF SCREEN:** | 135 |
| **TYPE OF SCREEN:** | PVC |
| **SLOT SIZE x LENGTH:** | 1/2 x 12 FT |
| **I.D. SCREEN:** | 4-1/2 |
| **TYPE OF SAND PACK:** | #2 FILTER (14/18) |
| **DIAMETER OF HOLE IN BEDROCK:** | 14-1/2 |
| **CORE/REAM:** | NA |
| **ELEVATION/DEPTH BOTTOM SCREEN:** | 52 |
| **ELEVATION/DEPTH BOTTOM OF SAND:** | 150 |
| **ELEVATION/DEPTH BOTTOM OF HOLE:** | 152 |
| **BACKFILL MATERIAL BELOW SAND:** | NA |
Treatment Trailer

Pulsating Metering Feed Pumps, Cycle Timer and Flow Meters
Stainless Steel Vessel with Bag Filter, Pressure Gauges

Electrical Control Panel
300 Gallon Polyethylene Mix Tanks with Recirculation Pumps, Heater

Biostimulation Injection
System Control Panel

Fire Extinguisher, Flow Meters, Piping and Valves
Control Panel, Flow Meters, Filter, Piping and Valves

Injection/Extraction Well
LactOil

Sodium Bicarbonate
APPENDIX C

BIO-TRAP – DNA SAMPLING PROTOCOL
**Sampling Instructions**

**Storage:**  
It is important to minimize the amount of time that Bio-Trap Samplers are stored prior to being installed in the field. The physical properties of the Bio-Trap Samplers that make them an ideal medium for collecting microbes also increase the chances of microbial or chemical contamination. Bio-Trap Samplers need to remain sealed and refrigerated (not frozen) until they can be installed in the field.  

*Note:* Clean latex gloves (or similar) should be used at all times when handling Bio-Trap Samplers.

**Installation:**  
- Prior to installing the Bio-Trap Sampler, the monitoring well may need to be purged if it has not been sampled in a while. If purging is necessary, MI recommends that three well volumes be removed to ensure contact with formation water and reduce well bore effect.  
- Attach the Bio-Trap Sampler’s nylon loop (provided) to a nylon line (not provided) and suspend the Bio-Trap Sampler at a depth where significant contaminant concentrations exist. If no data is available on the vertical distribution of contaminants, then suspend the Bio-Trap Sampler in the middle of the saturated screened interval.  
- If large fluctuations in the water level are anticipated during the period of incubation, the Bio-Trap Sampler should be suspended from a float (contact MI for further details). Be sure not to suspend the Bio-Trap in the NAPL zone.  
- Once installed, incubation times can vary depending upon the scope of the project (routine monitoring and stable isotope probing (SIP) - 30 days and “baited” - 60 days).

**Retrieval:**  
- Open the monitoring well and pull up the Bio-Trap Sampler. Cut and remove the braided nylon line used to suspend the Bio-Trap Sampler.  
- Transfer the recovered Bio-Trap Sampler to labeled (well number and date) zippered bags, seal and then double bag in a larger (one-gallon) zippered bag, immediately place on blue ice in a cooler.  
- Repeat the above for all Bio-Trap Samplers from the site. Individual zippered bags containing the Bio-Trap Samplers can be placed in the same one-gallon zippered bag (if there is enough space).  
- A chain of custody (COC) form must be included with each shipment of samples.  

**Hold time for this analysis is 24-48 hours.**

**Shipping Instructions**

**Packaging Samples:**  
1. Samples should be shipped in a cooler with ice or blue ice for next day delivery. If regular ice is used, the ice should be double bagged.  
2. A chain of custody form must be included with each shipment of samples. Access our chain of custody at [www.microbe.com](http://www.microbe.com).

**Shipment for Weekday Delivery:**  
Samples for weekday delivery should be shipped to: Sample Custodian  
Microbial Insights, Inc.  
10515 Research Drive  
Knoxville, TN 37932  
(865) 573-8188

**Shipment for Saturday Delivery:**  
Coolers to be delivered on Saturday must be sent to our FedEx Drop Location. To ensure proper handling the following steps must be taken:  
1. FedEx shipping label should be marked under (6) Special Handling, check Hold Saturday.  
2. The cooler must be taped with FedEx SATURDAY tape.  
3. The shipping label must be filled out with the Drop Location address below. Our laboratory name must be on the address label.  
4. You MUST notify by email customerservice@microbe.com with the tracking number of the package on Friday (prior to 4pm Eastern Time) to arrange for Saturday pickup. Please make sure you write “Saturday Delivery” in the subject line of the message. Without proper labeling and the tracking number, there is no guarantee that the samples will be collected.

Samples for **Saturday delivery** should be shipped to: Microbial Insights, Inc.  
FedEx Drop Location  
10601 Murdock Drive  
Knoxville, TN 37932  
(865) 300-8053

**Note:** Samples received for Saturday Delivery will be frozen immediately upon receipt by Microbial Insights staff to minimize changes in the microbial community.
APPENDIX D

RESULTS OF BIODEGRADATION PROCESSES
FIGURE C-1
BIOAUGMENTATION PILOT STUDY – CHLORINATED ETHANES
SITE 5 GROUNDWATER (OU 2)
NAS JRB WILLOW GROVE, PENNSYLVANIA

1,1,1-TRICHLOROETHANE  1,1-DICHLOROETHANE  1,1-DICHLOROETHENE  CHLOROETHANE

Biostimulation  Bioaugmentation
FIGURE C-2
BIOAUGMENTATION PILOT STUDY – CHLORINATED ETHENES
SITE 5 GROUNDWATER (OU 2)
NAS JRB WILLOW GROVE, PENNSYLVANIA

BIOAUGMENTATION PILOT STUDY – CHLORINATED ETHENES
SITE 5 GROUNDWATER (OU 2)
NAS JRB WILLOW GROVE, PENNSYLVANIA

Concentration (mg/L)

1,3-DICHLOROETHENE
CIS,1,3-DICHLOROETHENE
TETRACHLOROETHENE
TRICHLOROETHENE
VINYL CHLORIDE

Biotimulation
Bioaugmentation
FIGURE C-4
BIOAUGMENTATION PILOT STUDY – DISSOLVED GASES
SITE 5 GROUNDWATER (OU 2)
NAS JRB WILLOW GROVE, PENNSYLVANIA

05MVW15

05MVW185

TW-2

TW-3

TW-4

Site 5 Groundwater (OU 2) NAS JRB Willow Grove, Pennsylvania

Concentration (mg/L)

Biostimulation

Bioaugmentation

05MVW171
FIGURE C-5
BIOAUGMENTATION PILOT STUDY – DISSOLVED METALS
SITE 5 GROUNDWATER (OU 2)
NAS JRB WILLOW GROVE, PENNSYLVANIA
FIGURE C-6
BIOAUGMENTATION PILOT STUDY – ANIONS
SITE 5 GROUNDWATER (OU 2)
NAS JRB WILLOW GROVE, PENNSYLVANIA
FIGURE C-7
BIOAUGMENTATION PILOT STUDY - FIELD TEST KITS
SITE 5 GROUNDWATER (OU 2)
NAS JRB WILLOW GROVE, PENNSYLVANIA
FIGURE C-8
BIOAUGMENTATION PILOT STUDY – FIELD pH
SITE 5 GROUNDWATER (OU 2)
NAS JRB WILLOW GROVE, PENNSYLVANIA

Biodistillation
Bioaugmentation
FIGURE C-11
BIOAUGMENTATION PILOT STUDY – VOLATILE FATTY ACIDS
SITE 5 GROUNDWATER (OU 2)
NAS JRB WILLOW GROVE, PENNSYLVANIA
APPENDIX E

LAND USE CONTROLS INSPECTION CHECKLIST
SITE 5 (GROUNDWATER) LAND USE CONTROLS

- Prohibition of groundwater use for human consumption without Navy, EPA and PADEP approval
- Require that future structures contain measures to mitigate the potential for vapor intrusion from the subsurface
- Require that existing buildings, prior to reuse, install a system to mitigate potential for vapor intrusion from the subsurface or conduct a vapor intrusion investigation that documents there is no unacceptable risk to future occupants

SITE 5 (GROUNDWATER) LUC INSPECTION CHECKLIST

<table>
<thead>
<tr>
<th>Inspection Item</th>
<th>Y/N/NA</th>
<th>Summary of Inspection Performed/Comments</th>
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</thead>
<tbody>
<tr>
<td>Has site use changed since last inspection?</td>
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</tr>
<tr>
<td>Is there visual evidence of unauthorized groundwater use?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Is there any visual evidence of reuse of the existing buildings?</td>
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<td></td>
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<tr>
<td>If reuse of existing buildings has occurred, has a vapor intrusion mitigation system been installed or has an investigation documenting no unacceptable risk been performed?</td>
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<td></td>
</tr>
<tr>
<td>Is there visible evidence of new building construction?</td>
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</tr>
<tr>
<td>If new buildings have been constructed, do they contain vapor intrusion mitigation measures?</td>
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<td></td>
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</table>
## SITE 5 DOCUMENTATION CHECKLIST

<table>
<thead>
<tr>
<th>Inspection Item</th>
<th>Y/N/NA</th>
<th>Summary of Inspection Performed/Comments</th>
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</thead>
<tbody>
<tr>
<td>Are there correspondence records (emails, letters) on file documenting EPA and PADEP notifications regarding LUCs? If yes, answer questions below:</td>
<td></td>
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</tr>
<tr>
<td>Are activities inconsistent with LUCs?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Are corrective actions regarding activities inconsistent with LUCs?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Are there changes in procedures affecting LUCs?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Are there proposed land use changes?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Is there a proposed transfer or sale of the property?</td>
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</tbody>
</table>

**Navy Annual Certification:**

I hereby certify that a complete and thorough inspection and an evaluation of compliance with land use controls established for the site in the 2012 Record of Decision have been performed and that the items noted on this inspection form have been assessed with respect to the intent of the implemented remedial action objectives for the site.

_____________________________________________________________
Navy Representative     Title

_____________________________________________________________
Signature      Date

**Onsite Inspection Team:**

_____________________________________________________________
Lead Inspector      Title/Affiliation

_____________________________________________________________
Signature      Date

**Others present:**

_____________________________________________________________
Name                                Affiliation     Name                                Affiliation