

## Memorandum

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AECOM PRB Team

Subject **Town of Orleans, MA**  
**Water Quality and Wastewater Planning**  
**Task Number 3.3 – NT Demonstration Projects**  
**Technical Memorandum Draft for Preliminary Engineering Work Plan for**  
**Permeable Reactive Barriers**

Project Number 60476644

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Date February 26, 2016

### 1. Background

- a. This technical memorandum presents the Preliminary Engineering Work Plan for Permeable Reactive Barriers (PRBs). AECOM Technical Services, Inc. (AECOM) PRB Technical Team (AECOM and MT Environmental Restoration) prepared this Preliminary Engineering Work Plan for PRBs for the Town of Orleans. AECOM is providing water quality and wastewater planning and engineering services to the Town to reduce excessive nitrogen loading to the Town's ponds, estuaries and embayments.

### 2. Introduction

- a. The Project represents the first to implement a "Hybrid" approach under the Cape Cod 208 Water Quality Plan, which has been approved by both the United States Environmental Protection Agency (USEPA) and the Massachusetts Department of Environmental Protection (MassDEP). The Project consists of conceptual and preliminary design to update the Comprehensive Wastewater Management Plan (CWMP) completed by the Town in 2011 to reflect the Consensus Plan (Water Quality Management Plan) developed by the Town in 2015. The Project goal is to minimize the proposed sewer footprint (area of Town and number of properties to be sewer) to the greatest extent possible by maximizing the use of several non-traditional technologies (Coastal Habitat Restoration, Aquaculture, Floating Constructed Wetlands, and Permeable Reactive Barriers). The Hybrid Plan was vetted through the Orleans Water Quality Advisory Panel (OWQAP), a panel consisting of stakeholder representatives (Orleans Selectmen and representatives of engaged citizen constituencies), and liaisons from key town boards and commissions, organizations, neighboring towns, and regional, state, and federal partners. Potential alternative planning scenarios to meet water quality standards were developed for the OWQAP.

- b. The purpose of this preliminary engineering work plan is to describe proposed Demonstration Tests for PRBs. PRBs are a non-traditional wastewater treatment technology with the potential to reduce the levels of nitrate in the groundwater by treating groundwater biologically before it reaches sensitive surface water bodies. This work plan will identify selected Demonstration Test locations and present preliminary engineering design criteria. Additionally, initial permitting requirements, cost estimates, and monitoring plans will be presented. The monitoring plans will be incorporated into an overall Adaptive Management Plan which will be implemented to evaluate the impacts of the technologies on reducing nitrogen. AECOM is working closely with the Town, its Water Quality Advisory Panel, and the regulatory agencies including the Cape Cod Commission and MassDEP, as the Adaptive Management Plan is critical to obtaining one of the first watershed permits granted by MassDEP.
- c. The Demonstration Tests will provide data to assess the effectiveness and applicability of PRBs as a treatment alternative for the Town. It is expected that the tests will demonstrate the level of nitrate removal that can be achieved with PRBs and provide data to prepare a full scale design. The Demonstration Tests will be evaluated by the following performance objectives:
  - 1) Achieve satisfactory distribution of the carbon substrate solution into the subsurface;
  - 2) Establish and maintain necessary anaerobic (reducing) and groundwater flow conditions in the subsurface throughout the targeted treatment area;
  - 3) Demonstrate reduced nitrate concentrations and flux in groundwater through monitoring to extrapolate to reduction targets for full scale (total maximum daily load [TMDL]);
  - 4) Demonstrate performance, compliance monitoring, and assessment of treated water quality, including potential secondary water quality affects, through groundwater monitoring program;
  - 5) Evaluate time frame for technology performance; and
  - 6) Obtain data for engineering evaluations and to optimize full scale design and implementation.

### 3. Selection of Demonstration Test Location(s)

- a. AECOM evaluated numerous potential sites in the Town of Orleans, including locations identified by the Town, for consideration for placement of PRB Demonstration Tests in 2016. Property ownership and use, downgradient groundwater use, distance to shoreline, nitrate concentrations and flux, topography, overall ease of monitoring, and potential for full scale PRB implementation were among the criteria evaluated and rationale for selection of sites for performing the Demonstration Test. The resulting Technical Memorandum on Site Characterization for Permeable Reactive Barriers (Characterization Memo) is included as Appendix A, which includes figures showing the locations of each of the sites evaluated. The evaluation process narrowed the list of potential Demonstration Test sites to the following four locations:
  - 1) South Orleans Road at Tonset/Eldredge Parkway (Site B);
  - 2) Town Landfill (Site E);
  - 3) Main Street and Tonset Road (Site A); and
  - 4) Town Cove Gibson Road (Site C).

- b. Based on further evaluation for the preparation of this Work Plan, a preferred Demonstration Test site at Eldredge Park (Site B) was selected based on key location features, available data, and the ability to provide results representative of other areas in the Town. Two additional potential demonstration sites, including the Town Landfill (Site E) and Gibson Road at Asas Landing (Site C) were identified as test site options that may also be implemented with the preferred site, given sufficient funding. The landfill demonstration location is seen as highly advantageous, close in preference to the Eldredge Park location, and ideally would be implemented along with Eldredge Park. The locations of the recommended Demonstration Test sites are shown on Figure 3-1 and Figure 3-2.
- c. The Town-owned Eldredge Park Demonstration Test site is located in the parking lot area between the playing fields off Eldredge Parkway (Figure 3-3). This demonstration location supports full scale PRBs that may be located in Eldredge Park, along South Orleans Road, Tonset Road, and Main Street or some combination of these options. PRBs at one or more of these locations would be designed to reduce nitrogen loading to Town Cove. Several groundwater monitoring wells were installed for a separate investigation at the Police Station (less than 500 feet east), and the depth to groundwater is approximately 30 feet using these wells. A significant mass flux of nitrate in groundwater is expected at the preferred Demonstration Test location (estimated 710 kg/yr as calculated with WatershedMVP), and the groundwater flows from this area toward Town Cove to the northeast. The parking lot area provides sufficient room for both the layout of the PRB and upgradient and downgradient monitoring wells.
- d. The Orleans landfill is the second preferred location for a PRB Demonstration Test (Figure 3-4). An ongoing groundwater monitoring program has found significant concentrations of nitrate in groundwater at the landfill (10 to 40 ug/L). These concentrations are likely significantly higher than concentrations that may be found over a wide area of Town from septic system sources. Historical landfill and septage lagoon operations that began operation around 1950 are likely sources of nitrate in groundwater at the landfill. Ongoing yard waste composting may also be a contributing source of nitrate infiltrating with stormwater runoff. The depth to groundwater is approximately 45 feet below grade at the lowest point of land elevation at the landfill but increases significantly downgradient as the land surface is higher. The landfill is near the top of the Nauset watershed and groundwater flows from the landfill northeast in the direction of Town Cove. Estimates for travel time from the landfill to Town Cove are uncertain and may be as much as 50 years.
- e. A third potential Demonstration Test site location is a portion of Gibson Road at the intersection with Asas Landing (see Figure 4-4). This site is in a residential neighborhood, located approximately 250 feet east and upgradient from Town Cove. Asas Landing is perpendicular to Gibson Road, and a PRB orientation along Gibson Road will allow for monitoring at several different locations and depths downgradient along Asas Landing. The Gibson Road location is only recommended as a follow-on demonstration to be implemented after the Eldredge Park and/or landfill locations, because Gibson Road is located closer to Town Cove with limited buffer distance, and information gathering at the other locations would be essential prior to implementation of a Demonstration Test at Gibson Road. This test location could support a full scale PRB oriented along Gibson Road, Ruggles Road, and Tonset Road along the east side of Town Cove. The locations of proposed injection points and monitoring wells are anticipated to be located on Town-owned land (in the road and/or associated right of way).

#### 4. Basis of Design

- a. Nitrogen loading from point and non-point sources is impacting surface water quality in Orleans and Cape Cod in general. A significant portion of this nitrogen load is transported to surface water via groundwater flow. PRBs can intercept and remove part of this nitrogen load from the groundwater system.

The basis for designing effective PRB demonstration tests and full scale PRBs is a Conceptual Site Model (CSM) for the problem. The CSM is an understanding of conditions based on information including sources of nitrogen in groundwater, migration pathways, transport mechanisms, and fate of nitrogen in groundwater. Most of the current understanding of the problem has been developed through assessments of land use and sources of nitrogen, local groundwater data from investigations associated with water supplies, regional groundwater hydrogeology studies, and assumptions based on groundwater geochemistry.

Individual on-site septic systems are used to manage about 85 percent of the wastewater flow from residences and businesses on Cape Cod (Cape Cod Commission, 2013). Many of these systems are simple leaching pits and cesspools installed decades ago. Septic systems that process wastewater flows up to 10,000 gallons per day are regulated under Title 5, the state's sanitary code for on-site wastewater systems (310 CMR 15.00). These systems are permitted by local Boards of Health and the MassDEP. Title 5 septic systems were designed to remove pathogens and not nutrients. Dissolved nitrogen from waste material travels through a septic tank and into leach fields down to groundwater. Bacterial reactions transform organic nitrogen to ammonia in the septic tank, and below and downgradient of the leach field, under aerobic conditions, the ammonia is converted by bacteria to nitrate. As a result, nitrate-laden groundwater emanating from septic systems travels as a plume without significant attenuation in groundwater to Cape Cod's coastal waters (Cape Cod Commission, 2013). Additional nitrate from lawn fertilizer and stormwater infiltration adds to the groundwater nitrogen load. Areas of more dense development will have multiple plumes that may merge to form a large dilute nitrate plume, transporting a significant nitrogen mass or nitrogen load toward downgradient surface waters.

Regional groundwater flow systems have been mapped for the Nauset, Pleasant Bay, and Cape Cod Bay watersheds in the Town of Orleans. These maps show watershed boundaries or divides that separate one flow system from the next and may include approximate groundwater elevation contours. Groundwater generally flows from the highest water table elevations in the watershed (e.g. approximately 26 feet above sea level in the Nauset Watershed) downgradient toward the receiving surface water body (e.g. Town Cove). In addition to flowing horizontally downgradient, groundwater may flow vertically, recharging deeper portions of the aquifer 100 to 150 feet or more below sea level. Water table elevations vary locally resulting in deviations in local groundwater flow direction. Groundwater velocity will vary depending on the local groundwater gradient and hydraulic conductivity of the aquifer material. The aquifer material may contain less permeable clay, silt or fine sand or higher permeability medium sand and gravel. The groundwater velocity may vary from less than 0.1 feet per day to more than 3 feet per day depending on local conditions.

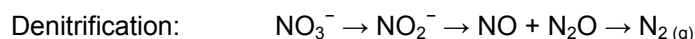
This CSM can be used to design PRB demonstration tests that will be representative of conditions over a wider area, ideally focused on a location with high nitrate flux through the PRB to prove the process, and provide key information for PRB design.

b. Hydrogeologic, Geochemical, and Nitrogen Data collection

- 1) AECOM is currently conducting hydrogeological investigations at representative sites in the Town to support the final design of the Demonstration Tests. Locations of monitoring wells sampled by AECOM are shown in Figures 4-1 through 4-4 and Figure 3-4 for the landfill. At each location, soil borings have been advanced to record soil classification with depth, and multi-level groundwater monitoring wells have been installed. Previously existing monitoring wells at selected locations are also being included in the investigation. Monitoring well locations will be surveyed for elevation and location, and the depth to groundwater will be measured and mapped to evaluate groundwater flow direction. Groundwater samples are being collected for laboratory analyses to assess groundwater quality related to PRB design and concentrations of nitrogen species. Each new well location has two or three discrete screened intervals to collect groundwater samples at different depths. Groundwater velocity at each site will be estimated using observed hydraulic gradient and soil conditions. Location and depth of the salt water interface will be identified where present within the investigated depth. Groundwater sampling results and related calculations will be available in March 2016.
- 2) The CSM is being updated through the current project with additional site specific investigations, gathering information on groundwater hydrogeology, geochemistry and actual nitrogen compound concentrations in groundwater within target watersheds, in particular the depth to groundwater, groundwater flow direction, groundwater flow rates, soil types, and vertical nitrate concentration profile.

c. PRB Treatment Process Description

- 1) PRBs are a passive treatment technology, designed in this application to intercept and treat nitrate in groundwater by biological denitrification before groundwater reaches downgradient surface waters. The PRB treatment zone is located in the groundwater saturated zone below the water table, where amendments are added to form the PRB. PRBs are typically oriented perpendicular to the direction of groundwater flow and rely on the natural groundwater gradient to carry the contaminant through the PRB (ITRC, 2011). The system is permeable because the amendments added do not interfere with groundwater flow, and nitrate is removed as groundwater passes through. A PRB would be most cost effective where groundwater transport of nitrogen is significant, with higher nitrate concentration and a relatively fast groundwater velocity, resulting in a high mass flux of nitrate through the treatment zone. It is this mass flux of nitrogen that contributes to nitrogen loading to downgradient surface waters.
- 2) As described in the Cape Cod Area Wide Water Quality Management Plan Update (Cape Cod Commission, 2015), PRBs are a non-traditional method for biologically mediated nitrate reduction or denitrification. This in-situ (in place in the ground) treatment method typically introduces a carbon food substrate into the groundwater, allowing naturally occurring microbes in the groundwater to consume the carbon substrate while respiring oxygen and creating anoxic conditions (without oxygen) favorable for denitrifying bacteria. Under anoxic or anaerobic conditions, maximum energy is gained by microbes using nitrate as an electron acceptor (denitrification reaction), followed by reduction of manganese, reduction of iron, and reduction of sulfate. Therefore, nitrate is the preferred electron acceptor to soil microbes after oxygen is consumed. This process of bacterial metabolism results in the conversion of nitrate to inert nitrogen gas and requires both anoxic conditions and sufficient food substrate for bacterial growth.



- 3) In-situ enhanced bioremediation via denitrification with PRBs has been implemented for treatment of nitrates in groundwater using various carbon substrate/electron donors, including using large scale PRBs (ITRC, 2011; Pinter, 2014). Recent sand column studies conducted with aquifer materials and groundwater from a Falmouth, Massachusetts site have shown very good nitrate removal performance using an organic carbon substrate for biostimulation (Terra Systems, 2016)). PRBs formed by the addition of a carbon substrate as an electron donor have also been applied at thousands of sites for treatment of chlorinated solvents. Naturally occurring bacteria that degrade these contaminants require sufficiently reducing conditions (sulfur-reducing and/or methanogenic conditions) to stimulate microbes to respire these compounds. In order to generate sufficiently reducing conditions, other competing electron acceptors (oxygen, nitrate, manganese, and sulfate) need to be consumed by other bacteria first. Therefore, at all successful enhanced bioremediation sites for chlorinated solvents, any nitrate in groundwater needs to be consumed via denitrification in order for anaerobic dechlorination reactions to occur. Nitrate concentrations in groundwater before and after application of emulsified vegetable oil at several AECOM sites are presented in Appendix B as examples.

## **5. Permitting**

The EPA Underground Injection Control (UIC) Program is responsible for regulating the construction, operation, permitting, and closure of injection wells that place fluids underground for storage and disposal. The UIC Program requirements were developed by EPA and designed to be adopted by states. The Massachusetts Department of Environmental Protection (MassDEP) UIC Program is defined in 310 CMR 27.00: Underground Injection Control Regulations and details the regulation of injection of fluids within Massachusetts.

To implement the Demonstration Test a UIC permit application (MassDEP form BRPWS 06) will be filed with MassDEP under the category "Aquifer Remediation." Similar injections of carbon substrates to enhance biodegradation of groundwater chemicals have been commonly implemented in Massachusetts, and many of these sites are exempt from the UIC registration process if the injections are conducted for waste site cleanup in accordance with the Massachusetts Contingency Plan (MCP, 310 CMR 40.0000) or similar federal statutes. In implementing the Demonstration Test all injections associated with the PRBs will comply with the requirements of the Massachusetts UIC regulations and the MCP requirements, including all required monitoring.

An example UIC permit is submitted alongside this work plan for the PRB Demonstration Test. The UIC permit application is included as Appendix C. A fee of \$585 for each site would be associated with filing the UIC permit. The UIC permit applications should be submitted at least 60 days in advance of the proposed PRB demonstration test start date.

## **6. Demonstration Test Design**

This section details the design components and critical assumptions for planning and implementing PRB Demonstration Tests.

### **a. Size of Demonstration Tests**

As described in Section 3, a prioritized list of two recommended PRB Demonstration Tests has been proposed. The proposed demonstration sites will generally each include one line of injection points spaced 10 feet apart. The approximate locations of the proposed PRBs are shown on Figure 3-3 and Figure 3-4 for Eldredge Park and the Landfill, respectively. Demonstration Test PRB lengths are as follows: (a) Eldredge Park 200 feet; and (b) Landfill Demonstration 50 feet.

If a Demonstration Test was to be implemented at the Gibson Road location (Site C), it is anticipated that this test would be approximately 100 feet in length. Future full-scale PRBs or sections or PRBs are anticipated to be longer (500 to 3000 feet, depending on the location); however, Demonstration Test locations are proposed to be shorter distances to assess construction/implementation and allow adequate monitoring of groundwater conditions in the vicinity of the PRBs for initial demonstration. For the Demonstration Test PRBs, a vertical treatment interval is anticipated from the top of the groundwater table to approximately 40 feet into the saturated soils. The total depth below land surface will also depend on the depth to groundwater at the location. Multi-level groundwater sampling events conducted on Cape Cod have identified bands of groundwater containing nitrate concentrations 25 to 40 feet thick (MT Environmental, 2015). The field groundwater investigation to be completed by AECOM in 2016 will provide appropriate data to more accurately define the necessary vertical treatment interval for the two proposed PRB locations.

b. Reactive Amendment Application Methods

PRBs have been designed and implemented through several construction methods, including backfilling an excavated trench with reactive media (using standard construction excavator), continuous trenching using one-pass trencher, drilling auger boreholes backfilled with reactive media, through injection for the application of reactive media, and electrochemical methods.

Various site-specific factors determine the method selected, including the depth and width of the PRB, the reactive media, quantity of reactive media, the site geology, and the surface/subsurface obstructions present (ITRC, 2011). The main options for construction are trench installations with wood mulch carbon substrate and injection (with or without permanent injection wells) of liquid organic carbon substrates such as emulsified vegetable oil. Table 6-1 provides the pros and cons of these construction methods.

**Table 6-1. Comparative Evaluation of Permeable Reactive Barrier Installation Methods**

<b>Conventional Excavator Installation - Mulch Permeable Reactive Barrier</b>	
<b>Advantages</b>	<b>Disadvantages</b>
<ul style="list-style-type: none"> <li>Mulch PRBs widely accepted groundwater treatment method and construction equipment readily available</li> </ul>	<ul style="list-style-type: none"> <li>Requires large construction equipment</li> </ul>
<ul style="list-style-type: none"> <li>Reactive media (mulch) has no potential to migrate</li> </ul>	<ul style="list-style-type: none"> <li>Requires soil handling and disposal plus area to stage soils</li> </ul>
<ul style="list-style-type: none"> <li>Treatment longevity of trench typically longer than injection-based methods</li> </ul>	<ul style="list-style-type: none"> <li>Reactive zone (residence time) limited to trench width (3-4 feet)</li> </ul>
	<ul style="list-style-type: none"> <li>Limited flexibility in alignment to accommodate above and below ground site features</li> </ul>
	<ul style="list-style-type: none"> <li>May lead to settling of ground surface over time</li> </ul>
	<ul style="list-style-type: none"> <li>Not suitable for placement in roadways due to settling</li> </ul>
	<ul style="list-style-type: none"> <li>Requires future rejuvenation (often by injection of emulsified vegetable oil), instead of by replacing the trench through excavation)</li> </ul>

	<ul style="list-style-type: none"> <li>• Limited to depth of 20 feet below surface, which would require placing PRB in proximity to surface water.</li> <li>❖ Not likely to reach target depths for treatment</li> <li>❖ PRB trench may not treat entire vertical zone required</li> <li>❖ Challenge to permit project adjacent to surface water</li> <li>❖ A PRB located very close to surface water resource would not provide sufficient downgradient travel time for stabilization of groundwater chemistry before groundwater discharge to the surface water (i.e., iron staining at surface water)</li> </ul>
<b>Injection – Food-grade carbon substrate</b>	
<b>Advantages</b>	<b>Disadvantages</b>
<ul style="list-style-type: none"> <li>• Locations of PRBs is flexible and can be located upgradient away from environmental resource areas.</li> </ul>	<ul style="list-style-type: none"> <li>• Liquid amendments can be transported short distances/diluted by groundwater flow (requires verification of stability).</li> </ul>
<ul style="list-style-type: none"> <li>• Carbon substrate injections widely accepted groundwater treatment method and equipment readily available.</li> </ul>	<ul style="list-style-type: none"> <li>• Injection PRBs likely would require replenishment sooner than trenches.</li> </ul>
<ul style="list-style-type: none"> <li>• Small equipment footprint (small drill rig, all pumps and mixing tanks contained to box truck/trailer.</li> </ul>	
<ul style="list-style-type: none"> <li>• Can be installed under roadways.</li> </ul>	
<ul style="list-style-type: none"> <li>• Limited impacts to traffic and abutters.</li> </ul>	
<ul style="list-style-type: none"> <li>• Orientation can be adjusted in the field to accommodate above and below ground site features (utilities, curbs, trees, overhead power lines).</li> </ul>	
<ul style="list-style-type: none"> <li>• Injection can generate a wider treatment zone (more residence time) than a trench filled with solid reactive media.</li> </ul>	
<ul style="list-style-type: none"> <li>• Application not limited by depth (for anticipated depths in Orleans).</li> </ul>	
<ul style="list-style-type: none"> <li>• Shorter field construction time than trenching.</li> </ul>	
<ul style="list-style-type: none"> <li>• Injection method can be pilot-tested at small scale cost-effectively.</li> </ul>	

Based on numerous disadvantages and potentially unacceptable environmental impacts, trench installation was considered and ruled out for PRB demonstrations in Orleans due to limited feasibility and prohibitive siting requirements. Due to shallow installation depth, trench-based PRBs would need to be located very close to surface water in resource areas, causing potential damage to natural resources and increasing permitting requirements and cost. Installation of trenches may cause significant disruption, and abutter concerns may be significant. In addition, trench locations would not provide sufficient downgradient travel time for stabilization of groundwater chemistry before groundwater discharge to the surface water. The most likely design will use soil borings for injection of slow-release organic carbon electron donor substrates, such as food-grade emulsified soy bean oil, to create a passive PRB capable of stimulating denitrifying bacteria to remove nitrate. These soil boring PRB installations would be located upgradient away from resource areas and could be installed with minimal impacts. Soil boring installation does not require permanent well covers at the surface that may be unacceptable in roadways. This concept was carried through in consideration of all potential PRB demonstration sites.

For the Demonstration Tests, PRBs are anticipated to be constructed through injection of reactive amendments to stimulate biological denitrification. Injected PRBs consist of a number of injection points arrayed perpendicular to groundwater flow and oriented in a configuration to establish a continuous zone of reactive media across a targeted width and vertical groundwater interval. Use of injection is proposed based on depths of treatment, anticipated locations of PRBs in/near roads and in residential or commercial zones, and known aboveground and subsurface utilities. Injection PRBs can be installed with small drill rig(s) and a truck or trailer with mixing tanks and pumps. Standard construction equipment would not be capable of reaching targeted depths (greater than 30 feet below grade), and one-pass trenchers are significantly more expensive than all other proposed methods. Excavation equipment and/or one-pass trenchers would be very disruptive to adjacent properties and traffic flow. Trenching alternatives are anticipated to have a longer field installation period than injection, and equipment for trenching methods requires a larger footprint (for both operations and equipment staging) than injection during operations. In addition, the trenching options would generate a significant volume of soil that would need to be disposed of off-site and would likely also require an area for stockpile staging. Injection points can also be adjusted in the field to accommodate above and below ground site features (utilities, curbs, trees, overhead power lines). Additional details on delivery of reactive media through injection are presented below.

c. PRB Demonstration Test Amendments and Systems

As discussed above there are various carbon sources that are available to be used as reactive media or electron donors. Solid substrates can be placed in augured boreholes. Substrates delivered as a liquid solution are most commonly injected.

Liquid solutions are anticipated for use for the Demonstration Test. Several proprietary and non-proprietary reductive amendments have been applied for enhancing anaerobic biodegradation in groundwater. Example amendments include water soluble substrates (e.g., lactate, molasses) and slow release substrates like emulsified vegetable oil (EVO).

For the PRB Demonstration Test, EVO is the recommended amendment based on the need to optimize PRB longevity. EVO contains only non-toxic, food grade materials, primarily soybeans, and is widely used in enhanced bioremediation for chlorinated solvents (as noted above). EVO is typically mixed with water to create an emulsion and allow for more effective distribution. After injection, EVO is relatively immobile in the subsurface and relies on the slow release of soluble compounds that are distributed by advection, dispersion, and diffusion in groundwater. EVO is typically present in the subsurface for two to five years based on AECOM and remediation industry experience, allowing biodegradation reactions to persist for an extended period of time (AFCEE, 2004). Commercially available, remediation-grade EVO generally contains approximately five percent food-grade sodium lactate as a rapidly biodegradable substrate to initiate generation of anaerobic conditions as well as Vitamin B12 Supplement that provides additional nutrients to further enhance microbial activity and the rate of denitrification.

Subsurface geology on Cape Cod consists of relatively permeable sandy formations with high groundwater flow velocities (1 to 3 feet per day). For injection of EVO into aquifers with higher groundwater flow rates, an EVO solution with a larger droplet size is recommended such that the EVO droplets will adhere to sand grains in the formation to minimize the advection of EVO after injection. A larger droplet size will also maximize the persistence of the carbon substrate within the PRB. It is anticipated that a site-specific modified EVO formulation will be used for this application, including but not limited to droplet size, vitamin supplements, and other minor components (for example, surfactants). Product information, including the Material Safety Data Sheets (MSDS) for proposed EVO substrate is presented in Appendix D.

For in-situ remediation technologies, delivery of an appropriate amount of injected amendments is a primary factor to achieving successful treatment. Sufficient carbon substrate/electron donor must be applied to establish reducing conditions in the PRB. Calculations supporting amendment dosages are presented in Appendix E. The Substrate Estimating Tool for Enhanced Anaerobic Bioremediation of Chlorinated Solvents developed for the Environmental Security Technology Certification Program (ESTCP) was used to support EVO quantities for the PRB Demonstration Tests. This tool estimates quantities of various carbon substrates to provide sufficient amendment for the sum of electron donor demand from electron acceptors (dissolved oxygen, nitrate, and sulfate) as well as dissolved volatile organic compounds if present. For the Demonstration Tests sites, the EVO dosages were determined primarily to meet the electron donor demand based on typical conditions on Cape Cod including expected nitrate concentrations. The ESTCP EVO dosage calculations will be revised, if necessary, based on groundwater sampling to be performed by AECOM in 2016. Anticipated quantities of EVO for the Demonstration Test are summarized in Table 6-2 based on the calculations provided in Appendix E.

The metabolism of added carbon substrate by soil microbes can result in a decrease in groundwater pH, and a neutralization agent (i.e., sodium bicarbonate) is sometimes injected with the carbon substrate to counteract changes in pH. In addition, groundwater pH has been observed to be between pH 5.5 and pH 6 across Cape Cod. Denitrifying bacteria are most active in circumneutral groundwater (pH 6 to 8), and sodium bicarbonate or other pH buffer could be considered based on pH conditions noted in the groundwater sampling to be conducted by AECOM in 2016.

**Table 6-2. Summary of Design Parameters for Permeable Reactive Barrier Demonstration Tests**

Parameter	Site B	Site E
Area Description	Parking lot between the playing fields off Eldredge Parkway	Town Landfill near Gift Shop
Depth to Ground Water	30-40 feet below grade	45-55 feet below grade
Demonstration Test PRB Length	200 feet	50 feet
Preliminary Target Treatment Thickness	40 feet	40 feet
Injection Point Spacing	10 feet	10 feet
Injection Points	20	5
Injection Target Pore Volume	6%	6%
Total Injection Volume (gal)	9,000	2,250
Injection Volume Per Point (gal)	450	450
Nitrate Concentration (mg/L)	5 - 15 mg/L	10 - 30 mg/L

d. Substrate Delivery

Injection of carbon substrates can be performed through semi-permanent PVC wells or directly through direct-push (i.e., GeoProbe®) rods. Advantages of semi-permanent wells are that future, follow-up injections can be completed without additional drilling activity, and the wells can be used as additional data collection points. Advantages of direct-push injections are that there is no well construction required so there is no added cost for well installation, maintenance, and abandonment. For the Demonstration Tests, the EVO will be injected into the subsurface using direct-push tooling. Advantages for the direct push injection method include:

- 1) Eliminates the need for installing and maintaining wells at proposed injection points that will be located in the road and other areas with vehicle traffic (i.e., parking lot). Such wells would be subject to damage from plows and other vehicles. Follow-up injection is not anticipated for the near-future based on the active lifetime of the selected EVO substrate (three to five years or more);
- 2) Avoids biological fouling (biofilm accumulation) problems in EVO injection wells that are not used for extended periods of time (maintaining wells and/or re-developing wells would be required prior to a future injection);
- 3) Avoids costs and effort associated with installing injection wells, including but not limited to drilling time and costs, elimination of soils for handling and disposal, and reduction of engineering oversight effort;

- 4) Reduces on-site construction time by not installing injection wells that would be disruptive to parcels of land used for the Demonstration Testing;
- 5) Costs associated with remobilization of direct-push injection equipment are relatively small compared to well maintenance costs; and
- 6) Injection amendment can be emplaced throughout a relatively deep interval in one direct push borehole.

Geological limitations observed during the Demonstration Test would be noted and could be rationale for incorporating injection wells for future/full-scale treatment. Injections to the groundwater will be performed using a regular-spaced line of injection points. Spacing of injection points will be approximately 10 feet, but actual spacing may vary in the field due to adjustments for surface and subsurface features. Injection using a row of closely spaced points is intended to establish a continuous barrier length to minimize potential for groundwater to flow through gaps in the reactive zone. Closely-spaced points reduces the injection volume of EVO at each point as well as the distribution of the EVO in the subsurface, which is intended to prolong the persistence of the EVO after injection. In addition, lateral dispersivity (an estimated measure of how particles flowing in groundwater stray to the sides from predominant groundwater flow direction) is generally low on Cape Cod. Therefore EVO and associated organic carbon and generated reducing conditions are expected to flow in a straight line and not spread out as groundwater flows from the injection point. Injection points will be offset at least five feet from known underground utilities (10 feet from water mains) or monitoring wells to minimize damage to utilities during drilling and to reduce the potential that the injected amendment does not short circuit through the utility conduits or well sand packs. Overhead utilities will also factor into the final location due to the safety concerns posed by the lines during injection point installation.

e. Application Dosage and Volume

Delivery of amendments is a primary factor to achieving a successful in-situ treatment. The main design considerations include test volume, soil porosity and grain size analysis, groundwater velocity, and amendment characteristics. Based on AECOM experience on other enhanced bioremediation projects, carbon substrate solutions will be injected at volumes equivalent to approximately five to fifteen percent of the pore volume in the Demonstration Test treatment areas (injection volume calculations provided in Appendix E). This volume is sufficient to generate reducing conditions favorable for denitrifying bacteria, not cause significant mounding during injections, and allow additional distribution of dissolved organic carbon and anaerobic conditions over the active lifetime of the EVO. In addition, it is preferred to limit the lateral distribution of the injected emulsion, and this is considered in the injection volume target. Based on this injection volume range, and the estimated total mass of EVO specified in Appendix E, EVO solutions shipped to the site (typically 60% EVO by weight in 260 gallon totes) will be diluted with water to the desired dosage to attain both the carbon loading and injection volume objectives.

f. Health and Safety and Site Security

A site-specific health and safety plan (HASP) will be prepared for the Demonstration Test to address safety precautions related to storage and handling the selected amendments, pressurized injection, and heavy equipment operation. In addition, the HASP will identify chemicals to be brought to the Site for use for groundwater treatment. The drilling/injection subcontractor will be required to prepare their own site-specific HASP to be furnished to the Engineer. The subcontractor's HASP will include a spill prevention and response plan to detail precaution and response measures. In addition, AECOM will prepare and submit a site-specific HASP for its staff providing oversight and other site visitors.

Appropriate security measures will be erected (temporary chain-link fence, lockable conex box, and/or similar) for the periods of field activities (drilling, injections) to prevent trespassing and vandalism. For site workers, exclusion zones will be established using caution tape, cones, and/or jersey barriers around the bulk storage area, the dilution and batching area, and active injection points. All workers near active injections will be required to wear appropriate personal protective equipment, including but not limited to eye-protection and high visibility vests. Traffic cones will be used to protect workers from traffic. Police detail will be required when working within high-traffic areas.

Prior to commencing any drilling or direct-push activities, Dig Safe notifications, and additional underground utility clearance will be conducted, if necessary. All known subsurface utilities will be fully marked with paint, flagging, and/or cones. Utility maps will be consulted and additional private underground utility mark out and/or clearance will be conducted, if necessary. To prevent damage to subsurface utilities pre-clearing will be performed to a depth of at least five feet for all boreholes, with the pre-cleared hole to have a diameter larger than the driller's subsurface equipment.

g. Field Injection Activities

Two phases of injection are proposed for completion of the Demonstration Test. An initial injection test would be performed using a small number of injection points at the test sites (one to five injection points). The injection test will evaluate field implementation and observations, including range of observed injection flow rates, observed injection pressures and EVO dilution rates and associated handling. Monitoring wells in proximity to the preliminary injection test points will be observed to measure how far EVO emulsion travels downgradient and crossgradient as a result of injection. Based on the results of the initial injection test, the design and implementation plan for the larger (more EVO application points) Demonstration Test will be adjusted. This monitoring and additional monitoring over time will be used to confirm the EVO is stable after injection. A description of how the field injection activities are anticipated to be conducted is provided below.

The EVO amendment will be shipped to the site as a liquid and will be stored in drums, totes, or other vendor supplied containers. The EVO containers will be stored inside a storage container or other protective structure.

An injection system for preparation, mixing, and injection of substrate solutions will consist of mixing tanks, mixers, pumps, piping, meters, valves, and fittings. All components will be selected from materials that are compatible for use with the selected amendments. Injection batches would be prepared by adding appropriate quantities of water to achieve the selected dilution concentration. It is anticipated that no hard pipe or trenching will be used between the solution mixing station and the injection point, and that mobile above-ground, hoses will be used to convey remedial solutions directly to the injection points. A manifold would likely be employed to inject into multiple injection wells simultaneously. Flow totalizers, pressure gauges, and shut-off valves will be included on each active injection leg connected to an injection point to monitor injection pressure, flow rates, and total volume added to each point. All systems would be leak-checked daily prior to injection by pressurizing the system with water to prevent spills from the injection system.

At each injection point, a direct-push drill rig will advance injection tooling to a targeted depth. Injection tooling can consist of a specialized injection tip, a screened interval, or similar device. A pre-determined volume will be injected at a targeted depth (or discrete depth interval), and then the injection tip will be advanced to the subsequent injection target depth (generally two to four feet deeper), and the process is repeated. This method of direct-push injection is referred to as top-down injection; however, tooling to inject from deepest depth upward (bottom-up) will also be

mobilized, as the method that works best varies by site. To the extent practical, injections of EVO will be performed at low pressures (less than 10 pounds per square inch [PSI]); however, higher injection pressures may be required for injecting at deeper depths proposed for the PRBs. Based on AECOM in-situ remediation experience with the selected amendments and working in similar soil types, it is estimated that the injection flow rates will range from 2 to 5 gallons per minute at each point. To minimize mounding and improve delivery, injection will generally not be performed at adjacent points at the same time. A field log will be maintained to record the solution composition, the volume of solution delivered into each injection well, the length of time required for injection, and the injection pressure.

Electricity to power remediation equipment may be provided by a gasoline-powered generator. Potable water for batching and injection may be provided by tanker truck or from a nearby hydrant. Prior to commencing injections the potable water source will be identified, and laboratory analysis may be performed for nitrates.

## **7. PRB Demonstration Test Performance Monitoring**

Performance monitoring of the PRB Demonstration Test will be performed to assess nitrate transformation, concentrations of other key indicators, and the distribution of the injected reagents. This section details the performance monitoring program.

- a. Groundwater samples will be collected from both existing monitoring wells (installed for initial characterization) and additional monitoring wells to be installed prior to installation of the Demonstration Test PRB. The monitoring well network for Demonstration Test performance monitoring is presented on Figure 7-1 and Figure 7-2 for the Eldredge Park and landfill PRBs, respectively. The monitoring well network for Demonstration Test sites includes monitoring wells upgradient and downgradient of the PRB to evaluate changes to nitrate and groundwater quality based on PRB performance. Monitoring wells downgradient of the PRB will be located at various distances away from the PRB to assess distance of emulsion travel, extent of reducing conditions for denitrification away from the PRB, potential for metals mobilization, and groundwater flow velocity. Monitoring wells cross-gradient of the PRBs will also be included, and hydraulic conductivity will be estimated in the cross-gradient and select downgradient monitoring wells to evaluate if there is any observed reduction in aquifer permeability as a result of the injection of EVO.

All performance monitoring wells will be constructed of two-inch schedule-40 PVC, with proposed screened intervals as shown on Table 7-1 and Table 7-2. New monitoring wells are anticipated to be installed using direct-push drill rigs, as this method was used to install monitoring wells near the PRB locations for characterization and was determined to be a cost-effective means of installing wells for collecting representative groundwater samples.

- b. Sampling Method, Frequency, and Analyses

Groundwater samples will be collected using a peristaltic pump, bladder pump or whale pump. Groundwater quality parameters will be measured in the field (pH, oxidation reduction potential (ORP), dissolved oxygen (DO), specific conductivity, temperature, turbidity), with particular attention to ORP (mV) and DO (mg/L) which will be used to evaluate the generation and distribution of reducing conditions. Samples will be collected after field water quality parameters stabilize, or after 30 minutes of purging if parameters do not stabilize sooner.

Groundwater samples will be collected prior to initiation of in-situ treatment to provide a comparative baseline to evaluate performance of the Demonstration Test. Baseline groundwater samples will be analyzed to determine pre-treatment concentrations of nitrate and other indicator parameters whose change will be indicative of the impact of Demonstration Test treatment processes.

The wells anticipated to be sampled as part of PRB Demonstration at the Landfill and Eldredge Park are presented on Table 7-1 and Table 7-2, respectively. In addition, a synoptic water level event will be conducted after additional monitoring wells are installed but prior to the start of Demonstration Test injections to further assess groundwater direction and gradient. The first baseline sampling event would be completed prior to the initial injection test.

Following completion of injections for the full Demonstration Tests, it is anticipated that groundwater sampling would be performed quarterly for a period of three years. Primary objectives of the post-injection sampling will be to:

- 1) Demonstrate reduction in nitrate concentrations in groundwater in monitoring wells compared to baseline samples and/or wells upgradient of the PRB;
- 2) Identify distance traveled by EVO emulsion;
- 3) Identify extent of generated reducing conditions;
- 4) Evaluate potential for reduction in aquifer permeability as a result of EVO application;
- 5) Evaluate persistence of EVO emulsion and anaerobic conditions favorable for denitrifying bacteria after PRB installation; and
- 6) Assess changes in groundwater monitoring parameters as a result of the PRB.

As a result of the generation of reducing conditions in groundwater, temporary mobilization of some metals native to the aquifer material may result. Laboratory analysis of select metals will be conducted as part of performance monitoring in select wells. Table 7-3 presents the monitoring parameters for the Demonstration Test performance monitoring. An overview of the Demonstration Test performance monitoring analyses and relevant to the PRB Demonstration Test sampling is shown below.

**Table 7-3 Summary of Analyses for Groundwater Performance Evaluation**

<b>Parameter</b>	<b>Relevance to PRB Demonstration Test</b>
Nitrate	Primary groundwater compound targeted for treatment.
Nitrite	Intermediate nitrogen species from the aerobic nitrification of ammonia to nitrate.
Ammonia	Reduced inorganic nitrogen species that occurs in proximity of leach fields and landfills.
Total Nitrogen	Analyses provides a summation of all organic and inorganic nitrogen species in groundwater as a result of leachfields and landfill.
CENSUS-DNA (Denitrifying Bacteria)	Analyses quantify relative abundance of denitrifying bacteria.
Metals (Fe, Mn, As)	Mobility of metals can be impacted by groundwater geochemistry changes, notably pH and ORP.
DOC	DOC
Sulfate	Sulfate will decrease with generation of sufficiently anaerobic conditions favorable for sulfate-reducing bacteria.
pH	Denitrification optimal pH (6.0 and 8.5). Groundwater pH can decrease as a result of fermentation of injected carbon substrates.
ORP	ORP will decrease with generation of reducing conditions following injection of carbon substrate.
Chloride	Chloride concentrations are higher in salt water, and higher concentrations would indicate influence of salt water intrusion.
Alkalinity	Denitrification reactions generate alkalinity (3.57 mg of CaCO <sub>3</sub> for each mg of nitrate reduced).
Boron	Boron is present in laundry detergents and is an indicator of groundwater flow emanating from leachfields.

**8. Schedule and Coordination**

This section presents a summary of the sequence of the major activities to be conducted as part of the PRB Demonstration Test.

- a. Baseline Groundwater Monitoring - Additional monitoring wells, as described in Section 7, will be installed. Monitoring wells will be surveyed, and groundwater elevations will be measured. One round of sampling for groundwater collection will be performed with samples sent to a laboratory for analysis of parameters identified in Section 7. Well installation is anticipated to be completed in approximately two weeks. Groundwater well sampling will be completed in one to two weeks.
- b. Initial Injection Test - Injections of EVO will be conducted at a small number of injection points at one or both of the two proposed sites (Eldredge Park and/or landfill). Injection tests will be conducted over approximately one week. Groundwater monitoring will be conducted for approximately four to six weeks following the initial injection.

- c. Final Design - Based on the results of the baseline groundwater monitoring and observations of the initial injection test the 100 percent design document for the Demonstration Test PRBs will be completed. It is anticipated that the final design will be completed three to four months after the initial injection test based on site-specific observations and if any major process changes are required from preliminary design.
- d. Demonstration Test Injection - Drilling and injection subcontractor(s) will mobilize for implementing the injections for the Demonstration Test PRBs. It is anticipated that field work will occur over a period of one to two months based on AECOM experience injection on similar sites.
- e. Demonstration Test Performance Monitoring - Following injection groundwater sampling to evaluate performance of the PRBs will be conducted. It is recommended to collect quarterly samples for a period of three years. Periodic reporting would be conducted to share results and observations with the Town, regulatory agencies, and the public.
- f. Subcontractors - Multiple subcontractors will be required to implement the PRB Demonstration Test including:
  - 1) Environmental Drilling – Drilling subcontractor(s) would install monitoring well and be utilized for direct-push drilling to support the injection of EVO;
  - 2) Injection Subcontractor – This subcontractor will be tasked with handling, batching, and injecting EVO solutions into injection points per the design. The injection subcontractor may provide their own rigs for direct-push injection and/or may be the same firm as the drilling subcontractor;
  - 3) Environmental Analytical Laboratory – A laboratory will be procured to complete all proposed chemical analysis of groundwater samples supporting the Demonstration Test; and
  - 4) Reactive amendments (EVO) – The reactive amendments would be procured for the PRB Demonstration Test. The amendments can be procured by the injection subcontractor, the Engineer, or directly by the Town.

## **9. Waste Disposal**

- a. Demonstration Test field activities are anticipated to generate wastes requiring disposal, including purge water from monitoring well sampling, soil cuttings from well installation, and other wastes generated by PRB installation activities.
- b. Well installation may generate soil cuttings. These cuttings will be placed into 55 gallon drums or a roll-off container. Each container will be labeled with the date of soil collection and the well bore hole where the cuttings were collected from. Soil samples will be collected for waste characterization, following which the soil will be disposed of at an approved disposal facility.
- c. PRB Demonstration Test derived waste may consist of empty totes, empty bags, pallets, personal protective equipment, and miscellaneous trash. The empty totes/drums will be shipped back to the EVO manufacturer for re-use if possible. Other Demonstration Test derived waste can be disposed of as municipal trash.

## **10. Cost Estimate**

To Be Added

**11. References**

Ahmad, F., McGuire, T.M., Lee, R.S., Becvar, E. - Considerations for the Design of Organic Mulch Permeable Reactive Barriers. Remediation, Winter 2007

Cape Cod Commission - Cape Code Regional Wastewater Management Plan Technology Assessment – Conventional Infrastructure, March 2013.

Cape Cod Commission - Cape Cod Area Wide Water Quality Management Plan Update, June 2015.

Interstate Technology & Regulatory Council (ITRC) - Permeable Reactive Barrier: Technology Update (PRB-5), November 2011

Pinter and Associates (Pinter) - Groundwater Denitrification Using a Permeable Reactive Barrier. Canadian Consulting Engineering Awards, 2014  
[http://www2.canadianconsultingengineer.com/awards/pdfs/2014/D2\\_GroundwaterDenitrificationBarrier.pdf](http://www2.canadianconsultingengineer.com/awards/pdfs/2014/D2_GroundwaterDenitrificationBarrier.pdf)

Terra Systems - Personal communications with Michael Lee, PhD, 2016

## Tables

**TABLE 7-1  
Non-Traditional Technologies - Permeable Reactive Barriers  
Demonstration Test - Groundwater Sample Locations, Analyses, and Rationale**

Monitoring Well ID/ Location	Depth to Water <sup>1</sup> (feet bgs)	Monitoring Well Screened Interval <sup>2</sup> (feet bgs)	Baseline Groundwater Analyses	Post-PRB (0.5 months)	Post-PRB (quarterly sampling for 3 years)	Rationale
<b>Demonstration Test 2 - 200-foot Permeable Reactive Barrier Installed Near Eldredge Park (Site B)</b>						
MW-BU2-C	20	20 - 30	Total Nitrogen, Ammonia Nitrogen, Nitrate Nitrogen, Nitrite Nitrogen, Dissolved Metals, Sulfate, Dissolved Organic Carbon, Methane	--	Total Nitrogen, Ammonia Nitrogen, Nitrate Nitrogen, Nitrite Nitrogen, Dissolved Metals, Sulfate, Dissolved Organic Carbon, Methane	Two multi-level monitoring well points with three screened intervals each. These sampling points will represent the upgradient conditions for the PRB Demonstration Test
MW-BU2-B	20	30 - 40	Total Nitrogen, Ammonia Nitrogen, Nitrate Nitrogen, Nitrite Nitrogen, Dissolved Metals, Sulfate, Dissolved Organic Carbon, Methane	--	Total Nitrogen, Ammonia Nitrogen, Nitrate Nitrogen, Nitrite Nitrogen, Dissolved Metals, Sulfate, Dissolved Organic Carbon, Methane	
MW-BU2-A	20	40 - 50	Total Nitrogen, Ammonia Nitrogen, Nitrate Nitrogen, Nitrite Nitrogen, Dissolved Metals, Sulfate, Dissolved Organic Carbon, Methane	--	Total Nitrogen, Ammonia Nitrogen, Nitrate Nitrogen, Nitrite Nitrogen, Dissolved Metals, Sulfate, Dissolved Organic Carbon, Methane	
MW-BU1-C	20	20 - 30	Total Nitrogen, Ammonia Nitrogen, Nitrate Nitrogen, Nitrite Nitrogen, Dissolved Metals, Sulfate, Dissolved Organic Carbon, Methane	--	Total Nitrogen, Ammonia Nitrogen, Nitrate Nitrogen, Nitrite Nitrogen, Dissolved Metals, Sulfate, Dissolved Organic Carbon, Methane	
MW-BU1-B	20	30 - 40	Total Nitrogen, Ammonia Nitrogen, Nitrate Nitrogen, Nitrite Nitrogen, Dissolved Metals, Sulfate, Dissolved Organic Carbon, Methane	--	Total Nitrogen, Ammonia Nitrogen, Nitrate Nitrogen, Nitrite Nitrogen, Dissolved Metals, Sulfate, Dissolved Organic Carbon, Methane	
MW-BU1-A	20	40 - 50	Total Nitrogen, Ammonia Nitrogen, Nitrate Nitrogen, Nitrite Nitrogen, Dissolved Metals, Sulfate, Dissolved Organic Carbon, Methane	--	Total Nitrogen, Ammonia Nitrogen, Nitrate Nitrogen, Nitrite Nitrogen, Dissolved Metals, Sulfate, Dissolved Organic Carbon, Methane	
MW-B1010-C	20	20 - 30	Total Nitrogen, Ammonia Nitrogen, Nitrate Nitrogen, Nitrite Nitrogen, Dissolved Metals, Sulfate, Dissolved Organic Carbon, Methane	Total Nitrogen, Nitrate Nitrogen, Dissolved Organic Carbon	Total Nitrogen, Ammonia Nitrogen, Nitrate Nitrogen, Nitrite Nitrogen, Dissolved Metals, Sulfate, Dissolved Organic Carbon, Methane	Three multi-level monitoring well points with three screened intervals will be monitored approximately 10 feet downgradient of the PRB. These sampling points will assess groundwater and nitrogen treatment immediately downgradient of the PRB, migration of carbon substrate (EVO), and evaluate distribution of dissolved organic carbon and denitrifying conditions
MW-B1010-B	20	30 - 40	Total Nitrogen, Ammonia Nitrogen, Nitrate Nitrogen, Nitrite Nitrogen, Dissolved Metals, Sulfate, Dissolved Organic Carbon, Methane	Total Nitrogen, Nitrate Nitrogen, Dissolved Organic Carbon	Total Nitrogen, Ammonia Nitrogen, Nitrate Nitrogen, Nitrite Nitrogen, Dissolved Metals, Sulfate, Dissolved Organic Carbon, Methane	
MW-B1010-A	20	40 - 50	Total Nitrogen, Ammonia Nitrogen, Nitrate Nitrogen, Nitrite Nitrogen, Dissolved Metals, Sulfate, Dissolved Organic Carbon, Methane	Total Nitrogen, Nitrate Nitrogen, Dissolved Organic Carbon	Total Nitrogen, Ammonia Nitrogen, Nitrate Nitrogen, Nitrite Nitrogen, Dissolved Metals, Sulfate, Dissolved Organic Carbon, Methane	
MW-B2010-C	20	20 - 30	Total Nitrogen, Ammonia Nitrogen, Nitrate Nitrogen, Nitrite Nitrogen, Dissolved Metals, Sulfate, Dissolved Organic Carbon, Methane	Total Nitrogen, Nitrate Nitrogen, Dissolved Organic Carbon	Total Nitrogen, Ammonia Nitrogen, Nitrate Nitrogen, Nitrite Nitrogen, Dissolved Metals, Sulfate, Dissolved Organic Carbon, Methane	
MW-B2010-B	20	30 - 40	Total Nitrogen, Ammonia Nitrogen, Nitrate Nitrogen, Nitrite Nitrogen, Dissolved Metals, Sulfate, Dissolved Organic Carbon, Methane	Total Nitrogen, Nitrate Nitrogen, Dissolved Organic Carbon	Total Nitrogen, Ammonia Nitrogen, Nitrate Nitrogen, Nitrite Nitrogen, Dissolved Metals, Sulfate, Dissolved Organic Carbon, Methane	
MW-B2010-A	20	40 - 50	Total Nitrogen, Ammonia Nitrogen, Nitrate Nitrogen, Nitrite Nitrogen, Dissolved Metals, Sulfate, Dissolved Organic Carbon, Methane	Total Nitrogen, Nitrate Nitrogen, Dissolved Organic Carbon	Total Nitrogen, Ammonia Nitrogen, Nitrate Nitrogen, Nitrite Nitrogen, Dissolved Metals, Sulfate, Dissolved Organic Carbon, Methane	
MW-B3010-C	20	20 - 30	Total Nitrogen, Ammonia Nitrogen, Nitrate Nitrogen, Nitrite Nitrogen, Dissolved Metals, Sulfate, Dissolved Organic Carbon, Methane	Total Nitrogen, Nitrate Nitrogen, Dissolved Organic Carbon	Total Nitrogen, Ammonia Nitrogen, Nitrate Nitrogen, Nitrite Nitrogen, Dissolved Metals, Sulfate, Dissolved Organic Carbon, Methane	
MW-B3010-B	20	30 - 40	Total Nitrogen, Ammonia Nitrogen, Nitrate Nitrogen, Nitrite Nitrogen, Dissolved Metals, Sulfate, Dissolved Organic Carbon, Methane	Total Nitrogen, Nitrate Nitrogen, Dissolved Organic Carbon	Total Nitrogen, Ammonia Nitrogen, Nitrate Nitrogen, Nitrite Nitrogen, Dissolved Metals, Sulfate, Dissolved Organic Carbon, Methane	
MW-B3010-A	20	40 - 50	Total Nitrogen, Ammonia Nitrogen, Nitrate Nitrogen, Nitrite Nitrogen, Dissolved Metals, Sulfate, Dissolved Organic Carbon, Methane	Total Nitrogen, Nitrate Nitrogen, Dissolved Organic Carbon	Total Nitrogen, Ammonia Nitrogen, Nitrate Nitrogen, Nitrite Nitrogen, Dissolved Metals, Sulfate, Dissolved Organic Carbon, Methane	



**TABLE 7-1**  
**Non-Traditional Technologies - Permeable Reactive Barriers**  
**Demonstration Test - Groundwater Sample Locations, Analyses, and Rationale**

Monitoring Well ID/ Location	Depth to Water <sup>1</sup> (feet bgs)	Monitoring Well Screened Interval <sup>2</sup> (feet bgs)	Baseline Groundwater Analyses	Post-PRB (0.5 months)	Post-PRB (quarterly sampling for 3 years)	Rationale
MW-B1100-C	20	20 - 30	Total Nitrogen, Ammonia Nitrogen, Nitrate Nitrogen, Nitrite Nitrogen, Dissolved Metals, Sulfate, Dissolved Organic Carbon, Methane	--	Total Nitrogen, Ammonia Nitrogen, Nitrate Nitrogen, Nitrite Nitrogen, Dissolved Metals, Sulfate, Dissolved Organic Carbon, Methane	Three multi-level monitoring well points with three screened intervals will be monitored approximately 100 feet downgradient of the PRB. These sampling points will assess groundwater and nitrogen treatment immediately downgradient of the PRB, migration of carbon substrate (EVO), and evaluate distribution of dissolved organic carbon and denitrifying conditions
MW-B1100-B	20	30 - 40	Total Nitrogen, Ammonia Nitrogen, Nitrate Nitrogen, Nitrite Nitrogen, Dissolved Metals, Sulfate, Dissolved Organic Carbon, Methane	--	Total Nitrogen, Ammonia Nitrogen, Nitrate Nitrogen, Nitrite Nitrogen, Dissolved Metals, Sulfate, Dissolved Organic Carbon, Methane	
MW-B1100-A	20	40 - 50	Total Nitrogen, Ammonia Nitrogen, Nitrate Nitrogen, Nitrite Nitrogen, Dissolved Metals, Sulfate, Dissolved Organic Carbon, Methane	--	Total Nitrogen, Ammonia Nitrogen, Nitrate Nitrogen, Nitrite Nitrogen, Dissolved Metals, Sulfate, Dissolved Organic Carbon, Methane	
MW-B2100-C	20	20 - 30	Total Nitrogen, Ammonia Nitrogen, Nitrate Nitrogen, Nitrite Nitrogen, Dissolved Metals, Sulfate, Dissolved Organic Carbon, Methane	--	Total Nitrogen, Ammonia Nitrogen, Nitrate Nitrogen, Nitrite Nitrogen, Dissolved Metals, Sulfate, Dissolved Organic Carbon, Methane	
MW-B2100-B	20	30 - 40	Total Nitrogen, Ammonia Nitrogen, Nitrate Nitrogen, Nitrite Nitrogen, Dissolved Metals, Sulfate, Dissolved Organic Carbon, Methane	--	Total Nitrogen, Ammonia Nitrogen, Nitrate Nitrogen, Nitrite Nitrogen, Dissolved Metals, Sulfate, Dissolved Organic Carbon, Methane	
MW-B2100-A	20	40 - 50	Total Nitrogen, Ammonia Nitrogen, Nitrate Nitrogen, Nitrite Nitrogen, Dissolved Metals, Sulfate, Dissolved Organic Carbon, Methane	--	Total Nitrogen, Ammonia Nitrogen, Nitrate Nitrogen, Nitrite Nitrogen, Dissolved Metals, Sulfate, Dissolved Organic Carbon, Methane	
MW-B3100-C	20	20 - 30	Total Nitrogen, Ammonia Nitrogen, Nitrate Nitrogen, Nitrite Nitrogen, Dissolved Metals, Sulfate, Dissolved Organic Carbon, Methane	--	Total Nitrogen, Ammonia Nitrogen, Nitrate Nitrogen, Nitrite Nitrogen, Dissolved Metals, Sulfate, Dissolved Organic Carbon, Methane	
MW-B3100-B	20	30 - 40	Total Nitrogen, Ammonia Nitrogen, Nitrate Nitrogen, Nitrite Nitrogen, Dissolved Metals, Sulfate, Dissolved Organic Carbon, Methane	--	Total Nitrogen, Ammonia Nitrogen, Nitrate Nitrogen, Nitrite Nitrogen, Dissolved Metals, Sulfate, Dissolved Organic Carbon, Methane	
MW-B3100-A	20	40 - 50	Total Nitrogen, Ammonia Nitrogen, Nitrate Nitrogen, Nitrite Nitrogen, Dissolved Metals, Sulfate, Dissolved Organic Carbon, Methane	--	Total Nitrogen, Ammonia Nitrogen, Nitrate Nitrogen, Nitrite Nitrogen, Dissolved Metals, Sulfate, Dissolved Organic Carbon, Methane	
MW-B2175-C	20	20 - 30	Total Nitrogen, Ammonia Nitrogen, Nitrate Nitrogen, Nitrite Nitrogen, Dissolved Metals, Sulfate, Dissolved Organic Carbon, Methane	--	Total Nitrogen, Ammonia Nitrogen, Nitrate Nitrogen, Nitrite Nitrogen, Dissolved Metals, Sulfate, Dissolved Organic Carbon, Methane	A multi-level monitoring well point on one transect with three screened intervals will be monitored approximately 175 feet downgradient of the PRB. These sampling points will assess groundwater and nitrogen treatment immediately downgradient of the PRB, migration of carbon substrate (EVO), and evaluate distribution of dissolved organic carbon and denitrifying conditions
MW-B2175-B	20	30 - 40	Total Nitrogen, Ammonia Nitrogen, Nitrate Nitrogen, Nitrite Nitrogen, Dissolved Metals, Sulfate, Dissolved Organic Carbon, Methane	--	Total Nitrogen, Ammonia Nitrogen, Nitrate Nitrogen, Nitrite Nitrogen, Dissolved Metals, Sulfate, Dissolved Organic Carbon, Methane	
MW-B2175-A	20	40 - 50	Total Nitrogen, Ammonia Nitrogen, Nitrate Nitrogen, Nitrite Nitrogen, Dissolved Metals, Sulfate, Dissolved Organic Carbon, Methane	--	Total Nitrogen, Ammonia Nitrogen, Nitrate Nitrogen, Nitrite Nitrogen, Dissolved Metals, Sulfate, Dissolved Organic Carbon, Methane	
MW-B1150-C	20	20 - 30	Total Nitrogen, Ammonia Nitrogen, Nitrate Nitrogen, Nitrite Nitrogen, Dissolved Metals, Sulfate, Dissolved Organic Carbon, Methane	--	Total Nitrogen, Ammonia Nitrogen, Nitrate Nitrogen, Nitrite Nitrogen, Dissolved Metals, Sulfate, Dissolved Organic Carbon, Methane	A multi-level monitoring well point on one transect with three screened intervals will be monitored approximately 150 feet downgradient of the PRB. These sampling points will assess groundwater and nitrogen treatment immediately downgradient of the PRB, migration of carbon substrate (EVO), and evaluate distribution of dissolved organic carbon and denitrifying conditions
MW-B1150-B	20	30 - 40	Total Nitrogen, Ammonia Nitrogen, Nitrate Nitrogen, Nitrite Nitrogen, Dissolved Metals, Sulfate, Dissolved Organic Carbon, Methane	--	Total Nitrogen, Ammonia Nitrogen, Nitrate Nitrogen, Nitrite Nitrogen, Dissolved Metals, Sulfate, Dissolved Organic Carbon, Methane	
MW-B1150-A	20	40 - 50	Total Nitrogen, Ammonia Nitrogen, Nitrate Nitrogen, Nitrite Nitrogen, Dissolved Metals, Sulfate, Dissolved Organic Carbon, Methane	--	Total Nitrogen, Ammonia Nitrogen, Nitrate Nitrogen, Nitrite Nitrogen, Dissolved Metals, Sulfate, Dissolved Organic Carbon, Methane	
<b>TOTAL</b>	48 wells		48	18	48	

**TABLE 7-2  
Non-Traditional Technologies - Permeable Reactive Barriers  
Demonstration Test - Groundwater Sample Locations, Analyses, and Rationale**

Monitoring Well ID/ Location	Depth to Water <sup>1</sup> (feet bgs)	Monitoring Well Screened Interval <sup>2</sup> (feet bgs)	Baseline Groundwater Analyses	Post-PRB (2, 7, 14 days)	Post-PRB (quarterly sampling for 3 years)	Rationale
<b>Demonstration Test 1 - Focused Injection Test at the Landfill with 5 injection points to assess transport of carbon substrate and changes to groundwater chemistry</b>						
MW-E6-C	55	45 - 55	Total Nitrogen, Ammonia Nitrogen, Nitrate Nitrogen, Nitrite Nitrogen, Dissolved Metals, Sulfate, Dissolved Organic Carbon, Methane	--	Total Nitrogen, Ammonia Nitrogen, Nitrate Nitrogen, Nitrite Nitrogen, Dissolved Metals, Sulfate, Dissolved Organic Carbon, Methane	Multi-level monitoring well point with three screened intervals. This sampling point will represent the upgradient location for the focused PRB Demonstration Test
MW-E6-B	55	55 - 65	Total Nitrogen, Ammonia Nitrogen, Nitrate Nitrogen, Nitrite Nitrogen, Dissolved Metals, Sulfate, Dissolved Organic Carbon, Methane	--	Total Nitrogen, Ammonia Nitrogen, Nitrate Nitrogen, Nitrite Nitrogen, Dissolved Metals, Sulfate, Dissolved Organic Carbon, Methane	
MW-E6-A	55	65 - 75	Total Nitrogen, Ammonia Nitrogen, Nitrate Nitrogen, Nitrite Nitrogen, Dissolved Metals, Sulfate, Dissolved Organic Carbon, Methane	--	Total Nitrogen, Ammonia Nitrogen, Nitrate Nitrogen, Nitrite Nitrogen, Dissolved Metals, Sulfate, Dissolved Organic Carbon, Methane	
MW-E1005-C	45	45 - 55	Total Nitrogen, Ammonia Nitrogen, Nitrate Nitrogen, Nitrite Nitrogen, Dissolved Metals, Sulfate, Dissolved Organic Carbon, Methane	Visual Observation, Total Nitrogen, Nitrate Nitrogen, Dissolved Organic Carbon	Total Nitrogen, Ammonia Nitrogen, Nitrate Nitrogen, Nitrite Nitrogen, Dissolved Metals, Sulfate, Dissolved Organic Carbon, Methane	Multi-level monitoring well point with three screened intervals. This sampling point will be located approximately 5 feet downgradient of PRB injection points to assess groundwater and nitrogen treatment immediately downgradient of the PRB and evaluate migration of carbon substrate (EVO)
MW-E1005-B	45	55 - 65	Total Nitrogen, Ammonia Nitrogen, Nitrate Nitrogen, Nitrite Nitrogen, Dissolved Metals, Sulfate, Dissolved Organic Carbon, Methane	Visual Observation, Total Nitrogen, Nitrate Nitrogen, Dissolved Organic Carbon	Total Nitrogen, Ammonia Nitrogen, Nitrate Nitrogen, Nitrite Nitrogen, Dissolved Metals, Sulfate, Dissolved Organic Carbon, Methane	
MW-E1005-A	45	65 - 75	Total Nitrogen, Ammonia Nitrogen, Nitrate Nitrogen, Nitrite Nitrogen, Dissolved Metals, Sulfate, Dissolved Organic Carbon, Methane	Visual Observation, Total Nitrogen, Nitrate Nitrogen, Dissolved Organic Carbon	Total Nitrogen, Ammonia Nitrogen, Nitrate Nitrogen, Nitrite Nitrogen, Dissolved Metals, Sulfate, Dissolved Organic Carbon, Methane	
MW-E1010-C	45	45 - 55	Total Nitrogen, Ammonia Nitrogen, Nitrate Nitrogen, Nitrite Nitrogen, Dissolved Metals, Sulfate, Dissolved Organic Carbon, Methane	Visual Observation, Total Nitrogen, Nitrate Nitrogen, Dissolved Organic Carbon	Total Nitrogen, Ammonia Nitrogen, Nitrate Nitrogen, Nitrite Nitrogen, Dissolved Metals, Sulfate, Dissolved Organic Carbon, Methane	Two multi-level monitoring well points with three screened intervals will be monitored approximately 10-15 feet downgradient of the PRB. These sampling points will assess groundwater and nitrogen treatment immediately downgradient of the PRB, migration of carbon substrate (EVO), and evaluate distribution of dissolved organic carbon and denitrifying conditions
MW-E1010-B	45	55 - 65	Total Nitrogen, Ammonia Nitrogen, Nitrate Nitrogen, Nitrite Nitrogen, Dissolved Metals, Sulfate, Dissolved Organic Carbon, Methane	Visual Observation, Total Nitrogen, Nitrate Nitrogen, Dissolved Organic Carbon	Total Nitrogen, Ammonia Nitrogen, Nitrate Nitrogen, Nitrite Nitrogen, Dissolved Metals, Sulfate, Dissolved Organic Carbon, Methane	
MW-E1010-A	45	65 - 75	Total Nitrogen, Ammonia Nitrogen, Nitrate Nitrogen, Nitrite Nitrogen, Dissolved Metals, Sulfate, Dissolved Organic Carbon, Methane	Visual Observation, Total Nitrogen, Nitrate Nitrogen, Dissolved Organic Carbon	Total Nitrogen, Ammonia Nitrogen, Nitrate Nitrogen, Nitrite Nitrogen, Dissolved Metals, Sulfate, Dissolved Organic Carbon, Methane	
MW-E1015-C	45	45 - 55	Total Nitrogen, Ammonia Nitrogen, Nitrate Nitrogen, Nitrite Nitrogen, Dissolved Metals, Sulfate, Dissolved Organic Carbon, Methane	Visual Observation, Total Nitrogen, Nitrate Nitrogen, Dissolved Organic Carbon	Total Nitrogen, Ammonia Nitrogen, Nitrate Nitrogen, Nitrite Nitrogen, Dissolved Metals, Sulfate, Dissolved Organic Carbon, Methane	
MW-E1015-B	45	55 - 65	Total Nitrogen, Ammonia Nitrogen, Nitrate Nitrogen, Nitrite Nitrogen, Dissolved Metals, Sulfate, Dissolved Organic Carbon, Methane	Visual Observation, Total Nitrogen, Nitrate Nitrogen, Dissolved Organic Carbon	Total Nitrogen, Ammonia Nitrogen, Nitrate Nitrogen, Nitrite Nitrogen, Dissolved Metals, Sulfate, Dissolved Organic Carbon, Methane	
MW-E1015-A	45	65 - 75	Total Nitrogen, Ammonia Nitrogen, Nitrate Nitrogen, Nitrite Nitrogen, Dissolved Metals, Sulfate, Dissolved Organic Carbon, Methane	Visual Observation, Total Nitrogen, Nitrate Nitrogen, Dissolved Organic Carbon	Total Nitrogen, Ammonia Nitrogen, Nitrate Nitrogen, Nitrite Nitrogen, Dissolved Metals, Sulfate, Dissolved Organic Carbon, Methane	
MW-E1020-C	45	45 - 55	Total Nitrogen, Ammonia Nitrogen, Nitrate Nitrogen, Nitrite Nitrogen, Dissolved Metals, Sulfate, Dissolved Organic Carbon, Methane	Visual Observation, Total Nitrogen, Nitrate Nitrogen, Dissolved Organic Carbon	Total Nitrogen, Ammonia Nitrogen, Nitrate Nitrogen, Nitrite Nitrogen, Dissolved Metals, Sulfate, Dissolved Organic Carbon, Methane	Multi-level monitoring well point with three screened intervals. This sampling point will be located approximately 20 feet downgradient of PRB injection points to assess groundwater and nitrogen treatment downgradient of the PRB and evaluate distribution of dissolved organic carbon and denitrifying conditions
MW-E1020-B	45	55 - 65	Total Nitrogen, Ammonia Nitrogen, Nitrate Nitrogen, Nitrite Nitrogen, Dissolved Metals, Sulfate, Dissolved Organic Carbon, Methane	Visual Observation, Total Nitrogen, Nitrate Nitrogen, Dissolved Organic Carbon	Total Nitrogen, Ammonia Nitrogen, Nitrate Nitrogen, Nitrite Nitrogen, Dissolved Metals, Sulfate, Dissolved Organic Carbon, Methane	
MW-E1020-A	45	65 - 75	Total Nitrogen, Ammonia Nitrogen, Nitrate Nitrogen, Nitrite Nitrogen, Dissolved Metals, Sulfate, Dissolved Organic Carbon, Methane	Visual Observation, Total Nitrogen, Nitrate Nitrogen, Dissolved Organic Carbon	Total Nitrogen, Ammonia Nitrogen, Nitrate Nitrogen, Nitrite Nitrogen, Dissolved Metals, Sulfate, Dissolved Organic Carbon, Methane	
MW-E1050-C	45	45 - 55	Total Nitrogen, Ammonia Nitrogen, Nitrate Nitrogen, Nitrite Nitrogen, Dissolved Metals, Sulfate, Dissolved Organic Carbon, Methane	--	Total Nitrogen, Ammonia Nitrogen, Nitrate Nitrogen, Nitrite Nitrogen, Dissolved Metals, Sulfate, Dissolved Organic Carbon, Methane	Multi-level monitoring well point with three screened intervals. This sampling point will be located approximately 50 feet downgradient of PRB injection points to assess groundwater and nitrogen treatment downgradient of the PRB and evaluate distribution of dissolved organic carbon and denitrifying conditions
MW-E1050-B	45	55 - 65	Total Nitrogen, Ammonia Nitrogen, Nitrate Nitrogen, Nitrite Nitrogen, Dissolved Metals, Sulfate, Dissolved Organic Carbon, Methane	--	Total Nitrogen, Ammonia Nitrogen, Nitrate Nitrogen, Nitrite Nitrogen, Dissolved Metals, Sulfate, Dissolved Organic Carbon, Methane	
MW-E1050-A	45	65 - 75	Total Nitrogen, Ammonia Nitrogen, Nitrate Nitrogen, Nitrite Nitrogen, Dissolved Metals, Sulfate, Dissolved Organic Carbon, Methane	--	Total Nitrogen, Ammonia Nitrogen, Nitrate Nitrogen, Nitrite Nitrogen, Dissolved Metals, Sulfate, Dissolved Organic Carbon, Methane	

**TABLE 7-2  
Non-Traditional Technologies - Permeable Reactive Barriers  
Demonstration Test - Groundwater Sample Locations, Analyses, and Rationale**

Monitoring Well ID/ Location	Depth to Water <sup>1</sup> (feet bgs)	Monitoring Well Screened Interval <sup>2</sup> (feet bgs)	Baseline Groundwater Analyses	Post-PRB (2, 7, 14 days)	Post-PRB (quarterly sampling for 3 years)	Rationale
MW-2S	75		Total Nitrogen, Ammonia Nitrogen, Nitrate Nitrogen, Nitrite Nitrogen, Dissolved Metals, Sulfate, Dissolved Organic Carbon, Methane	--	Total Nitrogen, Ammonia Nitrogen, Nitrate Nitrogen, Nitrite Nitrogen, Dissolved Metals, Sulfate, Dissolved Organic Carbon, Methane	Four existing monitoring wells (two pairs of multi-level wells) will be monitored as part of the Demonstration Test to assess any change in groundwater conditions at locations further downgradient of the PRB carbon substrate application. Data will be compared with sampling results dating back to 1994
MW-2D	75		Total Nitrogen, Ammonia Nitrogen, Nitrate Nitrogen, Nitrite Nitrogen, Dissolved Metals, Sulfate, Dissolved Organic Carbon, Methane	--	Total Nitrogen, Ammonia Nitrogen, Nitrate Nitrogen, Nitrite Nitrogen, Dissolved Metals, Sulfate, Dissolved Organic Carbon, Methane	
MW-5S	75		Total Nitrogen, Ammonia Nitrogen, Nitrate Nitrogen, Nitrite Nitrogen, Dissolved Metals, Sulfate, Dissolved Organic Carbon, Methane	--	Total Nitrogen, Ammonia Nitrogen, Nitrate Nitrogen, Nitrite Nitrogen, Dissolved Metals, Sulfate, Dissolved Organic Carbon, Methane	
MW-5D	75		Total Nitrogen, Ammonia Nitrogen, Nitrate Nitrogen, Nitrite Nitrogen, Dissolved Metals, Sulfate, Dissolved Organic Carbon, Methane	--	Total Nitrogen, Ammonia Nitrogen, Nitrate Nitrogen, Nitrite Nitrogen, Dissolved Metals, Sulfate, Dissolved Organic Carbon, Methane	
<b>TOTAL</b>	<b>22 wells</b>		<b>22</b>	<b>12</b>	<b>22</b>	

Notes:

bgs = Below Ground Surface

TBD - to be determined

TOC = Total Organic Carbon

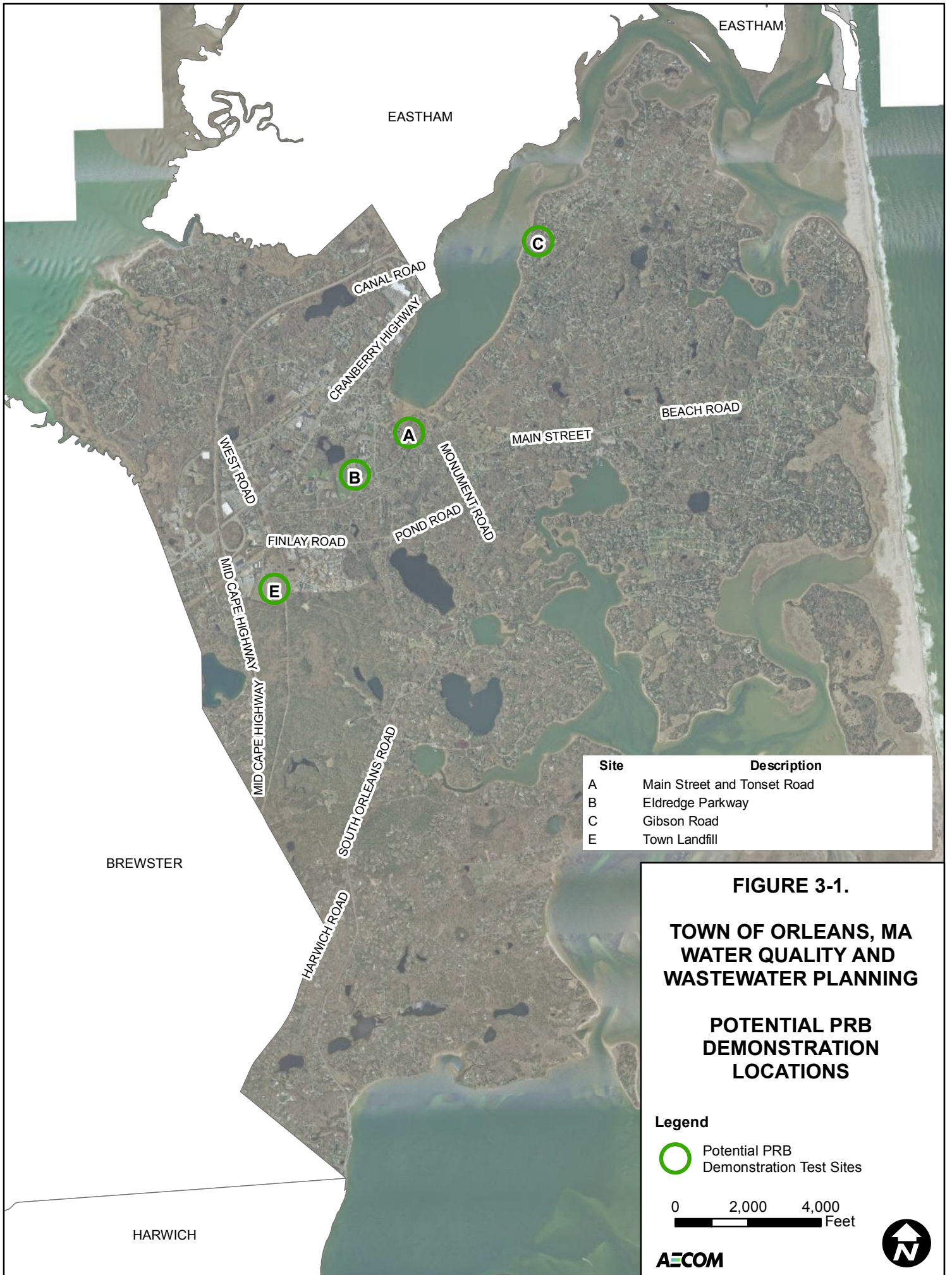
Dissolved Metals = Arsenic, Iron, Manganese

<sup>1</sup> - Depth to water, if estimated, shown in italics

<sup>2</sup> - Well screen interval, if estimated, shown in italics

<sup>3</sup> - Field measurements will be recorded for temperature, dissolved oxygen, pH, oxidation reduction potential, specific conductivity, and turbidity for all samples.

## Figures




Site	Description
A	Main Street and Tonset Road
B	Eldredge Parkway
C	Gibson Road
E	Town Landfill

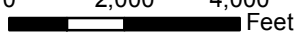
**FIGURE 3-1.**


**TOWN OF ORLEANS, MA  
WATER QUALITY AND  
WASTEWATER PLANNING**

**POTENTIAL PRB  
DEMONSTRATION  
LOCATIONS**

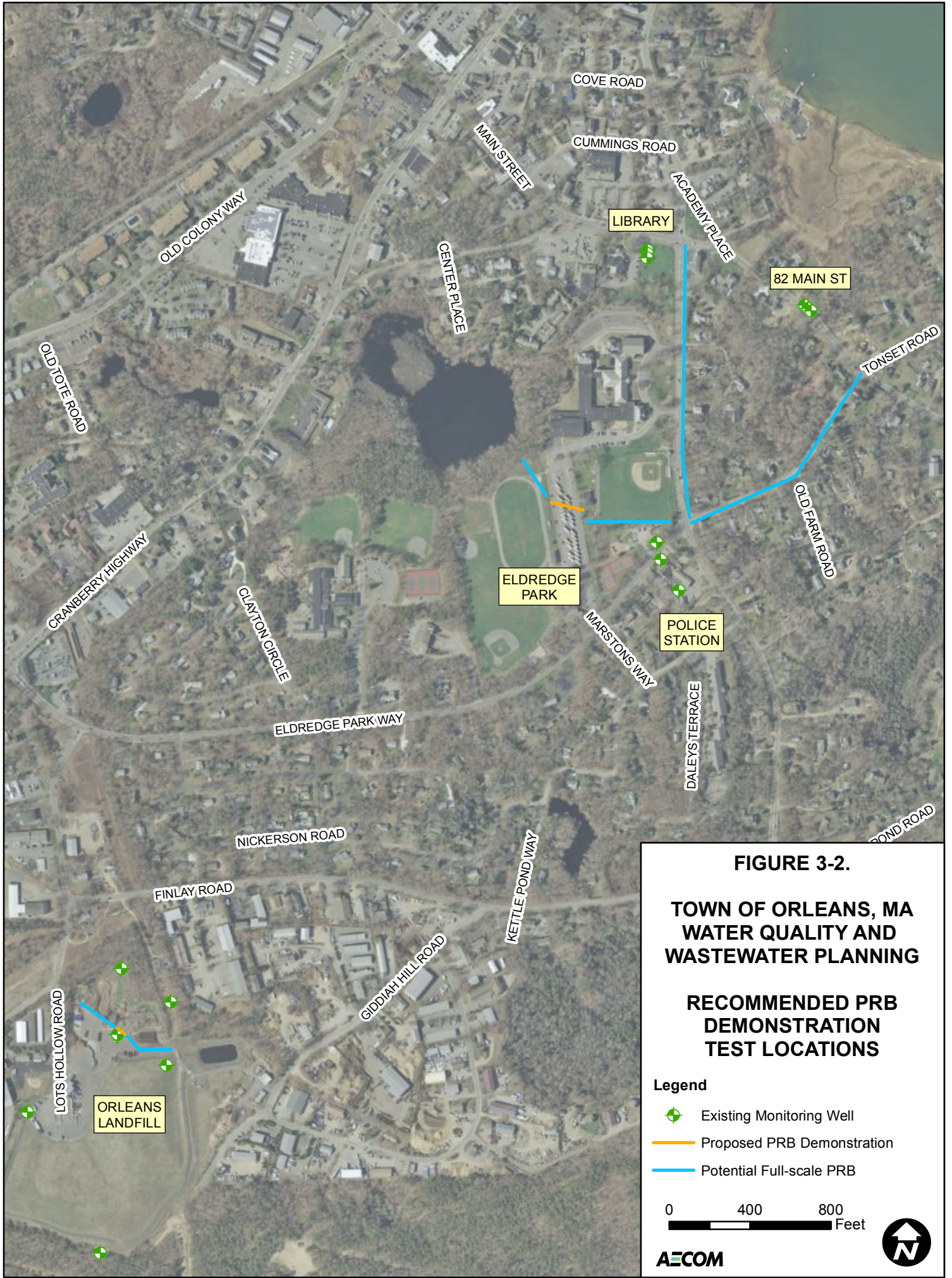
**Legend**

 Potential PRB Demonstration Test Sites

0      2,000      4,000  
 Feet



**AECOM**






C:\work\6047664\ORL\Maps\PRB\_Figure3-2\_RecommendedPRB.mxd

**FIGURE 3-2.**


**TOWN OF ORLEANS, MA  
WATER QUALITY AND  
WASTEWATER PLANNING**

**RECOMMENDED PRB  
DEMONSTRATION  
TEST LOCATIONS**

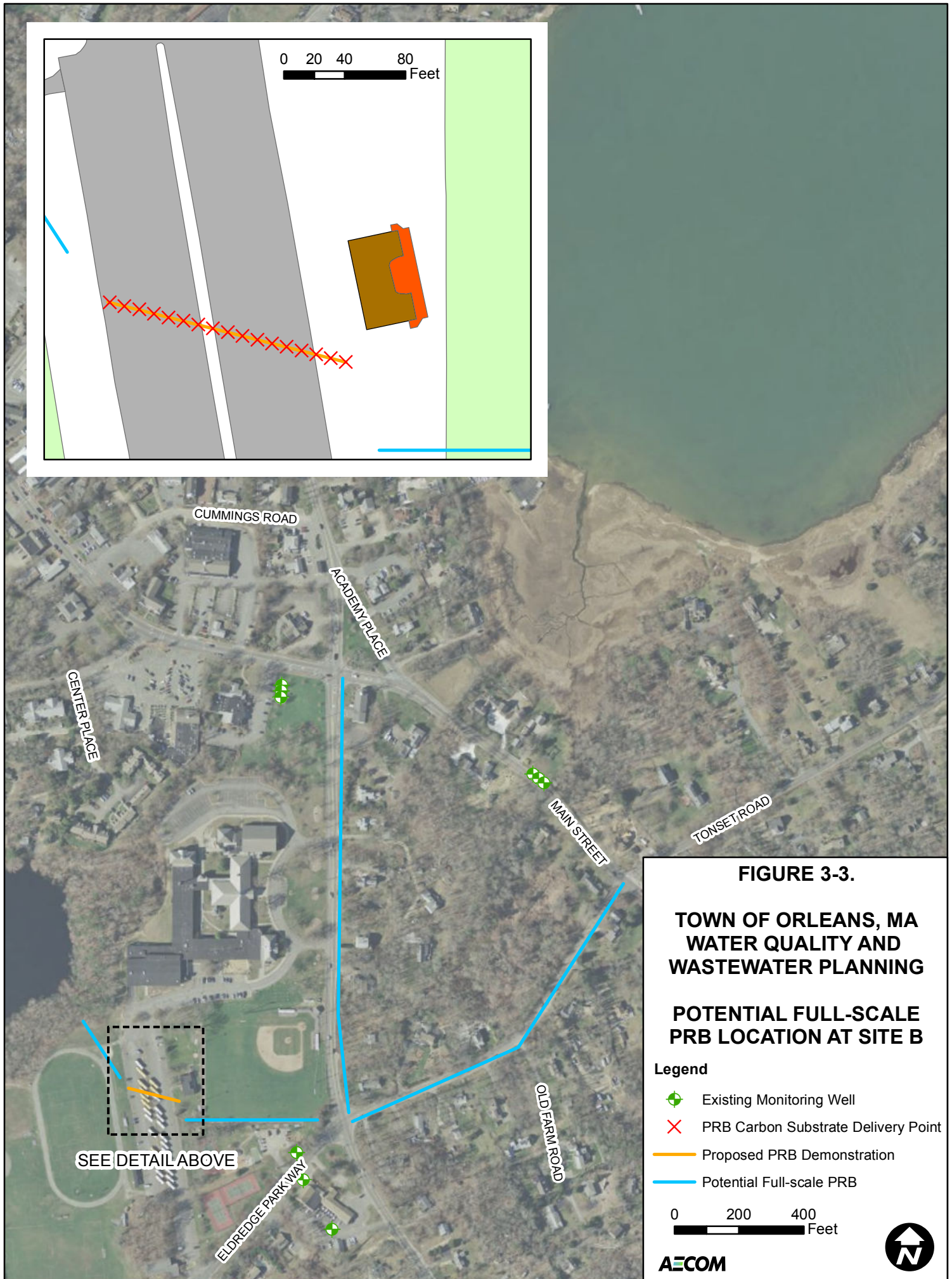
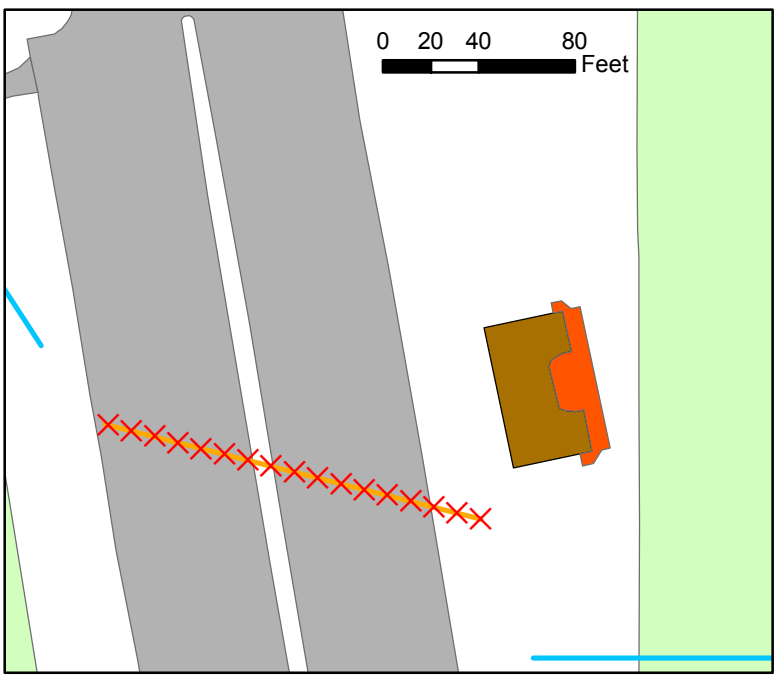
**Legend**

-  Existing Monitoring Well
-  Proposed PRB Demonstration
-  Potential Full-scale PRB

0      400      800  
 Feet

**AECOM** 

0 20 40 80 Feet



CUMMINGS ROAD

ACADEMY PLACE

CENTER PLACE

MAIN STREET

TONSET ROAD

OLD FARM ROAD

ELDRIDGE PARK WAY

SEE DETAIL ABOVE

**FIGURE 3-3.**

**TOWN OF ORLEANS, MA  
WATER QUALITY AND  
WASTEWATER PLANNING**

**POTENTIAL FULL-SCALE  
PRB LOCATION AT SITE B**

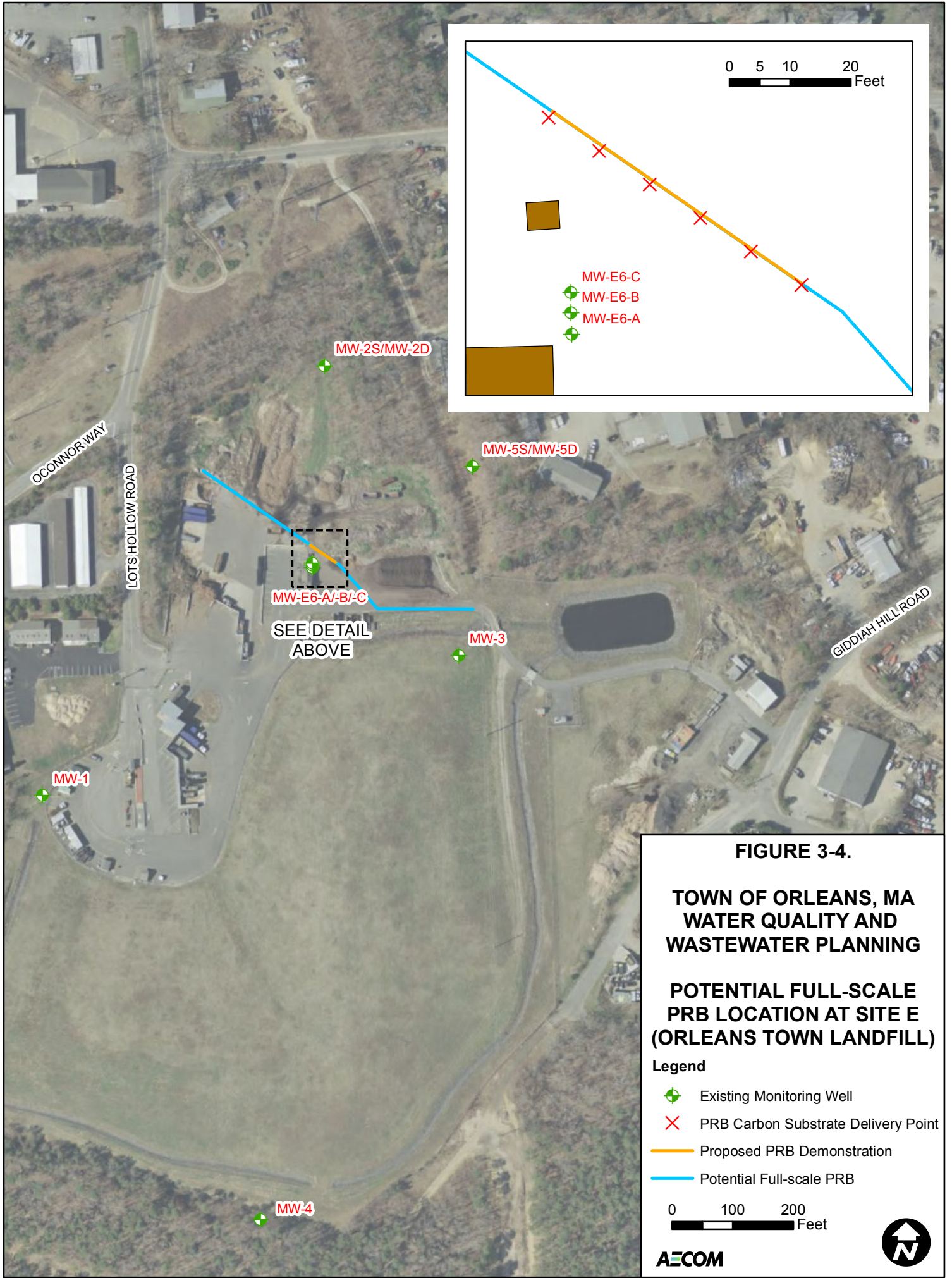
**Legend**

- Existing Monitoring Well
- PRB Carbon Substrate Delivery Point
- Proposed PRB Demonstration
- Potential Full-scale PRB

0 200 400 Feet

**AECOM**









**FIGURE 3-4.**

**TOWN OF ORLEANS, MA  
WATER QUALITY AND  
WASTEWATER PLANNING**

**POTENTIAL FULL-SCALE  
PRB LOCATION AT SITE E  
(ORLEANS TOWN LANDFILL)**

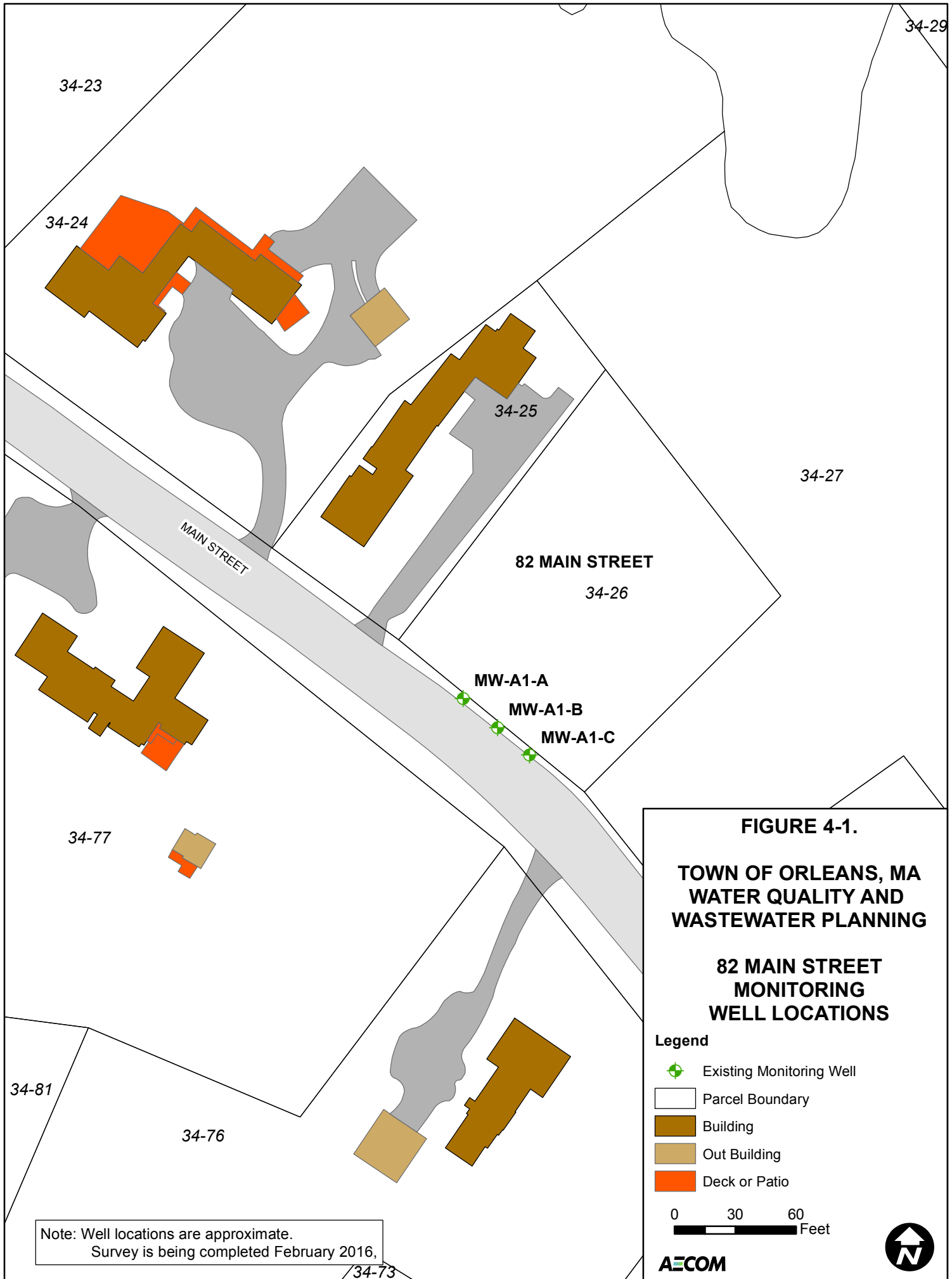
**Legend**

-  Existing Monitoring Well
-  PRB Carbon Substrate Delivery Point
-  Proposed PRB Demonstration
-  Potential Full-scale PRB

0 100 200  
Feet

**AECOM**










**FIGURE 4-1.**

**TOWN OF ORLEANS, MA  
WATER QUALITY AND  
WASTEWATER PLANNING**

**82 MAIN STREET  
MONITORING  
WELL LOCATIONS**

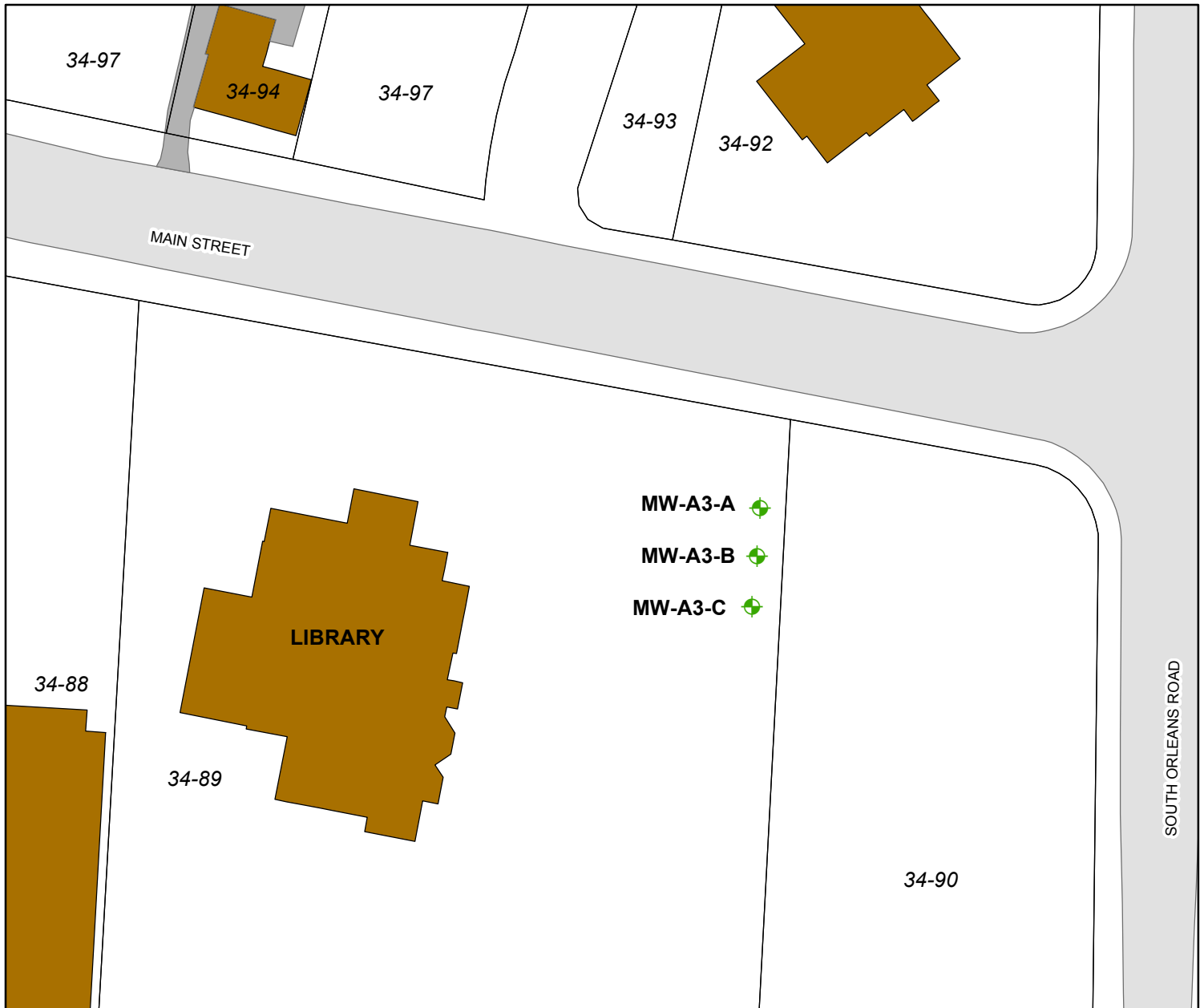
**Legend**




-  Existing Monitoring Well
-  Parcel Boundary
-  Building
-  Out Building
-  Deck or Patio

0 30 60  
Feet



Note: Well locations are approximate.  
Survey is being completed February 2016,



MW-A3-A   
 MW-A3-B   
 MW-A3-C 






LIBRARY

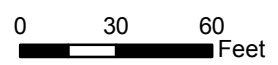
**FIGURE 4-2.**

**TOWN OF ORLEANS, MA  
 WATER QUALITY AND  
 WASTEWATER PLANNING**

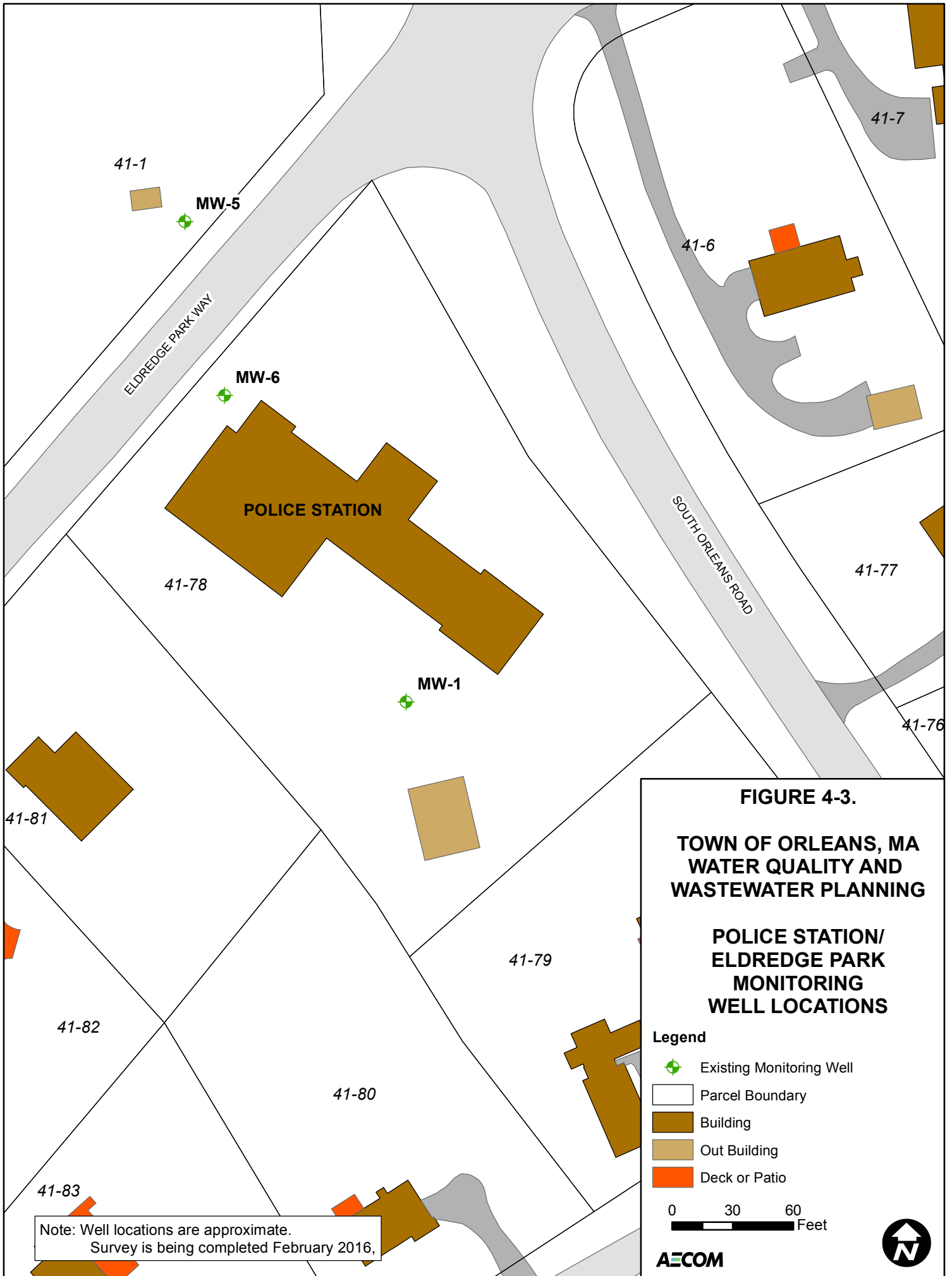
**LIBRARY  
 MONITORING  
 WELL LOCATIONS**

**Legend**

-  Existing Monitoring Well
-  Parcel Boundary
-  Building
-  Out Building
-  Deck or Patio



Note: Well locations are approximate.  
 Survey is being completed February 2016,








**FIGURE 4-3.**

**TOWN OF ORLEANS, MA  
WATER QUALITY AND  
WASTEWATER PLANNING**

**POLICE STATION/  
ELDRIDGE PARK  
MONITORING  
WELL LOCATIONS**

**Legend**

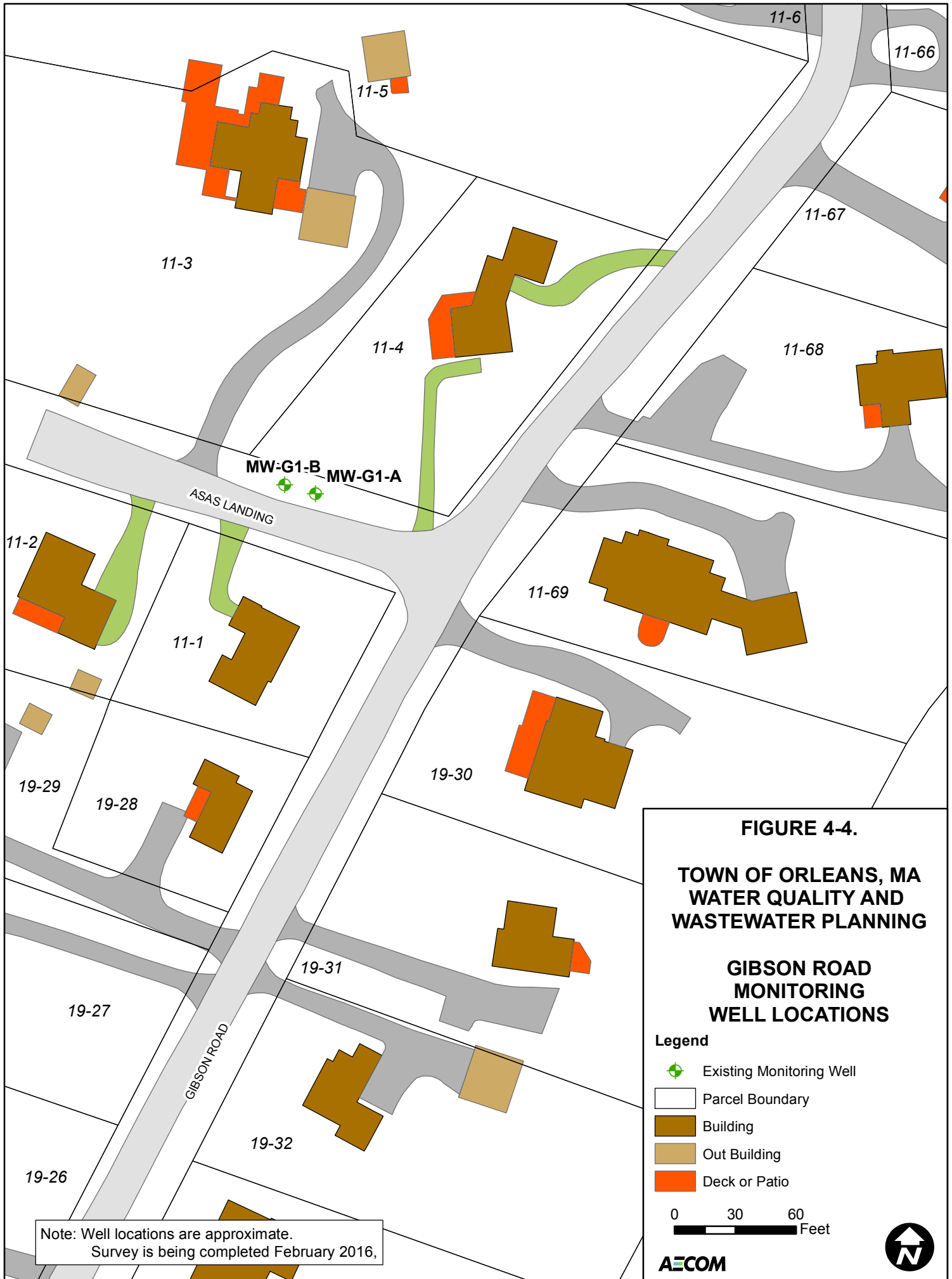
-  Existing Monitoring Well
-  Parcel Boundary
-  Building
-  Out Building
-  Deck or Patio

0 30 60  
Feet

**AECOM**



Note: Well locations are approximate.  
Survey is being completed February 2016,








**FIGURE 4-4.**

**TOWN OF ORLEANS, MA  
WATER QUALITY AND  
WASTEWATER PLANNING**

**GIBSON ROAD  
MONITORING  
WELL LOCATIONS**

**Legend**

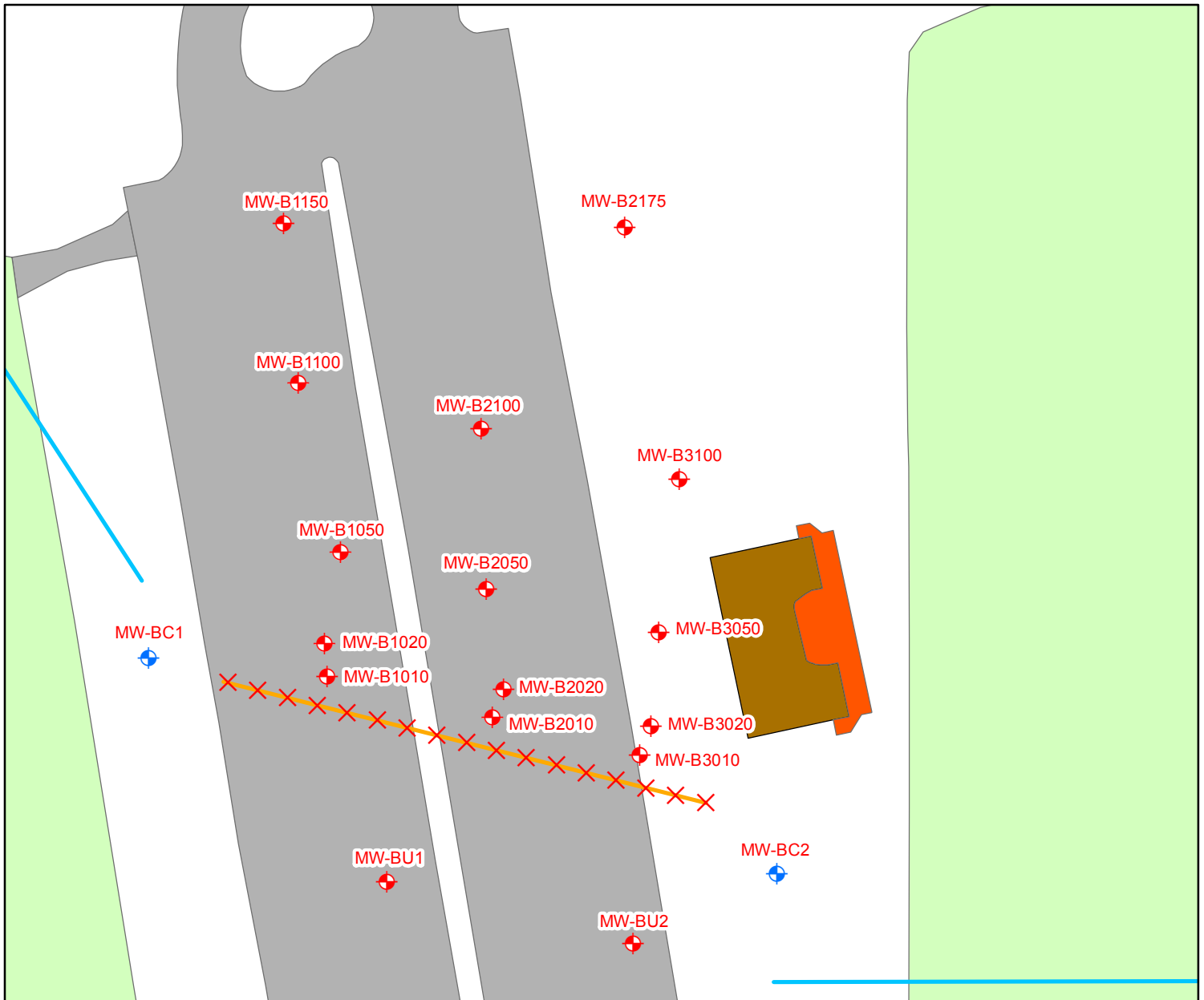
-  Existing Monitoring Well
-  Parcel Boundary
-  Building
-  Out Building
-  Deck or Patio

0 30 60  
Feet

**AECOM**



Note: Well locations are approximate.  
Survey is being completed February 2016,



**FIGURE 7-1.**

**TOWN OF ORLEANS, MA  
WATER QUALITY AND WASTEWATER PLANNING**

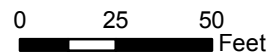
**PROPOSED PRB DEMONSTRATION LOCATION  
AT SITE B - ELDREDGE PARK**

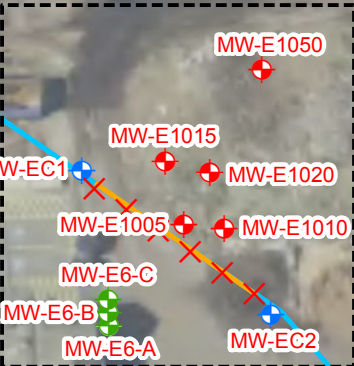
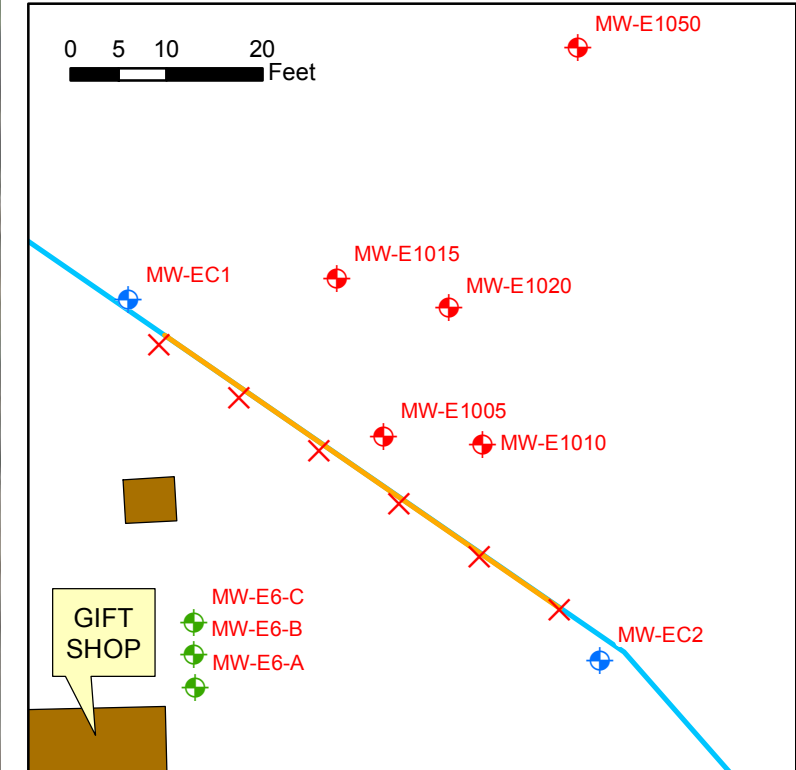
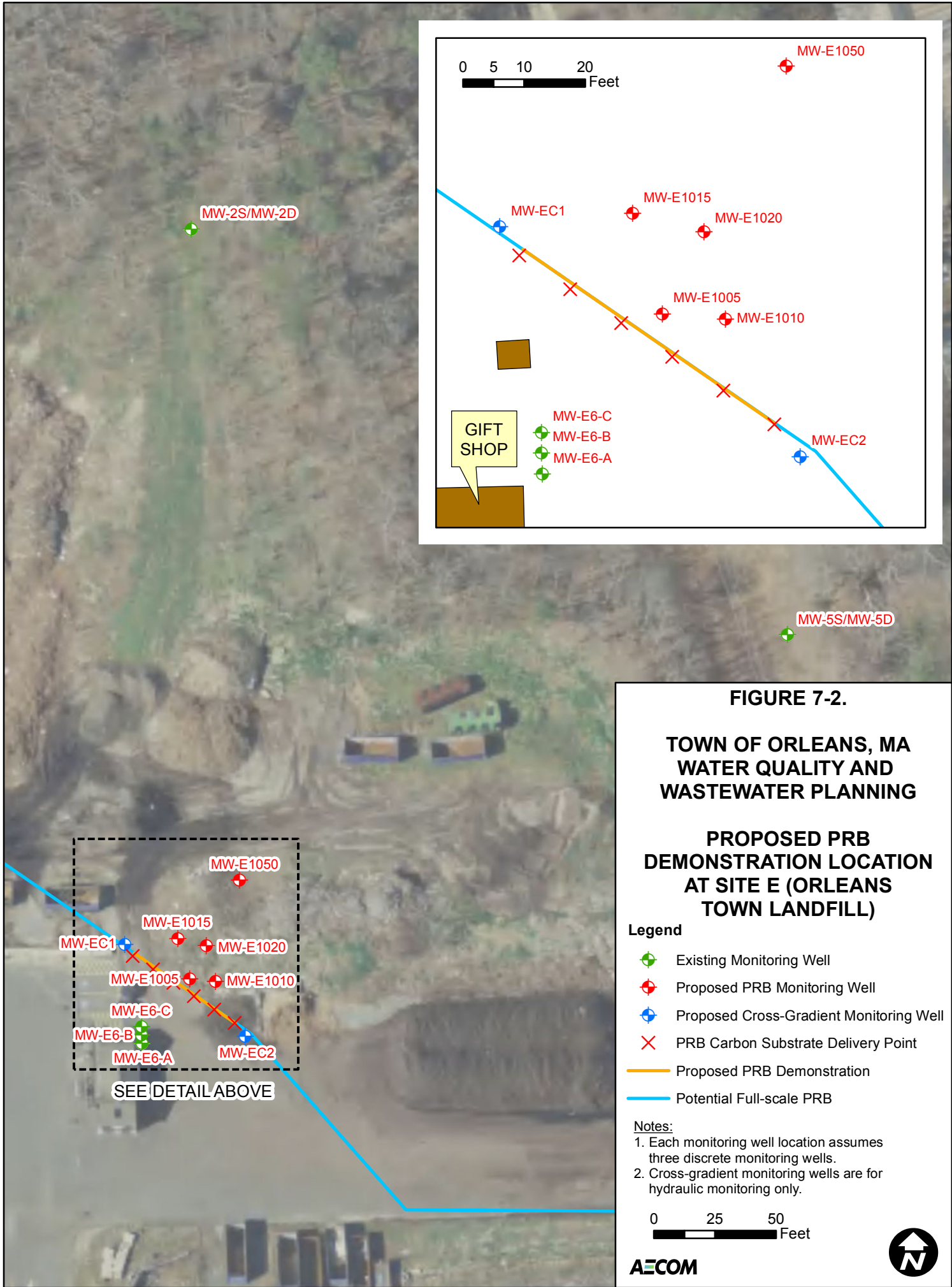
**Legend**

- |  |   |  |               |
|--|---|--|---------------|
|  | Proposed PRB Monitoring Well            |  | Pavement      |
|  | Proposed Cross-Gradient Monitoring Well |  | Grass         |
|  | Proposed PRB Demonstration              |  | Building      |
|  | Potential Full-scale PRB                |  | Out Building  |
|  | PRB Carbon Substrate Delivery Point     |  | Deck or Patio |

**Notes:**

1. Each monitoring well location assumes three discrete monitoring wells.
2. Cross-gradient monitoring wells are for hydraulic monitoring only.





**FIGURE 7-2.**

**TOWN OF ORLEANS, MA  
WATER QUALITY AND  
WASTEWATER PLANNING**

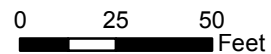
**PROPOSED PRB  
DEMONSTRATION LOCATION  
AT SITE E (ORLEANS  
TOWN LANDFILL)**

**Legend**

- Existing Monitoring Well
- Proposed PRB Monitoring Well
- Proposed Cross-Gradient Monitoring Well
- PRB Carbon Substrate Delivery Point
- Proposed PRB Demonstration
- Potential Full-scale PRB

**Notes:**

1. Each monitoring well location assumes three discrete monitoring wells.
2. Cross-gradient monitoring wells are for hydraulic monitoring only.



**Appendix A**

**Technical Memorandum on Site Characterization and Evaluation for  
Permeable Reactive Barriers**

**(Draft Submitted to the Town of Orleans on January 15, 2016)**

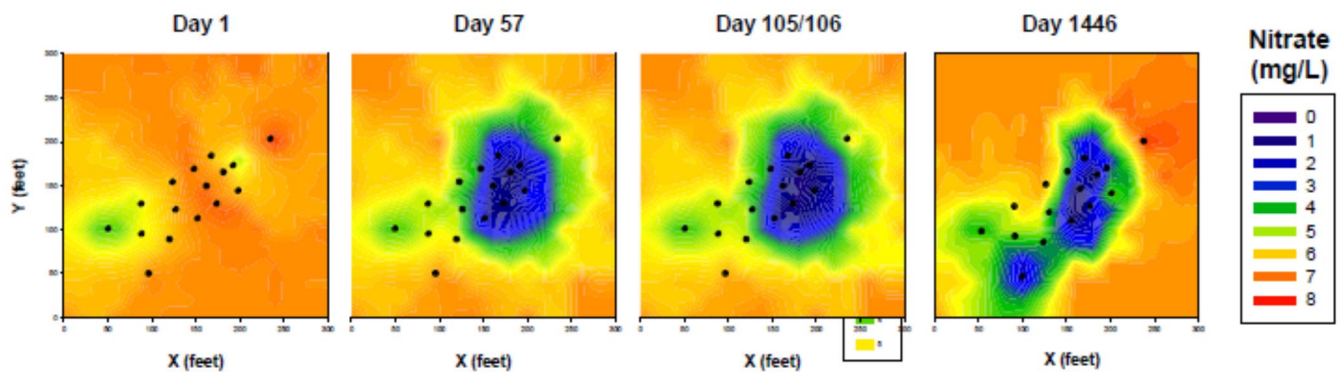
## **Appendix B**

### **Select AECOM Experience with Anaerobic Bioremediation and Nitrate Reduction**

## Appendix B – Select AECOM Experience With Anaerobic Bioremediation and Nitrate Reduction

### AECOM Explosives Depot Site

AECOM provided investigation, assessment and remediation services on numerous sites at a Department of Defense BRAC facility designated for closure. AECOM conducted bench and field pilot studies to evaluate biologically enhanced reductive treatment of nitrate as well as nitroaromatic and nitroazine explosives in groundwater. Baseline nitrate concentrations ranged between 6 and 15 mg/L. The field pilot studies tested different food-grade carbon amendments and the use of various injection systems (injection wells, direct-push injection). In addition, pilot tests were performed in different areas under a range of groundwater flow conditions. Multiple in-situ biobarriers ranging from 100 to 300 feet in length were established using a grid of injection points. The results of these studies demonstrated the feasibility of in-situ bioremediation of nitrate and explosives in groundwater. High levels of nitrate removal (>99%) were observed, and one area tested showed continued treatment up to 4 years after the initial injection. Both injection wells and direct-push methods were demonstrated to effectively promote in situ treatment of nitrate, including under relatively high flow conditions. The success of the pilot tests led to the development of a bioremediation based exit strategy to facilitate accelerated site closure that will reduce project lifecycle from 100 to about 10 years and with significant life cycle cost reduction compared to pump and treat.



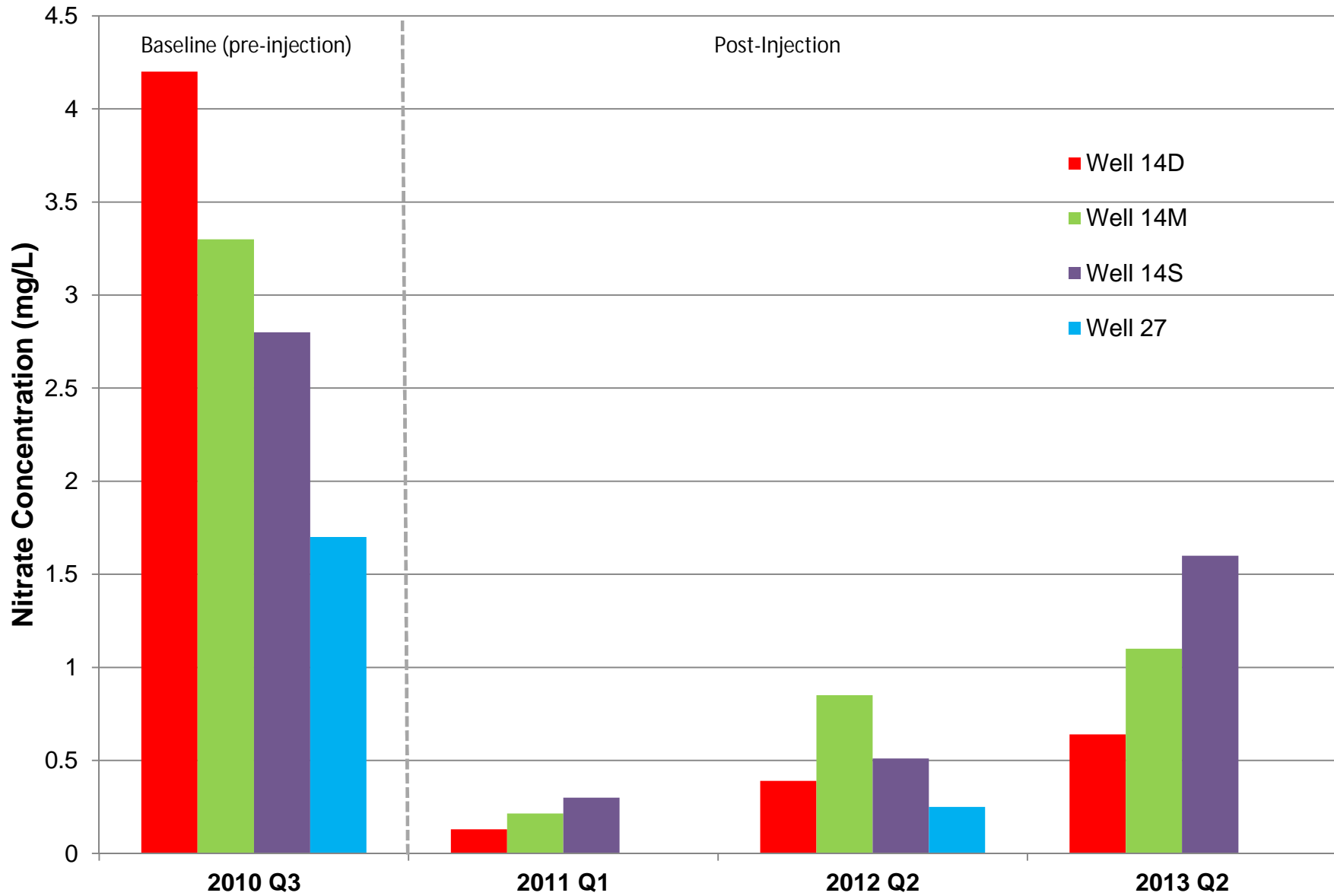
Time series of nitrate concentration after initial injection of food-grade carbon substrate (HRC)

### AECOM TCE EVO Bioremediation Site -

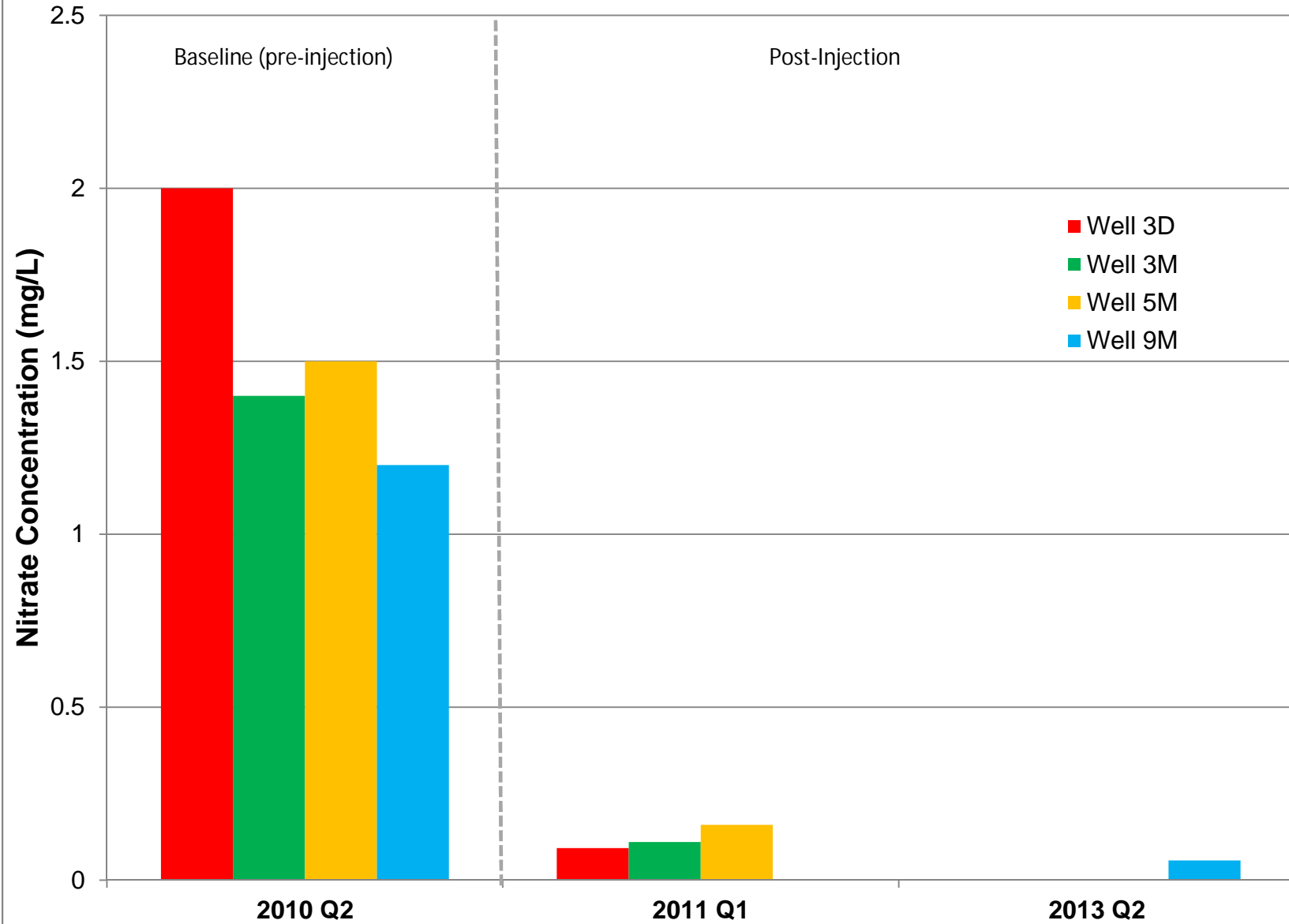
Full-scale bioremediation was implemented for treatment of trichloroethene (TCE) in groundwater at a site in New England. Emulsified vegetable oil (EVO) was the selected carbon substrate to enhance anaerobic biodegradation based on results of three pilot tests of multiple carbon substrates in two different areas. Full-scale bioremediation through injection of EVO was performed at two different areas of the site. Nitrate was analyzed for in select monitoring wells and indicated reduction in nitrate concentrations for a period of greater than three years. See pair of bar plots.

**AECOM Perchlorate EVO Bioremediation Site-** A pilot test was conducted at a Department of Defense facility in California to evaluate in-situ bioremediation for perchlorate in groundwater. EVO was the selected carbon substrate to enhance anaerobic biodegradation. Baseline nitrate concentrations ranged between 5 and 15 mg/L in the pilot test areas. The pilot test monitoring period was only six months, and successful biodegradation of perchlorate was observed. The pilot test monitoring also showed that nitrate was reduced to below detection limits (<0.25 mg/L) within one month of the injection of EVO. See attached line plot.

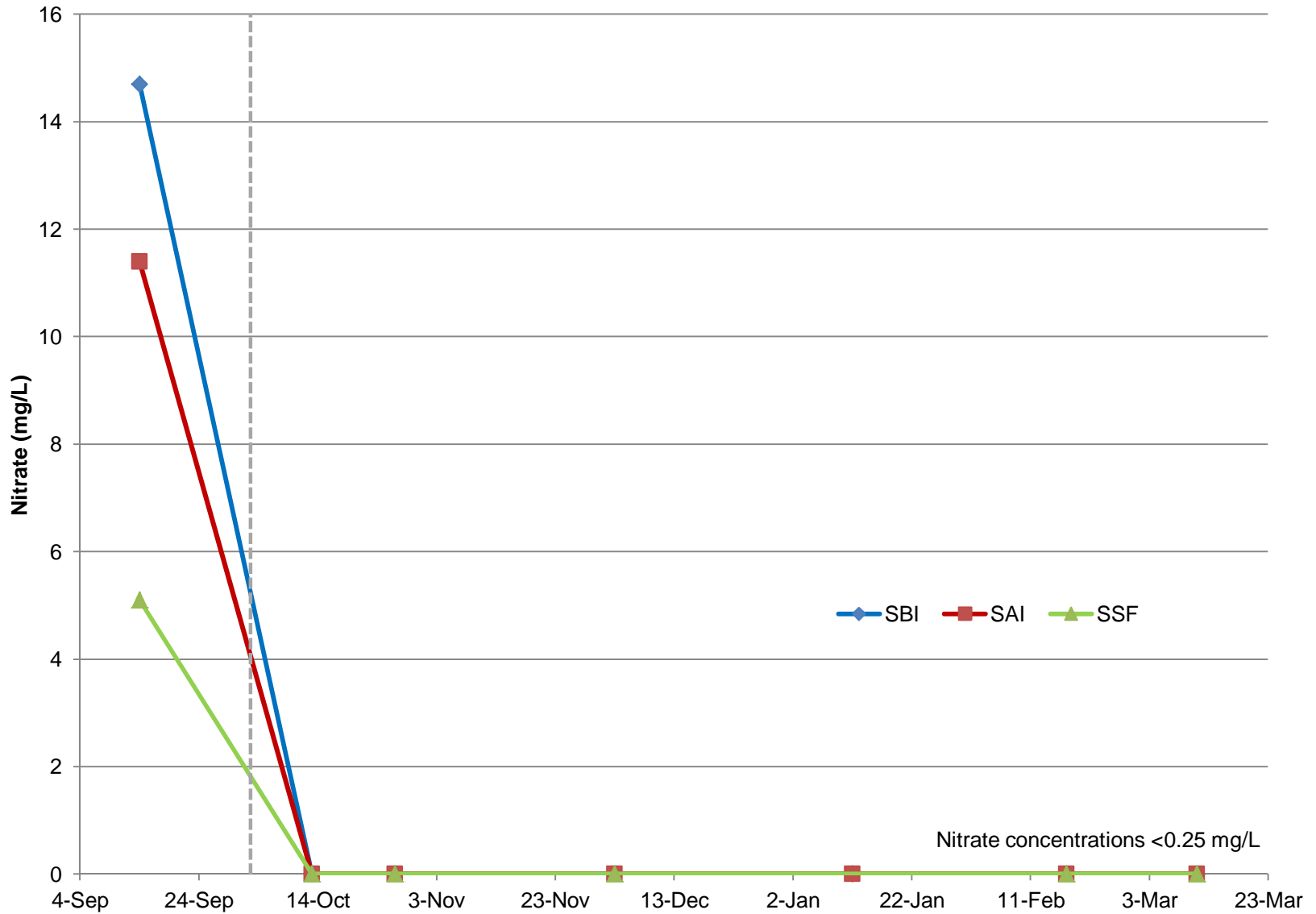
### Nitrate Concentrations in Groundwater AECOM TCE EVO Bioremediation Site (Area 1)



## Nitrate Concentrations in Groundwater AECOM TCE EVO Bioremediation Site (Area 2)



# Nitrate Concentrations in Groundwater AECOM Perchlorate EVO Bioremediation Site



**Appendix C**

**MassDEP Underground Injection Control Registration DRAFT Permit Application  
(Form BRP WS 06)**



# BRP WS 06 UIC Registration

**Note:** This application form only applies to the following types of Class V UIC wells. This form does not apply to unauthorized wells such as motor vehicle waste disposal wells.

- Motor Vehicle – Rinse Water, Snow/Ice Melt or Rain Drip
- Non-Contact Cooling Water Return Flow
- Subsidence Control
- Aquaculture Return Flow
- Aquifer Recharge/Recovery
- Other
- Saline Water Intrusion Barrier
- Experimental Technology
- Process Water and Wastewater Disposal
- Aquifer Remediation
- Special Drainage – Groundwater Infiltration (Does Not Include Public Water System Wells)
- Special Drainage – Swimming Pools

Refer to the “Instructions and Supporting Materials” document that corresponds to this UIC Registration form for detailed instructions regarding the completion of this form and the required attachments.

Transmittal Number (not required for 1 to 4 unit residential applications)

Transmittal # \_\_\_\_\_

## A. Registration Category & Fee

### Registration Category

1. Identify the type of registration activity you are conducting (check one):

- a. Registration of a New or Existing Unregistered UIC Well(s)
- b. Pre-Closure of an Unregistered or Registered UIC Well(s)
- c. Pre-Closure of an Unregistered or Registered UIC Well(s) and Conversion to New Well Type
- d. Modification of a UIC Registration Application that is Still Under Review at MassDEP
- e. Modification of an Existing UIC Registration that Does Not Include Increasing the Number of Registered Wells
- f. Modification of an Existing UIC Registration that Includes Increasing the Number of Registered Wells

**Note:** Conversion also requires submittal of a separate registration application for the new UIC Class V well type.

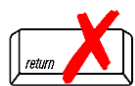
**Notes:** For the above Pre-Closure categories (items b and c), if you are submitting for a UIC well(s) that has received a MassDEP-issued UIC registration number, complete Sections A, B, L, and M of this application and for all other Sections only complete the data/information fields where you are entering new or revised information. For any of the above Modification categories (items d, e, and f), complete Sections A, B, and M of this application and for all other Sections only complete the data/information fields where you are entering new or revised information.

### For Modifications, Pre-Closures, or Pre-Closures and Conversions of a UIC Registered Well:

Enter UIC Registration Number (required):

UIC Registration # \_\_\_\_\_

**Important:** When filling out forms on the computer, use only the tab key to move your cursor - do not use the return key.





# BRP WS 06 UIC Registration

---

## A. Registration Category & Fee (cont.)

### Basic Well Information

2. Select your Well Category and enter your Well Type (see “Instructions and Supporting Materials Document” for this application form and list of well types from the beginning of this form):

**Well Category: Motor Vehicle**

- Motor Vehicle – Rinse Water, Snow/Ice Melt or Rain Drip

**Well Category: Other**

- Non-Contact Cooling Water Return Flow **with** Additives
- Non-Contact Cooling Water Return Flow with **NO** Additives
- Subsidence Control
- Other
- Aquaculture Return Flow
- Aquifer Recharge/Recovery
- Saline Water Intrusion Barrier
- Experimental Technology
- Process Water and Wastewater Disposal
- Aquifer Remediation
- Special Drainage – Groundwater Infiltration (Does Not Include Public Water System Wells)
- Special Drainage – Swimming Pools

3. Is the facility serviced by the UIC well(s) **both**:

a. For four (4) residential units or fewer; and,

b. Only used for residential purposes?  Yes  No

4. Are any of the wells included in this registration application also being used for another type of UIC Class V discharge?  Yes  No

5. If you answered “yes” to the above question 4, enter the well category and well type for the other type of discharge (refer to the Class V Injection Well Category, Well Type, and Fee Table in the Instructions):

---

Well Category

---

Well Type



# BRP WS 06 UIC Registration

---

## A. Registration Category & Fee (cont.)

### UIC Registration Fee

#### Notes:

*For Registration of More than One Type of Discharge* – This form may only be used to apply for UIC registration of the well types shown in the table at the top of Page 1. Only one type of UIC discharge (unique well category and well type combination [refer to BRP WS06 forms instructions]) shall be submitted per application form. A separate registration application, payment transmittal form, and applicable fee shall be submitted for each additional type of discharge even if one discharge well is used for more than one well category and well type combination.

*For Conversion of Unregistered Wells* - If your application is for the conversion of a well(s) that was not previously registered, you shall submit one application form, payment transmittal form, and applicable fee for the registration and closure or partial closure of each of the the unregistered well uses. You shall also submit a separate registration application form, payment transmittal form, and applicable fee for each type of new UIC Class V discharge well.

*For Conversion of Registered Wells* - If your application is for the conversion of a Registered UIC well(s), you shall submit a separate registration application form, payment transmittal form, and applicable fee for each type of new UIC Class V discharge. In addition one BRP WS06d Pre-Closure application must be submitted for the closure of the previous well use.

#### Fee Table Instructions

Determine which fee applies to your well(s) using the below fee table in conjunction with the answers you provided for Questions 1 (registration category), 2 (well type), and 3 (residential status).

Step 1: Find the Registration Category in the first row (this will limit the number of columns you have to choose from to either 1 or 2).

Step 2: In the second row find the one column that matches your response to Question 3.

Step 3: Follow this column downward to the row that matches your well category (selected in Question 2).



Massachusetts Department of Environmental Protection  
Bureau of Water Resources – Drinking Water Program

# BRP WS 06 UIC Registration

## A. Registration Category & Fee (cont.)

(from question 1 above)

(from question 2 above)

Your Registration Category Selection		1.a. or 1.f.		1.b. or 1.c.		1.d. or 1.e.
Your Answer to Question 3		Yes	No	Yes	No	Yes or No
Your Well Category	Your Well Type					
Motor Vehicle-Related	Motor Vehicle – Rinse Water, Snow/Ice Melt or Rain Drip					
Other	Non-Contact Cooling Water Return Flow <b>with</b> Additives	\$290		\$400		\$0
	Subsidence Control					
	Aquaculture Return Flow					
	Saline Water Intrusion Barrier					
	Other					
	Aquifer Recharge/Recovery					
	Non-Contact Cooling Water Return Flow with <b>NO</b> additives	\$110		\$220		
	Experimental Technology					
	Process Water and Wastewater Disposal	\$585		\$695		
	Aquifer Remediation					
Special Drainage – Groundwater Infiltration (Does Not Include Public Water System Wells)	\$0	\$110	\$0	\$220		
Special Drainage – Swimming Pools	\$0	\$290	\$0	\$400		

**Exceptions:** If the well is owned by a local or regional government the fee is \$0. If the well is owned by the Commonwealth of Massachusetts, the standard fees indicated above apply.

Enter fee here:           \$585          

**Annual Compliance Fee:** Currently there is no annual compliance fee associated with this Registration.



Massachusetts Department of Environmental Protection  
Bureau of Water Resources – Drinking Water Program

# BRP WS 06 UIC Registration

## B. Residential/Facility Information

Town of Orleans		Facility/Residential Street Address	
Facility/Residential Property Name		MA	02653
Orleans	City/Town	State	Zip Code

### Additional information (for facilities only):

Company Name (if appropriate)	(MassDEP Use Only) Facility #
Facility Public Water Supplier (PWS) ID# (if appropriate)	NAICS or SIC Code # (if applicable)
Facility Telephone Number	
Facility Mailing Address (if different from street address)	
City/Town	State Zip Code
EPA Hazardous Waste Generator ID # (if applicable)	EPA Hazardous Waste Generator ID # (if applicable)
Tenant Name (if applicable)	Tenant's EPA Haz. Waste Gen. ID# (if applicable)

## C. Current Status of Activity(ies) Being Registered (check one)

<input checked="" type="checkbox"/> Designed, but not yet constructed/modified/closed/converted	<input type="checkbox"/> Proposed activity partially completed or completed but not active
<input type="checkbox"/> Discharge discontinued but closure activities not completed	
<input type="checkbox"/> Proposed activity completed and active or closure completed	/ /
	Date placed in service (or closure completed)

Is the applicant requesting a waiver of the 30-day waiting period for closure applications?  Yes  No

If you answered "yes" to this question, indicate your reasons for requesting the waiver in a cover letter attached to this application.

## D. Owner/Operator Information

Town of Orleans	19 School Road	
Name of Owner	Address of Owner (enter "same" if same as facility)	
Orleans	MA	02653
City/Town	State	Zip Code
gmesurvey@town.orleans.ma.us		
Owner Email		
Owner's Legal Contact	Legal Contact Phone	Legal Contact Fax #
Name of Operator (if different from owner)	Address of Operator (enter "same" if same as facility)	
City/Town	State	Zip Code
Operator Email		
Operator's Legal Contact	Legal Contact Phone	Legal Contact Fax #





# BRP WS 06 UIC Registration

## I. Site Information (cont.)

Please list the type or types of other discharges:

---

---

Check any of the following that apply to this site:

- a.  Bureau of Waste Site Cleanup Priority Site \_\_\_\_\_  
If yes, file number
- b.  Bureau of Waste Site Cleanup Waiver Site \_\_\_\_\_  
If yes, file number
- c.  Superfund site \_\_\_\_\_  
If yes, Federal ID #

If the site is currently being regulated by the Bureau of Waste Site Cleanup, check any of the following that apply:

- Incident Response       Short Term Measure       Activity and Use Limitations (specify):

Confirm that the applicant has checked that the site does not have any activity restrictions with respect to limiting discharges on the site.

- No restrictions       Restrictions (Please explain; attach additional sheets if necessary)

### Location of Wells

Only enter the location of wells for the one well type you are including in this registration.

**Note: Latitude & Longitude are required data.** Well ID# is assigned by you and each well should have a unique ID#. Please check the closure box for any well(s) being completely closed to the well category and well type associated with this registration application.

If you need additional well locations, please provide all information on a separate sheet.

If you do not have access to a GPS unit, see instructions to this form for Internet tools that may be used to select well locations.



Massachusetts Department of Environmental Protection  
Bureau of Water Resources – Drinking Water Program

# BRP WS 06 UIC Registration

## I. Site Information (cont.)

Well ID (name and/or number)	Latitude in Decimal Degrees (e.g., 42.355767)	Longitude in Decimal Degrees (e.g., -71.060996)	Check here if well is either being physically closed or if all entry points (discharges) associated with this well category and well type will be discontinued.
			<input type="checkbox"/>
			<input type="checkbox"/>
			<input type="checkbox"/>
			<input type="checkbox"/>
			<input type="checkbox"/>
			<input type="checkbox"/>

Identify the method used for locating the latitude/longitude coordinates for the UIC Class V well(s) (check one):

Location Type (check one):

- Approximate location of well  
 Approximate center of area where discharge is located (i.e. center of drainfield or trench)

Accuracy – Estimated horizontal accuracy is less than (check one):

- +/-100 feet       +/- 500 feet       +/- 1,000 feet

Provide a narrative description of the site and the feature to be permitted. As an example: “The site is on the west side of Main Street, the third building north of High Street. The disposal field lies 100 feet off the southwest corner of the building.”

Injection points (method to be determined, likely direct-push) for application of solution of carbon substrate (diluted emulsified vegetable oil). Injection points would be spaced approximately 10 feet. In actual permit application description will be provided here for locations at Eldredge Park or Landfill. A separate UIC permit is required for each site.

### Attachments:

See instructions for this registration form for more details regarding the necessary attachments. Include the following:

- UIC Class V Well Motor Vehicle Rinse Water, Snow/Ice Melt, or Rain Drip Technical Compliance Form and Certification Statement (required for all registrations for this well type unless filing for Pre-Closure of all wells associated with this UIC registration application)
- Topographic or Orthophoto Map     Design Sheets     Site Plan (include bar scale)
- Existing Analytical Data     Narrative Statement     MSDS Sheets



# BRP WS 06 UIC Registration

## I. Site Information (cont.)

- Attach Well Completion Report (required for existing drilled wells)
- Cross Sectional Diagram Depicting All Underground Components of the UIC System
- Other information

## J. Injection Well Information

Number of Proposed New Wells

Maximum well depth

Number of Existing Wells

Month/Year of UIC well(s) construction (for existing wells)

Total Number of Existing Plus Proposed Wells

(do not include wells that are in a different UIC well category and well type (those must be registered under a separate UIC registration number))

### Well Construction (check all that apply):

- Drywell  Drilled Well  Manufactured System  Dug Well
- Improved Sinkhole  Drainfield/Leachfield  Trench Drain  Dustwater onto the ground
- Other (describe): Injection means to be determined. Direct push methods will likely be used.

Type of well seal (if applicable)

Well seal grout material

**Well Additives:** Are any well additives being used or proposed for use?  Yes  No

If you answered yes, attach a completed Proposal for Chemical Use (additive) in a UIC Class V Well supplemental form.

### Source of Injection Fluid and Potential Contaminants

Potable water (likely a hydrant)

None

Source of injection fluid #1

Potential contaminants for Source #1

Emulsified vegetable oil

None

Source of injection fluid #2

Potential contaminants for Source #2

Source of injection fluid #3

Potential contaminants for Source #3

Source of injection fluid #4

Potential contaminants for Source #4

### Treatment Devices:

If applicable, list any treatment devices prior to the injection point that will serve to remove contaminants from the water that is discharged into the UIC well(s) (attach specification sheets):

### Rate of Injection:

Maximum total rate of injection (of all wells combined) (gallons per minute): 50



# BRP WS 06 UIC Registration

## J. Injection Well Information (cont.)

**Note:** If maximum injection rate equals or exceeds 70 gallons per minute (100,000 gallons per day) and the source of the injection is from water withdrawn from a private source of groundwater or surface water, include a Water Management Act Program Form I with your UIC registration application.

Average discharge rate (gallons per day) 7,500

Month/Year ceased using well(s) for previous use(s) n/a

(only applies to wells being closed or converted if applicable)

### Number of Entry Points:

**Note:** the number of entry points equals the number of collection points to the system that are or will be discharging to the Class V UIC well(s). This includes each individual catch basin (including leaching catch basins which are considered both an entry point and a Class V UIC well), floor drain, sink, and process water collection point that discharges to the well.

# of entry points to existing system

Total # of entry points for proposed system (existing plus proposed)

### Well Setback Distances and Depths: (All distances must be provided in feet.)

Distance to nearest wetland or water body  
(enter "NA" if distance is greater than 200 feet)

Distance to nearest septic system  
(enter "NA" if distance is greater than 200 feet)

Distance to nearest building foundation (existing or proposed)  
(enter "NA" if distance is greater than 25 feet)

Distance to nearest property line  
(enter "NA" if distance is greater than 25 feet)

Depth to water table (feet)

Depth to bedrock (feet)

Soil type(s) at site - e.g., fill, sandy till, gravel, sand

Distance to nearest Public Water Supply source  
(e.g., well or reservoir; enter "NA" if distance is greater than 2,500')

Distance to nearest private drinking water well (existing or proposed)  
(enter "NA" if distance is greater than 1,250 feet)

## K. Additional Well-Type-Specific Information

This section contains several sub-sections of additional well information questions. Complete ONLY the sub-section that applies to your specific Well Type. All other sub-sections within this section should be left blank. If your Well Type is not listed below, leave Section K blank.

**Well Type = Aquifer Recharge/Recovery or  
Well Type = Saline Water Intrusion Barrier or  
Well Type = Subsidence Control:**

Is the proposed discharge "uncontaminated water" as defined in 314 CMR 5.00?

Yes     No



# BRP WS 06 UIC Registration

## K. Additional Well-Type-Specific Information (cont.)

**Well Type = Aquifer Remediation:**

What is the proposed use of the well(s)? (Check all that apply)

- Pump & Treat    Nutrient Addition    Construction Dewatering

**Well Type = Process Water and Wastewater Disposal or**

**Well Type = Special Drainage – Swimming Pool or**

**Well Type = Aquaculture Return Flow or**

**Well Type = Special Drainage – Groundwater Infiltration:**

Source of water (check all that apply):

- Private well    Surface Water    Public Water Supply    Ground Water

## L. Injection Well(s) or Activity(ies) Being Closed

**Note:** Section L should only be filled in if you are closing a well(s).

Is the closure being required by a federal, state, or local entity?    Yes    No

If yes, which regulatory entity? \_\_\_\_\_

\_\_\_\_\_  
Contact name for regulatory entity

\_\_\_\_\_  
Contact Phone

Number of Wells Being Closed with this Application \_\_\_\_\_

Will this proposed closure activity result in the complete closure of all wells associated with this registration application or with the existing UIC registration number?

- Yes    No

If you answered “no” to the above question, how many wells of this well category and well type will remain after the proposed closure activities have been completed?  
\_\_\_\_\_

Will the closure activities include the closure of one or more floor drains or plumbing alterations to redirect the discharge to a municipal sewer connection or industrial wastewater holding tank (IWHT)?

- Yes    No

If you answered yes you shall contact the local plumbing inspector to obtain the necessary plumbing permits/approvals and shall coordinate the scheduling of floor drain closure/plumbing alterations work with the plumbing inspector. You will be required to submit a copy of **Form WS1: Notice of Plumbing Inspector Approval to Seal Floor Drain** with your Post-Closure Notification Form. If applicable you shall also be required to submit copies of applicable municipal approvals for connecting your floor drains to the municipal sewer system or that you have applied for a MassDEP IWHT Certification.



# BRP WS 06 UIC Registration

## L. Injection Well(s) or Activity(ies) Being Closed (cont.)

The following three (3) data entry fields are only associated with the well type being registered with this application. Do not include the numbers of entry points associated with any converted new well type (if applicable).

Number of Entry Points to System before closure \_\_\_\_\_

Number of Entry Points proposed for closure \_\_\_\_\_

Number of Entry Points to System after closure \_\_\_\_\_

### Proposed or previously completed well closure activities (check all that apply):

Clean out well(s)                       Sample fluids/sediments in the bottom of the injection well(s).

Remove well(s) and any contaminated soil

Appropriate disposal of remaining fluids/sediments

Conversion to other Well Category/Type \_\_\_\_\_  
Well Category/Well Type

**Note:** a separate UIC registration application (BRP WS06) must be submitted for any conversion to a new well type.

Well and all entry points physically decommissioned

Partial Closure (some but not all entry points eliminated or well(s) still in use for other types of discharge)

Sample fluids/sediments from the area surrounding the injection well(s) (as applicable)

Other: \_\_\_\_\_

### Proposed Laboratory Analytical Parameters for Soil Sampling Activities:

**Note:** VOCs, VPH, EPH, and metals testing of soils are required for the closure of all motor vehicle wells.

VOCs (EPA method 8260C)    VPH    EPH    Metals (As, Ba, Cd, Cr, Pb, Hg, Ni, Se, Zn)

\_\_\_\_\_  
Other Soil Sampling Parameter

\_\_\_\_\_  
Other Soil Sampling Parameter

\_\_\_\_\_  
Other Soil Sampling Parameter

\_\_\_\_\_  
Other Soil Sampling Parameter

\_\_\_\_\_  
Other Soil Sampling Parameter

\_\_\_\_\_  
Other Soil Sampling Parameter

### Proposed Laboratory Analytical Parameters for Groundwater Sampling Activities:

\_\_\_\_\_  
Groundwater Sampling Parameter #1

\_\_\_\_\_  
Groundwater Sampling Parameter #2

\_\_\_\_\_  
Groundwater Sampling Parameter #3

\_\_\_\_\_  
Groundwater Sampling Parameter #4

\_\_\_\_\_  
Groundwater Sampling Parameter #5

\_\_\_\_\_  
Groundwater Sampling Parameter #6



# BRP WS 06 UIC Registration

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## M. Certifications for UIC Well(s) that is/are Being Registered for Continued Use or Proposed Future Use for the Well Type Activity Selected for this Application

### Operator

The injection well(s) described above is used for placement or injection of fluids into the ground. I understand that this well is subject to inventory requirements and compliance with the regulations under the Underground Injection Control Program established pursuant to the Safe Drinking Water Act, P.L. 93-523 and amendments, and UIC guidelines, and I hereby serve notice that the well is proposed or in service.

I agree:

1. That the well(s) described herein will not be used for discharges other than those described above (unless I have applied for and received the required Massachusetts and local government approvals);
2. That I will notify the MassDEP Drinking Water Program/UIC Program (on forms provided by the UIC program) if any of the information (including ownership, location or type of discharge, and installation of additional wells,) for the above well(s) changes, but before the change occurs (30-day minimum notice on ownership/operator and 60-day notice on all other changes) (ownership changes not required after a UIC registration number has been completely closed (i.e. all wells associated with the approved registration application have been closed and closure has been approved by MassDEP));
3. That I will notify the MassDEP Drinking Water Program/UIC Program (on forms provided by the UIC program) if the well(s) become(s) inactive;
4. That I will notify the MassDEP Drinking Water Program/UIC Program (on forms provided by the UIC program) when the above well(s) is no longer in use, but before physically decommissioning the well(s) and that I will file a Post-Closure Notification Form within seven days of completing the closure with the UIC program.
5. That I will maintain financial responsibility for the well described above; and,
6. That I will provide a sampling tap (approved by MassDEP) and allow sampling at the point of injection (not required for a closed well).

I certify under pains and penalties of law that I have personally examined and am familiar with the information submitted in this document and all attachments and based on my personal knowledge or inquiry of those agents immediately responsible for obtaining the information on my behalf, I believe the information is true, accurate, and complete. I am aware that there are significant penalties for submitting false information, including possible fines and imprisonment.

\_\_\_\_\_  
Signature of Operator

\_\_\_\_\_  
Date

\_\_\_\_\_  
Name of Operator

\_\_\_\_\_  
Position/Title



# BRP WS 06 UIC Registration

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## M. Certifications for UIC Well(s) that is/are Being Registered for Continued Use or Proposed Future Use for the Well Type Activity Selected for this Application (cont.)

**Owner (must be completed if owner has not signed above as operator)**

I certify that I have personally examined and am familiar with the information submitted in this document and agree to the installation, conversion, or closure of the discharge well(s) described in this application. I also agree that I will assume the responsibilities of the operator in the event that the operator leaves the property and a replacement operator has not been established and reported to MassDEP (on forms provided by the UIC program).

\_\_\_\_\_  
Signature of Owner

\_\_\_\_\_  
Date

\_\_\_\_\_  
Printed Name

\_\_\_\_\_  
Position/Title

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## N. Certifications for UIC Well(s) that is/are Being Registered for Complete Closure of all Future Activities Associated with the Well Type Selected for this Application

**Operator**

I certify under pains and penalties of law that I have personally examined and am familiar with the information submitted in this document and all attachments and based on my personal knowledge or inquiry of those agents immediately responsible for obtaining the information on my behalf, I believe the information is true, accurate, and complete. I am aware that there are significant penalties for submitting false information, including possible fines and imprisonment.

\_\_\_\_\_  
Signature of Operator

\_\_\_\_\_  
Date

\_\_\_\_\_  
Name of Operator

\_\_\_\_\_  
Position/Title

**Owner (must be completed if owner has not signed above as operator)**

I certify that I have personally examined and am familiar with the information submitted in this document and agree to the conversion or closure of the discharge well(s) described in this application.

\_\_\_\_\_  
Signature of Owner

\_\_\_\_\_  
Date

\_\_\_\_\_  
Printed Name

\_\_\_\_\_  
Position/Title

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Submit a signed and complete application package to: Send duplicate copies of this form to:

MassDEP  
Bureau of Resource Protection  
UIC Program  
One Winter Street, 5th Floor  
Boston, MA 02108

Local Board of Health  
Local Plumbing Inspector (for any applications involving the closure of floor drains or the installation of dual use ground source heat pump wells)

## **Appendix D**

### **Emulsified Vegetable Oil Product Information and Material Safety Data Sheet**

# Terra Systems, Inc.

## SRS<sup>®</sup>-FR Large Droplet Emulsified Vegetable Oil (EVO) Substrate for Fractured Rock Formations United States Patent No. RE40,448

The anaerobic bioremediation process uses either native or introduced microorganisms to degrade chlorinated solvents such as tetrachloroethene (PCE) and trichloroethene (TCE) to innocuous end products including ethene and ethane. An organic substrate must be added to the groundwater to generate reducing conditions and provide the necessary carbon and hydrogen to support biodegradation of the chlorinated solvents. The organic substrate can be a slow release substrate like Terra Systems' patented small droplet SRS<sup>®</sup> emulsified vegetable oil substrate. Terra Systems new and patented SRS<sup>®</sup>-FR, which has a larger droplet size is designed specifically for applications where adherence to the formation is key to making contact with the bacteria. It is designed to release bio-available hydrogen over a period of 3 to 5 years thus enhancing the long-term anaerobic biodegradation of the chlorinated solvents. SRS<sup>®</sup>-FR optimizes the naturally occurring biodegradation system by supplying the rate limiting factor (in this case hydrogen) in the degradation of CVOC's, certain pesticides/herbicides, perchlorate, and immobilization of certain metals (Cr, As, and some radionuclides).

### SRS<sup>®</sup>-FR Substrate Specifications

Terra Systems, Inc.'s manufacturing facility is configured to allow us to provide our customers with custom blended substrate packages without a cost premium. SRS<sup>®</sup>-FR package contains the following components:

Ingredient	Percent	SRS <sup>®</sup> -FR Emulsified Soybean Oil and Sodium Lactate Substrate
Food Grade Soybean Oil	60%	SRS <sup>®</sup> -FR is added to the groundwater to generate reducing conditions and provide the necessary carbon and hydrogen to support biodegradation of chlorinated solvents.
Food Grade Sodium Lactate	4 – 6%	At least 4% sodium lactate to rapidly generate anaerobic conditions.
Food grade Additives/ Preservatives/Proprietary Nutrients	<1%	Proprietary organic and inorganic nutrients such as yeast extract, nitrogen and phosphorus. Organic and inorganic nutrients have been shown to support the growth of the anaerobic microbial population.
Vitamin B <sub>12</sub>	<1%	At least 25 ppb of Vitamin B <sub>12</sub> , which has been demonstrated to be an important micronutrient to enhance dechlorination activity. He et al. 2007 investigated the effects of Vitamin B <sub>12</sub> on reductive dechlorination by <i>Dehalococcoides</i> . They found that <b>25 ppb of Vitamin B<sub>12</sub></b> gave the maximum stimulation of dechlorination.
Proprietary Emulsification Package	4-8%	The proprietary emulsion package combined with the large droplet size allows the soybean oil to adhere to the formation.
Droplet Size	NA	Mean Droplet size of 5 micron

### KEY BENEFITS OF SRS<sup>®</sup>-FR Emulsified Vegetable Oil (EVO) Substrate Include:

- Promotes biodegradation of PCE and TCE to non-toxic end products
- Large droplet size and proprietary emulsion package is ideal for maximum adherence.
- Low cost
- In situ application minimizes site disruptions
- Slow release formula eliminates continuous substrate additions
- SRS<sup>®</sup>-FR contains only non-toxic food grade materials, which results in green, sustainable remediation
- Can be used as a PRB to cut off plume migration
- Effective in source zones
- Reduces treatment time from decades to months and years

*For more information contact:*

**Michael Free**  
**Terra Systems, Inc. 1035 Philadelphia Pike Suite E, Wilmington, DE 19809**  
**(office): (302)798-9553 or (cell) 484-889-2214**  
**e-mail: [mfree@terrasystems.net](mailto:mfree@terrasystems.net)**  
**On the Web@ <http://www.terrasystems.net/>**



# 60% LARGE DROPLET SLOW RELEASE EMULSIFIED VEGETABLE OIL SUBSTRATE BUFFERED (SRS®-B) SAFETY DATA SHEET

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## 1. Product Identification

<b>Synonyms:</b>	60% Large Droplet Slow Release Substrate (SRS®-B) Buffered Emulsified Vegetable Oil (EVO)
<b>Recommended Use:</b>	Treatment of groundwater contaminated with chlorinated solvents and other anaerobically degradable compounds.
<b>Supplier:</b>	Terra Systems, Inc. 130 Hickman Road, Suite 1 Claymont, Delaware 19703 Telephone (302) 798-9553 Fax (302) 798-9554 <a href="http://www.terrasystems.net">www.terrasystems.net</a>

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## 2. Hazards Identification

### Emergency Overview

**Caution:** May cause eye irritation.

**Health Rating:** 1 - Slight

**Flammability Rating:** 1 - Slight

**Reactivity Rating:** 1 - Slight

**Contact Rating:** 1 - Slight

**Protective Equipment:** Goggles; Proper Gloves

**Storage Color Code:** Green (General Storage)

### Potential Health Effects

**Inhalation:** Not expected to be a health hazard. If heated, may produce vapors or mists that irritate the mucous membranes and cause irritation, dizziness, and nausea. Remove to fresh air. Possible irritant.

**Ingestion:** Not expected to be a health hazard via ingestion. Large doses may produce abdominal spasms, diarrhea, or rapid bowel evacuation.

**Skin Contact:** No adverse effects expected. May cause irritation or sensitization in sensitive individuals.

**Eye Contact:** May cause mild irritation, possible reddening.

**Chronic Exposure:** No information found.

**Aggravation of Pre-existing Conditions:** No information found.

### 3. Composition/Information on Ingredients

Ingredient	Synonyms	CAS #	Percent	Hazardous
Soy bean oil	Soya oil	8001-22-7	60%	No
Emulsifiers, lecithin, and proprietary nutrient package containing nitrogen, phosphorus and vitamin B <sub>12</sub>		Mixture	5 – 15%	No
Sodium lactate	2-hydroxypropionic acid sodium salt	72-17-3	<5%	Yes
Sodium Bicarbonate	Baking soda	144-5-8	<2	No
Magnesium Oxide	Magnesia	1309-48-4	<2	Yes
Water		7732-18-5	20 - 26%	No

The emulsifiers, lecithin, and nutrient package mixture is a trade secret and consists of ingredients of unknown acute toxicity.

### 4. First Aid Measures

<b>Inhalation:</b>	Not expected to require first aid measures. Remove to fresh air. Get medical attention for any breathing difficulty.
<b>Ingestion:</b>	If large amounts were swallowed, give water to drink and get medical advice.
<b>Skin Contact:</b>	Not expected to require first aid measures. Wash exposed area with soap and water. Get medical advice if irritation develops.
<b>Eye Contact:</b>	Immediately flush eyes with plenty of water for at least 15 minutes, lifting upper and lower eyelids occasionally. Get medical attention if irritation persists.

### 5. Fire Fighting Measures

<b>Fire:</b>	Flash point: >200 C (>392 F). Not considered to be a fire hazard. Isolate from heat and open flame.
<b>Explosion:</b>	Not considered to be an explosion hazard. Closed containers may explode if exposed to extreme heat.
<b>Fire Extinguishing Media:</b>	Dry chemical, foam, or carbon dioxide. Water spray may be ineffective on fire, but can protect fire-fighters and cool closed containers. Use fog nozzles if water is used.
<b>Special Information:</b>	In the event of a fire, wear full protective clothing and NIOSH-approved self-contained breathing apparatus with full face piece operated in the pressure demand or other positive pressure mode.



## 6. Accidental Release Measures

Clean-up personnel may require protective clothing. Absorb in sand, paper towels, "Oil Dry", or other inert material. Scoop up and containerize for disposal. Flush trace residues to sewer with soap and water. Containerized waste may be sent to an approved waste disposal facility.

---

## 7. Handling and Storage

Keep in a tightly closed container, stored in a cool, dry, ventilated area. Protect against physical damage. Containers of this material are not hazardous when empty since they do vapors or harmful substances; observe all warnings and precautions listed for the product. Do not store above 49 C (120 F). Keep container tightly closed and upright when not in use to prevent leakage.

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## 8. Exposure Controls/Personal Protection

<b>Airborne Exposure Limits:</b>	None established.
<b>Ventilation System:</b>	Not expected to require any special ventilation.
<b>Personal Respirators (NIOSH Approved):</b>	Not expected to require personal respirator usage.
<b>Skin Protection:</b>	Wear protective gloves and clean body-covering clothing.
<b>Eye Protection:</b>	Use chemical safety goggles and/or a full face shield where splashing is possible. Provide readily accessible eye wash stations and safety showers.
<b>Slips, Trips, and Falls:</b>	Material is slippery when spilled. Clean up with sand, paper towels, "Oil Dry", or other inert material.

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## 9. Physical and Chemical Properties

<b>Appearance:</b>	White liquid.
<b>Odor:</b>	Vegetable oil.
<b>Solubility:</b>	Miscible in water.
<b>Specific Gravity (water=1):</b>	0.95-0.98. 8.09 pounds per gallon.
<b>pH:</b>	6-9 (40% aqueous solution)
<b>% Volatiles by volume @ 21C (70F):</b>	Negligible.
<b>Boiling Point:</b>	≥ 100C (≥ 212F)
<b>Melting Point:</b>	No information found.
<b>Flash Point (F):</b>	No information found.
<b>Autoignition Temperature:</b>	No information found.
<b>Decomposition Temperature:</b>	No information found.
<b>Vapor Density (Air=1):</b>	No information found.
<b>Vapor Pressure (mm Hg):</b>	< 1.0 @ 20C (68F).
<b>Evaporation Rate (BuAc=1):</b>	No information found.
<b>Viscosity @23 C (73 F):</b>	213 centipoises (1.2 centipoises diluted 1:10)
<b>Partition Coefficient (octanol/water):</b>	No information found.

---

## 10. Stability and Reactivity

<b>Stability:</b>	Stable under ordinary conditions of use and storage.
<b>Reactivity:</b>	Not reactive under ordinary conditions.
<b>Hazardous Decomposition Products:</b>	Carbon dioxide and carbon monoxide may form when heated to decomposition.
<b>Hazardous Polymerization:</b>	Will not occur.
<b>Incompatibilities:</b>	Strong oxidizers, acids.
<b>Conditions to Avoid:</b>	Incompatibles. Isolate from heat and open flame.

---

## 11. Toxicological Information

<b>Soybean Oil:</b>	No information found on toxicology. It is not a carcinogen listed by IARC, NTP, NIOSH, OSHA, or ACGIH.
<b>Emulsifier/Nutrient Mixture:</b>	No information found on toxicology. It is not a carcinogen listed by IARC, NTP, NIOSH, OSHA, or ACGIH.
<b>Sodium Lactate:</b>	Oral rat LD50: 2,000 mg/kg. 100 mg caused mild irritation to rabbit eye in Draize test. This compound is not listed as a carcinogen by IARC, NTP, NIOSH, OSHA, or ACGIH.
<b>SRS-B:</b>	The toxicity of the mixture has not been measured.

---

## 12. Ecological Information

<b>Environmental Fate:</b>	No information found.
<b>Environmental Toxicity:</b>	No information found.
<b>Degradability:</b>	This product is completely biodegradable under both aerobic and anaerobic conditions.
<b>Soil Mobility:</b>	This compound will move with groundwater until the adsorbed onto the soil. Degradation products may be mobile.
<b>Bioaccumulation Potential:</b>	No information found.

---

## 13. Disposal Considerations

Whatever cannot be saved for recovery or recycling should be managed in an appropriate and approved waste disposal facility. Processing, use or contamination of this product may change the waste management options. State and local disposal regulations may differ from federal disposal regulations. Dispose of container and unused contents in accordance with federal, state and local requirements.

---

## 14. Transport Information

Not regulated.

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## 15. Regulatory Information



**OSHA STATUS:** This product is not hazardous under the criteria of the Federal OSHA hazard Communication Standard 29 CFR 1910.1200. However, thermal processing and decomposition fumes from this product may be hazardous as noted in Section 10.

**TSCA STATUS:** No component of this product is listed on the TSCA inventory.

**CERCLA (Comprehensive Response Compensation, and Liability Act):** Not reportable.

**SARA TITLE III (Superfund Amendments and Reauthorization Act)**

Section 312 Extremely Hazardous Substances: None

Section 311/312 Hazard Categories: Non-hazardous Under Section 311/312

Section 313 Toxic Chemicals: None

**RCRA STATUS:** If discarded in its purchased form, this product would not be a hazardous waste either by listing or by characteristic. However, under RCRA, it is the responsibility of the product user to determine at the time of disposal, whether a material containing the product or derived from the product should be classified as a hazardous waste. (40 CFR 261.20-24)

**CALIFORNIA PROPOSITION 65:** The following statement is made in order to comply with the California safe Drinking Water and Toxic Enforcement Act of 1986. The product contains no chemicals known to the State of California to cause cancer.

---

## 16. Other Information

**NFPA Ratings:**

Health: **1** Flammability: **1** Reactivity: **1**

**Date Prepared:**

June 23, 2014

**Revision Information:**

SDS Section(s) changed since last revision of document include: None.

**Disclaimer:**


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**Prepared by:**  
**Phone Number:**

Terra Systems, Inc.  
(302) 798-9553 (U.S.A.)

---

EOS PRO	PRODUCT INFORMATION SHEET Emulsified Oils Family																			
<p><b>Description</b></p> 	<p>EOS PRO (formerly 598B42) is a nutrient-enriched, DoD-validated, food-grade oil/water emulsion designed to quickly stimulate microbial activity while providing long-term nourishment to enhance anaerobic bioremediation of chlorinated solvents, nitrates, perchlorate, energetics, acid mine drainage, and other recalcitrant chemicals in contaminated groundwater. EOS PRO can also be used to reduce redox sensitive metals and radionuclides. The negative surface charges on the droplets combined with small droplet size promote effective transport in the subsurface.</p> <p>EOS PRO benefits:</p> <ul style="list-style-type: none"> <li>• Includes biostimulating vitamins and nutrients</li> <li>• Rapidly-biodegradable substrates to “jump start” bacterial growth</li> <li>• Slow release biodegradable substrates to promote long-term biological activity</li> <li>• Small oil droplet size</li> <li>• Negative surface charge</li> <li>• Neutral pH</li> <li>• Extensive third party validation</li> </ul> <p>EOS PRO incorporates the proven patented EOS® technologies that clients have trusted for more than a decade. Made in the USA with US farmed soybean oil.</p>																			
<p><b>Chemical &amp; Physical Properties</b></p>	<table border="1"> <thead> <tr> <th>Oil Emulsion Concentrate: EOS PRO</th> <th>Typical</th> </tr> </thead> <tbody> <tr> <td>Refined and Bleached US Soybean Oil (% by wt.)</td> <td>59.8</td> </tr> <tr> <td>Rapidly Biodegradable Soluble Substrate (% by wt.)</td> <td>4</td> </tr> <tr> <td>Other Organics (emulsifiers, food additives, etc.) (% by wt.)</td> <td>10</td> </tr> <tr> <td>Specific Gravity</td> <td>0.96 - 0.98</td> </tr> <tr> <td>pH (Standard Units)</td> <td>6.0 - 7.0</td> </tr> <tr> <td>Median Oil Droplet Size (microns)</td> <td>1.0</td> </tr> <tr> <td>Organic Carbon (% by wt.)</td> <td>74</td> </tr> <tr> <td>Mass of Hydrogen Produced (lbs. H<sub>2</sub> per lb. EOS PRO)</td> <td>0.25</td> </tr> </tbody> </table>		Oil Emulsion Concentrate: EOS PRO	Typical	Refined and Bleached US Soybean Oil (% by wt.)	59.8	Rapidly Biodegradable Soluble Substrate (% by wt.)	4	Other Organics (emulsifiers, food additives, etc.) (% by wt.)	10	Specific Gravity	0.96 - 0.98	pH (Standard Units)	6.0 - 7.0	Median Oil Droplet Size (microns)	1.0	Organic Carbon (% by wt.)	74	Mass of Hydrogen Produced (lbs. H <sub>2</sub> per lb. EOS PRO)	0.25
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<p><b>Packaging</b></p>	<p>Shipped in 55-gallon drums, 275-gallon IBC totes or bulk tankers (40,000 lbs.)</p>																			
<p><b>Handling &amp; Storage</b></p>	<p>EOS PRO is shipped as a ready-to-use concentrated emulsion that can be diluted with water in the field to prepare a high quality suspension for easy injection. EOS PRO has a low viscosity and can be distributed with commonly available pumps or continuous metering with a diluter (e.g., Dosatron™). Dilution ratios for EOS PRO commonly range from 4:1 to 20:1 (water: EOS PRO) depending on site conditions. EOS PRO injections should be followed with additional chase water to maximize distribution of EOS PRO into the formation.</p> <p>For best performance, use EOS PRO within 60 days of delivery and store at a temperature between 40°F (4°C) to 100°F (38°C).</p>																			



## MATERIAL SAFETY DATA SHEET

# EOS PRO, EOS LS, EOS 450, EOS XR

### 1. MANUFACTUER AND EMERGENCY CONTACT

**Manufacturer:**

**EOS Remediation, LLC**  
 1101 Nowell Road  
 Raleigh, NC 27607  
[www.EOSRemediation.com](http://www.EOSRemediation.com)  
**Phone:** 919-873-2204  
**Fax:** 919-873-1074

**24-Hour Emergency Contact:**

**ChemTel Inc.**  
 Phone: 1-800-255-3924  
**International**  
 Phone: 813-248-0585

**Date of Preparation:**  
 January 9, 2013

### 2. HAZARDOUS INGREDIENTS / IDENTITY INFORMATION

COMPONENT(S)	% by WEIGHT	CAS NO.	EXPOSURE LIMITS		
			OSHA PEL-TWA	ACGIH TLV-TWA	NIOSH REL-TWA
Soybean Oil	45 - 60*	8001-22-7	Mist: 15 mg/m <sup>3</sup> (total) 5 mg/m <sup>3</sup> (respirable)	NE	Mist: 10 mg/m <sup>3</sup> (total) 5 mg/m <sup>3</sup> (respirable)
Emulsifiers Trade Secret <sup>1,2</sup>	1 - 10	Proprietary	NE	NE	NE
Soluble Substrates Trade Secret <sup>1,2</sup>	4 - 8	Proprietary	Mist: 15 mg/m <sup>3</sup> (total) 5 mg/m <sup>3</sup> (respirable)	Mist: 10 mg/m <sup>3</sup>	NE
Organic Substrate Trade Secret <sup>1</sup>	0 - 10	Proprietary	NE	Mist: 10 mg/m <sup>3</sup>	NE
Food Additives / Preservatives Trade Secret <sup>1</sup>	0.1 - 1	Proprietary	NE	NE	NE
Nutrients / Extracts Trade Secret <sup>1,2</sup>	0 - 1	Proprietary	NE	NE	NE
Water	Balance	7732-18-5	NE	NE	NE

NE - Not established

1 - The precise composition of this product is proprietary information. A more complete disclosure will be provided to a physician in the event of a medical emergency.

2 - The soluble substrates and emulsifiers are generally recognized as safe for food contact.

\* - Percentage of soybean oil varies by product.

## 3. PHYSICAL / CHEMICAL CHARACTERISTICS

<b>pH:</b>	Neutral
<b>Boiling Point:</b>	212°F
<b>Specific Gravity:</b>	0.96-0.98; 0.92 (pure oil phase)
<b>Vapor Pressure:</b>	Not established
<b>Melting Point:</b>	Liquid at room temperature
<b>Percent Volatile by Volume (%):</b>	25 - 48 (as water)
<b>Vapor Density:</b>	Heavier than air
<b>Evaporation Rate:</b>	Not established
<b>Solubility in Water:</b>	Dispersible
<b>Appearance and Odor:</b>	White liquid with vegetable oil odor

## 4. FIRE AND EXPLOSION HAZARD DATA

<b>Flash Point:</b>	>300°F
<b>Flammable Limits:</b>	Not established
<b>Extinguishing Media:</b>	CO <sub>2</sub> , foam, dry chemical Note: Water, fog and foam may cause frothing and spattering.
<b>Special Fire Fighting Procedures:</b>	Wear self-contained breathing apparatus and chemical resistant clothing. Use water spray to cool fire exposed containers.
<b>Unusual Fire Hazards:</b>	Burning will cause oxides of carbon.
<b>Unusual Explosion Hazards:</b>	None

## 5. REACTIVITY DATA

<b>Stability:</b>	Stable
<b>Incompatibility:</b>	Strong acids and oxidizers
<b>Hazardous Decomposition Products:</b>	Thermal decomposition may produce oxides of carbon.
<b>Hazardous Polymerization:</b>	Will not occur
<b>Conditions to Avoid:</b>	None known

## 6. HEALTH HAZARD DATA

<b>Routes of Entry:</b>	Ingestion, dermal
<b>Health Hazards:</b>	
<b>Acute:</b>	Potential eye and skin irritant
<b>Chronic:</b>	None known
<b>Carcinogenicity:</b>	
<b>N.T.P:</b>	No
<b>IARC:</b>	No
<b>OSHA:</b>	No
<b>Signs and Symptoms of Exposure:</b>	None known
<b>Medical Conditions Aggravated by Exposure:</b>	None known

# MATERIAL SAFETY DATA SHEET

EOS<sub>PRO</sub>, EOS<sub>LS</sub>, EOS<sub>450</sub>, EOS<sub>XR</sub>

## Emergency First Aid Procedures:

<b>Inhalation:</b>	Remove to fresh air.
<b>Eyes:</b>	Flush with water for 15 minutes; if irritation persists see a physician.
<b>Skin:</b>	Wash with mild soap and water.
<b>Ingestion:</b>	Product is non-toxic. If nausea occurs, induce vomiting and seek medical attention.

## 7. PRECAUTIONS FOR SAFE HANDLING AND USE

<b>Handling and Storage:</b>	Do not store near excessive heat or oxidizers.
<b>Other Precautions:</b>	None
<b>Spill Response:</b>	Soak up with dry absorbent and flush area with large amounts of water.
<b>Waste Disposal Methods:</b>	Dispose of according to Federal and local regulations for non-hazardous waste.

## 8. CONTROL MEASURES

<b>Respiratory Protection:</b>	Not normally required.
<b>Ventilation:</b>	Local exhaust
<b>Protective Gloves:</b>	Recommended
<b>Eye Protection:</b>	Recommended
<b>Other Protective Clothing or Equipment:</b>	None

The information contained herein is based on available data and is believed to be correct. However, EOS Remediation, LLC makes no warranty, expressed or implied, regarding the accuracy of this data or the results to be obtained thereof. This information and product are furnished on the condition that the person receiving them shall make his/her own determination as to the suitability of the product for his/her particular purpose.

## **Appendix E**

### **Environmental Security Technology Certification Program – Supporting Calculations for EVO Amendment Dosages**

# SUBSTRATE ESTIMATING TOOL FOR ENHANCED ANAEROBIC BIOREMEDIATION OF CHLORINATED SOLVENTS

Version 1.2  
November 2010

## Site Data Input Table

TABLE S.1 - INPUT TABLE

## Calculation Tables

Table S.2 - Substrate  
Calculations in Hydrogen

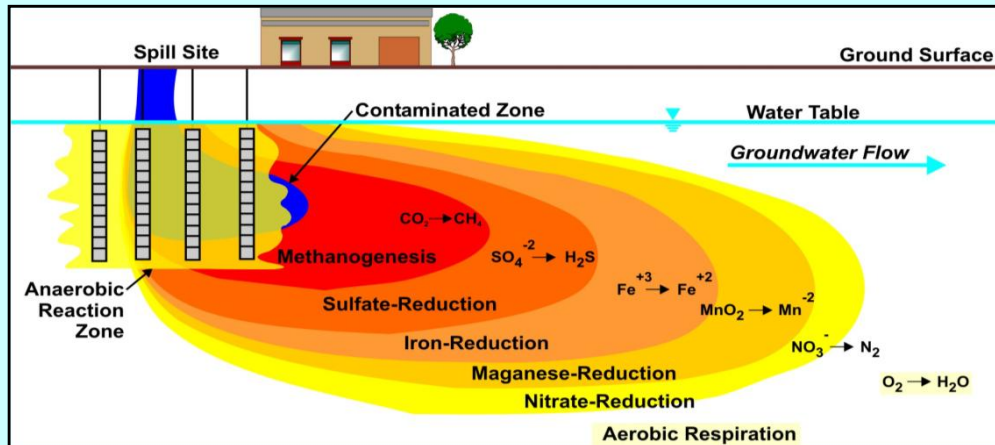
Table S.3 - Hydrogen Produced  
by Common Substrates

Table S.4 - Estimated  
Substrate Requirements for

## Output Summary Table

TABLE S.5 - OUTPUT TABLE

PRINT SUMMARY TABLE



This Substrate Estimating Tool for Enhanced Anaerobic Bioremediation of Chlorinated Solvents has been developed by Parsons Infrastructure & Technology Group, Inc. (Parsons) for the Environmental Security Technology Certification Program (ESTCP). This substrate estimating tool is made available on an as-is basis without guarantee or warranty of any kind, express or implied. The United States Government, Parsons, the authors, and the reviewers accept no liability resulting from the use of this substrate estimating tool or its documentation; nor does the above warrant or otherwise represent in any way the accuracy, adequacy, efficacy, or applicability of the contents hereof. This substrate estimating tool is intended solely for educational and site screening purposes. Implementation of the substrate estimating tool and interpretation or use of the results provided in the model are the sole responsibility of the user. The substrate estimating tool is provided free of charge for everyone to use, but is not supported in any way by the United States Government or Parsons. Mention of trade names in this report is for information purposes only; no endorsement is implied.

**Table S.1 Input for Substrate Requirements in Hydrogen Equivalents**

Site Name: **PRB Demonstration Test - Site B**

RETURN TO COVER PAGE

NOTE: Unshaded boxes are user input.				
1. Treatment Zone Physical Dimensions	Values	Range	Units	User Notes
Width (Perpendicular to predominant groundwater flow direction)	200	1-10,000	feet	
Length (Parallel to predominant groundwater flow)	10	1-1,000	feet	PRB orientation, 1 row of injection points
Saturated Thickness	40	1-100	feet	Assumed
Treatment Zone Cross Sectional Area	8000	--	ft <sup>2</sup>	
Treatment Zone Volume	80,000	--	ft <sup>3</sup>	
Treatment Zone Total Pore Volume (total volume x total porosity)	149,640	--	gallons	
Treatment Zone Effective Pore Volume (total volume x effective porosity)	149,640	--	gallons	
Design Period of Performance	3.0	.5 to 5	year	
Design Factor (times the electron acceptor hydrogen demand)	2.0	2 to 20	unitless	Lower design factor applied for denitrification PRB
<b>2. Treatment Zone Hydrogeologic Properties</b>				
Total Porosity	25%	.05-50	percent	Assumed value for well graded sands
Effective Porosity	25%	.05-50	percent	
Average Aquifer Hydraulic Conductivity	300	.01-1000	ft/day	Estimate from other Cape Cod sites
Average Hydraulic Gradient	0.002	0.0001-0.1	ft/ft	Estimate from other Cape Cod sites
Average Groundwater Seepage Velocity through the Treatment Zone	2.40	--	ft/day	
Average Groundwater Seepage Velocity through the Treatment Zone	876.0	--	ft/yr	
Average Groundwater Discharge through the Treatment Zone	13,108,464	--	gallons/year	
Soil Bulk Density	1.7	1.4-2.0	gm/cm <sup>3</sup>	
Soil Fraction Organic Carbon (foc)	0.02%	0.01-10	percent	
<b>3. Native Electron Acceptors</b>				
<b>A. Aqueous-Phase Native Electron Acceptors</b>				
Oxygen	3.0	0.01 to 10	mg/L	Average DO in AECOM wells along Main Street
Nitrate	15.00	0.1 to- 20	mg/L	Max. concentration based on monitoring wells near police station
Sulfate	10	10 to 5,000	mg/L	
Carbon Dioxide (estimated as the amount of Methane produced)	10.0	0.1 to 20	mg/L	
<b>B. Solid-Phase Native Electron Acceptors</b>				
Manganese (IV) (estimated as the amount of Mn (II) produced)	1	0.1 to 20	mg/L	Estimate from other Cape Cod sites
Iron (III) (estimated as the amount of Fe (II) produced)	20	0.1 to 20	mg/L	Estimate from other Cape Cod sites
<b>4. Contaminant Electron Acceptors</b>				
Tetrachloroethene (PCE)	0.000	--	mg/L	no CVOCs assumed
Trichloroethene (TCE)	0.000	--	mg/L	
Dichloroethene (cis-DCE, trans-DCE, and 1,1-DCE)	0.000	--	mg/L	
Vinyl Chloride (VC)	0.000	--	mg/L	
Carbon Tetrachloride (CT)	0.000	--	mg/L	
Trichloromethane ( or chloroform) (CF)	0.000	--	mg/L	
Dichloromethane (or methylene chloride) (MC)	0.000	--	mg/L	
Chloromethane	0.000	--	mg/L	
Tetrachloroethane (1,1,1,2-PCA and 1,1,2,2-PCA)	0.000	--	mg/L	
Trichloroethane (1,1,1-TCA and 1,1,2-TCA)	0.000	--	mg/L	
Dichloroethane (1,1-DCA and 1,2-DCA)	0.000	--	mg/L	
Chloroethane	0.000	--	mg/L	
Perchlorate	0.000	--	mg/L	
<b>5. Aquifer Geochemistry (Optional Screening Parameters)</b>				
<b>A. Aqueous Geochemistry</b>				
Oxidation-Reduction Potential (ORP)	50	-400 to +500	mV	Based on AECOM monitoring near Main St.
Temperature	16	5.0 to 30	°C	
pH	5.8	4.0 to 10.0	su	Based on AECOM monitoring near Main St.
Alkalinity	55	10 to 1,000	mg/L	
Total Dissolved Solids (TDS, or salinity)	100	10 to 1,000	mg/L	
Specific Conductivity	650	100 to 10,000	µs/cm	Based on AECOM monitoring near Main St.
Chloride	10	10 to 10,000	mg/L	
Sulfide - Pre injection	0.0	0.1 to 100	mg/L	
Sulfide - Post injection	0.0	0.1 to 100	mg/L	
<b>B. Aquifer Matrix</b>				
Total Iron	10000	200 to 20,000	mg/kg	
Cation Exchange Capacity	NA	1.0 to 10	meq/100 g	
Neutralization Potential	10.0%	1.0 to 100	Percent as CaCO <sub>3</sub>	

**NOTES:**

Table S.2 Substrate Calculations in Hydrogen Equivalents						
Site Name: PRB Demonstration Test - Site B		RETURN TO COVER PAGE				
NOTE: Open cells are user input.						
<b>1. Treatment Zone Physical Dimensions</b>		<b>Values</b>	<b>Range</b>	<b>Units</b>		
Width (Perpendicular to predominant groundwater flow direction)		200	1-10,000	feet		
Length (Parallel to predominant groundwater flow)		10	1-1,000	feet		
Saturated Thickness		40	1-100	feet		
Treatment Zone Cross Sectional Area		8000	--	ft <sup>2</sup>		
Treatment Zone Volume		80,000	--	ft <sup>3</sup>		
Treatment Zone Effective Pore Volume (total volume x effective porosity)		149,640	--	gallons		
Design Period of Performance		3.0	.5 to 5	year		
<b>2. Treatment Zone Hydrogeologic Properties</b>						
Total Porosity		0.25	.05-50			
Effective Porosity		0.25	.05-50			
Average Aquifer Hydraulic Conductivity		300	.01-1000	ft/day		
Average Hydraulic Gradient		0.002	0.1-0.0001	ft/ft		
Average Groundwater Seepage Velocity through the Treatment Zone		2.40	--	ft/day		
Average Groundwater Seepage Velocity through the Treatment Zone		876.0	--	ft/yr		
Average Groundwater Flux through the Treatment Zone		13,108,464	--	gallons/year		
Soil Bulk Density		1.7	1.4-2.0	gm/cm <sup>3</sup>		
Soil Fraction Organic Carbon (foc)		0.0002	0.0001-0.1			
<b>3. Initial Treatment Cell Electron-Acceptor Demand (one total pore volume)</b>						
<b>A. Aqueous-Phase Native Electron Acceptors</b>						
	Concentration (mg/L)	Mass (lb)	Stoichiometric demand (wt/wt h <sub>2</sub> )	Hydrogen Demand (lb)	Electron Equivalents per Mole	
Oxygen	3.0	3.75	7.94	0.47	4	
Nitrate (denitrification)	15.0	18.73	12.30	1.52	5	
Sulfate	10	12.49	11.91	1.05	8	
Carbon Dioxide (estimated as the amount of methane produced)	10.0	12.49	1.99	6.27	8	
<b>Soluble Competing Electron Acceptor Demand (lb.)</b>				<b>9.32</b>		
<b>B. Solid-Phase Native Electron Acceptors</b>						
(Based on manganese and iron produced)						
Manganese (IV) (estimated as the amount of Mn (II) produced)	1.4	461.16	27.25	16.92	2	
Iron (III) (estimated as the amount of Fe (II) produced)	20.0	6588.02	55.41	118.90	1	
<b>Solid-Phase Competing Electron Acceptor Demand (lb.)</b>				<b>135.82</b>		
<b>C. Soluble Contaminant Electron Acceptors</b>						
	Concentration (mg/L)	Mass (lb)	Stoichiometric demand (wt/wt h <sub>2</sub> )	Hydrogen Demand (lb)	Electron Equivalents per Mole	
Tetrachloroethene (PCE)	0.000	0.00	20.57	0.00	8	
Trichloroethene (TCE)	0.000	0.00	21.73	0.00	6	
Dichloroethene (cis-DCE, trans-DCE, and 1,1-DCE)	0.000	0.00	24.05	0.00	4	
Vinyl Chloride (VC)	0.000	0.00	31.00	0.00	2	
Carbon Tetrachloride (CT)	0.000	0.00	19.08	0.00	8	
Trichloromethane ( or chloroform) (CF)	0.000	0.00	19.74	0.00	6	
Dichloromethane (or methylene chloride) (MC)	0.000	0.00	21.06	0.00	4	
Chloromethane	0.000	0.00	25.04	0.00	2	
Tetrachloroethane (1,1,1,2-PCA and 1,1,2,2-PCA)	0.000	0.00	20.82	0.00	8	
Trichloroethane (1,1,1-TCA and 1,1,2-TCA)	0.000	0.00	22.06	0.00	6	
Dichloroethane (1,1-DCA and 1,2-DCA)	0.000	0.00	24.55	0.00	4	
Chloroethane	0.000	0.00	32.00	0.00	2	
Perchlorate	0.000	0.00	12.33	0.00	6	
<b>Total Soluble Contaminant Electron Acceptor Demand (lb.)</b>				<b>0.00</b>		
<b>D. Sorbed Contaminant Electron Acceptors</b>						
(Soil Concentration = Koc x foc x Cgw)						
	Koc (mL/g)	Soil Conc. (mg/kg)	Mass (lb)	Stoichiometric demand (wt/wt h <sub>2</sub> )	Hydrogen Demand (lb)	Electron Equivalents per Mole
Tetrachloroethene (PCE)	263	0.00	0.00	20.57	0.00	8
Trichloroethene (TCE)	107	0.00	0.00	21.73	0.00	6
Dichloroethene (cis-DCE, trans-DCE, and 1,1-DCE)	45	0.00	0.00	24.05	0.00	4
Vinyl Chloride (VC)	3.0	0.00	0.00	31.00	0.00	2
Carbon Tetrachloride (CT)	224	0.00	0.00	19.08	0.00	8
Trichloromethane ( or chloroform) (CF)	63	0.00	0.00	19.74	0.00	6
Dichloromethane (or methylene chloride) (MC)	28	0.00	0.00	21.06	0.00	4
Chloromethane	25	0.00	0.00	25.04	0.00	2
Tetrachloroethane (1,1,1,2-PCA and 1,1,2,2-PCA)	117	0.00	0.00	20.82	0.00	8
Trichloroethane (1,1,1-TCA and 1,1,2-TCA)	105	0.00	0.00	22.06	0.00	6
Dichloroethane (1,1-DCA and 1,2-DCA)	30	0.00	0.00	24.55	0.00	4
Chloroethane	3	0.00	0.00	32.00	0.00	2
Perchlorate	0.0	0.00	0.00	12.33	0.00	6
<b>Total Sorbed Contaminant Electron Acceptor Demand (lb.)</b>				<b>0.00</b>		

(continued)

Table S.2 Substrate Calculations in Hydrogen Equivalents					
<b>4. Treatment Cell Electron-Acceptor Flux (per year)</b>					
<b>A. Soluble Native Electron Acceptors</b>					
Concentration (mg/L)	Mass (lb)	Stoichiometric demand (wt/wt h <sub>2</sub> )	Hydrogen Demand (lb)	Electron Equivalents per Mole	
Oxygen	3.0	328.15	7.94	41.33	4
Nitrate (denitrification)	15.0	1640.76	10.25	160.07	5
Sulfate	10	1093.84	11.91	91.84	8
Carbon Dioxide (estimated as the amount of Methane produced)	10	1093.84	1.99	549.67	8
<b>Total Competing Electron Acceptor Demand Flux (lb/yr)</b>			<b>842.9</b>		
<b>B. Soluble Contaminant Electron Acceptors</b>					
Concentration (mg/L)	Mass (lb)	Stoichiometric demand (wt/wt h <sub>2</sub> )	Hydrogen Demand (lb)	Electron Equivalents per Mole	
Tetrachloroethene (PCE)	0.000	0.00	20.57	0.00	8
Trichloroethene (TCE)	0.000	0.00	21.73	0.00	6
Dichloroethene (cis-DCE, trans-DCE, and 1,1-DCE)	0.000	0.00	24.05	0.00	4
Vinyl Chloride (VC)	0.000	0.00	31.00	0.00	2
Carbon Tetrachloride (CT)	0.000	0.00	19.08	0.00	8
Trichloromethane ( or chloroform) (CF)	0.000	0.00	19.74	0.00	6
Dichloromethane (or methylene chloride) (MC)	0.000	0.00	21.06	0.00	4
Chloromethane	0.000	0.00	25.04	0.00	2
Tetrachloroethane (1,1,1,2-PCA and 1,1,2,2-PCA)	0.000	0.00	20.82	0.00	8
Trichloroethane (1,1,1-TCA and 1,1,2-TCA)	0.000	0.00	22.06	0.00	6
Dichloroethane (1,1-DCA and 1,2-DCA)	0.000	0.00	24.55	0.00	4
Chloroethane	0.000	0.00	32.00	0.00	2
Perchlorate	0.000	0.00	12.33	0.00	6
<b>Total Soluble Contaminant Electron Acceptor Demand Flux (lb/yr)</b>			<b>0.00</b>		
<b>Initial Hydrogen Requirement First Year (lb)</b>			<b>988.1</b>		
<b>Total Life-Cycle Hydrogen Requirement (lb)</b>			<b>2,673.9</b>		
<b>5. Design Factors</b>					
Microbial Efficiency Uncertainty Factor			2X - 4X		
Methane and Solid-Phase Electron Acceptor Uncertainty			2X - 4X		
Remedial Design Factor (e.g., Substrate Leaving Reaction Zone)			1X - 3X		
<b>Design Factor</b>			<b>2.0</b>		
<b>Total Life-Cycle Hydrogen Requirement with Design Factor (lb)</b>			<b>5,347.8</b>		
<b>6. Acronyms and Abbreviations</b>					
°C =degrees celsius	meq/100 g = milliequivalents per 100 grams				
µs/cm = microsiemens per centimeter	mg/kg = milligrams per kilogram				
cm/day = centimeters per day	mg/L = milligrams per liter				
cm/sec = centimeters per second	m/m = meters per meters				
ft <sup>2</sup> = square feet	mV = millivolts				
ft/day = feet per day	m/yr = meters per year				
ft/ft = foot per foot	su = standard pH units				
ft/yr = feet per year	wt/wt H <sub>2</sub> = concentration molecular hydrogen, weight per weight				
gm/cm <sup>3</sup> = grams per cubic centimeter					
kg of CaCO <sub>3</sub> per mg = kilograms of calcium carbonate per milligram					
lb = pounds					

**Table S.3**

**Hydrogen Produced by Fermentation Reactions of Common Substrates**

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Substrate	Molecular Formula	Substrate Molecular Weight (gm/mole)	Moles of Hydrogen Produced per Mole of Substrate	Ratio of Hydrogen Produced to Substrate (gm/gm)	Range of Moles H <sub>2</sub> /Mole Substrate
Lactic Acid	C <sub>3</sub> H <sub>6</sub> O <sub>3</sub>	90.1	2	0.0448	2 to 3
Molasses (assuming 100% sucrose)	C <sub>12</sub> H <sub>22</sub> O <sub>11</sub>	342	8	0.0471	8 to 11
High Fructose Corn Syrup (assuming 50% fructose and 50% glucose)	C <sub>6</sub> H <sub>12</sub> O <sub>6</sub>	180	4	0.0448	4 to 6
Ethanol	C <sub>2</sub> H <sub>6</sub> O	46.1	2	0.0875	2 to 6
Whey (assuming 100% lactose)	C <sub>12</sub> H <sub>22</sub> O <sub>11</sub>	342	11	0.0648	11
HRC <sup>®</sup> (assumes 40% lactic acid and 40% glycerol by weight)	C <sub>39</sub> H <sub>56</sub> O <sub>39</sub>	956	28	0.0590	28
Linoleic Acid (Soybean Oil, Corn Oil, Cotton Oil)	C <sub>18</sub> H <sub>32</sub> O <sub>2</sub>	281	16	0.1150	16

**Table S.4**

**Estimated Substrate Requirements for Hydrogen Demand in Table S.3**

Design Life (years): 3

Substrate	Design Factor	Pure Substrate Mass Required to Fulfill Hydrogen Demand (pounds)	Substrate Product Required to Fulfill Hydrogen Demand (pounds)	Substrate Mass Required to Fulfill Hydrogen Demand (milligrams)	Effective Substrate Concentration (mg/L)
Lactic Acid	2.0	119,476	119,476	5.42E+10	363
Sodium Lactate Product (60 percent solution)	2.0	119,476	247,875	5.42E+10	363
Molasses (assuming 60 percent sucrose)	2.0	113,501	189,168	5.15E+10	345
HFCS (assuming 40% fructose and 40% glucose by weight)	2.0	119,502	149,378	5.42E+10	363
Ethanol Product (assuming 80% ethanol by weight)	2.0	61,104	76,380	2.77E+10	185
Whey (assuming 100% lactose)	2.0	82,474	117,819	3.74E+10	250
HRC <sup>®</sup> (assumes 40% lactic acid and 40% glycerol by weight)	2.0	90,569	90,569	4.11E+10	220
Linoleic Acid (Soybean Oil, Corn Oil, Cotton Oil)	2.0	46,504	46,504	2.11E+10	141
Commercial Vegetable Oil Emulsion Product (60% oil by weight)	2.0	46,504	77,507	2.11E+10	141

**NOTES: Sodium Lactate Product**

1. Assumes sodium lactate product is 60 percent sodium lactate by weight.
2. Molecular weight of sodium lactate (CH<sub>3</sub>-CHOH-COONa) = 112.06.
3. Molecular weight of lactic Acid (C<sub>3</sub>H<sub>6</sub>O<sub>3</sub>) = 90.08 .
4. Therefore, sodium lactate product yields 48.4 (0.60 x (90.08/112.06)) percent by weight lactic acid.
5. Weight of sodium lactate product = 11.0 pounds per gallon.
6. Pounds per gallon of lactic acid in product = 1.323 x 8.33 lb/gal H<sub>2</sub>O x 0.60 x (90.08/112.06) = 5.31 lb/gal.

**NOTES: Standard HRC Product**

1. Assumes HRC product is 40 percent lactic acid and 40 percent glycerol by weight.
2. HRC<sup>®</sup> weighs approximately 9.18 pounds per gallon.

**NOTES: Vegetable Oil Emulsion Product**

1. Assumes emulsion product is 60 percent soybean oil by weight.
2. Soybean oil is 7.8 pounds per gallon.
3. Assumes specific gravity of emulsion product is 0.96.

**Table S.5 Output for Substrate Requirements in Hydrogen Equivalents**

Site Name:

PRB Demonstration Test - Site B

[RETURN TO COVER PAGE](#)

**1. Treatment Zone Physical Dimensions**

	Values	Units	Values	Units
Width (perpendicular to groundwater flow)	200	feet	61	meters
Length (parallel to groundwater flow)	10	feet	3.0	meters
Saturated Thickness	40	feet	12.2	meters
Design Period of Performance	3	years	3	years

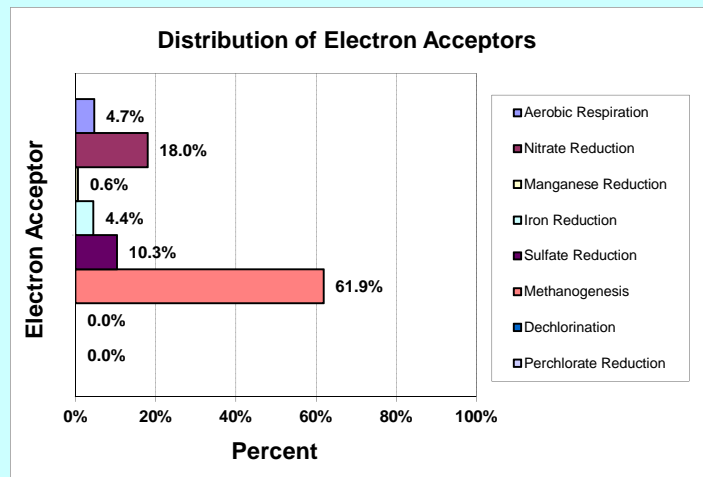
**2. Treatment Zone Hydrogeologic Properties**

	Values	Units	Values	Units
Total Porosity	0.25	percent	0.25	percent
Effective Porosity	0.25	percent	0.25	percent
Average Aquifer Hydraulic Conductivity	300	ft/day	1.1E-01	cm/sec
Average Hydraulic Gradient	0.002	ft/ft	0.002	m/m
Average Groundwater Seepage Velocity	2.40	ft/day	7.3E+01	cm/day
Average Groundwater Seepage Velocity	876	ft/yr	267.0	m/yr
Effective Treatment Zone Pore Volume	149,640	gallons	566,433	liters
Groundwater Flux (per year)	13,108,464	gallons/year	49,619,547	liters/year
Total Groundwater Volume Treated (over entire design period)	39,475,032	gallons total	149,425,075	liters total

**3. Distribution of Electron Acceptor Demand**

	Percent of Total	Hydrogen Demand (lb)
Aerobic Respiration	4.7%	124.459
Nitrate Reduction	18.0%	481.746
Sulfate Reduction	10.3%	276.575
Manganese Reduction	0.6%	16.923
Iron Reduction	4.4%	118.896
Methanogenesis	61.9%	1655.281
Dechlorination	0.0%	0.000
Perchlorate Reduction	0.0%	0.000
<b>Totals:</b>	<b>100.00%</b>	<b>2673.88</b>

Hydrogen demand in pounds/gallon:	6.77E-05
Hydrogen demand in grams per liter:	8.12E-03



**4. Substrate Equivalents: Design Factor =**

2.0

Product	Quantity (lb)	Quantity (gallons)	Effective Concentration (mg/L)	Effective concentration is for total volume of groundwater treated.
1. Sodium Lactate Product	247,875	22,534	363	as lactic acid
2. Molasses Product	189,168	15,764	345	as sucrose
3. Fructose Product	149,378	13,337	363	as fructose
4. Ethanol Product	76,380	11,070	185	as ethanol
5. Sweet Dry Whey (lactose)	117,819	sold by pound	250	as lactose
6. HRC®	90,569	sold by pound	220	as 40% lactic acid/40% glycerol
7. Linoleic Acid (Soybean Oil)	46,504	5,962	141	as soybean oil
8. Emulsified Vegetable Oil	77,507	9,937	141	as soybean oil

**Notes:**

- Quantity assumes product is 60% sodium lactate by weight.
- Quantity assumes product is 60% sucrose by weight and weighs 12 pounds per gallon.
- Quantity assumes product is 80% fructose by weight and weighs 11.2 pounds per gallon.
- Quantity assumes product is 80% ethanol by weight and weighs 6.9 pounds per gallon.
- Quantity assumes product is 70% lactose by weight.
- Quantity assumes HRC® is 40% lactic acid and 40% glycerol by weight.
- Quantity of neat soybean oil, corn oil, or canola oil.
- Quantity assumes commercial product is 60% soybean oil by weight.

# SUBSTRATE ESTIMATING TOOL FOR ENHANCED ANAEROBIC BIOREMEDIATION OF CHLORINATED SOLVENTS

Version 1.2  
November 2010

## Site Data Input Table

TABLE S.1 - INPUT TABLE

## Calculation Tables

Table S.2 - Substrate  
Calculations in Hydrogen

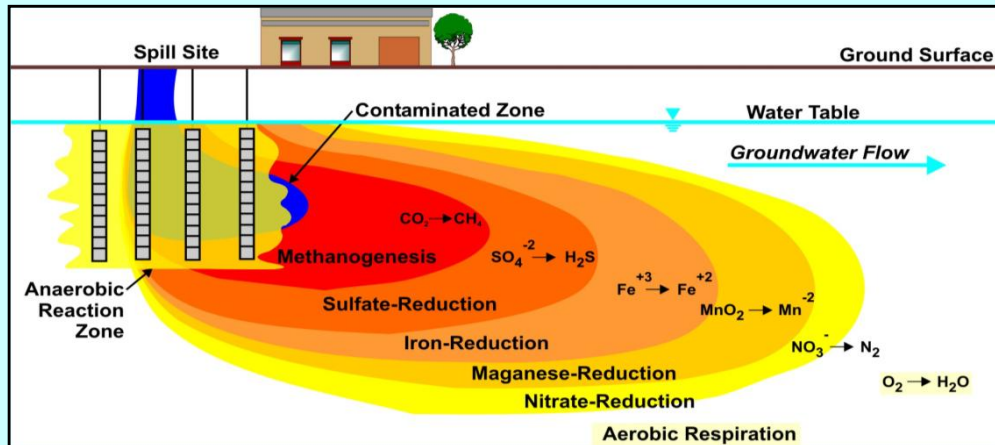
Table S.3 - Hydrogen Produced  
by Common Substrates

Table S.4 - Estimated  
Substrate Requirements for

## Output Summary Table

TABLE S.5 - OUTPUT TABLE

PRINT SUMMARY TABLE



This Substrate Estimating Tool for Enhanced Anaerobic Bioremediation of Chlorinated Solvents has been developed by Parsons Infrastructure & Technology Group, Inc. (Parsons) for the Environmental Security Technology Certification Program (ESTCP). This substrate estimating tool is made available on an as-is basis without guarantee or warranty of any kind, express or implied. The United States Government, Parsons, the authors, and the reviewers accept no liability resulting from the use of this substrate estimating tool or its documentation; nor does the above warrant or otherwise represent in any way the accuracy, adequacy, efficacy, or applicability of the contents hereof. This substrate estimating tool is intended solely for educational and site screening purposes. Implementation of the substrate estimating tool and interpretation or use of the results provided in the model are the sole responsibility of the user. The substrate estimating tool is provided free of charge for everyone to use, but is not supported in any way by the United States Government or Parsons. Mention of trade names in this report is for information purposes only; no endorsement is implied.

**Table S.1 Input for Substrate Requirements in Hydrogen Equivalents**

Site Name: **PRB Demonstration Test - Landfill**

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NOTE: Unshaded boxes are user input.				
	Values	Range	Units	User Notes
<b>1. Treatment Zone Physical Dimensions</b>				
Width (Perpendicular to predominant groundwater flow direction)	50	1-10,000	feet	Focused injection test
Length (Parallel to predominant groundwater flow)	10	1-1,000	feet	PRB orientation, 1 row of injection points
Saturated Thickness	40	1-100	feet	Assumed
Treatment Zone Cross Sectional Area	2000	--	ft <sup>2</sup>	
Treatment Zone Volume	20,000	--	ft <sup>3</sup>	
Treatment Zone Total Pore Volume (total volume x total porosity)	37,410	--	gallons	
Treatment Zone Effective Pore Volume (total volume x effective porosity)	37,410	--	gallons	
Design Period of Performance	3.0	.5 to 5	year	
Design Factor (times the electron acceptor hydrogen demand)	2.0	2 to 20	unitless	Lower design factor applied for denitrification PRB
<b>2. Treatment Zone Hydrogeologic Properties</b>				
Total Porosity	25%	.05-50	percent	Assumed value for well graded sands
Effective Porosity	25%	.05-50	percent	
Average Aquifer Hydraulic Conductivity	300	.01-1000	ft/day	Estimate from other Cape Cod sites
Average Hydraulic Gradient	0.002	0.0001-0.1	ft/ft	Estimate from other Cape Cod sites
Average Groundwater Seepage Velocity through the Treatment Zone	2.40	--	ft/day	
Average Groundwater Seepage Velocity through the Treatment Zone	876.0	--	ft/yr	
Average Groundwater Discharge through the Treatment Zone	3,277,116	--	gallons/year	
Soil Bulk Density	1.7	1.4-2.0	gm/cm <sup>3</sup>	
Soil Fraction Organic Carbon (foc)	0.02%	0.01-10	percent	
<b>3. Native Electron Acceptors</b>				
<b>A. Aqueous-Phase Native Electron Acceptors</b>				
Oxygen	2.0	0.01 to 10	mg/L	Based on AECOM monitoring near gift shop, 2016
Nitrate	30.00	0.1 to- 20	mg/L	Based on monitoring wells near landfill
Sulfate	10	10 to 5,000	mg/L	
Carbon Dioxide (estimated as the amount of Methane produced)	10.0	0.1 to 20	mg/L	
<b>B. Solid-Phase Native Electron Acceptors</b>				
Manganese (IV) (estimated as the amount of Mn (II) produced)	1	0.1 to 20	mg/L	Estimate from other Cape Cod sites
Iron (III) (estimated as the amount of Fe (II) produced)	20	0.1 to 20	mg/L	Estimate from other Cape Cod sites
<b>4. Contaminant Electron Acceptors</b>				
Tetrachloroethene (PCE)	0.000	--	mg/L	no CVOCs assumed
Trichloroethene (TCE)	0.000	--	mg/L	
Dichloroethene (cis-DCE, trans-DCE, and 1,1-DCE)	0.000	--	mg/L	
Vinyl Chloride (VC)	0.000	--	mg/L	
Carbon Tetrachloride (CT)	0.000	--	mg/L	
Trichloromethane ( or chloroform) (CF)	0.000	--	mg/L	
Dichloromethane (or methylene chloride) (MC)	0.000	--	mg/L	
Chloromethane	0.000	--	mg/L	
Tetrachloroethane (1,1,1,2-PCA and 1,1,2,2-PCA)	0.000	--	mg/L	
Trichloroethane (1,1,1-TCA and 1,1,2-TCA)	0.000	--	mg/L	
Dichloroethane (1,1-DCA and 1,2-DCA)	0.000	--	mg/L	
Chloroethane	0.000	--	mg/L	
Perchlorate	0.000	--	mg/L	
<b>5. Aquifer Geochemistry (Optional Screening Parameters)</b>				
<b>A. Aqueous Geochemistry</b>				
Oxidation-Reduction Potential (ORP)	150	-400 to +500	mV	Conservative estimate from other Cape Cod sites
Temperature	16	5.0 to 30	°C	Estimate from other Cape Cod sites
pH	5.8	4.0 to 10.0	su	Based on AECOM monitoring at landfill
Alkalinity	55	10 to 1,000	mg/L	
Total Dissolved Solids (TDS, or salinity)	100	10 to 1,000	mg/L	
Specific Conductivity	850	100 to 10,000	µs/cm	Based on AECOM monitoring at landfill
Chloride	10	10 to 10,000	mg/L	Estimate
Sulfide - Pre injection	0.0	0.1 to 100	mg/L	
Sulfide - Post injection	0.0	0.1 to 100	mg/L	
<b>B. Aquifer Matrix</b>				
Total Iron	10000	200 to 20,000	mg/kg	
Cation Exchange Capacity	NA	1.0 to 10	meq/100 g	
Neutralization Potential	10.0%	1.0 to 100	Percent as CaCO <sub>3</sub>	

**NOTES:**

<b>Table S.2 Substrate Calculations in Hydrogen Equivalents</b>						
<b>Site Name:</b>		<b>PRB Demonstration Test - Landfill</b>		<a href="#">RETURN TO COVER PAGE</a>		
NOTE: Open cells are user input.						
<b>1. Treatment Zone Physical Dimensions</b>						
Width (Perpendicular to predominant groundwater flow direction)	50	1-10,000	feet			
Length (Parallel to predominant groundwater flow)	10	1-1,000	feet			
Saturated Thickness	40	1-100	feet			
Treatment Zone Cross Sectional Area	2000	--	ft <sup>2</sup>			
Treatment Zone Volume	20,000	--	ft <sup>3</sup>			
Treatment Zone Effective Pore Volume (total volume x effective porosity)	37,410	--	gallons			
Design Period of Performance	3.0	.5 to 5	year			
<b>2. Treatment Zone Hydrogeologic Properties</b>						
Total Porosity	0.25	.05-50				
Effective Porosity	0.25	.05-50				
Average Aquifer Hydraulic Conductivity	300	.01-1000	ft/day			
Average Hydraulic Gradient	0.002	0.1-0.0001	ft/ft			
Average Groundwater Seepage Velocity through the Treatment Zone	2.40	--	ft/day			
Average Groundwater Seepage Velocity through the Treatment Zone	876.0	--	ft/yr			
Average Groundwater Flux through the Treatment Zone	3,277,116	--	gallons/year			
Soil Bulk Density	1.7	1.4-2.0	gm/cm <sup>3</sup>			
Soil Fraction Organic Carbon (foc)	0.0002	0.0001-0.1				
<b>3. Initial Treatment Cell Electron-Acceptor Demand (one total pore volume)</b>						
<b>A. Aqueous-Phase Native Electron Acceptors</b>						
	Concentration (mg/L)	Mass (lb)	Stoichiometric demand (wt/wt h <sub>2</sub> )	Hydrogen Demand (lb)	Electron Equivalents per Mole	
Oxygen	2.0	0.62	7.94	0.08	4	
Nitrate (denitrification)	30.0	9.37	12.30	0.76	5	
Sulfate	10	3.12	11.91	0.26	8	
Carbon Dioxide (estimated as the amount of methane produced)	10.0	3.12	1.99	1.57	8	
<b>Soluble Competing Electron Acceptor Demand (lb.)</b>				<b>2.67</b>		
<b>B. Solid-Phase Native Electron Acceptors</b>						
(Based on manganese and iron produced)						
Manganese (IV) (estimated as the amount of Mn (II) produced)	1.4	115.29	27.25	4.23	2	
Iron (III) (estimated as the amount of Fe (II) produced)	20.0	1647.00	55.41	29.72	1	
<b>Solid-Phase Competing Electron Acceptor Demand (lb.)</b>				<b>33.95</b>		
<b>C. Soluble Contaminant Electron Acceptors</b>						
	Concentration (mg/L)	Mass (lb)	Stoichiometric demand (wt/wt h <sub>2</sub> )	Hydrogen Demand (lb)	Electron Equivalents per Mole	
Tetrachloroethene (PCE)	0.000	0.00	20.57	0.00	8	
Trichloroethene (TCE)	0.000	0.00	21.73	0.00	6	
Dichloroethene (cis-DCE, trans-DCE, and 1,1-DCE)	0.000	0.00	24.05	0.00	4	
Vinyl Chloride (VC)	0.000	0.00	31.00	0.00	2	
Carbon Tetrachloride (CT)	0.000	0.00	19.08	0.00	8	
Trichloromethane ( or chloroform) (CF)	0.000	0.00	19.74	0.00	6	
Dichloromethane (or methylene chloride) (MC)	0.000	0.00	21.06	0.00	4	
Chloromethane	0.000	0.00	25.04	0.00	2	
Tetrachloroethane (1,1,1,2-PCA and 1,1,2,2-PCA)	0.000	0.00	20.82	0.00	8	
Trichloroethane (1,1,1-TCA and 1,1,2-TCA)	0.000	0.00	22.06	0.00	6	
Dichloroethane (1,1-DCA and 1,2-DCA)	0.000	0.00	24.55	0.00	4	
Chloroethane	0.000	0.00	32.00	0.00	2	
Perchlorate	0.000	0.00	12.33	0.00	6	
<b>Total Soluble Contaminant Electron Acceptor Demand (lb.)</b>				<b>0.00</b>		
<b>D. Sorbed Contaminant Electron Acceptors</b>						
(Soil Concentration = Koc x foc x Cgw)						
	Koc (mL/g)	Soil Conc. (mg/kg)	Mass (lb)	Stoichiometric demand (wt/wt h <sub>2</sub> )	Hydrogen Demand (lb)	Electron Equivalents per Mole
Tetrachloroethene (PCE)	263	0.00	0.00	20.57	0.00	8
Trichloroethene (TCE)	107	0.00	0.00	21.73	0.00	6
Dichloroethene (cis-DCE, trans-DCE, and 1,1-DCE)	45	0.00	0.00	24.05	0.00	4
Vinyl Chloride (VC)	3.0	0.00	0.00	31.00	0.00	2
Carbon Tetrachloride (CT)	224	0.00	0.00	19.08	0.00	8
Trichloromethane ( or chloroform) (CF)	63	0.00	0.00	19.74	0.00	6
Dichloromethane (or methylene chloride) (MC)	28	0.00	0.00	21.06	0.00	4
Chloromethane	25	0.00	0.00	25.04	0.00	2
Tetrachloroethane (1,1,1,2-PCA and 1,1,2,2-PCA)	117	0.00	0.00	20.82	0.00	8
Trichloroethane (1,1,1-TCA and 1,1,2-TCA)	105	0.00	0.00	22.06	0.00	6
Dichloroethane (1,1-DCA and 1,2-DCA)	30	0.00	0.00	24.55	0.00	4
Chloroethane	3	0.00	0.00	32.00	0.00	2
Perchlorate	0.0	0.00	0.00	12.33	0.00	6
<b>Total Sorbed Contaminant Electron Acceptor Demand (lb.)</b>				<b>0.00</b>		

(continued)

Table S.2 Substrate Calculations in Hydrogen Equivalents					
<b>4. Treatment Cell Electron-Acceptor Flux (per year)</b>					
<b>A. Soluble Native Electron Acceptors</b>					
	Concentration (mg/L)	Mass (lb)	Stoichiometric demand (wt/wt H <sub>2</sub> )	Hydrogen Demand (lb)	Electron Equivalents per Mole
Oxygen	2.0	54.69	7.94	6.89	4
Nitrate (denitrification)	30.0	820.38	10.25	80.04	5
Sulfate	10	273.46	11.91	22.96	8
Carbon Dioxide (estimated as the amount of Methane produced)	10	273.46	1.99	137.42	8
<b>Total Competing Electron Acceptor Demand Flux (lb/yr)</b>			<b>247.3</b>		
<b>B. Soluble Contaminant Electron Acceptors</b>					
	Concentration (mg/L)	Mass (lb)	Stoichiometric demand (wt/wt H <sub>2</sub> )	Hydrogen Demand (lb)	Electron Equivalents per Mole
Tetrachloroethene (PCE)	0.000	0.00	20.57	0.00	8
Trichloroethene (TCE)	0.000	0.00	21.73	0.00	6
Dichloroethene (cis-DCE, trans-DCE, and 1,1-DCE)	0.000	0.00	24.05	0.00	4
Vinyl Chloride (VC)	0.000	0.00	31.00	0.00	2
Carbon Tetrachloride (CT)	0.000	0.00	19.08	0.00	8
Trichloromethane ( or chloroform) (CF)	0.000	0.00	19.74	0.00	6
Dichloromethane (or methylene chloride) (MC)	0.000	0.00	21.06	0.00	4
Chloromethane	0.000	0.00	25.04	0.00	2
Tetrachloroethane (1,1,1,2-PCA and 1,1,2,2-PCA)	0.000	0.00	20.82	0.00	8
Trichloroethane (1,1,1-TCA and 1,1,2-TCA)	0.000	0.00	22.06	0.00	6
Dichloroethane (1,1-DCA and 1,2-DCA)	0.000	0.00	24.55	0.00	4
Chloroethane	0.000	0.00	32.00	0.00	2
Perchlorate	0.000	0.00	12.33	0.00	6
<b>Total Soluble Contaminant Electron Acceptor Demand Flux (lb/yr)</b>			<b>0.00</b>		
<b>Initial Hydrogen Requirement First Year (lb)</b>			<b>283.9</b>		
<b>Total Life-Cycle Hydrogen Requirement (lb)</b>			<b>778.5</b>		
<b>5. Design Factors</b>					
Microbial Efficiency Uncertainty Factor				2X - 4X	
Methane and Solid-Phase Electron Acceptor Uncertainty				2X - 4X	
Remedial Design Factor (e.g., Substrate Leaving Reaction Zone)				1X - 3X	
			<b>Design Factor</b>	<b>2.0</b>	
<b>Total Life-Cycle Hydrogen Requirement with Design Factor (lb)</b>			<b>1,557.1</b>		
<b>6. Acronyms and Abbreviations</b>					
°C =degrees celsius	meq/100 g = milliequivalents per 100 grams				
µs/cm = microsiemens per centimeter	mg/kg = milligrams per kilogram				
cm/day = centimeters per day	mg/L = milligrams per liter				
cm/sec = centimeters per second	m/m = meters per meters				
ft <sup>2</sup> = square feet	mV = millivolts				
ft/day = feet per day	m/yr = meters per year				
ft/ft = foot per foot	su = standard pH units				
ft/yr = feet per year	wt/wt H <sub>2</sub> = concentration molecular hydrogen, weight per weight				
gm/cm <sup>3</sup> = grams per cubic centimeter					
kg of CaCO <sub>3</sub> per mg = kilograms of calcium carbonate per milligram					
lb = pounds					

**Table S.3**

**Hydrogen Produced by Fermentation Reactions of Common Substrates**

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Substrate	Molecular Formula	Substrate Molecular Weight (gm/mole)	Moles of Hydrogen Produced per Mole of Substrate	Ratio of Hydrogen Produced to Substrate (gm/gm)	Range of Moles H <sub>2</sub> /Mole Substrate
Lactic Acid	C <sub>3</sub> H <sub>6</sub> O <sub>3</sub>	90.1	2	0.0448	2 to 3
Molasses (assuming 100% sucrose)	C <sub>12</sub> H <sub>22</sub> O <sub>11</sub>	342	8	0.0471	8 to 11
High Fructose Corn Syrup (assuming 50% fructose and 50% glucose)	C <sub>6</sub> H <sub>12</sub> O <sub>6</sub>	180	4	0.0448	4 to 6
Ethanol	C <sub>2</sub> H <sub>6</sub> O	46.1	2	0.0875	2 to 6
Whey (assuming 100% lactose)	C <sub>12</sub> H <sub>22</sub> O <sub>11</sub>	342	11	0.0648	11
HRC <sup>®</sup> (assumes 40% lactic acid and 40% glycerol by weight)	C <sub>39</sub> H <sub>56</sub> O <sub>39</sub>	956	28	0.0590	28
Linoleic Acid (Soybean Oil, Corn Oil, Cotton Oil)	C <sub>18</sub> H <sub>32</sub> O <sub>2</sub>	281	16	0.1150	16

**Table S.4**  
**Estimated Substrate Requirements for Hydrogen Demand in Table S.3**

Design Life (years): 3

Substrate	Design Factor	Pure Substrate Mass Required to Fulfill Hydrogen Demand (pounds)	Substrate Product Required to Fulfill Hydrogen Demand (pounds)	Substrate Mass Required to Fulfill Hydrogen Demand (milligrams)	Effective Substrate Concentration (mg/L)
Lactic Acid	2.0	34,787	34,787	1.58E+10	422
Sodium Lactate Product (60 percent solution)	2.0	34,787	72,172	1.58E+10	422
Molasses (assuming 60 percent sucrose)	2.0	33,047	55,079	1.50E+10	401
HFCS (assuming 40% fructose and 40% glucose by weight)	2.0	34,795	43,493	1.58E+10	422
Ethanol Product (assuming 80% ethanol by weight)	2.0	17,791	22,239	8.07E+09	216
Whey (assuming 100% lactose)	2.0	24,013	34,305	1.09E+10	292
HRC <sup>®</sup> (assumes 40% lactic acid and 40% glycerol by weight)	2.0	26,370	26,370	1.20E+10	256
Linoleic Acid (Soybean Oil, Corn Oil, Cotton Oil)	2.0	13,540	13,540	6.14E+09	164
Commercial Vegetable Oil Emulsion Product (60% oil by weight)	2.0	13,540	22,567	6.14E+09	164

**NOTES: Sodium Lactate Product**

1. Assumes sodium lactate product is 60 percent sodium lactate by weight.
2. Molecular weight of sodium lactate (CH<sub>3</sub>-CHOH-COONa) = 112.06.
3. Molecular weight of lactic Acid (C<sub>3</sub>H<sub>6</sub>O<sub>3</sub>) = 90.08 .
4. Therefore, sodium lactate product yields 48.4 (0.60 x (90.08/112.06)) percent by weight lactic acid.
5. Weight of sodium lactate product = 11.0 pounds per gallon.
6. Pounds per gallon of lactic acid in product = 1.323 x 8.33 lb/gal H<sub>2</sub>O x 0.60 x (90.08/112.06) = 5.31 lb/gal.

**NOTES: Standard HRC Product**

1. Assumes HRC product is 40 percent lactic acid and 40 percent glycerol by weight.
2. HRC<sup>®</sup> weighs approximately 9.18 pounds per gallon.

**NOTES: Vegetable Oil Emulsion Product**

1. Assumes emulsion product is 60 percent soybean oil by weight.
2. Soybean oil is 7.8 pounds per gallon.
3. Assumes specific gravity of emulsion product is 0.96.

**Table S.5 Output for Substrate Requirements in Hydrogen Equivalents**

Site Name:

PRB Demonstration Test - Landfill

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**1. Treatment Zone Physical Dimensions**

	Values	Units	Values	Units
Width (perpendicular to groundwater flow)	50	feet	15	meters
Length (parallel to groundwater flow)	10	feet	3.0	meters
Saturated Thickness	40	feet	12.2	meters
Design Period of Performance	3	years	3	years

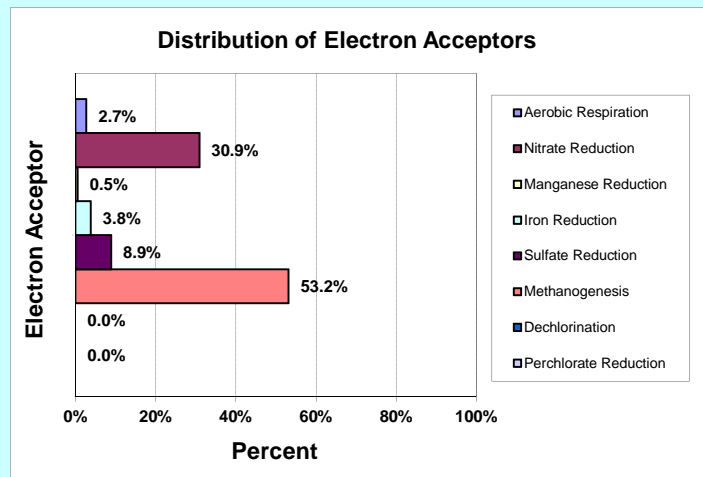
**2. Treatment Zone Hydrogeologic Properties**

	Values	Units	Values	Units
Total Porosity	0.25	percent	0.25	percent
Effective Porosity	0.25	percent	0.25	percent
Average Aquifer Hydraulic Conductivity	300	ft/day	1.1E-01	cm/sec
Average Hydraulic Gradient	0.002	ft/ft	0.002	m/m
Average Groundwater Seepage Velocity	2.40	ft/day	7.3E+01	cm/day
Average Groundwater Seepage Velocity	876	ft/yr	267.0	m/yr
Effective Treatment Zone Pore Volume	37,410	gallons	141,608	liters
Groundwater Flux (per year)	3,277,116	gallons/year	12,404,887	liters/year
Total Groundwater Volume Treated (over entire design period)	9,868,758	gallons total	37,356,269	liters total

**3. Distribution of Electron Acceptor Demand**

	Percent of Total	Hydrogen Demand (lb)
Aerobic Respiration	2.7%	20,743
Nitrate Reduction	30.9%	240,873
Sulfate Reduction	8.9%	69,144
Manganese Reduction	0.5%	4,231
Iron Reduction	3.8%	29,724
Methanogenesis	53.2%	413,820
Dechlorination	0.0%	0.000
Perchlorate Reduction	0.0%	0.000
<b>Totals:</b>	<b>100.00%</b>	<b>778.53</b>

Hydrogen demand in pounds/gallon:	7.89E-05
Hydrogen demand in grams per liter:	9.45E-03



**4. Substrate Equivalents: Design Factor =**

2.0

Product	Quantity (lb)	Quantity (gallons)	Effective Concentration (mg/L)	Effective concentration is for total volume of groundwater treated.
1. Sodium Lactate Product	72,172	6,561	422	as lactic acid
2. Molasses Product	55,079	4,590	401	as sucrose
3. Fructose Product	43,493	3,883	422	as fructose
4. Ethanol Product	22,239	3,223	216	as ethanol
5. Sweet Dry Whey (lactose)	34,305	sold by pound	292	as lactose
6. HRC®	26,370	sold by pound	256	as 40% lactic acid/40% glycerol
7. Linoleic Acid (Soybean Oil)	13,540	1,736	164	as soybean oil
8. Emulsified Vegetable Oil	22,567	2,893	164	as soybean oil

**Notes:**

- Quantity assumes product is 60% sodium lactate by weight.
- Quantity assumes product is 60% sucrose by weight and weighs 12 pounds per gallon.
- Quantity assumes product is 80% fructose by weight and weighs 11.2 pounds per gallon.
- Quantity assumes product is 80% ethanol by weight and weighs 6.9 pounds per gallon.
- Quantity assumes product is 70% lactose by weight.
- Quantity assumes HRC® is 40% lactic acid and 40% glycerol by weight.
- Quantity of neat soybean oil, corn oil, or canola oil.
- Quantity assumes commercial product is 60% soybean oil by weight.