

Memorandum

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Subject **Town of Orleans, MA
Water Quality and Wastewater Planning
Task Number 4.c.3 – Adaptive Management Plan – Final Technical Memorandum
for Non-Traditional Technology Performance Analysis**

Project Number 60476644

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Date 05/16/16

1. Introduction

The purpose of this Technical Memorandum (TM) is to present a systematic program for monitoring three non-traditional water improvement technologies: Shellfish, Floating Constructed Wetlands (FCW), and Permeable Reactive Barriers (PRBs) in ponds and estuaries in the Town of Orleans. References to non-traditional technologies that improve water quality and remove nitrogen are also included in the Cape Cod Commission Section 208 Plan Update, and the Orleans Consensus Plan and related documents.

There are several different aspects of non-traditional demonstration projects that should be quantified through monitoring, such as:

- Nitrogen (N) removal;
- Changes in water quality parameters such as turbidity and dissolved oxygen;
- Changes in nutrient retention and flux (e.g. coupled nitrification-denitrification) in underlying and nearby sediments;
- Project logistics during installation, operation and maintenance;
- Actual capital, operation and maintenance costs;
- Survival and growth of shellfish;
- Macrophyte survival and productivity (biomass and turnover) for FCW;
- Groundwater characteristics for PRBs; and
- Attributes of the carbon substrate such as distribution, and performance for PRBs.

To enable quantification as well as evaluation of these parameters for shellfish and FCW, monitoring plans are tailored to specific project locations, and are based on consideration of site features such as tidal inflows and outflows, water circulation and residence time, various physical and chemical attributes of the site (e.g., temperature, salinity, light, nutrients, sediment and depth), carbon balance, biological production and consumer biomass, expected nitrogen uptake relative to current nitrogen load and the size of the demonstration project.

The goal of the monitoring plan for a PRB is to validate patterns of N concentrations and groundwater flow to establish nitrate flux, patterns of substrate distribution, and the level of nitrate removal that is possible at the selected location.

Figure 1 shows the proposed locations for PRB, a FCW and shellfish demonstrations in several locations as described below.

2. Introduction: Demonstration Project Descriptions

A. Permeable Reactive Barrier (PRB) Project Description

Two TMs that detail the planning and design for a PRB demonstration in Orleans have been prepared:

- Site Characterization and Evaluation for Permeable Reactive Barriers (PRB-TM-1); and
- Draft Preliminary Engineering Work Plan for Permeable Reactive Barriers (PRB-TM-2).

Based on detailed evaluations described in PRB-TM-1, a preferred Demonstration Test site at Eldredge Park was selected based on key location features including existing available data, and the ability to provide results representative of other areas in the Town (Figure 1). Two additional potential demonstration sites are the Town Landfill and Gibson Road at Asa's Landing. These sites were identified as test site options and could also be implemented with the Eldredge Park project, given sufficient funding. Of the two additional sites, the Town Landfill demonstration location is viewed as highly advantageous, close in preference to the Eldredge Park location, and ideally would be implemented along with Eldredge Park.

The Town-owned Eldredge Park Demonstration site is located in the parking lot area between the playing fields off Eldredge Parkway. 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. A significant mass flux of nitrate in groundwater is expected at the Eldredge Park Demonstration site location (estimated 710 kg/yr as calculated with Watershed MVP), 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.

As detailed in PRB-TM-2, the first step in implementing a PRB in Orleans is to conduct Demonstration Tests. 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 determine the level of nitrate removal that can be achieved with PRBs and provide the data that is needed to prepare a full scale design. The Demonstration Tests will be evaluated by the following performance objectives:

- Achieve satisfactory distribution of the carbon substrate solution into the subsurface;



Figure 1 - Proposed locations for PRB, a FCW and shellfish demonstrations

- Establish and maintain necessary anaerobic (reducing) and groundwater flow conditions in the subsurface throughout the targeted treatment area;
- Demonstrate reduced nitrate concentrations and flux in groundwater through monitoring to extrapolate to total maximum daily load (TMDL) reduction targets for full scale implementation;
- Demonstrate PRB performance, TMDL compliance monitoring, and assess changes in water quality in the upgradient versus downgradient monitoring stations, including potential secondary water quality affects, through a groundwater monitoring program;
- Evaluate time frame for technology performance; and
- Obtain data for engineering evaluations and to optimize full scale design and implementation.

B. Floating Constructed Wetland (FCW) Project Description

Two TMs that detail the planning and design for a FCW demonstration in Orleans have been prepared:

- Site Characterization and Evaluation for Floating Constructed Wetlands (FCW-TM-1); and
- Floating Constructed Wetland NT Demonstration Project Work Plan (FCW-TM-2).

Kescayo Gansett (Lonnie's Pond) was selected as the preferred demonstration location (Figure 1). As detailed in FCW-TM-2, the most effective method to capture the nitrogen load in surface water entering Lonnie's Pond using FCWs, is to locate the units directly in front of two distinct discharge areas: the drainage pipe located in the northwest section of the pond, just north of the public access ramp, or the herring run water control structure and fish ladder, located in the southwest section of the pond, south of the public access ramp; and, to further characterize differences in water quality between the freshwater entering the pond and the salt water entering the pond, the second FCW unit should be located near the mouth of the tidal channel that connects the pond with The River.

Figure 2 is a schematic and installation of a FCW project. System components include:

- **Floating modules** which are constructed out of 4-inch welded HPDE pipe. Each rectangular module is approximately 6 feet by 12.5 feet and is divided into 2 sections. Mesh (1.5-inch hex HDPE mesh) is welded to the underside of each module. The modules and islands are custom units built for this demonstration project. Each module has welded flanges so they can be bolted together. Nine modules are bolted together to form a cluster. Each cluster is anchored using helical embedment anchors and are tied to other clusters with ½-inch double braided polyester rope. There will be a total of two units, each approximately 200 feet by 80 feet. Each FCW module is covered in a plant based polymer with openings to allow for planting plugs without cutting the blanket.
- **Anchoring** of the islands is achieved by using helical embedment anchors driven into the seabed. The final type and number of anchors and mooring lines is evaluated as the design progresses, but the current estimate is that four anchors and four mooring cables are required per nine-module cluster. Helical anchors provide benefits including high pull strength, and easy installation and removal.

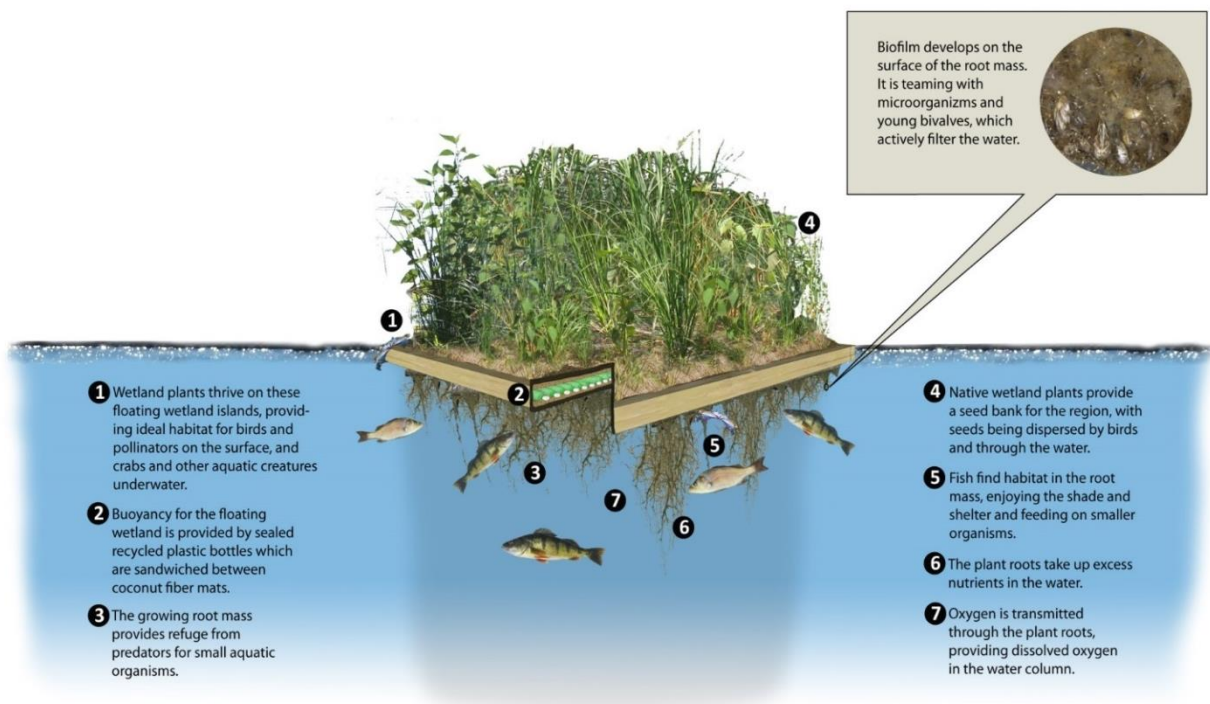


Figure 2 - FCW Schematic and Installation

- Mooring lines** for the islands utilize a combination of galvanized steel cable and elastic mooring units. The combination will allow for continual tension of the mooring lines for minimal impact to the benthic environment, even at low tide, while also allowing the structure to move with the changing tides. Elastic mooring reduces floating island movement by keeping the island close to its constructed footprint while also dampening the movement of the individual units. The anchor, mooring and connection systems are designed to resist forces approaching from all directions. The mooring and unit-to-unit connections are designed with redundancy to prevent the floating islands from becoming detached and free-floating around the pond. Each FCW unit is secured to the seabed by one line and secured internally with redundant unit-to-unit connections.
- Initial species** to be planted is *Spartina alterniflora*, which is obtained from local sources approved by the Town of Orleans. *S. alterniflora* was determined to be the most suitable for the initial planting due to its proven ability to quickly become established in the first growing season in salt waters. Plants are placed on one-foot centers, for a total of 72 plants per unit. The roots of the *S. alterniflora* will grow from the surface through the porous matrix to the subaquatic environment, and will thus be available to the subaqueous community as habitat. After the first growing season, a diversity of plants can be added to the islands at the beginning of the growing season.
- Waterfowl fencing** is placed around each unit to deter use of the mats by waterfowl and shorebirds. Fencing will include posts along the edges of the islands, and string and flagging attached to the posts that crisscross the islands. The waterfowl fencing is removed after the first growing season.

C. Shellfish Project Descriptions

Two TMs that detail the planning and design for a shellfish demonstration in Orleans have been prepared:

- Site Characterization and Evaluation for Aquaculture/Shellfish Propagation (SHEL-TM-1); and
- Preliminary Engineering Design and Work Plan for Preferred Site(s) (SHEL-TM-2).

The following four demonstration projects were described in SHEL-TM-2 and shown in Figure 1:

- Increased Quahog Population and Propagation in Town Cove and Pleasant Bay
- Lonnie's Pond Oyster Singles Installation
- Quanset Oyster Bed with Bottom Planting
- Enhanced Shellfish Aquaculture in Pleasant Bay and Town Cove

Eastern oyster larvae (*Crassostrea virginica*) produced in a hatchery can be "set" on cultch after a larval stage spent feeding in the water column. This spat can also be induced to set on microscopic shell fragments to produce seemingly unattached "singles". When attached to a substrate, this spat, invisible to the naked eye, is often called "spat-on-shell" or "remote set". The waters of Pleasant Bay do not have a naturally-occurring oyster population that could spawn. To establish an oyster bed in areas where there is no natural set, remote set can be used to introduce oysters into the growing environment if water and sediment conditions are appropriate for oyster growth and production.

1) Baseline Quahog Population and Propagation Planning

Key reasons for this demonstration project:

- Assess potentially suitable bottom conditions for enhanced quahog planting;
- Establishment of a baseline population count to quantify success of future propagation efforts, and determine capacity for additional quahogs; and
- Quantification of quahog populations in areas historically planted as part of municipal propagation.

In Town Cove and parts of Pleasant Bay, expansion of municipal quahog propagation is recommended to establish maximum practical densities that can be grown and harvested to allow significant water quality changes to occur and be correlated to numbers of new quahogs. Historically, quahogs have been grown successfully through the Town's propagation program, and there is suitable bottom in both Town Cove and Pleasant Bay for increased quahog planting. Based on site reviews, it was determined that there are existing populations of quahogs throughout Town Cove and Pleasant Bay. Prior to undertaking a quahog demonstration project baseline population numbers should be established. This will provide an estimate of current quahog densities in specific areas and increase the Town's understanding of where additional quahogs could be planted as part of a demonstration project.

Once the baseline population is established, the specific quantities and sizes of additional quahogs can be recommended as part of an expanded quahog propagation program for certain areas in Town Cove and Pleasant Bay.

2) Oyster Singles In Floating Bags in Lonnie's Pond

Key reasons for a demonstration project in Pleasant Bay terminal ponds:

- Water quality is most degraded in terminal ponds;
- Oyster gear-based systems create diverse habitats that provide ecosystems services;
- A demonstration is needed to determine whether oysters can uptake nitrogen and make a measurable improvement in water quality in terminal ponds;
- Terminal ponds have fine-grained, soft sediment that is often anoxic, which precludes bottom-planting;
- Oyster singles will be maintained in floating bags; and
- Predation and disease may be minimized by growing larger seed stock in the first year.

The first year plan for Lonnie's Pond is to grow between 170,000 – 340,000 oyster singles, starting at a size of at least ½ inch, in floating bags. The foundational work conducted by the Cape Cod Cooperative Extension in Lonnie's Pond (Clark, 2007) provides two valuable insights that form the basis of this demonstration design. First, oyster remote set will grow successfully in Lonnie's Pond. Second, bottom planting remote set leads to very high mortality due to predation and siltation. The current phased approach builds on these lessons and focuses on growing oysters that are functioning at adult size for the purpose of water quality and sediment assessments.

This demonstration design also mitigates against the known issues with predation and siltation by maintaining the oysters in floating gear. Monitoring of water quality, sediment impacts, and oyster growth and nitrogen content will provide critical evidence regarding the environmental aspects of shellfish cultivation. This information will help define future shellfish cultivation programs. Additionally, operation and maintenance costs and local stakeholder responses will be documented to inform future decision making.

3) Quanset Oyster Bed Installation

Key reasons for a demonstration project in Quanset:

- Oyster beds are often created by growing remote set (spat-on-shell) in gear for a period of time, then bottom-planting on suitable substrate;
- Oyster beds have higher density than gear-based systems per unit area, and create diverse habitats that provide ecosystems services;
- Demonstration needed to determine whether oyster beds can become a self-sustaining population in Pleasant Bay; and
- Predation and disease must be considered for this growing option.

The oyster bed demonstration projects involve growing remote sets and planting them in suitable areas, resulting in bed-like grow-out under the diverse environmental conditions experienced over the course of a typical Pleasant Bay growing season. Remote sets are firm substrates, or cultch, such as hard clam shells, with oyster spat attached. The methodology proposed for establishing an oyster bed off-bottom in trays in the terminal ponds of Pleasant Bay is modeled after a successful program in Mashpee, MA. Candidate

ponds include Meetinghouse Pond, Kescayo Gansett (Lonnie's) Pond, Arey's Pond, and sections of The River and Namequoit. Paw Wah Pond is also a possibility, but a relay out of this area will be required once the oysters are large enough to be harvested because this pond is currently closed to shellfishing. These ponds will be evaluated with the town to determine the preferred site.

The technique for establishing an oyster bed in the Quanset Pond area is similar to techniques used throughout Cape Cod, and recently implemented successfully in West Falmouth Harbor, MA. Both techniques begin with installing remote sets in trays and/or floating bags for an initial growing period. Harvest occurs by bringing trays to shore and opening this area to recreational harvest. In the Quanset area, remote sets could be bottom planted after approximately eight weeks. The remote sets will likely be planted under the bags and trays in which they were initially grown. The significant benefit of planting remote sets after a maturation period is that it allows the oyster spat to mature in a protected environment, thus reducing predation and mortality. Planting remote sets when oysters have reached over 1.5 inches (38 mm) in size also reduces mortality caused by siltation. Harvest occurs by opening this area to recreational harvest.

Growing out remote sets in both trays as well as floating bags with bottom-planting will enable an evaluation of the growth and survival rates of each technique. Moreover, evaluating the potential for a bottom-planting oyster remote set at Quanset will help determine the feasibility of expanding oyster beds in other part of Pleasant Bay where there is suitable substrate, such as areas along the Upper and Lower River, Namequoit, and Pochet. Maintaining oyster beds in off-bottom trays is a technique that is replicable to any area in Orleans where the bottom is not a suitable substrate for direct planting. Meetinghouse Pond, Kescayo Gansett (Lonnie's) Pond, Arey's Pond, Paw Wah and sections of The River and Namequoit are all suitable areas for remote sets in off-bottom trays.

4) Shellfish Aquaculture

Key reasons for a shellfish aquaculture demonstration project:

- In Orleans, there are twelve aquaculture leases in Pleasant Bay and one in Town Cove. Eastham has approximately thirteen leases in Town Cove;
- Aquaculture improvements would increase the number of shellfish being grown in Orleans;
- Meaningful dialogue with growers is needed to build an understanding of the practical extent to which shellfish aquaculture can contribute to the town's water quality goals;
- Working with growers will also help define the needs of this group relative to the town's numerical goals for N removal using shellfish; and
- Explore the possibility of additional leases in Town Cove.

The demonstration methodology proposed for Little Pleasant Bay involves working with the growers on the town's existing private shellfish leases. There are currently 12 leases in Pleasant Bay with an average size of 1.75 acres. Typically, single oysters are raised from seed to harvest size in trays, bags and cages. Seed is sometimes purchased at a size large enough to install directly in gear. Smaller seed requires grow-out in an on-shore upweller. In total, growers are harvesting approximately 700,000 oysters annually from the leases in Pleasant Bay. Harvesting occurs year-round. To avoid ice damage over the winter, shellfish are submerged to deeper depths or are bottom-planted.

Working with growers can create opportunities to demonstrate the water quality benefits as well as implementation logistics and practical densities of oyster aquaculture. Part of the reason for conducting demonstrations is to learn site-specific factors and adjust farming practices accordingly. Local growers have decades of field experience working in Pleasant Bay and Town Cove, and have learned how to manage and operate within the varying conditions in this location. They have evolved systems based on trial and error for anticipating weather and other events that impact shellfish survival. Successful farming requires local knowledge because implementation techniques need to be tailored to a given site. This project entails working with growers to optimize shellfish harvest numbers by identifying the needs of this group to increase numbers grown. A preliminary monitoring plan has already been developed for this site and is contained in the "Phase I: Orleans Shellfish Operations and Program Expansion Plan" Technical Memorandum dated June, 2015.

The expansion of private leases for oyster aquaculture in certain areas of Town Cove is also an important option to pursue. Oyster aquaculture in gear, off the bottom would be the only method of growing in this area due to the oyster drill population. The expansion of private grants requires several permitting steps beginning with a recommendation from the Board of Selectmen to the MA Division of Marine Fisheries (DMF). A study of the feasibility of expanding private aquaculture leases is needed to assess the Town's interest in this approach for shellfish aquaculture in Town Cove.

This demonstration will build on these established growing methods, and includes three components:

- Discussions with growers to evaluate current growing practices, and opportunities for improving operations;
- Working with growers to establish a total number of shellfish that can be grown and harvested annually for all leases in aggregate; and
- Evaluate areas in Town Cove for expanding shellfish leases.

3. Monitoring Plans

In this section, monitoring programs for each non-traditional technology are presented:

A. PRB Demonstration Monitoring for Initial Characterization and Demonstration Planning

As detailed in PRB-TM-2, AECOM is currently performing initial subsurface site characterizations at representative sites in Orleans. These hydrogeological investigations provide critical information to support the final design of PRB demonstration tests. At four locations, including 82 Main Street, Snow Library, the police station and the landfill, data from soil borings have been collected 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 this investigation. Monitoring well locations are surveyed for elevation and location, and the depth to groundwater is 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 is estimated using observed hydraulic gradient and soil conditions. Location and depth of the salt water interface is identified where present within the investigated depth. Groundwater sampling results and related calculations are available as of March 2016 and are being used to inform demonstration test design.

The approximate locations of the proposed PRB demonstrations are shown on Figures 3 and 4 for Eldredge Park and the landfill, respectively. Demonstration test PRB lengths are 200 feet at Eldredge Park and 50 feet at the Landfill site, and include one line of injection points spaced 10 feet apart. Demonstration test locations are proposed to be shorter distances than full scale PRBs to assess construction/implementation and allow adequate monitoring of groundwater conditions in the vicinity of the PRBs as an initial validation of performance. 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). However, the initial subsurface groundwater investigations currently underway will provide appropriate data to more accurately define the necessary vertical depth of injected Emulsified Vegetable Oils (EVO) for the two proposed PRB demonstration locations.

Installing and monitoring a demonstration PRB involves a phased approach. Phase I includes baseline groundwater monitoring, and an initial injection test. Using the results of Phase I monitoring, a final design can be prepared. Phase II involves installing a PRB demonstration based on this final design, and monitoring performance over a period of three years. These activities involve:

Phase I: Baseline Groundwater Monitoring - Additional monitoring wells 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 Table 1. Well installation is anticipated to occur over a period of two weeks. Sampling groundwater wells will be completed over a period of one to two weeks.

Phase I: 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.

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 expected 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.

Phase II: 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.

Phase II: 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.

PRB Demonstration Monitoring for Performance

Monitoring wells are located upgradient and downgradient of the PRB to evaluate changes to nitrate and groundwater quality. Monitoring wells downgradient are positioned 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.

Performance monitoring of the PRB demonstration test will assess three key parameters, including nitrate transformation, concentrations of other key indicators, and spatial distribution of the injected reagents. Primary objectives of performance monitoring sampling are to:

- Demonstrate reduction in nitrate concentrations in groundwater in monitoring wells compared to baseline samples and/or wells upgradient of the PRB;
- Identify distance traveled by EVO emulsion;
- Identify extent of generated reducing conditions;
- Evaluate potential for reduction in aquifer permeability as a result of EVO application;
- Evaluate persistence of EVO emulsion and anaerobic conditions favorable for denitrifying bacteria after PRB installation;
- Assess changes in groundwater monitoring parameters as a result of the PRB; and
- Determine whether temporary mobilization of some metals native to the aquifer material is occurring.

All performance monitoring wells will be constructed of two-inch schedule-40 PVC, with proposed screened intervals as shown in Appendix A for Eldredge Park and the landfill (Tables 7-1 and 7-2 of PRB TM-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. 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 PRB Demonstration treatment processes.

In addition to sampling the installed wells, a synoptic water level event will be conducted after additional monitoring wells are installed but prior to the start of the demonstration test injections to further assess groundwater direction and gradient. The first baseline sampling event would be completed prior to the initial injection test. Laboratory analysis of select metals will also be conducted as part of performance monitoring in select wells.

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. This program includes collection of groundwater samples from both existing monitoring wells (used for initial characterizations) as well as the installation of additional monitoring wells.

Table 1 - Summary of Analyses for Groundwater Performance Evaluation

Parameter	Relevance to PRB Demonstration Test
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	Analysis 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	Dissolved Organic Carbon as food source for denitrifying bacteria
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	Oxidation-Reduction potential 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 ₃ for each mg of nitrate reduced).
Boron	Boron is present in laundry detergents and is an indicator of groundwater flow emanating from Soil Absorption Systems.

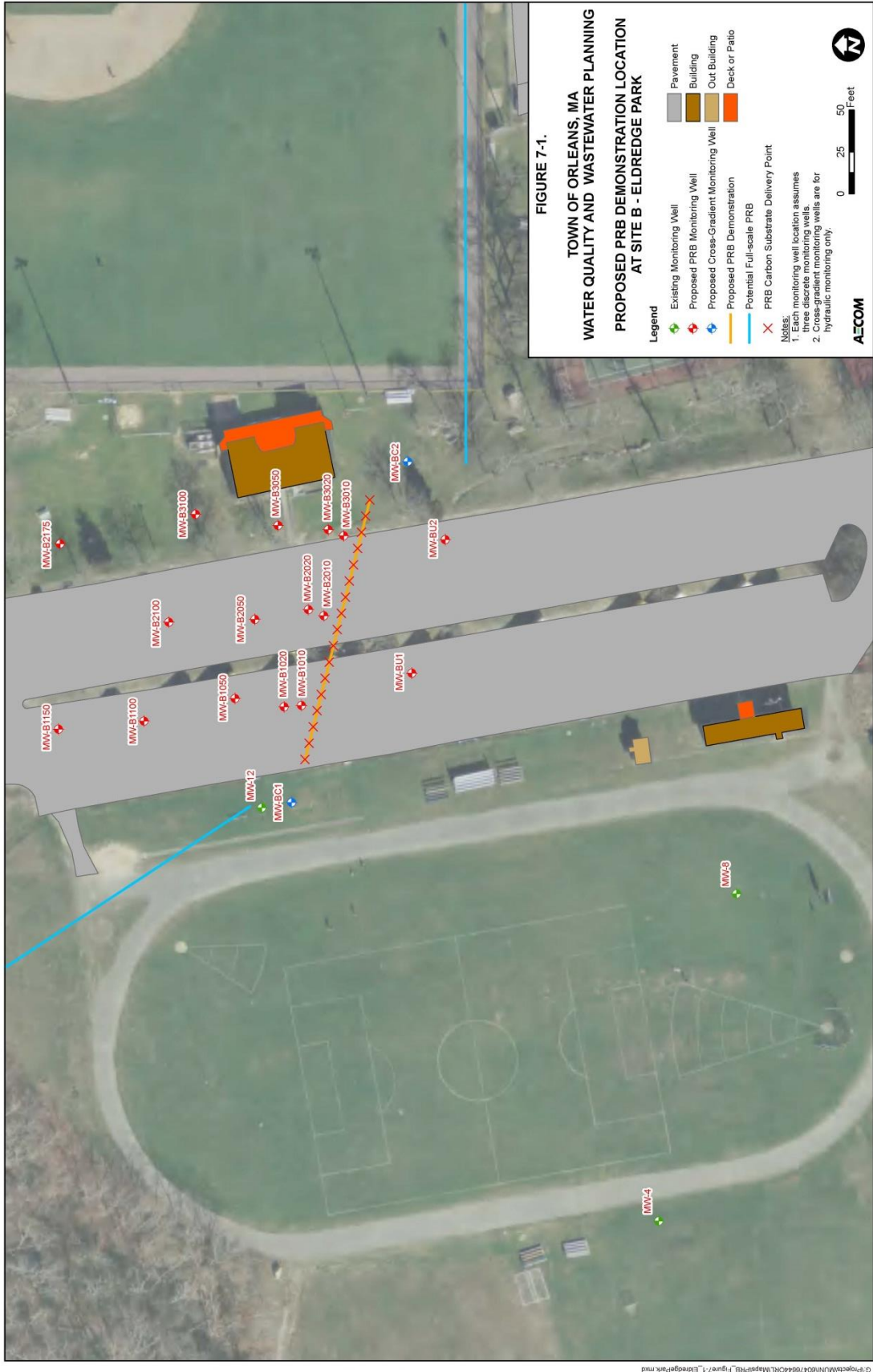


Figure 3 - Eldredge Park Monitoring Wells and PRB Location

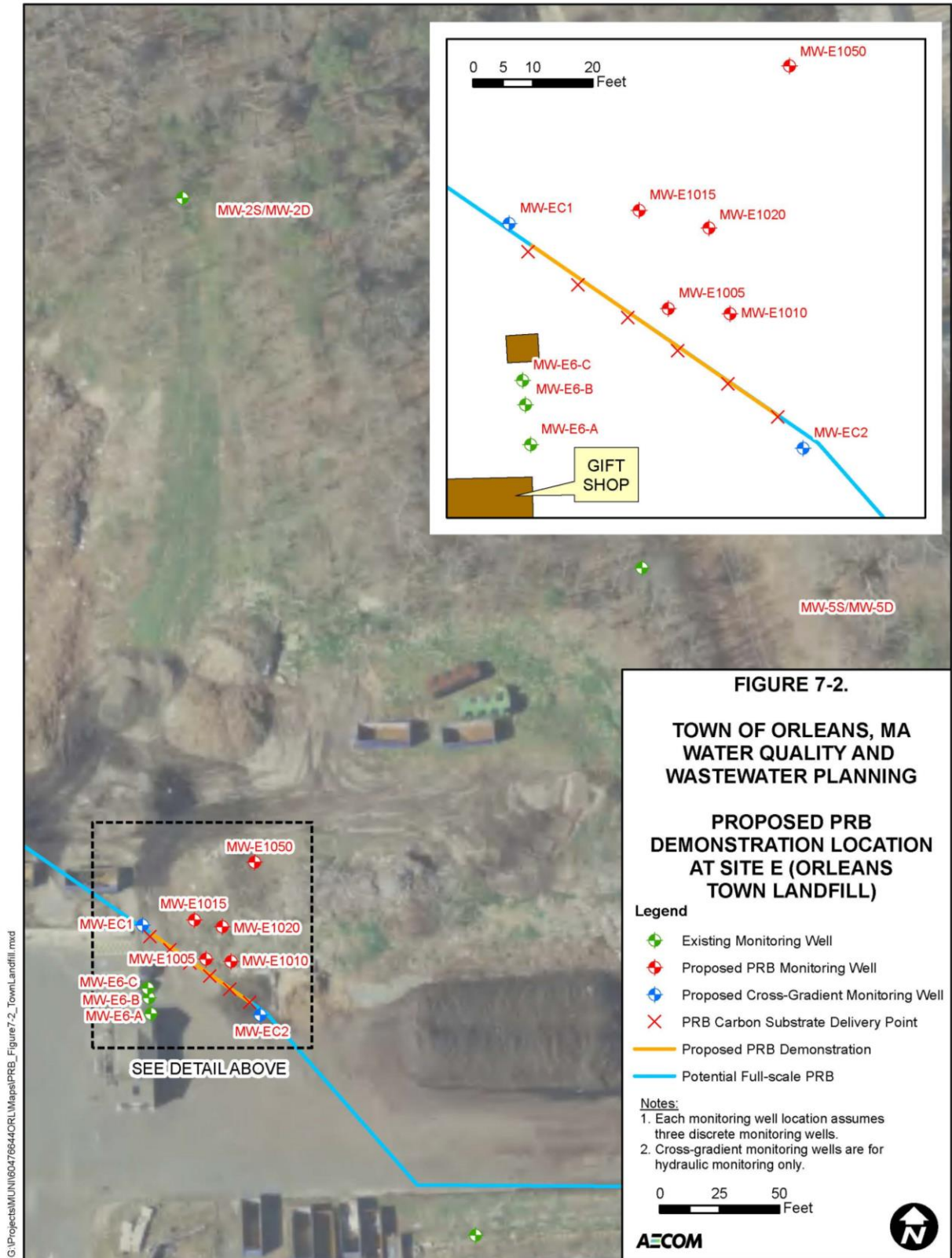


Figure 4 - Landfill Monitoring Wells and PRB Location

B. Floating Constructed Wetlands Monitoring

The objective of this monitoring protocol is to evaluate the effectiveness of a FCW deployed in Lonnie's Pond to reduce nutrients, especially nitrogen. For this evaluation, the focus of the monitoring will include in situ water quality sampling as well as assessments of standing macrophyte dry weight biomass and nutrient uptake performance. The data collected for the Lonnie's Pond FCW will be compared to other performance data on existing estuarine floating wetlands and from other natural marshes that can provide reference conditions and an understanding of relative performance (National Aquarium and Waterfront Partnership of Baltimore, Inc. 2011).

Additionally, small round samples of the FCW material "pucks" will be attached to the undersides of the FCW. Each puck is approximately 100 mm in diameter and 15 mm thick, weighing on average 3.5 to 4.0 grams. A subset will be removed seasonally to collect data on biofilm establishment and colonization by invertebrates.

1) Estimation of Nitrogen Uptake Rates by Biofilm Community

Existing literature on biofilm nitrogen removal rates/primary production will be reviewed to identify the anticipated range of nitrogen removal rates that could occur from the FCW. If needed, a laboratory study may be conducted to further refine N removal rates. Seasonal measurements of redoximorphic conditions (ie. temperature, oxygen, acidity, iron, manganese) will be made of each island to determine if the conditions exist for nitrification or denitrification. A calculation of the combination of the macrophyte biomass and epiphyte biofilm nutrient absorption and uptake will be made.

2) In-Situ Water Quality Analysis

Water quality will be sampled in three ways: using continuous dataloggers; using a hand-held probe to collect discrete readings; and using grab samples that are then sent to a lab for analysis.

- Water quality and current data will be collected throughout the growing season in fifteen minute intervals using YSI 6600V2 continuous data sondes. Continuous water quality parameters will include temperature, DO, turbidity, chlorophyll and salinity. The sondes will be deployed on either side (landward and seaward) of the four FCW systems, for a total of eight sondes. The data will be collected to determine if there are measurable water quality differences on either side of the FCWs.
- Discrete water quality measurements and grab samples will be taken at weekly intervals during the growing season (April 15 thru September 30).
- Discrete onsite water quality parameters will be measured using a hand-held YSI 556 MPS probe, and will be taken on the landward and seaward sides at each of the four FCWs at the same level in the water column during each monitoring event for the following parameters: temperature, conductivity, salinity, DO, and pH.
- Paired grab samples will be taken on the landward and seaward sides at each of the four FCW systems at the same level in the water column during each monitoring event, and will then be sent to a qualified lab for analysis of the following constituents: nitrite (NO_2) and nitrate (NO_3), total N, total suspended solids (TSS), ammonium (NH_4) and chlorophyll a.

Once each season throughout the year a minimum of three per baseflow water quality samples will be taken for nutrient and physical chemical measurements at each inflow, as well as a minimum of three stormflow samples.

3) Lab Analysis

Aboveground biomass of vegetation on the FCW will be harvested at the end of the growing season after a full year of establishment. The roots will remain intact in order to facilitate growth in subsequent years. Plant biomass will be air-dried and sub-sampled. These sub-samples will be oven-dried at 70 degrees C for 24 hours and weighed. Additional sub-samples will be combined in an ashing oven in the lab to determine the ash-free dry weight (AFDW). The data will be used to determine the dry weight aboveground biomass and, combined with seasonal diurnal curve measurements, an estimate of the net primary production of the wetland in relation to overall community metabolism. Estimates of seedling dry weights will be deducted from the aboveground biomass in order to attain a more accurate biomass of the growth achieved in the first year. Carbon and nitrogen will be assessed using standard methods to evaluate nutrient uptake by the marsh community. Thus, total mass of C and N in the aboveground biomass will be estimated by multiplying nutrient content percentage by the total biomass.

Biofilm analysis will be employed by deploying an array of pucks made of the same FCW material, approximately 100 mm in diameter and 15 mm thick weighing on average 3.5 to 4.0 grams. Six pucks each will be constructed and evenly spaced and attached to the FCW unit. Each floating wetland will have one rack attached. Seasonally, a rack will be randomly selected from one FCW with two pucks randomly selected from each for analysis of biofilm establishment and colonization by invertebrates.

4) Maintenance Requirements

Visual inspection of the FCWs will occur on a monthly basis. The main purpose of the maintenance inspections will be to confirm that project integrity is maintained and to document any changes to the units or the surrounding area. Maintenance activities will include the following:

- Inspection to confirm integrity of all submerged hardware and anchoring, and above water tethering and waterfowl fencing;
- Health of plants, and replanting of seedlings where necessary;
- Removal of man-made and natural debris; and
- Periodic inspection for signs of vandalism, natural degradation of base material, mechanical (tearing), waterfowl use, or UV damage (discoloration).

C. Shellfish Demonstration Performance Monitoring Program

The purpose of implementing shellfish demonstrations in Orleans is to determine the extent to which shellfish can be grown to achieve water quality improvement goals as well as compliance with water quality standards. Monitoring of both ecological parameters as well as implementation success will provide information that is needed for this water quality improvement planning and decision making. As part of implementing a comprehensive Performance Monitoring Program, a project specific Quality Assurance Policy Plan (QAPP) is recommended.

Proposed demonstrations are in the Pleasant Bay and Nauset Harbor watersheds. Through the Pleasant Bay Alliance's Monitoring Program, baseline data exists in Meetinghouse Pond, Arey's Pond, Keyscayo Gansett (Lonnie's) Pond, and Quanset Pond. While there are monitoring stations near the existing shellfish grants in Little Pleasant Bay, the first step for this demonstration is to establish baseline conditions directly within the shellfish grant areas.

It is recommended that for implementing shellfish projects in Nauset Harbor (Town Cove and Mill Pond) the first step is to reinstate water quality monitoring at the WMO-26 to WMO-35 monitoring stations. This is needed to establish pre-installation baseline conditions. Monitoring at these stations, except for the three Sentinel Stations (WMO-25, WMO-24, and WMO-38) has not been reported since 2005. Also required prior to implementation of any demonstration project for seeding additional quahogs is to conduct a standing stock assessment for quahog populations in Town Cove and Pleasant Bay in any areas considered for demonstration locations.

1) In-Situ Water Quality Monitoring

To quantify any water quality changes that result from the demonstration projects, twice monthly sampling from May – September should include the following parameters at both water surface and bottom locations (where depth is greater than 5 feet) within the sampling stations: Total Nitrogen (TN), nitrate + nitrite, ammonia, dissolved organic nitrogen (DON), dissolved inorganic nitrogen (DIN), particulate organic nitrogen (PON), Temperature, Chlorophyll *a*, Pheophytin *a*, Orthophosphate, Salinity, Dissolved oxygen (DO), and Transparency (Secchi depth). Continuous monitoring of Chlorophyll *a*, DO and turbidity is recommended at one location within the demonstration site and one location outside the growing area. Figure 5 shows the two potential demonstration sites in Lonnie’s Pond, with proposed monitoring stations.

Table 2 shows the frequency and timing of sampling that should occur for water quality monitoring, and illustrates the framework for monitoring reporting based on the seven recommended locations depicted in Figure 5. Both surface and bottom sampling is assumed. The actual program will be defined in collaboration with the firm responsible for water quality monitoring.

Table 2 - Illustration of Water Quality Sampling Program

STATION ID	May 1 - 15	May 16 - 31	Jun 1 - 15	Jun 16 - 30	Jul 1 - 15	Jul 16 - 31	Aug 1 - 15	Aug 16 - 31	Sept 1 - 15	Sept 16 - 30	Oct 1 - 15	TOTAL SAMPLES
	Surface and Bottom											
LDS1	2	2	2	2	2	2	2	2	2	2	2	22
LDS2	2	2	2	2	2	2	2	2	2	2	2	22
LDS3	2	2	2	2	2	2	2	2	2	2	2	22
LDS4	2	2	2	2	2	2	2	2	2	2	2	22
LDS5	2	2	2	2	2	2	2	2	2	2	2	22
LDS6	2	2	2	2	2	2	2	2	2	2	2	22
PBA-15	2	2	2	2	2	2	2	2	2	2	2	22
subtotal:												154
QA/QC (10%)												15
Total Samples												169

The seven water quality sampling locations recommended include six Lonnie’s Demonstration Stations (LDS) and the Sentinel Station in Lonnie’s Pond (PBA-15). Siting and sampling locations will be finalized after consulting with the firm hired to complete the monitoring program for this demonstration. These seven stations are as follows:

- LDS1: Inlet to Lonnie’s Pond (source);
- LDS2: Storm drain from Cranberry Bog (source);
- LDS3: Herring Run (source);
- LDS3, LDS4 and LDS5: Within oyster growing area; and

- PBA-15: Sentinel Station (middle of pond).

LDS1, LDS2 and LDS3 are included for the first year to measure whether these point sources contribute significant nitrogen inputs over the sampling season that impact overall water quality or measured results within the oyster growing area. The Sentinel Station is included to establish baseline conditions. The three stations within the oyster growing area (LDS4, LDS5 and LDS6) provide triplicate samples for monitoring the impact of oysters on water quality.

Lonnie's Pond South

- = Possible 1-Acre Demo Location
- ▲ = Water Quality Monitoring Station



Lonnie's Pond North

- = Possible 1-Acre Demo Location
- ▲ = Water Quality Monitoring Station



Figure 5 - Two Potential Demonstration Locations in Lonnie's Pond with proposed monitoring station locations.

2) Measuring Changes in Sediment and Benthic Flux Associated with Oyster Aquaculture

Analysis of enhanced sediment denitrification that can be attributed to oyster aquaculture is critical to determining the impact of oysters on the estuary in which they are grown. This analysis includes collecting sediment core samples and incubating them under in situ conditions during the period of maximum denitrification rates in summer (July–September); and collecting time series measurements of total dissolved nitrogen, nitrate + nitrite and ammonium. The rate of oxygen uptake is also necessary in order to: (1) evaluate sediments relative to organic matter deposition rates; and (2) develop a general nitrogen model for oyster impacts to the nitrogen cycle in the sediments.

Assays should be performed on cores collected throughout the oyster aquaculture area (directly under the oyster aquaculture rafts and along a 100m transect extending south). The results should show any spatial pattern and rate of nutrient exchange between the sediments and water column, and whether these rates are affected by the cultivation of oysters in each demonstration location.

Excess nitrogen gas (N₂) is measured using membrane-inlet mass spectrometry (MIMS). N₂ produced by denitrification is precisely detected by analysis of its ratio with the inert gas Argon. Water samples should be collected and stored to prevent gas exchange or bubble formation. In the laboratory, sample water is pumped at ml/min rates through a gas permeable membrane in order to extract gas into the mass spectrometer inlet. Based on data from a single monitoring station located in the center of Lonnie's Pond (PBA-15), dissolved oxygen levels are below the target threshold for health of 6 mg/L, but not anoxic in the center of Lonnie's Pond (Figure 6).

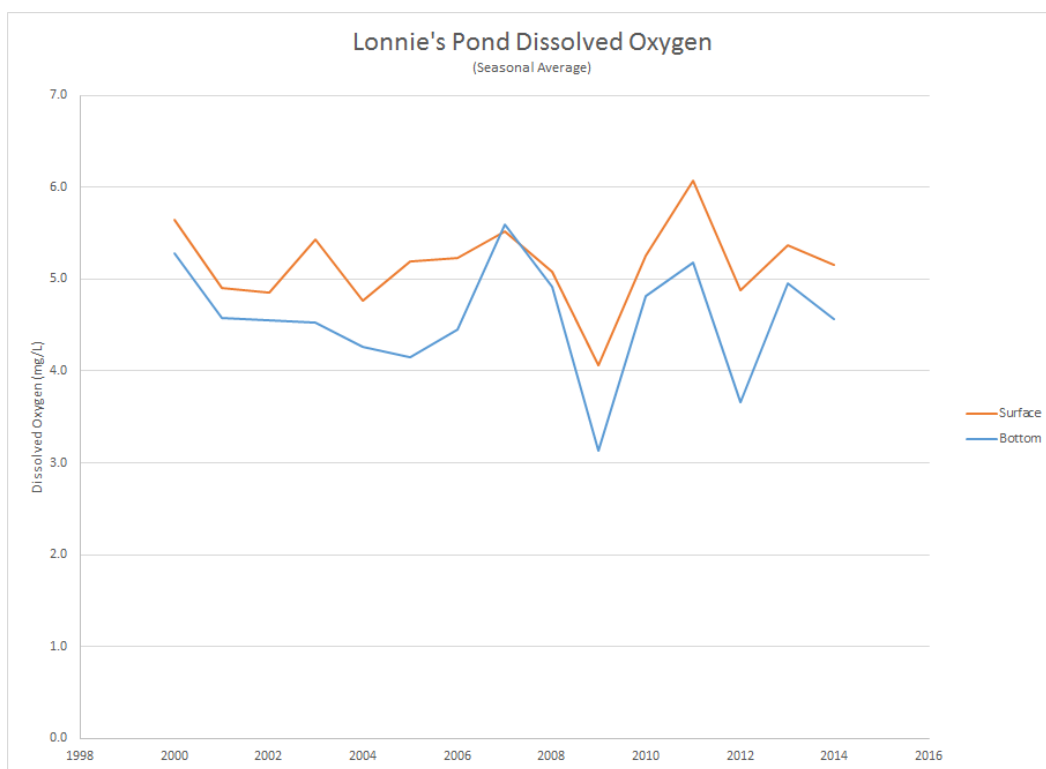


Figure 6 - Dissolved Oxygen Concentrations in Lonnie's Pond

3) Baseline Quahog Population and Propagation Planning

This program is implemented by conducting a baseline population survey for a number of areas in Town Cove and Pleasant Bay. Appendix A of SHEL-TM-2 includes a list of the areas that have been historically planted in Orleans. Three, ten meter transects should be defined through the two ends and center of selected quahog planting areas. For each transect, five separate square meter sample areas should be surveyed for all organisms. Quahog numbers will then be used as the baseline density. A detailed scope of work will be developed prior to soliciting bids for professional services to conduct this survey.

4) Water Quality Monitoring: Quanset Pond Demonstration

Year 1 monitoring will establish baseline conditions, while oyster growth viability testing is underway. Final reporting for Year 1 will include:

- Baseline water quality conditions;
- Size classes by length for one year of growth;
- Tray area covered per bag of remote set;
- Review of viability of site for shellfish growth;
- Assessment of operation and maintenance requirements of trays;
- Useful modifications to tray design;
- Recommendations on the type of shellfish grown and whether there should be a mix of species; and
- Assessment of abutter compatibility and use conflicts.

To establish whether there is a shellfish impact on water quality, ten (10) sampling stations are proposed. As shown in Figure 7, these stations are located above, within and directly below the proposed oyster reef two-acre growing area (shown as blue rectangle), enabling direct analysis of the water as it flows across the growing areas. In addition, a benthic infaunal survey of the growing area should be conducted to establish a baseline benthic macrofauna density and species diversity to enable future quantification of the overall impact to habitat through creation of the oyster reef.



Figure 7 - Map of Recommended Sampling Stations for Quanset

5) Water Quality Monitoring Locations: Little Pleasant Bay Demonstration

To establish whether there is an effect on water quality from the additional oysters being grown, ten (10) sampling stations are proposed. As shown in Figure 8, these stations are located within and directly below the grant areas, enabling direct analysis of the water as it flows through the growing areas.



Figure 8 - Map of Recommended Sampling Stations for Little Pleasant Bay

6) Monitoring Shellfish Growth and Survival and Habitat Changes

In addition to water quality sampling, monitoring the numbers of shellfish, as well as growth and survival rates is also recommended. Remote set and single oysters should be randomly sampled both from floating bags and from trays, and measured every two weeks to establish a growth rate. Survival should be quantified monthly in both floating bags and trays. Before the oysters are bottom planted in the first growing season, population density should be established, and population counts should be made. Observations regarding predation and other stressors should be recorded. The population density should also be measured at the beginning of the second growing season.

Additionally, observations regarding increased biological diversity should be made and documented. A basic assessment of species (e.g., shrimp, crabs and fish) in the vicinity of the growing area should be made prior to installing the demonstrations. This can be accomplished by observing and recording organisms in the water column as well as sorting and identifying benthic infauna in the laboratory. Weekly observations of any species that were not initially present in the water column but have been attracted to the area because of oysters due to the structure created by the floating gear or trays should be recorded.

The first year report documenting the demonstration projects at the end of the first season should include:

- Population density and overall population counts;
- Number and percent of oyster survivorship for first growing season;
- Evaluation of growth rates and survival in trays versus floating bags (if applicable);

- Size classes by length for one year of growth;
- Predators;
- Area of bottom covered by remote set (if applicable);
- Review of viability of site for shellfish growth;
- Assessment of operation and maintenance requirements of trays versus floating bags (if applicable);
- Useful modifications to the site selection criteria for shellfish;
- Recommendations on the type of shellfish grown and whether there should be a mix of species; and
- Assessment of abutter compatibility and use conflicts.

To determine nitrogen uptake from the oysters growing in floating bags, a measure of the nitrogen content in the shell and soft tissue should be performed for each size class of oyster, as follows:

- Measure dry weights of shellfish tissue and shell separately, using a pooled sample of 10 to 20 animals;
- Measure the percentage of N in tissue and shell separately, using a pooled sample of 10 to 20 animals;
- Tabulate wet weight to dry weight correlations using regression analysis;
- Determine nitrogen uptake by total weight of shellfish in each size class;
- Use correlation between the total wet weight of shellfish (shell and tissue) in each size class and dry weight; and
- Multiply by percent nitrogen for size class.

7) Data Collection Needs Summary

a) Data Collection Needs Summary for Year 1 PRB Demonstration

- Baseline groundwater monitoring: one month to install wells and collect samples;
- EVO initial injection test monitoring: four to 6 weeks following initial injection of EVO; and
- Demonstration performance monitoring: once prior to EVO injection, then quarterly for three years.

b) Data Collection Needs Summary for Year 1 FCW Demonstration:

- Water quality analysis in Lonnie's Pond:
 - Continuous data sondes installed; and
 - Discrete measurements using grab samples/probes.
- Plant community structure on FCW;
- Laboratory analysis of vegetation biomass;

- Laboratory analysis of biofilms and invertebrates on pucks; and
- Laboratory analysis of root mats of redoximorphic conditions for denitrification potential.

c) Data Collection Needs Summary for Year 1 Shellfish Demonstrations

- Quahog population survey in Pleasant Bay and Town Cove;
- Baseline water quality in terminal pond selected for demonstration;
- Baseline water quality in Quanset Pond;
- Baseline water quality in shellfish private lease area in Pleasant Bay;
- Baseline biological diversity and predators in terminal pond selected for demonstration;
- Baseline biodiversity and predators in Quanset Pond;
- Baseline biodiversity, predators and disease in shellfish private lease area in Pleasant Bay;
- Baseline sediment denitrification rates in terminal pond;
- Baseline sediment denitrification rates in Quanset Pond;
- Project viability study monitoring:
 - Shellfish growth and survival;
 - Project logistics during installation, operation and maintenance; and
 - Expense tracking.

d) Data Collection Needs Summary for Year 2 Shellfish Demonstrations

- Water quality monitoring in quahog propagation sites in Pleasant Bay and Town Cove;
- Water quality in terminal pond selected for demonstration;
- Water quality in Quanset Pond;
- Water quality in private shellfish lease area in Pleasant Bay;
- Biodiversity and predators in terminal pond selected for demonstration;
- Biodiversity and predators in Quanset Pond;
- Biodiversity, predators and disease in shellfish private lease area in Pleasant Bay;
- Sediment denitrification rates in selected terminal pond;
- Sediment denitrification rates in Quanset Pond; and
- Project Monitoring for Non Water Quality Factors:
 - Shellfish growth and survival;
 - Project logistics during installation, operation and maintenance; and
 - Expense tracking.

4. Recommended Actions for 2016

The following monitoring activities should proceed during the spring and summer of 2016:

- Baseline groundwater monitoring: one month to install wells and collect samples;
- EVO initial injection test monitoring: four to 6 weeks following initial injection of EVO;
- Baseline water quality monitoring for shellfish demonstrations;
- Disease/predation study for shellfish demonstration; and
- Baseline population study for quahogs.

For PRBs, these initial hydrogeologic and EVO injection studies are needed to finalize the demonstration design. For shellfish projects, baseline water quality, quahog populations and predation should be established this season in anticipation of a full-scale demonstration installed next season (Spring/summer 2017). The FCW monitoring program includes monitoring after installation. Since this is not planned to occur in 2016, no monitoring for FWCs is recommended.

5. References

Clark, H., 2007. Lonnie's Pond Shellfish Aquaculture Assessment Report. Prepared for Cape Cod Cooperative Extension.

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