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Memorandum

To	George Meservey, Director of Planning & Community Development
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Subject	**Town of Orleans, MA** **Water Quality and Wastewater Planning** **Task Number 12.1.B – NT Demonstration Projects** **Task 12.1.B.2 - Technical Memorandum: Permeable Reactive Barriers (PRB) Full-Scale Watershed Planning - Final**
Project Number	60476644
From	Thomas Parece, P.E., AECOM Project Manager
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1. Introduction

This Technical Memorandum has been prepared to identify potential full-scale Permeable Reactive Barrier (PRB) locations for implementation in accordance with the overall objectives of the Town of Orleans Amended Comprehensive Wastewater Management Plan (ACWMP). The ACWMP was developed in accordance with the Cape Cod 208 Water Quality Plan, which has been approved by both the United States Environmental Protection Agency (US EPA) and the Massachusetts Department of Environmental Protection (MassDEP).

The ACWMP is a "hybrid" plan that includes provisions for use of conventional wastewater treatment and non-traditional technologies, including PRBs, to remediate nitrate in groundwater. The PRB is a remediation technology that intercepts and removes nitrogen in groundwater at key locations in the watersheds before it discharges to sensitive embayments. Using a non-traditional technology allows for a reduction in sewer collection system coverage and wastewater treatment facility costs while still achieving nitrogen control objectives.

A PRB demonstration project is currently underway at the Eldredge Parkway site at the Nauset Regional Middle School in Orleans. The PRB was implemented in November 2016 and was designed for evaluating of PRB performance. Over the last four years, the project has shown that a PRB is effective in removing nitrate in groundwater. As part of the ACWMP, the Town is planning to install additional PRBs to reduce the nitrate load from nitrate impacted watersheds and estuaries in a cost-effective manner.

Three major watersheds have been identified for PRB groundwater remediation. These include the watersheds to Pleasant Bay, Nauset Estuary and Rock Harbor shown in Figure 1. A planning document Technical Memorandum "Permeable Reactive Barriers Implementation Plan for Full-Scale PRBs" (Implementation Plan) was prepared for the Town of Orleans dated August 6, 2018 and included details on the design and logistics of implementation of full-scale PRBs. The Implementation Plan for full-scale PRBs is in Appendix A and is also available on the Town of Orleans website https://www.town.orleans.ma.us/water-quality-and-wastewater-planning/pages/permeable-reactive-barriers-prb.

2. Orleans Nitrogen Load Reduction Objectives

The watersheds recharging Pleasant Bay, Nauset Estuary and Rock Harbor in Orleans include numerous sub-watersheds that discharge to creeks, rivers and salt ponds as shown in Figure 1. Total Maximum Daily Loads (TMDLs) define the maximum nitrogen load that the water body can receive from all sources, including watersheds, while still meeting necessary water quality criteria. To develop embayment specific TMDLs, the Massachusetts Estuaries Project (MEP) assessed nitrogen loading to the estuaries using an analytical method called the Linked Watershed-Embayment Management Modeling Approach. The model links watershed nitrogen inputs with surface water circulation and nitrogen characteristics to establish nitrogen loading threshold concentrations that must be achieved to restore and maintain water quality standards within the embayments. Exceeding thresholds has significant environmental consequences. For embayments that exceed the TMDL, corrective actions are needed to reduce nitrogen loading to achieve TMDLs in compliance with the federal Clean Water Act and state law.

Threshold nitrogen concentration and TMDLs were developed with results from analysis by MEP documented in technical reports prepared for Pleasant Bay, Rock Harbor and the Nauset Estuary (MEP 2006, MEP 2007, MEP 2012, respectively). The MassDEP and US EPA have approved nitrogen TMDLs for Pleasant Bay. Additional TMDLs are undergoing review by the regulatory agencies. TMDL thresholds and target goals for these estuaries are discussed in more detail below.

A. Pleasant Bay TMDLs

Pleasant Bay is connected to the Atlantic Ocean and is characterized by three main basins including Little Pleasant Bay, Pleasant Bay and Chatham Harbor. The bay has numerous sub-embayments. These sub-embayments are at particular risk of eutrophication from high nitrogen loads entering by direct groundwater discharge and by restricted tidal exchange. The main basins in or adjacent to Orleans include Pleasant Bay Main Basin and Little Pleasant Bay. Sub-embayments in Orleans include Meetinghouse Pond, the Upper and Lower River, Lonnie's Pond (also known as Kescayo Gansett Pond), Namequoit River and Aries Pond, Paw Wah Pond, Quanset Pond, and Pochet Inlet. The estimated nitrate loads to each of the watersheds and sub-watersheds are detailed in the MEP issued report "Massachusetts Estuaries Project Linked Watershed-Embayment Model to Determine Critical Nitrogen Loading Thresholds for the Pleasant Bay System, Massachusetts" in May 2006.

In June 2017, the Select Boards of Brewster, Chatham, Harwich, and Orleans voted to sign a Resolution of the Towns sharing the Watershed of Pleasant Bay, endorsing the Pleasant Bay Composite Nitrogen Management Analysis as an accurate representation of each Town's share of the current nitrogen load and its responsibility to remove nitrogen in Pleasant Bay (Pleasant Bay Alliance, March 2017). The agreed Town of Orleans share of the Pleasant Bay Watershed nitrogen load is 6,980 kilograms per year (kg/yr) targeting sub-embayments as shown on Table 1.

The Towns also agreed to participate in a Watershed Permit Pilot Project with the Pleasant Bay Alliance, MassDEP, US EPA and the Cape Cod Commission (CCC) to pursue efficiencies and cost savings through coordinated implementation of nutrient management actions. The Pleasant Bay Watershed Permit was issued by MassDEP in August 2018 in accordance with M.G.L. c. 21, § 27(6) and Section 2A of Chapter 259 of the Acts of 2014.

At this time, the Town of Orleans has targeted 100 percent of its share of the nitrogen load to be removed by non-traditional technologies for Lonnie's Pond, Arey's Pond, Lower River, Namequoit River, Paw Wah Pond, Quanset Pond, Pochet, Pleasant Bay Main Basin and Little Pleasant Bay. Other sub-embayment removal goals have smaller targets for non-traditional technologies including 2 percent for Meetinghouse Pond, which will be mainly addressed with conventional wastewater collection and treatment system and 54 percent for the Upper River. Given the expected favorable economic benefits of utilizing non-traditional technologies, the current objective for full-scale PRB selection in this evaluation was to consider all feasible locations within the Pleasant Bay Watershed.

B. Nauset Harbor Embayment System TMDLs

The Nauset Harbor Embayment System in Orleans and Eastham is connected to the Atlantic Ocean and is comprised of open waters including Nauset Harbor, Town Cove, Nauset Marsh (located behind Nauset Barrier Beach) and three sub-embayments: Salt Pond, Wood Cove and Mill Pond. The Nauset Harbor Estuary watershed is shared by the Towns of Orleans, Eastham and Brewster. The most impacted areas with impaired habitat and therefore the focus of nitrogen load reduction in Orleans, include the upper reach at Town Cove and the semi-enclosed Mill Pond and Wood Cove sub-embayments. The Salt Pond sub-embayment in Eastham is also at risk of eutrophication. MEP issued the report "Linked Watershed-Embayment Approach to Determine Critical Nitrogen Loading Thresholds for the Nauset Harbor Embayment System, Towns of Orleans and Eastham, Massachusetts" in 2012 to support TMDLS for the estuary.

The Nauset Embayment System exceeds the MEP established TMDL requiring measures to lower the combined watershed nitrate load to the estuary (Howes et. al., 2012). The Town Cove nitrate TMDL is 21,432 kg/yr with a Target Threshold Watershed Load (comprised of natural background, fertilizer, runoff and septic system loads) of 4,368 kg/yr. According to the MEP report, the existing Watershed Load is 11,532 kg/yr. Therefore, a reduction of 7,164 kg/yr of nitrogen load is necessary to restore and maintain the Town Cove's water quality below the Target Threshold Load. Orleans has identified a PRB technology removal target or goal of 566 kg/yr for Town Cove. The objective for full-scale PRB selection in this evaluation was to consider all feasible locations within the Nauset Watershed.

C. Rock Harbor Embayment System TMDLs

The Rock Harbor Embayment System is in the Towns of Orleans and Eastham. Rock Harbor is a man-made harbor at the mouth of a tidal river and salt marsh and opens to Cape Cod Bay to the north. Significant habitat quality impairment and the presence of algal mats have been observed in the lower reach harbor area, while the upper reach marsh area has a higher quality habitat. MEP issued the report "Linked Watershed-Embayment Approach to Determine Critical Nitrogen Loading Thresholds for the Rock Harbor Embayment System, Towns of Orleans, Massachusetts" in December 2008 to support TMDLs for the estuary. The Rock Harbor System total TMDL 1,827 kg/yr with at Target Threshold Watershed Load of 1,358. The Present Watershed Load, comprised of natural background, fertilizer, runoff, WWTF and septic system loads, is 3,309 kg/yr, leaving 1,951 kg/yr to be removed. The Orleans' PRB technology removal target for nitrate is 634 kg/yr. The objective in this evaluation was to consider all possible locations within the Rock Harbor Watershed.

3. Site Selection Process

The PRB site selection process documented in this technical memorandum has identified 14 potential PRB locations within the sub-watersheds to Pleasant Bay, 3 PRB locations in the Nauset watershed and 1 location within the Rock Harbor watershed. PRBs were identified using local roadway names. Location and physical characteristics of the potential PRBs are included in Table 2 and shown on Figure 2.

A variety of information sources were used to support the PRB selection process. Land use was reviewed in the Orleans Geographic Information System https://www.town.orleans.ma.us/planning-department/pages/gis-mapping. Hydrogeologic information including groundwater flow and watershed delineations were gathered from MEP reports and from the regional USGS Monomoy Lens groundwater model (Walter and Whealan, 2005). Additional groundwater data were obtained from a 1990s CCC investigation of soils, water level and water quality data across the Town of Orleans. The CCC gathered soil boring and water level data from numerous previous investigations and installed additional soil borings and monitoring wells to evaluate soil and groundwater elevations throughout Orleans. These data were summarized in a report titled "Orleans Water Table Mapping Project, Orleans Massachusetts", dated May 1995.

Full scale PRB location screening considered overall nitrogen remediation objectives, environmental conditions, land use, downgradient water use, topography, wastewater nitrogen load upgradient within the capture zone of the PRB and practical limitations to cost effective implementation of the technology.

4. PRB Characteristics and Initial Siting Criteria

Initial PRB siting criteria were used to assess potential full-scale PRB locations in each of the three major watersheds. Criteria included:

- Locating PRBs along roadways that are cross-gradient to the regional groundwater flow direction and within a watershed requiring long term groundwater remediation;
- The depth to groundwater, generally less than 40 feet (depth affects costs and may affect feasibility);
- The accessibility of the PRB for installation, upgradient and downgradient monitoring well installation, and long-term monitoring; and
- The location where groundwater discharges to the most sensitive upper reaches of the estuary where possible.

A PRB screening matrix was developed to identify relevant characteristics and record results of assessments of effectiveness discussed below. Candidate locations were mapped, depth to groundwater was estimated based on topography and groundwater elevation contours and the vertical extent of the PRB was defined. Screening included evaluation of roadway orientation upgradient of target embayments, considering sub-watersheds to determine PRB location and PRB total length. The road layout and land use assessment utilizing the Orleans Geographic Information System (GIS) database was followed up with field surveys.

5. Detailed Analysis of PRB Effectiveness

Potential PRB locations identified in the initial screening were assessed for effectiveness of nitrogen mass removal by evaluating:

- The dimensions of the proposed PRB;
- Groundwater flow direction;
- The density of wastewater nitrogen sources upgradient of and within the capture zone of the PRB; and
- The ability in aggregate to achieve PRB nitrate mass remediation goals given the current assumptions.

The density of septic system wastewater nitrogen sources was assessed by estimating the number of parcels within the capture zone or area of groundwater intercepted by the PRB and then calculating the nitrogen load generated in that area with specified assumptions. A feasible PRB installation depth of approximately 70 to 80 feet below ground surface was assumed. This depth limitation and the depth to groundwater affects the size of the upgradient capture zone of a PRB. The upgradient area of groundwater that will flow through the PRB is limited because groundwater generally flows deeper into the aquifer as it moves towards the receiving water. Once it reaches the receiving water body groundwater moves up to discharge. At a certain distance upgradient, groundwater originating further upgradient will flow under the PRB and groundwater from that area cannot be treated by the PRB.

AECOM developed a groundwater flow model for the Town of Orleans based on the USGS, Sagamore and Monomoy flow lens Model (Walter and Whealan 2005). This model has been previously used to evaluate groundwater mounding and alterations to groundwater flow paths resulting from the proposed WWTF Groundwater Discharge at 32 Lots Hollow Road and 43 Lots Hollow Road in Orleans (AECOM, 2018). The model is also suitable for evaluating the area contributing groundwater to the proposed PRBs. The capture zone area was estimated by using the model to backtrack particles, simulating a drop of water’s flow path, upgradient of each PRB. This was accomplished by using MODPATH (Pollock, 1994) in conjunction with the MODFLOW (McDonald and Harbaugh, 1988) software.

The wastewater load within the defined capture zone was then estimated by counting parcels within the capture zone and assigning an annual nitrogen load for the PRB. This estimate considers wastewater related nitrogen only and does not account for fertilizer applied to the land and atmospheric deposition of nitrogen within the capture zone. The wastewater load estimate assumed one house per parcel. The parcel nitrate load assigned was based on a reference wastewater nitrogen concentration of 26.25 mg/L used in MEP studies and a town-wide average water use of 150 gallons per day per parcel based on Orleans water records for 2014 and 2015. The estimated annual nitrogen load generated per parcel was 5.44 kg/yr.

Nitrogen from fertilizer, atmospheric deposition, and the presence of multi-unit condominiums on one parcel would increase the estimated nitrogen load in the capture zone. MassDEP has indicated a preference for use of actual nitrogen flux data and PRB nitrogen removal performance for determining the nitrogen load removal credit assigned to PRBs. However, the MEP based estimate of 5.44 kg/yr has been used as a surrogate in this evaluation. Ultimately PRB performance will be measured by actual groundwater nitrogen load and PRB reduction as determined through groundwater monitoring.

Prior to assigning a nitrate load to each parcel, the parcels were reviewed for land use type and mapped conservation land and parcels without obvious development were not counted. The parcel count is included in Table 3. PRB lines, particle backtracks, and highlighted parcels show the capture zones and counted parcels on Figure 2. For the purposes of site selection screening, the assumed nitrogen load removal by PRBs is 80 percent of the wastewater load generated within the capture zone. Current monitoring of the Eldredge Parkway Demonstration PRB indicates a greater than 80 percent nitrogen removal efficiency. However, it is anticipated that an 80 percent efficiency will be selected as the target for PRB management over time, triggering replenishment of PRB carbon source once average efficiency drops below 80 percent.

The estimated annual nitrogen load in the capture zone of each PRB was normalized to PRB length to assess load reduction on a kilogram per linear foot per year (Kg/LF/yr) basis for comparison with other potential PRBs. The estimated PRB efficiency considering all locations ranged from 0.09 to 0.40 Kg/LF/yr. PRBs in each major watershed were ranked for efficiency and given a rank as shown in Table 3.

The calculated efficiency was supplemented with a qualitative evaluation of PRB location relative to the most impacted sub-embayments based on MEP modeled total nitrogen concentrations and embayment specific non-traditional technology goals to guide potential funding and implementation planning.

6. Implementation Cost

AECOM has estimated the implementation cost for each PRB installation based on $1,230.00 per linear foot of PRB line. This cost includes:

- Town administration;
- Engineering design;
- Monitoring well installation and baseline sampling;
- Injection contractor and sub-state costs; and
- Engineering oversight of implementation.

PRB implementation costs range from $492,000 for a 400-foot PRB to $8,979,000 for a 7,300-foot PRB as shown in Table 4. Additional future costs will include long term monitoring, replacement costs for any damaged monitoring wells and subsequent substrate injection events. These costs were developed for the Wastewater Infrastructure Long Term Financial Plan that will address a phased implementation schedule for selected PRBs over a 10-year period.

7. Life Cycle Cost Analysis

A Life Cycle Cost Analysis (LCCA) was performed to compare PRBs and Traditional Systems. The purpose of this LCCA was to estimate the overall costs of PRBs and Traditional Systems and to utilize the information to assist the Town in selecting the alternative which will provide the lowest overall cost (implementation plus operation and maintenance) based on a cost per kg nitrate removed.

For both the PRBs and Traditional Systems, numerous costs associated with implementation (e.g. planning, design, bidding, construction, etc.) plus operation and maintenance of each the alternative was estimated. The following summarizes the unit costs utilized for the LCCA.

PRBs

Description	Unit Cost
Implementation Cost [1] ($/LF)	$1,230
Replacement Cost [2] ($/LF Annual basis)	$63
Monitoring Cost [3] ($/LF)	$17

Notes:

1. Unit costs developed based on the Eldredge Park Way PRB Demonstration Project.
2. Replacement costs will occur every 15 years for PRB reinjection.
3. Monitoring costs represent an average on $/LF basis. This may vary by location due to reporting efforts and costs.

Traditional Systems

Description	Unit Cost
Collection System and Pumping Stations	
Gravity Sewer (lf)	$425
Low-Pressure Sewer (lf)	$200
Pumping Station (each)	$1,500,000
Force Main (lf)	$200
Highway Crossing (l.s.)	$500,000
O&M Cost ($/gal)	$1.75
WWTF and Aquifer Recharge	
WWTF ($/gal)	$100
Force Main (lf)	$200
Effluent Disposal ($/gal)	$10
O&M Cost ($/gal)	$3.25

Notes:

1. Based on the Average of Bids Received on May 6, 2020 for Contract 2019-02 - Downtown Area Collection System and Pumping Stations
2. O&M Cost Based on Estimated O&M Cost for Contract 2019-02 - Downtown Area Collection System and Pumping Stations
3. Based on the Average of Bids Received on May 13, 2020 for Contract 2019-01 - Downtown Area WWTF and Effluent Disposal
4. O&M Cost Based on Estimated O&M Cost for Contract 2019-01 - Downtown Area WWTF and Effluent Disposal

The LCCA utilized the following assumptions:

Factors	N Removal
Term at 30, 60 and 100 Years	Utilized 26.25 mg/l per MEP Studies
Interest Rate at 1.5%	PRBs - 80% Removal from Watershed
Inflation at 3.0%	Traditional System - 100% Removal from Watershed

The PRB LCCA costs (on a cost per kg nitrate removed basis) were than compared to the Traditional System LCCA costs (on a cost per kg nitrate removed basis). Conclusions are as follows:

1. When compared to Traditional Systems approximately:
   a. 80 percent of the proposed PRBs are more cost effective (on a cost per kg nitrate removed basis) over a 30-year life-cycle cost analysis; and
   b. 27 percent of the proposed PRBs are more cost effective (on a cost per kg nitrate removed basis) over a 100-year life-cycle cost analysis.
2. The proposed PRBs at Granny's, Richwood, Blossom and Norseman are more cost effective (on a cost per kg nitrate removed basis) compared to the Traditional Systems based on the 30-year, 60-year and 100-year life-cycle costs.
3. The proposed PRBs at Winslow, Gosnold and Rock Harbor are not as cost effective (on a cost per kg nitrate removed basis) as compared to the Traditional Systems based on the 30-year, 60-year and 100-year life-cycle costs.

Refer to the following summary; Table 4 for the 30-year, 60-year and 100-year life-cycle cost analysis for PRBs; and Table 5 for the 30-year, 60-year and 100-year life-cycle cost analysis for Traditional Systems.

Comparison of PRBs and Tranditional Systems on a Cost per kg Nitrate Removed Basis

PRB Description	LCCA at 30 Years		LCCA at 60 Years		LCCA at 100 Years	
	PRBs	Traditional System	PRBs	Traditional System	PRBs	Traditional System
Pleasant Bay Estuary						
Monument	X			X		X
Keziah's	X			X		X
Mayflower	X		X			X
Namequoit, Ridge & Lockwood	X		X			X
Quonset 1, 2, & 3	X		X			X
Granny's	X		X		X	
Winslow		X		X		X
Richwood	X		X		X	
Duck Hole	X			X		X
Gosnold		X		X		X
Briar Spring	X			X		X
Blossom	X		X		X	
Nauset Estuary						
Tonset Road and Main Street	X			X		X
Norseman	X		X		X	
Rock Harbor Estuary						
Rock Harbor		X		X		X
Totals	**12**	**3**	**7**	**8**	**4**	**11**

8. Consideration of Current Groundwater Use for Water Supply

Groundwater is currently used for water supply throughout the Town of Orleans. The Town operates municipal wells and has a water main distribution system servicing much of the Town. Private potable water supply wells are scattered throughout the Town with concentrations of these wells in certain areas. Parcels with private wells are shown on Figure 2. PRBs were only considered at locations downgradient of zones of contribution to municipal wells. AECOM assessed the distribution of private wells through town records and identified several potential private wells and parcels with potential private wells downgradient of PRBs. Parcels with private wells near potential PRBs appear to also be located adjacent to town municipal water mains and will need to be connected to town water to avoid any potential secondary water quality effects to potable water and to facilitate permitting PRB injection through the Massachusetts Underground Injection Control Program.

9. Conclusions

The performance of PRBs was considered against specific nitrogen reduction goals for non-traditional technologies. In certain watersheds, such as the watersheds to Town Cove and Meetinghouse Pond, traditional wastewater treatment will provide most of the nitrogen load reduction necessary to achieve TMDLs. Enhanced aquaculture will be also be pursued as an additional non-traditional technology but will not be assigned a specific share of the non-traditional remediation goal for watershed permitting in current planning.

The PRB siting criteria that specifies locating PRBs along roadways that are cross-gradient to the regional groundwater flow direction is important for access and feasible installation. However, this criterion also significantly limits the locations that can be selected. This limitation is considered the single most restrictive criterium for placement of PRBs, affecting PRB options and achievement of nitrogen remediation goals. Areas with significant concentrations of private wells were also avoided in locating PRBs due to concern for potential impacts to drinking water quality. A modified approach to PRB installation may be necessary to select additional locations or other alternatives may be necessary to achieve remediation goals. The ability of PRBs to achieve specific watershed goals are discussed in more detail below.

A. Pleasant Bay PRBs

A total of fourteen PRBs were identified in the Pleasant Bay Watershed. PRBs were placed in targeted sub-watersheds to the extent possible. Nitrogen removal requirements for sub-embayments are presented in Table 1. Nitrogen remediation requirements for Quanset Pond were included with Pleasant Bay/Little Pleasant Bay in this analysis due to difficulties in addressing Quanset Pond directly, giving a total of nine remediation goals used for comparison to estimate nitrogen load reductions. Measures of PRB effectiveness in relation to remediation goals are presented in Table 3 including:

- Estimated sewer load reduced (kg/yr) at 80% PRB efficiency;
- Percentage of embayment non-traditional technology goal achieved; and
- Estimated PRB efficiency (kg/LF/yr).

The nine targeted sub-watersheds cannot be fully remediated with PRBs to exceed the required non-traditional technology targets with the given assumptions. The overall projected PRB nitrogen reduction for Pleasant Bay based on the given assumptions was 2,115 kg/yr which is less than half the total Pleasant Bay non-traditional technology remediation goal of 4,966 kg/yr. However, the proposed PRBs could remove a significant percentage, ranging from 29 percent to 70 percent of the required removal load to impacted sub-watersheds.

The most efficient PRB in the Pleasant Bay watershed on a kilograms-of-nitrogen removed per linear foot per year basis was the Ridge (Ridgewood Road) PRB with a nitrogen removal efficiency of 0.27 Kg/LF/yr. In combination, the Ridge PRB and the Namequoit (Namequoit Road) PRB achieved an estimated 70 percent reduction in targeted nitrogen load to the Namequoit River. The Namequoit River is also an upper reach priority embayment that is significantly impacted by nitrogen load. Nitrogen load reduction in upper reaches of the estuary is a priority because upper reaches are the most impacted and nitrogen reduction in upper reaches will also benefit all lower areas in the estuary closer to the inlet to the bay.

Four PRB locations were identified in the Pochet Neck Stream and Pochet watersheds which is also a priority upper reach of the estuary with significant impact from nitrogen load. In combination these PRBs would remove 48 percent of the 1,564 kilograms of nitrogen load targeted for Pochet.

PRB locations could not be identified for Arey's Pond mainly due to roadway orientation and developed parcel locations. Meetinghouse Pond watershed will be remediated with conventional wastewater treatment and no PRB were located in the Meetinghouse Pond sub-watershed.

B. Nauset Estuary PRBs

Three potential PRBs were identified for the Nauset Estuary with a total projected nitrogen remediation of 866 kg/yr, which significantly exceeds the non-traditional technology goal of 566 kg/yr for Town Cove. The Tonset PRB was the largest identified and could be considered to help achieve the 7,164 kg/yr of nitrogen load reduction necessary to restore and maintain the Town Cove's water quality on an interim basis, treating existing load already in the groundwater while traditional wastewater systems are brought online. The relatively small 750-foot-long Main Street PRB was projected to be very efficient with a nitrogen removal of 0.4 Kg/LF/yr while the much longer Tonset PRB had a significantly lower nitrogen removal efficiency of 0.06 Kg/LF/yr.

C. Rock Harbor PRBs

One PRB location was identified for Rock Harbor along Rock Harbor Road that is estimated to remove 305 kg/yr of nitrogen which is less than half the Rock Harbor non-traditional remediation goal of 634 kg/yr. The Rock Harbor PRB had a relatively low nitrogen removal efficiency of 0.08 kg/LF/yr.

The results of the effort to identify potential full-scale PRB locations indicated there are many viable options for PRBs. Preliminary analysis indicates some locations are clearly more efficient and cost effective than others. PRBs identified in this process do not fully achieve nitrogen remediation goals for non-traditional technologies and additional alternatives may be required. The identified PRBs do however provide an important starting point for implementation of non-traditional technologies and are expected to provide for significant nitrogen removal. Actual groundwater data from field investigations will be necessary to confirm expected PRB performance in relation to remediation goals and may indicate higher effectiveness by accounting for additional nitrogen sources and/or higher source strength than considered in the screening assumptions. Groundwater data and a calculated mass flux of nitrogen is the MassDEP's preferred method for assessing PRB performance. The field data collected from monitoring wells will be used to assess the actual mass of nitrogen intercepted by the PRB on an annual basis.

Each of the potential PRB locations were evaluated based on the following considerations:

- Estimated PRB Efficiency (kg/LF/yr)
- Ability to meet PRB Non-traditional technology goal (kg/yr)
- Life Cycle Cost Analysis (PRBs vs Traditional System)
- Secondary Water Impacts (Public and Private Water Supplies: Existing and Future)
- Location of PRBs vs. Wastewater Service Areas
- PRB location with regards to embayment
- Watershed Compliance (N Reduction)
- Environmental Response (Short Term vs. Long Term)
- Implementation Costs (Capital Improvement Plan)

Critical factors include the estimated PRB efficiency (Kg/LF/yr), location, and ability to contribute to remedial goals (percent nitrogen reduction). Even PRBs with relatively low efficiency can be beneficial if sufficient length can be installed to achieve significant nitrogen reduction (% N reduction). In some cases, short length PRBs with high efficiency but low % N reduction can be worthwhile and are cost effective. In addition, PRB location with respect to the upper reach or head of the estuary matters. The upper reaches are the most impacted by eutrophication from nitrogen loading, with documented overload of nutrients. Reducing nitrogen loading in the upper estuary improves water quality throughout the bay. The following table presents the results of the evaluation as well as identifies as to whether the location is feasible for PRB implementation.

Embayment	PRB Name	Remarks	Feasible PRB Location (Y / N)
Pleasant Bay Estuary (Orleans)			
Meetinghouse Pond	None	N/A Conventional treatment	N/A
Lonnies Pond / Kescayo Gansett River	Monument	• High priority upper reach • Higher efficiency • Significant % N reduction	Y
Aery's Pond	None	Fails to meet siting criteria	N
Upper River	Keziahs	• High priority upper reach • Moderate efficiency • Significant % N reduction	Y
Lower River	Mayflower	• High priority upper reach • Moderate efficiency • Low % N reduction	Y
Namequoit River	Namequoit	• High priority upper reach • Higher efficiency • Highest % N reduction	Y
	Ridge	• High priority upper reach • Highest efficiency • Highest % N reduction	Y
Pah Wah Pond	Lockwood	• High priority upper reach • Moderate efficiency • Lower % N reduction	Y
Quanset and Pleasant Bay Main Basin	Quonset 1,2,3	• High priority upper reach • Moderate efficiency • Significant % N reduction	Y
	Grannys	• Lower priority location • Higher efficiency • Moderate % N reduction	Y
	Winslow	• Lower priority location • Low efficiency • Low % N reduction	N

Embayment	PRB Name	Remarks	Feasible PRB Location (Y / N)
Pochet	Richwood	• Lower priority location • Higher efficiency • Significant % N reduction	Y
	Duck Hole	• High priority upper reach • Lower efficiency • Significant % N reduction	Y
	Gosnold	• High priority upper reach • Low efficiency • Moderate % N reduction	Y
	Briar Spring	• High priority upper reach • Moderate efficiency • Significant % N reduction	Y
	Blossom	• High priority upper reach • Higher efficiency • Low % N reduction	Y
Nauset Estuary (Orleans)			
Town Cove	Tonset	• High priority upper reach • Low efficiency • High % reduction	Y
	Main	• High priority upper reach • High efficiency • High % reduction	Y
Mill Pond	Norseman	• Lower priority location • Higher efficiency • Significant % reduction	Y
Rock Harbor Estuary (Orleans)			
Rock Harbor	Rock Harbor	• High priority upper reach • Lower efficiency • Significant % reduction	Y

Not all feasible PRBs are recommended for implementation and some of the feasible PRBs are less beneficial than others and should be installed after the more advantageous locations. The Rock Harbor PRB and the Nauset Watershed Tonset PRB are in areas adjacent to planned conventional wastewater treatment service areas and would be better served by extending the conventional system. The Rock Harbor and Tonset PRBs are therefore not recommended for additional investigation. The potential Winslow PRB in the Pleasant Bay Watershed does not rank high enough to be considered for implementation due to projected low efficiency and low nitrogen removal, in addition to being in an area that does not affect the upper reaches or a confined sub-embayment of Pleasant Bay.

Implementation of the remaining feasible PRBs in the watersheds to Nauset Estuary and Pleasant Bay should move forward. In Nauset Estuary the recommended PRBs include the Main Street PRB adjacent to Town Cove, a relatively short cost effective PRB at a location that could provide a significant short-term benefit prior to the water quality improvements resulting from the Downtown conventional system. If implemented this PRB could address nitrogen already released to groundwater and migrating to Town Cove over the next 20 years. The Norseman PRB is also a relatively short PRB that is cost effective and would improve water quality in the Mill Pond sub-embayment. These locations should be investigated as described in the Next Steps presented below.

The remaining 13 PRBs in the Pleasant Bay Watershed should also move forward in the process and be investigated to confirm hydrogeologic conditions and water quality. A priority for implementation should be established based on the additional information and consideration of efficiency and nitrogen reduction potential.

10. Next Steps

Additional effort is necessary to confirm potential PRB locations and plan the appropriate sequencing of PRB implementation. Additional criteria for final selection of PRB locations will include site specific investigations and evaluations as follows:

A. Continue PRB Watershed Planning in order to reduce nitrogen based on the results of the Eldredge Park PRB Demonstration Test and previous Watershed Planning Activities. Conduct (a) field investigations; (b) subsurface investigations; and (c) sampling, analysis and evaluation on the following:

- Two potential PRB locations in the Nauset Estuary
  - ✓ Main Street
  - ✓ Norseman
- Thirteen potential PRB locations in the Pleasant Bay Estuary
  - ✓ Blossom
  - ✓ Briar Spring
  - ✓ Duck Hole
  - ✓ Gosnold
  - ✓ Grannys
  - ✓ Keziahs
  - ✓ Lockwood
  - ✓ Mayflower
  - ✓ Monument
  - ✓ Namequoit
  - ✓ Quonset 1,2,3
  - ✓ Richwood
  - ✓ Ridge

B. Field Investigations

- Perform field investigations to confirm suitability of the proposed PRB locations along roadways; types of utilities present; roadway ownership; accessibility for upgradient and downgradient monitoring well installation and long-term monitoring; and potential environmental impacts.
- Based on Board of Health information, verify the location and status of any private wells located in the vicinity of the proposed PRBs.
- Field investigations to occur on up to ten PRB locations.

C. Subsurface Investigations

- Perform subsurface investigations to obtain subsurface geologic condition and to confirm groundwater flow directions and water quality.
- Subsurface investigations to occur as follows:
  - ✓ Part 1 – Conduct drilling operations with soil sampling, groundwater profiling, and groundwater monitoring well installation and sampling at up to three locations at each potential PRB site. Based on the information obtain, evaluate the feasibility of each location as a potential PRB location and conduct additional subsurface investigations at sites which are deemed feasible.
  - ✓ Part 2 – Conduct drilling operations with soil sampling, groundwater profiling, and groundwater monitoring well installation and sampling at up to five additional locations at each potential PRB site identified as feasible.

D. Sampling, Analysis and Evaluation

- Obtain hydrogeologic information and results of groundwater analyses and conduct an evaluation to develop a baseline nitrogen concentration profile, geologic and geochemistry data to support a cost-effective implementation.
- Sampling and evaluation to occur on up to eight monitoring well locations at each PRB.

E. Regulatory and Local Coordination

- Coordinate with the MassDEP, the Town of Orleans and the Pleasant Bay Alliance to discuss planning activities, the results of the investigations and the evaluation of the proposed PRB site. Setup and participate in up to two meetings.
- Update the Town's webpage to include documents and presentations prepared as part of this phase of the project.

F. Update the Full-Scale Watershed Planning Report – Update the Full-Scale Watershed Planning Report to incorporate the planning activities, the results of the investigations and the evaluation of the proposed PRB sites.

G. Meetings

- Prepare for and conduct two public meetings with the Select Board, Board of Water and Sewer Commissioners, Planning Department and the public at large to obtain stakeholder input;
- Prepare for and conduct four coordination meetings Board of Water and Sewer Commissioners, Planning Department and Department of Public Works and Natural Resources the public at large to obtain stakeholder input.

This Technical Memorandum provides information for review by public stakeholders to facilitate ongoing public involvement in the process. Prior to final selection, location-specific assessment are necessary to confirm existing conditions and the nature of hydrogeological conditions and groundwater chemistry to estimate nitrogen flux at PRB locations.

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Tables

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Table 1
Orleans PRB Selection Matrix

Pleasant Bay Estuary (Orleans)

Embayment	PRB Name	MEP Watershed ID	Length (ft)	Roads	Saturated Depth (ft)	Depth Range to GW (ft)	Estimated Parcels	Estimated Sewer Load reduced (kg/yr) at 80% PRB Efficiency	Embayment Non-Traditional Technology Goal (kg/yr)	Estimated kg/LF/yr	Pleasant Bay Watershed PRB kg/yr Efficincy Rank	PRB Installation Cost Estimate	30-year LCCA for PRB (Present Worth)	Evaluation Notes
Meeting House Pond	None						**0**	**0**	**40**					
Lonnies Pond/Kescayo Gansett River							**41**	**178**	**284**					
Lonnies Pond/Kescayo Gansett River	Monument	25, 26 Lonnies Pond/Kescayo Gansett River	1,675	Monument	30	25 to 50	41	178		0.11	**8**	$2,060,250	$4,889,900	Upper Reach Priority embayment
Aerys Pond	None						**0**	**0**	**113**					
Upper River							**26**	**113**	**202**					
Upper River	Keziahs	41 Upper River	1,250	Keziahs	30	15 to 40	26	113		0.09	**9**	$1,537,500	$3,775,700	Upper Reach Priority embayment
Lower River							**35**	**152**	**517**					
Lower River	Mayflower	28 Lower River	1,700	Pershing, Kenneth	30	10 to 30	35	152		0.09	**11**	$2,091,000	$4,969,200	
Namequoit River							**56**	**244**	**348**					
Namequoit River	Namequoit	30 Namequoit River	1,000	Namequoit Road	30	10 to 40	27	117		0.12	**6**	$1,230,000	$7,577,200	Upper Reach Priority embayment
Namequoit River	Ridge	30 Namequoit River	460	Ridgewood Rd	30	10 to 30	29	126		0.27	**1**	$565,800	d with Namequoit PRB	Upper Reach Priority embayment
Pah Wah Pond							**35**	**152**	**413**					
Pah Wah Pond	Lockwood	32 Pah Wah Pond	1,230	Lockwood	30	5 to 15	35	152		0.12	**5**	$1,512,900	d with Namequoit PRB	Upper Reach Priority embayment
Quanset and Pleasant Bay Main Basin							**122**	**531**	**1485**					
Quanset and Pleasant Bay Main Basin	Quonset 1,2,3	33, 37 Pleasant Bay and Quanset Pond	1,745	Towhee, Lake Dr, Oyster	30	10 to 40	43	187		0.11	**7**	$2,146,350	$5,071,900	Upper Reach Priority embayment
Quanset and Pleasant Bay Main Basin	Grannys	33, 37 Pleasant Bay and Quanset Pond	650	Grannys Ln	30	15 to 20	24	104		0.16	**4**	$799,500	$2,174,200	Upper Reach Priority embayment
Quanset and Pleasant Bay Main Basin	Winslow	33, 37 Pleasant Bay and Quanset Pond	1,150	Winslow Dr and Way	30	5 to 40	14	61		0.05	**14**	$1,414,500	$3,496,900	Upper Reach Priority embayment
Quanset and Pleasant Bay Main Basin	Richwood	33, 37 Pleasant Bay and Quanset Pond	890	Richwood Farm	30	10 to 15	41	178		0.20	**2**	$1,094,700	$2,805,100	Upper Reach Priority embayment
Pochet							**171**	**744**	**1,564**					
Pochet	Duck Hole	35 Pochet Neck Stream	4,100	High View, Old Duck Hole, Lovell	30	5 to 35	68	296		0.07	**12**	$5,043,000	$11,335,800	Upper Reach Priority embayment
Pochet	Gosnold	34, 35 Pochet and Pochet Neck Stream	2,081	Gosnold,	30	10 to 30	29	126		0.06	**13**	$2,559,630	$5,966,700	Upper Reach Priority embayment
Pochet	Briar Spring	34 Pochet	2,906	Briar Spring	30	10 to 35	59	257		0.09	**10**	$3,574,380	$8,168,400	Upper Reach Priority embayment
Pochet	Blossom	35 Pochet	400	Blossom , Sparrowhawk	30	30 to 40	15	65		0.16	**3**	$492,000	$1,513,400	Upper Reach Priority embayment
Pleasant Bay Estuary (Orleans)			**21,237**				**486**	**2,115**	**4,966**			**$26,121,510**	**$61,744,400**	
	Average Efficiency kg/LF/yr									**0.10**				

Nauset Estuary (Orleans)

Embayment	PRB Name	MEP Watershed ID	Length (ft)	Roads	Saturated Depth (ft)	Depth Range to GW (ft)	Estimated Parcels	Estimated Sewer Load reduced (kg/yr) at 80% PRB Efficiency	Embayment Non-Traditional Technology Goal (kg/yr)	Estimated kg/LF/yr	Pleasant Bay Watershed PRB kg/yr Efficincy Rank	PRB Installation Cost Estimate	30-year LCCA for PRB (Present Worth)	Evaluation Notes
Town Cove							**171**	**744**	**566**					
Town Cove	Tonset	5 Town Cove	7,300	Gibson, Tonset	30	10 to 30	93	405		0.06	**3**	$8,979,000	$22,059,000	Upper Reach Priority embayment
Town Cove	Main	5 Town Cove	850	Main	40	5 to 10	78	339		0.40	**2**	$1,045,500	luded with Tonset PRB	Upper Reach Priority embayment
Mill Pond							**28**	**122**						
Mill Pond	Norseman	8 Mill Pond	580	Norsemans Road, Mill Pond Rd	40	10 to 35	28	122		0.21	**1**	$713,400	$1,999,700	Upper Reach Priority embayment
Nauset Estuary (Orleans)			**8,730**				**199**	**866**				**$10,737,900**	**$24,058,700**	
	Average Efficiency kg/LF/yr									**0.22**				

Rock Harbor Estuary (Orleans)

Embayment	PRB Name	MEP Watershed ID	Length (ft)	Roads	Saturated Depth (ft)	Depth Range to GW (ft)	Estimated Parcels	Estimated Sewer Load reduced (kg/yr) at 80% PRB Efficiency	Embayment Non-Traditional Technology Goal (kg/yr)	Estimated kg/LF/yr	Pleasant Bay Watershed PRB kg/yr Efficincy Rank	PRB Installation Cost Estimate	30-year LCCA for PRB (Present Worth)	Evaluation Notes
Rock Harbor Main	**Rock Harbor**						**70**	**305**	**634**					
Rock Harbor	Rock Harbor	3 Rock Harbor Main	3,940	Rock Harbor	50	5 to 15	70	305		0.08	1	$103,425	$10,896,700	Upper Reach Priority embayment
Rock Harbor Estuary (Orleans)	**Rock Harbor**		**3,940**				**70**	**305**	**634**	**0.08**		**$4,846,200**	**$10,896,700**	

PRB Townwide Potential Total			**33,907**				**755**	**3,286**				**$41,705,610**	**$96,699,800**	

Table 2
Orleans PRB Selection Matrix - PRB Characteristics

Pleasant Bay Estuary (Orleans)

Embayment	PRB Name	MEP Watershed ID	PRB Length (ft)	Roads	Saturated Thickness of PRB (ft)	Depth Range to Groundwater (ft)
Meeting House Pond	None					
Lonnies Pond/ Kescayo Gansett River						
Lonnies Pond/Kescayo Gansett River	Monument	25, 26 Lonnies Pond/Kescayo Gansett River	1,675	Monument	30	25 to 50
Aerys Pond	None					
Upper River						
Upper River	Keziahs	41 Upper River	1,250	Keziahs	30	15 to 40
Lower River						
Lower River	Mayflower	28 Lower River	1,700	Pershing, Kenneth	30	10 to 30
Namequoit River						
Namequoit River	Namequoit	30 Namequoit River	1,000	Namequoit Road	30	10 to 40
Namequoit River	Ridge	30 Namequoit River	460	Ridgewood Rd	30	10 to 30
Pah Wah Pond						
Pah Wah Pond	Lockwood	32 Pah Wah Pond	1,230	Lockwood	30	5 to 15
Quanset and Pleasant Bay Main Basin						
Quanset and Pleasant Bay Main Basin	Quonset 1,2,3	33, 37 Pleasant Bay and Quanset Pond	1,745	Towhee, Lake Dr, Oyster	30	10 to 40
Quanset and Pleasant Bay Main Basin	Grannys	33, 37 Pleasant Bay and Quanset Pond	650	Grannys	30	15 to 20
Quanset and Pleasant Bay Main Basin	Winslow	33, 37 Pleasant Bay and Quanset Pond	1,150	Winslow Dr and Way	30	5 to 40
Quanset and Pleasant Bay Main Basin	Richwood	33, 37 Pleasant Bay and Quanset Pond	890	Richwood Farm	30	10 to 15
Pochet						
Pochet	Duck Hole	35 Pochet Neck Stream	4,100	High View, Old Duck Hole, Lovell	30	5 to 35
Pochet	Gosnold	34, 35 Pochet and Pochet Neck Stream	2,081	Gosnold,	30	10 to 30
Pochet	Briar Spring	34 Pochet	2,906	Briar Spring	30	10 to 35
Pochet	Blossom	34 Pochet	400	Blossom , Sparrowhawk	30	30 to 40
Pleasant Bay Estuary (Orleans)			**21,237**			

Nauset Estuary (Orleans)

Embayment	PRB Name	MEP Watershed ID	PRB Length (ft)	Roads	PRB Saturated Thickness (ft)	Depth Range to Groundwater (ft)
Town Cove						
Town Cove	Tonset	5 Town Cove	7,300	Gibson, Tonset	30	10 to 30
Town Cove	Main	5 Town Cove	850	Main	40	5 to 10
Mill Pond						
Mill Pond	Norseman	8 Mill Pond	580	Norsemans Road, Mill Pond Rd	40	10 to 35
Nauset Estuary (Orleans)			**8,730**			

Rock Harbor Estuary (Orleans)

Embayment	PRB Name	MEP Watershed ID	PRB Length (ft)	Roads	PRB Saturated Thickness (ft)	Depth Range to Groundwater (ft)
Rock Harbor Main	Rock Harbor					
Rock Harbor	Rock Harbor	3 Rock Harbor Main	3,940	Rock Harbor	50	5 to 15
Rock Harbor Estuary (Orleans)	Rock Harbor		**3,940**			

PRB Townwide Potential Total			**33,907**			

Table 3
Orleans PRB Selection Matrix - Effectiveness

Pleasant Bay Estuary (Orleans)

Embayment	PRB Name	MEP Watershed ID	PRB Length (ft)	Estimated Number of Parcels	Estimated Sewer Load reduced (kg/yr) at 80% PRB Efficiency	Embayment Non-Traditional Technology Goal (kg/yr)	Percentage Removed	Estimated PRB Efficiency (kg/LF/yr)	PRB Watershed Efficincy Rank (kg/yr)	Evaluation Notes
Meeting House Pond	None			**0**	**0**	**40**	**0**			Traditional Technology to be Used
Lonnies Pond/Kescayo Gansett River				**41**	**178**	**284**	**63**			
Lonnies Pond/Kescayo Gansett River	Monument	Gansett River	1,675	41	178			0.11	**8**	Upper Reach Priority embayment
Aerys Pond	None			**0**	**0**	**113**	**0**			
Upper River				**26**	**113**	**202**	**56**			
Upper River	Keziahs	41 Upper River	1,250	26	113			0.09	**9**	Upper Reach Priority embayment
Lower River				**35**	**152**	**517**	**29**			
Lower River	Mayflower	28 Lower River	1,700	35	152			0.09	**11**	Upper Reach Priority embayment
Namequoit River				**56**	**244**	**348**	**70**			
Namequoit River	Namequoit	30 Namequoit River	1,000	27	117			0.12	**6**	Upper Reach Priority embayment
Namequoit River	Ridge	30 Namequoit River	460	29	126			0.27	**1**	Upper Reach Priority embayment
Pah Wah Pond				**35**	**152**	**413**	**37**			
Pah Wah Pond	Lockwood	32 Pah Wah Pond	1,230	35	152			0.12	**5**	Upper Reach Priority embayment
Quanset and Pleasant Bay Main Basin				**122**	**531**	**1,485**	**36**			
Quanset and Pleasant Bay Main Basin	Quonset 1,2,3	Pond	1,745	43	187			0.11	**7**	Upper Reach Priority embayment
Quanset and Pleasant Bay Main Basin	Grannys	Pond	650	24	104			0.16	**4**	Lower Priority
Quanset and Pleasant Bay Main Basin	Winslow	Pond	1,150	14	61			0.05	**14**	Lower Priority
Quanset and Pleasant Bay Main Basin	Richwood	Pond	890	41	178			0.20	**2**	Lower Priority
Pochet				**171**	**744**	**1,564**	**48**			
Pochet	Duck Hole	35 Pochet Neck Stream	4,100	68	296			0.07	**12**	Upper Reach Priority embayment
Pochet	Gosnold	Stream	2,081	29	126			0.06	**13**	Upper Reach Priority embayment
Pochet	Briar Spring	34 Pochet	2,906	59	257			0.09	**10**	Upper Reach Priority embayment
Pochet	Blossom	35 Pochet	400	15	65			0.16	**3**	Upper Reach Priority embayment
Pleasant Bay Estuary (Orleans)			**21,237**	**486**	**2,115**	**4,966**	**43**			

Nauset Estuary (Orleans)

Embayment	PRB Name	MEP Watershed ID	PRB Length (ft)	Estimated Number of Parcels	Estimated Sewer Load reduced (kg/yr) at 80% PRB Efficiency	Embayment Non-Traditional Technology Goal (kg/yr)	Percentage Removed	Estimated PRB Efficiency (kg/LF/yr)	PRB Watershed Efficincy Rank (kg/yr)	Evaluation Notes
Town Cove				**171**	**744**	**566**	**131**			
Town Cove	Tonset	5 Town Cove	7,300	93	405			0.06	**3**	Upper Reach Priority embayment
Town Cove	Main	5 Town Cove	850	78	339			0.40	**1**	Upper Reach Priority embayment
Mill Pond				**28**	**122**	**0**				
Mill Pond	Norseman	8 Mill Pond	580	28	122			0.21	**2**	Lower Priority
Nauset Estuary (Orleans)			**8,730**	**199**	**866**	**566**	**153**			

Rock Harbor Estuary (Orleans)

Embayment	PRB Name	MEP Watershed ID	PRB Length (ft)	Estimated Number of Parcels	Estimated Sewer Load reduced (kg/yr) at 80% PRB Efficiency	Embayment Non-Traditional Technology Goal (kg/yr)	Percentage Removed	Estimated PRB Efficiency (kg/LF/yr)	PRB Watershed Efficincy Rank (kg/yr)	Evaluation Notes
Rock Harbor Main	**Rock Harbor**			**70**	**305**	**634**	**48**			
Rock Harbor	Rock Harbor	3 Rock Harbor Main	3,940	70	305			0.08	**1**	Upper Reach Priority embayment
Rock Harbor Estuary (Orleans)	**Rock Harbor**		**3,940**	**70**	**305**	**634**	**48**			

PRB Townwide Potential Total			**33,907**	**755**	**3,286**					

Table 4
Orleans PRB Selection Matrix - Cost

Orleans Potential Full Scale PRBs - Pleasant Bay

Embayment	PRB Name	MEP Watershed ID	PRB Length (ft)	PRB Installation Cost Estimate (Using Avg. $/LF)	30-year LCCA for PRB	60-year LCCA for PRB	100-year LCCA for PRB
Meeting House Pond	None						
Lonnies Pond/Kescayo Gansett River							
Lonnies Pond/Kescayo Gansett River	Monument	25, 26 Lonnies Pond/Kescayo Gansett River	1,675	$2,060,250	$4,889,900	$11,771,500	$29,263,500
Aerys Pond	None						
Upper River							
Upper River	Keziahs	41 Upper River	1,250	$1,537,500	$3,775,700	$9,105,000	$22,593,400
Lower River							
Lower River	Mayflower	28 Lower River	1,700	$2,091,000	$4,969,200	$11,956,900	$29,715,300
Namequoit River							
Namequoit River	Namequoit	30 Namequoit River	1,000	$1,230,000	$7,577,200	$18,219,500	$45,400,700
Namequoit River	Ridge	30 Namequoit River	460	$565,800		Included with Namequoit PRB	
Pah Wah Pond							
Pah Wah Pond	Lockwood	32 Pah Wah Pond	1,230	$1,512,900		Included with Namequoit PRB	
Quanset and Pleasant Bay Main Basin							
Quanset and Pleasant Bay Main Basin	Quonset 1,2,3	33, 37 Pleasant Bay and Quanset Pond	1,745	$2,146,350	$5,071,900	$12,209,000	$30,358,200
Quanset and Pleasant Bay Main Basin	Grannys	33, 37 Pleasant Bay and Quanset Pond	650	$799,500	$2,174,200	$5,274,000	$13,024,100
Quanset and Pleasant Bay Main Basin	Winslow	33, 37 Pleasant Bay and Quanset Pond	1,150	$1,414,500	$3,496,900	$8,444,200	$20,954,000
Quanset and Pleasant Bay Main Basin	Richwood	33, 37 Pleasant Bay and Quanset Pond	890	$1,094,700	$2,805,100	$6,785,400	$16,804,500
Pochet							
Pochet	Duck Hole	35 Pochet Neck Stream	4,100	$5,043,000	$11,335,800	$27,203,000	$67,830,500
Pochet	Gosnold	34, 35 Pochet and Pochet Neck Stream	2,081	$2,559,630	$5,966,700	$14,355,900	$35,730,300
Pochet	Briar Spring	34 Pochet	2,906	$3,574,380	$8,168,400	$19,624,000	$48,891,500
Pochet	Blossom	35 Pochet	400	$492,000	$1,513,400	$3,693,000	$9,072,400
Pleasant Bay Estuary (Orleans)			**21,237**	**$26,121,510**	**$61,744,400**	**$148,641,400**	**$369,638,400**

Orleans Potential Full Scale PRBs - Nauset Estuary

Embayment	PRB Name	MEP Watershed ID	PRB Length (ft)	PRB Installation Cost Estimate (Using Avg. $/LF)	30-year LCCA for PRB	60-year LCCA for PRB	100-year LCCA for PRB
Town Cove							
Town Cove	Tonset	5 Town Cove	7,300	$8,979,000	$22,059,000	$52,885,100	$132,049,100
Town Cove	Main	5 Town Cove	850	$1,045,500		Included with Tonset PRB	
Mill Pond							
Mill Pond	Norseman	8 Mill Pond	580	$713,400	$1,999,700	$4,855,300	$11,973,500
Nauset Estuary (Orleans)			**8,730**	**$10,737,900**	**$24,058,700**	**$57,740,400**	**$144,022,600**

Orleans Potential Full Scale PRBs - Rock Harbor

Embayment	PRB Name	MEP Watershed ID	PRB Length (ft)	PRB Installation Cost Estimate (Using Avg. $/LF)	30-year LCCA for PRB	60-year LCCA for PRB	100-year LCCA for PRB
Rock Harbor Main	**Rock Harbor**						
Rock Harbor	Rock Harbor	3 Rock Harbor Main	3,940	$4,846,200	$10,896,700	$26,158,100	$65,232,700
Rock Harbor Estuary (Orleans)			**3,940**	**$4,846,200**	**$10,896,700**	**$26,158,100**	**$65,232,700**

PRB Townwide Potential Total			**33,907**	**$41,705,610**	**$96,699,800**	**$232,539,900**	**$578,893,700**

Table 5
Orleans Traditional Costs for Potential Full Scale PRB Areas

Orleans Traditional Costs for Potential Full Scale PRBs - Pleasant Bay

Embayment	PRB Name	Number of Parcels	Gravity Sewer (LF)	Low-Pressure Sewer (LF)	Pumping Station	Force Main (LF)	Highway Crossing	30-year LCCA for Traditional Treatment of PRB Area	60-year LCCA for Traditional Treatment of PRB Area	100-year LCCA for Traditional Treatment of PRB Area
Meeting House Pond	None									
Lonnies Pond/Kescayo Gansett River										
Lonnies Pond/Kescayo Gansett River	Monument	56	-	5,100	1	2,800	-	$11,229,800	$15,734,500	$27,359,400
Aerys Pond	None									
Upper River										
Upper River	Keziahs	38	-	4,620	1	1,050	0	$10,035,300	$14,393,400	$25,650,700
Lower River										
Lower River	Mayflower	39	-	6,120	1	2,400	-	$12,765,500	$18,543,100	$33,692,900
Namequoit River										
Namequoit River	Namequoit	112	-	12,030	1	2,330	-	$19,643,800	$29,703,600	$56,663,500
Namequoit River	Ridge	Included with Namequoit PRB								
Pah Wah Pond										
Pah Wah Pond	Lockwood	Included with Namequoit PRB								
Quanset and Pleasant Bay Main Basin										
Quanset and Pleasant Bay Main Basin	Quonset 1,2,3	48	-	7,370	1	6,925	-	$15,991,500	$22,244,300	$38,615,600
Quanset and Pleasant Bay Main Basin	Grannys	34	-	3,650	1	4,200	-	$10,881,800	$15,022,900	$25,634,900
Quanset and Pleasant Bay Main Basin	Winslow	33	-	3,100	1	1,100	-	$8,991,300	$12,956,400	$23,135,400
Quanset and Pleasant Bay Main Basin	Richwood	57	-	5,000	1	-	-	$11,027,600	$16,752,400	$31,824,500
Pochet										
Pochet	Duck Hole	49	-	12,240		-	-	$13,930,300	$22,394,800	$45,712,100
Pochet	Gosnold	43	-	5,250	1	1,450	-	$10,909,800	$15,672,600	$28,034,500
Pochet	Briar Spring	65	-	7,855	1	2,000	-	$14,027,700	$20,485,700	$37,516,300
Pochet	Blossom	22	-	1,925	1	1,350	-	$7,749,600	$10,875,800	$18,740,100
Pleasant Bay Estuary (Orleans)								**$147,184,000**	**$214,779,500**	**$392,579,900**

Orleans Traditional Costs for Potential Full Scale PRBs - Nauset Estuary

Embayment	PRB Name	Number of Parcels	Gravity Sewer (LF)	Low-Pressure Sewer (LF)	Pumping Station	Force Main (LF)	Highway Crossing	30-year LCCA for Traditional Treatment of PRB Area	60-year LCCA for Traditional Treatment of PRB Area	100-year LCCA for Traditional Treatment of PRB Area
Town Cove										
Town Cove	Tonset	229	11,000	9,850	1	3,500	-	$38,691,600	$57,626,500	$109,101,700
Town Cove	Main	Included with Tonset PRB								
Mill Pond										
Mill Pond	Norseman	37	-	3,200	1	7,000	-	$12,338,300	$16,772,700	$28,160,100
Nauset Estuary (Orleans)								**$51,029,900**	**$74,399,200**	**$137,261,800**

Orleans Traditional Costs for Potential Full Scale PRBs - Rock Harbor

Embayment	PRB Name	Number of Parcels	Gravity Sewer (LF)	Low-Pressure Sewer (LF)	Pumping Station	Force Main (LF)	Highway Crossing	30-year LCCA for Traditional Treatment of PRB Area	60-year LCCA for Traditional Treatment of PRB Area	100-year LCCA for Traditional Treatment of PRB Area
Rock Harbor Main	**Rock Harbor**									
Rock Harbor	Rock Harbor	81	0	8200	0	0	1	$10,994,600	$17,218,300	$34,367,700
Rock Harbor Estuary (Orleans)								**$10,994,600**	**$17,218,300**	**$34,367,700**

Traditional Costs for PRB Townwide Potential Total							**$209,208,500**	**$306,397,000**	**$564,209,400**

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Figures

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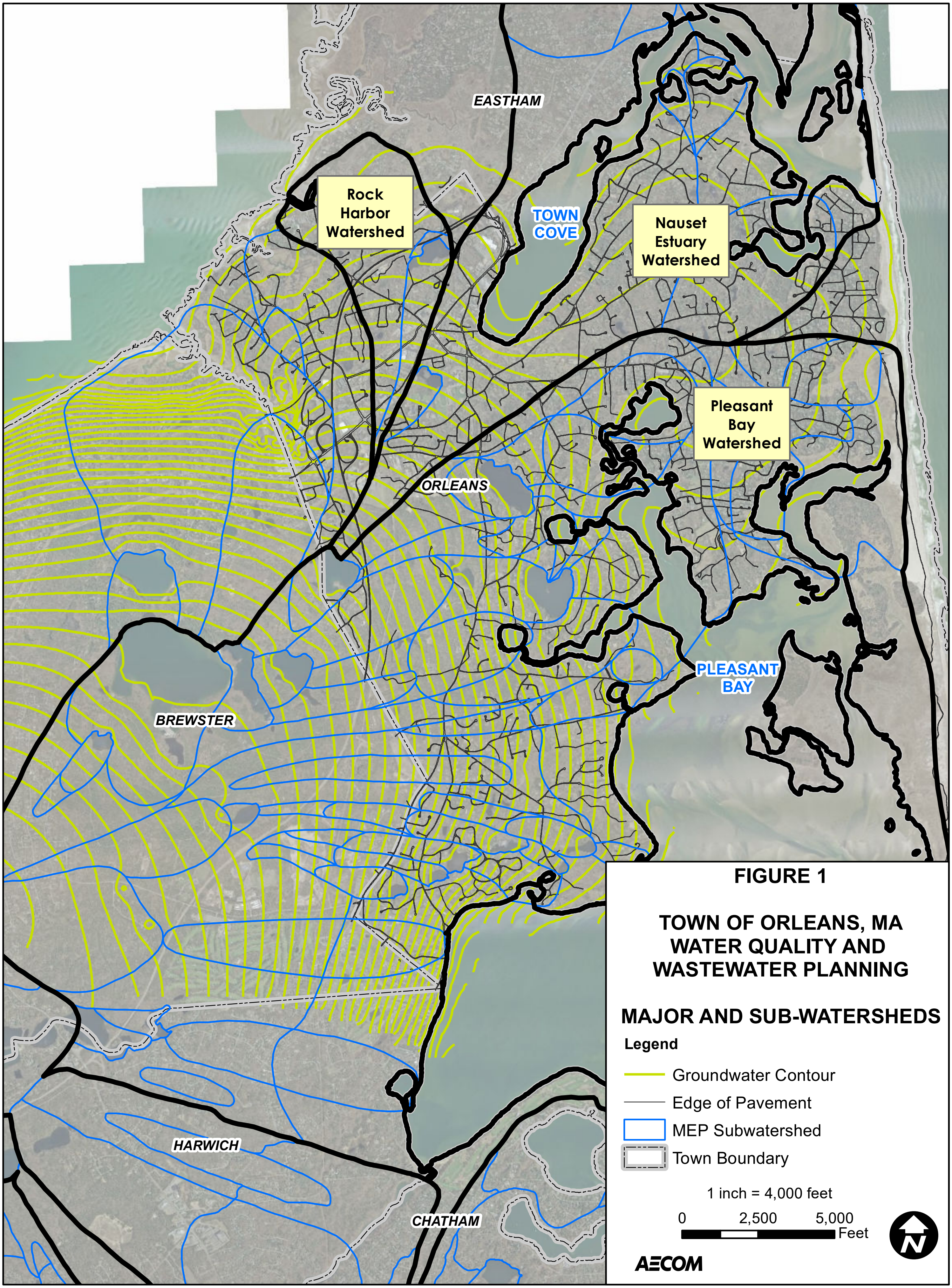

FIGURE 1

TOWN OF ORLEANS, MA WATER QUALITY AND WASTEWATER PLANNING

MAJOR AND SUB-WATERSHEDS

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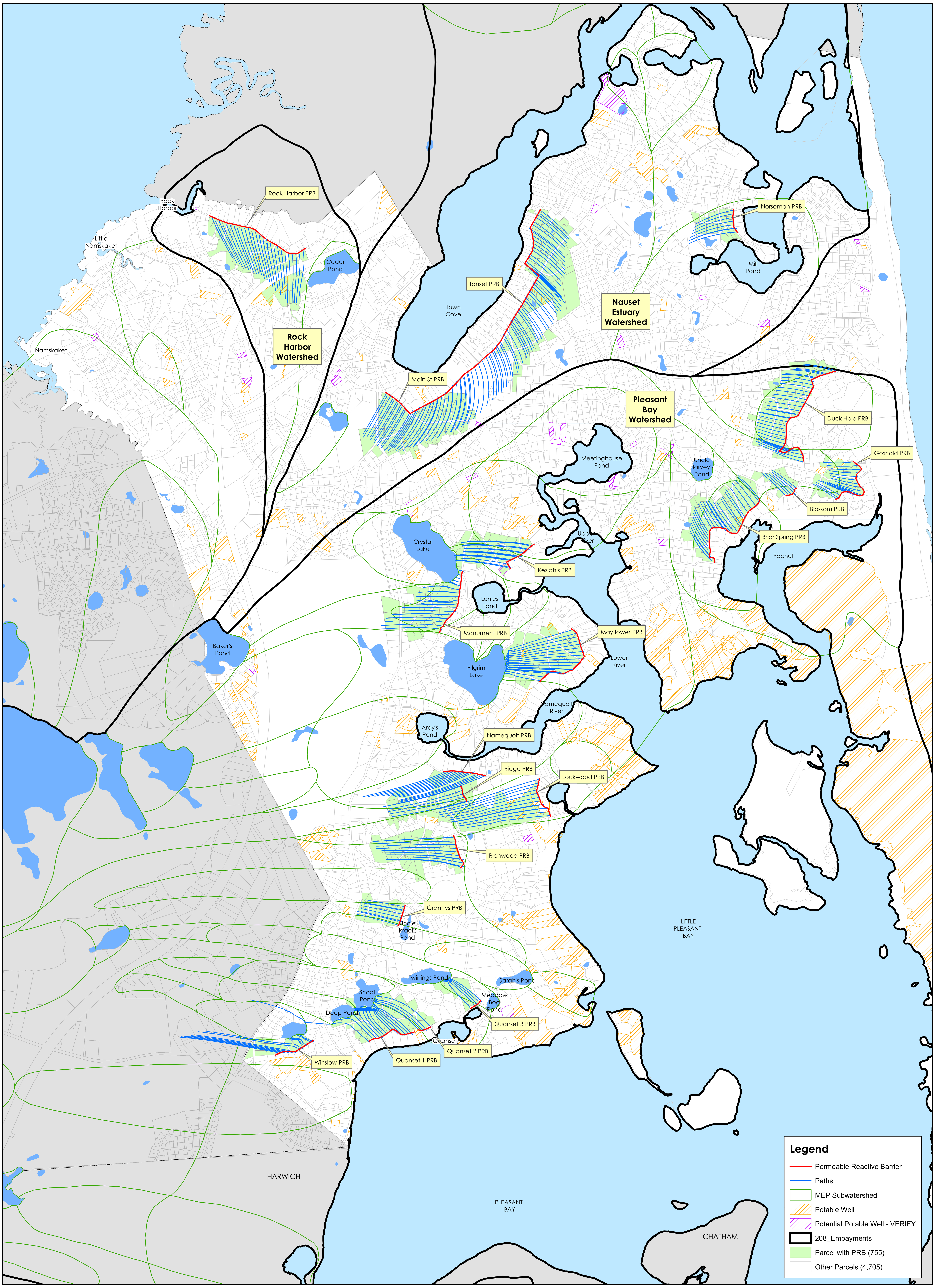
FIGURE 2
PARTICLE TRACKING

TOWN OF ORLEANS
MASSACHUSETTS

AUGUST 2020

N

0 600 1,200 2,400 3,600 4,800
Feet



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Appendix A: Implementation Plan for Full-Scale PRBs

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Memorandum

To	George Meservey, Director of Planning & Community Development
CC	Betsy Shreve, AICP, AECOM Project Director James Begley, LSP, MT Environmental AECOM PRB Team
Subject	**Town of Orleans, MA** **Water Quality and Wastewater Planning** **Task 11.1.B.2 - Permeable Reactive Barriers (PRB)** **Implementation Plan for Full-Scale PRBs - Final**
Project Number	60476644
From	Thomas Parece, P.E., AECOM Project Manager
Date	August 6, 2018

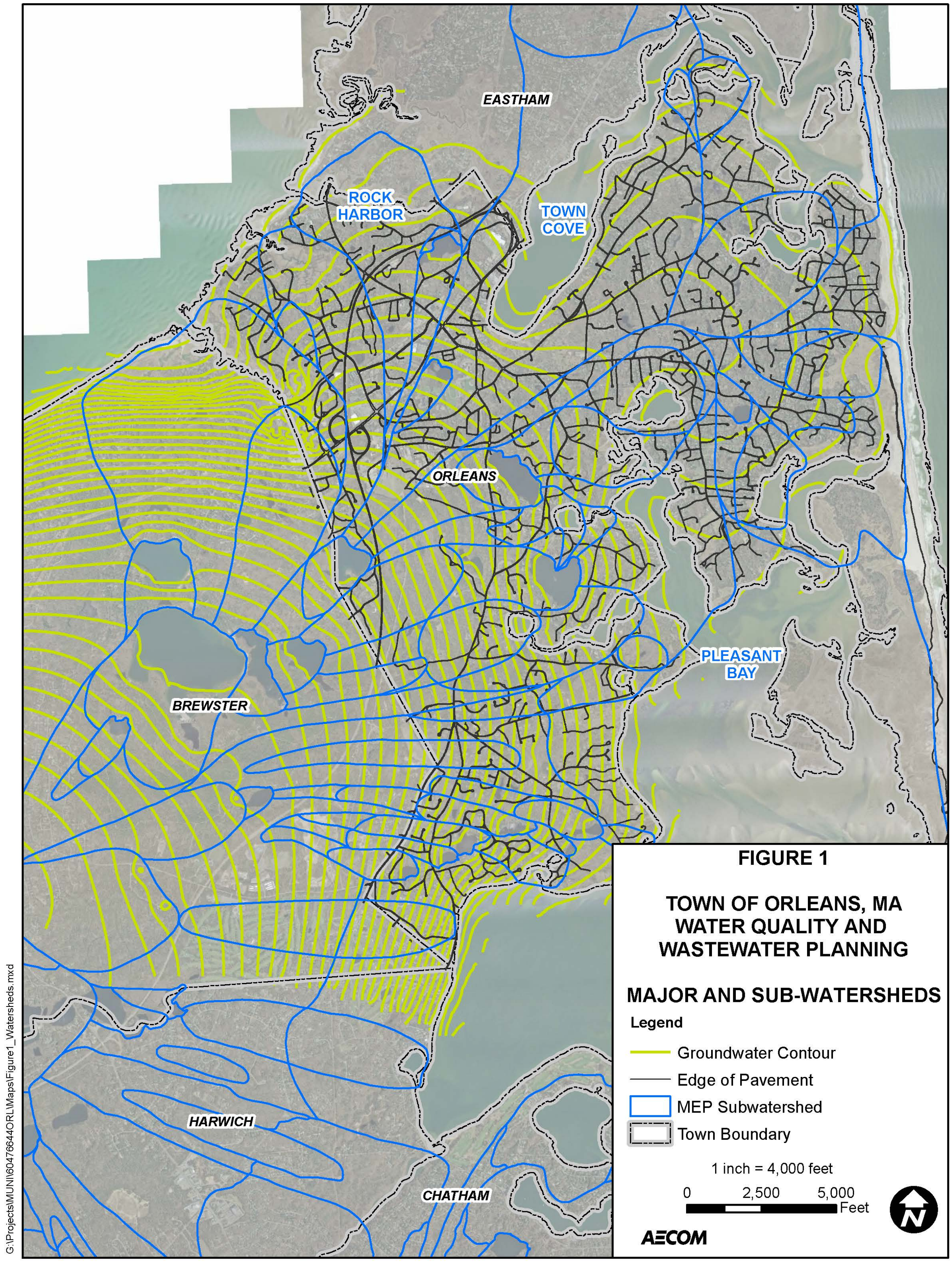
Approvals	Date	Signature / Initials
George Meservey, Orleans, MA Director of Planning & Community Development		

1. Introduction

This full-scale Permeable Reactive Barrier (PRB) Implementation Plan has been developed on behalf of the Town of Orleans Massachusetts (the Town) and includes preliminary design information and planning steps necessary for successful application of PRBs to reduce nitrogen loading to estuaries in Orleans. The estuaries include Rock Harbor, Nauset Estuary, and Pleasant Bay with proposed PRB systems in their respective watersheds. The PRBs will treat watershed nitrate prior to discharge to surface waters and be located to provide the most cost-effective treatment. The objective of this Implementation Plan is to provide preliminary design information and identify actions necessary to permit and install the PRBs and achieve verified nitrogen reductions. This plan identifies several potential PRB locations, but final locations will be selected after assessment of potential sites and public input on the proposed locations.

2. Background

Major watersheds in the Town include Nauset Harbor and Pleasant Bay sub-watersheds within the Atlantic Ocean watershed, and Namskaket Creek, Little Namskaket Creek, and Rock Harbor sub-watersheds within the Cape Cod Bay watershed. The groundwater system comprising these watersheds is part of the Monomoy Lens of the Cape Cod Aquifer. These major watersheds are characterized by numerous sub-watersheds contributing groundwater discharge to freshwater ponds, and estuaries including bays, salt ponds, and inlets as shown in Figure 1. Nitrogen in the form of nitrate, mainly from septic systems and fertilizer use is released to groundwater in the watersheds and then moves as a large dilute plume with groundwater flow and eventually discharges to the estuaries and coastal waters. This groundwater source of nitrogen is combined with additional sources such as stormwater runoff and fertilizer resulting in significant nitrogen loading to the surface water. When nitrogen loading reaches a certain threshold, it causes eutrophication or over enrichment of nutrients in estuaries resulting in algae blooms, scum layers, unpleasant odors, and periodic fish kills due to low oxygen conditions.


EASTHAM
ROCK HARBOR
TOWN COVE
ORLEANS
PLEASANT BAY
BREWSTER
HARWICH
CHATHAM
FIGURE 1
TOWN OF ORLEANS, MA
WATER QUALITY AND
WASTEWATER PLANNING
MAJOR AND SUB-WATERSHEDS
Legend
Groundwater Contour
Edge of Pavement
MEP Subwatershed
Town Boundary
1 inch = 4,000 feet
0
2,500
5,000
Feet
AECOM
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To address these concerns and comply with the Clean Water Act, the Town prepared a Comprehensive Wastewater Management Plan (CWMP) in December 2010. In response to comments on the CWMP, the Town re-evaluated its previously recommended approach to nitrogen control, which focused on installation of an extensive sewage collection system and new treatment facility with discharge at the Tri-Town Septage Treatment Facility site.

Subsequently, a draft Amended Comprehensive Wastewater Management Plan (ACWMP) was developed to document proposed changes including a revised Hybrid Plan. The ACWMP was developed in accordance with the Cape Cod 208 Water Quality Plan, which has been approved by both the United States Environmental Protection Agency (US EPA) and the Massachusetts Department of Environmental Protection (MassDEP).

The 25 percent Preliminary Design Report (PDR) plans for sewers in two areas including approximately 330 parcels encompassing the Downtown Area and approximately 406 parcels within the Meetinghouse Pond Area.

As this time, the revised ACWMP Hybrid Plan also included provisions for use of non-traditional technologies including PRBs and shellfish propagation to control nitrogen including an ongoing aquaculture demonstration in Lonnies Pond. Demonstrations for both PRBs and shellfish propagation are currently underway. Using these non-traditional technologies allows for reduced sewer collection system coverage while still achieving nitrogen control objectives. Permeable Reactive Barriers (PRBs) provide a way to intercept nitrogen in groundwater at key locations in the watersheds before it reaches sensitive embayments.

A PRB Demonstration Test has been implemented at the Eldredge Park Way location in Orleans to assess feasibility, determine PRB nitrogen removal efficiency, and assess the environmental sustainability of the alternative. The demonstration project was implemented in November 2016, was expanded in June 2018 and is subject to an intensive ongoing monitoring program to quantify nitrogen removal and secondary water quality effects. The cost for the three year demonstration test (investigations, implementation, expansion and monitoring) is approximately $917,000. Preliminary monitoring data indicate that the PRB is serving to reduce nitrogen concentrations in groundwater without significant secondary water quality impacts. Information gained through the demonstration will be utilized in determining final engineering details for full-scale implementation, refining monitoring plans, and predicting nitrogen removal efficiency for cost effectively achieving water quality goals.

3. Permeable Reactive Barrier Technology

A PRB is a passive treatment technology, designed in this application to in tercept and treat nitrate in groundwater through biological denitrification before the groundwater reaches downgradient surface waters. The PRB treatment zone is installed in the groundwater saturated zone below the water table, where amendments are added by injection to form the PRB. PRBs are typically oriented perpendicular to the direction of groundwater flow as shown in Figure 2 and rely on the natural groundwater gradient to carry nitrate to the PRB. The system is permeable because the injected amendments are designed not to interfere with groundwater flow, only removing nitrate as the groundwater passes through.

Key Terms

Permeable Reactive Barrier (PRB)
A zone of enhanced denitrification formed in the path of a dissolved nitrate plume.

Denitrification
Biological conversion of nitrate in water to inert nitrogen gas by naturally occurring bacteria. Denitrification: $NO_3^- \rightarrow N_2$ (gas)

PRB Amendment
Emulsified vegetable oil (EVO) used to provide dissolve organic carbon to stimulate naturally occurring bacteria in groundwater to transform nitrate to inert nitrogen gas.

Preliminary Design
Provides a concept with typical layout, materials, and steps to install the PRBs and associated cost elements.

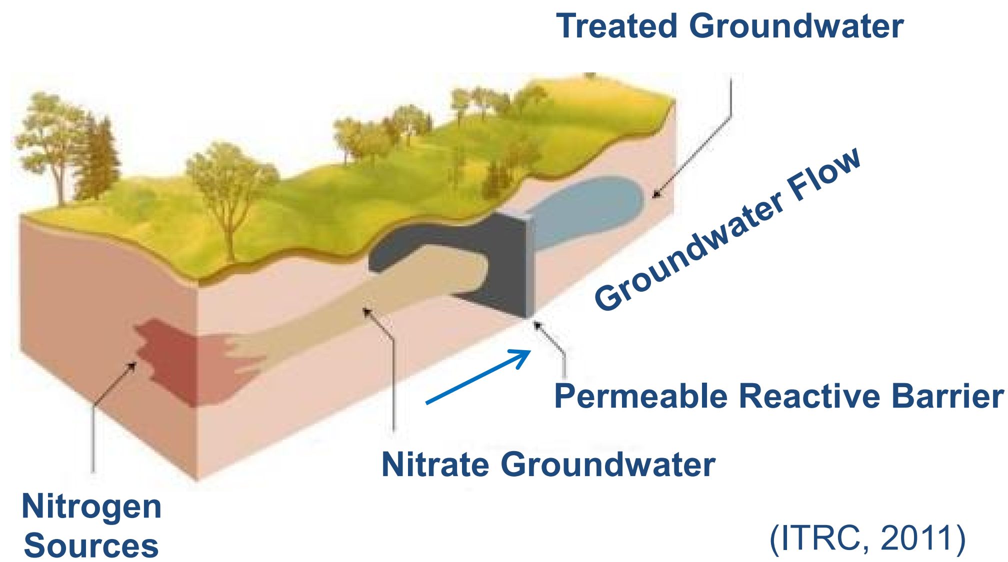

Figure 2 - Permeable Reactive Barrier

The injected amendment used to form the PRB is typically emulsified vegetable oil (EVO), a source of dissolved organic carbon that stimulates naturally occurring microbes in the groundwater to consume the dissolved organic carbon while respiring oxygen and creating anoxic conditions (without oxygen) favorable for denitrifying bacteria. The denitrifying bacteria then continue to use the dissolved organic carbon while respiring nitrate. This process of bacterial metabolism results in the conversion of nitrate to inert nitrogen gas. The PRB will need to be rejuvenated with additional EVO injections following an extended period of operation to replenish the consumed organic carbon.

4. Water Quality Goals

A. General

Development of surface water quality goals in the form of Total Maximum Daily Loads (TMDLs) is required by the Federal Clean Water Act. To develop embayment specific TMDLs, the Massachusetts Estuaries Project (MEP) have assessed nitrogen loading to the estuaries using an analytical method called the Linked Watershed-Embayment Management Modeling Approach. The model links watershed nitrogen inputs with surface water circulation and nitrogen characteristics. The TMDLs define the maximum nitrogen loads that the water bodies can receive while still meeting necessary water quality criteria. Corrective actions are then necessary to reduce nitrogen loading to below the TMDLs.

TMDLs developed by MEP have been documented in technical reports prepared for Pleasant Bay, Rock Harbor, and the Nauset Estuary (MEP 2006, MEP 2007, MEP 2012). Based on the TMDLs developed by the MEP, the MassDEP and US EPA have approved nitrogen TMDLs for Pleasant Bay. Additional TMDLs are undergoing review by the regulatory agencies. MEP assessments of Namskaket and Little Namskaket Creeks indicated no exceedances of developed TMDLs.

B. Pleasant Bay TMDLs

Pleasant Bay is connected to the Atlantic Ocean and is characterized by three main basins including Little Pleasant Bay, Pleasant Bay, and Chatham Harbor. The bay has a long shoreline and numerous sub-embayments. These sub-embayments are at particular risk of eutrophication from high nitrogen loads entering by direct groundwater discharge and restricted tidal exchange. Main basins in or adjacent to Orleans include Pleasant Bay Main Basin and Little Pleasant Bay. The sub-embayments in Orleans include Meetinghouse Pond, the Upper and Lower River, Lonnies Pond, Namequoit River and Aries Pond, Paw Wah Pond, Quanset Pond, and Pochet Inlet.

MEP issued the report "Linked Watershed-Embayment Model to Determine Critical Nitrogen Loading Thresholds for the Pleasant Bay System, Orleans, Chatham, Brewster and Harwich, Massachusetts" in May 2006 that included proposed TMDLs for the system. On June 23, 2017 the Select Boards of Brewster, Chatham, Harwich and Orleans voted to sign a Resolution of the Towns sharing the Watershed of Pleasant Bay, endorsing the Pleasant Bay Composite Nitrogen Management Analysis as an accurate representation of each Town's share of current attenuated nitrogen load and its responsibility to remove nitrogen in Pleasant Bay (Pleasant Bay Alliance, March 2017). The agreed Town of Orleans share of attenuated Pleasant Bay Watershed nitrogen load is 6,980 kg/yr. The Towns sharing the watershed of Pleasant Bay entered an inter-municipal memorandum of agreement in 2018 to coordinate resource management of Pleasant Bay among the member Towns through the Pleasant Bay Alliance. The Pleasant Bay Alliance developed nitrogen removal requirements by Town and by Sub-embayment identifying these requirements is shown on Table 1 (Pleasant Bay Alliance March 2017).

C. Nauset Harbor Embayment System TMDLs

The Nauset Harbor Embayment System in Orleans and Eastham is comprised of open waters including Nauset Harbor and Town Cove, Nauset Marsh, located behind Nauset Barrier Beach, and three sub-embayments including Salt Pond, Wood Cove, and Mill Pond. The Nauset Harbor Estuary watershed is in the Towns of Orleans, Eastham, and Brewster. The most impacted areas with impaired habitat, and therefore the focus of nitrogen load reduction in Orleans, include the upper reach at Town Cove and the semi-enclosed Mill Pond and Wood Cove sub-embayments. The Salt Pond sub-embayment in Eastham is also at risk of eutrophication. MEP issued the report "Linked Watershed-Embayment Approach to Determine Critical Nitrogen Loading Thresholds for the Nauset Harbor Embayment System, Towns of Orleans and Eastham, Massachusetts" in 2012 that included TMDLS for the estuary.

Based on the draft ACWMP, the required nitrogen removal by Orleans for the Nauset system is 5,442 kg/yr, with a PRB technology removal target of 566 kg/yr focused on Town Cove.

D. Rock Harbor TMDLs

The watershed for Rock Harbor is in the Towns of Orleans and Eastham. Rock Harbor is a man-made harbor at the mouth of a tidal river and salt marsh and opens to Cape Cod Bay to the north. Significant habitat quality impairment and the presence of algal mats have been observed in the lower reach harbor area, while the upper reach marsh area has higher quality habitat. MEP issued the report "Linked Watershed-Embayment Approach to Determine Critical Nitrogen Loading Thresholds for the Rock Harbor Embayment System, Towns of Orleans, Massachusetts" in December 2008 that included TMDLs for the estuary.

Based on the draft ACWMP, the required nitrogen removal by Orleans for Rock Harbor is 1,463 kg/yr, with a PRB technology removal target of 634 kg/yr.

Table 1 - Pleasant Bay Composite Nitrogen Management Analysis
Nitrogen Removal Requirements by Town and by Sub-embayment (kg/yr)
(Pleasant Bay Alliance March 2017)

Pleasant Bay Composite Nitrogen Management Analysis
Table 1. Nitrogen Removal Requirements by Town and by Subembayment (kg/yr)

Subembayment	Brewster	Chatham	Harwich	Orleans	Total
Meetinghouse Pond				1,876	1,876
Town Percent of Total Removal				100%	100%
Lonnies Pond	14			284	298
Town Percent of Total Removal	5%			95%	100%
Areys Pond	29			113	142
Town Percent of Total Removal	20%			80%	100%
The River - Upper	3			375	378
Town Percent of Total Removal	1%			99%	100%
The River - Lower	6			518	524
Town Percent of Total Removal	1%			99%	100%
Namequoit River	19			348	367
Town Percent of Total Removal	5%			95%	100%
Paw Wah Pond				413	413
Town Percent of Total Removal				100%	100%
Quanset Pond	29			227	256
Town Percent of Total Removal	11%			89%	100%
Round Cove	1		1,209		1,210
Town Percent of Total Removal	0.1%		99.9%		100%
Muddy Creek Upper		193	584		777
Town Percent of Total Removal		25%	75%		100%
Muddy Creek Lower		584	986		1,570
Town Percent of Total Removal		37%	63%		100%
Ryder's Cove		1,954			1,954
Town Percent of Total Removal		100%			100%
Crows Pond		0			0
Town Percent of Total Removal		-			-
Bassing Harbor		0			0
Town Percent of Total Removal		-			-
Frost Fish Creek		803			803
Town Percent of Total Removal		100%			100%
Pochet				1,569	1,569
Town Percent of Total Removal				100%	100%
Pleasant Bay (including Little Pleasant Bay)	2,161	542	1,620	1,257	5,580
Town Percent of Total Removal	39%	10%	29%	22%	100%
Chatham Harbor		0			0
Town Percent of Total Removal		-			-
Total (All Subembayments)	2,262	4,076	4,399	6,980	17,717
Town Percent of Total Removal	13%	23%	25%	39%	100%

Notes:
1. Blue shading denotes entries that are greater than 5% of total (more than 886 kg/yr).
2. Blue shaded entries account for 71% of overall requirement.
3. See Table A-2 and A-3 in Appendix A for derivation of load removal requirements.

5. Implementation Approach and Phasing of PRB Installations

A. General

Criteria and conditions that will drive the phasing of full scale PRB installations include:

- The progress and outcome of the ongoing PRB Demonstration Test;
- Regulatory permitting timelines;
- Selection and access to proposed PRB locations;
- Availability of staffing resources and implementation funds;
- Availability of carbon substrate, subcontractors, and equipment for monitoring well installation and PRB injection; and
- Adaptive management of PRB implementation.

The PRB design process will include four general steps. These steps are outlined below with approximate time frames:

- Initial planning (this Technical Memorandum);
- Preliminary assessments of potential PRB locations and coordination with stakeholders including public workshops (6-months);
- Investigation of short listed locations with hydrogeologic assessments to confirm groundwater flow, actual water quality, and feasibility (9-months); and
- Full-design (1-year).

B. Development of Project Costs

PRB implementation costs have been developed based on estimated linear feet of PRB implementation defined in the ACWMP and cost information from the demonstration test at Eldredge Parkway location. These costs are outlined in Table 2 and include:

- Town Administration and Engineering;
- Engineering - Planning/Consultation;
- Engineering – Design;
- Contractor mobilization and demobilization;
- Monitoring well drilling and installation;
- Monitoring plan and baseline assessment;
- PRB Injections and materials;
- First year monitoring program implementation; and
- Projected annual replacement costs for monitoring wells and PRB rejuvenation injections.

Key Terms

Implementation Costs
Related to costs to Implement or install the proposed PRB. Implementation Costs are generally financed through a loan or bond program. This provides up front funding for implementation, with principal and interest payments spread out over time.

Annual Operations and Maintenance (O&M) Costs
Related to the day-to-day running and upkeep of the system. O&M Costs include items such as labor, utilities, chemicals, etc.

Annual Replacement Costs
Related to the replacement and/or repair of monitoring wells that have been damaged as well as the annualize cost to re-inject EVO.

Annual Monitoring Costs
Related to the annual compliance monitoring determined by the MassDEP. Annual Monitoring Costs include items such as labor and laboratory analysis.

Table 2 - Estimated Costs (July 2018)

Component	Implementation Cost	Annual O&M Cost	Annual Replacement Cost	Annual Monitoring Cost
Site 1 – Rock Harbor Watershed (4,700 LF)				
Design	$518,600			
Implementation, O&M and Monitoring	$4,148,700	$0		$178,600
Replacement			$745,300	
Site 2 – Pleasant Bay Watershed (1,900 LF)				
Design	$210,700			
Implementation, O&M and Monitoring	$1,685,400	$0		$78,300
Replacement			$307,100	
Site 3 – Nauset Harbor Watershed (2,200 LF)				
Design	$244,500			
Implementation, O&M and Monitoring	$1,956,000	$0		$89,100
Replacement			$354,500	

Notes:

1. The design is expected to occur within a one-year period following site selection. The implementation, O&M, and monitoring is expected to begin after the design year, pending appropriation of funding at the prior year's Town Meeting/Special Town Meeting. The annualized replacement costs are anticipated to begin the year following implementation.
2. The estimated linear feet of PRB for the three sites is based on the 2015 Conceptual Approach developed by Stantec for the Town of Orleans. The estimated costs presented are based on these lengths and are expected to vary based on actual length determined during design development.

AECOM has no control over costs of labor, materials, competitive bidding environments and procedures, unidentified field conditions, financial and/or market conditions or other factors likely to affect the opinion of probable project costs all of which are and will unavoidably remain in a state of change. It is further understood that the probable project costs are a "snapshot in time" and that the reliability of this opinion of probable project costs will inherently degrade over time.

The probable project costs need to be indexed on a common "baseline". The construction industry uses the Engineering News Record (ENR) Construction Cost Index (www.enr.com) that is based on construction and materials costs throughout the United States. Therefore, the probable project costs contained herein are based on an ENR Construction Cost Index of 11117 for July 2018.

The probable project costs will need to be updated based on the actual implementation year.

C. Regulatory Permitting

Massachusetts Section 2A of Chapter 259 of the Acts of 2014 required MassDEP to develop a watershed permitting approach to address and optimize nitrogen management measures intended to restore water quality. Planning for Watershed Permits is included in the approved Cape Cod Nitrogen Management Plan (the 208 Plan Update) developed pursuant to Section 208 of the federal Clean Water Act. The 208 Plan Update designates Cape Cod Towns as Waste Treatment Management Agencies (WMAs) responsible for meeting TMDLs on a watershed basis.

In addition to the Watershed Permit, site specific permitting requirements for PRBs will depend on the proposed location. PRBs will be proposed outside of wetland resource areas and sensitive environmental locations where possible. The preferred approach is to install PRBs through Town roads or rights-of-way or potentially on Town-owned properties. Potential permitting requirements and approving authorities are included in Table 3 and described below.

Table 3 - Potential Permit Requirements Depending on Location

Permit	Regulation	Administrating Agency
Massachusetts Environmental Policy Act Permit	Massachusetts Environmental Policy Act Unit	MEPA Unit
Underground Injection Control Registration	Safe Drinking Water Act	MassDEP
Section 106 & Chapter 254 Historic Preservation Act Compliance	Section 106 of the National Historic Preservation Act	Massachusetts Historical Commission
Massachusetts Endangered Species Act Project Review	Massachusetts Endangered Species Act	Massachusetts Division of Fisheries and Wildlife Natural Heritage & Endangered Species Program
Notice of Intent/Order of Conditions	Wetlands Protection Act/ Rivers Protection Act	Town of Orleans Conservation Commission and MassDEP
Road Opening Permits	Massachusetts Chapter 82A Sections 40 through 40D	Town of Orleans Highway Department

D. Massachusetts Environmental Policy Act

PRB projects may be subject to the Massachusetts Environmental Policy Act (MEPA) 301 CMR 11.00. MEPA review is required when one or more review thresholds are met or exceeded and the subject matter of at least one review threshold is within MEPA jurisdiction. In determining whether a Project is subject to MEPA jurisdiction or meets or exceeds any review thresholds it may be necessary to consider all proposed PRBs together to avoid segmentation concerns.

An Environmental Notification Form (ENF) describing the project and potential environmental impacts along with any feasible measures to mitigate potential environmental damage is submitted to the Executive Office of Energy and Environmental Affairs (EEA). EEA solicits comments from the public and state agencies. Following public comment and consultation, the EEA issues a Certificate stating whether an Environmental Impact Report (EIR) is needed and what the scope of the EIR should include, if required. If the EIR is not required, the state permitting agencies can issue the required permits and the project can go forward. Projects located in designated Areas of Critical Environmental Concern require ENF and a Mandatory EIR. Both Pleasant Bay and Rock Harbor are located within state-designated Areas of Critical Environmental Concern.

E. Underground Injection Control Registrations

PRBs will require a MassDEP issued Underground Injection Control (UIC) Registration to comply with UIC Regulations. The UIC Program is responsible for regulating the implementation, 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 MassDEP UIC Program, defined in 310 CMR 27.00: Underground Injection Control Regulations, details the regulation of injection of fluids within Massachusetts.

To implement a PRB a UIC permit application (MassDEP form BRPWS 06) must be filed with MassDEP under the category “Aquifer Remediation”. The application would include the design parameters and layout of the PRB along with a Water Quality Monitoring Plan. 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. PRBs will be implemented in compliance with the requirements of the Massachusetts UIC regulations, including all required monitoring. A fee of $585 for each PRB 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 implementation start date. Status reports documenting PRB implementation and monitoring results are subsequently submitted to MassDEP.

F. Historic Preservation Act

At certain locations project review by the Massachusetts Historical Commission (MHC) may be necessary. The MHC administers the Historic Preservation Act. Any projects that require funding, licenses, or permits from any state agency must be reviewed by MHC in compliance with Massachusetts General Laws Chapter 9, sections 26-27C. This law creates the MHC, the office of the State Archaeologist, and the State Register of Historic Places among other historic preservation programs. It provides for MHC review of state projects, State Archaeologist’s Permits, the protection of archaeological sites on public land from unauthorized digging, and the protection of unmarked burials. The regulations that guide MHC review of state funded, licensed or permitted projects are published in 950 CMR 71. These regulations set up a process for the identification of historic properties, assessment of effect, and consultation among interested parties to avoid, minimize, or mitigate any adverse effects. Projects on slopes or uplands adjacent to rivers, lakes, ponds and the ocean are generally considered to be more sensitive to the presence or archaeological artifacts than other locations. Following consultation with MHC, a Project Notification Form (PNF) is submitted to initiate MHC review. The PNF includes a description of the proposed project, existing conditions, and past development of disturbances in the project area.

G. Massachusetts Endangered Species Act Project Review

Projects and activities within rare species habitat must file with the Natural Heritage & Endangered Species Program (NHESP) for review and approval. Habitats in Massachusetts have been mapped as Priority & Estimated Habitats and maps are available on-line. In review, NHESP determines whether the project, as proposed, will impact state-listed species and their habitats and whether or not a project or activity as proposed will result in a "Take" of state-listed species. Projects may have to be revised to avoid a “Take” or be subject to conditions or restrictions to avoid impacts to state-listed species and their habitats and must meet the performance standards for the issuance of a Conservation and Management Permit.

H. Wetlands Protection Act/Rivers Protection Act

If the PRB project is located within 100 feet of a wetland resource area or within 200 feet of a designated riverfront area a Notice of Intent must be submitted for review by the Orleans Conservation Commission. The Commission will issue an Order of Conditions for an approved project.

I. Road Opening Permit

Additional local permits will include Road Opening Permits where PRBs are implemented by injecting through roadways. PRBs systems implementation and monitoring well installation will also likely require agreements for access to private property, mainly for the installation and sampling of monitoring wells.

6. Project Management and Predesign Planning

A. Implementation Team

The successful implementation of PRBs will require coordination between consultant/contractors and the Town of Orleans, including coordination of location access and permit approvals from Town, county, and state authorities. Teams will include:

- Designated Town Officials and Legal staff;
- Consultant staff, with Injection, Drilling, and Laboratory Sub-contractors; and
- Public Participation Coordinator.

It is anticipated that the Town of Orleans will assign a Town Project Manager within the Department of Public Works and Natural Resources and/or an Owner’s Program Manager for implementation coordination. The Consultant will work with the Town Project Manager and a team of specialty subcontractors to plan and implement PRBs. Due to the nature of the project, Town legal staff assistance will be needed to coordinate location access and assistance with permitting. A public participation coordinator will help facilitate public involvement in the project.

B. Pre-implementation Tasks

A detailed project schedule and project progress tracking and reporting system will be developed to identify action items to keep the project on course. The limits of target geographic areas and limits on existing land use for PRB implementation will be developed to inform location selection and monitoring program design and assure that planning is integrated with the ACWMP.

A process for review of specific potential PRBs and location selection, including public participation, will be developed by the Implementation Team to screen candidate PRB sites. The process will include coordination with the US EPA, MassDEP, Cape Cod Commission, and the Pleasant Bay Alliance, a municipal organization formed by the Towns of Orleans, Chatham, Harwich and Brewster to coordinate the resource management plan for the Pleasant Bay Area of Critical Environmental Concern and watershed. It is anticipated that coordination with the Town of Eastham will also be included in the process where PRBs may address shared resources (e.g. Nauset Estuary and Rock Harbor). Following development of a location short list, selected locations will be subject to further investigation to determine specific land use, location of utilities, and an initial groundwater assessment that will be integrated with Water Quality Monitoring Plans described below.

C. Locations Specific Assessment, Baseline Assessment, and Water Quality Monitoring Plans

Potential PRB locations will be reviewed and selected for implementation in accordance with the overall objectives of the Town Comprehensive Wastewater Management Plan, which includes priority areas. Prior to final selection, a location-specific assessment will be necessary to confirm the nature of hydrogeological conditions and groundwater chemistry for PRB design and monitoring plan development and to develop site specific costs on a cost per kilogram of nitrogen removed basis. The cost per kilogram will depend on implementation and monitoring costs, the dimensions of the PRB, and the flux of nitrate through the specific location.

Water Quality Monitoring Plans will be developed for each PRB location. The monitoring program will be developed based on the Conceptual Site Model for PRBs described below and will be developed in a phased approach. The first phase incorporates the initial location assessment, then builds in the baseline assessment needed before PRB implementation at a selected site, and finally the performance monitoring plan that will be used to track PRB efficiency and water quality affects. The assessments will include groundwater profiling and monitoring well sampling and analyses to assess nitrate mass flux and hydrogeologic conditions. Primary objectives of the monitoring plans are to:

- Evaluate potential PRB locations for selection and design based on mass flux of nitrate and feasibility of implementation;
- Assess potential reduction in nitrate concentrations in groundwater compared to baseline samples and/or wells upgradient of the PRB;
- Identify distance traveled by EVO emulsion and DOC;
- Identify extent of generated reducing conditions;
- Assess hydraulic performance;
- Evaluate persistence of EVO emulsion and anaerobic conditions favorable for denitrifying bacteria after PRB injection; and
- Assess changes in groundwater monitoring parameters.
- Estimate the cost per kilogram of nitrate removal.

The monitoring program will be designed to be dynamic and continuously evaluated to adjust the selected monitoring parameters and frequency of monitoring based on data collected and observations. A list of groundwater monitoring parameters is included in Table 4.

Table 4 - Summary of Potential Analyses for Groundwater 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 septic system leach fields and landfills.
TKN	Total Kjeldahl Nitrogen (TKN) is the total concentration of organic nitrogen and ammonia.
Total Nitrogen	Analyses provide a summation of all organic and inorganic nitrogen species in groundwater as a result of leach fields and landfill.
CENSUS-DNA (Denitrifying Bacteria)	Analysis quantifies 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 (DOC) is the limiting factor in enhancing denitrification-and is increased by injection of EVO. DOC tracks the area of influence of the PRB.
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 (ORP) will decrease with generation of reducing conditions following injection of carbon substrate.
Chloride	Chloride concentrations indicate potentially infiltrating stormwater.
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 leach fields.

D. Adaptive Management

Coordinated implementation of PRBs is necessary to incorporate the Adaptive Management Approach as outlined in the CWMP, where non-structural elements such as PRBs can be implemented in a way that first documents their effectiveness and then allows their full application with predictable results and regulatory support, with the overall goal of reducing the cost of the structural elements. Adaptive Management Plan elements directly related to PRB implementation will require identification of tasks necessary to monitor and refine PRB placement, monitoring programs, and design and implementation methods moving forward. PRB monitoring programs can be integrated with long-term surface water quality monitoring programs for performance evaluation and optimization.

E. Environmental Considerations

Careful selection of PRB installation locations outside sensitive resource areas will be the primary means of minimizing environmental impact. Compliance with environmental permits will be necessary to assure environmental protection and permit requirements will be included in the progress tracking and recording system. Groundwater monitoring results from the Demonstration Test will be used to gauge the potential for secondary impacts to groundwater quality.

F. Conceptual Site Model for PRBs

Site specific PRB implementation assessment will be based on a Conceptual Site Model (CSM) developed for this project for PRBs based on groundwater conditions and the expected fate and transport of large dilute nitrate plumes on Cape Cod. The general (or Cape Cod) CSM is presented with a visualization in Figure 3 and described below.

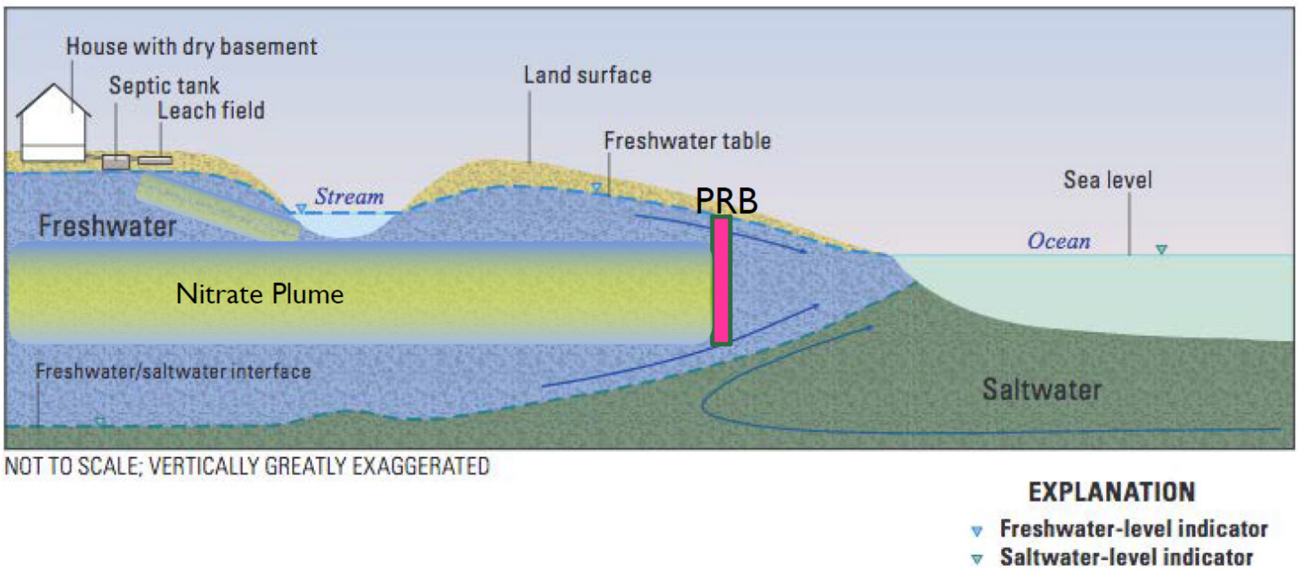

Figure 3 - Visual of Nitrate Plume Treatment PRB
Modified from USGS

Elements of the CSM include the following:

- 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.
- The presence of nitrate and nitrate concentrations varies depending on the strength or number of sources upgradient of a location and on the geochemistry of the groundwater. The geochemistry affects fate and transport of nitrogen. Generally septic system nitrogen and nitrogen from fertilizers are released to aerobic groundwater where nitrate is the dominant and most persistent form of nitrogen. Where groundwater travels deep over long distances and into anoxic conditions, natural attenuation may occur. Under these circumstances the profile of nitrate concentrations from shallow to deep in groundwater may indicate that the highest concentrations are generally in shallower groundwater and lower concentrations at depth (see example in Figure 4 below). The profile will in part depend on the distance from sources to the PRB. In recharge areas the plume will move deeper as it travels downgradient.

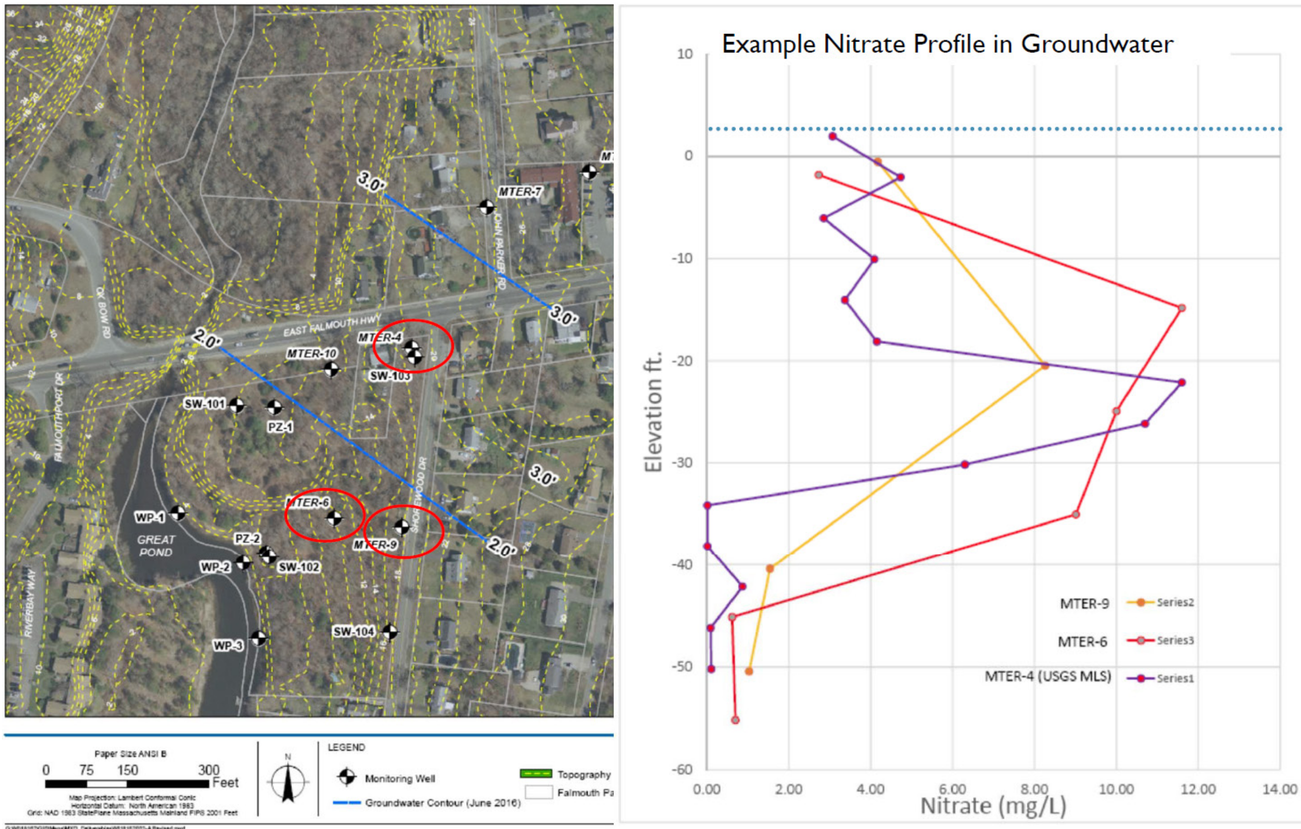

Figure 4 - Example Concentration Profile Nitrate in Groundwater on Cape Cod

- Groundwater flow through freshwater ponds may attenuate nitrogen concentrations.
- 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 and 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.
- There may also be layering present in the aquifer material, with layers of more permeable coarser sand and gravel having higher hydraulic conductivity stratified with lower permeability fine sand, silt, or very low hydraulic conductivity clay layers. Mass flux of nitrate would be greater in more permeable layers with faster groundwater flow even if the concentration in lower permeability layers is similar.
- The nitrate treatment PRB will be installed to efficiently intercept the mass flux of nitrate in groundwater upgradient of the surface water to be protected.

The above CSM can be used to develop a site specific CSM to assist in PRB location assessment, PRB design, and development of site specific PRB groundwater monitoring plans. The assessments will include the installation of a set of initial monitoring wells and include groundwater profiling to confirm conditions at depth below the water table. Groundwater profiling will include an assessment of hydraulic conductivity and groundwater chemistry, including redox conditions and one or more nitrogen profiles for the location. Following evaluation of test results and confirmation of location selection, additional monitoring wells will be installed and sampled to establish sufficient information to confirm baseline conditions for comparison and performance assessment once the PRB is in place.

G. Conceptual PRB System Design

PRB conceptual design plans include an overview of installation activities, standard treatment layouts, facilities, and processes to be used to implement the PRB. The PRBs will be installed by injecting a diluted emulsified vegetable oil (EVO) substrate formulation specifically developed to treat nitrate in Cape Cod groundwater. The EVO is injected along a transect line that cuts across the plume of nitrate at the target PRB treatment location. The volume and mixture/type of EVO used to form the PRB will be designed based on the mass flux of nitrate and competing electron acceptors predicted with location specific assessment data. The assessment data may identify high flux zones that can then be targeted as the most cost-effective treatment locations and depths.

Key Terms

Mass flux
A rate measurement specific to a defined area, which is usually a subset of a plume cross section expressed as mass/time/area (e.g., g/d/m2) (ITRC 2010).

Conceptual Site Model (CSM)
Descriptive tool to help understand groundwater conditions and large dilute nitrate plumes on Cape Cod.

Hydraulic Gradient
Groundwater flows down the hydraulic gradient - water table elevations are determined by measuring the depth to water in three or more similar monitoring wells in an area and can then be used to triangulate the hydraulic gradient and horizontal flow direction.

The EVO will be injected with direct push rigs injection rigs (Figure 5) along an injection pathway set perpendicular or close to perpendicular to the groundwater flow direction. The direct push rigs use hydraulics and a vibratory hammer to drive hollow steel rods that serve as piping to the target injection depths. Target injection depths are expected to be up and potentially exceeding 100 feet below ground surface. Injections will be completed with a bottom up approach where the rig will drive direct push rods with typically 4 or 8-foot stainless steel laser cut screens at the bottom of the rods down to the deepest treatment interval. Following the first injection, the screen will be sequentially raised one screen length for subsequent injections until the top of the injection interval is reached.

Direct injection points (without permanent injection well structures) will be located 10 to 15 feet apart depending on the expected radius of influence of injected EVO at each PRB location as determined in the preliminary assessment. The layout and design injection depth will depend on the characteristics of the specific PRB location determined in the location specific assessment.

Design specifications include:

- Depth to ground water;
- PRB length (Linear Feet);
- Target treatment thickness;
- Injection point spacing;
- Number of injection points;
- EVO specification, dilution and additives;
- Injection pressure;

Figure 5 - Direct Injection Rig

- Injection target pore volume;
- Total injection volume (gal); and
- Injection volume per point (gal).

Where possible, PRBs will be implemented along the edge of roadways to minimize implementation related impacts. The objective is to install the PRB in such a way that, following injection, the only indication of the presence of the PRB on the land surface will be the flush mounted surface structure associated with the tops of monitoring wells.

The injection substrate will be delivered to a central staging location or the PRB location in bulk in plastic reusable totes in box trailers, diluted on-site with water to the required strength, and injected. Typically, multiple injection points will be injected simultaneously.

Given the potential length of full scale PRBs, significant advanced planning and coordination with suppliers and field crews will be required. Logistical considerations include:

- A single primary/central staging area will be needed for temporary storage of concentrated EVO in 275-gallon totes. Concentrated volumes required for each specific day can be pulled out of the central staging areas using fork lifts and loaded onto box trucks to move to secondary staging areas adjacent to injection areas. For projects with anticipated multiple secondary staging areas, the use of multiple box trucks can be utilized to minimize any downtime involved with transporting adequate EVO volumes.
- A hydrant water supply and/or water truck will be needed for supplying dilution water near each injection area. Required water supply flow on demand is approximately 40 to 60 gallons per minute.
- Alternatively, diluted EVO batches can be prepared at the central staging area and transported to injection areas on a daily or as-needed basis. Based on weight of water, approximately 6 to 8 totes are near the maximum volume (1,500 to 2,000 gallons) that can be carried in a box truck.
- EVO deliveries to central storage should be sequenced to keep minimum 2 to 3-day buffer to absorb faster/slower injection rates than anticipated. A daily delivery/consumption chart should be prepared and used to coordinate demand and delivery.
- Cumulative injection rates are important to maintain for large volume injections. To sustain high injection rates, 4 to 8 manifolded or dedicated injection lines may need to be operated simultaneously. At high flow rates appropriate staff levels will be needed to coordinate batching, injection, and transport of stock solution, diluted solutions, and/or water.
- Allowable working hours and days will need to be estimated prior to project implementation to effectively deliver EVO and to manage and maintain the injection schedule.
- Traffic flaggers and/or coordination with police for details will be important for maintaining safe working conditions. Police detail may be needed at the central staging area to minimize traffic disturbances with many large trucks arriving at a single location.

The injected EVO provides a long-term source of dissolved organic carbon within and immediately downgradient of the PRB. The dissolved organic carbon is a source of food for naturally occurring groundwater bacteria that will first utilize available oxygen in groundwater for respiration followed by denitrifying bacteria that will utilize nitrate for respiration. This natural process converts available nitrate nitrogen to inert nitrogen gas which is commonly present in groundwater. Once the required biological activity is established the PRB is expected to remove nitrate in groundwater for an extended period of years. The nitrogen load reduction that will be achieved can be predicted with the mass flux of nitrate identified in the assessment.

The process of establishing the PRB biological community in the treatment zones is expected to take several months based on the lag time for increases in naturally occurring biomass. The amount of time required to confirm the increase in biological activity (or biomass) will depend in part on the distance to downgradient monitoring wells along with groundwater velocity and travel time.

eventually, the efficiency of nitrate treatment will begin to decline once the carbon source starts to be depleted. Depletion is expected to occur in high mass flux areas first and will be indicated by decreasing dissolved organic carbon levels and increasing nitrate concentration at downgradient monitoring wells. Once the treatment efficiency decreases to a defined tolerance limit, rejuvenation of the PRB by subsequent injection will be required. The ongoing Demonstration Test is being monitored to assess longevity to provide specific guidance for PRBs in Orleans; expected operational time frames range from 5 to 10 years or more.

H. Post Implementation Tasks

Following implementation of individual PRBs an As-built Completion Report will be prepared documenting implementation, final inspections, and updated Water Quality Monitoring Plans. The report can then be used in conjunction with the Adaptive Management Approach, post installation monitoring, and reporting to track progress toward water quality goals.

7. References

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