

## Memorandum

To George Meservey, Director of Planning & Community Development

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AECOM PRB Team

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 Town of Orleans, Massachusetts - DRAFT**

Project Number 60476644

From Thomas Parece, P.E., AECOM Project Manager

Date February 26, 2020

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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 installed in November 2016 and was designed for evaluating of PRB performance. Over the last three years, the project has shown that a PRB is effective in removing nitrate in groundwater. As part of the ACWMP, the Town is looking at installing 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 is appended to this document for reference.

## 2. Orleans Nitrogen Load Reduction Objectives

The watersheds recharging Rock Harbor, Nauset Estuary and, especially Pleasant Bay, include numerous sub-watersheds that discharge to creeks, rivers and salt ponds as shown in Figure 1. Achieving surface water quality goals in the form of Total Maximum Daily Loads (TMDLs) is required. 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. TMDLs define the maximum nitrogen load that the water body can receive while still meeting necessary water quality criteria. 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). 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 (aka 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 subwatersheds 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.

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, 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 is to consider all feasible locations within the Pleasant Bay Watershed except Meetinghouse Pond, which the town plans to sewer.

## B. Town Cove/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 TMDLs for Rachel Cove, Woods Cove, and Mill Pond, all sub-watersheds with Orleans, are not exceeded, thus a reduction in nitrate load in these watersheds is not necessary.

## C. Rock Harbor Embayment System TMDLs

The watershed for the Rock Harbor 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.

## 3. Site Selection Process

The PRB site selection process documented in this technical memorandum has identified 14 potential PRB locations within the subwatersheds 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.
- 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:

- Hydrogeologic conditions including the estimated permeable of subsurface soils and groundwater gradient.
- The density of wastewater nitrogen sources upgradient of and within the capture zone of the PRB.
- The ability in aggregate to achieve PRB nitrate mass remediation goals given the current assumptions.

The potential nitrogen load reduction that can be achieved with a PRB can be predicted with an assessment of the mass flux of nitrate in groundwater that will pass through the PRB. Mass flux in groundwater is defined as the contaminant mass moving across a unit area of aquifer perpendicular to the groundwater flow direction. In the absence of sufficient mass flux data from groundwater assessment the potential mass flux can be estimated with a series of assumptions. For this analysis the number of parcels upgradient within the capture zone of the PRB was used to estimate the relative efficiency of PRBs for ranking. Additional modeling of nitrogen load by SMAST is necessary to refine the estimate for comparison to nitrogen remediation goals for non-traditional technologies.

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 calculating the nitrogen load generated in that area with a set of assumptions. The feasible PRB installation depth of approximately 70 to 80 feet below ground surface limits 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 migrates downgradient towards the receiving water. When groundwater reaches surface water bodies it will discharge vertically up from depth where possible. Subsurface marine discharge can be complicated by bottom sediment conditions. The capture zone upgradient of the PRB can be modeled based on expected horizontal and vertical groundwater flow.

AECOM developed a groundwater flow model for the Town of Orleans based on the USGS, Sagamore and Monomoy flow lense 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 And 43 Lots Hollow in Orleans (AECOM, 2018).

The model is also suitable for evaluating the area contributing groundwater to the proposed PRBs. The capture area was estimated by using the model to backtrack particles 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. This estimate considers wastewater related nitrogen only and does not account for fertilizer and atmospheric deposition of nitrogen within the capture zone. The wastewater load estimate assumed one owner and one house per parcel. The nitrate load assigned was assigned based on a reference wastewater nitrogen concentration of 55 mg/L and a town-wide average water use of 122 gallons per day per parcel based on Orleans water records for 2014 and 2015 (Metcalf & Eddy, 2003). The estimated annual nitrogen load generated per parcel was 9.27 kg/yr.

The 55 mg/L wastewater nitrate concentration is a surrogate concentration that provides the best value for comparison to wastewater strength assumed for design of the planned conventional wastewater treatment facility in Orleans. The average water use selected provides a surrogate for actual water use for comparison of PRB locations is this Draft Technical Memorandum. SMAST is currently tasked with completing a Pleasant Bay scenario run that represents current Town thinking on nitrogen management that will include modeling the nitrogen load from all sources treated by the proposed PRBs. The SMAST nitrogen load analysis will be used to update the current estimate for Pleasant Bay when available.

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. The actual nitrogen flux across the PRBs will be verified through groundwater assessment prior to final location selection.

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 kg/linear foot per year basis for comparison with other potential PRBs. The estimated PRB efficiency considering all locations ranged from 0.09 to 0.68 kg/linear foot per year. The most efficient PRB identified in the screening all watersheds is the section of PRB along Main Street upgradient of Town Cove. 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. Cost

AECOM has estimated cost for PRB installation at \$1,485.00 per linear foot of PRB line. This cost includes:

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

PRB implementation costs range from \$594,000 for a 400-foot PRB to \$10,840,500 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 are currently being 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. Conclusions

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, however, the ability to achieve remediation goals is based on identified assumptions and will strongly depend on the actual mass of nitrogen load in the capture zone. The nitrogen remediation targets discussed in the following sections are based on specific planned 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 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.

### A. Pleasant Bay PRBs

PRBs in the Pleasant Bay main watershed were located in targeted sub-watersheds to the extent possible. Nitrogen removal requirements have been specified for ten sub-embayments as presented in Table 1. Nitrogen removal or 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 for comparison with estimated septic load reductions presented in Table 3. Of the nine targeted embayment, PRBs were identified for four that may exceed the required non-traditional technology targets with the given assumptions. For the majority of the remaining embayments the remediation goals were not achieved but the proposed PRBs remove a significant percentage of the required load. Good PRB locations could not be identified for Meetinghouse Pond which will mainly be remediated with conventional wastewater treatment and for Arey's Pond. The overall projected nitrogen reduction for Pleasant Bay based on the given assumptions was 4,505 kg/yr close to the total non-traditional technology remediation goal of 4,966 kg/yr.

### B. Nauset Estuary PRBs

Three potential PRBs were identified for the Nauset Estuary with a total projected nitrogen remediation of 1,845 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, while traditional wastewater systems are brought online and to treat existing load already in the groundwater.

### C. Rock Harbor PRBs

One PRB location was identified for Rock Harbor along Rock Harbor Road that is estimated to remove 649 kg/yr of nitrogen and may achieve the Rock Harbor non-traditional remediation goal of 634 kg/yr with the given assumptions.

## 8. Next Steps

More work is necessary to assess and confirm potential PRB locations and determine the appropriate sequencing of PRB implementation. When available, the SMAST nitrogen load analysis will be used to update the current estimate nitrogen load reduction for Pleasant Bay.

Additional criteria for final selection of PRB locations will include:

- Public stakeholder input;
- Confirmed groundwater flow directions, baseline nitrogen concentration profile, and geochemistry data supporting cost-effective application; and
- Confirmed suitable subsurface geologic condition based on site specific field investigations.

This Technical Memorandum provides information for review by public stakeholders to facilitate public involvement. Prior to final selection, a location-specific assessment will be necessary to confirm the nature of hydrogeological conditions and groundwater chemistry at PRB locations. The assessments will include groundwater profiling and monitoring well sampling and analyses to assess subsurface conditions and determine nitrogen mass flux at specific locations.

## 9. References

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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 Efficiency Rank	PRB Installation Cost Estimate	Present Worth 20 yrs	Evaluation Notes
Meeting House Pond	None						0	0	40					
Lonnie's Pond/Kescayo Ganssett River		25, 26 Lonnie's Pond/Kescayo Ganssett River					41	304	284					
Lonnie's Pond/Kescayo Ganssett River	Monument		1,675	Monument	30	25 to 50	41	304	0	0.18	8	\$2,487,375		Upper Reach Priority embayment
<b>Aerys Pond</b>	None						0	0	113					
Upper River	Kenahs		1,250	Kenahs	30	15 to 40	26	193	202	0.15	9	\$1,856,250		Upper Reach Priority embayment
Lower River	Mayflower		1,700	Pershing, Kenneth	30	10 to 30	35	260	517	0.15	11	\$2,524,500		
<b>Namequoit River</b>	Namequoit Ridge		1,000	Namequoit Road	30	10 to 40	56	415	348	0.20	6	\$1,485,000		Upper Reach Priority embayment
Namequoit River			460	Ridgeway Rd	30	10 to 30	27	215	413	0.47	1	\$683,100		Upper Reach Priority embayment
<b>Pah Wah Pond</b>	Lockwood		1,230	Lockwood	30	5 to 15	35	260	1485	0.21	5	\$1,826,550		Upper Reach Priority embayment
<b>Quanset and Pleasant Bay Main Basin</b>	Quanset 1,2,3		1,745	Towhee, Lake Dr, Oyster	30	10 to 40	43	319	1485	0.18	7	\$2,591,325		Upper Reach Priority embayment
Quanset and Pleasant Bay Main Basin	Granny's		650	Granny's	30	15 to 20	24	178	1485	0.27	4	\$865,250		
Quanset and Pleasant Bay Main Basin	Winslow		1,150	Winslow Dr and Way	30	5 to 40	14	104	1485	0.09	14	\$1,707,750		
Quanset and Pleasant Bay Main Basin	Richwood		890	Richwood Farm	30	10 to 15	41	304	1,564	0.34	2	\$1,321,650		
<b>Pochet</b>	Duck Hole		4,100	High View, Old Duck Hole, Lovell	30	5 to 35	68	504	1,564	0.12	12	\$6,088,500		Upper Reach Priority embayment
Pochet	Gosnold		2,081	Gosnold,	30	10 to 30	29	215	1,564	0.10	13	\$3,090,285		Upper Reach Priority embayment
Pochet	Briar Spring		2,906	Briar Spring Blossom , Sparrowhawk	30	10 to 35	59	438	1,564	0.15	10	\$4,315,410		Upper Reach Priority embayment
Pochet	Blossom		400	Blossom , Sparrowhawk	30	30 to 40	15	111	1,564	0.28	3	\$594,000		Upper Reach Priority embayment
<b>Pleasant Bay Estuary (Orleans)</b>			<b>21,237</b>				<b>486</b>	<b>3,604</b>	<b>4,966</b>			<b>\$31,536,945</b>		
Average Efficiency kg/LF/yr											0.16			

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 Efficiency Rank	PRB Installation Cost Estimate	Present Worth 20 yrs	Evaluation Notes
<b>Town Cove</b>	Tonset Main		7,300	Gibson, Tonset Main	30	10 to 30	93	690	566	0.09	3	\$10,940,500		Upper Reach Priority embayment
Town Cove			850		40	5 to 10	78	578	566	0.68	2	\$1,862,250		Upper Reach Priority embayment
<b>Mill Pond</b>	Norseman		580	Norseman Road, Mill Pond Rd	40	10 to 35	28	208	566	0.36	1	\$861,300		Upper Reach Priority embayment
<b>Nauset Estuary (Orleans)</b>			<b>8,730</b>				<b>199</b>	<b>1,476</b>	<b>566</b>			<b>\$12,964,050</b>		
Average Efficiency kg/LF/yr											0.38			

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 Efficiency Rank	PRB Installation Cost Estimate	Present Worth 20 yrs	Evaluation Notes
<b>Rock Harbor Main</b>	Rock Harbor		3,940	Rock Harbor	50	5 to 15	70	649	634	0.13	1	\$216,700		Upper Reach Priority embayment
Rock Harbor							70	519	634	0.16		\$5,850,900		
<b>Rock Harbor Estuary (Orleans)</b>			<b>3,940</b>				<b>70</b>	<b>649</b>	<b>634</b>			<b>\$5,850,900</b>		
<b>PRB Townwide Potential Total</b>			<b>33,907</b>				<b>755</b>	<b>5,729</b>				<b>\$50,351,895</b>		

**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)
<b>Meeting House Pond</b>	None					
<b>Lonnies Pond/ Kescayo Gansett River</b>						
Lonnies Pond/Kescayo Gansett River	Monument	25, 26 Lonnies Pond/Kescayo Gansett River	1,675	Monument	30	25 to 50
<b>Aerys Pond</b>	None					
<b>Upper River</b>						
Upper River	Keziahs	41 Upper River	1,250	Keziahs	30	15 to 40
<b>Lower River</b>						
Lower River	Mayflower	28 Lower River	1,700	Pershing, Kenneth	30	10 to 30
<b>Namequoit River</b>						
Namequoit River	Namequoit	30 Namequoit River	1,000	Namequoit Road	30	10 to 40
Namequoit River	Ridge	30 Namequoit River	460	Ridgeway Rd	30	10 to 30
<b>Pah Wah Pond</b>						
Pah Wah Pond	Lockwood	32 Pah Wah Pond	1,230	Lockwood	30	5 to 15
<b>Quanset and Pleasant Bay Main Basin</b>						
Quanset and Pleasant Bay Main Basin	Quanset 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
<b>Pochet</b>						
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
<b>Pleasant Bay Estuary (Orleans)</b>			<b>21,237</b>			

**Nauset Estuary (Orleans)**

Embayment	PRB Name	MEP Watershed ID	PRB Length (ft)	Roads	PRB Saturated Thickness (ft)	Depth Range to Groundwater (ft)
<b>Town Cove</b>						
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
<b>Mill Pond</b>						
Mill Pond	Norseman	8 Mill Pond	580	Norsemans Road, Mill Pond Rd	40	10 to 35
<b>Nauset Estuary (Orleans)</b>			<b>8,730</b>			

**Rock Harbor Estuary (Orleans)**

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

<b>PRB Townwide Potential Total</b>			<b>33,907</b>			
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**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)	Estimated PRB Efficiency (kg/LF/yr)	PRB Watershed Efficiency Rank (kg/yr)	Evaluation Notes
Meeting House Pond	None			0	0	40			
Lomies Pond/Kesayo Gansett River	Monument	Gansett River	1,675	41	304	284	0.18	8	Upper Reach Priority embayment
Aerys Pond	None			0	0	113			
Upper River				26	193	202			
Upper River	Keziahs	41 Upper River	1,250	26	193	517	0.15	9	Upper Reach Priority embayment
Lower River	Mayflower	28 Lower River	1,700	35	260		0.15	11	Upper Reach Priority embayment
Namequoit River	Namequoit	30 Namequoit River	1,000	27	519	348	0.20	6	Upper Reach Priority embayment
Namequoit River	Namequoit Ridge	30 Namequoit River	460	29	215		0.47	1	Upper Reach Priority embayment
Pah Wah Pond	Lockwood	32 Pah Wah Pond	1,230	35	260	413	0.21	5	Upper Reach Priority embayment
Quanset and Pleasant Bay Main Basin				122	905	1,485			
Quanset and Pleasant Bay Main Basin	Quanset 1,2,3	Pond	1,745	43	319		0.18	7	Upper Reach Priority embayment
Quanset and Pleasant Bay Main Basin	Grammys	Pond	650	24	178		0.27	4	Lower Priority
Quanset and Pleasant Bay Main Basin	Winslow	Pond	1,150	14	104		0.09	14	Lower Priority
Quanset and Pleasant Bay Main Basin	Richwood	Pond	890	41	304		0.34	2	Lower Priority
Pochet				171	1,268	1,564			
Pochet	Duck Hole	35 Pochet Neck Stream	4,100	68	504		0.12	12	Upper Reach Priority embayment
Pochet	Gosnold	Stream	2,081	29	215		0.10	13	Upper Reach Priority embayment
Pochet	Briar Spring	34 Pochet	2,906	59	438		0.15	10	Upper Reach Priority embayment
Pochet	Blossom	35 Pochet	400	15	111		0.28	3	Upper Reach Priority embayment
<b>Pleasant Bay Estuary (Orleans)</b>			<b>21,237</b>	<b>486</b>	<b>3,708</b>	<b>4,966</b>			

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)	Estimated PRB Efficiency (kg/LF/yr)	PRB Watershed Efficiency Rank (kg/yr)	Evaluation Notes
Town Cove				171	1,268	566			
Town Cove	Tonset	5 Town Cove	7,300	93	690		0.09	3	Upper Reach Priority embayment
Town Cove	Main	5 Town Cove	850	78	578		0.68	1	Upper Reach Priority embayment
Mill Pond				28	208				
Mill Pond	Norseman	8 Mill Pond	580	28	208	566	0.36	2	Lower Priority
<b>Nauset Estuary (Orleans)</b>			<b>8,730</b>	<b>199</b>	<b>1,476</b>	<b>566</b>			

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)	Estimated PRB Efficiency (kg/LF/yr)	PRB Watershed Efficiency Rank (kg/yr)	Evaluation Notes
Rock Harbor Main	Rock Harbor			70	519.121834	634			
Rock Harbor	Rock Harbor	3 Rock Harbor Main	3,940	70	519	634	0.13	1	Upper Reach Priority embayment
<b>Rock Harbor Estuary (Orleans)</b>	<b>Rock Harbor</b>		<b>3,940</b>	<b>70</b>	<b>519</b>	<b>634</b>			

PRB Townwide Potential Total									
			<b>33,907</b>	<b>755</b>	<b>5,703</b>				

**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
<b>Meeting House Pond</b>	None			
<b>Lonnies Pond/Kescayo Gansett River</b>				
Lonnies Pond/Kescayo Gansett River	Monument	25, 26 Lonnies Pond/Kescayo Gansett River	1,675	\$2,487,375
<b>Aerys Pond</b>	None			
<b>Upper River</b>				
Upper River	Keziahs	41 Upper River	1,250	\$1,856,250
<b>Lower River</b>				
Lower River	Mayflower	28 Lower River	1,700	\$2,524,500
<b>Namequoit River</b>				
Namequoit River	Namequoit	30 Namequoit River	1,000	\$1,485,000
Namequoit River	Ridge	30 Namequoit River	460	\$683,100
<b>Pah Wah Pond</b>				
Pah Wah Pond	Lockwood	32 Pah Wah Pond	1,230	\$1,826,550
<b>Quanset and Pleasant Bay Main Basin</b>				
Quanset and Pleasant Bay Main Basin	Quonset 1,2,3	33, 37 Pleasant Bay and Quanset Pond	1,745	\$2,591,325
Quanset and Pleasant Bay Main Basin	Grannys	33, 37 Pleasant Bay and Quanset Pond	650	\$965,250
Quanset and Pleasant Bay Main Basin	Winslow	33, 37 Pleasant Bay and Quanset Pond	1,150	\$1,707,750
Quanset and Pleasant Bay Main Basin	Richwood	33, 37 Pleasant Bay and Quanset Pond	890	\$1,321,650
<b>Pochet</b>				
Pochet	Duck Hole	35 Pochet Neck Stream	4,100	\$6,088,500
Pochet	Gosnold	34, 35 Pochet and Pochet Neck Stream	2,081	\$3,090,285
Pochet	Briar Spring	34 Pochet	2,906	\$4,315,410
Pochet	Blossom	35 Pochet	400	\$594,000
<b>Pleasant Bay Estuary (Orleans)</b>			<b>21,237</b>	<b>\$31,536,945</b>

**Orleans Potential Full Scale PRBs - Nauset Estuary**

Embayment	PRB Name	MEP Watershed ID	PRB Length (ft)	PRB Installation Cost Estimate
<b>Town Cove</b>				
Town Cove	Tonset	5 Town Cove	7,300	\$10,840,500
Town Cove	Main	5 Town Cove	850	\$1,262,250
<b>Mill Pond</b>				
Mill Pond	Norseman	8 Mill Pond	580	\$861,300
<b>Nauset Estuary (Orleans)</b>			<b>8,730</b>	<b>\$12,964,050</b>

**Orleans Potential Full Scale PRBs - Rock Harbor**

Embayment	PRB Name	MEP Watershed ID	PRB Length (ft)	PRB Installation Cost Estimate
<b>Rock Harbor Main</b>	<b>Rock Harbor</b>			
Rock Harbor	Rock Harbor	3 Rock Harbor Main	3,940	\$5,850,900
<b>Rock Harbor Estuary (Orleans)</b>			<b>3,940</b>	<b>\$5,850,900</b>

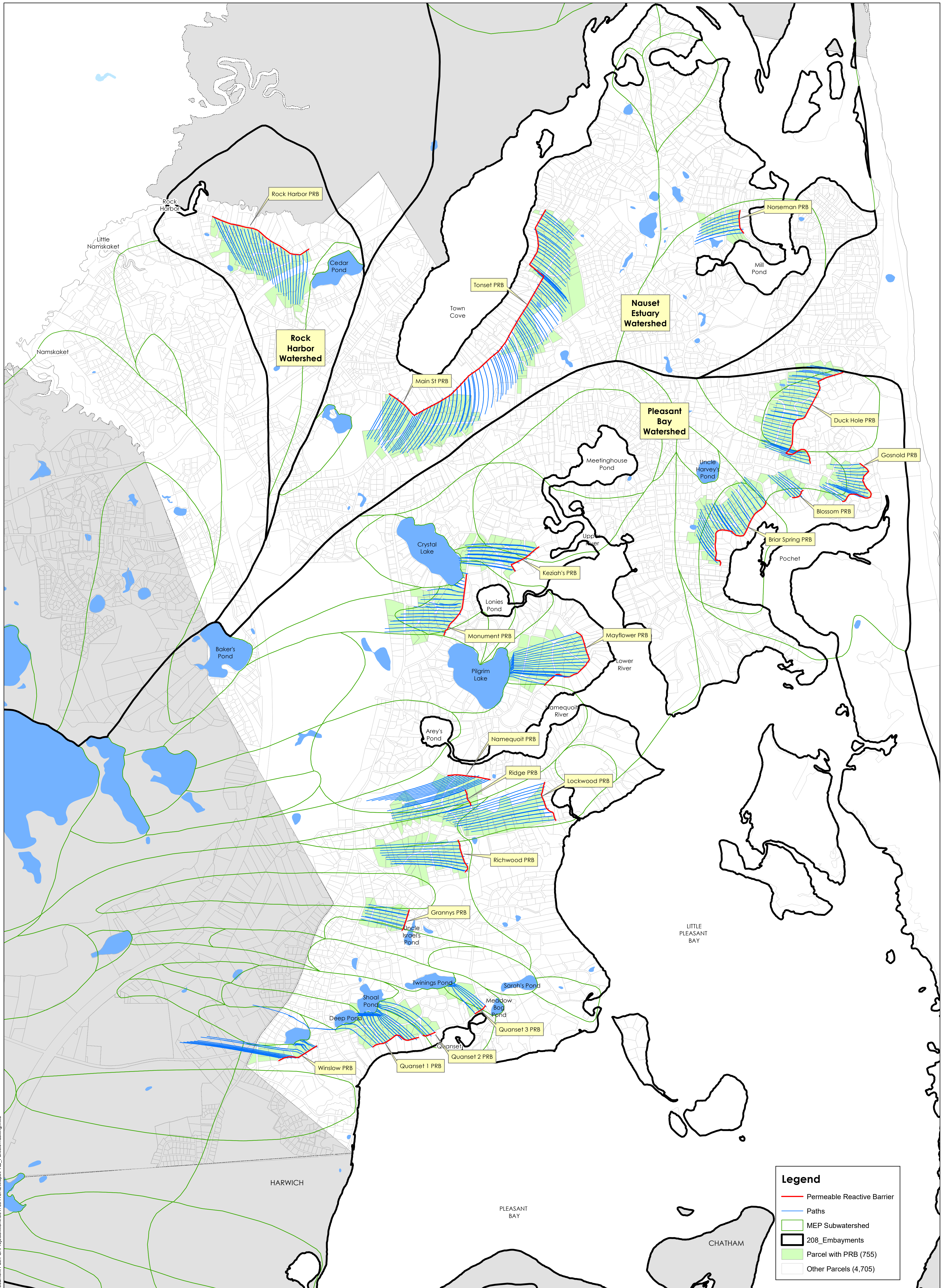
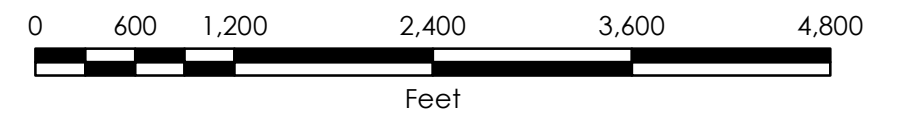
<b>PRB Townwide Potential Total</b>			<b>33,907</b>	<b>\$50,351,895</b>
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**Figures**

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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

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

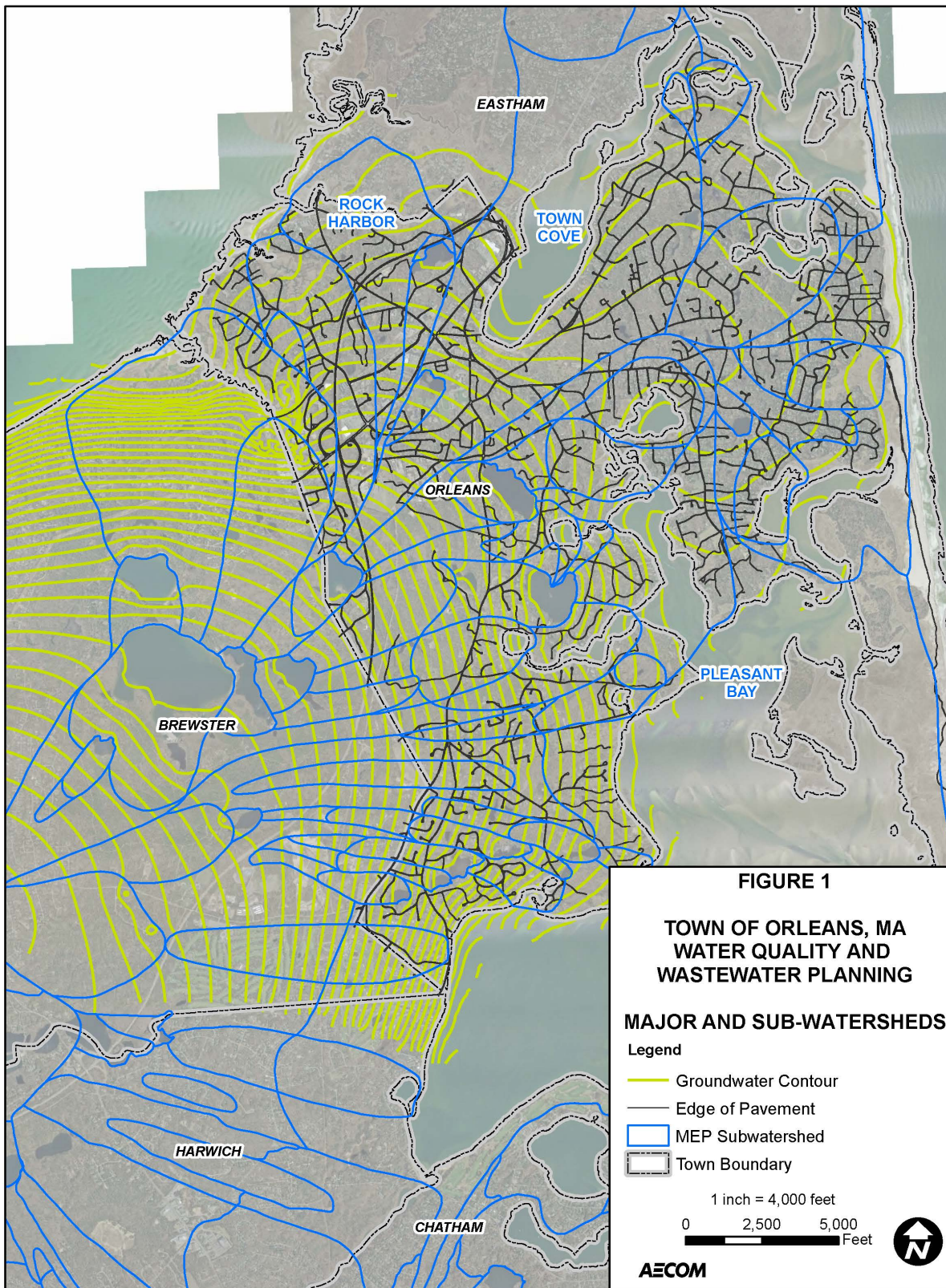
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### 1. Introduction

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.



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 Lonnie's 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 intercept 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.

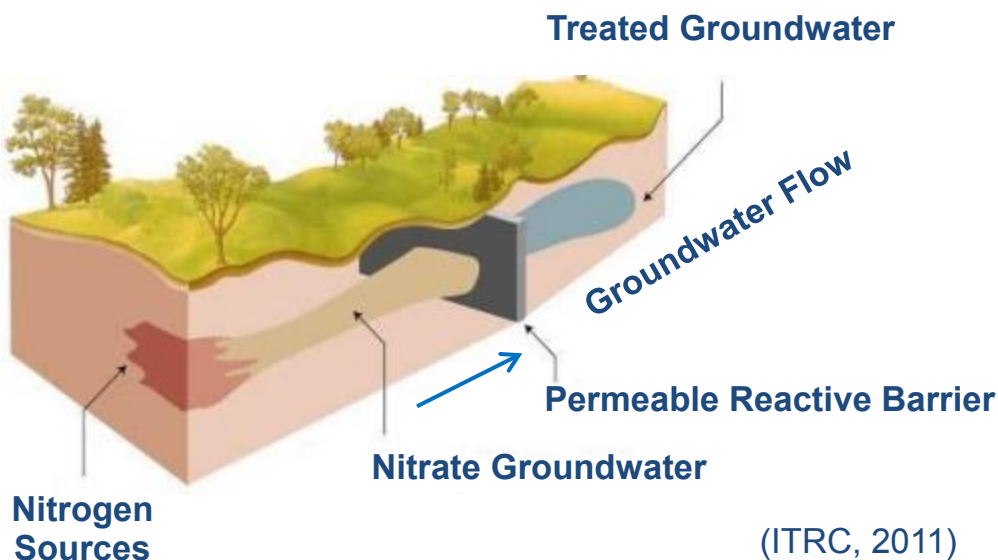
**Key Terms**

**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:  $\text{NO}_3^- \rightarrow \text{N}_2$  (gas)

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

**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
<b>Site 1 – Rock Harbor Watershed (4,700 LF)</b>				
Design	\$518,600			
Implementation, O&M and Monitoring	\$4,148,700	\$0		\$178,600
Replacement			\$745,300	
<b>Site 2 – Pleasant Bay Watershed (1,900 LF)</b>				
Design	\$210,700			
Implementation, O&M and Monitoring	\$1,685,400	\$0		\$78,300
Replacement			\$307,100	
<b>Site 3 – Nauset Harbor Watershed (2,200 LF)</b>				
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](http://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 <sub>3</sub> for each mg of nitrate reduced).
Boron	Boron is present in laundry detergents and is an indicator of groundwater flow emanating from leach fields.

**D. Adaptive Management**

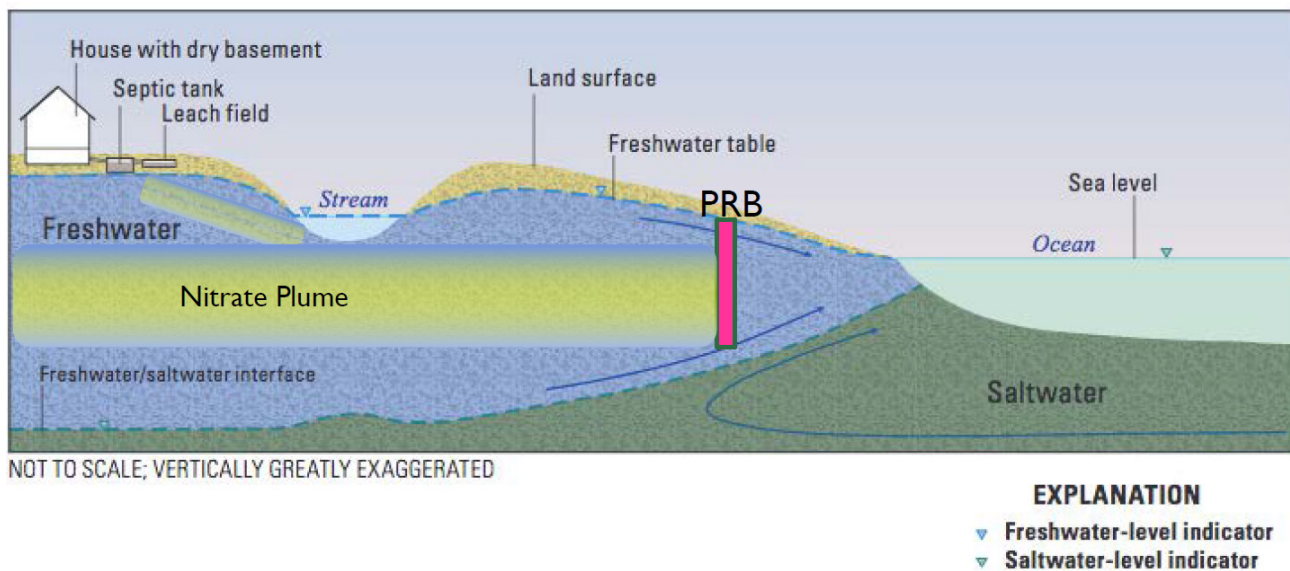
Coordinated implementation of PRBs is necessary to incorporate the Adaptive Management Approach as outlined in the CWMP, where non-structural elements such as PRBs can be implemented in a way that first documents their effectiveness and then allows their full application with predictable results and 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**

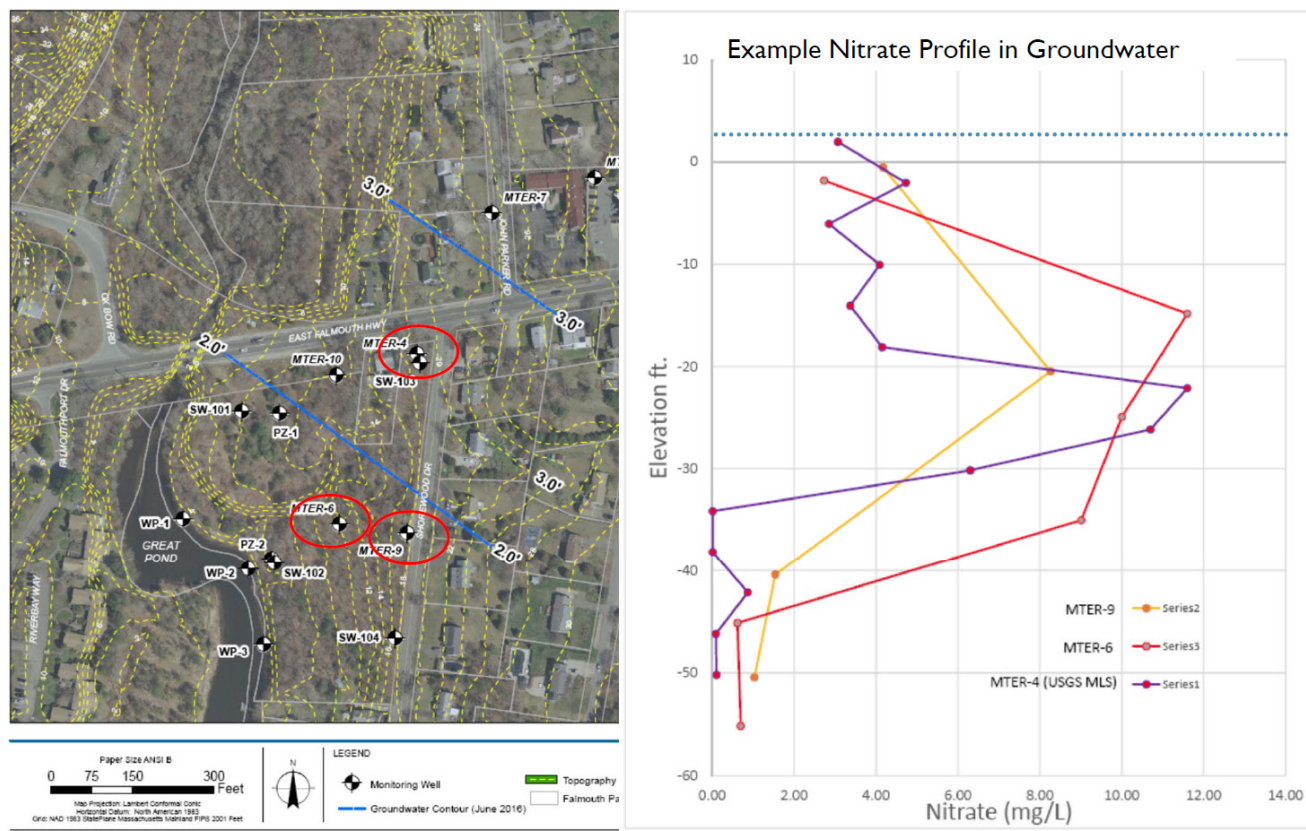
Site specific PRB implementation assessment will be based on a Conceptual Site Model (CSM) developed for this project for PRBs based on groundwater conditions and the expected fate and transport of large dilute nitrate plumes on Cape Cod. The general (or Cape Cod) CSM is presented with a visualization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

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;

**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/m<sup>2</sup>) (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.



**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.

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