

Cover Page

Name of Project: Field Scale Validation of Permeable Reactive Barriers for Non-Point Source Groundwater Nitrogen Remediation

Project Abstract: Excessive nitrogen loading from septic systems has negatively impacted the water quality and ecology of Southeast New England watersheds. The major goal of this project is to validate and optimize a cost-effective method for remediating nitrogen-enriched groundwater before it enters marine waters. This will be accomplished through the installation of a pilot-scale Permeable Reactive Barrier (PRB) within the Great Pond watershed (Falmouth, MA); the PRB will consist of subsurface injection of a liquid carbon source to stimulate the bacterial conversion of nitrate to inert nitrogen gas. It is anticipated that this small-scale PRB alone will remove upwards of 530 kg N/year from entering Great Pond, equivalent to the annual N load to groundwater of 130 residences, and is an important part of the overall strategy for achieving compliance with state water quality regulations in this watershed. Our study will be combined with results from local ongoing PRB demonstration projects to produce an open source PRB engineering design manual that will enable wider-scale adoption of this unique solution to a major water quality threat across our region.

Applicant Organization: Woods Hole Oceanographic Institution, 266 Woods Hole Road, Woods Hole, MA 02543-1501

Applicant DUNS and EIN: 00-176-6682 (DUNS), 04-2105850 (EIN)

Application point of contract: Ms. Theresa Gordon, Pre-Award Manager, Grant and Contract Services.
Contact: tgordon@whoi.edu; 508-289-2619

Project leader: Dr. Matthew Charette, Senior Scientist. Contact: mcharette@whoi.edu; 508-289-3205

Nature of Organization: Private, Non-profit; Tax Exempt with 501(c)3

Partner Organizations: Falmouth Water Quality Management Committee, Cape Cod Commission

Location of Project: 0 Shorewood Dr., E. Falmouth, Massachusetts 02536

Cost:

Total amount of request: \$298,598

Total amount of non-federal match: \$111,723

Total project cost: \$410,321

Match percentage: 37%

Signature of Organizational Leader:



Dr. Laurence Madin

Deputy Director and Vice President for Research, Woods Hole Oceanographic Institution

Peer-to-peer Learning Project? No

Field Scale Validation of Permeable Reactive Barriers for Non-Point Source Groundwater Nitrogen Remediation

PROJECT NARRATIVE

Project Purpose—Nitrogen loading from septic systems and fertilizers has negatively impacted the water quality and ecology of Southeastern New England (SNE) coastal embayments. As a result, the use and enjoyment of coastal waters throughout this region are being compromised. To solve this problem through centralized wastewater infrastructure in low housing density watersheds would be costly; this has driven investigations of alternative solutions by many municipalities in SNE. One promising alternative is the Permeable Reactive Barrier (PRB), which is an in the ground (*in-situ*) groundwater treatment tool that involves addition of amendment(s) in the flow path of a chemical to be treated (**Fig. 1**). In the case of nitrate, the most prevalent form of nitrogen in groundwater impacting coastal waters, a carbon source is injected to stimulate bacteria that carry out denitrification, the process of converting nitrate in groundwater to inert nitrogen gas. When sited near an impacted water body, PRBs are unique in that they will treat multiple non-point sources of nitrate that percolate into the aquifer, including septic systems, storm water, fertilizer and precipitation, before they enter the marine environment. This includes the years-to-decades worth of nitrate that is already in the groundwater and making its way toward the coastline. This project is designed to collect the necessary data to demonstrate to towns in SNE that PRBs will reliably remove nitrate in a cost-effective manner from areas where installing a sewer network would be impractical or cost-prohibitive.

Project Description—The PRB at the center of this project will be installed at 0 Shorewood Drive, a Town of Falmouth (MA)-owned parcel. The design for this 120 ft PRB is based on an already completed hydrogeological survey commissioned by EPA that included characterization of soil conditions, groundwater flow magnitude/direction, as well as nitrate (and other water quality parameters) distributions (**Figs. 2 & 3**). The entire PRB will be installed using a row of temporary injection points that are spaced 10 feet apart. The vertical extent of the PRB is 20 ft, designed to capture and treat a near-ground surface nitrate plume with concentrations of up to 14 mg/L. There are two main options for the carbon source in this type of a PRB: wood chips or emulsified vegetable oil (EVO), a food-grade substrate that includes refined soybean oil. Wood chips are generally low cost and long-lasting; however, the installation costs are high since they must be emplaced by excavation. Further, to install wood via trenching at significant depth below the water table may not be feasible, and would require significant disturbance of the land surface. In contrast, EVO is easily injected through small diameter points using conventional drill rigs. The low solubility of EVO in water means that it will remain largely in place, and is slowly biodegraded in most groundwater systems such that a single injection may provide efficient, passive groundwater treatment for several years. For these reasons, EVO will be used in this study.

The key unknown variable for determining the operational cost of a PRB is design life, which will be tested by injecting a 12 mo. and 24 mo. supply of EVO on opposite halves of the PRB. In this way, we are designing the PRB to “fail” within the project performance period so that we will know exactly how much EVO is needed for a full-scale system that should last between 5-10 years between injections. To monitor performance, monitoring wells will be installed upstream, within, and downstream of the PRB. These wells will be sampled before the injection of EVO to determine baseline conditions (nitrate concentrations and flow rates) and to ensure that the EVO is injected within the optimal depth interval. Post injection, the wells will be sampled quarterly for two years, with measurements to include a comprehensive list of chemical constituents beyond nitrate (e.g. heavy metals) to ensure that groundwater chemical conditions are not adversely impacted by the PRB. EPA survey data indicates that this pilot-scale PRB alone is expected to remove upwards of 530 kg N/year from entering Great Pond (Falmouth, MA), equivalent to the annual N load to groundwater of 130 residences, at the head of the estuary where sewerage the less-dense, larger parcels is cost-prohibitive. This project is an important part of the overall strategy for achieving Total Maximum Daily [nitrogen] Load (TMDL)-compliance in this watershed.

This project builds upon work to evaluate potential sites for PRBs undertaken by the EPA and USGS as well as the Town of Falmouth through a grant from the Cape Cod Water Protection Collaborative. This work

Field Scale Validation of Permeable Reactive Barriers for Non-Point Source Groundwater Nitrogen Remediation

characterized the groundwater chemistry and hydrogeology of the Shorewood site and enabled a conceptual PRB design and monitoring plan to be formulated. Briefly, soil borings on the property showed highly permeable glacial sand and gravel outwash deposits to at least 80 ft. below ground surface. The horizontal groundwater flow direction was found to be to the southwest (toward upper Great Pond) at a rate of ~2-4 ft/day. All well locations showed significant nitrate concentrations of up to 14 mg/L (**Fig. 2**) within a well-defined stratigraphic layer. Overall, the conditions are favorable for treatment of nitrate via PRB. For the above reasons, our proposed project is “shovel-ready” and well positioned for success.

This project would not be the first of its kind in the region, yet there are several important design characteristics that require further testing before PRBs will be adopted by the many interested municipalities. Two small-scale wood-chip based PRBs were installed along the shores of Waquoit Bay (Falmouth) in the early 2000s; they operated as expected in terms of nitrate removal, but were occasionally infiltrated by seawater during extreme tides and storm surge. Despite their apparent longevity (wood chip PRBs have been known to operate at full capacity for more than a decade), we eliminated them from consideration as a carbon source for this project because they cannot be easily installed at depth, which is a requirement for any PRB other than those installed within a beach where the water table is very close to ground surface. To date, one EVO-based PRB for nitrate treatment has been installed on Cape Cod (Orleans) and one is in the final planning stages (Martha’s Vineyard [MV], funded by SNEP in 2018). The Orleans project demonstrated the efficacy of an EVO PRB for denitrification, but the groundwater flow rates within the Orleans PRB are about ten times slower than those measured at 0 Shorewood. While groundwater flow at the proposed MV PRB was not measured at the time the proposal was awarded, nitrate concentrations in test wells at the site are 2-4x lower than at our proposed site. As such, the PRB proposed herein would test the performance of this technology under high groundwater velocity and high nitrate concentrations while also assessing different EVO dosages. These are important distinctions since the combination of these factors result in the highest mass flux (kg/day), which factor heavily into reducing the cost of nitrogen treatment (\$/kg removed) since the EVO is estimated to be more than half of the overall cost for PRBs of the design proposed herein.

One of the challenges for PRB design is that the chemical composition of the groundwater may vary from location to location. For example, groundwater pH, which is an important factor for the bacteria that perform the denitrification process, may not be the same for all promising PRB locations across the region; groundwater pH readings from the Shorewood site are somewhat lower (4.3 to 6.0) than other locations on Cape Cod considered for PRBs. To address this issue, we propose to undertake a series of laboratory based simulations known as column studies, where local nitrate-rich groundwater is filtered through local soil (in a pipe) with added EVO. Several soil treatments will be performed to evaluate the pH dependence of denitrification and retention factor of EVO for Cape Cod soils and bacterial communities. These experiments will determine the need for a buffering agent to maintain groundwater pH within the observed optimal range. Previous column studies performed by Terra Systems, Inc. using Falmouth soil and groundwater resulted in modifications to EVO properties to make the amendment “stickier” to soil to minimize migration of oil and extend the longevity of the PRB. Better understanding of pH for optimizing nitrate removal and buffer dosage will support improved performance at PRB installations that use EVO and therefore more constrained estimates of cost for removal of nitrate.

With respect to permits, our team has already initiated discussions with the MassDEP regarding our grant proposal application and the Underground Injection Control (UIC) program. We therefore have a good sense of the level of detail that will be required for the UIC permit and expect the turnaround time to be relatively fast. With respect to the Falmouth Conservation Commission, the location of the PRB falls outside the jurisdiction of the Wetlands Protection Act and local regulations. Monitoring wells within 100 feet of a Resource Area have already been located at this site, under a negative determination for a Request for Determination of Applicability (RDA). At the current level of planning and design, no wells are to be located within designated Resource Areas.

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We will develop a Quality Assurance Project Plan (QAPP) that meets EPA’s requirements for projects involving groundwater monitoring. We will use the EPA QAPP Development Tool for plan preparation guidance, which covers required elements including project management, sample analysis/data acquisition, data validation, and standard operating protocols. A draft of the QAPP will be submitted to EPA at least 30 days prior to collection of any groundwater samples. The overall project timeline is shown in Table 1.

Table 1. Month-by-month project timeline for major tasks and deliverables.

Task	Month	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	
Permit Application and Site Prep		X																														
Quality Assurance Project Plan		X																														
Monitoring Well Installation/Baseline Survey			X																													
PRB Installation			X	X																												
Performance Monitoring				X			X			X		X			X			X			X		X		X							
Advisory Committee Meeting		X			X			X			X		X			X			X		X		X		X			X		X		X
Outreach Event					X											X														X		
PRB Best Practices Manual Preparation																												X	X	X		
Progress Reporting to EPA						X						X						X					X								X	

Impact—Encompassing over 8,000 acres, the Great Pond watershed is the largest in Falmouth. Great Pond fails to meet water quality standards due to excessive nitrogen inputs, a result of extensive development of single-family homes over the past 50 years, and 100 percent of the eelgrass that was present in a 1951 survey has been lost (Mass. Estuaries Report for Great Pond). Of all the controllable sources of nitrogen pollution, 82 percent is attributed to on-site wastewater treatment systems and 18 percent comes from runoff including impervious surfaces and fertilizers. This project is part of a comprehensive solution for achieving TMDL-compliance in the Great Pond watershed. There are two main subsections of this watershed, an upper region north of route 28 and a lower region south of route 28; the lower watershed is densely developed, with most lots under 10,000 sq ft. Approximately 260 homes in this lower watershed have already been connected to the town sewer system, with an additional 1,500 connections in the planning phase. However, for remediating the nitrogen load coming from the upper watershed, alternative technologies are expected to be more cost effective because the long distances between properties make sewerage impractical. The expected nitrogen-removal of this PRB (530 kg/y) has been calculated using the three rounds of water quality samples from this location plus data on groundwater travel time from water table wells. If successful, extending this PRB by an additional 180 ft would be feasible at this site, which could remove an additional 800 kg N/year (~200 residential properties annual N output), removing approximately 59% of the remaining required N to meet the TMDL once planned sewerage in the lower watershed has been completed.

Beyond Great Pond, this project will demonstrate a technology that has widespread replicability for Falmouth’s other south coast watersheds that are also category 5 impaired waters, including Green Pond, Bournes Pond and Waquoit Bay as well as Falmouth’s six west facing estuaries. Multiple towns on Cape Cod are considering future installation of denitrification PRBs with combined lengths of hundreds to thousands of linear feet consistent with the Cape Cod 208 Water Quality Plan. However, to raise the confidence level of towns and regulatory agencies with respect to installing PRBs in impaired watersheds, more in-ground demonstrations are needed that will provide data on the injection/distribution of EVO and longevity of the PRB to support cost-effective pricing for the actual installation. The result of this project will be a denitrification PRB design guidance with description of the process and critical parameters needed to design and install a PRB, and to quantify its performance. Improved design tools are needed for denitrification PRBs in SNE, as this environment is unique relative to existing design tools for bioremediation using EVO (e.g. chlorinated solvents in lower permeability soils). This information will become an open and detailed source for local communities as well as wastewater planners. A complete report, including all design parameters and assumptions, data collected and a summary of all findings will be included in the final report to help other communities evaluate the feasibility of this option at other sites and perform preliminary design calculations.

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Project Team—Matt Charette is a Senior Scientist at WHOI; since 1998, he has specialized in the study of coastal groundwater systems and their influence on the chemistry of the coastal ocean, including nitrogen cycling in nearshore aquifers. He has published nearly 50 peer-reviewed papers in this area alone, many of them focused on Cape Cod watersheds. The PI is also a member of Falmouth's Water Quality Management Committee (WQMC), which has been actively studying alternatives to sewerage and will serve as an advisory body for this project. Kristen Rathjen of Science Wares, a consultant to the WQMC, will serve as project manager, which would include coordination with project partners, oversight of the performance evaluation program, and fulfillment of the reporting requirements. Paul Henderson, a Research Associate at WHOI with 15 years of experience in nutrient analysis and groundwater sampling, will be responsible for the field sampling and chemical analyses. The Terra Systems, Inc. team will be led by Michael Lee, Ph.D. and Fritz Hostrop. Dr. Lee has 30 years of experience in conducting laboratory studies and application of in situ bioremediation for petroleum, chlorinated solvents, hexavalent chromium, and nitrate-contaminated sites. He holds the first US patent for EVO for use in bioremediation. Fritz Hostrop is an engineer with extensive experience in Massachusetts. In-Situ Oxidative Technologies, Inc. (ISOTEC) is a full-service environmental firm that specializes in groundwater and soil treatment and has performed more than 2,000 field injections over the past 24 years. ISOTEC's team of engineers, scientists, and field technicians will be led by Paul Dombrowski, P.E. Mr. Dombrowski, who is based in Massachusetts, has over 15 years of experience with in-situ treatment of soil and groundwater, including 6 EVO PRB projects, one of which was the first EVO denitrification PRB field demonstration located in Orleans, MA. ISOTEC has implemented PRBs using a number of other remediation amendments including chemical oxidants, zero valent iron, and injectable activated carbon. Tim Pasakarnis, a Cape Cod Commission (CCC) hydrologist that has participated in PRB installations, will join the WQMC PRB working group to lend his expertise to the project to support planning, data interpretation and dissemination of results to the wider region.

Outreach and Communications—A major focus of this study is to present the project findings in a way that provides operable information to other communities—this focus is what sets our project apart from ongoing PRB efforts in the region described above. To this end, we will produce an open source manual on PRB design and installation that covers topics from permitting to nitrogen removal quantification. The manual will include two easy to use Excel based tools for: (1) engineering calculations for electron donor (EVO) mass and volume requirements (including the lifespan of the injection) and (2) calculating the nitrogen removal potential and treatment cost given local groundwater hydrogeology. These files will be disseminated electronically via the CCC's Nutrient Mitigation Technology matrix (<http://www.cch2o.org/Matrix/>) for PRBs website. The project completion report will include engineering calculations for electron donor mass and volume required, final PRB design and rationale, field installation details, budget evaluations, monitoring results, reinjection schedule and a cost per kilogram of nitrogen removed benchmark. This report will include key considerations and lessons-learned for other communities seeking to evaluate PRBs as a best management practice for groundwater nitrogen removal and would be a case-study companion to the guide that the EPA and the CCC are preparing for characterizing the hydrogeology of a potential PRB site. Finally, we will present our results at both local and national conferences. Locally, we would aim to present at the annual Cape Coastal Conference, which is sponsored by the Waquoit Bay National Estuarine Research Reserve. This meeting draws several hundred key stakeholders from local towns as well as across the northeast region. In addition to attending the regional SNEP meeting in Boston, we will attend the National Summit on Coastal and Estuarine Restoration and Management in Ft. Lauderdale, FL, the annual meeting of the American Geophysical Union, the International Symposium on Bioremediation and Sustainable Environmental Technologies sponsored by Battelle, and the Annual International Conference on Soils, Sediments, Water, and Energy hosted at U. Mass-Amherst. These national and international meetings will allow us to showcase our results to a wider audience, which may result in the adoption of this technology on a scale much wider than southeast New England.

Field Scale Validation of Permeable Reactive Barriers for Non-Point Source Groundwater Nitrogen Remediation

SNEP Watershed Grant Proposal - Budget Table					
Cost Item or Category	Cost Basis	RAE SNEP Request	Non-Federal Match	Match Source	Total Project Cost
Personnel					
Mat Charette	152 hrs	15,975			15,975
Paul Henderson	570 hrs	32,288			32,288
Falmouth WQMC volunteers	252 hrs @ \$24.69/ hr		6,222	In-kind	6,222
Falmouth WQMC Consultant	600 hrs		30,000	In-kind	30,000
Cape Cod Commission hydrologist	48 hrs		5,000	In-kind	5,000
					-
Total Personnel		48,263	41,222		89,485
Fringe					
Fringe, WHOI	47.99%	23,162			23,162
Total Fringe		23,162	-		23,162
Travel					
EPA Meeting	Air/hotel/ground/reg. fee	2,167			2,167
National Meeting	Air/hotel/ground/reg. fee	2,567			2,567
Total travel		4,734	-		4,734
Equipment					
					-
					-
Total Equipment		-	-		-
Supplies					
Lab Supplies	See text	14,307			14,307
					-
Total Supplies		14,307	-		14,307
Contractual					
ISOTEC	See Text	120,000	61,333		
Outside Analyses	See Text	4,000			
Total Contractual		124,000	61,333		185,333
Other					
In-house Analyses	See text	9,482			9,482
					-
Total Other		9,482	-		9,482
TOTAL DIRECT		223,948	102,555		326,503
Total Modified Direct Costs					
Indirect		74,650	9,168	WHOI discretionary	83,818
TOTAL		298,598	111,723		410,321
<i>Non-Federal Match as a Percentage of Request: 37%</i>					

Field Scale Validation of Permeable Reactive Barriers for Non-Point Source Groundwater Nitrogen Remediation

BUDGET NARRATIVE

Personnel

Matt Charette Salary—Matt Charette will serve as project leader for the grant and is responsible for the successful completion of the project including coordination with project partners, oversight of the performance evaluation program, and fulfillment of the reporting requirements. He will serve as supervisor of Paul Henderson, who will be conducting the field work and laboratory analyses. Lastly, he will oversee the outreach and education aspects of the grant in collaboration with partner organizations, and presentation of results at national meetings. For these activities, he is budgeting 1.0 month of salary over the 30-month grant.

Paul Henderson Salary—Mr. Henderson will be responsible for pre-field work preparation, collection of quarterly groundwater samples from the PRB monitoring wells, and most laboratory analyses of the groundwater samples. For these activities, he is budgeted at 3.75 months over the 30 month grant.

In Kind Participation—The Town of Falmouth's Water Quality Management Committee is charged with "guiding and advancing solutions to the water quality issues that affect the Town's watersheds". They will serve as the advisory body to the PI including assistance with local approvals, as a forum for public updates on grant progress, and review of outreach and education materials. Their estimated in-kind contribution is 252 hours @ \$24.69/hr over the 30-month project. The consultant to the Water Quality Management Committee Kristen Rathjen (Science Wares) will serve as project manager, which would include coordination with project partners, oversight of the performance evaluation program, and fulfillment of the reporting requirements (in-kind contribution of 600 hrs @ \$50/hr = \$30,000). In year 1 of the project, the consultant will develop our QAPP and oversee subcontractor installation of the PRB. The consultant would also lead the outreach and education aspects of the grant in collaboration with partner organizations, and presentation of results at local meetings. For these activities, the Town of Falmouth will provide 600 hours of funding for the consultant (@ \$50/hr) over the 30-month grant. Cape Cod Commission hydrogeologist Tim Pasakarnis will join each of the WQMC's PRB working group meetings over the course of the project. We estimate 48 hours of his time for a total in-kind salary contribution of \$5,000.

Travel

Travel costs—Dr. Charette will attend the SNEP regional meeting as well as the RAE National Summit on Coastal and Estuarine Restoration and Management in Ft. Lauderdale, FL during October 2020. In the final 6 months of the project, he will showcase the results of the study to a wider audience at a national meeting of Coastal & Estuarine Research Federation, American Geophysical Union, or equivalent. Travel expenses are based on round trip airfare to California plus 5 nights hotel, 6 days of meals and incidentals, and ground transportation costs.

Supplies

Laboratory Materials and Supplies—A budget of \$14,307 is requested for field, lab, and analytical supplies. This includes all consumable materials required for field work and laboratory-based analysis (e.g., sample bottles, pumps, tubing, piezometers, chemicals, filters, filtration hardware, glassware, sensors for water quality analysis) as well as all consumable materials required for conducting chemical analyses within the Charette lab at WHOI (e.g. water purification cartridges, test tubes, chemicals).

Contractual

Permeable Reactive Barrier Construction—WHOI will partner with Isotec and Terra Systems for installation of the PRB. ISOTEC will serve as prime subcontractor and will be responsible for overall PRB installation including equipment mobilization, field injection of the EVO, maintaining field logs throughout the process and reporting on the installation. The installation is expected to take 17 field days. Their total budget is \$120,000

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(SNEP) plus \$61,333 of non-federal matching, which includes a combination of in-kind services, discounts and company-funded research and development. Major SNEP funded budget items include equipment and labor for the PRB injection (\$39,488) and 5,900 gallons of food-grade EVO (\$44,927). Major cost-share items are reduced UIC permit preparation fees, a 20% discount on the EVO, design and technical document preparation, and ~2/3 discount of the laboratory-based sand column experimental costs. Both firms will donate their time for attendance at meetings of the working group. Their letter of partnership (attached) includes a statement of work as well as a detailed breakdown of their anticipated costs. Note that since Terra Systems will subcontract with ISOTEC, ISOTEC has added a 10% administrative charge on all Terra Systems related costs (discounted from their normal administrative rate of 15%). In partnering with these firms, WHOI will adhere to all rules and regulations set forth by the EPA regarding contracting, sub-awards and purchases.

Other

In house and outside analytical services—Analytical facility service charges are included in the budget for groundwater chemical analyses. Two WHOI-based facilities will be used for nitrogen and trace metal analyses (\$9,482). Outside facilities will be used for major cations/anions, dissolved organic carbon, and total alkalinity (\$4,000). The costs assume quarterly sampling of 16 discrete aquifer depths over two years (128 samples for each chemical analysis).

Fringe Benefits

Employee benefits have been proposed using composite weighted average rates for the 2019-2021 project period that are the total assignable to salaries of regular employees including paid absences (see table below). The period composite rates are weighted averages of the specific rates for each fiscal year in accordance with WHOI's 2019 provisional rate agreement (dated 12/21/2018) and 2019 Provisional Forward Pricing Letter (dated 2/12/2019) with the Office of Naval Research. The largest component, retirement, is a result of WHOI having to cover employee benefits earned under a defined benefit (pension) program that was terminated for new employees in 2010, as well as the defined contribution program that replaced it.

Component	2019	2020	2021
Retirement	19.22%	24.73%	27.05%
Health & Dental	10.72%	12.53%	13.26%
FICA	7.30%	6.77%	6.88%
Workers Comp	0.35%	0.37%	0.37%
Disability	0.92%	0.93%	0.93%
Other benefits	1.88%	2.11%	2.12%

Indirect Costs

Woods Hole Oceanographic Institution has a government negotiated overhead rate of 65% on most direct costs. The portion of our indirect costs budget that exceeds the maximum 25% rate allowed by the EPA SNEP competition (\$9,168) will be covered by WHOI from the discretionary funds account and is included here as institutional cost share.

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FIGURES AND MAPS

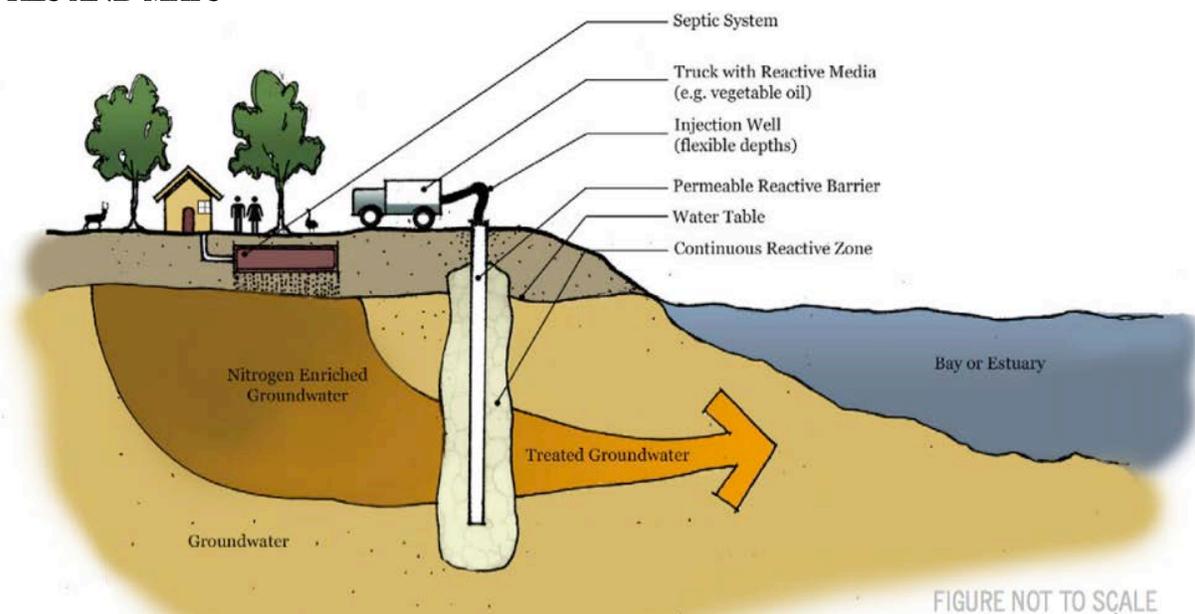


Figure 1. Conceptual diagram for an injection well permeable reactive barrier of the type proposed herein. Source: Cape Cod Commission.

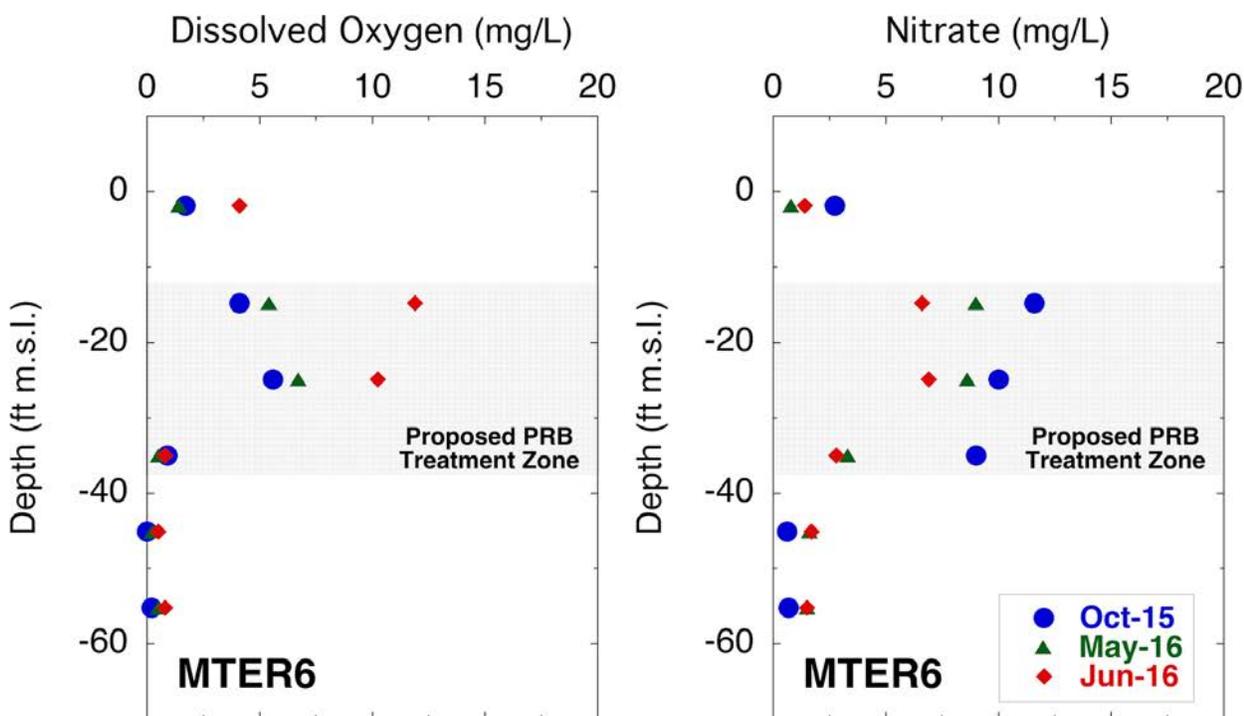
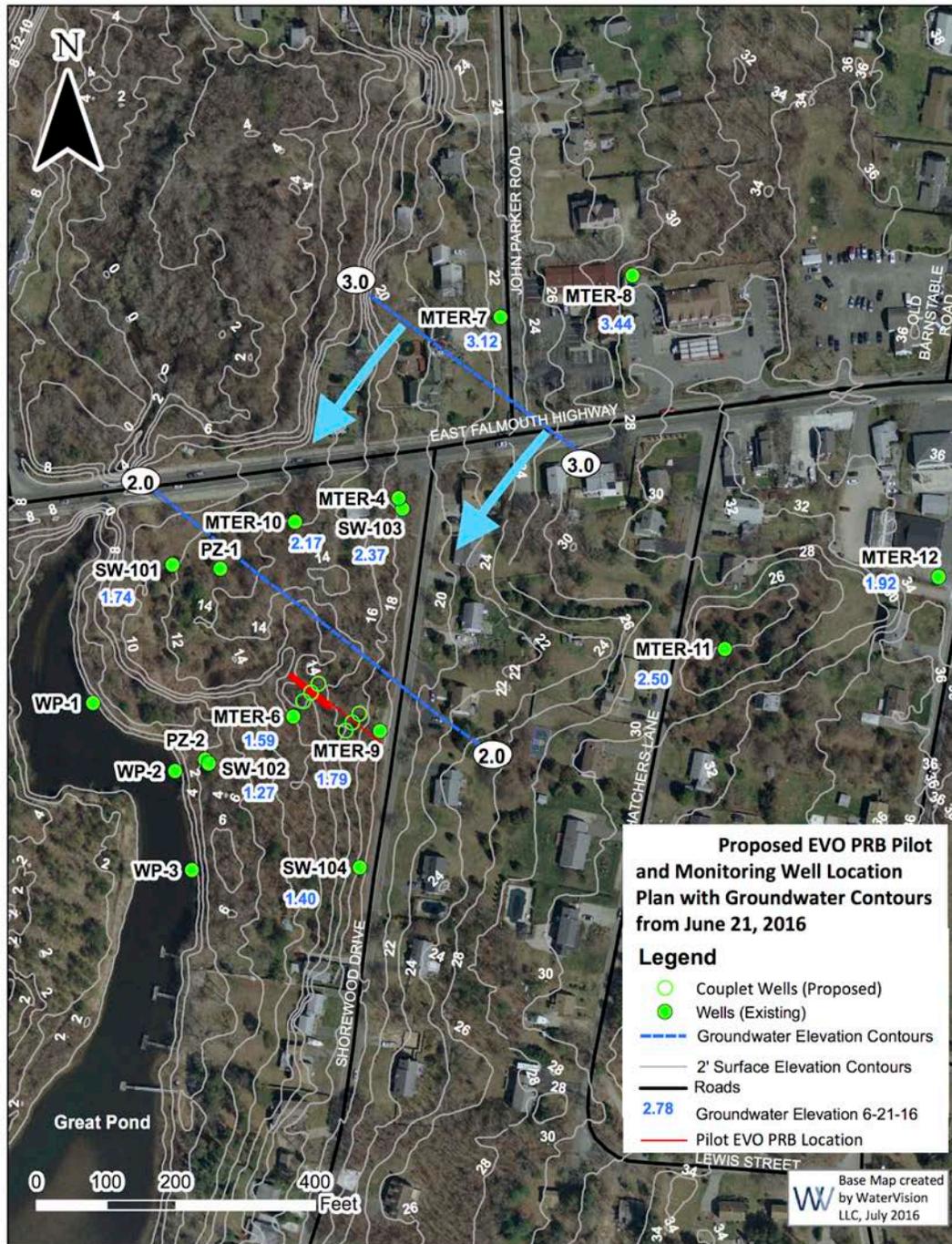


Figure 2. Dissolved oxygen and nitrate concentrations in groundwater at the MTER6 multilevel monitoring wells from the 0 Shorewood site. Well cluster MTER6 is most closely aligned with the proposed PRB installation and the PRB treatment interval is shown in shaded gray. See Fig. 3 for well locations.

Field Scale Validation of Permeable Reactive Barriers for Non-Point Source Groundwater Nitrogen Remediation



Sources: Aerial photography 2013-2014 and Roads from Mass GIS, Elevation contours from Cape Cod Commission, Site surveys completed by Falmouth Public Works Department and CEI to NAVD 88 vertical datum. MTER well locations are approximate.

Figure 3. Permeable Reactive Barrier design for 0 Shorewood Drive, including groundwater flow direction (blue arrows), location of the PRB (solid red line), and six new monitoring well locations (open green circles). Existing monitoring wells, which were included in the WaterVision baseline hydrogeological survey, are indicated by solid green circles.

EDWARD J. MARKEY
MASSACHUSETTS

United States Senate

SUITE SD-255
DIRKSEN BUILDING
WASHINGTON, DC 20510-2107
202-224-2742

COMMITTEES:
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May 23, 2019

Mr. Thomas Ardito, Director
Southeast New England Watershed Grants Program
PO Box 476
Saunderstown, RI 02874

**RE: Southeast New England Program (SNEP) Grant Application
Woods Hole Oceanographic Institution**

Dear Mr. Ardito:

I write in support of the application submitted by the Woods Hole Oceanographic Institution (WHOI), in partnership with the Cape Cod Commission and the Falmouth Water Quality Management Committee, for funding under the Environmental Protection Agency's Southeast New England Program (SNEP). WHOI seeks \$298,598 to install a Permeable Reactive Barrier (PRB) on a town-owned parcel at 0 Shorewood Drive in East Falmouth. The project will help achieve water quality-compliance in this watershed at a lower cost than a traditional centralized wastewater treatment system. With this SNEP grant, Falmouth will ensure the protection of one of the area's most cherished environmental landmarks.

The watershed filters into the Great Pond, a 17-acre natural kettle pond that also facilitates recreational activities for the Town of Falmouth. In a 2017 report provided by the Massachusetts Estuaries Project (MEP), it was found that the Great Pond system exceeded its threshold for nitrogen levels, resulting in compromised water quality. This small-scale PRB is expected to remove upwards of 530 kg of nitrogen per year that would otherwise filter into Great Pond, which will help restore the body of water to water-quality compliance.

This PRB is the preferred method to rehabilitate the water in Great Pond, as a traditional centralized wastewater treatment would cost the Town hundreds of millions of dollars. WHOI also plans to produce a PRB manual and toolkit so that other surrounding towns can take advantage of this economically advantageous option.

Mr. Ardito
May 23, 2019
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I appreciate the work that the EPA and the SNEP grant program does to make it possible for local entities to restore important environmental anchors, such as the Great Pond. I thank you for your full and fair consideration of the application put forth by WHOI in partnership with the Cape Cod Commission and the Falmouth Water Quality Management Committee. Should you have any questions or concerns, please contact Rory Clark in my Boston office at (617) 565-8519.

Sincerely,



Edward J. Markey
United States Senator

WILLIAM R. KEATING

9TH DISTRICT, MASSACHUSETTS

COMMITTEE ON FOREIGN AFFAIRS

SUBCOMMITTEES

RANKING MEMBER

TERRORISM, NONPROLIFERATION, AND TRADE
EUROPE, EURASIA, AND EMERGING THREATS

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COUNTERTERRORISM AND INTELLIGENCE
TRANSPORTATION SECURITY



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May 29, 2019

Thomas Ardito, Director
Southeast New England Watershed Grant Program
P.O. Box 476
Saunderstown, RI 02874

Dear Mr. Ardito,

I am writing to express my support for the EPA-SNEP grant application entitled "*Field Scale Validation of Permeable Reactive Barriers for Non-Point Source Groundwater Nitrogen Remediation.*"

As you know, water bodies across southeastern Massachusetts are suffering from excessive inputs of nitrogen due mainly to wastewater from septic systems, which is carried to bays and estuaries by rivers and groundwater. The cost to deal with this problem through traditional wastewater collection systems has been estimated to be \$5.2-7.6 billion on Cape Cod alone. As a result, towns in the region are considering lower cost alternative solutions such as permeable reactive barriers (PRB), which have the ability to treat nitrogen contaminated groundwater before it reaches the coastline.

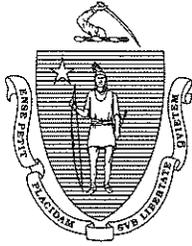
This proposed pilot-scale PRB would represent an important proof-of-concept, which is needed before municipalities are willing to invest taxpayer dollars in this relatively new approach to nitrogen remediation. Further, the project is of a scale that, if successful, will lead to improvements of water quality to the impaired Great Pond watershed.

Thank you for your full and fair consideration of supporting this worthy application.

Regards,

A handwritten signature in blue ink that reads "Will R. Keating".

William R. Keating
Member of Congress



The Commonwealth of Massachusetts

HOUSE OF REPRESENTATIVES
STATE HOUSE, BOSTON 02133-1054

DYLAN FERNANDES
STATE REPRESENTATIVE
BARNSTABLE, DUKES AND NANTUCKET

STATE HOUSE, ROOM 472
TEL. (617) 722-2013
Dylan.Fernandes@MAhouse.gov

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Post Audit and Oversight
Redistricting

Thomas Ardito, Director
Southeast New England Watershed Grant Program
P.O. Box 476
Saunderstown, RI 02874

Dear Director Ardito,

We write to you in support of the Woods Hole Oceanographic Institution's (WHOI) application to the Environmental Protection Agency's Southeast New England Program. WHOI is working in conjunction with the Town of Falmouth and the Cape Cod Commission to install a permeable reactive barrier (PRB) in East Falmouth to prevent upwards of 530 kg of nitrogen per year from entering Great Pond. This is equal to removing the annual nitrogen load of 130 residences.

Great Pond is a staple of the Falmouth community, local blue economy, and estuary system, providing not only a home for diverse ecosystems, but also supporting recreational and commercial activities such as boating, swimming, shell fishing, and fin fishing. In a 2017 report, the Massachusetts Estuaries Project found that Great Pond's water quality was in critical condition because of exorbitant levels of nitrogen. The Town of Falmouth and the Cape Cod Commission are working to restore Great Pond and the installation of a PRB would go a long way in dramatically improving water quality and achieving TMDL-compliance in this watershed.

We thank you for your consideration of this application and please feel free to reach out to our offices with any questions or concerns.

Sincerely,



Dylan Fernandes
State Representative
*Falmouth, Martha's
Vineyard, and Nantucket*



David Vieira
State Representative
3rd Barnstable District



Vinny deMacedo
State Senator
Plymouth and Barnstable

3225 MAIN STREET • P.O. BOX 226
BARNSTABLE, MASSACHUSETTS 02630



CAPE COD
COMMISSION

(508) 362-3828 • Fax (508) 362-3136 • www.capecodcommission.org

May 17, 2019

Dr. Matt Charette
Director, Woods Hole Sea Grant
Senior Scientist, Department of Marine Chemistry and Geochemistry
Woods Hole Oceanographic Institution (MS #25)
Woods Hole, MA 02543
(508) 289-3205

Dear Matt,

I am pleased to commit to partnering with you on a key outreach activity of your EPA SNEP proposal entitled "Field Scale Validation of Permeable Reactive Barriers for Non-Point Source Groundwater Nitrogen Remediation". The Cape Cod Commission is a branch of the Barnstable County regional government dedicated to "leading, supporting, and enforcing the development of regional plans, policies, regulations, and infrastructure to guide and manage growth" and supporting "the 15 Cape Cod towns with professional and cost-effective planning and technical support services". A significant portion of our effort in recent years has focused on regional water quality management planning - specifically providing our stakeholders with tested, innovative alternatives to centralized wastewater treatment, which is estimated to cost upwards of \$4 billion dollars to implement Cape-wide.

Your project would serve as an important contribution to these efforts, and if funded I would be happy to collaborate in two ways. First, as an environmental engineer with over 10 years of experience in groundwater remediation, I would serve as a member of the Town of Falmouth Water Quality Management Committee's PRB Working Group. I would attend the quarterly meetings, allowing me to provide input throughout project implementation, and to convey the progress and results of your study to other towns on Cape Cod that are considering this technology. Second, I would provide guidance in designing materials for incorporation into the PRB page of our Technologies Matrix, a web resource for town planners who are investigating alternative nutrient mitigation technologies and policies. For these efforts, I estimate 48 hours of in-kind support, which is equivalent to \$5,000.



I look forward to the opportunity to collaborate on this project, which will generate real-world permeable reactive barrier data and implementation guidance on Cape Cod to help better inform decisions at the local level in Falmouth and throughout the greater Cape Cod region as well.

Sincerely,



Timothy Pasakarnis, Ph.D.
Water Resource Analyst
Cape Cod Commission

cc: Kristy Senatori, Executive Director

11 Princess Road
Suite A
Lawrenceville, New Jersey 08648
(609) 275-8500 phone

54 Hillside Road
Newton Highlands, Massachusetts 02461
(617) 370-4050 phone



May 20, 2019

Woods Hole Oceanographic Institution
Department of Marine Chemistry and Geochemistry (MS #25)
Woods Hole, MA 02543
Attention: Mr. Matthew Charette, Senior Scientist

**RE: *Partnering on Southeast New England Program
Denitrification Permeable Reactive Barrier
0 Shorewood Drive Site, Falmouth, MA***

Dear Mr. Charette:

In-Situ Oxidative Technologies, Inc. (ISOTEC) is pleased to be a partner with the Woods Hole Oceanographic Institution and the Town of Falmouth in the grant application for a Southeast New England Program (SNEP) Watershed Grant for a denitrification permeable reactive barrier (PRB). Since 1995 ISOTEC have been leaders in the field of in-situ groundwater and soil treatment, including development of proprietary in-situ chemical oxidation and reduction technologies. ISOTEC is dedicated to resolving complex environmental issues, and we are eager to support the proposed permeable reactive barrier with our 24 years of experience in treatment design, effective field injection, and data interpretation.

ISOTEC is well-suited to support WHOI and the Town of Falmouth on this project. ISOTEC assisted in the design and performed the injections for the installation of the emulsified vegetable oil (EVO) denitrification PRB field demonstration located in Orleans, MA. ISOTEC has supported post-injection PRB performance evaluation and has presented on the results and lessons learned at the Battelle International Symposium on Bioremediation and Sustainable Environmental Technologies in 2017 and 2019 and at the Waquoit Bay Reserve Coastal Training Program on Using Permeable Reactive Barriers to Address Nitrogen Pollution in April 2017.

If WHOI is selected for the grant, ISOTEC will provide the following services to WHOI:

- Prepare groundwater in-situ treatment design plan;

- Prepare Underground Injection Control (UIC) application form BRPWS 06 and submit to Massachusetts Department of Environmental Protection;
- Conduct bench-scale testing (with TerraSystems, Inc.);
- Install new monitoring wells to assess performance of the PRB;
- Procure EVO and pH buffer for injection;
- Provide staff, equipment, and materials to inject EVO solutions to establish the PRB; and
- Co-author a design manual for Denitrification PRBs.

ISOTEC will be supported by TerraSystems, Inc. in developing the treatment plan, the Underground Injection Control application, identifying dosage concentrations, and conducting bench-scale testing. ISOTEC and TerraSystems have a history of technical cooperation, and ISOTEC has collaborated with and injected TerraSystems remediation amendments at 10 different sites in the past 24 months (three of these sites included EVO PRBs). Individually and together ISOTEC and TerraSystems have experience with design for PRBs for groundwater treatment. However, denitrification PRBs in permeable aquifers are a unique situation to many remediation projects and the existing remedial design tools. Through the recognition of this need, we want to utilize our collective experience working with biological treatment of groundwater to establish a PRB design guidance to achieve cost-effective treatment for nitrogen for communities in Southeast New England and in other regions.

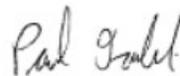
Costs for ISOTEC and TerraSystems to complete the above activities are outlined in Table 1 attached, which includes a combination of in-kind services valued at more than \$60,000 (combined from ISOTEC and TerraSystems) for preparation of treatment design plan and UIC application, discounts on field injection services and amendment, and company-funded research and development of a design manual.

ISOTEC would like to thank Woods Hole Oceanographic Institution and the Town of Falmouth for the opportunity to be a partner for this grant. Please let us know if we can provide any additional support for the grant application. If you have any questions or need additional information, please feel free to contact Paul at (617) 902 9383.

Very truly yours,
In-Situ Oxidative Technologies, Inc.

Prasad Kakarla

Prasad Kakarla, P.E. (NJ)
Technical Director



Paul M. Dombrowski, P.E. (MA)
Senior Remediation Engineer

Attachment: Table 1

**Table 1. ISOTEC and TerraSystems Summary of Costs
Denitrification Permeable Reactive Barrier (PRB)
Shorewood Site, Falmouth, MA
May 2019**



Permeable Reactive Barrier Design Parameters Design Scenario	Reduced Size Two-Variable Scenario	
PRB DESIGN CRITERION		
PRB Width (ft)	60	60
Vertical Interval (ft)	24	24
PRB Length (ft)	12	12
Porosity	0.3	0.3
PRB Pore Volume (gallons)	38,776	38,776
PRB Design Life (months)	24	12
Total Injection Volume (gallons) ¹	6,200	6,200
	12,400	
Emul. Vegetable Oil Dosage	20%	10%
Emul. Vegetable Oil Stock (gallons) ²	2,100	1,000
Injection Flow Rate (gal/d, first+last)	2,000	
Injection Flow Rate (gal/d, middle)	4,200	
Injection Days	4	
SOW WITH STANDARD COSTS		
UIC Permit Preparation		\$3,000
PRB Design and Technical Documentation		\$10,250
PRB Injection (equipment, labor) ³		\$45,305
PRB Amendments ⁴ (w/ 15% markup)	\$37,166	\$19,008
Well Installation (12 wells, 6 locations)		\$22,000
Bench Scale Testing ⁵ (w/ 15% markup)		\$17,300
PRB Design Manual		\$23,000
Meetings (4-5) TSI & ISOTEC		\$4,304
TOTAL		\$181,333
SOW WITH DISCOUNTED COSTS		
UIC Permit Preparation ⁶		\$585
PRB Design and Technical Documentation		\$1,500
PRB Injection Discounted ³		\$39,488
PRB Amendments Discounted 20% ⁵ (w/ 10% markup)	\$29,547	\$15,380
Well Installation (12 wells, 6 locations)		\$22,000
Bench Scale Testing ⁵ (w/ 10% markup)		\$5,500
PRB Design Manual		\$6,000
Meetings (4-5) TSI & ISOTEC		\$0
TOTAL		\$120,000
IN KIND CONTRIBUTIONS TOTAL		\$61,333
% DISCOUNT		34%

Notes:

- Total injection volume includes emulsified vegetable oil and dilution water.
- TSI's Emulsified Vegetable Oil, Slow Release Substrate - Nitrate Reduction (SRS-NR) is a large droplet emulsion with 60% soy bean oil and an anionic surfactant to minimize migration of emulsified vegetable oil.
- Costs assume non-prevailing, non-union wage rates. Cost assume that Town of Falmouth or WHOI are responsible for site access, water supply, private utility markout (other than State Dig Safe), and baseline/post-treatment performance monitoring. Cost includes tracked skid loader with forklift attachment for unloading and relocation of amendments and installation of 100 ft of temporary fencing. Cost assumes work is not performed between Memorial Day and Labor Day.
- PRB amendments include emulsified vegetable oil, sodium lactate, & pH buffer (calcium carbonate), freight, and tax.
- Bench Scale Testing to evaluate denitrification and reduction of competing electron acceptors at pHs ranging from 7 to 3.5 and determine retardation factor for SRS-NR emulsion migration. Soil samples from each column at end of study to be cultured to characterize bacteria speciation.
- UIC Permit Preparation includes \$585 fee to MassDEP. If Town of Falmouth becomes owner/operator of the UIC permit, the fee is \$0.



TOWN OF FALMOUTH

Office of the Town Manager & Selectmen

59 Town Hall Square, Falmouth, Massachusetts 02540

Telephone (508) 495-7320

Fax (508) 457-2573

May 30, 2019

Matt Charette
Director, Woods Hole Sea Grant
Senior Scientist, Department of Marine Chemistry and Geochemistry
Woods Hole Oceanographic Institution (MS#25)
Woods Hole, MA 02543

Subject: EPA-Southeast New England Program (SNEP) Grant Proposal

During its regularly scheduled meeting of Monday, May 20, 2019, the Falmouth Board of Selectmen voted unanimously to approve the Water Quality Management Committee as a project partner with the Woods Hole Oceanographic Institution in a submission of a grant proposal to EPA-Southeast New England Program (SNEP) to fund the installation of a permeable reactive barrier at 0 Shorewood Drive, East Falmouth.

Sincerely,

Julian M. Suso
Town Manager

cc: Board of Selectmen
Eric Turkington, Chair, Water Quality Management Committee

**WATER QUALITY MANAGEMENT COMMITTEE
TOWN HALL SQUARE FALMOUTH MA 02540**

May 6, 2019

TO: Julian Suso, Town Manager and Board of Selectmen
FR: Eric Turkington, Chair

RE: Approval of the Water Quality Management Committee as a project partner with the Woods Hole Oceanographic Institution in submission of a grant proposal to EPA-Southeast New England Program [SNEP] to fund the installation of a permeable reactive barrier at 0 Shorewood Drive, East Falmouth. The Water Quality Management Committee will provide \$36,222 of in-kind services.

Background:

Prior groundwater studies have shown that a town-owned parcel under the jurisdiction of the Selectmen located at the corner of Rt. 28 and Shorewood Drive, East Falmouth is a good location for installation of a permeable reactive barrier [PRB] to intercept nitrogen in the groundwater prior to discharge to Great Pond, an impaired estuary.

Proposal:

The Woods Hole Oceanographic Institution proposes to be the project leader for installation of a 120' long PRB. The technical consultant to the Water Quality Management Committee would serve as the project manager, providing coordination with project partners and fulfilling reporting requirements, valued at \$30,000. The WQMC would serve as an advisory body and public forum for education and outreach, valued at \$6,222. The project will last 30 months. Total grant request is \$410,321 with \$298,598 requested from EPA funds and \$111,723 in matching funds including the \$36,222 in in-kind services from Town of Falmouth.

The WQMC unanimously recommended approval of this grant proposal at their May 2, 2019 meeting.