Nitrate White Paper

ISOTEC

terrasystems

I. The Problem

Figure 1 Effects of excess nitrate (Boston Globe, 2011)

Cape Cod is one of seven sole source aquifers in the United States; sole source aquifers are designated where groundwater provides the 'sole or principal' source of drinking water to the area. The sandy Cape Cod Aquifer underlies all of Cape Cod from the Canal to the tip of Provincetown, including the Islands. Groundwater quality can be affected by a variety of contaminants including chemicals (solvents, household cleaners), petroleum products (gasoline, fuel oil), metals (iron), and inorganic materials (salt, nitrate), adversely affecting water quality.

Nitrate in groundwater flows unattenuated and discharges to water bodies where it provides excess nutrients to biota, leading to algal blooms, overgrowth or unwanted species, scum and/or odors (eutrophication). Eutrophication results in many adverse effects including decreasing water quality, creating nuisance conditions, adversely effecting recreation, amenities, and farming, and decreasing the surrounding land values.

The two largest controllable nitrogen sources on Cape Cod are septic systems and lawn fertilizer. Nitrogen, in the form of urea and other organic materials in wastewater, is converted into nitrate (NO_3^-) by on-site septic tank and leach field systems. The partially treated wastewater is then infiltrated to groundwater via leaching fields, infiltrators, or cesspools where it mixes with and travels unattenuated in the natural groundwater flow. Lawn fertilizers are high in nitrogen. Improper and excess application results in excess nitrogen discharger to the groundwater.

Nitrate is typically stable under aerobic conditions in groundwater. As a result, nitrate-laden plumes travel without significant attenuation from septic system(s) to ponds, water bodies and coastal waters of Cape Cod, Massachusetts (MA).

II. All Communities Are Affected

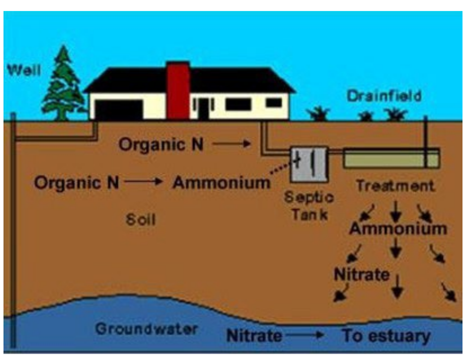


Figure 2 Typical Septic System Operation (Source: Oyster Pond Environmental Trust, 2022)

Septic systems are used to manage about 85 percent of the wastewater flow on Cape Cod (Cape Cod Commission, 2013). Five Wastewater Treatment Plants (WWTPs) are located on the Cape providing wastewater collection and treatment in the local communities. The expansion of these systems to expand their capacity or service areas is expensive and requiring significant intrusion to install pipelines and lift stations as well as connections to each household. Smaller satellite or cluster systems provide treatment for more than forty housing complexes, commercial areas, and schools. Expansion of these smaller plants would also be expensive and intrusive. Thus, most residents rely on septic systems for the collection and discharge of wastewater. In 2004, over 120,000 septic systems were identified on Cape Cod (Wright-Pierce et. al., 2004).

Most simply, septic systems provide retention to settle solids and remove floatables, allowing the 'clean' wastewater to flow into the drain field where it infiltrates directly into the ground. Many existing septic systems are simple leaching pits and cesspools installed decades ago. Most septic systems (33-70%) are operated seasonally resulting in seasonal fluctuations, exasperating summer conditions. Septic systems that process wastewater flows up to 10,000 gallons per day are regulated under Title 5 (Massachusetts State Sanitary Code 310 CMR 15.00) and permitted by local Boards of Health and the MassDEP. Title 5 septic

"The politics of wastewater is difficult. On the Cape, towns are the primary fiscal agents involved in building wastewater systems. Appropriations on a municipal level that authorize borrowing require a two-thirds vote of the local legislative town meeting body. In the Town of Barnstable that is the Town Council. In the other 14 towns the legislative body is town meeting." (Cape Cod Commission, 2015).

systems are designed to remove pathogens, but not nutrients such as nitrate. Newer innovative/alternative (I/A) systems can provide additional treatment to transform nitrate, however such stems are site-specific, requiring retrofit and expansion of existing systems and are costly to operate and maintain. Existing traditional septic treatment systems are not effective at removing nitrate.

The cost to bring Cape Cod communities in compliance with the Clean Water Act has been estimated to be at least $4 billion. This cost resulted in the consideration of a range of other treatment options (Section III). Regulating wastewater is under local control, typically involving the local Zoning, Board of Health (mandated sewer tie-ins where available, use of I/A systems) and Conservation Commission, and Public Works (for municipal systems).

Septic systems represent more than 90% of the total load of wastewater-derived nitrogen for the coastal watersheds in Cape Cod, and approximately 80% of the nitrogen that enters Cape Cod's watersheds comes from septic systems (Cape Cod Commission, 2015).

The Massachusetts Bays National Estuary Partnership (Massbays) empowers local communities to "protect, restore, and enhance their costal habitats and provide technical support for better decision making." As part of this partnership, the Massachusetts Estuaries Project (MEP) determined nitrogen loads for watersheds on Cape Cod using a detailed model and data collection. A Total Maximum Daily Load (TMDL) provides a calculation of the maximum amount of pollutant (nitrate) that any water body can receive without exceeding water quality standards. TMDLs are planning parameters that allow evaluation of setting goals for reducing or eliminating pollutants. The Massachusetts Department of Environmental Protection (MassDEP) provides a list of the Draft and Final TMDLs by Watershed (searched 2023). Presently,

- draft nitrate TMDLs are available for one watershed on Cape Cod,
- final nitrate TMDLs are available for seventeen watersheds on Cape Cod, and
- final nitrate TMDLs are available for eight watersheds on the Islands (Martha's Vineyard and Nantucket).

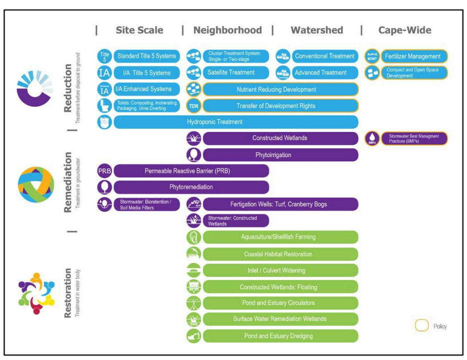


Figure 3 Alternative Nitrate Strategies (Source: 208 Plan, 2015)

III. Alternatives

"Possible solutions to address pond water quality are extensive, and the Commission is in the process of building an organized database of solutions to specifically address the health of ponds across the region. Threats to pond water quality extend from within a pond to the entire watershed, necessitating multiple approaches and scales of solutions. While some solutions have been implemented for decades, providing lessons from their application, other solutions are new and still being researched by scientists across the country." (Cape Cod Commission, 2021)

In 2020 the Cape Cod Commission updated a Technologies Matrix spreadsheet, compiling a list of potential technologies to address remediation, listing Permeable Reactive Barrier (PRB) technologies as providing 70 to 75% nitrogen reduction. (Technologies Matrix | Cape Cod Commission)

Removal of nitrate may be accomplished by several methods

- Installation/expansion of community wastewater plants
  - installing sewer lines to treatment plants, providing treatment plants with tertiary removal processes, and discharging treated effluent to the ocean
  - community-based approaches require installation of sewerage piping, individual connections, and conveyance piping/pump. Obtrusive construction may provide cost effective solutions in densely developed areas but is expensive in sparsely populated areas.
  - The multimillion-dollar financial burdens for community sewage solutions are typically borne in the tax rates and mandated betterment charges.
- Requiring tertiary denitrification systems (I/A systems under Title 5) treatment at each private septic system
  - installing improved systems at each septic system requiring increased short- and long-term cost, requiring more space for additional infrastructure.
  - typically require complete replacement of aged infrastructure at each location. This may not be possible at small/tightly spaced homes and in locations proximal to water bodies.
  - financial burdens for MassDEP approved nitrate removal septic systems are borne by each system owner (~$30,000).
- Nontraditional approaches
  - installation of PRBs to remove commingled nitrate plumes from multiple septic systems prior to discharging to water bodies.
  - PRBs may be sized to meet estuary nitrate Total Maximum Daily Loads (TMDL) and installed in select areas parallel to the water shore to treat combined nitrate impacts as a community protection mechanism.
  - Other nontraditional approaches may also be considered including Eco toilets, fertilizer bans, constructed wetlands, phytoremediation, fertigation wells, shellfish bed restoration, aquaculture, floating wetlands, dredging and inlet modification.

Ultimate selection of applicable approach(es) depends on each communities' situation and needs (i.e., ownership and use, surrounding land use and density, downgradient groundwater use, distance to shoreline, nitrate concentrations and flux, topography, site conditions, access, and presumed dimensions) but may include a hybrid all three of these approaches. The use of PRBs can minimize the costs of sewering and upgrading private systems, while providing an unobtrusive passive approach for 5+ years.

IV. Permeable Reactive Barriers (PRBs)

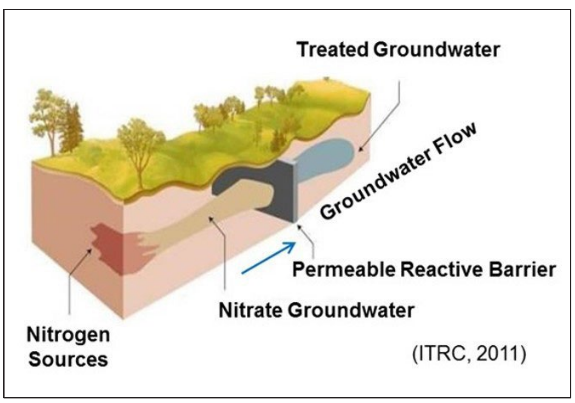


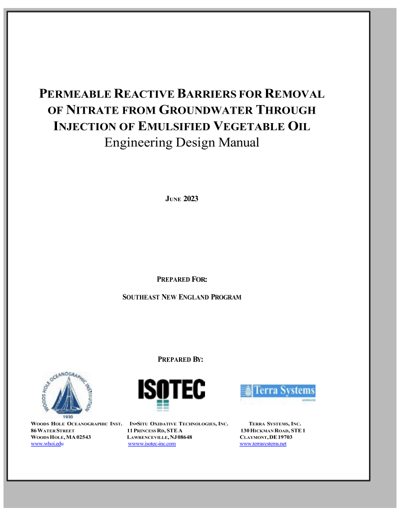
Figure 4 PRB Schematic - Intercepting and Treating Nitrate

PRBs provide a passive treatment approach for in-situ (in place in the ground) treatment of groundwater. The term "barrier" is not used in the traditional sense, PRBs intercept and treat the groundwater before the groundwater reaches a sensitive receptor. PRBs thusly provide a treatment zone between the nitrate source(s) and the discharge location (e.g., the river, pond, embayment, estuary, or ocean). This treatment zone consists of an area of organic substrate placed in the soil. Organic substrates can be mulch, sawdust, or other wood products, or emulsified vegetable oil (EVO). As groundwater flows through the reactive area, natural biodegradation converts nitrate to nitrogen, effectively removing the nitrate from groundwater before it is released into the water. PRBs are ideally oriented perpendicular to the direction of groundwater flow and rely solely on the natural groundwater gradient to carry the contaminant(s) through the PRB. Because the reactive area remains permeable, the PRB does not interfere with or redirect groundwater flow.

PRBs are widely used for the treatment of a wide range of chemicals in groundwater, including chlorinated solvents, petroleum hydrocarbons, metals, and nitrogen compounds. The earliest groundwater treatment PRBs were installed in the early 1990s, and PRBs have been utilized at hundreds of sites over the past three decades. (ITRC, 2011; ITRC, 2005, USEPA et al, 1998).

V. Costs

Figure 5 Geoprobe injection of Demonstration PRB on Cape Cod



PERMEABLE REACTIVE BARRIERS FOR REMOVAL OF NITRATE FROM GROUNDWATER THROUGH INJECTION OF EMULSIFIED VEGETABLE OIL
Engineering Design Manual

JUNE 2023

PREPARED FOR:

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The Cape Cod Commissions' Technologies Matrix contained estimates of PRBs by trench and injection methods based upon the Barnstable County Cost Report (BCCR) updated in 2014 by AECOM (AECOM 2014).

Terra Systems, Inc., and In-Situ Oxidative Technologies, Inc. (ISOTEC) prepared an Engineering Design Manual as part of U.S. Environmental Protection Agency (USEPA) Southeast New England Program (SNEP) Watershed Grant. SNEPWG19-12-WHOI. The Woods Hole Oceanographic Institution (WHOI) is the lead organization on the grant. Partner Organizations include the Town of Falmouth and its Water Quality Management Committee and the Cape Cod Commission with contributions from ISOTEC, Terra Systems, Inc., and Science Wares, Inc. This document, *"Permeable Reactive Barriers For Removal Of Nitrate From Groundwater Through the Injection Of Emulsified Vegetable Oil,"* is intended to assist coastal communities in Southeast New England and beyond in design for reduction of groundwater nitrogen transport to surface waters.

The objectives of this design manual are to assist communities to cost effectively consider, plan, design, implement, and monitor denitrification PRBs to address nitrogen in groundwater. At full-scale, future installation may entail combined lengths of hundreds to thousands of linear feet of PRBs in municipalities on Cape Cod, Long Island, and other coastal areas as well as in agricultural areas where fertilizer use has resulted in elevated concentrations of nitrogen species to groundwater. This manual was developed with focus on engineering design of denitrification PRBs through injection of carbon substrate electron donor. The manual recognizes that PRBs may not be the solution for all locations; biological PRBs are one key tool in the "nitrate reduction toolbox." The use of this tool will depend on several variables which are described in this manual. To support this engineering design manual, the *"Emulsified Vegetable Oil Loading Calculator for Denitrification Permeable Reactive Barriers"* was developed. The calculator allows input of a variety of Site parameters and developed design information and estimated costs for further consideration of a PRB Option.

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APPENDIX A Permeable Reactive Barriers (208 Plan, Cape Cod Area Wide Water Quality Management Plan Update (Cape Cod Commission, 2015).

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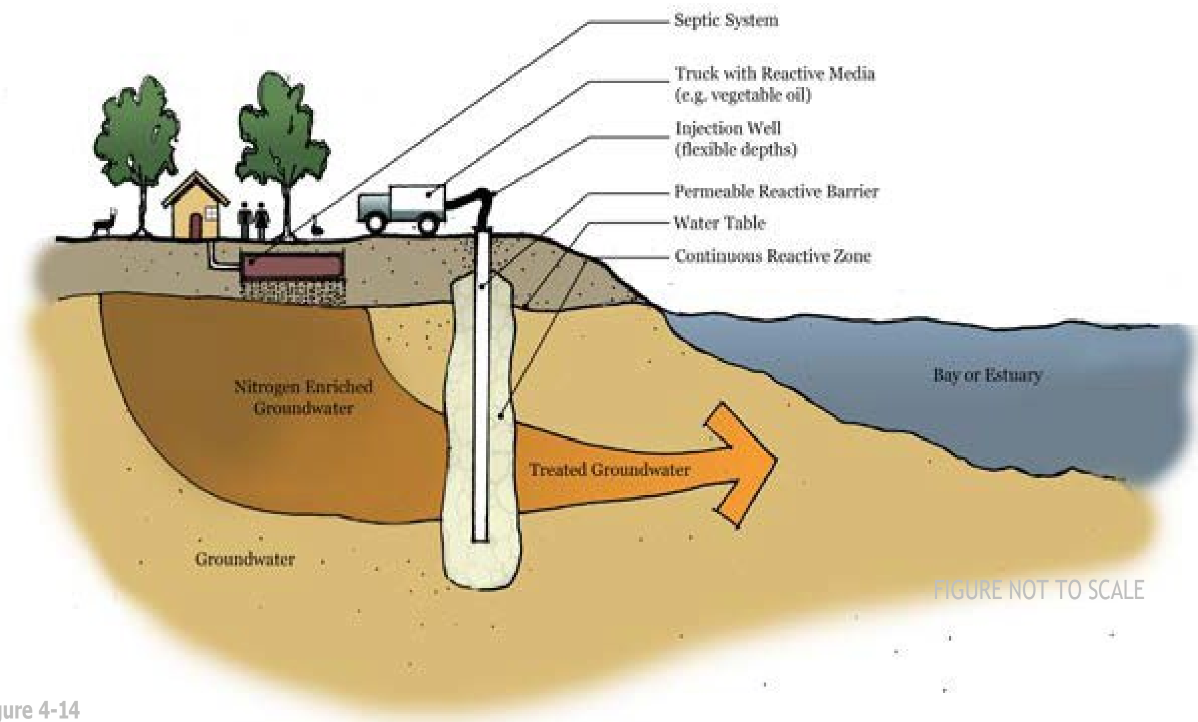

Figure 4-14

Permeable Reactive Barriers (PRBs) Injection Well Method

PRB

SCALE: SITE/NEIGHBORHOOD
APPROACH: REMEDIATION

SCENARIO PLANNING: SELECTED FOR USE
IDENTIFIED FOR PILOTING

DESCRIPTION

A permeable reactive barrier (PRB) is an in-situ (installed within the aquifer) treatment zone designed to intercept nitrogen enriched groundwater. Through use of a carbon source, microbes in the groundwater uptake the nitrogen, denitrifying the groundwater. An injection Well PRB system typically uses a series of injection wells to introduce the carbon source (medium) into the groundwater.The injection wells can be installed to depth greater than the PRB trench method. The injection well PRB method can be used in combination with the PRB trenching method described previously. As groundwater flows through the medium, microbes naturally occurring in the groundwater consume the carbon source, as well as oxygen, developing an anaerobic environment. This process releases nitrogen gas to the atmosphere, reducing the groundwater nitrogen load before reaching the estuary.

Technology Performance

Nitrogen Removal 75% to 95%

Phosphorus Removal 50% to 95%

$279	$1,310
Removal Cost per kg N (avg life cycle)	Removal Cost per kg P (avg life cycle)
20 years	1 to 10 years
Useful Life	Time to See Resul