Permeable Reactive Barriers

A Non-Traditional Technology to Reduce Nitrogen Flux and Meet Estuary Nitrogen TMDLs

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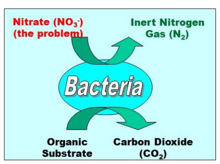
Introduction

- Nitrogen-enriched groundwaters entering coastal waters negatively impact water quality and ecology of these water bodies due to eutrophication, which can result in fish kills, native eelgrass being replaced by macroalgae, unpleasant odors, and accumulation of anoxic sediments.
- Excessive nitrogen discharge from groundwater to surface water has a significant financial impact in Southern New England and other coastal communities due to losses in commercial fishing, property values, and tourism revenue streams.
- ~85% wastewater is discharged to septic systems on Cape Cod, MA, and as a result nitrate-laden groundwater travels as plumes without significant attenuation into coastal waters.
- USEPA announced in 2013 a new collective framework for implementing the Clean Water Act (CWA) Section 303(d) program with states to implement a water-quality based approach to the CWA.
- The cost to bring Cape Cod communities in compliance through traditional wastewater treatment and sewering is estimated to be $4.6 to $6.2 billion.
- To reduce the overall cost, the Cape Cod 208 Water Quality Management Plan would implement non-traditional technologies to reduce nitrate flux to coastal waters in addition to traditional wastewater treatment.
- Denitrification permeable reactive barriers (PRBs) are one of the primary non-traditional technologies.
  - Future installation of PRBs with combined lengths of hundreds to thousands of linear feet are being considered in Cape Cod towns.

Denitrification PRB

- Denitrification is a process where bacteria use nitrate as terminal electron acceptor and convert nitrate to inert nitrogen gas

$$NO_3^- \rightarrow NO_2^- \rightarrow NO + N_2O \rightarrow N_{2\,(g)}$$



- Denitrifying bacteria are ubiquitous in soils
- PRBs are a passive, in-situ treatment approach by intercepting groundwater before reaching a sensitive receptor (e.g., surface water)
- A denitrification PRB is designed to enhance activity of naturally occurring anaerobic denitrifying bacteria
  - Introduce carbon substrate
  - Aerobic microbes respire to create anoxic conditions
  - Denitrifying bacteria consume nitrate

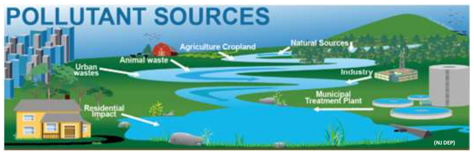
What are TMDLs?

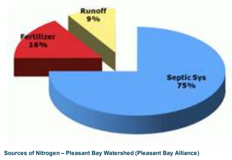
TMDLs = Total Maximum Daily Load

- The USEPA 2013 method advances impaired waters through development of TMDLs.
- TMDLs are calculated values of the mass of a pollutant that a water body can accept.
- Being a mass load-based standard, a specific concentration target does not need to be met to achieve water quality restoration goals.

$$TMDL = \Sigma\,(WLA, LA, MOS)$$

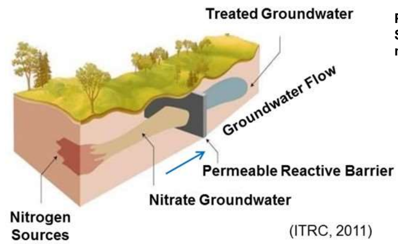
- WLA (waste load allocations) include point sources
- LA (load allocations) include nonpoint sources and background
- MOS (margin of safety)

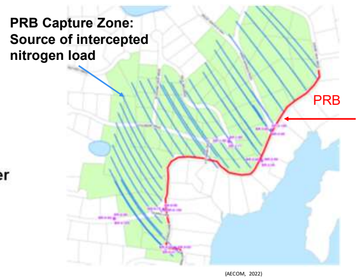




Sources of Nitrogen – Pleasant Bay Watershed (Pleasant Bay Alliance)

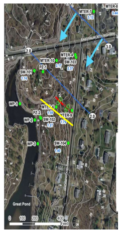
- **Mass load reduction is the treatment objective**
  - PRB does not need to meet a target concentration
  - PRB(s) can be located to only treat the portion of the WLA or LA with highest nitrogen flux





PRB Challenges on Cape Cod

- Permeable sandy subsurface soils with fast groundwater flow (0.3-2 feet per day)
- Depth to groundwater: 20-75+ feet bgs
- High fluxes of oxygen and nitrate (20-40+ mg/L)
- Highly developed region
- Public concern of migration of oil and impacts to surface water
- Persistence/rejuvenation frequency

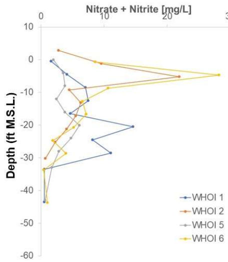


PRB Design

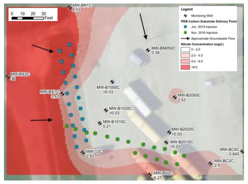
- An engineering design manual and spreadsheet tool for denitrification PRBs was prepared with support of a SNEP Watershed Grant to assist communities to cost effectively consider, plan, design, implement, and monitor denitrification PRBs.

PRB Best Design Practices

- Locate PRB based on nitrate flux
- Geology and hydrogeology need to be understood both laterally and vertically
- Identifying groundwater flow direction is critical
  - Groundwater flow direction can vary seasonally
  - Install adequate wells for determining flow direction
  - Orient PRBs perpendicular to flow direction
- Estimate seepage velocity at the PRB
  - Need to quantify site-specific hydraulic conductivity & gradient
  - Hydraulic conductivity can vary vertically & spatially across PRB
- Identify vertical zones of higher nitrogen flux



- Record water quality parameters
  - pH
  - Dissolved oxygen
  - Terminal electron acceptors
- Pilot Testing is Valuable
  - Injection flow & pressure
  - Reagent distribution
  - Injection methods & tools
  - Secondary groundwater impacts (metals, pH)
  - Identify clear pilot test objectives
- PRB width should allow a residence time of 7 to 14 days to ensure contact with nitrate and oxygen
- Injection volume should be a minimum of 15% of pore volume



- EVO dosage needs to consider nitrate concentrations, terminal electron acceptors, and hydrogeology
- Establish monitoring program to assess performance
  - Monitoring wells within and downgradient of PRB.
  - Collect baseline water quality parameter data (pre-injection) to support design and for post-injection evaluation
- PRBs demonstrated to remove nitrate for 5 to 10+ years