Permeable Reactive Barriers: A Non-Traditional Technology to Reduce Nitrogen Flux and Meet Estuary Nitrogen TMDLs

Paul M. Dombrowski, P.E. (pdombrowski@isotec-inc.com); Fritz Hostrop, Michael Lee, Ph.D., and Richard Raymond, Jr. (Terra Systems, Inc. Claymont, DE);
James Begley (MT Environmental Restoration, Plymouth, MA); Thomas Parece, P.E., Julianne Marrion, P.E., and Betsy Shreve, AICP (AECOM, Chelmsford, MA)

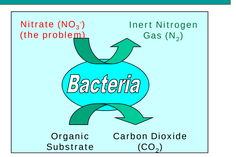
Introduction

- ~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 eventual overall cost, the Cape Cod 208 Water Quality Management Plan would implement traditional wastewater treatment in combination with non-traditional technologies for reducing nitrate mass flux to coastal waters.
- 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 numerous Cape Cod municipalities

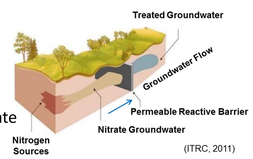
Denitrification PRB

- 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)
- PRBs are oriented perpendicular to the direction of groundwater flow.
- 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



(ITRC, 2011)

What are TMDLs?

- This approach advances impaired waters through development of total maximum daily load (TMDLs)
- TMDLs represent a mass load based standard to achieve water quality restoration goals versus a target concentration standard.

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

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

- Denitrification PRB do not need to meet a target concentration and can be located to only treat the portion of the WLA or LA having the highest nitrogen load or flux

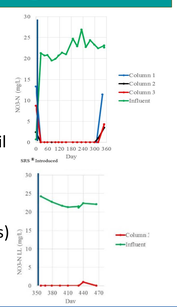
PRB Challenges on Cape Cod

- Permeable sandy subsurface soils with fast groundwater flow (1-3 feet per day)
- Depth to groundwater: 35-75+ 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

FIGURE 1. Orleans on Cape Cod

TerraSystems Bench Scale Testing

- Column reactors to evaluate Emulsified Vegetable Oil (EVO) for effectiveness, persistence, and migration
  - Flow rate = 1.2 feet/day
  - 2 dosages of SRS®-SD and SRS®-SD+ZVI
- Complete removal of 20-26 mg/L nitrate over 310 days (87-92 pore volumes)
- TerraSystems created a modified EVO formulation (SRS®-NR) to be stickier to soil with larger EVO droplet (5 micron), an anionic surfactant, and without lactate
- On Day 355 all 3 columns connected together (11.4') and fed SRS®-NR
- Sustained nitrate removal at 2.9 mg/L TOC in effluent (compared with nitra break through when TOC decreased to less than 4 mg/L in SRS®-SD column tests)
- SRS®-NR formulation retained on soil matrix better than SRS®-SD and emulsion did not appear in effluent



Field Demonstration

Initial Injection – November 2016

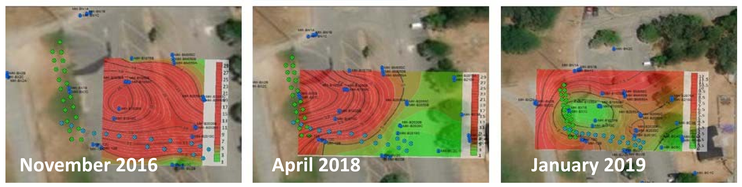
- 110 foot PRB
- 17 Injection Points with 10-foot spacing
- Oriented with 1 and 2 rows
- 36 to 68 feet bgs
- 10,800 gallons injected (14% pore volume)
- SRS®-NR (diluted 4.3:1) + Sodium Bicarbonate
- Monitoring well network upgradient and 10-75 feet downgradient of PRB

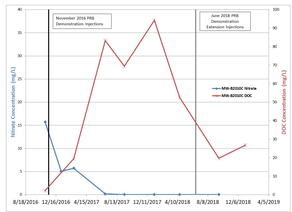
PRB Extension – June 2018

- Extend PRB by 100 feet
- 20 Injection Points with 10-foot spacing
- Oriented with 2 rows
- 32 to 70 feet bgs
- 14,800 gallons injected (14% pore volume)
- SRS®-NR (diluted 4.3:1) + Sodium Lactate + Sodium Bicarbonate

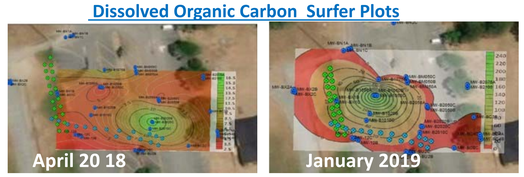
Demonstration Test Results

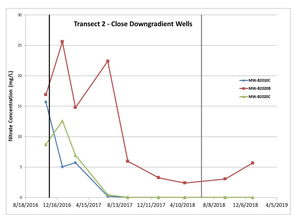
Nitrate Surfer Plots





Dissolved Organic Carbon Surfer Plots





- More than 2 years of quarterly monitoring to date
- Dissolved organic carbon (DOC) and nitrate changes used to estimate horizontal groundwater flow (~0.22 feet per day)
- Nitrate concentrations of 10-25 mg/L nitrate, estimate nitrogen flux reduction estimated to be **0.6 kg N/ft-yr**