Micro-Siting and Nitrogen Removal Efficacy of Liquid Injection Permeable Reactive Barriers (PRBs) in Residential Watersheds of S.E. MA

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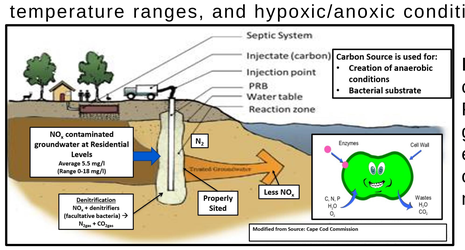
Introduction

As development of coastal watersheds increases, nutrient loads to groundwater and particularly nitrogen (NO_3^-, NO_2^-, and NH_4) have also increased significantly. In addition to the known health impacts that nitrogen (as nitrate) can have on people through drinking water, nitrogen enrichment of coastal waters results in system-wide decline in water and habitat quality. At present, the estuaries of S.E. Massachusetts are experiencing negative impacts from watershed nitrogen inputs resulting in eutrophication and declines in aquatic resources. As a result of wide-spread estuarine nitrogen enrichment, a variety of techniques are being explored by towns throughout S.E. Massachusetts to mitigate watershed nitrogen inputs to their estuaries. One of the technologies seeing increasing interest due to its moderate cost, ease of installation, and low impact to the environment is installation of liquid injection permeable reactive barriers (PRBs). PRBs, which have been in use for point-source pollution since the 1990s, provide passive treatment to remove a variety of groundwater transported constituents. To address nitrogen pollution, utilize a denitrification pathway to reduce nitrate to inert nitrogen gas.

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

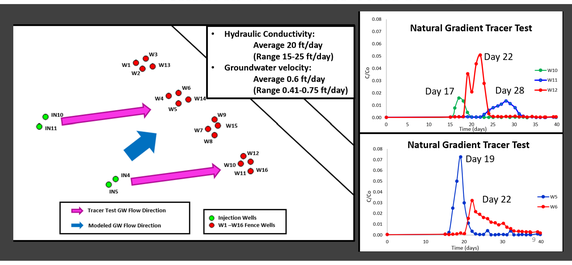
Denitrification is a microbial process where anerobic bacteria, which are abundant in aquatic environments, utilize nitrate as an electron acceptor as part of their respiration. However, these bacteria are active only under specific environmental conditions; they require a labile carbon source, suitable pH and temperature ranges, and hypoxic/anoxic conditions.



In addition to specific microbial conditions, the placement of the PRB to provide maximum groundwater treatment is essential and must be evaluated on a site-by-site basis through micro-siting.

Pilot Site

Natural Gradient Tracer Test



Siting and Installation Methods

To determine the best placement for the PRB, an initial investigation and site visit were conducted to determine:

- Ease of access to the site
- The distance to downgradient water bodies
- Local and regional land use, geology, and hydrology

After the initial assessment, an in-depth investigation was conducted to verify:

- The depth to groundwater table
- The concentration and distribution of nitrate and other oxidation-reduction sensitive constituents
- The thickness and depth of the treatment zone
- Modeled groundwater flow direction
- The heterogeneity of the aquifer

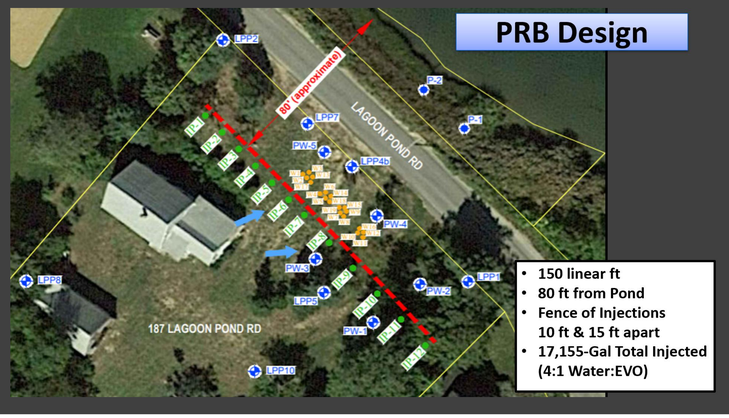
Then, a natural gradient tracer test was performed to confirm:

- The groundwater flow direction and velocity
- The hydraulic conductivity
- The total nitrogen load to the PRB

Finally, the PRB was installed:

- An emulsified vegetable oil (EVO) mixed with water was injected under pressure

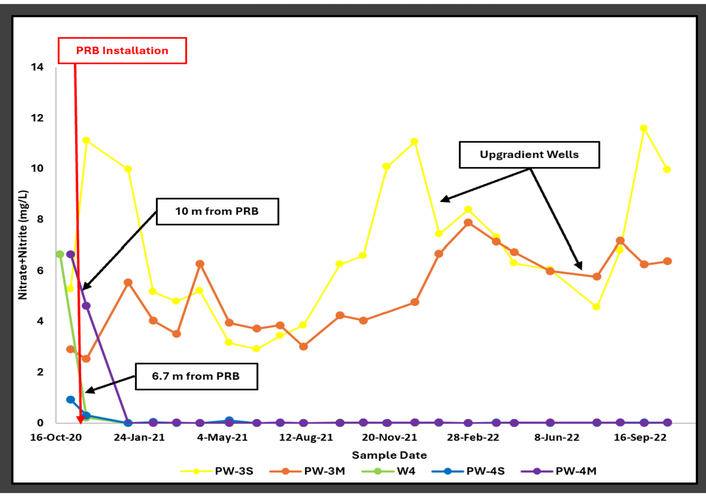
PRB Installation Location



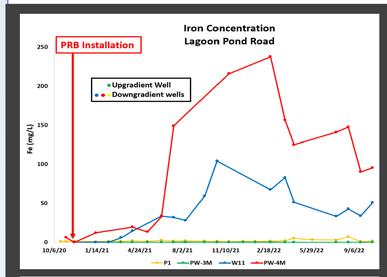
Results

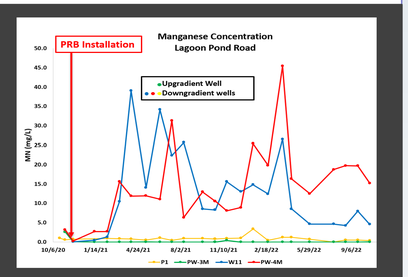
- Depth to groundwater is shallow (0.5 – 2.5 m below ground surface)
- Soils are coarse to fine with some silty/clay
- Nitrate is the dominant form of nitrogen and shows vertical gradients
- Nitrogen levels correspond with average residential impact
  - › Nitrate/Nitrite: Average 5.5 mg/l (Range 0-18 mg/l)
- Groundwater is fresh at the Site, salinities <0.2 PSU
- High nitrate levels found in oxygenated groundwater
- Tracer test indicates groundwater flow is towards Lagoon Pond and perpendicular to the installed PRB location
- Hydraulic Conductivity: 20 ft/day (15-25 ft/day)
- Groundwater velocity: average 0.6 ft/day (0.41 - 0.75 ft/day)
- Downgradient of the PRB nitrate is reduced by 98.6% or 1-2 kg N removed / linear m of PRB per year.
- Elevated levels of arsenic, iron, and manganese were observed on-site after the installation; however, none were above background levels at the edge of Lagoon Pond.
- Based on preliminary biodegradation rate experiments the amount of EVO may affect the degradation rates.

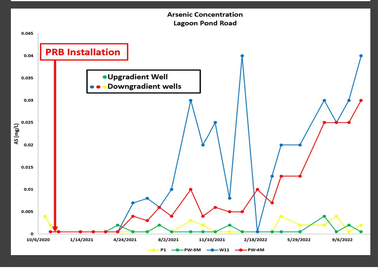
Nitrate Concentrations



Secondary Reactions

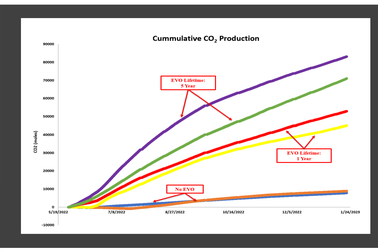






Secondary reactions (such as the mobilization of arsenic, ferrous iron, and manganese) that occur under reducing conditions created by the PRB were monitored to evaluate their impact to groundwater and receiving water bodies.

EVO Biodegradation Rate



Future work will include experiments to determine the minimum lifespan of the EVO under accelerated (30ºC) anerobic conditions by measuring the net carbon production:

$$(C\text{-}CO_2 + C\text{-}CH_4).$$

Acknowledgements

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