

**Project name:**  
Mill Pond Study**Project ref:**  
60550782.21.4**From:**  
Tim Harrison**Date:**  
September 22, 2025 (Rev. January 16, 2026)**To:**  
George Meservey, Town of Orleans**CC:**

# Memo

**Subject:** Orleans Nitrogen Management in Mill Pond Sub-Watershed: Permeable Reactive Barriers

The Town of Orleans (Town of Orleans) has identified ten options for reduction in nitrogen load in the Mill Pond sub-watershed to improve water quality in this sub-watershed.

This memorandum addresses the option to implement permeable reactive barriers (PRBs) to reduce groundwater nitrogen load.

## Description and PRB Evaluation

This option involves the installation of one or more PRBs within the Mill Pond sub-watershed of the Nauset Pond Watershed. A PRB as proposed consists of a series of injection points along with monitoring wells placed both upgradient and downgradient of injection points. These wells allow for tracking changes in groundwater quality and are installed at select locations to monitor water quality and the effectiveness of the PRB.

PRBs work best when installed perpendicular to the direction of groundwater (GW) flow. They are often placed beneath roadways which makes installation easier and avoids impacts to private property.

Different media types are available to create a PRB. For Orleans, an emulsified vegetable oil (EVO) has been proposed for its ability to be injected below the water table. The EVO serves as a food source for bacteria that are naturally occurring in the aquifer. With food/carbon limitations removed, the bacteria can reduce additional nitrogen, especially under anoxic (non-oxygen) conditions created by the EVO and bacteria. The EVO needs to be replenished periodically as it is consumed. This is accomplished by reinjecting EVO in the same area as the initial installation.

For this study four potential PRB locations were identified as shown in Figure 1 below. These locations were based on estimated groundwater flow direction and the locations of existing septic systems. Figure 1 also shows the USGS subwatershed boundary (white line) for Mill Pond sub-watershed; the inset highlights the extent of the Mill Pond Subwatershed.

These four locations were evaluated utilizing the Town's three-dimensional groundwater flow model established for previous studies. The model is based on an existing USGS grid model (USGS, 2006) but has been refined to a 100' x 100' horizontal grid as opposed to the original 400' x 400' grid. AECOM estimated groundwater elevations and flow directions using the groundwater model and surface elevations using data provided in the Town GIS.

Figure 2 shows steady state water table and groundwater flow conditions within the Mill Pond Study area, specifically Mill Pond to the Mill Race. The purple lines outline the subwatershed area that would benefit Mill Pond, while the blue lines indicate groundwater flow within that area. Based on this analysis:

- The Mill Pond Study subwatershed is a subset of the USGS Mill Pond Subwatershed;
- The Blue Rock/High Ridge PRB initially identified does not benefit the Study area and is therefore excluded from the remainder of the analysis;
- The Brick Hill PRB length is reduced to the limit of the Mill Pond Study subwatershed;
- The Deer Run PRB length is reduced to the limit of the Mill Pond Study subwatershed; and
- The Deer Run PRB length is reduced to eliminate the portion of the initial definition of the PRB that is parallel to groundwater flow.

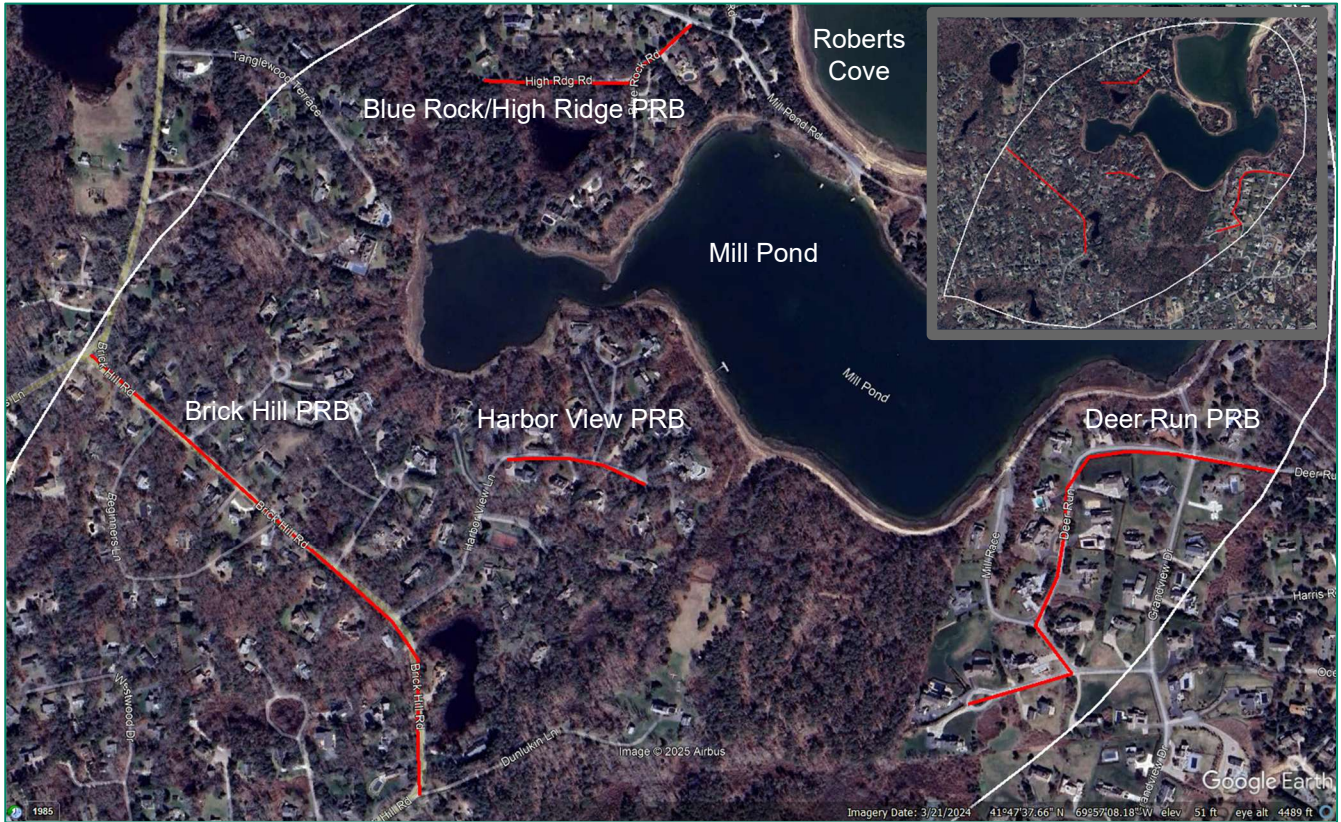


Figure 1: Initial PRB Locations and Extents

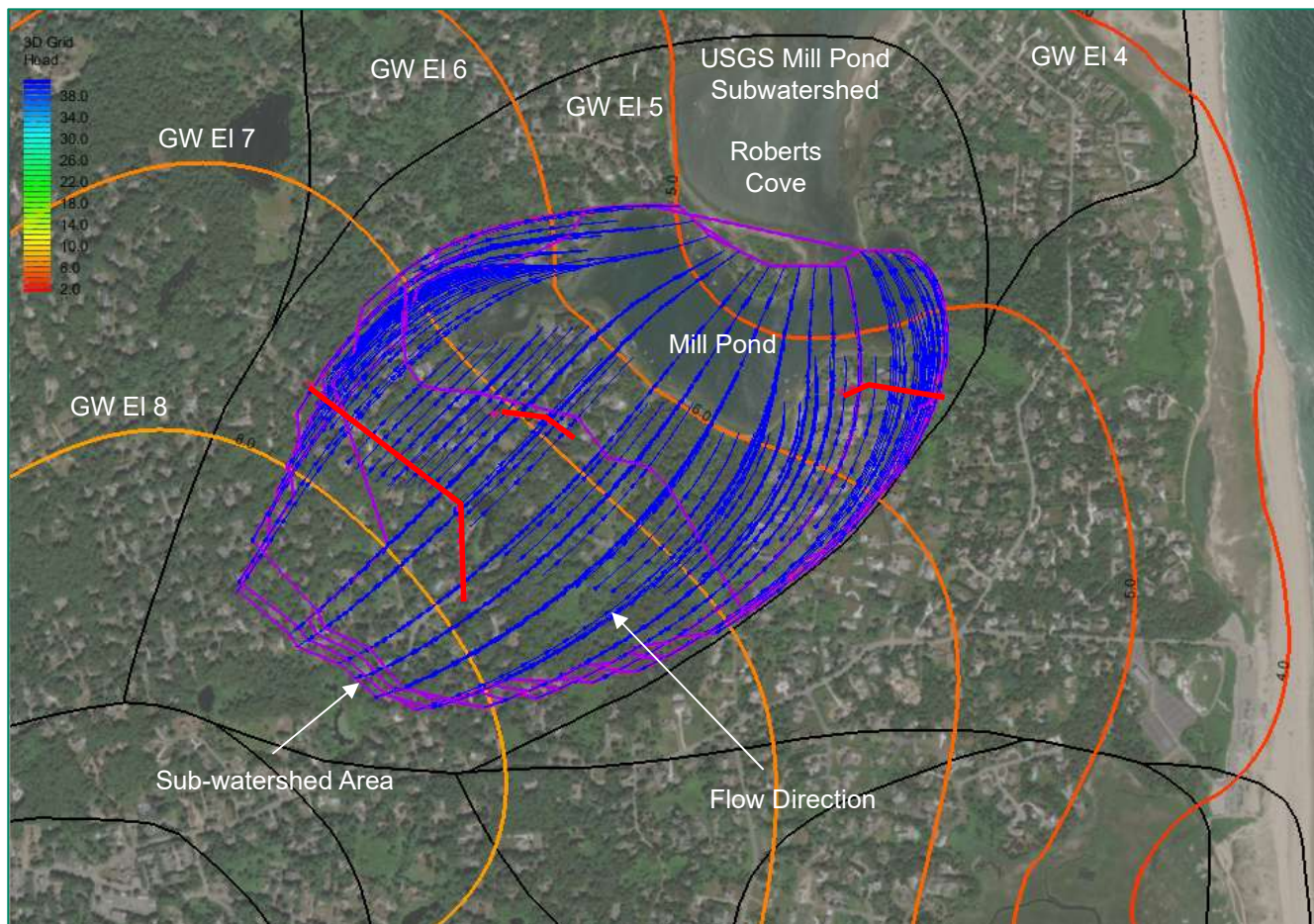


Figure 2: Mill Pond Study Area Watershed and PRBs

## Ownership and Control

PRBs are anticipated to be owned, operated, and maintained by the Town. The injection wells and monitoring wells, depending on location of the PRB, may be located within town-owned roads, within easements, or on private property. If placed on private property, an easement for construction, operation, and maintenance would be required.

## Performance

PRBs are a proven nitrogen removal alternative. For permitting and to be most effective, they require a hydrogeologic study to understand local groundwater quality, flow direction, and soil conditions. The Town established an EVO PRB pilot program in 2016 that has confirmed the importance of this type of study. The pilot program has demonstrated the effectiveness and potential long-term benefits of PRBs.

AECOM estimated the nitrogen load reduction to the Mill Pond Study Area Watershed. For this analysis, it is assumed that each PRB can remove approximately 80% of the total groundwater nitrogen load passing through the PRB. The Massachusetts Estuaries Project (MEP) Nauset Harbor Study (2012) assumed a total nitrogen loading rate of 6.6 kilograms per year per parcel (kg/yr/parcel). The effective reduction rate is therefore assumed to be 5.3 kg/yr/parcel. This approach provides a reasonable estimate of long-term PRB performance. The need for replenishment will be determined through routine monitoring of nitrogen concentrations in wells located upstream and downstream of each PRB.

The total nitrogen removed is calculated using the number of properties within each PRB's model estimated "capture area." The size of the capture area is largely dependent on the length and depth of the PRB. A PRB that extends deeper into the groundwater is more likely to capture nitrogen from properties further upgradient of the PRB. While this depth is a factor that can be modified during system design, for purposes of this Study it is assumed that each of the three PRBs extends approximately forty feet below the water table.

Figure 3 shows the capture area of the PRBs based on these assumptions using the Town's model. Table 1 summarizes the PRB dimensions, the approximate number of properties within the capture areas of each PRB and the corresponding estimates of nitrogen removal. This number of properties is an estimate as the capture area is sensitive to groundwater flow direction, septic system location, and other site specific information that would be gathered and refined as part of the hydrogeologic investigation and design process.

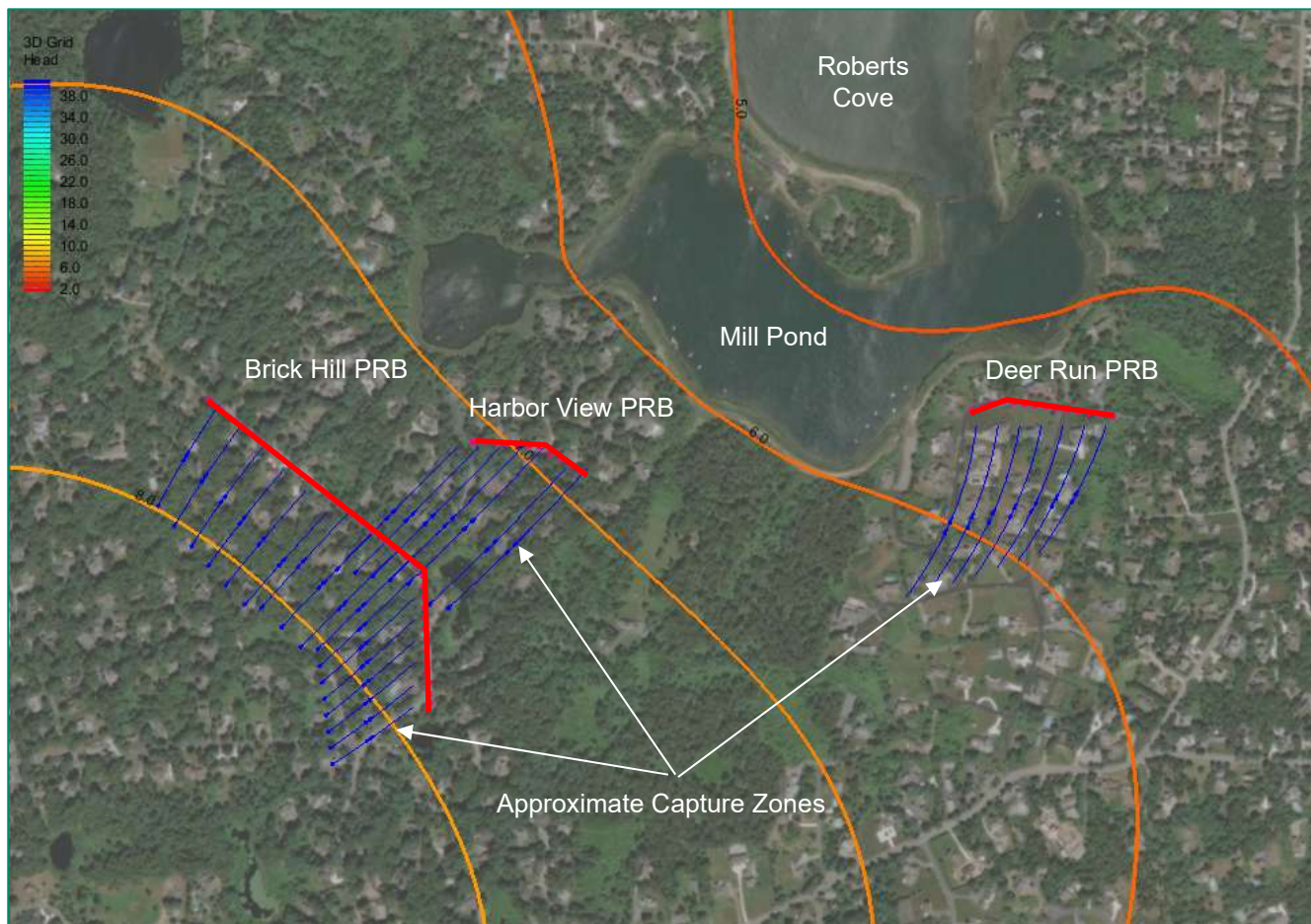


Figure 3: PRB Capture Areas

Table 1. PRB Dimensions and Performance

PRB Location	Length (ft)	Groundwater Elevation	Surface Elevation	PRB Depth	Approx. Parcels within Capture Area	Nitrogen Removal (kg/yr)
Deer Run	650	5-6	30-45	65-80	14	74
Harbor View	600	7	60-70	90-100	8	42
Brick Hill	1,900	7-8	45-60	80-95	32	170

The target nitrogen reduction goal established for comparison purposes for this Study is 750 kg/yr. The Deer Run, Harbor View, and Brick Hill PRBs would achieve approximately 10%, 6%, and 23% of that goal, respectively. This suggests that PRBs can make a meaningful contribution, but are unlikely to be a stand-alone solution and would need to be combined with other nitrogen-reduction strategies to achieve the overall water quality goals.

For comparison:

- The Lonnie's Pond aquaculture project currently takes 67 kg/yr of credit which is comparable to the Deer Run PRB; and
- Since the PRB nitrogen removal rate (5.3 kg/yr/parcel) is close to the traditional sewer removal rate (5.4 kg/yr/parcel), an equivalent number of properties would need to be sewered to achieve the same benefit as identified in Table 1.

## Costs

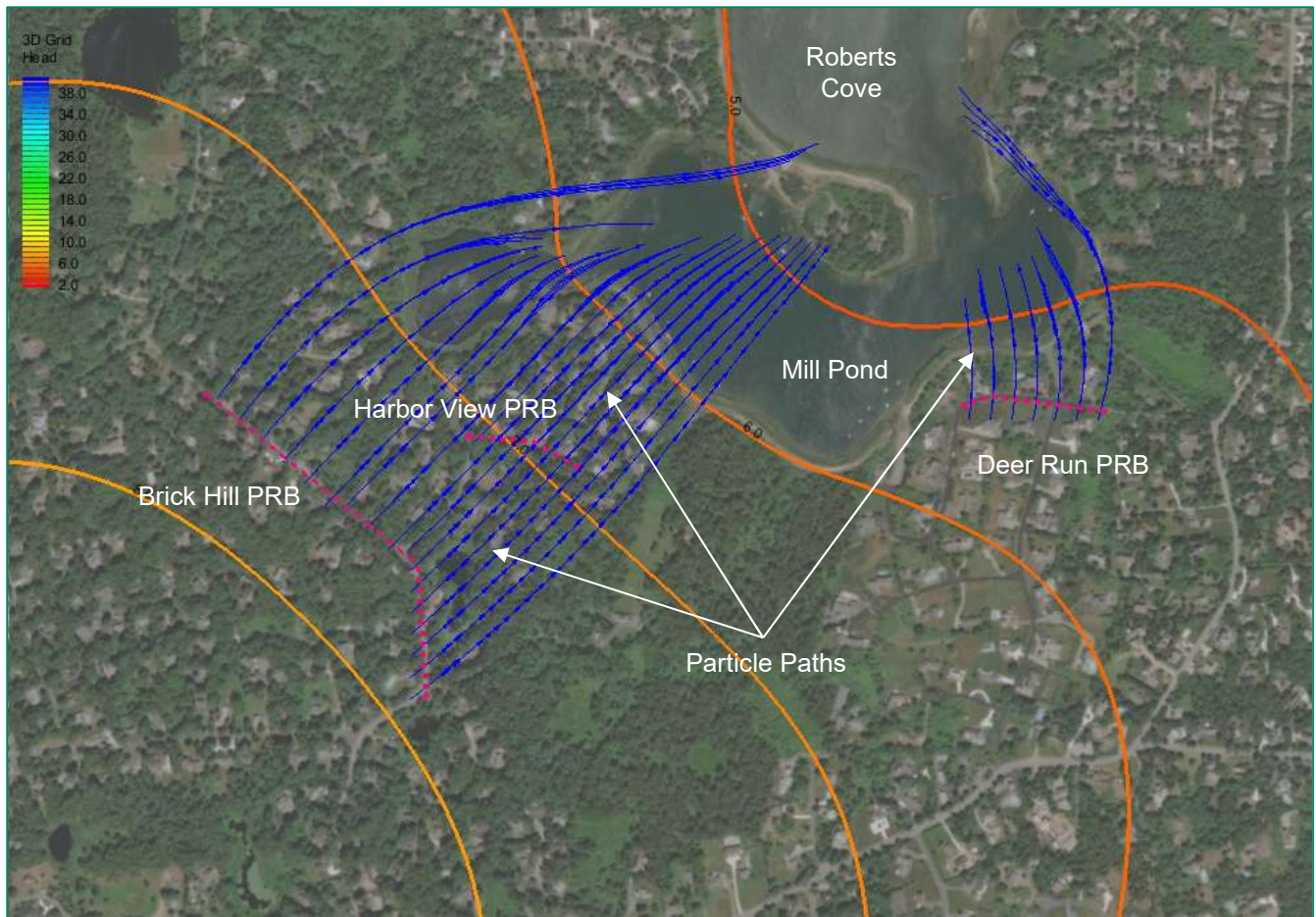
Prior PRB evaluations by the Town have shown that initial costs of PRBs are lower than equivalent sewerage but in some cases the ongoing O&M costs could flip the lifecycle cost comparisons to favor sewerage. It is important to keep in mind that the Harbor View and Brick Hill PRBs, as currently envisioned, are relatively deep PRBs and may incur higher construction costs.

## Speed in Water Quality Improvement

One of the benefits of PRBs over traditional sewerage can be the more rapid water quality benefit to the embayment. The timeframe for water quality improvement can be shorter if the PRB is located closer to the embayment than the sewered parcels.

The embayment water quality improvement timeframe for PRBs was estimated using the Town's groundwater model. The model accounts for both the horizontal and vertical groundwater flow. The model simulated groundwater flow direction and travel time between the PRBs and the Mill Pond embayment.

Figure 4 shows the horizontal direction of groundwater flow using particle traces. Table 2 summarizes the range of travel times and representative time to benefit for each of the three PRBs.



**Figure 4: PRB Treated Water Horizontal Travel Paths**

**Table 2. PRB Travel Times**

PRB Location	Approximate Travel Time to Mill Pond (yrs)	Representative Time to Benefit (yrs)
Deer Run	1-20	5
Harbor View	3-6	<5
Brick Hill	2-25	10-15

## Predictability of Performance

Once the PRB is established the nitrogen removal is relatively predictable on a year-to-year basis. Performance over time can be monitored to estimate total nitrogen removed and determine EVO reinjection frequency.

This is a non-traditional technology and will require a traditional backup such as sewers, similar to how the Town is applying the aquaculture at Lonnie’s Pond. A backup approach for nitrogen removal is only required once nitrogen removal is regulated and credits are sought.

## Reliability

PRBs are reliable once established. There are no moving, mechanical, or electrical components. As noted above, regular monitoring for nitrogen removal is required for documentation of nitrogen removal efficacy and planning for EVO reinjection.

## Need for Large Town Capital Expenditure

Orleans has committed to remove a significant amount of nitrogen in the Pleasant Bay watershed under the 2018 Watershed Permit. The costs of that commitment means that the Town may have limited ability to undertake nitrogen removal projects in other watersheds, such as the Nauset Harbor system. In certain locations, PRBs are less expensive to install than traditional sewerage and treatment. There is the potential that the Town could budget a nitrate reduction project(s) such as PRBs within the Mill Pond Study subwatershed, however this will depend on estimated costs, Town Meeting approval, debt capacity, and other competing Town capital needs.

## Regulatory Acceptability

Massachusetts Department of Environmental Protection (Mass DEP) has signaled that nitrogen removal credit through PRBs is likely. Mass DEP continues to engage in multiple PRB pilot projects, including in Falmouth. Additionally, PRBs were described in the Town's Amended Comprehensive Wastewater Management Plan (ACWMP, 2024) as a potential nitrogen control measure as well as in the Pleasant Bay Watershed Permit and related documents, all of which were reviewed and approved by DEP. The Town also previously submitted a Project Evaluation Form (PEF) for State Revolving Funding (SRF) program for PRBs and the PEF was included in the 2022 Intended Use Plans (IUP), further indicating Mass DEP's support for PRBs. The Town withdrew the PEF prior to advancing to the application phase of the SRF program. Parameters for a demonstration project and confirmation of the monitoring and reporting requirements around PRBs should be confirmed with Mass DEP.

## Public Acceptability

The Town, to our knowledge, has not received negative feedback around PRBs. As noted above, locating wells on private roads or property would require the Town to go through an easement process. Doing so may trigger additional feedback on PRB acceptability.

## Flexibility in Face of Unknown TMDL and Applicability to a Phased Approach

PRBs can be paired with other nitrogen reduction projects but this requires planning to do so. The capture area for the PRB is upgradient from the physical location of the PRB. If projects are implemented within the PRB capture area that remove septic or other nitrogen load sources then that nitrogen is not removed by the PRB, thus reducing the cost effectiveness of the PRB and reducing the nitrogen available to the microbes.

As noted above, PRBs are unlikely to exceed any removal requirements set by a future, unknown Total Maximum Daily Load (TMDL). Should PRBs be implemented ahead of establishment of a TMDL then future nitrogen reduction projects could potentially be scaled smaller than without the PRBs in place.

## Environmental Impacts

Construction impacts are relatively minor compared to other alternatives such as sewerage that require significant excavation. Installation of PRBs is a safe operation where risks can be mitigated through barriers and readiness for spill response. Operational impacts are low as well as there are no power requirements and infrequent, minor use of vehicles for well monitoring.

While the Deer Run and Harbor View PRBs offer the advantage of producing benefits relatively quickly, their proximity to the water bodies may produce unintended consequences, such as iron and manganese precipitating at the edge of the water body. This is of particular concern for the Deer Run PRB, as it is only about 250 feet from Mill Pond. Additional study will help to characterize the impacts, the likelihood of those impacts, and potential mitigation options.

## Impact on the Orleans WWTF

The existing Orleans wastewater treatment facility (WWTF) has a finite capacity to treat and dispose of municipal wastewater. It will need to be expanded to handle all of the wastewater that would be collected in the current sewer master plan. PRBs would reduce the volume of wastewater from this service area, helping to defer the expected large capital expense of WWTF expansion. This alternative may not ultimately reduce the future capacity of the WWTF and it would not impact the timing of the expansion.

## Ease of Implementation

Since the facility would be owned by the Town, no oversight, monitoring, or control of private facilities would be required. Town meeting appropriations would be needed for the feasibility study, design, and construction of PRBs. Easements for construction, operation, and maintenance would be required for any wells (injection or monitoring) located on private property or private roads.

## Summary of Advantages and Disadvantages

Permeable reactive barriers have these principal benefits:

- Passive nitrogen removal leading to low O&M costs;
- Avoidance of wastewater flow to the WWTF; and
- Relatively good ability to phase implementation with planning.

The principal drawbacks include:

- Would require a traditional contingency plan with nitrogen regulation; and
- Uncertainty about environmental impacts with close proximity to the water body.