WATERVISION LLC TECHNICAL MEMORANDUM

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Subject: Supplemental Sampling Summary Memorandum

Site Characterization for Design of Pilot-Scale Permeable Reactive Barriers for Nitrogen Reduction in Groundwater on Cape Cod - Supplemental Fieldwork at Prince Cove, Barnstable, Massachusetts

Date: May 11, 2017

Introduction and Purpose

The Prince Cove site located on Prince Avenue in Barnstable, MA was chosen as an initial site characterization (ISC) location as part of the Pilot Scale PRB Project under Contract #: EP-BPA-13-W-0001. After completing and reporting on the ISC work in Fall 2016 (WaterVision LLC, 2016), the Prince Cove site was chosen by the project team for additional site characterization, but not for a Full Hydrogeologic Assessment.

A WaterVision LLC summary memorandum (WaterVision LLC, 2016) describes the site work completed in 2016 and provides background on subsurface sediment characteristics, groundwater levels and gradients, groundwater velocity estimates, and site-wide water quality. The monitoring wells and sample locations for the site work are shown in Figure 1. In summary, the following characteristics that are relevant to this follow-up work were observed:

- Subsurface sediments encountered were medium to coarse sand underlain by fine to medium sands. A four-foot-thick layer of fine sand with silt and clay was also encountered at depth and appears to impact vertical flow.
- A significant thickness of organic fine to medium sand thought to be marsh deposits was encountered at shallow depth at PC-2.
- Depth to groundwater is 3 to 10 ft. below ground surface (bgs).

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- Vertical hydraulic gradients indicate upward flow potential to -30 ft. relative to mean sea level (msl) with variably upward and downward gradients between different pairs of deeper piezometers.
- Shallow groundwater likely discharges to the salt marsh and Prince Cove.
- Groundwater velocities are estimated at 1.5 to 4.5 ft./day.
- The highest nitrate-N concentration detected in a water table well was 2.5 mg-N/L at PC-6.
- Nitrate concentrations are greatest in the zone between -0 and -40 feet msl and drop off significantly below these elevations. In this zone concentrations of nitrate-N were detected between 1.4 and 2.3 mg-N/L.
- Low nitrate-N and reducing conditions were encountered below -40 ft. msl.
- Chloride follows a similar concentration profile to nitrate and is likely indicative of septic system and/or road salt influence.
- Nitrate concentrations are not as high near the water table than as at 10 to 40 feet below the water table, likely due to the introduction of uncontaminated rainfall recharge from the surface.
- At PC-2, marsh deposits were encountered in the subsurface and the concentration of nitrate-N at this well was 0.1 mg-N/L and evidence of reducing conditions (low DO and redox potential) are exhibited. These are similar to conditions in a wetland setting and support the potential for denitrification to occur.
- The unit mass flux estimated for Barnstable is 26.8 g/day/m using the greater horizontal hydraulic gradient of 0.011. Where estimated using the lower gradient of 0.003, the mass flux was calculated as 7.5 g/day/m.

The additional work proposed included:

- Installation of an upgradient well PC-5 to better define groundwater flow directions and horizontal groundwater flow gradients in the project area. This well was installed on town-owned land in the vicinity of existing well PC-7.
- Installation of the PCZ-1a to -1f well cluster (six wells) adjacent to PC-1 completed at various depths to define water quality changes and vertical flow characteristics near the Prince Cove Marina.
- Location and elevation survey of the new wells (completed by the Town of Barnstable Public Works Department).
- Collection of a round of water levels and water quality samples at all wells.
- Laboratory analysis of stable nitrogen isotopes at selected well locations to evaluate possible denitrification with depth and in areas of generally lower observed dissolved oxygen and nitrate near the Prince Cove marina. The locations sampled for this parameter included piezometers PCZ-13, PCZ-23,

PCZ-30, PCZ-35, PCZ-43, PCZ-50, located adjacent to PC-4, and wells PCZ-1a and PCZ-1b adjacent to well PC-1.

The completion of this work is intended to assist the town and a local watershed protection organization, the Three Bays Conservancy, with completion of a pilot PRB installation in this location.

Work Performed

Well Installation and Collection of Continuous Core Samples

Well installation and core sampling was completed on November 30 and December 1, 2016. Boring advancement and well installation was performed using a Geoprobe direct-push drilling rig operated by New England Geotech, Inc. of Jamestown, Rhode Island. The track-rig-mounted Model 7822dt was used for site work. Danna Truslow, PG of WaterVision LLC oversaw boring advancement, well installation, and core sampling.

Wells were installed at two locations as shown in Figure 1. Well PC-5 was installed on town-owned land near the top of an upland area adjacent to Prince Cove. The boring for the well was completed to a depth of 60 feet and a continuous sediment core was collected at five-foot intervals. Saturated sediments were encountered at approximately 36 feet below land surface. A two-inch PVC well was completed to a depth of 40 feet with a five-foot well screen at 35 to 40 feet below ground surface.

The well cluster adjacent to PC-1 included completion of six 2–inch-diameter PVC wells completed with one foot of screen. The sediment characteristics of the continuous core were used to determine the optimal depth of each well in the cluster. The boring was continued to 70 feet below ground surface and wells were completed to depths of 16, 23, 34, 41, 53, and 67 feet below ground surface. These wells were labeled as PCZ-1a (shallowest well) to -1f deepest well. This nomenclature is different than that used previously at the piezometer cluster near PC-4. The nested wells at that cluster are named PCZ-13 to PCZ-88, where the suffix indicates the depth of the screen below ground surface. We have retained that nomenclature for the individual wells in the cluster and PCZ-4 for the cluster as a whole.

Well completion details for these new wells are included in Table 1 and boring logs for these new wells are included in Appendix A along with the logs for the pre-existing wells completed for the ISC.

Well Elevation and Location Survey

In January 2017, the survey team from the Barnstable Department of Public Works (DPW) surveyed the location and elevation of the newly installed wells. The elevations are based on the NAVD 88 datum established by the DPW on nearby fire hydrants on Prince Avenue. The latitude, longitude and elevation data for the new wells were provided to WaterVision LLC for interpretation of the newly collected stratigraphic and water level data and completion of this supplemental report.

Water Level Measurement and Water Quality Sampling

Water level measurement and water quality sampling took place on December 14, 2016 and January 25, 2017. Selected wells were sampled in December as explained below and the remaining site wells were sampled in January. This fieldwork included:

1. Measuring water levels at all wells, piezometers, and well clusters,
2. Purging wells and piezometers/ well clusters,
3. Measuring field water quality parameters, and
4. Sampling each water table well, piezometers to a depth of 60 feet bgs, and the PCZ-1 well cluster for laboratory analysis for a range of parameters.

Danna Truslow and Sarah Large of WaterVision LLC completed all field measurements and sampling.

Calibration of field water quality meters was completed before sampling began. Field parameter values on each meter were also checked at the end of the day against parameter standards to gauge any drift during the day. A Yellow Springs Instrument (YSI) Model 556 Pro multi-parameter sonde was used for field parameter sampling.

Upon arrival at the site all wells and piezometers were opened and well caps removed to allow equilibration with the atmosphere. If dedicated tubing was present in the wells this was also removed to allow for measurement. Water levels were then measured to the nearest hundredth of a foot with a Solinst water level meter.

Well purging and sampling commenced after water level measurement was complete. Dedicated low-density polyethylene (LDPE) tubing had been placed in all piezometers and wells during the well installation task. A Geotech peristaltic pump was used to purge the piezometer clusters and a Grundfos Redi-Flo or Whale

submersible pump was used to purge the water table and multi-level wells. All wells were purged of at least three well volumes or until field parameter measurements stabilized.

Water temperature, pH, dissolved oxygen (DO), specific conductance, and oxidation/reduction potential (ORP) were regularly measured using the YSI as purging continued. A visual description of the purged water was also noted. Initial field parameter values were measured using the calibration cup, however after initial sediment buildup in the well cleared, field parameter measurement continued using the flow-through chamber to allow for more accurate DO measurements and for improved parameter stabilization during sampling. All field measurements and observations were noted on field sheets.

December 14th, 2016

The weather for December 14th was in the low 40s with clear skies and a slight breeze. The following wells were purged and sampled on this day: PCZ-13, PCZ-23, PCZ-30, PCZ-35, PCZ-43, PCZ-50, PCZ-60, PCZ-1a, and PCZ-1b. A duplicate sample was also taken at PCZ-50 (PCZ-50 DUP).

January 25th, 2017

The weather for January 25th was cloudy and in the 30s. The following wells were purged and sampled on this day: PC-1, PC-2, PC-4, PC-5, PC-6, PC-7, and PCZ-1c, -1d, -1e, and -1f. A duplicate sample was taken at PC-4 (PC-4 DUP).

Water samples were taken in laboratory-provided pre-preserved sample bottles for the following parameters:

Table 2 – Water Quality Parameters Sampled for Supplemental ISC, Prince Cove, Barnstable, MA

Name	Type
Nitrate-N, Nitrate / Nitrate-N, Total Kjeldahl Nitrogen	General chemistry
Chloride, Sulfate, Total Alkalinity	General chemistry
Organic carbon (dissolved)	Carbon analyses
Iron (dissolved), Manganese (dissolved), Arsenic (dissolved)	Metals
Stable Nitrogen Isotopes in Nitrate ($\boldsymbol{\delta^{15}N-NO_3}$)	Isotope analyses

Samples taken for δ^{15} N-NO_3 analyses were first field-filtered with a 0.01-micron cartridge filter before collection into sample bottles. Two sample bottles were filled at each sample location. These samples were to be fully frozen before laboratory delivery so adequate headspace was kept in these bottles to allow for water expansion during freezing. The locations sampled for this parameter included PCZ-13, PCZ-23, PCZ-30, PCZ-35, PCZ-43, PCZ-50, PCZ-1a, and PCZ-1b.

Samples were then taken for dissolved iron, manganese, and arsenic and for dissolved organic carbon analyses. These samples were field-filtered with a 0.45-micron cartridge filter before collection into sample bottles. Water samples collected for the remaining analyses were not field-filtered.

Field-collected samples for standard laboratory analyses were kept on ice in laboratory-provided coolers until delivery to Alpha Analytical Laboratory in Westborough, Massachusetts. The stable nitrogen isotope samples were immediately cooled, then frozen for approximately 24 hours. The samples were carefully wrapped and placed into insulated shipping containers with blue ice packs to keep the samples frozen. The samples were then overnight-shipped to the University of California at Davis Stable Isotope Laboratory in Davis, California. Duplicate samples for δ^{15} N-NO_3 analysis taken at all well locations were kept frozen and on reserve in case the initial samples did not stay frozen or were deemed unusable by the laboratory upon delivery. When the results of the nitrate-N general-chemistry analyses were received from Alpha Analytical, those results were provided to UC-Davis for use in the isotope analyses.

WaterVision LLC maintained custody of all samples until delivery to Alpha Analytical laboratory or via overnight delivery by Federal Express to the University of California at Davis Stable Nitrogen Isotope Laboratory in Davis, California.

Results

Subsurface Stratigraphy

Sediments encountered at PC-5 were similar to those encountered at wells PC-4, PC-6, and PC-7. Fine to medium sands were encountered near the surface and graded to medium to coarse sand below the water table which was encountered about 35 feet below land surface. The PCZ-1 boring was completed to a depth of 70 feet. Medium to coarse sand was encountered to about 45 feet below land surface. A zone of red-orange coarse sand was identified at 22 to 23 feet below ground surface. At about 45 feet below ground, a very fine to medium sand was encountered to about 63 feet where sediments transitioned to medium sand to the bottom of the boring at 70 feet. This stratigraphy is similar to that found at other

well locations at this site. The very fine to medium sand unit encountered at PCZ-1 was also noted in PC-4 during the ISC. This finer material was not observed during completion of PC-5. Boring and well installation logs are included in Appendix A and well installation data on these and existing site wells are listed in Table 1.

Groundwater Levels and Horizontal Gradients

Ground water level measurements and elevations and horizontal flow gradients are listed in Table 3a and 3b. Estimated groundwater elevation contours and groundwater flow directions at the site are illustrated on Figure 2.

The estimated groundwater flow direction is southeast to south with flow directed towards the salt marsh near PC-4 and towards Prince Cove at PC-1. The horizontal gradient (Table 3b) measured during the January 25, 2017 water level round indicates a gradient of 0.003 between PC-5 and PC-2 increasing to 0.01 between PC-2 and PC-1 near the edge of Prince Cove. Similarly, the gradient between PC-7 and PC-6 is 0.002 but increases between PC-6 and PC-4 near the edge of the salt marsh to a gradient of 0.009. Both these high gradient and low gradient zones are considered below in evaluating potential flux of nitrate in groundwater.

Vertical gradients

Vertical gradients were calculated between adjacent wells or piezometers at the PCZ-1 well cluster and at the PCZ-13 to PCZ-88 piezometers adjacent to PC-4. At the PCZ-1 well cluster adjacent to PC-1, a slight upward gradient was measured between the shallow wells, then vertical gradients turned downward to a depth of about 42 feet bgs. The gradient then turned upward in the zone below these wells to a depth of about 66 feet bgs.

At the PCZ-4 cluster, a slightly downward gradient was measured just below the water table between PCZ-23 and PCZ-13. Below this depth, upward to strongly upward gradients were measured to a depth of 43 feet. Below this gradients varied between adjacent piezometers from slightly upward to slightly downward gradients to a depth of 88 feet below ground surface.

Water Quality

The results of water quality sampling are included in Tables 4, 5, and 6 and illustrated in Figures 3, 4, 5, and 6. Laboratory reports are included in Appendix B.

The concentration of NO3-N in shallow groundwater samples for the December 2016-January 2017 round of sampling are shown in Figure 3. NO3-N concentrations at wells PC-4, PC-6, and PC-7 were 2.0 to 3.5 mg-N/L. These concentrations are

somewhat higher than during previous sampling periods in March and April of 2016. Groundwater sampled from wells PC-5, PC-2 and PC-1 had NO3-N concentrations below 1 mg-N/L. These concentrations are similar (at PC-1 and PC-2) to spring 2016 concentrations. Dissolved oxygen was measured between 5.9 and 8.0 mg/L during this round at PC-4, PC-6 and PC-7. At PC-1 and PC-2 DO was markedly lower at 1.5 to 2.3 mg/L. At new well PC-5, DO was measured at 7.9 mg/L.

Figure 4 illustrates the concentration of NO3-N, DO, and dissolved organic carbon (DOC) detected with depth at the piezometer cluster adjacent to PC-4 and at the PCZ-1 well cluster. Stable nitrogen isotope composition (reported as δ^{15}N in $^{0}/_{00}$) is also included in this figure.

The concentration of NO3-N is less than 3 mg-N/L in the upper three wells of the cluster to an elevation of -22 ft. msl. Below this depth, the concentration drops to 0.25 mg/L at -29 ft. msl (PCZ-1d) and is only tentatively identified below this elevation at PCZ-1e and PCZ-1f. DO peaks at -22 ft. msl (PCZ-1c) at 10 mg/L then drops to 3.2 mg/L at PCZ-1f (-54 ft. msl). The concentration of DOC is only tentatively identified at all sampled wells at a concentration below 0.5 mg/L. Stable nitrogen isotope analysis (δ^{15}N –NO^{3}) was completed only for PCZ-1a and PCZ-1b in this well cluster. These were selected for analysis because nitrate-N and DO concentrations measured in shallow wells PC-1 and PC-2 during the ISC were lower than at other shallow wells within the study area. This suggested that denitrification could be active in this area. The δ^{15}N ratios at these wells were 3.36 and 3.37 $^{0}/_{00}$ respectively.

At piezometer cluster PCZ-4, the upper six piezometers were sampled to an elevation of -47 ft. msl. Like the PCZ-1 well cluster NO3-N was below 3 mg-N/L at all sample points and the highest concentration was measured at -11 to -22 ft. msl. DO was relatively high (10.7 to 11.4 mg/L) to -22 ft. msl but dropped steadily below that elevation to 0.4 at -47 ft. msl (PCZ-60). The δ^{15}N ratio was measured at piezometers PCZ-13 to PCZ-50 in this cluster. Below this depth nitrate-N was found to be below detection limits during the spring 2016 sampling and δ^{15}N cannot be measured if nitrate is not detectable. The ratios were 5.74 to 6.20 $^{0}/_{00}$ at all piezometers but PCZ-30 where a value of 3.41 $^{0}/_{00}$ was measured. This lower ratio is similar to the shallow samples analyzed at PCZ-1a and -1b.

Figure 5 compares the changing concentration of NO3-N, total alkalinity, chloride, and sulfate with depth at the PCZ-1 wells and PCZ-4 piezometers. At PCZ-1 the concentration of chloride drops significantly with depth from nearly 40 mg/L to less than 13 mg/L below -30 ft. msl. Sulfate and alkalinity increase somewhat between -20 and -30 ft. msl and decline below this elevation. At the PCZ-4 piezometer cluster, chloride is low in the shallowest piezometer then increases somewhat to

above 20 mg/L at -30 ft. msl. Sulfate and total alkalinity concentrations are stable at approximately 5 mg/L and 8 mg/L respectively then increase to 14 and 22 mg/L in the deepest piezometer screened at -47 ft. msl.

Figure 6 illustrates the concentrations of DO, and dissolved iron, manganese, and arsenic with depth at the PCZ-1 well cluster and PCZ-4 piezometer cluster. At PCZ-1 iron is variable with depth and generally corresponds to the more mild pattern in dissolved manganese at the same depths. Arsenic remains below detection limits at all wells at the well cluster. At the PCZ-4 piezometers both iron and manganese are below detection limits to PCZ-43 (-30 ft. msl) below which both dissolved metals increase. Dissolved iron reaches a concentration of 7.2 mg/L at PCZ-60 (-47 ft. msl). DO drops significantly below PCZ-35 (-22.5 ft. msl) to a concentration of 0.42 at PCZ-60 (-47 ft. msl).

Oxidation-reduction potential (ORP) measured at the well and piezometer clusters (Table 5 & 6) drops from 160 mV at PCZ-1c to a value of -30 millivolts (mV) at PCZ-1f (-55 ft. msl). At PCZ-4 piezometers, ORP drops sharply from 237 mV at PCZ- 50 (-37 ft. msl) to 5.3 at PCZ-60 (-47 ft. msl).

Discussion

The additional well installation and sampling at Barnstable provided valuable spatial information on groundwater movement and gradients and water quality changes with depth close to the point of apparent discharge to surface water.

Groundwater Flow

With the additional data provided by water levels at PC-5, interpretation of the groundwater levels collected during sampling suggest that the hydraulic gradient is moderate then increases markedly near the point of discharge to either the salt marsh near PC-4 or Prince Cove. The vertical gradient data does not suggest strong upward gradients near the water table but upward gradients were measured below -30 ft. msl near PCZ-1.

Nitrate-N contamination depths

The nitrate-N concentration profiles illustrated in Figure 4 suggest a zone of nitrate contamination that is approximately 40 feet deep at PC-4. A reducing environment is suggested by concentrations of DO, dissolved iron and manganese, and ORP below -40 ft. msl at this piezometer cluster. Nitrate was below detection limits below this elevation as well during the last round of sampling.

The thickness of the zone of elevated nitrate at PCZ-1 appears to be less than 30 feet, lying between elevations 0 and -30 ft. msl. Although DO drops significantly at depth and ORP also decreases significantly below -40 ft. msl, dissolved iron and manganese concentrations suggest conditions are not as reducing at PCZ-1 as in the PCZ-4 piezometers at depth.

Stable nitrogen isotope ratios

The additional measurement of δ^{15}N ratios was added to this round of sampling to evaluate whether denitrification is occurring at the project site. The two stable isotopes of nitrogen are ^{15}N and ^{14}N. The organisms (anaerobic bacteria) that effect denitrification preferentially utilize ^{14}N so that ^{15}N becomes enriched compared to ^{14}N during these biological reactions (Pabich, 2001). The ratio of $^{15}N/^{14}N$ is captured as δ^{15}N (reported in parts per thousand, $^{0}/_{00}$):

$$\delta^{15}N = 1000\frac{s-a}{a}$$

where, a = relative abundance of ^{15}N in atmospheric air, and
s = relative abundance of ^{15}N in the sample.

δ^{15}N has a stable value of 0.366 $^{0}/_{00}$ in air in the atmosphere (Kendall, 1998). This ratio can be analyzed for NH_4, NO_3, or N_2 in groundwater to determine the ratio δ^{15}N. The δ^{15} of nitrate-N was analyzed for this study since it is the species of interest at the Shorewood site. For clarity, stable nitrogen isotope analyses completed for this study are listed as $\delta^{15}N–NO_3$ to specify that the ratio was measured in nitrate-N. Measurements of $\delta^{15}N–NO_3$ have been used at a variety of sites to understand the extent of denitrification in groundwater and to evaluate the sources of nitrate-N detected in groundwater based on apparent enrichment of ^{15}N (Cravotta, 1997; Robertson & Merkely, 2009; Kendall, 2007; Degnan et al. 2015).

The variation in $\delta^{15}N–NO_3$ values in groundwater can reflect different sources of nitrate-N and fractionation due to biological processes. The Barnstable site is in a moderately developed area and is underlain by a sand and gravel aquifer with a water table that is less than 10 feet below land surface. Therefore there are likely multiple sources of nitrate contributing to the subsurface concentrations. These include infiltrating precipitation, vehicle emission deposition, fertilizer, and septic discharge. A review of stable isotope concentrations by Kendall et al. (2007) includes the following range of $\delta^{15}N–NO_3$ ($^{0}/_{00}$) for these sources:

Precipitation for the Cape Cod area	-5.4 to -3.5
Vehicle Emissions	-13 to +3.7
Fertilizer – inorganic	-4 to +4

Fertilizer – organic	+2 to +30
Animal and human waste	+10 to +20

A recent study of the impacts of blasting on water quality also provided some ranges of $\delta^{15}N–NO_3$ from septic systems in southern New Hampshire (Degnan et al., 2015). Groundwater downgradient from septic influence was found to have ratios between 11.4 and 15.3 $^0/_{00}$. The higher ratio was in an area of low DO, where denitrification may have been active. Others reported $\delta^{15}N–NO_3$ in groundwater downgradient of septic systems as 7 $^0/_{00}$ (Fogg et al., 1998) and 8.1 to 13.9 $^0/_{00}$ (Aravena et al., 1993).

The sampling program at Prince Cove identified a groundwater $\delta^{15}N–NO_3$ between 3.27 and 6.20 $^0/_{00}$. Values at PCZ-4 increase slightly with depth from 5.74 to 6.20 $^0/_{00}$ which could indicate some modest denitrification, but the value at PCZ-30 at elevation -18 ft. msl has a much lower value of 3.41. $\delta^{15}N–NO_3$ was also analyzed at PCZ-1a and PCZ-1b and similar ratios were detected at these shallow wells at 3.36 and 3.27. With the limited data available it is not possible at this time to determine the significance of the lower ratios at PCZ-1a and -b and PCZ-30.

Overall, significant denitrification does not appear to be indicated at the shallow wells sampled based on the stable nitrogen isotope values generated during this round of sampling. The deeper piezometers in the PCZ-4 cluster, where conventional parameters suggest denitrification is occurring, are not analyzable for $\delta^{15}N–NO_3$ due to concentrations of NO_3-N near or below method detection limits.

Mass Flux of Nitrate

The mass flux calculations for Barnstable were revised based on the most recent data as shown in Table 7. For the ISC, the higher gradient and lower gradient scenarios discussed above were both analyzed. Since the higher gradient near the shoreline was documented at both the PCZ-4 and PCZ-1 locations, it is useful to estimate the flux using these characteristics. The PRB would likely be placed along Prince Avenue or closer to the shoreline and thus the gradient along the PRB would vary between the two gradient scenarios. The calculated mass flux based on the PC-4 location nitrate and gradient data results in a total of 25.3 grams/day/meter.

Conclusions

The ISC conclusions have been revised below to reflect the data newly collected in this supplemental investigation.

- Subsurface sediments encountered were medium to coarse sand underlain by fine to medium sands. A significant thickness of fine sand with silt and some clay was also encountered at depth at both PCZ-1 and PCZ-4. The presence of this finer-grained layer may impact vertical flow.
- A significant thickness of organic fine to medium sand thought to be marsh deposits was encountered at shallow depth at PC-2.
- Depth to groundwater is 3 to 34 ft. bgs from the shore at PC-1 to the upland area near PC-5. Close to the shore and marsh, the depth to water is 3 to 8 feet bgs.
- The overall vertical gradient is upward in the PCZ-4 area below -11 ft. msl and below -30 ft. msl near PCZ-1. Shallow groundwater likely discharges to the salt marsh and Prince Cove.
- A zone of elevated nitrate is approximately 30-feet thick at PCZ-1 and 40-feet thick at PCZ-4. In this zone, concentrations of nitrate-N were detected between 1.2 and 2.9 mg-N/L.
- Nitrate concentrations are lower near the water table than at depth, likely due to the introduction of uncontaminated rainfall recharge from the surface.
- Groundwater velocities are estimated at 1.5 to 4.5 ft./day.
- The highest nitrate-N concentration detected in a water table well was 3.5 mg-N/L at PC-6 during the most recent sampling in January 2017.
- Low nitrate-N and reducing conditions were encountered below -40 ft. msl at PCZ-4 and below -30 ft. msl at PCZ-1.
- At PC-2, marsh deposits were encountered in the subsurface and the concentration of nitrate-N at this well was 0.1 mg-N/L suggesting reducing conditions (low DO and redox potential). These are similar to conditions in a wetland setting and may allow for denitrification to occur.
- The limited $\delta^{15}N–NO_3$ analysis for this study did not suggest significant denitrification at the wells sampled. However $\delta^{15}N–NO_3$ analysis could not be completed at PCZ-60 as nitrate-N was below detection limits during this round. Analysis of $\delta^{15}N\text{-}N_2$ in groundwater from the deeper PCZ-1 and PCZ-4 wells might be helpful to further define the extent of denitrification.
- The unit mass flux estimated for Barnstable was estimated at 25.3 g/day/m using the current NO_3-N data and the greater hydraulic gradient confirmed near PCZ-4. This compares to the 26.8 g/day/ m calculated from data collected during the ISC using the greater horizontal hydraulic gradient of 0.011.

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TABLES

Supplemental Sampling Summary Memorandum

Site Characterization for Design of Pilot-Scale Permeable Reactive Barriers for Nitrogen Reduction in Groundwater on Cape Cod - Supplemental Fieldwork at Prince Cove, Barnstable, Massachusetts

Table 1 - Well/Piezometer Construction Details - Prince Cove, Barnstable, MA								
Well designation	**Date of installation**	**Total Depth of boring/ core (ft)**	**Surveyed land surface elevation (ft msl)***	**Surveyed top of PVC well casing (ft msl)**	**Total depth of well (ft)**	**Top of screen (feet bgs)****	**Bottom of screen (feet bgs)**	**Elevation of bottom of screened interval (ft msl)**
PC-1	1/19/16	25	12.09	11.63	15	10	15	-2.9
PCZ-1a	11/30/16		12.66	12.36	16	15	16	-3.3
PCZ-1b	11/30/16		12.53	12.34	23	22	23	-10.5
PCZ-1c	11/30/16		12.44	12.16	35	34	35	-22.6
PCZ-1d	11/30/16		12.47	12.16	42	41	42	-29.5
PCZ-1e	11/30/16		12.31	12.01	54	53	54	-41.7
PC-1f	11/30/16	68	12.33	11.8	67	66	67	-54.7
PC-2	1/21/16	25	7.71	7.12	13	8	13	-5.3
PC-4	1/20/16	90	12.78	12.46	13	8	13	-0.2
PCZ-13	1/21/16	13	12.19		13	12	13	-0.8
PCZ-23	1/21/16	23	12.30		23	22	23	-10.7
PCZ-30	1/21/16	30	12.38		30	29	30	-17.6
PCZ-35	1/21/16	35	12.54		35	34	35	-22.5
PCZ-43	1/21/16	43	12.64		43	42	43	-30.4
PCZ-50	1/21/16	50	12.78		50	49	50	-37.2
PCZ-60	1/20/16	60	12.70		60	59	60	-47.3
PCZ-70	1/20/16	70	12.58		70	69	70	-57.4
PCZ-80	1/20/16	80	12.48		80	79	80	-67.5
PCZ-88.5	1/20/16	90	12.35		88.5	87.5	88.5	-76.2
PC-5	12/1/16	60	41.55	41.17	40	35	40	1.6
PC-6	1/20/16	25	11.28	10.87	11	11	16	-4.7
PC-7	1/19/16	25	13.30	12.98	14	9	14	-0.7

* field surveyed to NAVD 88 by CEI - March 2016 and by Town of Barnstable Public Works Department January 2017

** bgs - below land surface

Table 3a - Water Levels and Groundwater Elevations at Wells and Piezometers - March 2016 to January 2017
Prince Cove, Barnstable, MA

Well	Top of PVC Casing (ft. msl)	Depth to Water (ft. below top of PVC casing) 3/7/2016	Water Surface Elevation (ft. msl) 3/7/2016	Depth to Water (ft. below top of PVC casing) 4/18/2016	Water Surface Elevation (ft. msl) 4/18/2016	Depth to Water (ft. below top of PVC casing) 1/25/17	Water Surface Elevation (ft. msl) 1/25/17
2-inch water table wells							
PC-1	11.63	9.62	2.01	9.00	2.63	8.82	2.81
PC-2	7.12	2.83	4.29	2.52	4.60	2.38	4.74
PC-4	12.46	8.80	3.66	8.56	3.90	8.81	3.65
PC-5	41.17	NI	NI	NI	NI	33.72	7.45
PC-6	10.87	5.32	5.55	5.10	5.77	5.18	5.69
PC-7	12.98	6.18	6.80	5.86	7.12	6.39	6.59
Well	**Top of PVC Casing (ft. msl)**	**Depth to Water (ft. below top of PVC casing) 3/7/2016**	**Water Surface Elevation (ft. msl) 3/7/2016**	**Depth to Water (ft. below top of PVC casing) 4/18/2016**	**Water Surface Elevation (ft. msl) 4/18/2016**	**Depth to Water (ft. below top of PVC casing) 1/25/17**	**Water Surface Elevation (ft. msl) 1/25/17**
1-inch diameter piezometer cluster adjacent to well PC-4							
PCZ-13	12.04	8.38	3.66	8.35	3.69	8.40	3.64
PCZ-23	12.05	8.38	3.67	8.31	3.74	8.46	3.59
PCZ-30	12.23	7.82	4.41	7.89	4.34	8.03	4.20
PCZ-35	12.23	7.74	4.49	7.81	4.42	8.02	4.21
PCZ-43	12.33	7.43	4.90	7.50	4.83	7.68	4.65
PCZ-50	12.62	7.91	4.71	8.45	4.17	7.97	4.65
PCZ-60	12.63	7.82	4.81	7.98	4.65	7.96	4.67
PCZ-70	12.50	8.69	3.81	7.75	4.75	7.95	4.55
PCZ-80	12.31	9.02	3.29	8.74	3.57	7.74	4.57
PCZ-88.5	12.26	8.82	3.44	8.75	3.51	7.91	4.35
2-inch diameter well cluster adjacent to well PC-1							
PCZ-1a	12.36	NI	NI	NI	NI	9.43	2.93
PCZ-1b	12.34	NI	NI	NI	NI	9.38	2.96
PCZ-1c	12.16	NI	NI	NI	NI	9.23	2.93
PCZ-1d	12.16	NI	NI	NI	NI	9.28	2.88
PCZ-1e	12.01	NI	NI	NI	NI	8.86	3.15
PCZ-1f	11.80	NI	NI	NI	NI	8.31	3.49

NI - Not installed for this measurement period

Table 3b - Horizontal and Vertical Gradients at Wells and Piezometers - March 2016 to January 2017
Prince Cove, Barnstable, MA

Well	Top of PVC Casing (ft. msl)	Horizontal Gradient - 3/7/2016		Horizontal Gradient - 4/18/2016		Horizontal Gradient - 1/25/17	
2" water table wells							
PC-1	11.63	PC-2 to PC-1	0.011	PC-2 to PC-1	0.009	PC-5 to PC-2	0.003
PC-2	7.12					PC-2 to PC-1	0.009
PC-4	12.46						
PC-5	41.17					PC-7 to PC-6	0.002
PC-6	10.87	PC-7 to PC-6	0.003	PC-7 to PC-6	0.003	PC-6 to PC-4	0.009
PC-7	12.98						
Well	**Top of PVC Casing (ft. msl)**	**Vertical Gradient - 3/7/2016**		**Vertical Gradient - 4/18/2016**		**Vertical Gradient - 1/25/2017**	
1"diameter piezometer cluster adjacent to well PC-4							
PCZ-13	12.04						
PCZ-23	12.05	0.001	slightly upward	0.005	slightly upward	-0.005	slightly downward
PCZ-30	12.23	0.106	strongly upward	0.086	strongly upward	0.087	strongly upward
PCZ-35	12.23	0.016	upward	0.016	upward	0.002	slightly upward
PCZ-43	12.33	0.051	strongly upward	0.051	upward	0.055	strongly upward
PCZ-50	12.62	-0.024	downward	-0.082	strongly downward	0.000	flat
PCZ-60	12.63	0.010	slightly upward	0.048	upward	0.002	slightly upward
PCZ-70	12.50	-0.100	strongly downward	0.010	upward	-0.012	downward
PCZ-80	12.31	-0.052	strongly downward	-0.118	strongly downward	0.002	slightly upward
PCZ-88	12.26	0.019	upward	-0.007	slightly downward	-0.027	downward
2" diameter well cluster adjacent to well PC-1							
PCZ-1a	12.36	NI	NI	NI	NI		
PCZ-1b	12.34	NI	NI	NI	NI	0.004	slightly upward
PCZ-1c	12.16	NI	NI	NI	NI	-0.002	slightly downward
PCZ-1d	12.16	NI	NI	NI	NI	-0.008	slightly downward
PCZ-1e	12.01	NI	NI	NI	NI	0.022	upward
PCZ-1f	11.80	NI	NI	NI	NI	0.027	upward

NI - Not installed for this measurement period

Vertical gradient rankings
0.05 or greater - strongly upward
0.009 to 0.049- upward
less than 0.09 - slightly upward

-0.05 or greater - strongly downward
-0.009 to - 0.049- downward
less than- 0.009 - slightly downward

Table 4 Barnstable - Prince Cove 2-inch Monitoring Well Groundwater Data Summary

Sample ID/Location	PC-1						PC-2						PC-4						PC-5	
Sampling Date	3/7/16		4/18/16		1/25/17		3/7/16		4/18/16		1/25/17		3/7/16		4/18/16		1/25/17		1/25/17	
Field Measurements																				
pH (SU)	5.71		5.47		5.67		5.46		5.07		5.92		4.97	R	5.53		6.55		6.06	
Temperature (°C)	9.7		10.9		10.22		7.6		9.4		9.97		9.5		10.6		9.4		11.2	
Dissolved Oxygen (DO; mg/L)	1.7		4.1		2.3		0.8		4.1		1.5		5.4		5.8		5.9		7.9	
Specific Conductance (uS/cm)	110		113.8		115		128		149.5		128		117		109.9		92		169	
Redox Potential (ORP; mV)	123.5		216.2		220		22		135.6		30.1		-121.1	R	211.1		187		182	
Laboratory Analyses																				
pH (SU)	6.0		6.1		NM		5.5		5.5		NM		6.0		6		NM		NM	
Nitrate as N (mg/L)	0.64		0.97		0.34		0.1		0.086	J	0.12		1.4		1.6		2.4		0.34	
Nitrite as N (mg-N/L)	<0.001		<0.010		<0.019		0.010	J	0.05	U,E	<0.019		<0.001		0.05	U	<0.019		<0.019	
Ammonia as N (mg-N/L)	0.067	J	0.03	J	NM		<0.021		0.045	J,E	NM		<0.021		0.04	J	NM		NM	
Total Kjeldahl Nitrogen (TKN) (mg-N/L)	0.16	J	0.123	J	0.118	J	0.423		0.127	J,E	0.161	J	<0.093		0.089	J	<0.066		0.080	J
Total Nitrogen (mg-N/L)	0.64		0.97		0.34		0.52		<0.30		<0.066		1.4		1.6		2.4		0.34	
Orthophosphate (mg/L)	0.002	J	<0.001		NM		0.003	J	<0.001		NM		0.009		0.005		NM		NM	
Total Alkalinity (mg CaCO3/L)	10.6		9.9		13.9		3.4		3.7		3.3		8.40		8.8		9.3		2.3	
Chloride (mg/L)	23.4		20.5		29.8		28.7		32.2		34.6		20.2		19.2		20.7		62.1	
Sulfate (mg/L)	10.7		7.66		11.2		16.1		16		16.5		8.38		8.8		6.28		4.42	
Dissolved Iron (mg/L)	0.075		<0.020		<0.01		1.3		0.89	E	0.54		<0.020		<0.20		<0.01		0.12	
Dissolved Manganese (mg/L)	0.075		0.0331		0.021		0.133		0.138		0.128		0.0151		0.0106		0.006	J	0.228	
Dissolved Boron (mg/L)	0.0446		0.0464		NM		0.0175	J	0.0162	J	NM		0.0207	J	0.0256	J	NM		NM	
Dissolved Arsenic (mg/L)	0.0022	J	<0.0020		<0.002		<0.0020		<0.0020		<0.002		0.0026	J	<0.0020		<0.002		<0.002	
Dissolved Organic Carbon (mg/L)	1.2		1.3		0.95	J	1.6		1.2		1.3		1		0.77	J	0.37	J	0.66	J

J - Data indicates a presence of a compound that meets the identification criteria. The result is less than the quantitation limit but greater than zero. The concentration given is an approximate value.

R - Suspected error in field pH and ORP measurements

NS - Not Sampled / NM -Not Measured

E - Exceeds RPD of 20% with duplicate sample

Grey shading indicates data that should not be relied upon due to QA/QC concerns

Table 4 Barnstable - Prince Cove 2-inch Monitoring Well Groundwater Data Summary

Sample ID/Location	PC-6						PC-7					
Sampling Date	3/8/16		4/18/16		1/25/17		3/8/16		4/18/16		1/25/17	
Field Measurements												
pH (SU)	5.67		5.54		6.39		4.3	R	5.50		6.51	
Temperature (°C)	9.1		9.7		10.3		8.8		9.2		9.52	
Dissolved Oxygen (DO; mg/L)	3.9		5.8		6.0		8.1		8.8		8.1	
Specific Conductance (uS/cm)	142		150.1		112		263		238		113	
Redox Potential (ORP; mV)	160.3		218.2		46.3		-80.6	R	251.3		141	
Laboratory Analyses												
pH (SU)	5.7		5.9		NM		5.7		6		NM	
Nitrate as N (mg/L)	2.5		2.6		3.5		1.7		1.8		2	
Nitrite as N (mg-N/L)	0.012	J	<0.010		<0.019		<0.010		<0.010	U	<0.019	
Ammonia as N (mg-N/L)	0.043	J	0.075	U	NM		0.045	J	<0.028		NM	
Total Kjeldahl Nitrogen (TKN) (mg-N/L)	0.230	J	0.3	U	<0.066		0.151	J	<0.066		<0.066	
Total Nitrogen (mg-N/L)	2.5		2.6		3.5		1.7		1.8		2	
Orthophosphate (mg/L)	0.004	J	<0.001		NM		0.006		<0.001		NM	
Total Alkalinity (mg CaCO3/L)	8.6		8.6		7.4		14.4		13.8		10.4	
Chloride (mg/L)	20.6		28.9		24		46.5		51.8		30.2	
Sulfate (mg/L)	10.1		10.7		9.64		8.52		8.92		7.74	
Dissolved Iron (mg/L)	0.15		<0.020		1.9		<0.020		<0.020		0.02	J
Dissolved Manganese (mg/L)	0.0135		0.0155		0.212		0.248		0.0294		0.006	J
Dissolved Boron (mg/L)	0.0159	J	0.0194	J	NM		0.018	J	0.0156	J	NM	
Dissolved Arsenic (mg/L)	0.0027	J	<0.0020		0.002	J	<0.0020		0.0023	J	<0.002	
Dissolved Organic Carbon (mg/L)	0.9	J	0.7	J	0.46	J	2.2		0.77	J	0.47	J

J - Data indicates a presence of a compound that meets the identification criteria. The result is less than the quantitation limit but greater than zero. The concentration given is an approximate value.

R - Suspected error in field pH and ORP measurements

NS - Not Sampled / NM -Not Measured

E - Exceeds RPD of 20% with duplicate sample

Grey shading indicates data that should not be relied upon due to QA/QC concerns

Table 5 Barnstable - Prince Cove Piezometer and Well Cluster Data Summary

Sample ID/Location	PCZ-13						PCZ-23						PCZ-30			
Elevation of well screen	-1						-11						-18			
Sampling Date	3/8/16		4/18/16		12/14/16		3/8/16		4/18/16		12/14/16		3/8/16		4/18/16	
Field Measurements																
pH (SU)	4.89	R	5.49		5.25		4.98	R	5.48		5.26		4.76	R	5.43	
Temperature (°C)	9.99		10.3		10.3		10.47		10.5		10		10.4		10.4	
Dissolved Oxygen (DO; mg/L)	8.0		9.7		11.4		6.3		6.7		10.7		6.6		7.9	
Specific Conductance (uS/cm)	98		85.4		84		125		111.6		119.1		124		113.3	
Redox Potential (ORP; mV)	-111.3	R	253.4		229.0		-147.9	R	258.4		256.6		-130.8	R	249.7	
Laboratory Analyses																
pH (SU)	5.8		5.9		NM		5.8		5.8		NM		5.8		5.8	
Nitrate as N (mg/L)	1.4		1.3		1.2		2.3		2.4		2.6		2.2		2.2	
D15N air (0/00)	NM		NM		5.74		NM		NM		6.03		NM		NM	
Nitrite as N (mg-N/L)	<0.010		<0.010		<0.019		<0.010		<0.010		<0.019		<0.010		<0.010	
Ammonia as N (mg-N/L)	0.022	J	<0.028		NM		0.061	J,E	<0.028		NM		0.066	J	<0.028	
Total Kjeldahl Nitrogen (TKN) (mg-N/L)	0.170	J	0.131	J	0.08	J	0.127	J	0.076	J	0.098	J	0.142	J	<0.066	
Total Nitrogen (mg-N/L)	1.4		1.3		1.2		2.3		2.4		2.6		2.2		2.2	
Orthophosphate (mg/L)	0.013		0.013		NM		0.012		0.010		NM		0.01		0.009	
Total Alkalinity (mg CaCO3/L)	8.5		8.5		8.1		9.5		9.3		8.40		8.8		8.7	
Chloride (mg/L)	14.6		14.6		12.9		19.9		19		19.1		19.9		20.7	
Sulfate (mg/L)	5.23		5.73		5.22		4.52		5.16		5.14		4.29		4.86	
Dissolved Iron (mg/L)	0.021	J	<0.020		<0.0090		< 0.020		<0.020		<0.0090		0.046	J	<0.020	
Dissolved Manganese (mg/L)	0.0052	J	0.0027	J	<0.0016		< 0.0020		0.0024	J	<0.0016		<0.0020		<0.0020	
Dissolved Boron (mg/L)	0.0115	J	0.011	J	NM		0.0304		0.0318		NM		0.0226	J	0.0206	J
Dissolved Arsenic (mg/L)	0.0025	J	0.002	J	<0.0019		< 0.0020		0.002	J	<0.0019		0.0028	J	0.0023	J
Dissolved Organic Carbon (mg/L)	0.46	J	0.96	J	0.38	J	0.56	J	0.58	J	0.38	J	0.65	J	0.55	J

Notes:

J - Data indicates a presence of a compound that meets the identification criteria. The result is less than

R - Suspected error in field pH and ORP measurements

NS - Not Sampled / NM -Not Measured

E - Exceeds RPD of 20% with duplicate sample

Gray shading indicates data that should not be relied upon due to QA/QC concerns

Table 5 Barnstable - Prince Cove Piezometer and Well Cluster Data Summary

Sample ID/Location			**PCZ-35**						**PCZ-43**					
Elevation of well screen			**-23**						**-30**					
Sampling Date	12/14/16		3/8/16		4/18/16		12/14/16		3/7/16		4/19/16		12/14/16	
Field Measurements														
pH (SU)	5.17		4.17	R	5.49		5.32		5.42	R	5.50		5.28	
Temperature (°C)	10.5		10.27		10.3		10.3		10.01		10.4		10.2	
Dissolved Oxygen (DO; mg/L)	10.3		6.4		7.4		10.8		7.7		7.3		8.1	
Specific Conductance (uS/cm)	114.8		125		110.2		118.6		123		112.3		127.7	
Redox Potential (ORP; mV)	250.9		-94.8	R	258.0		250.8		-119.9	R	207.8		242.9	
Laboratory Analyses														
pH (SU)	NM		5.7		5.8		NM		6.1		5.8		NM	
Nitrate as N (mg/L)	2.3		2.3		2.4		2.6		2.3		2.6		2.3	
D15N air (0/00)	3.41		NM		NM		6.04		NM		NM		6.11	
Nitrite as N (mg-N/L)	<0.019		<0.010		<0.010		<0.019		<0.010		<0.010		<0.019	
Ammonia as N (mg-N/L)	NM		<0.021		0.066	J	NM		0.025	J	<0.028		NM	
Total Kjeldahl Nitrogen (TKN) (mg-N/L)	0.067	J	0.113	J	<0.066		0.088	J	0.095	J	<0.066		0.082	J
Total Nitrogen (mg-N/L)	2.3		2.3		2.4		2.6		2.3	E	2.6		2.3	
Orthophosphate (mg/L)	NM		0.006		0.007		NM		0.005		0.002	J	NM	
Total Alkalinity (mg CaCO3/L)	8.1		9.30		8.7		8.70		12.4		9.9		9.10	
Chloride (mg/L)	18.6		19.8		19.4		19.1		19.9		18.7		21.8	
Sulfate (mg/L)	5.29		4.31		4.81		5.12		4.94		5.69		5.19	
Dissolved Iron (mg/L)	<0.0090		0.10		0.044	J	<0.0090		1.5		0.078		0.039	J
Dissolved Manganese (mg/L)	<0.0016		0.0098	J	0.0026	J	<0.0016		0.0348		0.0057	J	0.0021	J
Dissolved Boron (mg/L)	NM		0.0269	J	0.0248	J	NM		0.0283	J	0.0286	J	NM	
Dissolved Arsenic (mg/L)	<0.0019		0.0027	J	<0.0020		<0.0019		0.0031	J,E	0.0031	J	<0.0019	
Dissolved Organic Carbon (mg/L)	0.42	J	0.89	J	0.53	J	0.36	J	0.52	J	0.54	J	0.33	J

Notes:

J - Data indicates a presence of a compound that meets the identification criteria. The result is less than

R - Suspected error in field pH and ORP measurements

NS - Not Sampled / NM -Not Measured

E - Exceeds RPD of 20% with duplicate sample

Gray shading indicates data that should not be relied upon due to QA/QC concerns

Table 5 Barnstable - Prince Cove Piezometer and Well Cluster Data Summary

Sample ID/Location	PCZ-50						PCZ-60						PCZ-70			
Elevation of well screen	-37						-47						-57			
Sampling Date	3/7/16		4/19/16		12/14/16		3/8/16		4/19/16		1/25/17		3/8/16		4/19/16	
Field Measurements																
pH (SU)	5.05	R	5.65		5.3		6.17		6.41		7.33		6.51		6.75	
Temperature (°C)	10.2		10.5		10.2		9.91		10.5		9.96		10.05		10.5	
Dissolved Oxygen (DO; mg/L)	4.2		7.3		5.5		0.9		0.7		0.4		0.1		0.6	
Specific Conductance (uS/cm)	124		122.4		125.5		144		123.8		101		112		109.0	
Redox Potential (ORP; mV)	-117.4	R	210.4		237.3		3.9		-18.7		5.3		-52.5		-59.5	
Laboratory Analyses																
pH (SU)	6.3		6		NM		6.1		6.6		NM		6.2		6.8	
Nitrate as N (mg/L)	2		2.8		2.0		<0.019		<0.019		<0.019		0.021	J	0.028	J
D15N air (0/00)	NM		NM		6.2		NM		NM		NM		NM		NM	
Nitrite as N (mg-N/L)	0.02		<0.010		<0.019		0.014	J	<0.010		<0.019		<0.010		<0.010	
Ammonia as N (mg-N/L)	<0.021		<0.028		NM		0.043	J	0.042	J	NM		0.066	J	0.054	J
Total Kjeldahl Nitrogen (TKN) (mg-N/L)	<0.093		0.086	J,E	0.080	J	0.261	J	0.14	J	<0.066		0.135		0.156	J
Total Nitrogen (mg-N/L)	2		2.8		2.0		<0.30		<0.30		<0.030		<0.30		<0.30	
Orthophosphate (mg/L)	0.006		0.005	E	NM		0.002	J	0.14		NM		0.002		0.138	
Total Alkalinity (mg CaCO3/L)	14.5		11.6	E	11.0		18.1		23.4		22.1		15.8		24.8	
Chloride (mg/L)	19.7		19.7		20.2		17.6		16.7		18.2		11.7		13.1	
Sulfate (mg/L)	6.20		6.28		6.11		13.6		14.2		13.9		9.53		11.1	
Dissolved Iron (mg/L)	0.64		0.09		<0.0090		8.0		7.1		7.2		6.3		7	
Dissolved Manganese (mg/L)	0.0702		0.0158		<0.0016		0.197		0.149		0.163		0.158		0.162	
Dissolved Boron (mg/L)	0.0211	J	0.0253	J	NM		0.0169	J	0.0147	J	NM		0.0081	J	0.008	J
Dissolved Arsenic (mg/L)	0.0042	J	0.002	J	<0.0019		0.0045	J	0.0037	J	<0.002		0.0061		0.0063	
Dissolved Organic Carbon (mg/L)	1.2		0.45	J	0.32	J,E	1.1		0.49	J	0.32	J	0.43		0.52	J

Notes:

J - Data indicates a presence of a compound that meets the identification criteria. The result is less than

R - Suspected error in field pH and ORP measurements

NS - Not Sampled / NM -Not Measured

E - Exceeds RPD of 20% with duplicate sample

Gray shading indicates data that should not be relied upon due to QA/QC concerns

Table 5 Barnstable - Prince Cove Piezometer and Well Cluster Data Summary

Sample ID/Location	**PCZ-80**				**PCZ-88**			
Elevation of well screen	**-67**				**-76**			
Sampling Date	3/7/16		4/19/16		3/7/16		4/19/16	
Field Measurements								
pH (SU)	6.88		6.48		6.52		6.16	
Temperature (°C)	9.47		10.85		9.69		10.63	
Dissolved Oxygen (DO; mg/L)	0.8		1.6		0.3		0.4	
Specific Conductance (uS/cm)	86		96		78		85	
Redox Potential (ORP; mV)	-63.8		-27.5		-20.7		8.2	
Laboratory Analyses								
pH (SU)	6.5		6.8		6.4		6.6	
Nitrate as N (mg/L)	0.058	J	0.02	J	0.025	J	<0.019	
D15N air (0/00)	NM		NM		NM		NM	
Nitrite as N (mg-N/L)	0.030	J	<0.010		0.03	J	<0.010	
Ammonia as N (mg-N/L)	0.063	J	0.053	J	0.025	J	<0.028	
Total Kjeldahl Nitrogen (TKN) (mg-N/L)	0.182	J	0.146	J	0.204	J	0.085	J
Total Nitrogen (mg-N/L)	<0.30		<0.30		<0.30		<0.30	
Orthophosphate (mg/L)	0.005		0.065		0.009		0.05	
Total Alkalinity (mg CaCO3/L)	17.4		20.3		13.4		15.7	
Chloride (mg/L)	10.7		10.3		10.2		9.98	
Sulfate (mg/L)	9.41		9.66		9.84		10.2	
Dissolved Iron (mg/L)	11		4.8		7.6		3.2	
Dissolved Manganese (mg/L)	0.245		0.122		0.105		0.0501	
Dissolved Boron (mg/L)	0.0085	J	0.0074	J	0.0106	J	0.0077	J
Dissolved Arsenic (mg/L)	0.0101		0.0053		<0.0020		0.003	J
Dissolved Organic Carbon (mg/L)	3.2		0.82	J	0.46	J	0.46	J

Notes:

J - Data indicates a presence of a compound that meets the identification criteria. The result is less than

R - Suspected error in field pH and ORP measurements

NS - Not Sampled / NM -Not Measured

E - Exceeds RPD of 20% with duplicate sample

Gray shading indicates data that should not be relied upon due to QA/QC concerns

Table 6 - Barnstable - Prince Cove Piezometer and Well Cluster Data Summary

Sample ID/Location	**PCZ-1a**		**PCZ-1b**		**PCZ-1c**		**PCZ-1d**		**PCZ-1e**		**PCZ-1f**	
Elevation of Screen	**-3**		**-11**		**-23**		**-30**		**-42**		**-55**	
Sampling Date	12/14/16		12/14/16		1/25/17		1/25/17		1/25/17		1/25/17	
Field Measurements												
pH (SU)	5.97		6.61		5.78		6.58		6.73		7.5	
Temperature (°C)	12.74		13.15		11.22		10.9		10.7		10.8	
Dissolved Oxygen (DO; mg/L)	5.2		5.8		10.0		7.9		7.4		3.2	
Specific Conductance (uS/cm)	180		149		116		66		56		64	
Redox Potential (ORP; mV)	186		152		160		80		98		-30	
Laboratory Analyses												
pH (SU)	NM		NM		NM		NM		NM		NM	
Nitrate as N (mg/L)	2.6		2.9		2.4		0.25		0.064	J	0.074	J
D15N air (0/00)	3.36		3.27		NM		NM		NM		NM	
Nitrite as N (mg-N/L)	<0.019		<0.019		<0.019		<0.019		<0.019	J	<0.019	J
Ammonia as N (mg-N/L)	NM		NM		NM		NM		NM		NM	
Total Kjeldahl Nitrogen (TKN) (mg-N/L)	<0.066		0.125		<0.066		0.115	J	0.091		0.171	J
Total Nitrogen (mg-N/L)	2.6		2.9		2.4		<0.30		<0.30		<0.30	
Orthophosphate (mg/L)	NM		NM		NM		NM		NM		NM	
Total Alkalinity (mg CaCO3/L)	6.0		6.30		7.7		12.7		9.5		11.3	
Chloride (mg/L)	39.1		27.0		27.8		13.1		11.2		11	
Sulfate (mg/L)	3.56		6.34		9.06		5.91		6.89		6.68	
Dissolved Iron (mg/L)	0.11		0.55		0.02	J	1.6		0.28		1.2	
Dissolved Manganese (mg/L)	0.134		0.0869		0.007	J	0.233		0.091		0.15	
Dissolved Boron (mg/L)	NM		NM		NM		NM		NM		NM	
Dissolved Arsenic (mg/L)	<0.0019		<0.0019		<0.002		0.002		<0.002		<0.002	
Dissolved Organic Carbon (mg/L)	0.44	J	0.52	J	0.4	J	0.36	J	0.28	J	0.37	J

Notes:
J - Data indicates a presence of a compound that meets the identification criteria. The result is less than the quantitation limit but greater than zero. The
NS - Not Sampled / NM - Not Measured
E - Exceeds RPD of 20% with duplicate sample

FIGURES

Supplemental Sampling Summary Memorandum

Site Characterization for Design of Pilot-Scale Permeable Reactive Barriers for Nitrogen Reduction in Groundwater on Cape Cod - Supplemental Fieldwork at Prince Cove, Barnstable, Massachusetts

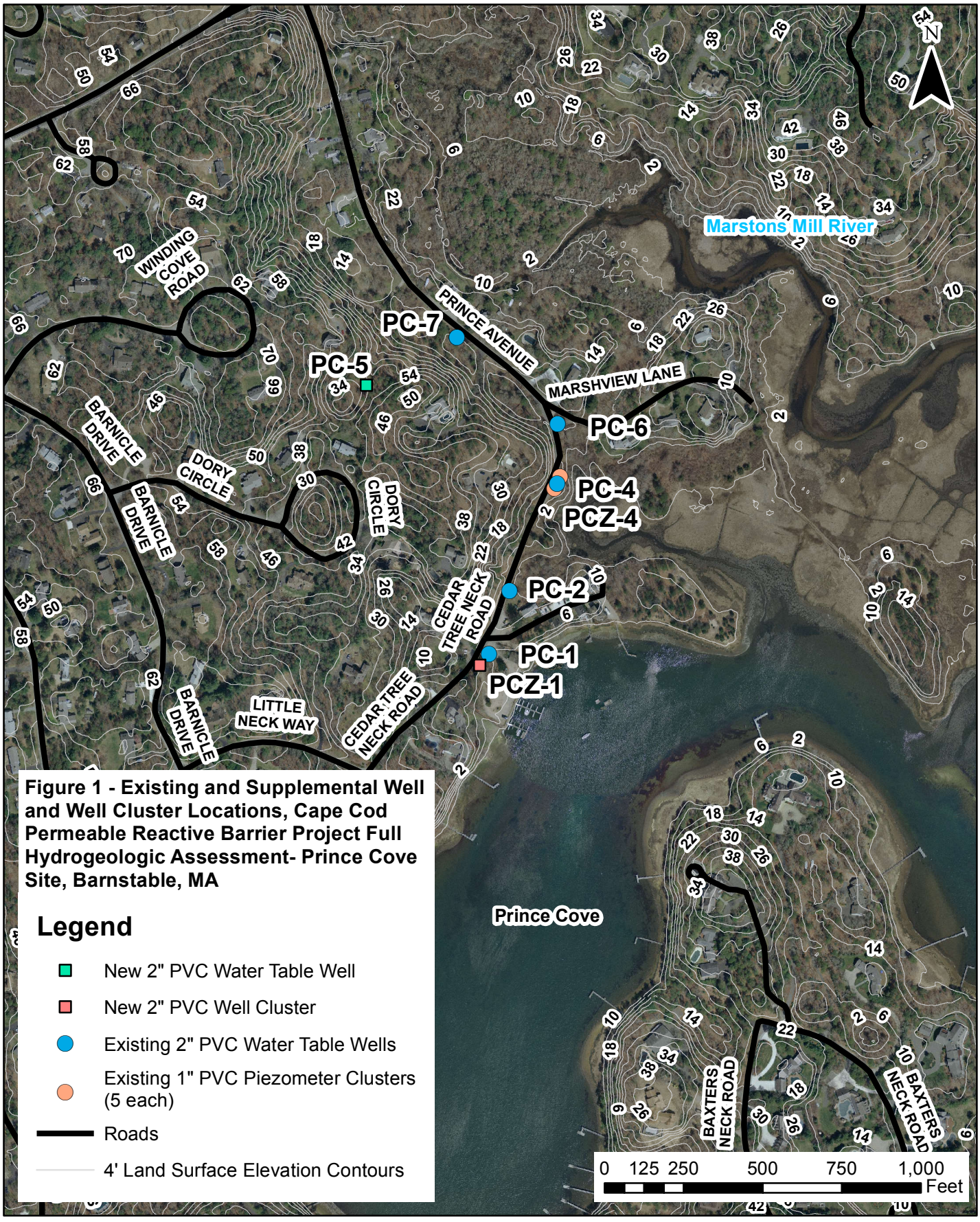


Figure 1 - Existing and Supplemental Well and Well Cluster Locations, Cape Cod Permeable Reactive Barrier Project Full Hydrogeologic Assessment- Prince Cove Site, Barnstable, MA

Legend

- New 2" PVC Water Table Well
- New 2" PVC Well Cluster
- Existing 2" PVC Water Table Wells
- Existing 1" PVC Piezometer Clusters (5 each)
- Roads
- 4' Land Surface Elevation Contours

Sources: Aerial photography 2013-2014 and Roads from Mass GIS, Parcel Boundaries and Elevation Contours from Cape Cod Commission. Surveyed Groundwater Monitoring Well and Piezometer Cluster locations from WaterVision LLC.

Map created by
WaterVision, LLC
March 2017

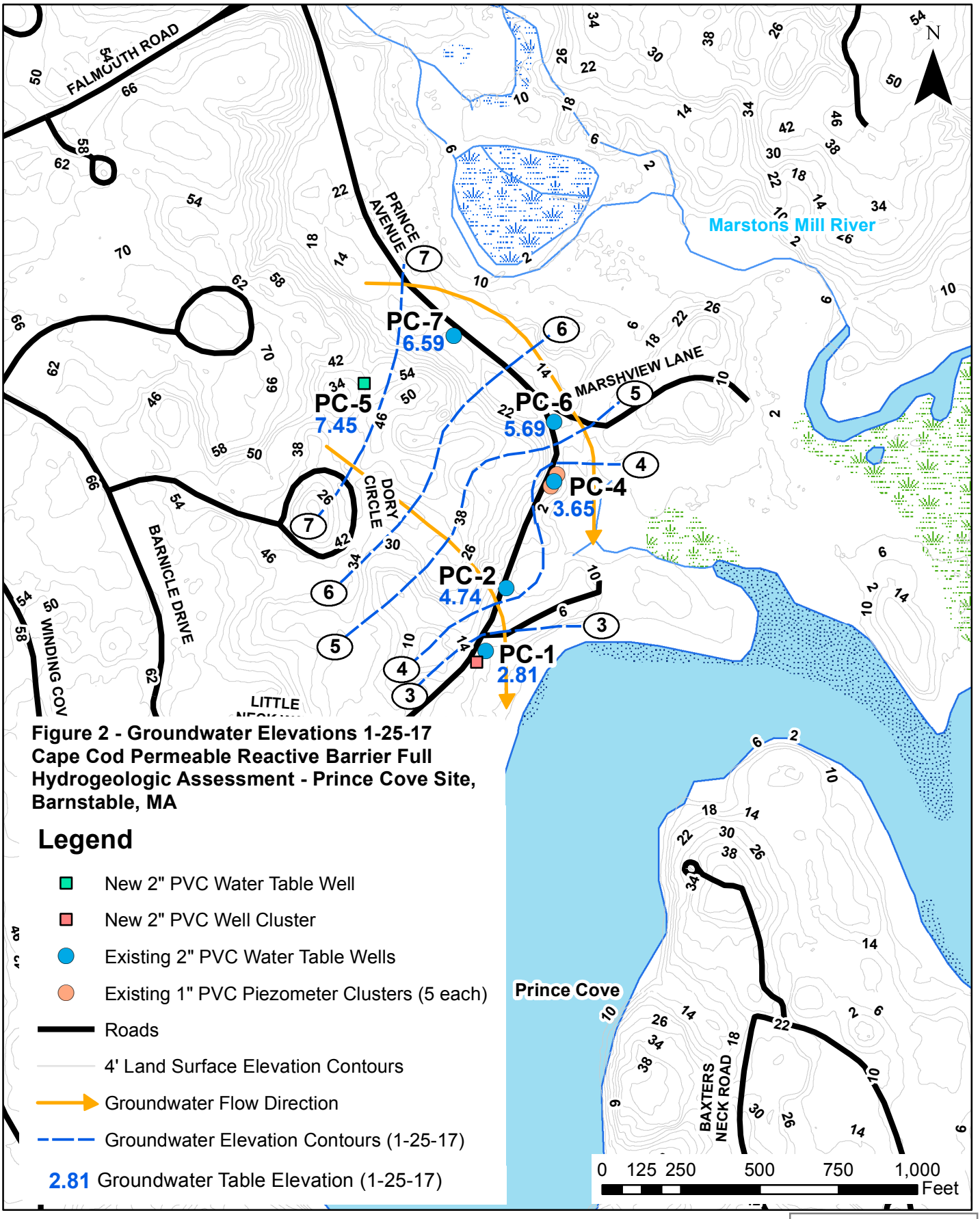


Figure 2 - Groundwater Elevations 1-25-17
Cape Cod Permeable Reactive Barrier Full Hydrogeologic Assessment - Prince Cove Site, Barnstable, MA

Legend

- New 2" PVC Water Table Well
- New 2" PVC Well Cluster
- Existing 2" PVC Water Table Wells
- Existing 1" PVC Piezometer Clusters (5 each)
- Roads
- 4' Land Surface Elevation Contours
- Groundwater Flow Direction
- Groundwater Elevation Contours (1-25-17)
- 2.81 Groundwater Table Elevation (1-25-17)

Sources: Aerial photography 2013-2014 and Roads from Mass GIS, Parcel Boundaries and Elevation Contours from Cape Cod Commission, Surveyed Groundwater Monitoring Well and Piezometer Cluster locations, Grouwater Table Elevations, Groundwater Elevation Contours, and Groundwater Flow Direction from WaterVision LLC.

Map created by WaterVision, LLC
March 2017

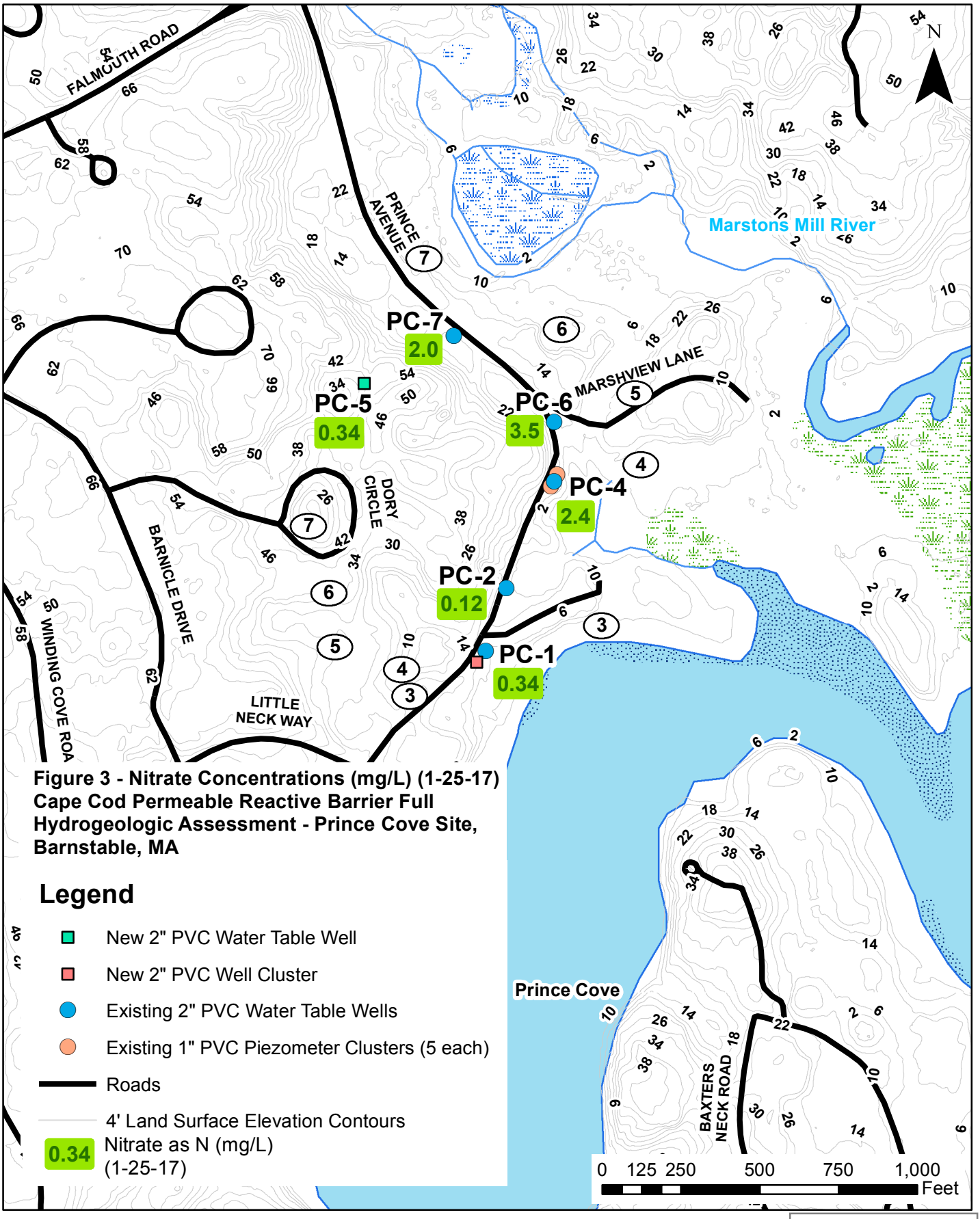


Figure 3 - Nitrate Concentrations (mg/L) (1-25-17) Cape Cod Permeable Reactive Barrier Full Hydrogeologic Assessment - Prince Cove Site, Barnstable, MA

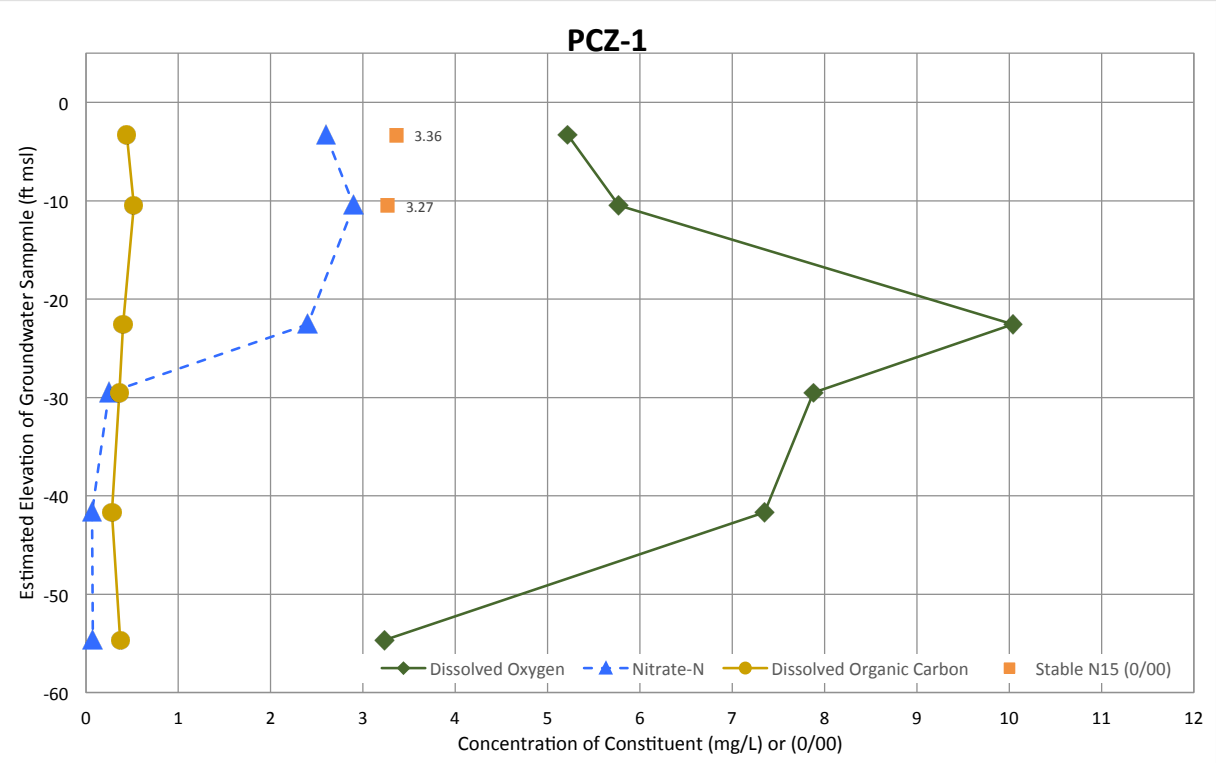
Legend

- New 2" PVC Water Table Well
- New 2" PVC Well Cluster
- Existing 2" PVC Water Table Wells
- Existing 1" PVC Piezometer Clusters (5 each)
- Roads
- 4' Land Surface Elevation Contours
- 0.34 Nitrate as N (mg/L) (1-25-17)

Sources: Aerial photography 2013-2014 and Roads from Mass GIS, Parcel Boundaries and Elevation Contours from Cape Cod Commission, Surveyed Groundwater Monitoring Well and Piezometer Cluster locations, and Nitrate as N from WaterVision LLC.

Map created by
WaterVision, LLC
March 2017

Figure 4 – Variation of Nitrate-N, Stable Nitrogen Isotope, Dissolved Oxygen, and Dissolved Organic Carbon Prince Cove, Barnstable, MA, Dec 2016 to Jan 2017



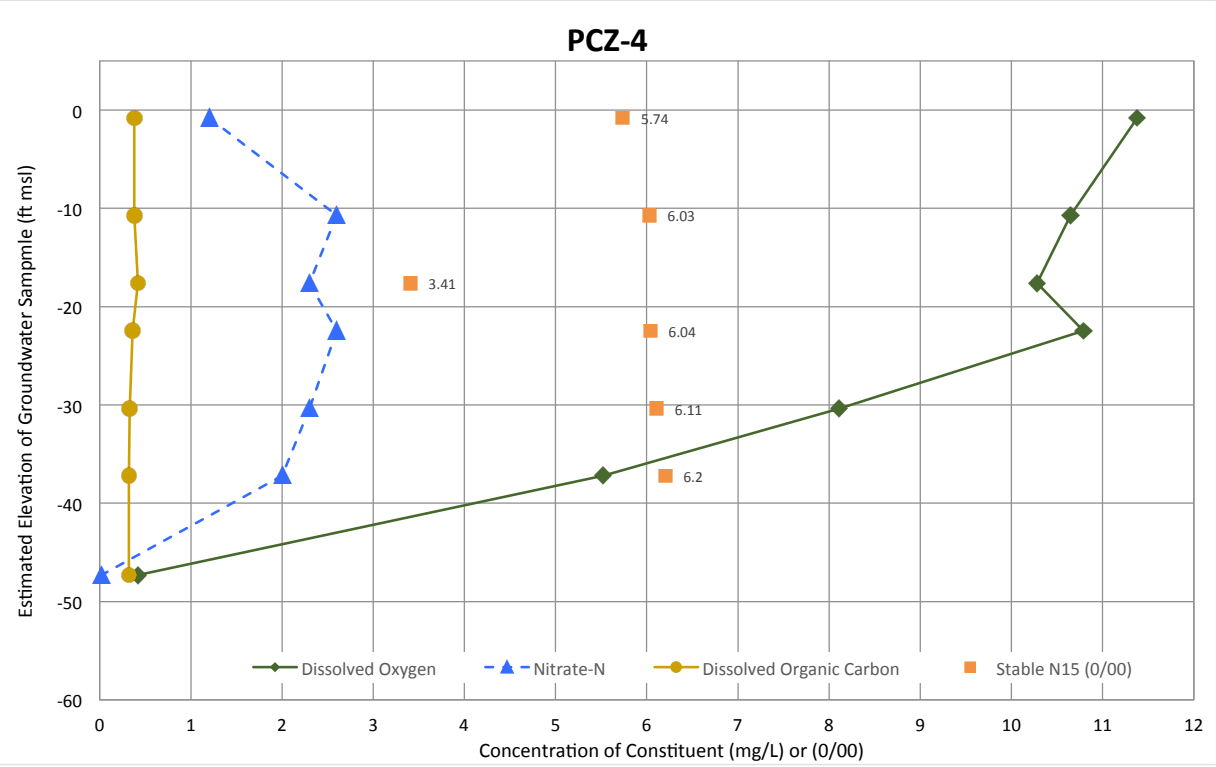
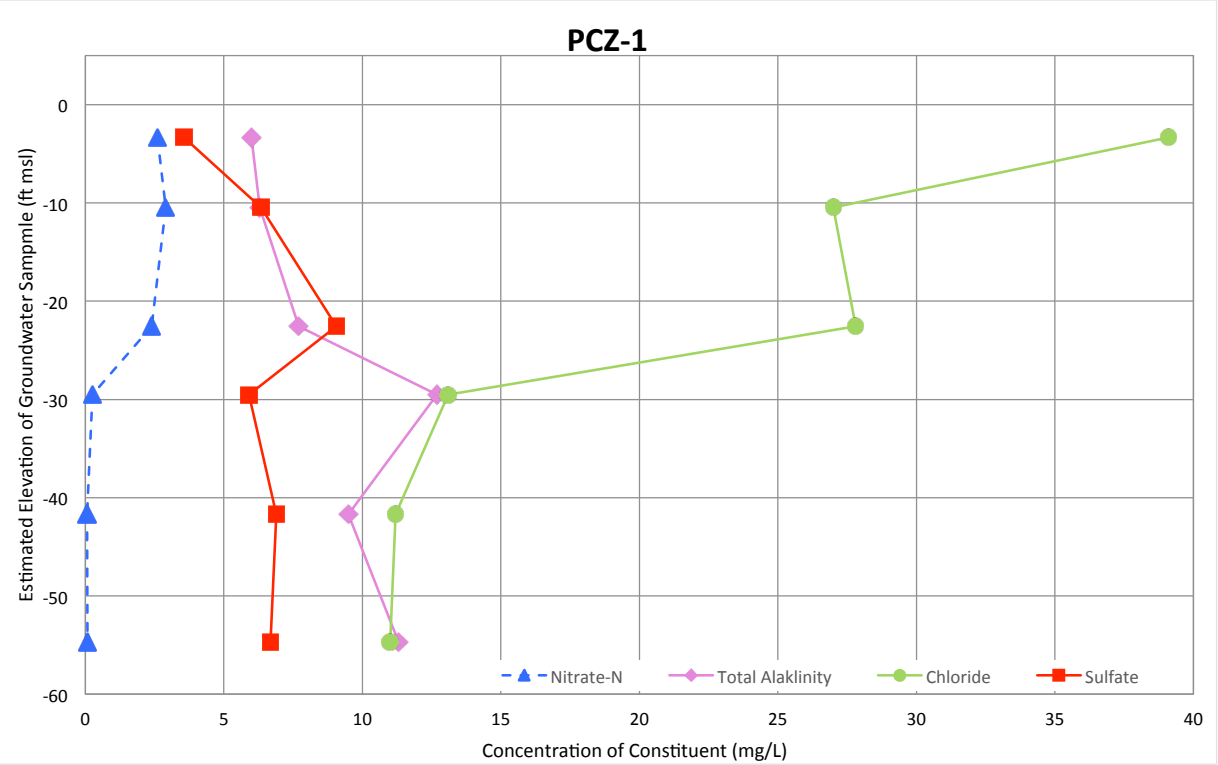


Figure 5 – Variation of Nitrate-N, Total Alkalinity, Chloride, and Sulfate
Prince Cove, Barnstable, MA, Dec 2016 to Jan 2017



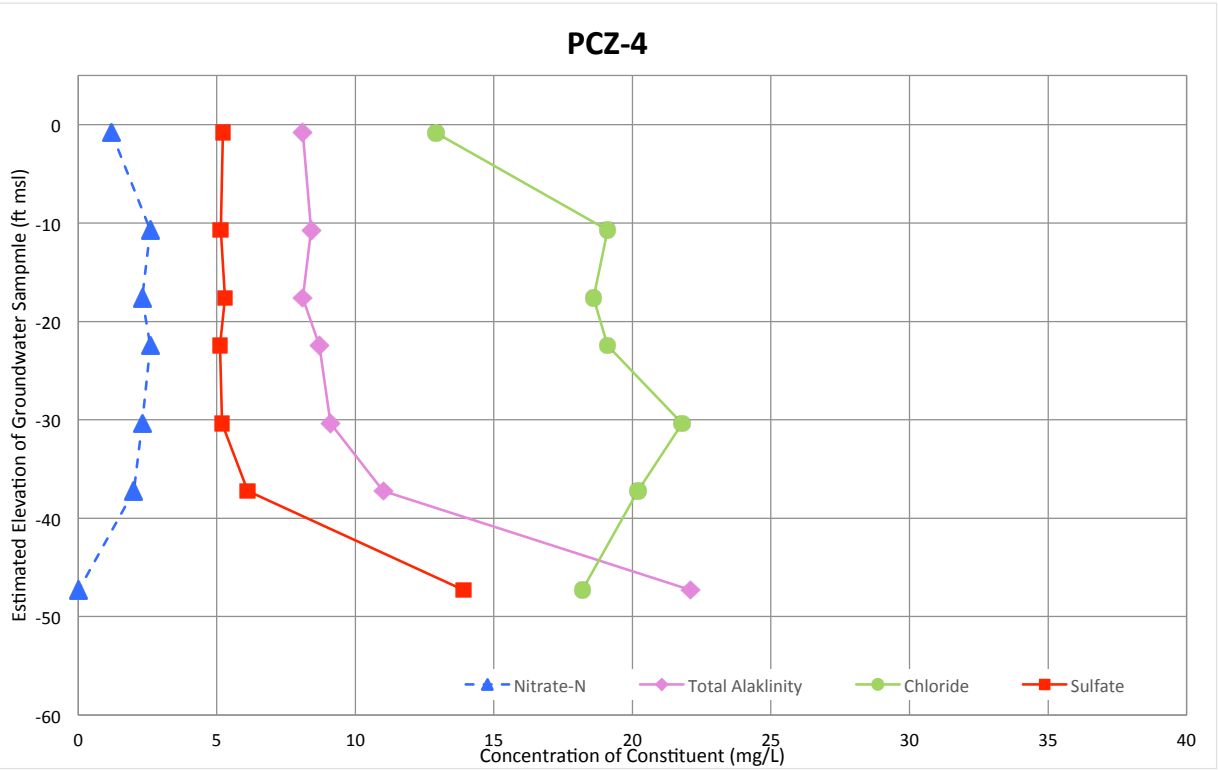


Figure 6 – Variation of Dissolved Oxygen, Dissolved Iron, Dissolved Manganese, and Dissolved Arsenic Prince Cove, Barnstable, MA, Dec 2016 to Jan 2017