Savery Pond
East Bog Hydrogeologic Reconnaissance Investigation

MAY 2020

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1.0 INTRODUCTION

This document presents the methods and results of piezometer installation, water-level measurement, hydrogeologic interpretation and water-quality sampling performed on the fallowed cranberry bog ("site") located on the east side of Savery Pond in Ellisville, Massachusetts.

A critically positive step in Ellisville watershed restoration occurred in October of 2016, when the Town of Plymouth ("Town") acquired the site through an action of Plymouth Town Meeting, supported by the Community Preservation Act. By simply taking the cranberry bog out of commercial production, the Town eliminated a major source of nutrient applications in the watershed. The Town has additional plans to reduce the transport of legacy nutrients from the site's sediments into rest of the watershed by removing water-control infrastructure that currently permits limited quantities of surface-water flow from the fallowed bog into Savery Pond.

This investigation is aimed at increasing understanding of hydrologic conditions and nutrient occurrence at the site. The Town has kindly supported this project, not least by granting access to the site for testing and sampling purposes. The work documented herein was performed by the Savery Pond Conservancy (formerly the "Savery Pond Project" of Friends of Ellisville Marsh) and volunteers in June 2018, with a second sampling event in November 2018 and a third sampling in May 2020. The site layout and location of monitoring points is shown on **Figure 1**.

The original project scope was developed to:

- Install 3 shallow drive-point piezometers on the perimeter of the East Bog Site ("site");
- Measure depth-to-water (DTW) in each piezometer;
- Survey the piezometer elevations and calculate water-level elevations (WLE's);
- Estimate the direction of groundwater flow beneath the bog; and,
- Sample the groundwater and assess nutrient concentrations.

The Savery Pond Conservancy ("SPC") originally assumed a conceptual hydrogeologic model where groundwater beneath the site is an expression of the regional water table, such that our investigation would characterize local flow directions and groundwater quality in the regional water-table aquifer. During our investigation we found that groundwater beneath the site appears to be perched atop a naturally occurring, dense confining layer, such that the uppermost water table occurs above regional groundwater elevations. The perched water-table elevation appears to be equivalent to water levels in about 4,300 linear feet of ditches that surround and bisect the bog. Because the perched groundwater beneath the site is mainly expected to interact with the ditches (no dominant groundwater flow direction), and because hand-driven piezometers could not be advanced through the dense confining unit into the regional aquifer, we reduced our scope to include fewer piezometers.

This investigation was performed by a licensed hydrogeologist[1] with assistance from SPC volunteers. Study results provide improved understanding of hydrogeologic and water-quality conditions associated with the East Bog. Our methodology, results and interpretation are presented below.

2.0 SUMMARY OF FINDINGS & CONCLUSIONS

1. SPC characterized hydrogeologic conditions beneath the site by excavating two test holes, installing one piezometer and surveying groundwater elevations in the piezometer and the regional aquifer. The site is underlain by a shallow perched aquifer comprised of saturated peat lying over a dense perching layer. The peat is topped by 1-2 feet of anthropogenic sand, emplaced during historic cranberry operations. Groundwater levels in the perched aquifer are about 4.4 feet higher than Savery Pond and about 6 feet higher than the regional aquifer. Perched-aquifer water levels are roughly equivalent to water levels in the ditches that surround and bisect the bog, such that the aquifer and the ditches are hydraulically connected.
2. Shallow groundwater beneath the site footprint is recharged by direct precipitation and could also receive subsurface inflow from neighboring areas (*if* the perching layer extends into adjacent, higher-elevation areas). Shallow groundwater beneath the site discharges via both surface-water and groundwater pathways. The surface-water path leads to Savery Pond, as water control structures on the bog have been observed to convey ditch water to the excavated canal that extends from Savery Pond to a former pumphouse alongside the site. Flow from the canal into the pond is suggested by occurrences of observably altered water quality in the pond at the mouth of the canal. The groundwater path occurs as perched water seeps downward to the regional aquifer, where it either flows towards the pond or eastward towards the coast. Depending on the topography of the perching layer, perched groundwater could also discharge directly into the canal, into the pond, or into joints in the discharge pipe that connects the bog ditches to the canal. Perched groundwater movement is expected to be relatively slow, since the peat deposits appear to exhibit low permeability.
3. SPC collected limited samples to characterize water quality in the perched aquifer, the ditches, the (ditch-fed) discharge pipe, and the canal. The constituent of greatest concern is phosphorus, a key nutrient that sustains algal blooms in freshwater features. Sampling was limited to three events and showed that:
    - Dissolved phosphorus (orthophosphate) in the ditches, discharge pipe and perched aquifer was on the order of 0.16 to 0.35 mg/l, which is approximately 10x higher than typical total phosphorus (TP) concentrations measured in Savery Pond (0.02 – 0.04 mg/l). Pond samples taken just above bottom

[1] Peter Schwartzman, SPC Board Member

sediments have shown TP concentrations as high as 0.2 mg/l, presumably associated with summer release of adsorbed legacy nutrients.

- TP in the ditches and (ditch-fed) discharge pipe has ranged from 0.23 to 1.5 mg/l, which is significantly higher than the typical pond concentrations noted above.
- Phosphorus concentrations in the canal are lower than in the ditches and higher than typical pond concentrations.

4. Phosphorus in the site groundwater and ditch-water may be sourced from: 1) legacy nutrients accumulated from historic fertilizer applications (e.g. adsorbed to iron oxides in the anthropogenic sands) and 2) decomposition of organic matter in the peat. Nutrients from septic systems at the adjacent Indianhead Resort could also be conveyed towards the site if the perched aquifer underlies these facilities and if flow directions lead towards the site. Documenting this connection would likely require access to the adjacent property to install piezometers.
5. Recommendations for future data collection will depend on the new hydrologic equilibrium established once upcoming modifications to water-control infrastructure are in place. Future data collection should be oriented towards understanding hydrologic and nutrient pathways established under the new equilibrium.
6. Development of a Savery Pond Management Plan is currently underway. The effort is managed by the Town's Department of Marine and Environmental Affairs (DMEA) and performed by UMass Dartmouth School for Marine Science & Technology (SMAST). The Plan will include both a "water budget" and a "nutrient budget" for the pond. Management practices at the "East Bog" have recently undergone significant changes. In order to assess the influences of past, recent and future site management practices on nutrient cycling, simplifying assumptions will need to be applied. The data presented in this report may be useful for constraining recent site conditions.
7. Better understanding of nutrient cycling associated with the "West Bog" (across the pond) would benefit the pond nutrient budget.

3.0 WATER-CONTROL INFRASTRUCTURE

The former bog comprises about 6.5 acres of the Town's 11.5-acre parcel. The bog is surrounded by about 2,500 linear feet of perimeter ditches and is bisected by about 1,800 linear feet of interior ditches (**Figure 1**). Current water-control infrastructure is shown on **Figure 2**, and includes:

- An excavated "canal" that extends from the pond to a pump-house adjacent to the former bog. The canal is about 300-feet long and 10-feet wide. A pump intake previously extended from the pump-house to the canal, such that pumping drew water into the canal from the pond.

- A smaller-diameter (e.g. 16-inch) discharge pipe that extends from the canal to the perimeter ditch (location S-4 on **Figure 1**). This corrugated pipe is capable of conducting drainage from the bog ditches into the canal.
- A vertical control structure, also comprised of smaller-diameter corrugated pipe, set on the perimeter ditch near location S-2. The structure is designed to house boards that control the water-level in the ditches and outflow to the canal via the discharge pipe.
- A large-diameter, horizontal control structure, known as the "main spillway", also positioned near location S-2. The structure is comprised of corrugated culvert pipe and was recently fitted with a flap valve to prevent entrance of water from the perimeter ditch. The horizontal culvert connects to a vertical vault on the ditch bank which contains a boarded control structure. Prior to installation of the flap valve, the culvert was open ended and the boards controlled the water level in the ditches. Pumping from the canal was presumably routed to the vertical vault where it overtopped the boards and flooded the former bog. Removal of boards allowed the bog to drain back to the canal, although SPC is unfamiliar with the drainage conveyance.

4.0 PIEZOMETER INSTALLATIONS

SPC acquired 3 Solinst stainless-steel drive points along with various lengths of threaded steel pipe and couplings in order to construct the piezometers. The Model 615N drive points are approximately 1.5-feet long and 1-inch diameter and were adapted to connect to 1-inch black steel pipe. SPC used 4-inch PVC pipe to construct above-ground locking caps for the piezometers and used a small quantity of "Quikrete" concrete mix to fix the caps in place. The originally intended installation procedure was to:

1) Use a shovel and a post-hole digger to excavate a roughly 12-inch diameter hole to a depth of 2.5 feet.
2) Use a flat-ended, heavy steel rod to make a pilot hole for the piezometer, typically to a depth of around 4 feet.
3) Note groundwater occurrence in the shovel hole or pilot hole (where present).
4) Insert the piezometer/steel-pipe assembly into the pilot hole and advance downward using a post driver until achieving 5 feet of penetration below the observed water table or until driving resistance precludes further advancement ("refusal").
5) Measure depth to water (DTW) in piezometer to confirm that the piezometer contains at least 5 feet of saturation.

Solinst Drive Point

6) Install the locking PVC well cap around piezometer pipe within 12-inch hole using a combination of native-soil backfill and Quikrete to hold well cap in place.
7) Obtain GPS location coordinates.

Field conditions prevented driving the piezometers down to 5 feet below the observed water table. A dense confining layer was encountered beneath surficial soils that prevented further advancement of the piezometers. Installation of the drive points within or below the confining layer was considered undesirable because it would provide WLE's and water-quality data that are not indicative of conditions in the uppermost aquifer. Upon consideration of *actual* field conditions, piezometers (a dual-depth pair) were installed at only one location (MW-2). A single piezometer was initially installed at a second location (MW-1) but was later abandoned. The rationale for installing just one piezometer pair is discussed in the "Interpretation" section below.

Piezometer Wellhead

MW-2 Installation

The dual-piezometer pair (MW-2) was installed within the former cranberry bog along the northwestern site boundary (**Figure 1**). The following soil profile was observed to a depth of around 3 feet below land surface (BLS):

- 0 – 0.5 feet: sandy top soil and cranberry plant root mass
- 0.5 – 1.5 feet: gray sandy soil
- 1.5 – 2.5 feet: black, sandy peat soil
- 2.5 – 3 feet: wet black peat (muck), sulfur smell

Soil observations could not be made beneath 3 feet, but insertion and removal of the steel rod suggested relatively loose mucky soils, and the drive point was easily driven to 6.5 feet BLS before it encountered a dense layer that was difficult to penetrate. Advancement beneath 6.5 feet was limited to about ½ inch per 30 strokes of the post driver, and only 6-inches of the dense layer were penetrated (total depth of 7 feet BLS). The drive-point screen extends from around 5.7 to 6.7 feet BLS and is predominantly positioned above the top of this dense layer. The entire piezometer assembly was 9 feet long and has 2.0 feet of stickup above the land surface. During installation, water was noted in the excavation at about 3 feet BLS.

DTW measurement within the drive point piezometer *initially* revealed a lower water level than the 3-foot DTW observed within the excavation. Because this difference might suggest a downward vertical hydraulic gradient within the mucky soils, a second piezometer was installed to a depth of 3.3 feet BLS to allow measurement of WLE as a function of depth. The shallower piezometer was constructed of 1-inch PVC pipe with a PVC cap glued on the bottom and 1/16-inch holes drilled in multiple locations in the bottom 1.5 feet. The PVC piezometer had a total length of 4.75 feet with a stick-up of 1.4 feet above land surface. The two piezometers were strapped together with a hose clamp.

DTW was measured during the installation (6/15/18) and on 6/19/18 when water-quality samples were taken:

Piezometer	Completion Depth	6/15/18 DTW	6/19/18 DTW
Shallow (33”)	1.8 – 3.3 feet BLS	2.2 feet BLS	2.1 feet BLS
Deep (67”)	5.7 – 6.7 feet BLS	4.9 feet BLS	2.1 feet BLS
Difference	3.7 feet	2.7 feet	None

The 6/19/18 measurements reflect conditions after shallow groundwater was able to equilibrate to the two piezometers. These data suggest no significant vertical hydraulic gradient within the mucky soils that overlie the dense layer, although it is also possible that leakage along the 1-inch steel pipe could have equalized water levels between the two piezometer completions.

A laser level was used on 6/15/18 to compare the WLE in the shallow piezometer and the adjacent dich (about 8 feet away). The comparison showed that the two WLE’s were essentially the same (within 0.1 feet of one another). In addition, comparison of surveyed WLE’s in MW-2 to that of Savery Pond measured in August 2018 shows that WLE’s in the perched aquifer (and presumably the ditches) were 4.4 feet higher than the pond elevation (Section 5). WLE’s in the canal previously used to draw water towards the intake of the bog pump are equivalent to WLE’s in the pond, since there is no hydraulic obstruction between the pond and the far end of the canal.

MW-1 Installation

The single piezometer (MW-1) was installed just outside the cranberry bog on the southwest edge of the site (between the former bog and the former access road). Beneath about 0.5 feet of grassy topsoil, a sandy, silty loam was observed in the shovel excavation between 0.5 and 2.5 feet BLS. Several cobbles were removed during the excavation. Beneath 2.5 feet BLS, manipulation of the steel rod (insertion, removal, sledge hammering) suggested tighter, siltier soils, with possible occasional cobbles. Advancement became difficult at 4.5 feet BLS, at which point the drive-point piezometer assembly was inserted and driven to 5.5 feet BLS. Advancing the drive point was very difficult, with 30 strokes of the post driver yielding only ¼ to ½ inch of movement. Refusal was called after accomplishing 1 foot of penetration. Because *every* drive yielded small gains, conditions between 4.5 and 5.5 feet BLS were interpreted as more likely dense clay than a cobbly formation. There was no evidence of cobbles (e.g. “bouncing” of the drive point) within this interval.

DTW within the drive-point piezometer was 3.8 feet BLS, which appeared to be roughly equivalent to the WLE in the adjacent ditch. Based on the hydrogeologic interpretation below, it was decided that MW-1 was not needed for monitoring and the piezometer was abandoned by detaching the steel pipe from the drive point, leaving the remnant 1.5-foot drive point 5 feet underground, and backfilling the hole with the excavated soil.

5.0 HYDROGEOLOGIC INTERPRETATION

It is not surprising that a cranberry bog was constructed at the East Bog Site, as hydrogeologic conditions are favorable for keeping saturation out of the root zone when needed yet flooding the bog during harvest. The site appears to be underlain by a dense, compact layer that restricts downward groundwater movement towards the regional water-table aquifer. This low-permeability layer causes "perched" conditions, where shallow groundwater collects atop a "perching layer" and exhibits a local water-table elevation above the regional aquifer[2]. The perched water table elevation appears to be equivalent to water-levels in the site ditches and is likely controlled by the water-level maintained in the ditches by the vertical control structure described in Section 3. In August 2018, perched groundwater in MW-2 was measured to be 4.4 feet higher than Savery Pond and estimated to be about 6 feet higher than in the underlying regional water-table (**Figure 3**). These water-level differences, along with groundwater flow patterns in the regional aquifer, are further documented in the Friends of Ellisville Marsh's "*Savery Pond 2018 Water Levels and Streamflow Report*" (FoEM, 2019). Detailed descriptions of the regional water-table aquifer and its hydraulic connection to surface-water features developed by the U.S. Geological Survey can be found in studies by Hansen & Lapham (1992) and Masterson et al (2009).

Because the perched aquifer has a higher water-level elevation than the regional aquifer, it locally discharges *to* the regional aquifer rather than receiving groundwater inflow *from* the regional aquifer. Discharge to the regional aquifer can occur via slow downward leakage through the low-permeability perching layer or can occur directly if there are locations where the perching layer pinches out. The water-level difference between the perched aquifer and Savery Pond also suggests that perched groundwater may discharge to the pond via subsurface flow. Finally, since the perched aquifer is hydraulically connected to the ditches, and because the ditches have been observed to discharge to the canal during wet conditions via the vertical control structure, a surface-water route exists for both perched groundwater and ditch water to reach the pond. SPC volunteers have observed and documented multiple instances of flow entering the vertical control structure and exiting the discharge pipe. Discharge observations have ranged from just a trickle during dry conditions in June 2018 to visual estimates on the order of 20-30 gallons per minute (gpm) during wet conditions in November 2018. **Figure 4** shows water entering the vertical control structure and exiting the discharge pipe (*videos documenting flow are available upon request*). In addition, SPC volunteers have noted altered pond water quality at the mouth of the canal (e.g. foam, increased algal occurrence), thus suggesting a component of flow from the canal into the pond.

It is reasonable to expect that a portion of the water in the ditches originates as shallow groundwater associated with the perched system. The perched aquifer underlying the site is recharged by direct precipitation and may receive groundwater inflow ("subflow") from perched groundwater in adjacent areas. Local residents note prolonged occurrence of water in the ditches even during periods of low precipitation, and such prolonged occurrence is likely groundwater fed. LiDAR topographic mapping in **Figure 5** shows that the site is surrounded by areas of higher elevation. If portions of these areas are also

[2] The formal definition of a perched aquifer includes an unsaturated zone between the bottom of the perching layer and the underlying water table. Without fully penetrating the low-permeability layer, it cannot be determined whether the regional aquifer is unconfined beneath the perching layer or whether the perching layer locally confines the regional aquifer. However, it is common vernacular to refer to a thin saturation of surficial soils above a shallow low-permeability unit as "perched".

underlain by the perching layer (or similar perching layers), groundwater recharge may be directed toward the site. It is worth noting that prolonged occurrence of water in the ditches has continued even after the bog was taken out of commercial production in late-2016, thus suggesting a natural source (i.e. groundwater) rather than reliance on irrigation applications. The duration of standing water in the ditches may be influenced, in part, by management of the adjustable ditch gate.

As noted above, water in the combined ditch/perched-aquifer system is expected to reach Savery Pond via both surface and subsurface pathways. Groundwater flow is likely very slow in the peat soils that underlie the site. Low permeability of the peat soils is suggested both by very low well yield during sampling of MW-2 (discussed below) and the time required for the groundwater to equilibrate to the shallow and deep piezometers after installation (discussed above). Similarly, transmission of shallow groundwater to the ditches is expected to be relatively slow.

6.0 RATIONALE FOR FINAL PIEZOMETER INSTALLATIONS

The rationale for not installing a permanent piezometer at location MW-1 and not installing a third piezometer follows:

- WLE's in shallow piezometers on the perimeter of the site appear to be equivalent to WLE's in the nearby ditches.
- The ditch system surrounds and bisects the site. All ditches are interconnected and share the same WLE. Thus, WLE's measured in the perched aquifer near the ditches are all expected to be similar and would not demonstrate a groundwater flow direction.
- Although a groundwater flow direction may be measurable in the underlying regional aquifer, it was not possible to advance the piezometers into the regional aquifer because the perching layer was too dense.

Monitoring WLE's in MW-1 is unlikely to yield information on groundwater flow patterns in the perched aquifer. However, after further consideration, it was recognized that MW-1 might have been useful for sampling groundwater *quality* immediately outside the ditch system. During installation, MW-1 exhibited a perching layer similar to MW-2 (although overlying sediments were mineral rather than organic). If samples were taken from MW-1, additional mapping of shallow groundwater would likely be needed to understand the source of groundwater in the well. Groundwater flow directions locally inferred[3] in the *regional* aquifer suggest easterly flow from one of the bathroom septic drainfields on Indianhead Resort towards the site (**Figure 3**); however, the exact location of the drainfield is unknown, nor is it known whether the perched aquifer extends that far west of the bog. Additionally, a second septic drainfield (likely associated with a bathroom and a trailer waste dump station) is located immediately south of the bog, and underlying occurrence of the perched aquifer is similarly unknown. The site parcel

[3] Groundwater flow directions are *inferred* based on expected relationships and regional water-table mapping (Hansen & Lapham, 1992) where locally measured water-level elevations are unavailable.

boundary does not extend far from the perimeter ditches; thus, mapping local shallow groundwater occurrence and flow would likely require cooperation from Indianhead Resort. If desired, additional perched-aquifer piezometers could be installed along the eastern and southern property boundaries (preferably using a truck-mounted auger rather than a drive point). However, the source of sampled groundwater would remain unknown without piezometers installed on the neighboring property. It should also be noted that additional piezometers or wells tapping the regional aquifer south of Savery Pond would be required to elevate interpreted flow directions from “inferred” to “estimated based on *actual* measurements”.

7.0 WATER-QUALITY SAMPLING, RESULTS AND INTERPRETATION

SPC is interested in how nutrient concentrations in the perched aquifer below the fallowed bog compare to those in the pond and the regional aquifer. We returned to the site on 6/19/18 (several days after MW-2 was installed) to measure static water levels and obtain groundwater samples from both the shallow and deep piezometer completions. Sampling was performed by purging with a Solinst ½-inch stainless-steel bailer. SPC first purged both completions dry in order to allow fresh (representative) groundwater to re-enter the piezometers. Because water levels in both completions recovered *very* slowly after purging, SPC had to bail the completions multiple times over several hours and combine samples from both completions to obtain sufficient sample volume[4]. The combined sample was stored in a clean, unpreserved plastic bottle and maintained in an iced cooler over the sampling period and subsequent transport to the lab (Envirotech Laboratories in Sandwich MA). The combined sample was turbid, black in color, and had a sulfur smell. Because the total combined volume (~250 ml) was less than typically requested by the lab (500 ml), and because SPC was interested in *dissolved* groundwater chemistry, we asked the lab to filter the sample, dilute it to obtain sufficient volume, and correct for the dilution once concentrations were measured.

Combining samples from both the shallow and deep piezometer completions was seen as representative because the minimum separation between completions is only 2.4 feet and both completions exhibited the same groundwater levels. As previously noted, the ditch system surrounding and bisecting the site also exhibited the same WLE as the piezometers. In order to further evaluate the interpreted hydraulic connection between the perched aquifer and the ditch system, SPC decided to sample the ditch system close to the adjustable ditch gate that provides an outlet to the canal that connects the former bog to Savery Pond. We also sampled the canal just downstream (and across from) of the bog discharge pipe. These supplemental sampling locations are shown on **Figure 1**. The ditch sample (from S-1) was brownish in color (similar to dilute ice tea) and the canal sample (from S-3) was relatively clear. Samples were similarly taken in clean,

[4] Additional consideration of the chemical effect of the extended sampling time may be warranted, and SPC may refine the procedure for sampling MW-2 based on suggestions from a qualified lab.

unpreserved plastic bottles with sufficient volume obtained for the lab. Bottles were immediately delivered to the lab after the last sample was collected[5].

SPC visited the site several times during wetter months in late 2018. On 11/12/18 we took a repeat sample from the perimeter ditch immediately adjacent to the vertical control structure (location S-2 on **Figure 1**). Water was seen flowing out of the ditch into the structure at this time. During a third sampling event on 5/5/20 we directly sampled the discharge pipe that flows into the canal (location S-4 on **Figure 1**). Flow from the pipe was estimated at around 15-20 gpm at this time. Samples were taken, handled and delivered to the lab similar to the description above.

The following table presents the laboratory results. For the 6/19/18 sample set, due to the focus on dissolved nutrients in groundwater, the sample from MW-2 was only analyzed for orthophosphate and nitrate/nitrite. Because surface water in the ditch was expected to have more organic matter, the ditch sample (from S-1) was also analyzed for total phosphorus, ammonia and total Kjeldal nitrogen (TKN). Total nitrogen was calculated by adding TKN, nitrate and nitrite. The canal sample (at S-3) was simply analyzed for orthophosphate and total phosphorus. For the 11/12/18 sample, taken from the perimeter ditch at S-2, SPC had the lab add analyses for total iron and manganese. Analysis of the 5/5/20 discharge-pipe sample focused on nitrogen and phosphorus species.

Parameter	Method	Reportable Limit	6/19/18 Results			11/12/18 Results	5/5/20 Results
			Ditch (S-1)	Pond Canal (S-3)	MW-2	Ditch (S-2)	Discharge Pipe (S-4)
Kjeldal Nitrogen	SM4500-Norg B-C	0.6	1.9	NA	NA	0.90	0.85
Ammonia-N	SM4500 NH3 C	0.5	BRL	NA	NA	BRL	NA
Nitrate-N	EPA 300.0	0.01	BRL	NA	0.64	BRL	BRL
Nitrite-N	EPA 300.0	0.006	BRL	NA	BRL	BRL	BRL
Total Nitrogen	Calculation	NA	1.9	NA	NA	0.90	0.85
Total Phosphorus (P)	SM 4500-P-B,E	0.005	0.483	0.158	NA	1.48	0.227
Ortho Phosphorus (P)	SM 4500-P	0.005	0.346	0.074	0.303	0.31	0.164
Total Iron	EPA 200.7	0.005	NA	NA	NA	1.12	NA
Manganese	EPA 200.7	0.005	NA	NA	NA	0.031	NA

Notes: All values in mg/l. "BRL" = below reportable limit. "NA" = not analyzed

[5] The recommended sampling methodology notes that use of plastic bottles has the potential to reduce measured phosphorus concentrations due to potential adsorption onto the bottle walls. Thus, reported concentrations might potentially underestimate phosphorus concentrations. Bases on conversations with several labs, SPC concludes that sampling in plastic bottles without preservative is not expected to result in false increases in measured concentrations. Future sampling will be performed in glass bottles.

The following observations may provide useful context for the above results:

- Orthophosphate concentrations from 6/19/18 measured in the piezometer and the ditch are very similar and around four-times higher than observed in the pond canal. Orthophosphate from the ditch remained similar between 6/19/18 and 11/12/18 but was slightly lower in the (ditch-fed) discharge pipe on 5/5/20.
- In the 6/19/18 and 5/5/20 sample sets, total phosphorus (TP) was just slightly higher than orthophosphate in the ditch and discharge-pipe water, thus suggesting that most of the measured phosphorus was dissolved. In the 11/12/18 sample set, total phosphorus in ditch water was 5x larger than dissolved. Both samples had a similar "dilute ice tea" appearance.
- Total phosphorus from the three ditch (and ditch-fed discharge-pipe) sampling events was measured at concentrations about 10x to 100x higher than typical TP values observed in Savery Pond during prior summer monitoring (FoEM, 2017). Summer pond TP values typically range from 0.02 to 0.04 mg/l, although concentrations on the order of 0.2 mg/l were observed in samples taken near the bottom of the pond (potentially associated with sediment regeneration of TP into the overlying water column during anoxic conditions). *Orthophosphate* in the ditch and the piezometer was also measured at concentrations about 10x higher than typical TP values observed in Savery Pond. To date, pond orthophosphate sampling has been limited to summer and early fall.
- Background phosphorus concentrations in the regional aquifer are expected to be negligible on a regional scale (although localized impairment could occur from septic systems or fertilizer applications). In August 2017, SPC sampled seven domestic wells located west of Savery Pond and submitted a composite sample to Envirotech Laboratories. The lab results showed no detect on orthophosphate (less than the detection limit of 0.005 mg/l) and a nitrate concentration of 0.26 mg/l. Groundwater flow directions on **Figure 3** suggest that only 5 residential septic systems occur upgradient of Savery Pond; however, one of the bathrooms at the Indianhead Resort[6] (presumably associated with its own dedicated septic system) *may* be upgradient. Groundwater level data are unavailable beneath the Indianhead Resort.
- The Cape Cod PALS Program[7] developed a subregional impaired threshold criteria for TP of 0.01 mg/l based on sampling over 175 Cape Cod ponds (most of which were considered impaired by nutrients) and identifying the lower 25th percentile concentrations.
- Both the 6/19/18 and the 11/12/18 ditch samples show detectable TKN but no detectable nitrate/nitrite. This may be consistent with anoxic (reducing) conditions, where micro-organisms break down the nitrate to get at the oxygen in the nitrate molecule.

[6] http://www.indianhead-resort.com/wp-content/uploads/2016/06/map.pdf
[7] http://www.capecodgroundwater.org/ponds-estuaries/stewardship-program/

Detailed interpretation of the water-quality data is beyond the scope of this report. It is worth noting that the similar orthophosphate concentrations in the piezometer and the ditch are consistent with the interpreted hydraulic connection between these two features. Higher TP measured in the 11/12/18 ditch sampling may reflect a greater presence of organic matter, although the 6/19/18 and the 11/12/18 ditch samples looked similar. Concurrent sampling of the ditch and the canal on 6/19/18 showed lower phosphorus levels in the canal, but still elevated relative to typical pond concentrations. Occurrence of such elevated phosphorus in the onsite piezometer and ditches (and less-so in the canal) could be attributed to a variety of factors, including:

- Decomposition of organic matter in the naturally peaty soils that underlie the fallowed bog.
- Prior land-use activities at the fallowed bog. While under commercial operation, the bog received regular applications of fertilizers and other chemicals, some of which may still be adsorbed to the bog soil. Analysis by Kennedy et al (2018) suggests that a significant portion of stored phosphorus occurs in the anthropogenic sand deposits relative to the underlying peat.
- The influence of septic effluent from the campground resort adjacent to the site. The campground resort has a large onsite septic system (LOSS) installed in the early 1970's that services 167 individual and 4 group campsites. The LOSS is reportedly located near the building located along the southern edge of the site map (page 2). It is unknown whether the shallow perched aquifer extends south to this location or whether septic effluent predominantly infiltrates to the regional aquifer.

The role of nutrients discharged from the site to Savery Pond can be addressed as part of the nutrient budget for the pond. Recent streamflow monitoring in Herring Brook at the Savery Pond outlet control structure showed baseflows ranging from around 0.2 to 0.6 cfs in 2018 (a relatively wet year). This baseflow is supported by discharge from the regional aquifer and represents *just a portion* of the total pond flushing associated with regional groundwater entering Savery Pond (FoEM, 2019). Site discharge to the pond likely occurs via both surface-water and groundwater pathways. The surface-water pathway can be estimated by observations of pipe discharge to the canal, which ranged from "just a trickle" during the 2018 dry season to around 15-30 gpm (0.03-0.06 cfs) during the 2018 wet season. The groundwater component cannot be directly measured but might be conservatively estimated by performing a water budget on the site. Both discharge rates and nutrient concentrations are required to perform a nutrient budget analysis.

8.0 CONSIDERATIONS FOR FURTHER STUDY

As previously mentioned, the Town intends to remove water-control structures related to pumping and draining the former bog. These modifications are aimed at diminishing the direct introduction of legacy nutrients from site sediments (and associated water) into both Savery Pond and downstream portions of the watershed. Given these upcoming modifications, detailed recommendations for future monitoring would be premature.

Based on our current understanding of the site, SPC suggests the following considerations for future action:

- The current site configuration allows variable rates of discharge into Savery Pond via (observed) surface-water pathways (and (inferred) groundwater pathways. Removing the vertical control structure will eliminate the current surface-water pathway, cause onsite groundwater levels to rise (to some degree), and create a new site equilibrium between inflow- and outflow pathways. The new equilibrium may increase any existing groundwater flow from the former bog to the pond. SPC recommends that any future data collection supports understanding the new hydrologic equilibrium.
- The new hydrologic equilibrium will alter nutrient pathways, with the intention of benefitting Savery Pond. New hydrologic conditions could affect redox (oxidation/reduction) states at the site, thus affecting nutrient mobility. Similar to hydrologic analysis, SPC recommends that any future data collection be geared towards understanding the chemical conditions and nutrient pathways that develop after modification of water-control structures.
- SPC and the Town are currently sponsoring development of a management plan for Savery Pond that includes data collection in the spring, summer and fall of 2020. One goal of the management plan is to analyze how various nutrient-related processes have affected nutrient concentrations in the pond (i.e. performing a “nutrient budget”) and identifying how processes can be changed to reduce nutrient loading. Land-use practices at the East Bog site have recently undergone significant changes. In order to assess the influences of past, recent and future practices on nutrient cycling, simplifying assumptions will need to be applied. The data presented in this report may be useful for constraining nutrient-budget elements associated with *recent* conditions.
- In addition to these considerations and recommendations regarding the “East Bog” site, SPC notes that a better understanding of hydrologic and water-quality conditions associated with the “West Bog” may be useful for Savery Pond water-budget and nutrient-budget analyses. The “West Bog” (located across Savery Pond) reportedly does not exhibit standing water in ditches but is reportedly flooded during harvest.

9.0 ACKNOWLEDGMENTS AND PROJECT CONTACT

SPC wishes to express gratitude to the Town of Plymouth and the Community Preservation Committee for working to acquire and preserve the site and make it available for study. The Town’s Department of Marine and Environmental Affairs has provided essential leadership in the attempt to better understand nutrient cycling and its effect on recurring algal blooms; in particular, environmental technician Kim Tower has been a dedicated supporter of scientific investigations in Ellisville for more than a decade.

We also express gratitude to SPC volunteer Roger Janson, who has tirelessly contributed to data collection and the design, construction and installation of monitoring equipment.

Readers interested in more information about this investigation or about Savery Pond in general can contact SPC at: savery@ellisvillemarsh.org. More information about Savery Pond can be found at www.saverypond.org.

10.0 References

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Figure 1
Locations of Piezometers, Supplemental Sampling Points and Ditches

Savery Pond
2018 East Bog Characterization

Control Structures on Perimeter Ditch

Discharge Pipe (left) and Abandoned Pump Intake (right) on Savery Pond Canal

Figure 2
Water-Control Infrastructure at East Bog

Savery Pond
2018 East Bog Characterization

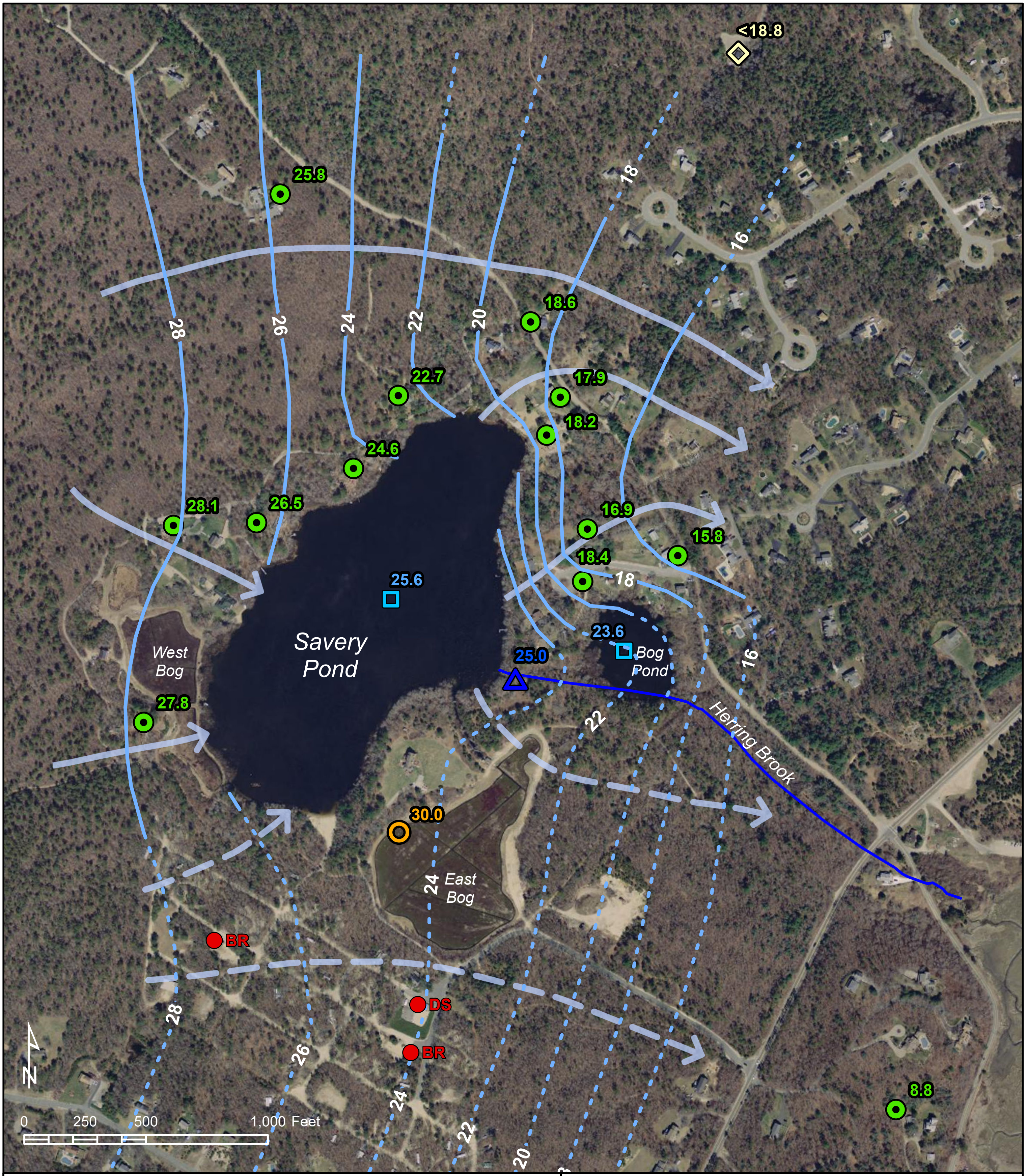

Figure 3
Groundwater Elevations & Interpreted Flow Directions in the Regional Aquifer

Savery Pond
2018 East Bog Characterization

8.8 WLE (feet, NAVD88)
Private Well
Municipal Well
Monitoring Well (Perched)
Pond Gage
Stream Gage
Indianhead Resort Facilities
BR=Bathroom, DS=Dump Station

Herring Brook
Groundwater Flow Direction
Water Table Contour (feet NAVD88)
(dashed where inferred)

SPC

Water from Ditch Overtopping Control Board and Flowing into Small Culvert (12/2/18)

Pipe Outflow into Savery Pond Canal (12/2/18)

Figure 4
Water Discharge from Bog to Pond Canal

Savery Pond
2018 East Bog Characterization

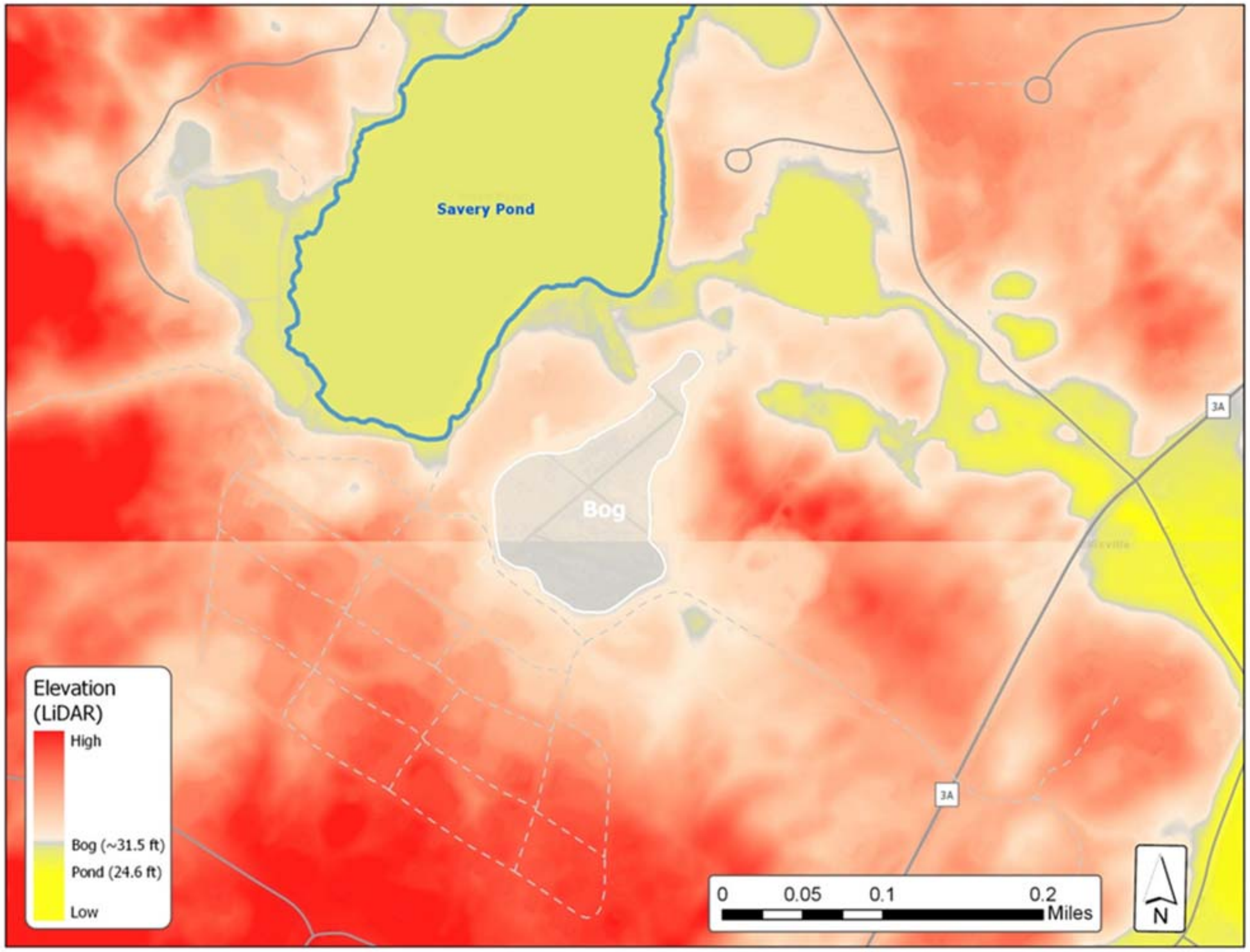

Figure 5
Local Topographic Elevations

Savery Pond
2018 East Bog Characterization