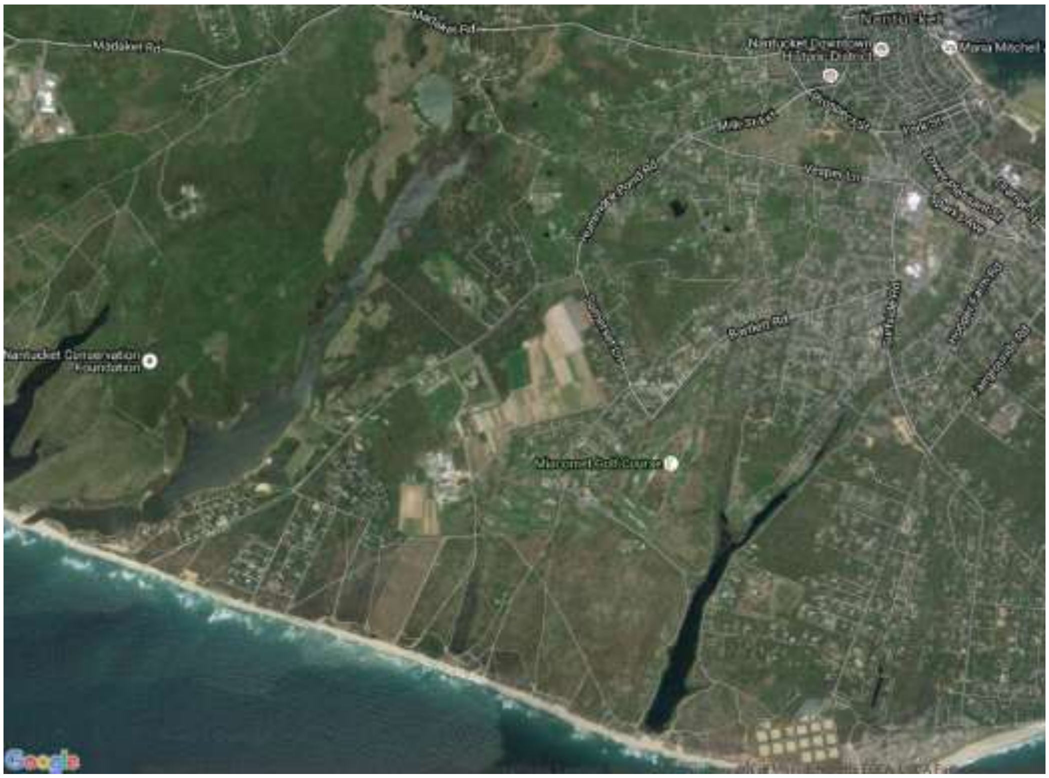
604b STUDY OF PHOSPHORUS SOURCES TO HUMMOCK AND MIACOMET PONDS
Final Report

Project 2015-04/604



Prepared by Water Resource Services, Inc.

For the Town of Nantucket in conjunction with the Nantucket Pond Coalition, with technical and administrative support from the Nantucket Land Council

March 3, 2017

Study of Phosphorus Sources to Hummock and Miacomet Ponds
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Acknowledgment and Disclaimer

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Non-Technical Summary

Hummock and Miacomet Ponds suffer from algae blooms, with cyanobacteria often dominant and posing a public safety threat through possible toxicity. Considerable past effort has been devoted to assessing nitrogen loading to these ponds, with only secondary effort expended on phosphorus loading. While nitrogen is usually the more limiting factor in saltwater, phosphorus most commonly controls algae biomass in freshwater and many cyanobacteria have a way to avoid nitrogen limitation. Reliable control of cyanobacteria blooms therefore involves control of phosphorus.

Concentrations of nitrogen and phosphorus were assessed in groundwater around each pond and surficial sediments from multiple locations were tested for iron-bound phosphorus and organic content, two features important to internal recycling of phosphorus. Oxygen was assessed in each pond, including at the sediment-water interface, where low oxygen can foster excessive release of phosphorus. Algae blooms were also tracked in spring and summer of 2016. Work was carried out under an approved plan funded by a program run by the MA DEP with funds provided by the federal government under Section 604b of the Clean Water Act. Results were put in the context of a loading analysis whereby the relative importance of known sources could be compared and the level of input reduction necessary to achieve desirable conditions could be estimated.

Phosphorus in Hummock and Miacomet Ponds comes largely from internal recycling, loading from the organic bottom sediments that cover about 120 acres of Hummock Pond and 38 acres of Miacomet Pond and are subject to low oxygen conditions much of the summer. Some release under higher oxygen conditions through decay of organic matter may also be important. The addition of saltwater to both ponds historically through breaching of barrier beaches is likely to have depleted iron in affected sediment, limiting the capacity to bind phosphorus. This effect is apparent in the half of Miacomet Pond closest to the ocean, as the rest of the pond was drained to mudflats during breaching, and may still be influential even though breaching has not been conducted in over a decade. Breaching is conducted twice per year in Hummock Pond, spring and fall, and affects the entire pond, although there is a salinity gradient with the largest values near the ocean and the lowest in Head of Hummock at the northern end.

In order to make phosphorus consistently limiting and low enough to prevent cyanobacteria blooms, the internal phosphorus loading in each pond must be addressed. No other source of phosphorus is large enough to provide the level of reduction needed. For both ponds, control of internal loading of phosphorus may be sufficient to eliminate cyanobacteria blooms, but additional reductions from groundwater or surface runoff would provide further protection and prolong the benefits of any action taken in either pond to reduce internal loading.

Options for reducing available phosphorus in each pond to the extent necessary to prevent cyanobacteria blooms have been narrowed down to dredging and inactivation. Dredging would represent true restoration and is highly desirable, but is also very expensive and the permitting process is complicated. If there is the financial support to pursue this option, a detailed feasibility study would be needed. Inactivation involves the application of a phosphorus binder, most often aluminum, targeting either the water column (low dose) or the sediment (high dose). Which approach to use depends on site specific features, and it is recommended that a low dose treatment be attempted at Miacomet Pond to assess effectiveness and longevity before undertaking more expensive actions.

Rooted plants were not the subject of this study, but create nuisance conditions in some areas now, which can be expected to worsen if water clarity is improved through phosphorus and algae control. Dredging would solve most plant problems as well as reduce internal phosphorus loading, but may be cost prohibitive. Evaluating alternatives, the primary options are herbicide application or a harvesting program. As most problem plants in both ponds are seed producing annual species, annual maintenance will be needed, and harvesting is likely to be more acceptable in the permitting process. Hydroraking may be needed to control emergent plants in narrow portions of both ponds where encroachment threatens access if recreational utility has priority as a management goal.

Introduction and Background

Both Hummock and Miacomet Ponds are statutory Great Ponds under the laws of the Commonwealth of Massachusetts and represent major public recreational resources on Nantucket (Figure 1). Hummock Pond covers at least 142 acres in area when connected to the ocean, but can expand to about 267 acres with spring rain and no breaching of the barrier to the ocean, and has covered as much as 427 acres under flood conditions. Miacomet Pond covers approximately 43.5 acres; inclusion of emergent wetland area sometimes inflates the Miacomet Pond area to as much as 47.3 acres. Both are shallow (Figures 2 and 3), not deep enough to have any pronounced or lasting thermal stratification, although there may be vertical gradients of oxygen and other water quality features at times. Hummock Pond averages 6.5 feet deep during summer, with maximum areal coverage corresponding to a mean depth of about 10 feet. Average water depth in Miacomet Pond is 4.0 feet, although this pond has been connected to the ocean by human activity in the past, causing lower water levels.

Hummock and Miacomet Ponds have been connected to the ocean historically, but barrier beaches formed long ago and naturally limit tidal influence. The barrier beach at the south end of Hummock Pond has been intentionally breached in spring and fall in most years for several decades. The opening is created by backhoe and tends to last about a week, during which the water level in the pond drops substantially. Inflow of saltwater during high tides causes further exchange and flushing of the pond, followed by gradual filling by precipitation and groundwater after the breach closes. The barrier beach at Miacomet Pond has also been intentionally breached in the past, with an intent to alleviate flooding in the area, but the last clearly documented opening of the pond to the ocean was in spring of 2005 (Conant 2006).

Both ponds experience algae blooms in summer, including cyanobacteria at potentially hazardous levels. Watershed delineation (Figure 4) suggests that Hummock Pond has a surface watershed of about 2227 acres and a groundwater drainage area that is not congruent with the surface watershed and covers about 2000 acres (NEAR 2006). The direct surface drainage area for Miacomet Pond (Figure 5) covers 653 acres, with that area and another 387 acres contributing groundwater (Woodard and Curran 2014).

Extensive field work and modeling has evaluated nitrogen loading in conjunction with the Massachusetts Estuaries Program (MEP). Some previous modeling (ASA 2001) included phosphorus as well as nitrogen, but the emphasis has clearly been on nitrogen in these coastal systems. In-lake phosphorus levels are known to be elevated, but there has been no focused assessment of the sources of phosphorus supporting algae blooms. With low atmospheric inputs and minimal overland runoff or stream flow, the likely sources are groundwater and internal release from sediment. Groundwater will be influenced by both wastewater disposal and stormwater infiltration. This project seeks to sample groundwater entering the lake and test surficial sediments to determine the potential for those sources to supply enough phosphorus to support observed blooms. Additional work seeks to assess blooms and oxygen status critical to release of phosphorus from sediments. This project advances planning for nutrient reductions to improve the conditions of these ponds, and complements the work done to date by the Town, SMAST, and independent researchers. This project will also provide data to MA DEP for potential development of a TMDL for phosphorus for each lake.

Figure 1. Hummock and Miacomet Ponds location on Nantucket.

Figure 2. Hummock Pond water depth measured in 2006. (From Conant 2006)

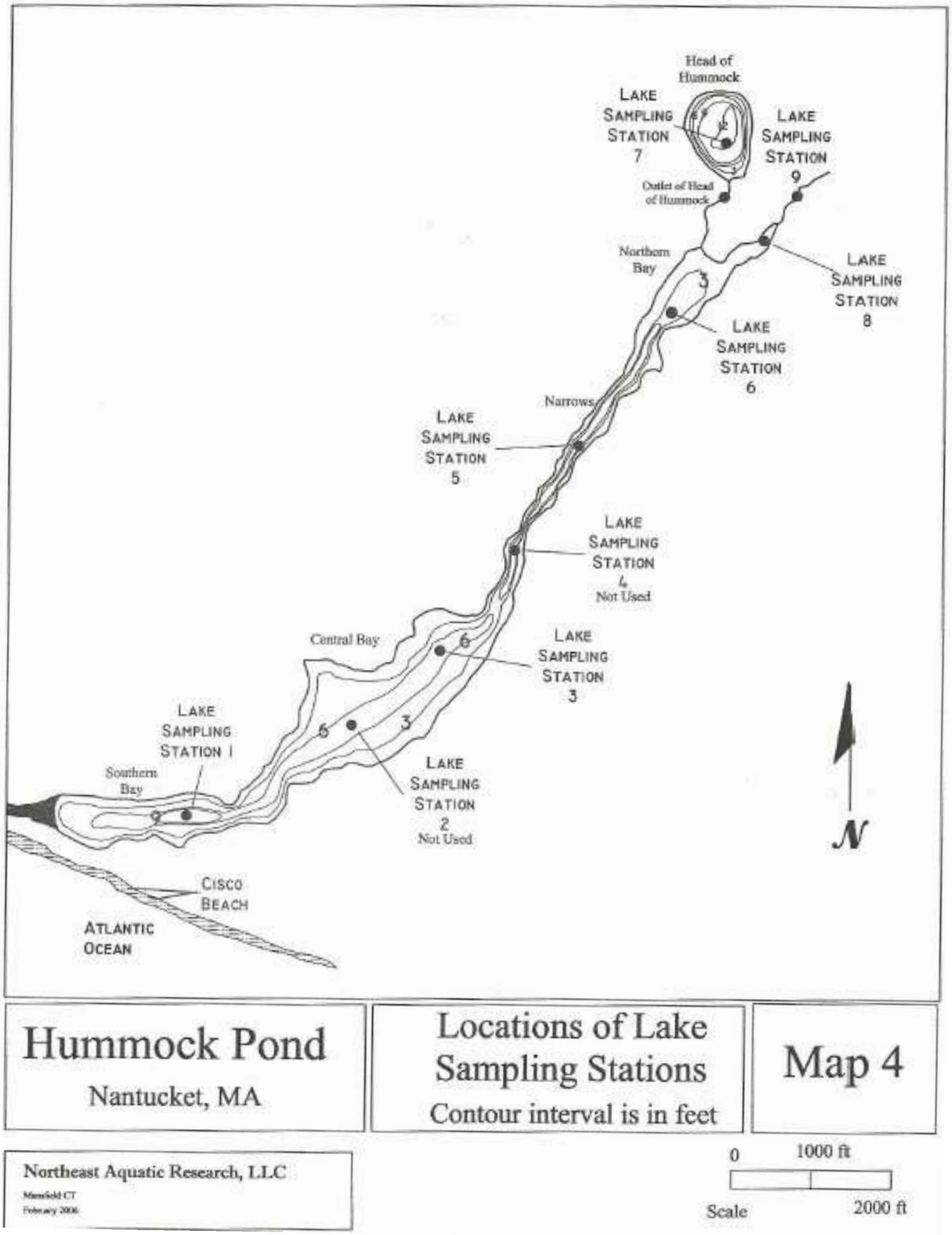


Figure 3. Miacomet Pond water depths measured in 2016. (From WRS 2016a)

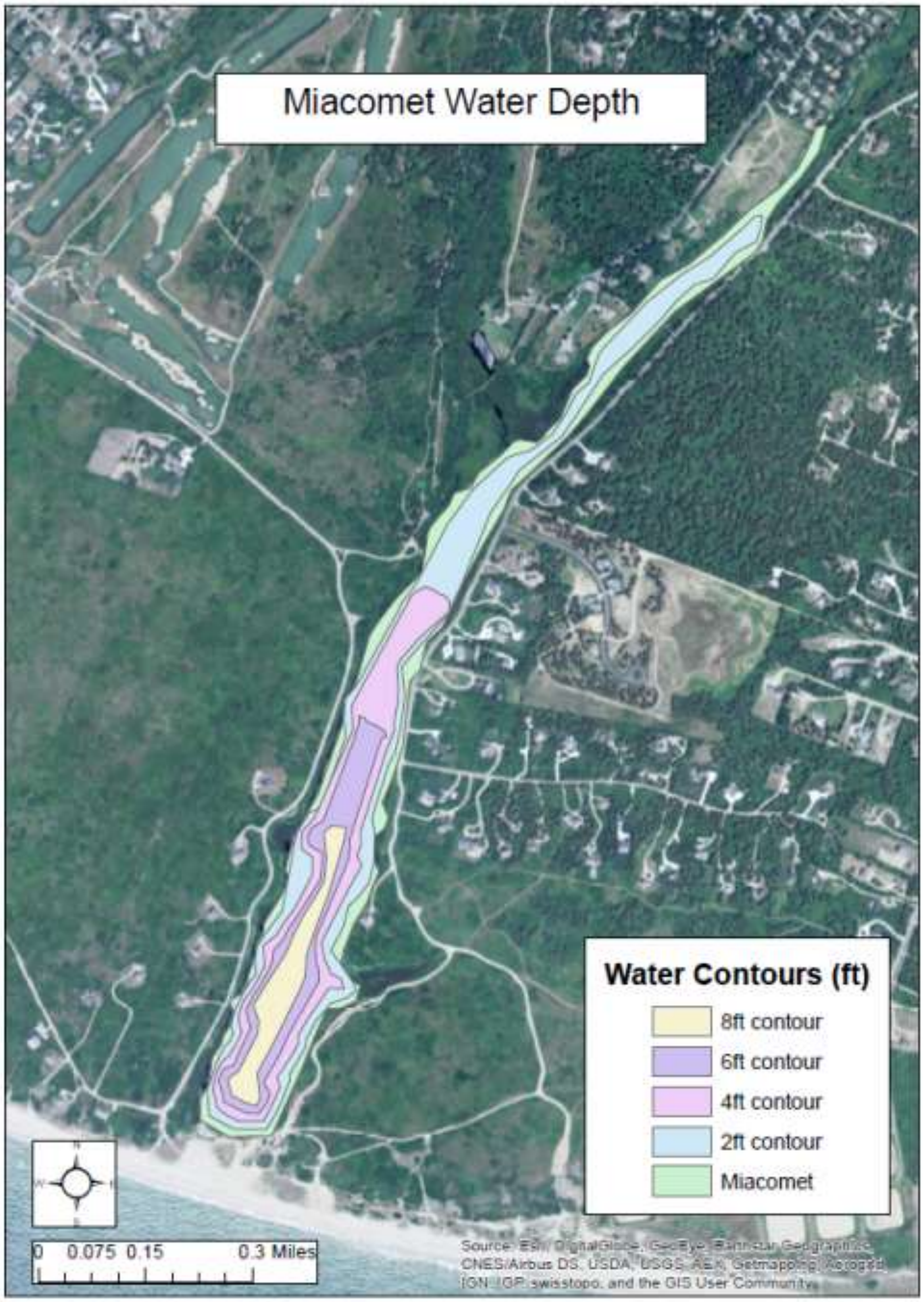


Figure 4. Hummock Pond watershed. (from NEAR 2006)

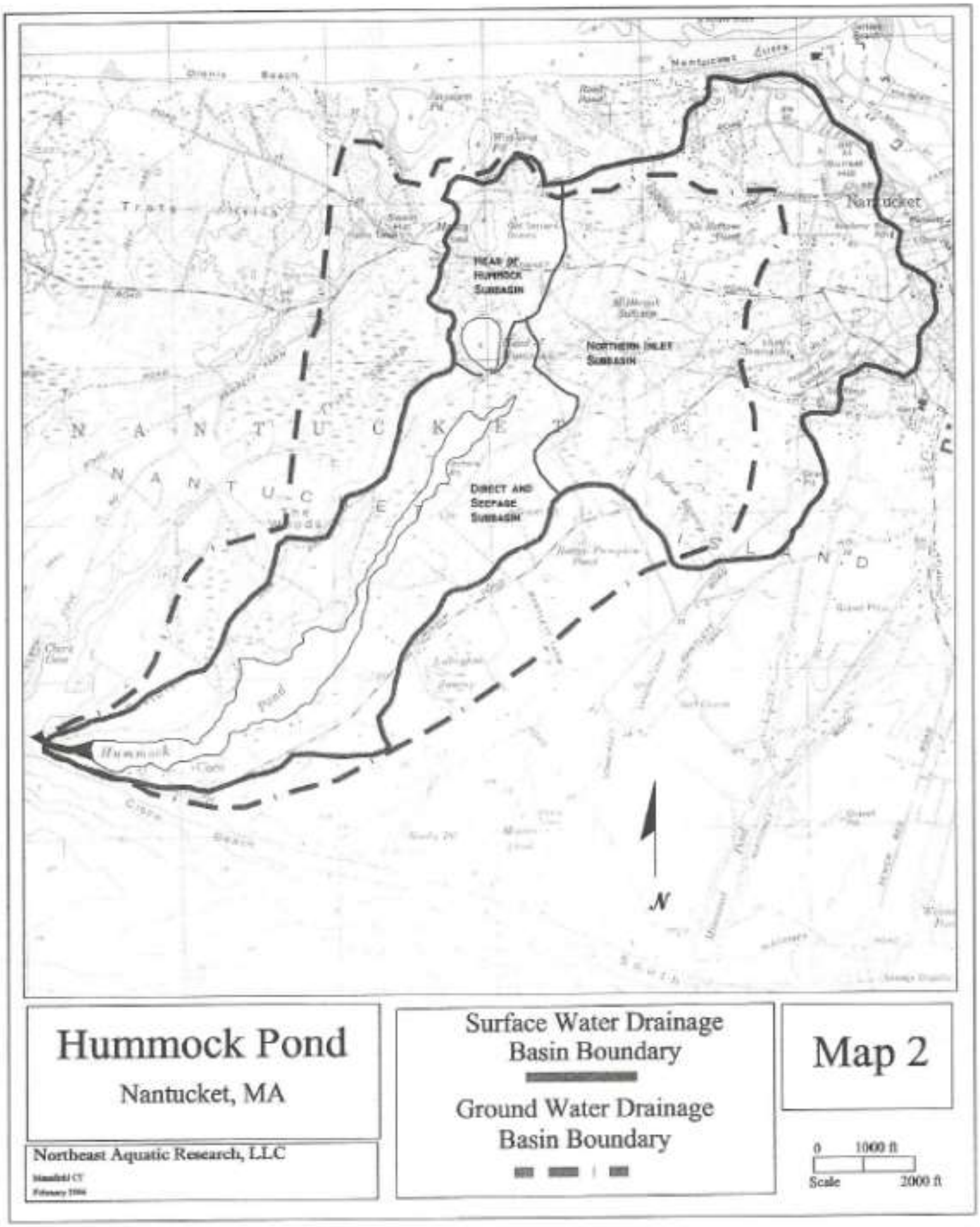
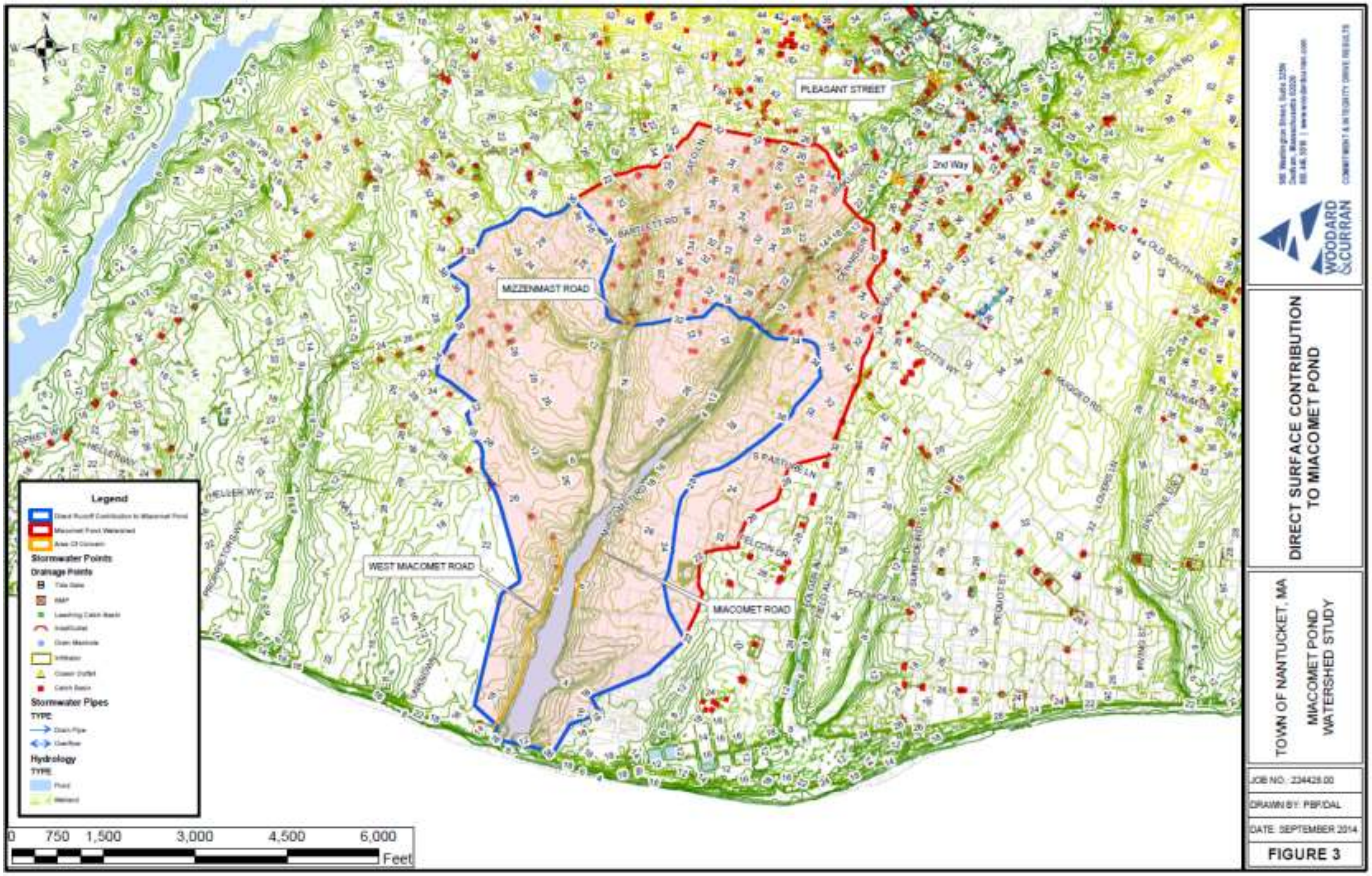


Figure 5. Miacomet Pond watershed. (from Woodard & Curran 2014)



Historic nutrient data are available from multiple sources (town water quality reports and consultant reports dating from the early 1990s to the present). There are some gradients along the length of these linear ponds, but consideration of pondwide average values provides useful insights. Total phosphorus (TP) was assessed in Hummock Pond for many years (Figure 6), but recently there has been a shift to just measuring soluble reactive phosphorus (SRP), a dissolved subset of TP. The theory is that in saline habitats P will not be limiting and SRP adequately represents available P. Yet loss of consistency in P measurements is lamentable, as TP and SRP values are not directly comparable. P remains important in Hummock Pond, even if nitrogen appears to be the limiting nutrient for many algae. Values for TP >20 µg/L represent a distinct bloom hazard, so virtually all recorded values for TP or SRP are high in Hummock Pond.

Nitrate and ammonium are forms of dissolved nitrogen readily available to plants and algae. Values >300 µg/L are potentially problematic, but recorded pondwide averages are routinely lower (Figure 7). This does not mean there is no problem, as these forms may be rapidly assimilated into plant or algae tissue and converted to organic N. Low values indicate N limitation of growth, but not necessarily low growth. Values for nitrate N appear relatively stable over time and very low, while ammonium N values suggest a decline from moderate to low values over the last two decades. Concentrations of organic and total N in excess of about 500 µg/L are considered elevated. For Hummock Pond, all concentrations since 1998 are elevated (Figure 8).

Water clarity in Hummock Pond has generally been low, fluctuating around a long-term annual average of about 1 m (Figure 9). Low clarity may result from algae blooms, but can also relate to resuspended sediment in these shallow ponds. Residents report a variety of colors, not all associated with algae, so Secchi values are not a highly reliable surrogate for algae in the ponds.

In Miacomet Pond, older TP data were less available, SRP was substituted for a time, but both TP and SRP have been assessed more recently (Figure 10). Nearly all TP values are >40 µg/L, suggesting strong bloom potential. SRP values have fluctuated around the 20 µg/L mark and are nearly all >10 µg/L, lower than TP but still a concern. Patterns for forms of N (Figures 11 and 12) were similar to those for Hummock Pond; nitrate and ammonium N are generally low, suggesting low N availability to algae, while organic and total N are high, suggesting substantial biomass. Secchi transparency is similar to that in Hummock Pond (Figure 13), with all annual average values between 1 and 2 m. Low clarity may be due to algae, but can also be related to resuspended sediment.

There is no substantial gradient of water clarity along the long (S-N) axis of either pond (Figure 14), using data from 2012-2016. As noted previously, water clarity relates as much to sediment resuspension as algae in these ponds. There is a slight gradient of increasing N from the ocean end to the upland end of each pond (Figure 15), which also coincides with a gradient of developed land; most of the watersheds of each pond are landward of the ponds, and the pattern suggests that N delivered with groundwater is a dominant source. There is a fairly strong gradient of SRP in both ponds (Figure 16) and TP in Miacomet Pond (Figure 17, 2015-2016 data) going from the ocean end to the inland end. This could indicate either groundwater inputs or differential internal recycling along that axis. There is a slight gradient of total chlorophyll-a (chlorophyll-a plus phaeophyton) in Miacomet and a stronger gradient in Hummock Pond (Figure 18). Values in Miacomet Pond are all undesirably high, while values on the ocean side of station HUM5 in Hummock Pond are moderately acceptable on average and values on the inland side of HUM5 are excessive. These gradients are consistent with those observed in reports from before 2012, suggesting no major shift in processes or conditions in Hummock or Miacomet Ponds in the last two decades or more.

Figure 6. Hummock Pond phosphorus concentrations

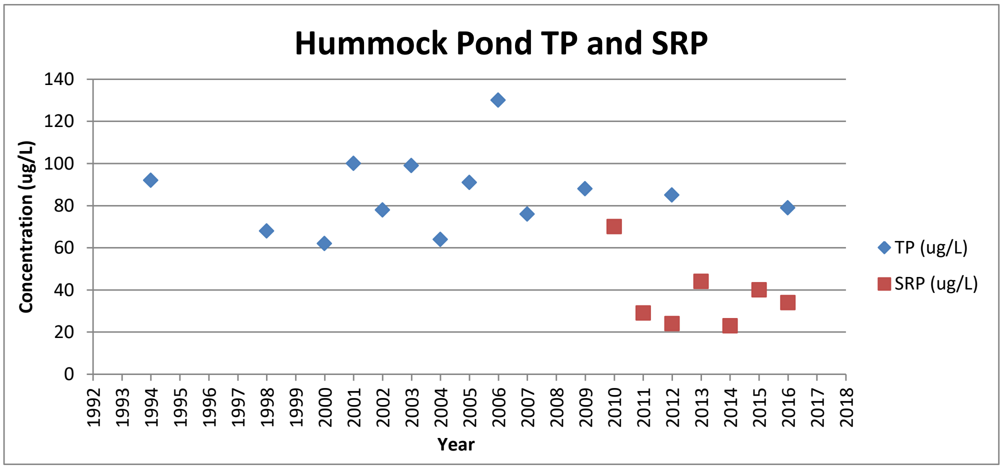


Figure 7. Hummock Pond dissolved nitrogen concentrations

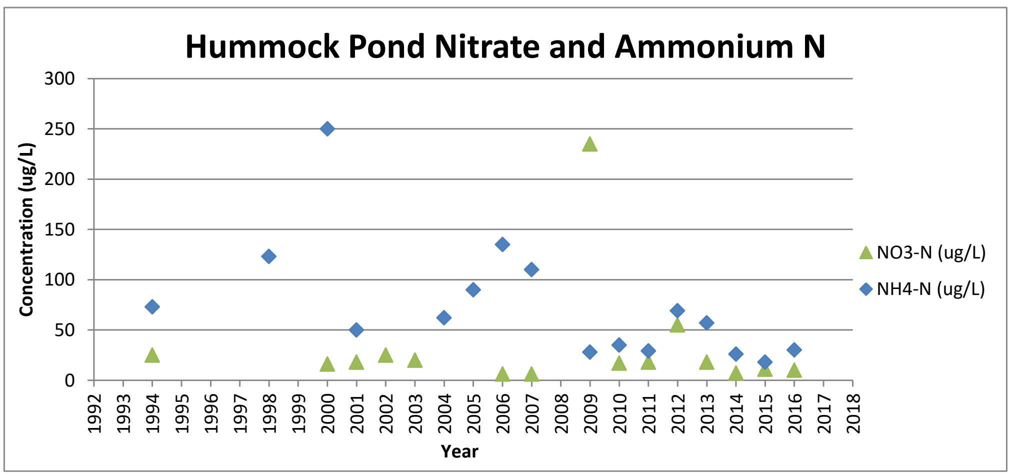


Figure 8. Hummock Pond organic and total nitrogen concentrations

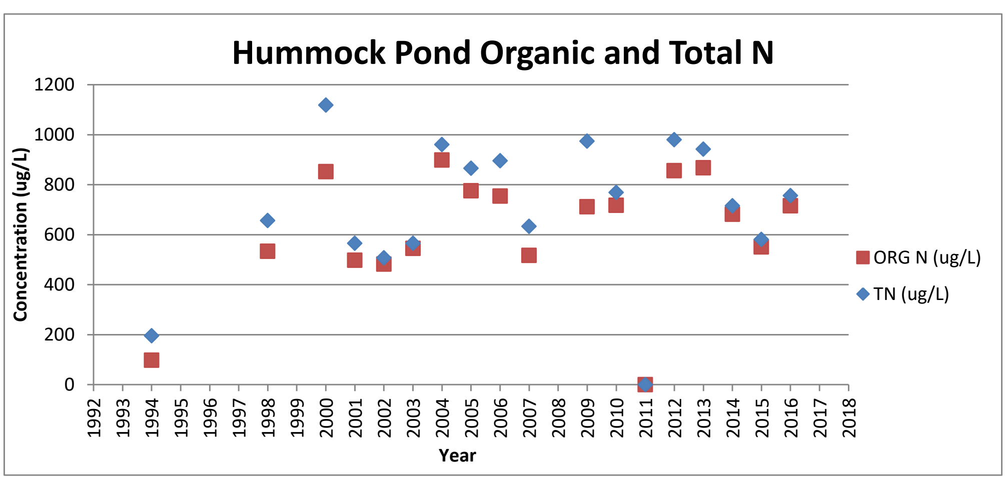


Figure 9. Hummock Pond Secchi transparency

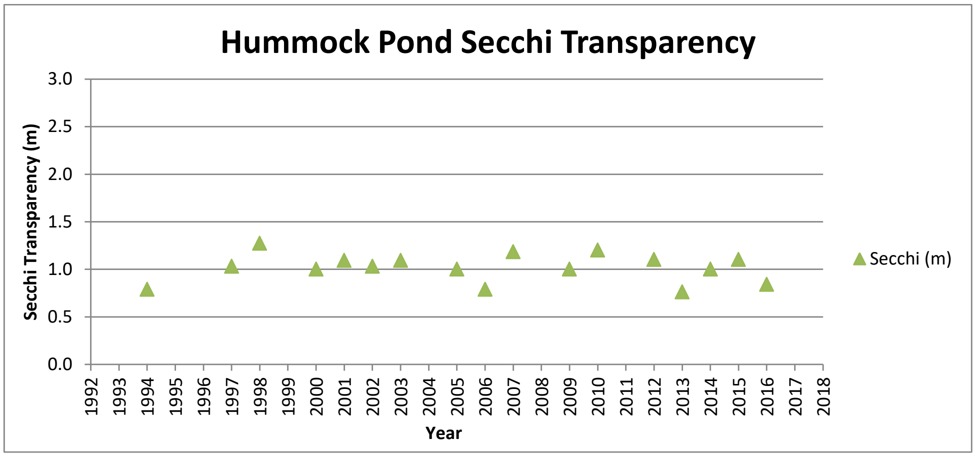


Figure 10. Miacomet Pond phosphorus concentrations

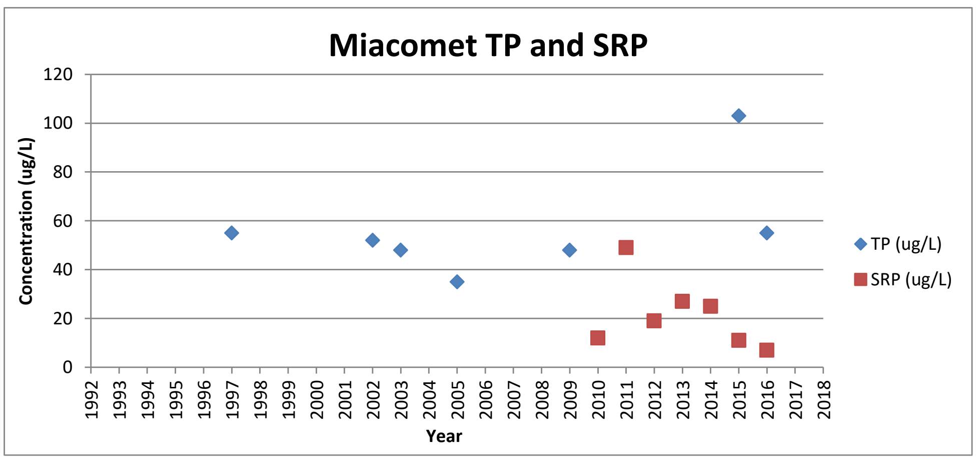


Figure 11. Miacomet Pond dissolved nitrogen concentrations

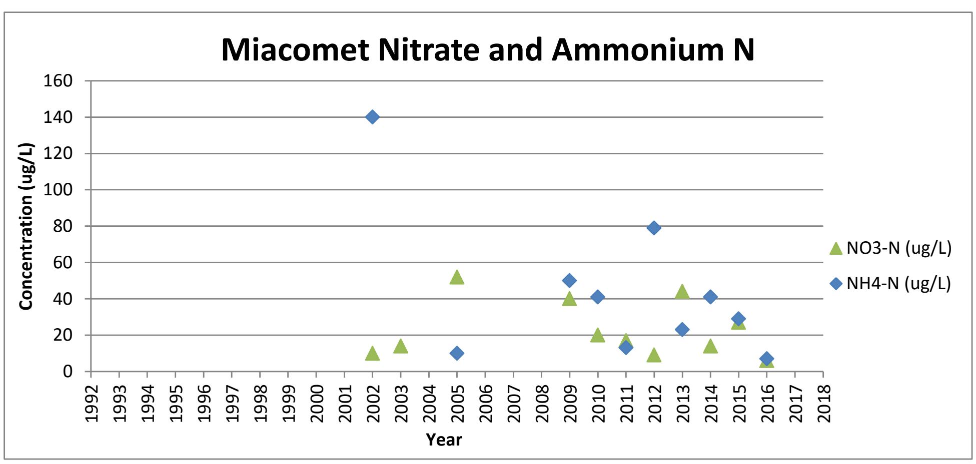


Figure 12. Miacomet Pond organic and total nitrogen concentrations

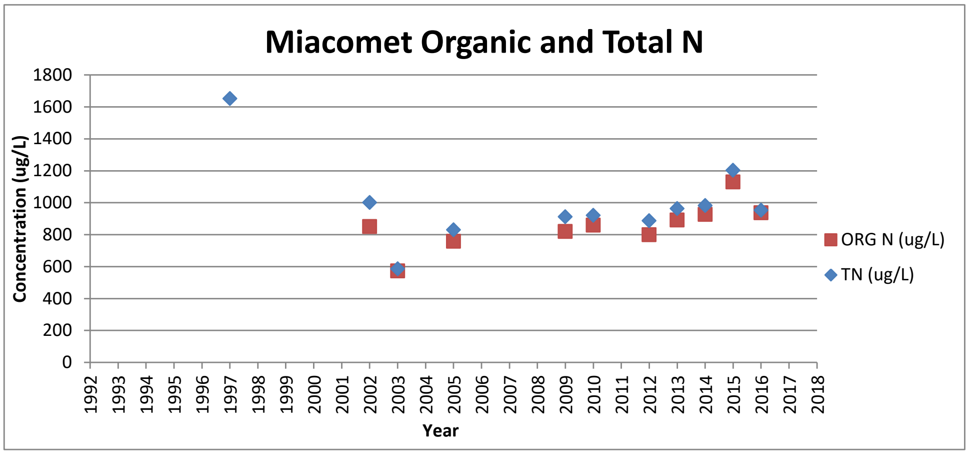


Figure 13. Miacomet Pond Secchi transparency

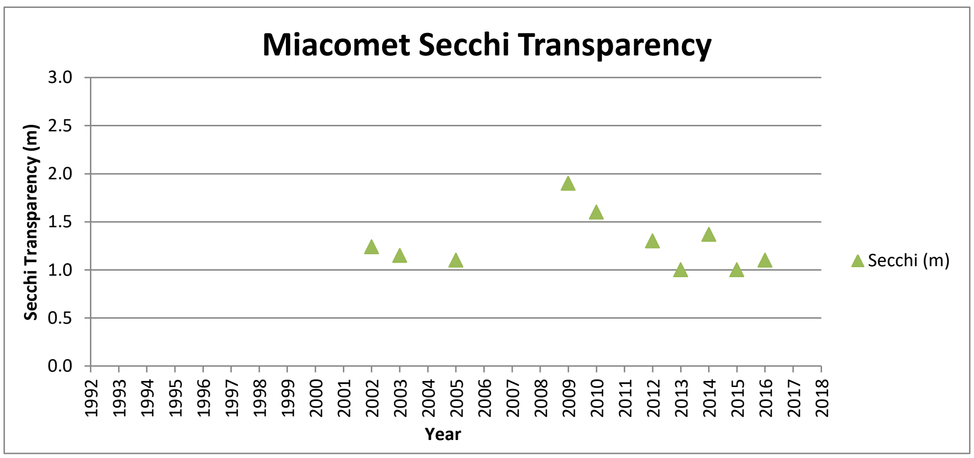


Figure 14. Spatial distriubution of Secchi transparency

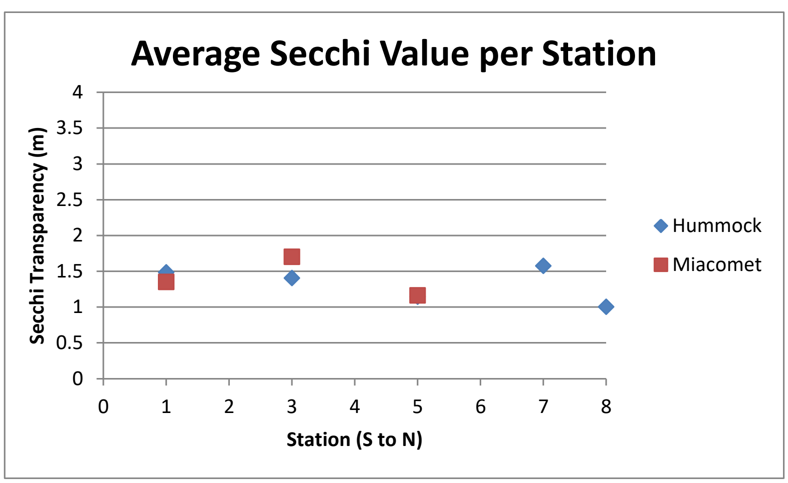


Figure 15. Spatial distribution of total nitrogen values

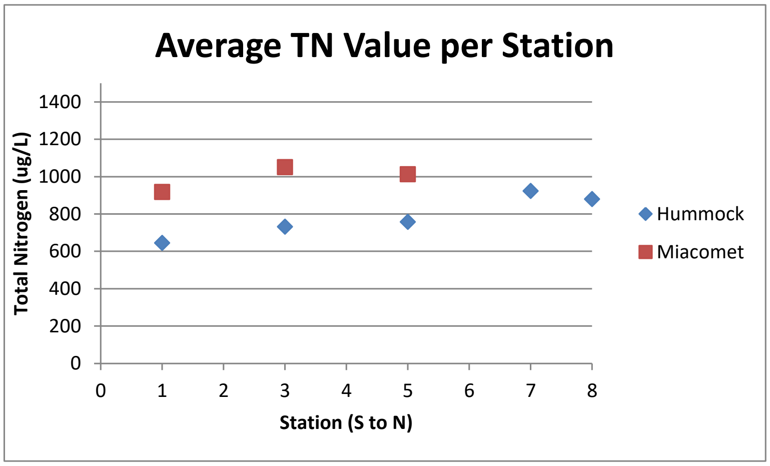


Figure 16. Spatial distribution of soluble reactive phosphorus values

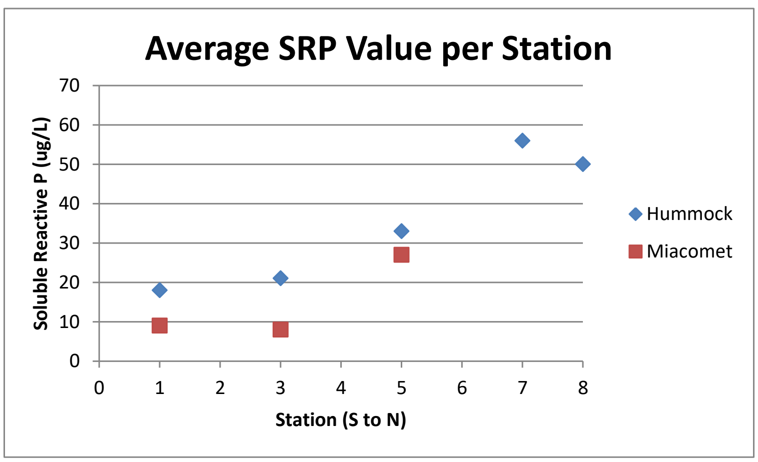


Figure 17. Spatial distribution of total phosphorus values

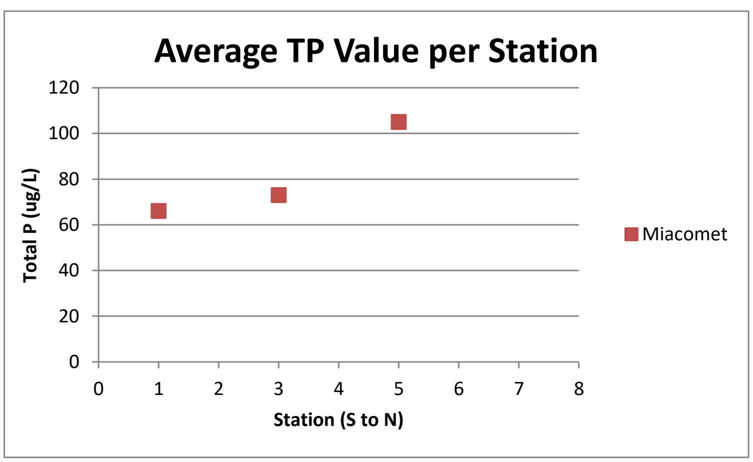
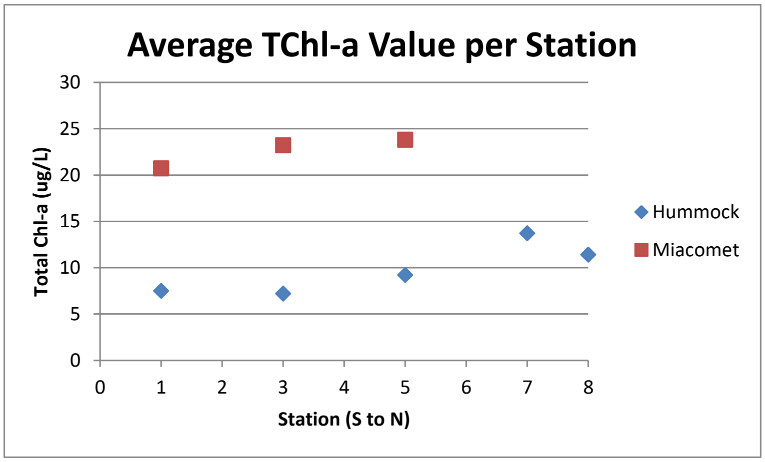


Figure 18. Spatial distribution of total chlorophyll-a values



Other water quality features have been assessed that have some bearing on this investigation. The temperature has a typical seasonal pattern, with lows in the winter and highs in the summer, but Nantucket has a moderate climate with higher lows and lower highs than mainland sites. Oxygen varies with temperature, but with both ponds being shallow and not strongly stratified, mixing is frequent and low oxygen values in the water column are rare. In some cases values have dropped below the 5 mg/L standard for support of all aquatic life, but values low enough to affect sediment-water interactions (i.e. < 2 mg/L) are not found in the record. However, virtually all programs stop measuring some distance above the sediment interface, and the potential exists for lower oxygen levels at that interface. Assessing oxygen near the sediment surface is one task in this project.

Salinity and conductivity are measures of dissolved solids, with salinity on a different scale and used for seawater environments where dissolved solids levels are much higher than most freshwater systems that apply conductivity. As both of these ponds have been opened to the ocean at times, measurements on the salinity scale have been appropriate where we would normally expect to measure only conductivity. Freshwater has a salinity well below 1 part per thousand (ppt) whereas open ocean water has a salinity of 30 ppt or slightly more (about 31 ppt near the Hummock Pond breach in recent years based on SMAST and town data). Exchanges of water between the ocean and these ponds have resulted in pond salinities of 4 to 20 ppt immediately after the exchange ended, with a gradient from south to north (high to low). For Miacomet Pond, values tend to return to freshwater levels in less than a year, and the pond has not been opened to the ocean in over a decade, so it is considered to be a freshwater system at this time. Hummock Pond, on the other hand, is opened to the ocean twice per year and does not completely revert to a freshwater system between openings. Annual average salinities range from 3 to 7 ppt over the range of stations sampled, with the highest values at the south end near the ocean and the lowest values at the north end in Head of Hummock Pond.

The subject ponds are not currently listed as impaired for nutrients, but should be recommended to be listed as impaired in the next assessment cycle by MassDEP. Once they are listed as impaired by nutrients MassDEP may, as resources allow, use the data to prepare a TMDL.

Project Approach and Methods

A Quality Assurance Project Plan (QAPP) was developed and approved for this project (WRS 2016b), and was followed. Methods are laid out in detail in that document. In summary, there are four main field tasks in this project:

1. Collection of groundwater around the ponds for assessment of nutrient levels and use in estimated groundwater loads of N and P.
2. Collection of surficial sediment and testing for available P and related features to allow estimation of possible internal loading within the ponds.
3. Assessment of oxygen status near the sediment-water interface to determine if sediment P might be mobilized under anoxic conditions.
4. Sampling and characterization of any algae blooms to further our understanding of what algae are dominant.

Data generated from these tasks will then be used in the context of past assessments in a simple model to evaluate likely loading sources to the pond and the level of reduction necessary to meet use goals. All field work was conducted in the summer half of 2016.

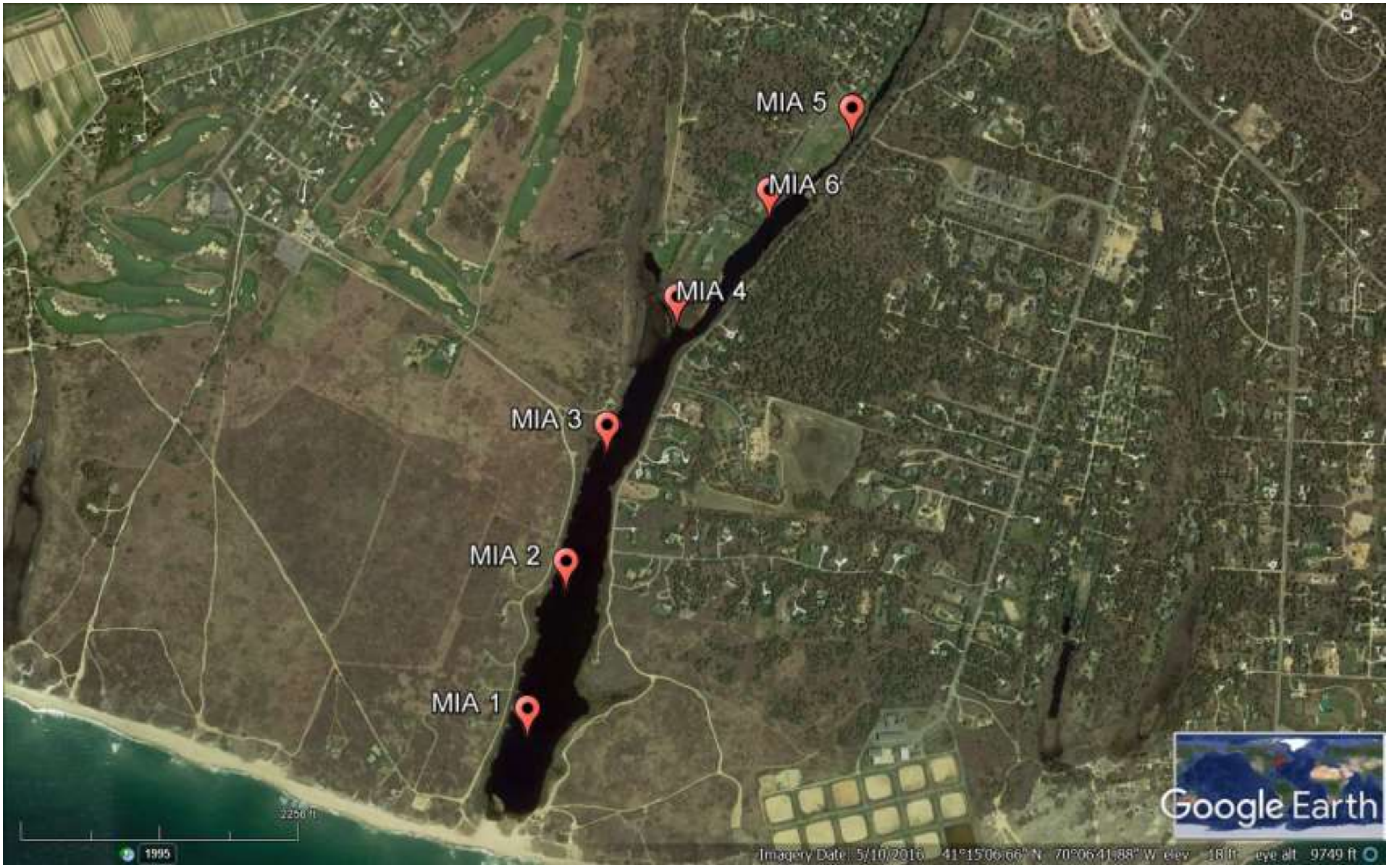
Final stations for groundwater sampling were not selected as part of QAPP development. Figures 19 and 20 show the shoreline segments applied for groundwater sampling in Hummock and Miacomet Pond, respectively. Stations for sediment and oxygen assessments were as planned in the QAPP and are shown in Figures 21 and 22. All sampling stations shown were samples for sediments. Oxygen assessments were conducted at stations HUM1, 3, 5, 7 and 8 in Hummock Pond and at stations MIA1, 3 and 5 in Miacomet Pond. Algae were collected wherever conditions warranted further investigation.

Figure 19. Groundwater sampling segments in Hummock Pond in 2016.

Figure 20. Groundwater sampling segments in Miacomet Pond in 2016.

Figure 21. Sediment and oxygen assessment points in Hummock Pond in 2016.

Figure 22. Sediment and oxygen assessment points in Miacomet Pond in 2016.



Project Task Results

Groundwater Sampling

Sampled shoreline segments were based on land use, soils, slope and vegetation. A total of 13 segments were sampled at Hummock Pond and 10 segments were sampled at Miacomet Pond. Fewer Hummock Pond segments were sampled due to access difficulties on the western shore; dense Phragmites stands extend into the pond, making it hard to access shallow areas for sampling. As the western shore is uninhabited and fairly uniform, fewer segments on that side were considered adequate for characterization. Each segment was sampled once by deploying a Littoral Interstitial Porewater (LIP) sampler to collect influent groundwater near shore, with multiple subsamples composited per shoreline segment. Samples were filtered to remove any entrained particulates and properly preserved for later lab analysis of total dissolved P, dissolved Fe, nitrate N and ammonium N.

Complete details of sampling and results are provided in the Appendix. Key data for loading analysis are provided in Table 1, while selected data for each pond are displayed in Figures 23 and 24. There are two important components of loading, concentration and inflow. This task addresses concentrations of N and P entering the ponds via groundwater.

From the perspective of N loading, the main forms moving in the groundwater are nitrate and ammonium, and the sum of the two is defined here as the dissolved inorganic nitrogen, or DIN. Values in excess of about 500 µg/L would be considered elevated, while values less than about 100 µg/L would raise little concern. Concentrations associated with groundwater at Hummock Pond were generally moderate around Head of Hummock (210-290 µg/L), moderate to low along the east side of the pond (65-320 µg/L), and moderate to very high on the west side (290-21,005 µg/L). It is rather surprising that the very high values, mostly linked to extremely high ammonium concentrations, are associated with undeveloped tracts of conservation land on the west side of Hummock Pond (Figure 23). This groundwater may be largely stagnant and anoxic, moving very slowly and impacted by decay of vegetation like the extensive Phragmites stands found on that side of the pond. The values for areas potentially impacted by developed land are low to moderate, lower than expected. With substantial groundwater flow there could still be a significant load from this area, but east side groundwater does not appear to be a dominant influence on pond N content.

At Miacomet Pond, DIN concentrations were variable but generally moderate to slightly high (Figure 24). One relatively low value (95 µg/L) was obtained at station MLIP1 adjacent to undeveloped land, although with developed land within its likely zone of contribution. Other values ranged from 205 to 1405 µg/L, with the second highest value directly downgradient of the golf course. Yet no extreme values were detected at Miacomet Pond, in comparison to Hummock Pond.

Phosphorus does not move as well as N through soil, even sandy soil, but low oxygen conditions or long periods of loading can result in higher levels of P in groundwater. Values in excess of about 100 µg/L would be considered high, while values less than 20 µg/L would be considered low. At Hummock Pond, dissolved P concentrations in groundwater were low to moderate around Head of Hummock (9-67 µg/L) and along the eastern shore (3-45 µg/L), while values were moderate to high on the undeveloped western side (40-290 µg/L). This pattern is consistent with observations for DIN, and suggests that decomposition and limited groundwater movement on the

Table 1. Summary of groundwater data from 2016 sampling.

Shoreline Segment	Average NH4+NO3 - N (ug/L)	Average Diss. P (ug/L)	Average Diss. Fe (ug/L)	Fe:P ratio
Hummock Pond				
HLIP 1	280	9	15600	1733.3
HLIP 2	290	16	360	22.5
HLIP 3	210	67	30	0.4
HLIP 4	95	5	20	4.0
HLIP 5	320	10	40	4.0
HLIP 6	190	3	10	4.0
HLIP 7	75	22	8550	388.6
HLIP 8	65	44	310	7.0
HLIP 9	118	45	2925	65.0
HLIP 10	21005	290	13	0.0
HLIP 11	290	40	9	0.2
HLIP 12	19440	260	258	1.0
HLIP 13	13810	120	8	0.1
Miacomet Pond				
MLIP 1	95	3	40	16.0
MLIP 2	680	7	110	15.7
MLIP 3	1005	20	26100	1305.0
MLIP 4	335	50	46600	932.0
MLIP 5	205	58	47700	822.4
MLIP 6	315	510	95	0.2
MLIP 7	755	145	83	0.6
MLIP 8	690	200	46	0.2
MLIP 9	1405	320	71	0.2
MLIP 10	525	220	50	0.2

western side may be a factor. At Miacomet Pond, dissolved P concentrations in groundwater are low at the inland end of the pond and increase to high levels down both sides of the pond toward the ocean.

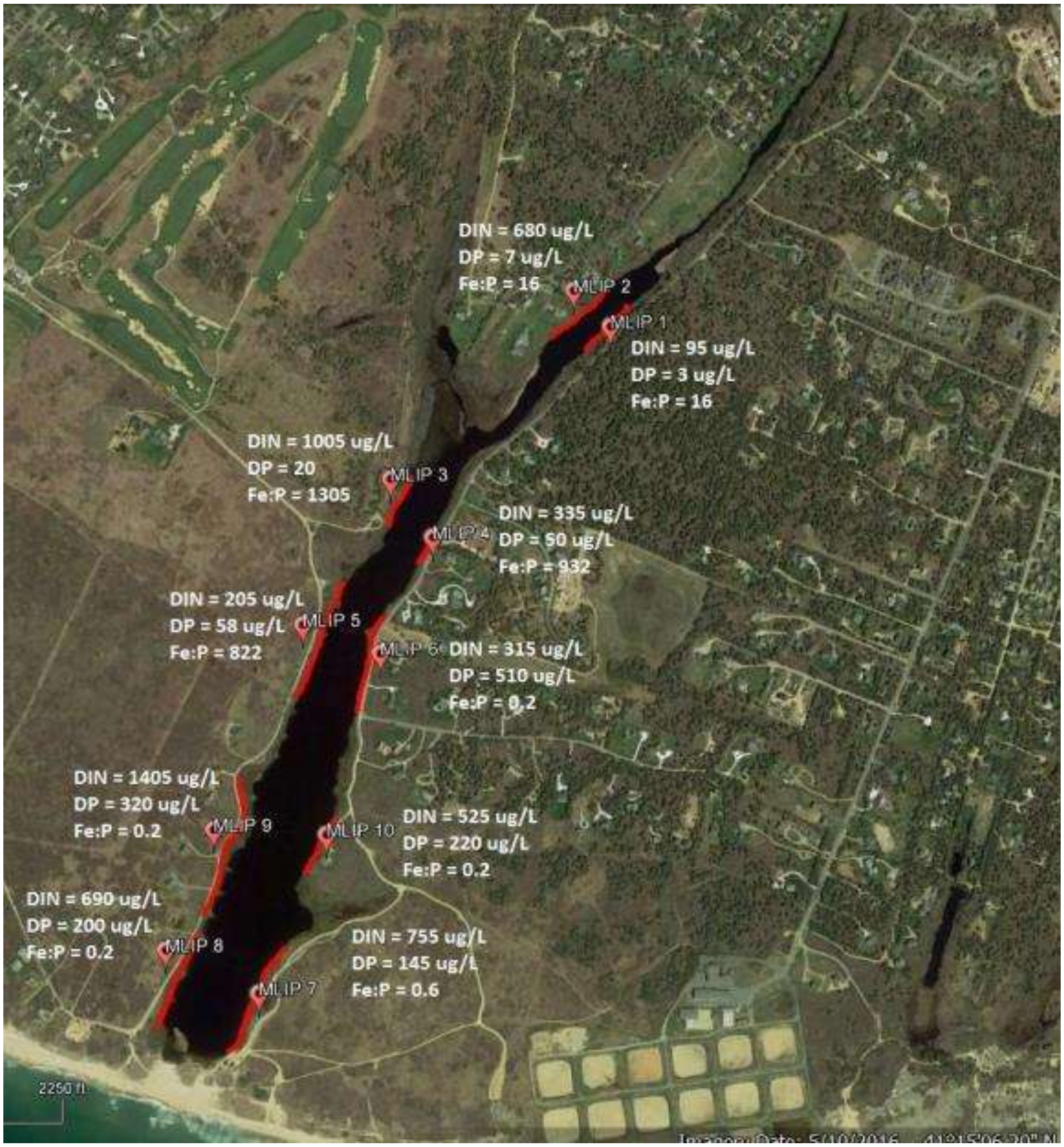
While dissolved phosphorus is viewed as mobile in groundwater, its actual availability once it reaches the ponds is constrained by the amount of dissolved iron travelling with the phosphorus. Under oxygenated conditions in the ponds, iron and phosphorus can be expected to combine to form insoluble precipitates, limiting P availability. Where the mass of iron is more than about ten times that of P, and certainly where iron is present at more than 20 times the P concentration, very low P availability is expected. The settled precipitates may support rooted plant growths or allow later release of P if anoxic conditions develop, but direct support of algae blooms from groundwater would not be expected with high iron in incoming groundwater.

Figure 23. Selected Hummock Pond groundwater features

The pattern of dissolved iron in groundwater was fairly striking at both ponds. There were few intermediate values at Hummock Pond, with low ratios of Fe to P on the western side and a mix of high and low values on the eastern side. Fe:P ratios at Miacomet Pond were lowest at the ocean end of the pond and much higher toward the inland end, with a sharp divide about mid-pond, between stations MLIP5 and MLIP6. It appears likely that years of saltwater influence on both ponds affects iron levels in the groundwater; high sulfates in seawater tend to react with iron in exposed soil to create insoluble compounds. While iron may continue to move toward the pond from upgradient areas, frequent interaction of seawater with soils near the pond likely conditions them for low iron availability.

For Hummock Pond, which is subject to twice annual saltwater influx that affects the entire pond, the effect is pondwide if a bit erratic. For Miacomet Pond, the inland half of which has been drained to a mudflat when open to the ocean in the past, the impact appears to be focused on the "downstream" or oceanside portion of the pond. Ultimately what this means is that available P will enter Hummock Pond in groundwater mainly from the west, from Head of Hummock to near the ocean, while available P will enter Miacomet in groundwater from both sides but mainly in the oceanside half of the pond. Concentrations will be linked to flow to derive loads later.

Figure 24. Selected Miacomet Pond groundwater features



The ASA study in 2001 involved groundwater measurements, but no actual data could be found from that study. Sutherland (2013) examined groundwater from three wells around Head of Hummock and found P concentrations averaging 30 µg/L in the east and north wells and 80 µg/L in the west well. These values are slightly higher than the 2016 values for HLIP1, 2 and 3, which correspond to the east, north and west wells respectively, but the 2016 values are within the range observed over 20 samplings of the wells by Sutherland in 2011 and 2012. DIN values recorded by Sutherland averaged 142, 312 and 146 for the east, north and west wells, compared to 280, 290 and 210 µg/L measured in 2016; 2016 values are within the range of the 20 measurements made in 2011-2012.

Surficial Sediment Sampling

Surficial sediment was sampled at 8 locations in Hummock Pond and 6 locations in Miacomet Pond, corresponding to water quality stations sampled in previous studies. Samples were collected with an Ekman dredge and only the upper 10 cm of sediment were collected for testing. Samples were tested for TP, Fe-P, percent solids and percent organic matter, allowing calculation of available Fe-P and its relation to TP and other key sediment features. The intent of this task is to determine the amount of phosphorus potentially available for exchange with overlying water or to support benthic growths of algae that might later rise into the water column.

Complete data from this effort are contained in the appendix. Key features for each station and related calculations are provided in Table 2, while graphic representations of the most insightful values is provided for Hummock Pond in Figure 25 and for Miacomet Pond in Figure 26. There are two features that matter the most when considering the influence of sediment on algae growth: the concentration of available P in the sediment (typically assessed as Fe-P and expressed as mg P per kg dry weight sediment) and the mass of that available P in the upper layer of surficial sediment (usually taken as the top 4-10 cm and expressed as g P per square meter of sediment).

Values <100 mg/kg are considered low, while values >500 mg/kg are regarded as high. The relevant scale for the mass of available P per square meter depends on water depth and overall pond volume relative to the contributing area; the deeper the water and larger the pond volume relative to the contributing sediment area, the higher the available P mass must be to influence P concentration in the overlying water. As a rough rule, for every meter of average water depth, a sediment Fe-P mass of at least 0.4 g/m^2 will be needed to supply enough P to support algae blooms. For Hummock Pond with a mean depth close to 2 m, a sediment Fe-P value >0.8 g/m^2 will be of concern, while in Miacomet Pond with a mean depth of about 1.2 m, values >0.5 g/m^2 may cause problems.

In Hummock Pond (Table 2, Figure 25) there is a discernible gradient of Fe-P concentration from moderate values near the ocean end of the pond (100-373 mg/kg) to higher values (448-808 mg/kg) in the central part of the pond, to extreme values in the narrows and upstream, including in Head of Hummock Pond (647-1572 mg/kg). With differences in solids content over space, the mass of Fe-P in the upper 4 cm of sediment at the sampled stations exhibits less of a gradient, but values for HUM6-8 are distinctly higher (4.08-8.30 g/m^2) than values for other stations (1.34-3.34 g/m^2) except HUM2 (5.01 g/m^2). Values at all stations are well above the calculated problem threshold of 0.8 g/m^2.

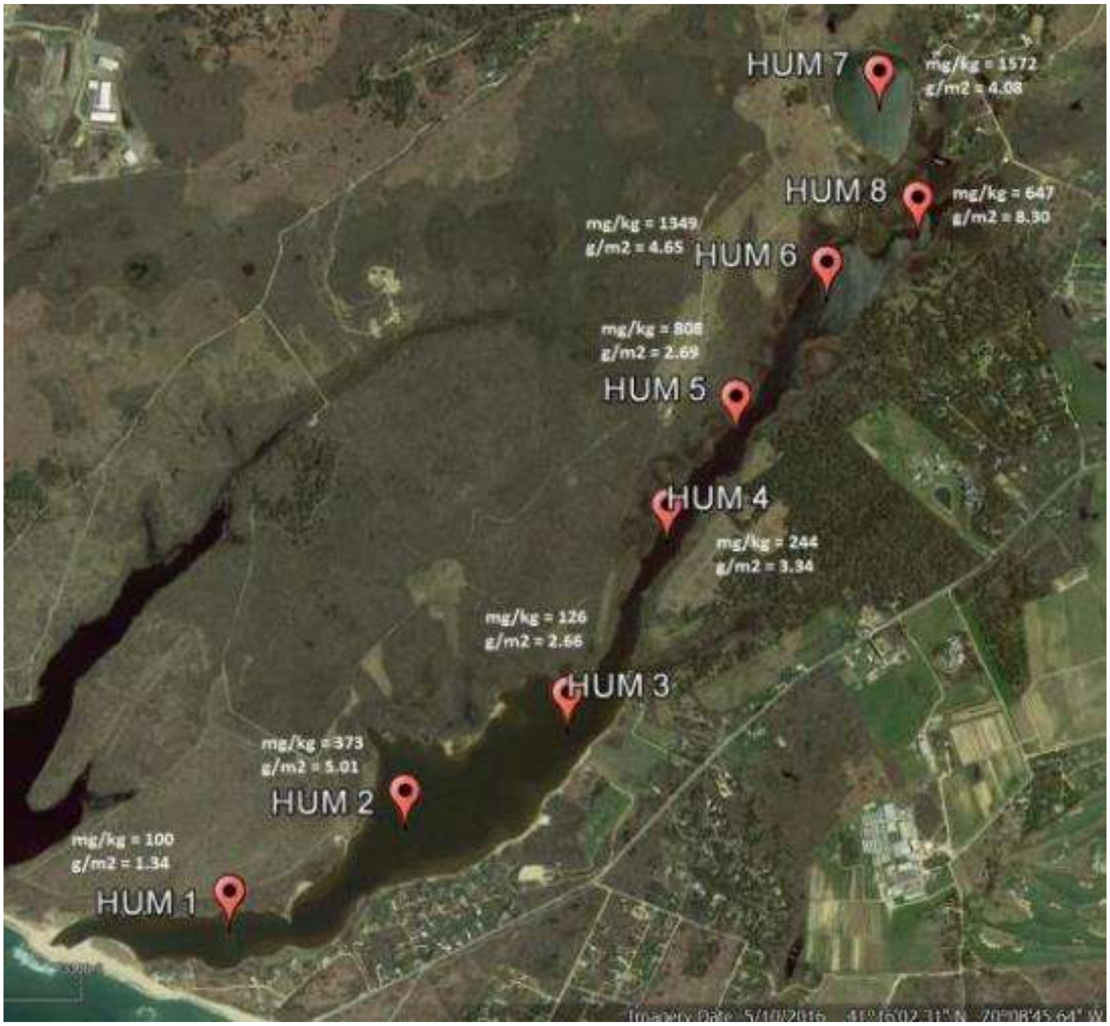
In Miacomet Pond (Table 2, Figure 26) there is variation over space but no clear gradient. Fe-P concentrations ranged from 152 to 703 mg/kg and averaged 384 mg/kg. The mass of Fe-P in the upper 4 cm of sampled sediment ranged from 1.39 to 2.30 g/m^2 with an average just over 2 g/m^2. All values represent a potential threat and could support substantial algae growth, but there are no extreme values as observed in the inland end of Hummock Pond.

A simple calculation that sheds light on how much P might be released from sampled sediment under anoxic conditions is provided in Table 2. It is rare for more than 10% of the sediment Fe-P to be released in a summer season, and with limited anoxia, that release rate might be as low as 1%. With an average of close to 2 m of water over sediment in Hummock Pond and 1.2 m over sediment in Miacomet Pond, the P concentration in the overlying water can be estimated. Values for Hummock Pond at a 10% release rate range from 67 to 415 µg/L and averages 200 µg/L, with

Table 2. Summary of sediment data from 2016 sampling.

Station	HUM1	HUM2	HUM3	HUM4	HUM5	HUM6	HUM7	HUM8		MIA1	MIA2	MIA3	MIA4	MIA5	MIA6
Solids Content (%)	28	28	44	28.5	23	12	6.3	11		14	11	19	6.3	17	9.2
Organic Content (%)	6.3	28.2	75.7	18.4	24.9	45.4	5.6	8.3		13.7	13.1	7.5	3.7	5.4	6.8
Total Phosphorus (mg/kg DW)	263	927	278	1616	1,110	2,250	3,100	929		643	753	734	740	916	668
Fe-P (mg/kg DW)	100	373	126	244	808	1,349	1,572	647		336	423	152	703	282	408
Depth of Sediment Interacting (cm)	4	4	4	4	4	4	4	4		4	4	4	4	4	4
Volume of Sediment Interacting per m2 (m3)	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040		0.040	0.040	0.040	0.040	0.040	0.040
Specific Gravity of Sediment	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20		1.20	1.20	1.20	1.20	1.20	1.20
Percent Solids (as a fraction)	0.280	0.280	0.440	0.285	0.230	0.120	0.063	0.110		0.140	0.110	0.190	0.063	0.170	0.092
Mass of Sediment Interacting (kg/m2)	13.4	13.4	21.1	13.7	11.0	5.8	3.0	5.3		6.7	5.3	9.1	3.0	8.2	4.4
Mass of P Available for Release (g/m2)	1.34	5.01	2.66	3.34	2.69	4.65	4.08	8.30		2.26	2.23	1.39	2.13	2.30	1.80
10% Release to Avg Water Depth (ug/L)	67.2	250.7	133.1	166.9	134.7	232.7	204.0	415.0		185.1	183.1	113.6	174.3	188.6	147.7
5% Release to Avg Water Depth (ug/L)	33.6	125.3	66.5	83.4	67.3	116.4	102.0	207.5		92.5	91.5	56.8	87.1	94.3	73.8
1% Release to Avg Water Depth (ug/L)	6.7	25.1	13.3	16.7	13.5	23.3	20.4	41.5		18.5	18.3	11.4	17.4	18.9	14.8

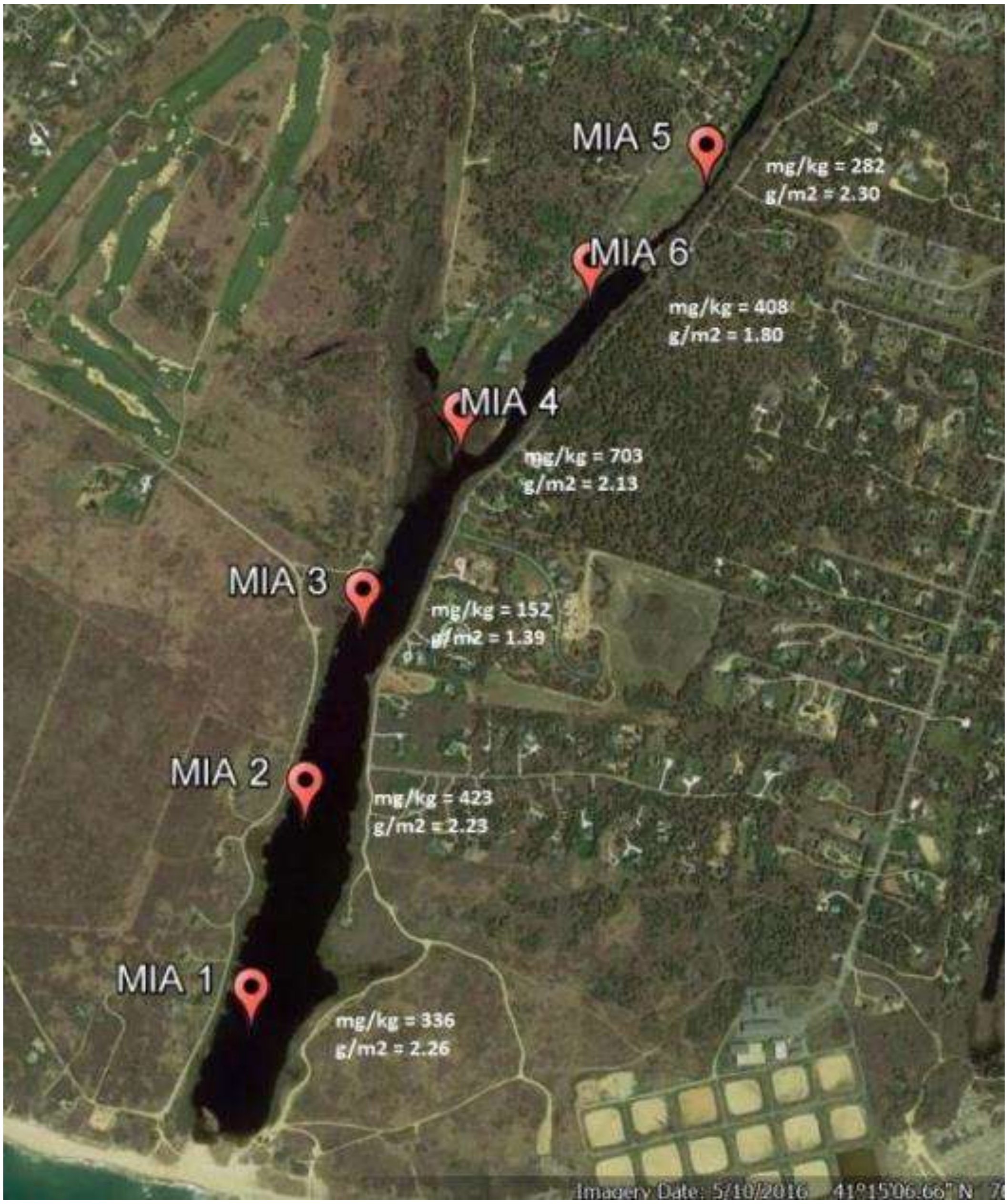
Figure 25. Selected Hummock Pond sediment features



values >20 µg/L associated with algae blooms. At only 1% the range is 7 to 42 µg/L and averages 20 µg/L, still high enough to cause problems. For Miacomet Pond, a 10% release rate would yield P increases of 114 to 189 µg/L with an average of 165 µg/L, while a 1% release rate would produce a P increase of 11 to 19 µg/L with an average of 17 µg/L. Again, the potential for internal loading from sediment P reserves is substantial and represents a very real threat of algal blooms.

Release of P from Fe compounds depends on reactions that occur under very low oxygen conditions, and release into water with higher oxygen results in co-precipitation and limited P availability. In deep water, where released P is in an area with minimal light, it may not be available to algae attempting to grow higher in the water column. However, neither Hummock nor Miacomet Pond is deep enough to have too little light for algae to grow at the sediment-water interface, so anoxia in that area will be enough to allow released P to be used by algae. Cyanobacteria are noted for growing at low light at the sediment-water interface while taking up extra P, then forming gas pockets and floating upward where higher light allows more rapid growth. Synchronous rises can form blooms quickly, and the extra P in rising cells allows growth and bloom expansion even if the overlying water has limited P.

Figure 26. Selected Miacomet Pond sediment features



The area covered by potentially contributing sediment is important to overall loading, and would include mainly organic deposits; sandy sediments tend to have low Fe-P concentrations. Examination of Hummock Pond during drawdowns associated with barrier beach breaching indicates significant organic sediment accumulations in water more than 2 feet deep, representing an area of about 120 acres, although there are sandy patches in deeper water and soft sediment accumulation in some shallower areas such as around HUM8. Mapping of sediment in Miacomet Pond by WRS in 2016 as a separate project provided soft sediment contours that indicate coverage by organic muck in water about 2 feet deep, representing an area of about 38 acres. However, a thin veneer of organic sediment over coarse sand is observed in some areas at the inland end of the pond, and some emergent wetland areas are not counted as part of the pond area in this case.

There is another complication relating to internal loading in each pond, however. Release of phosphorus can occur under oxic conditions where there is either a high rate of decomposition of organic matter or where water chemistry leads to binding of iron that would otherwise sequester P under oxic conditions. This latter situation is most often observed with seawater intrusion, as seawater is high in sulfates and the sulfur preferentially binds with iron to form insoluble complexes. With less iron available to bind P, P release from sediments can be substantial even with oxygen at the sediment-water interface.

Miacomet is likely to suffer to some extent from the first mechanism, with decay of organic matter releasing some P, although probably not as much as via the anoxic mechanism. In Hummock Pond there is a major threat of oxic release due to sulfate addition with seawater in the twice annual opening of the pond to the ocean; SMAST measurements have indicated oxic release of P from Hummock Pond sediments, probably on the order of that expected under anoxic conditions.

Oxygen Assessment

Oxygen status of the ponds was assessed with a dissolved oxygen (DO) probe that measures oxygen and temperature at 0.5 m intervals from surface to bottom, with the deepest measurements collected at the sediment-water interface and in the sediment itself. Assessment occurred on 5 dates between late June and early October, usually in the early morning or late afternoon when lowest oxygen is most likely to be encountered at the sediment-water interface. T/DO profiles were collected at previously assessed water quality stations (HUM1, 3, 5, 7 and 8, and MIA1, 3 and 5). Conductivity/salinity was checked at each station as well, to better characterize the reported gradient along a north-south transect, and Secchi transparency was recorded. Complete data are provided in the appendix. The areal and temporal extent of low oxygen can be calculated and factored into calculation of P loading from surficial sediment.

Average conductivity in Hummock Pond during this study ranged from a low of 3590 µS, which equates to a salinity of 2.3 ppt, to 14,460 µS, which is the same as a salinity of 8.6 ppt. There was both a longitudinal gradient, with higher values at the ocean end of the pond and lower values in Head of Hummock Pond, and a temporal gradient, with values declining over time at all locations between May and October. The barrier beach at Hummock Pond was breached in April 2016, opening the pond to the ocean for 19 days, and the fall breach did not occur until after sampling was completed. Average conductivity for the period was just over 8000 µS, equating to an average salinity of just under 5 ppt.

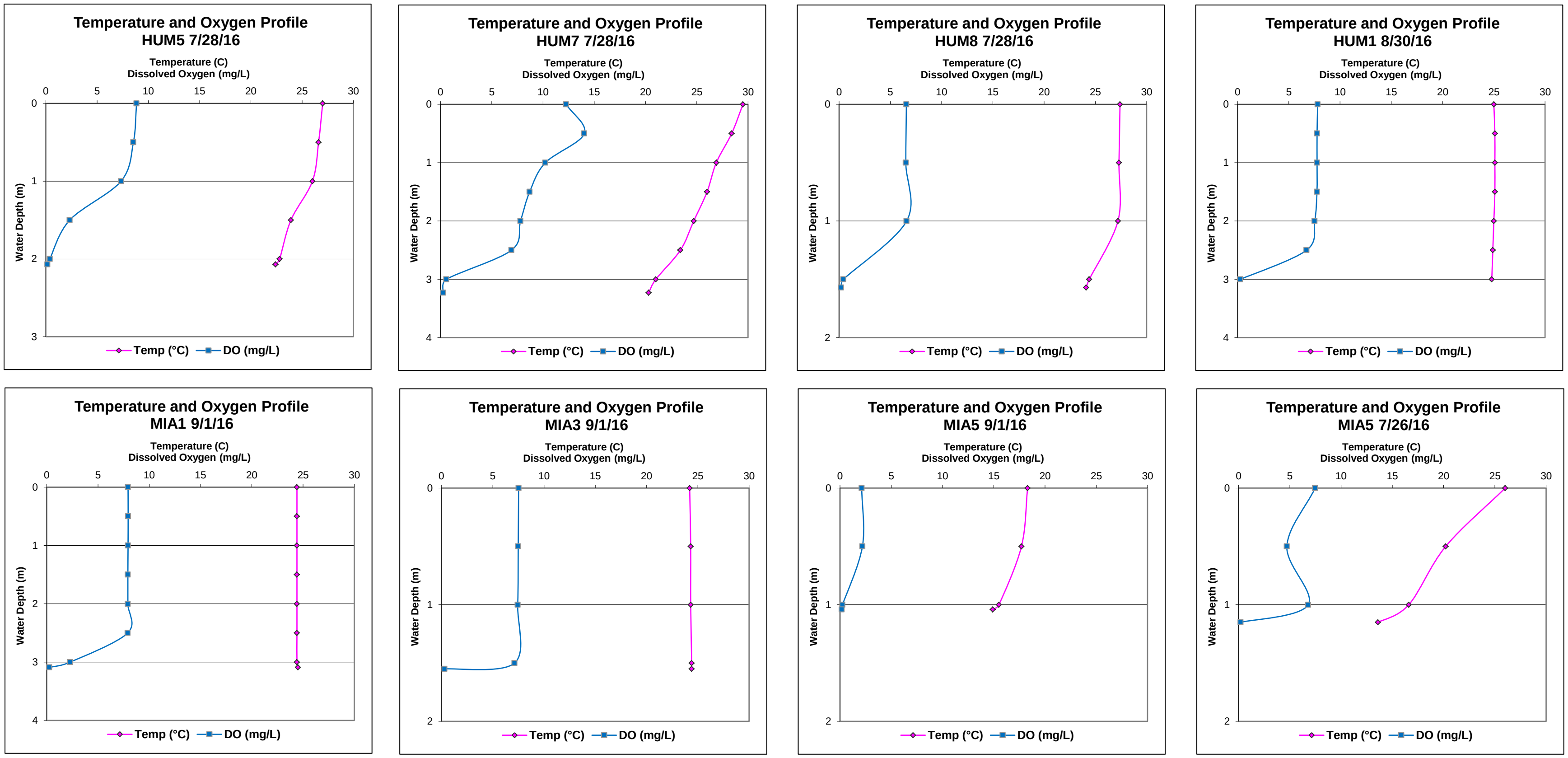
Conductivity in Miacomet Pond ranged from 157 to 211 µS, all considered moderate for freshwater, with no discernible longitudinal gradient. No saltwater intrusion into the pond is indicated. No breaching of the barrier beach at Miacomet Pond has occurred for over a decade.

Oxygen values more than half a meter above either pond bottom were nearly always >2 mg/L and usually >4 mg/L, suggesting no severe hypoxia or anoxia in the water column. However, measurements very close to the sediment-water interface were frequently <0.5 mg/L in both ponds. HUM1 and HUM3 at the ocean end of the pond rarely exhibited any significant oxygen stress, while values for HUM5, HUM7 and HUM8 were routinely low at the sediment-water interface between late June and early October. All three assessed stations in Miacomet exhibited low oxygen at the sediment-water interface on nearly all dates. Example DO profiles (Figure 27) illustrate the situation in each pond.

Strong temperature gradients were not observed in Hummock Pond, but slight thermal gradients were observed, with 3 C degrees being enough to reduce mixing at least during calm periods. This suggests limited thermal resistance to mixing but an active sediment oxygen demand that depresses oxygen and likely fosters P release near the sediment-water interface. Even with uniform temperatures, oxygen was low right at the sediment-water interface.

Vertical thermal gradients were not detected at stations MIA1 or MIA3 in the shallower Miacomet Pond, but were observed on nearly all dates at MIA5 over only one meter of water depth. It is likely that groundwater inflow is substantial in this area, as bottom temperatures were indicative of groundwater while surface water temperatures were more typical of the rest of the pond. Oxygen concentrations were low at the sediment-water interface at all three stations on nearly all dates, but were lower overall in the water column at MIA5. Both entry of anoxic groundwater and greater decay of organic matter accumulated in this area may be responsible.

Figure 27. Example temperature and dissolved oxygen profiles from Hummock (top) and Miacomet (bottom) Ponds



Algae Bloom Characterization

Algae have been assessed as part of routine monitoring in the past, and it is known that cyanobacteria bloom in both Hummock and Miacomet Ponds. Sample bottles containing preservative vials were provided to designated pond monitors to facilitate collection of algae whenever a bloom was observed. Samples could be whole water samples, representing the apparent condition of the water, or concentrated samples of wind-blown phytoplankton accumulations or observed algal mats, whatever best represents what was observed in the ponds. Preserved samples were sent to WRS for analysis at the conclusion of the summer collection process. Samples were subjected to quantitative microscopic analysis by standard methods. A total of 10 samples were collected in 2016 as part of this program, although additional samples were collected and analyzed by Town of Nantucket staff as part of routine monitoring.

Complete data are provided in the appendix, while biomass is summarized in Figure 28. The yellow line at 1000 µg/L represents an approximate threshold below which no use impairment is expected in a waterbody. The black line at 3000 µg/L represents the algal biomass concentration above which use impairment is usually observed.

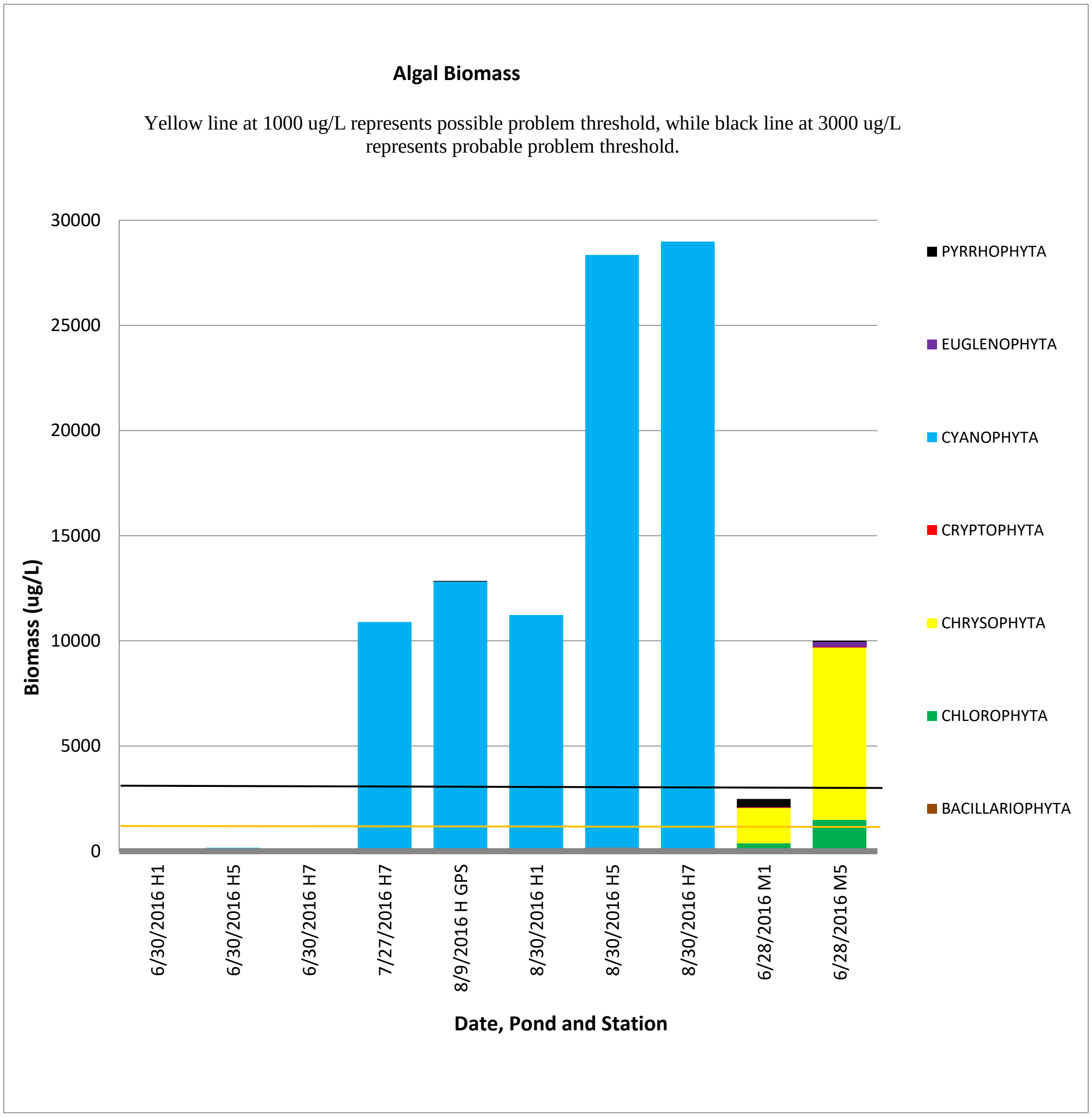
Late June samples from Hummock Pond contained only small amounts of algae, but did include the bloom-forming cyanobacterium *Dolichospermum* (formerly known as *Anabaena*). This genus has been observed in many past collections from Hummock Pond. By late July a serious bloom had developed and continued through August. An additional cyanobacterium, *Anabaenopsis*, joined *Dolichospermum* in August, but the main bloom did not appear to be a succession of cyanobacteria as is often observed in eutrophic lakes in summer. Elevated P concentrations and limiting nitrate and ammonium concentrations appeared to favor and support these cyanobacteria. Several types of diatoms, green algae and dinoflagellates were also observed, but cyanobacteria represented the vast majority of cells and biomass in Hummock Pond in summer of 2016.

In Miacomet Pond, discoloration of the water in May prompted sampling by town staff, and the algae appeared to be members of the chrysophyta (golden algae) from pictures, although the genus was not identifiable. Patchy blooms of *Dolichospermum* were observed in June, subsiding by late June. No further cyanobacteria blooms were observed in 2016. A bloom dominated by the colonial, flagellated, chrysophyte *Dinobryon* was sampled in late June 2016. No other samples were collected from Miacomet Pond by this program in 2016.

Species of *Dolichospermum* observed are types that often start as growths at the sediment-water interface then rise into the water column. There is indication, however, that once in the water column of Hummock Pond, algae are supported by elevated available P concentrations and may proliferate and continue a bloom for an extended period of time. In Miacomet Pond the available P in the water column is lower, and blooms appear to be more transient, probably depending more on reserves accumulated in cells before rising into the water column.

Both ponds appear to have a background algal flora of diatoms and golden algae that would be expected in sandy coastal ponds, but the excessive P concentrations coupled with limiting levels of available nitrogen lead to major cyanobacteria blooms during warmer periods. In the case of Hummock Pond, the breaching of the barrier beach lowers the N concentration in the pond substantially in the spring, setting the stage for N limitation while encouraging more available P, a recipe for fostering cyanobacteria growth. Lowering N concentrations is an appropriate activity in estuarine or marine situations, but must be accompanied by P reduction in coastal ponds to avoid cyanobacteria blooms.

Figure 28. Phytoplankton biomass in 2016 samples.



Data Quality Review

The measurement performance criteria to support the project objectives were described in the QAPP and include elements of accuracy, precision, detection limits, resolution, bias, completion, representativeness and comparability. Data accuracy is most often assessed with the use of spiked samples or blanks. There were no indications of problems from lab spikes and blanks at Envirotech Laboratories, where groundwater samples were analyzed. However, one field blank for Hummock Pond groundwater exhibited an ammonium N value of 110 µg/L while the detection limit was 20 µg/L, and two field blanks for Miacomet Pond groundwater yielded dissolved P concentrations well above the detection limit of 5 µg/L (Appendix). Based on the results for other stations on those dates, many of which were lower than the blanks, it appears that a bad batch of distilled water was used for field blanks. Accuracy with sediment samples is mainly assessed with spiked samples. Spiked sediment samples for this project resulted in 97% recovery, a very acceptable value. Field meters used to assess temperature, oxygen and conductivity were calibrated and appeared to perform well; there is no suspicion of inaccurate values from those readings.

Precision is assessed mainly through duplicate samples. Duplicate groundwater samples had generally acceptable relative percent differences; values >20% resulted only from values close to the detection limit, and many duplicate values were within 10% of each other when a threshold of 25% had been set in the QAPP. Precision of sediment samples was more problematic, with one duplicate sample having disparate values for organic content, Fe-P and total P, and the other having substantial difference between Fe-P values. The lab is still investigating this problem, but the results have only limited bearing on calculations based on average values. Precision for field instrument measurements appears to have been very high. Repeat algal analysis indicated precision close to 10%.

Detection limits were met and resolution of values on relevant scales for each assessed feature was considered adequate. No systematic bias was detected in any analysis. All planned sediment and oxygen measurements were obtained, but physical site limitation reduced the number of ground water segments in Hummock Pond and fewer algae samples were collected than expected, although collected data are considered adequate for the intended assessment. All samples appear representative and comparability to past corresponding data appears sufficient.

No resampling was deemed necessary, although the sediment testing lab is re-analyzing several samples to attempt to understand why precision was low. There may be inaccuracies relating to some individual data points, but taken as a collective data set and compared to relevant past data, the data appear acceptable for use in further calculations. Most intended comparisons involve fairly major changes that would not erroneously be derived from data with inherent error at the level perceived for this data set.

Data Analysis

Data collected and described so far indicate that groundwater is a source of N and P, but at variable and not typically very high concentrations, and that surficial sediments represent a large potential source of available P, with low oxygen in surficial sediments that will increase availability of iron-bound P at the sediment-water interface. Here we examine how these sources are likely to fit into overall N and P loads to Hummock and Miacomet Ponds.

There are four potential sources of inflow to each pond and two additional sources of nutrients that have minimal associated flow (Tables 3 and 4). Precipitation is based on long-term records, adjusted for more recent patterns, and estimates of nutrient content are consistent with other studies and models as applied to southern New England. Atmospheric inputs are rarely a dominant component of nutrient loading to landlocked ponds, and by bracketing plausible N and P concentrations we believe we have adequately characterized that input source. Atmospheric inputs can be a major source to estuarine or marine areas, as related precipitation falls on a very large water surface, but for land-bound ponds with limited surface area and larger watersheds, other sources of N and P tend to be more important. For ponds, the typical levels of N and P in precipitation in this area tend to lead to acceptable water quality, so the presence of algae blooms in Hummock and Miacomet Ponds suggests that other sources are important.

There does not appear to be any significant surface water inflow to Hummock Pond, but flooding in areas around Miacomet and observation of drainage patterns suggest that some surface water does reach Miacomet Pond during storms, mainly in spring when the water table is high. We estimate that about 10% of the potential surface flow is actually realized, compared to values of 25 to 40% in areas with less sandy soils or more urbanization. There is considerable uncertainty associated with this estimate, but it provides a starting point for comparison and future investigation as needed. Concentrations of N and P are from the second quartile of an extensive database established for developed land and represent a reasonable bracketing of likely input concentrations for this system.

Surface inflows during storms are often a dominant source of nutrients to lakes, but are less of a factor in sandy coastal areas such as Cape Cod and the islands, as overland flow is less in this area. The primary concerns at Miacomet are "unsanctioned" access points created on public land to facilitate boat launching in the pond, as these become conduits for storm runoff. There are fewer such access points at Hummock Pond, and runoff from the developed properties on the east side represent the greatest concern. In all cases, these appear to be minor sources individually, and it is not clear that they add up to a major source, but they are controllable sources.

Groundwater inflow is likely to be a major source of water to the ponds, and N moves readily through soils, while the movement of P is subject to many factors, including available binding sites on soil and oxygen status of the groundwater. One task of this project was to assess N and P concentrations in groundwater entering the ponds, providing actual estimates of N and P for use in calculations. Measurement of groundwater flow was beyond our scope, but has been the subject of other investigations. A model constructed by Applied Science Associates in 2001 suggested groundwater flow through the Miacomet basin of 0.02 to 0.14 m^3/sec, with a mean of 0.06 m^3/sec. Not all of this would necessarily enter the pond, and we have assumed that about half of the groundwater movement is underflow that bypasses the pond and have extended this assumption to Hummock Pond with adjustment for a larger contributing area.

Table 3. Estimated water, nitrogen and phosphorus loads to Hummock Pond.

	Hummock				
Loading Component	Assumptions/Data	Water		N	P
		Ac-Ft	m3	kg	kg
Pond volume	142 ac @ 6.5 feet deep	923	1140000		
Precipitation/yr	43.6 in on 142 ac = 1.1 m on 56.8 ha	516	637000		
	N@200-400 ppb, P@10-30 ppb			127-255	6.4-19.1
Surface inflow/yr	None known; minimal runoff potential	0	0		
				0	0
Groundwater inflow/yr	Same rate as for Miacomet with watershed of 2000 ac suggests mean of 0.115 m3/s, half reaches pond	1470	1813500		
	18 inches of recharge over 2000 acres, half reaching pond	1500	1851000		
	Averages for HUM1-6, 13 for 87.5% of flow, N@2171 ppb, P@33 ppb, MIA7-12 for 12.5% of flow, N@6832 ppb, P@ 117ppb			5095	81
	Include only HUM3-6,13 and HUM8, 10-12 P where Fe:P<10:1, flow@53.6% mean est. for HUM3-6, 13, flow@8.4% mean est. for HUM8, 10-12				65
Seawater inflow/yr	Two breaches per year, 25% of volume each time	462	570000		
	N@300-400 ppb, P@20-40 ppb			171-228	11.4-22.8
Waterfowl	No significant liquid input	0	0		
	66 birds/yr @ N= 1.0 kg/bird-yr and P= 0.2 kg/bird/yr			66	13.2
Sediment release	No liquid input	0	0		
	Anoxic: 5-10% of Fe-P over 120 acres, P@4 g/m2, N release @ 2XP release			194-388	97-194
	Oxic: 5-10% of Fe-P over 120 acres, P@4 g/m2, N release @ 2XP release			194-388	97-194
Best Est. Total		2461	3027000	6134	399

Table 4. Estimated water, nitrogen and phosphorus loads to Miacomet Pond.

	Miacomet				
Loading Component	Assumptions/Data	Water		N	P
		Ac-Ft	m3	kg	kg
Pond volume	43.5 ac @ 4.0 feet deep	174	215000		
Precipitation/yr	43.6 in on 43.5 ac = 1.1 m on 17.4 ha	158	195000		
	N@200-400 ppb, P@10-30 ppb			39-78	2.0-5.9
Surface inflow/yr	Watershed yield = 1.0-1.3 cfsm, area=1.02 mi2, 10% as runoff	72.4-94.1	89300-116100		
	N@3000-4000 ppb, P@100-200 ppb			268-464	8.9-23.2
Groundwater inflow/yr	ASA 2001 study gives 0.02-0.14 m3/s, mean=0.06 m3/s, half reaching pond	256-1789 (767)	315500-2207500 (946000)		
	Sutherland 2012 indicates 18 inches of recharge over 1040 ac, half reaches pond	780	962500		
	Avg MLIP1&2 for 30% of flow, N@388 ppb, P@5 ppb; MLIP3 for 40% of flow, N@1005 ppb, P@20 ppb; MLIP4 for 20% of flow, N@335 ppb, P@50 ppb; Avg MLIP5-10 for 10% of flow, N@653 ppb, P@242 ppb			621	41.7
	Include only MIA6-10 P where Fe:P<10:1, flow@10% mean est.				26.6
Seawater Inflow/yr	Not connected to ocean in a decade	0	0		
				0	0
Waterfowl	No significant liquid input	0	0		
	24 birds/yr @ N= 1.0 kg/bird-yr and P= 0.2 kg/bird/yr			24	4.8
Sediment release	No liquid input	0	0		
	Anoxic: 10% of Fe-P over 38 acres, P@2 g/m2, N release @ 2XP release			62	31
	Oxic: 5% of Fe-P over 38 acres, P@2 g/m2, N release @ 2XP release			31	15.5
Best Est. Total		1011	1248000	1163	98

It is also known from past work going back to Horsley and Witten in 1990 and applied by others more recently that about 18 inches of annual precipitation becomes groundwater recharge. We have again assumed that half actually reaches the pond. The two independent estimates of groundwater flow result in very similar water loading for each pond, adding some confidence to the estimates, but these are subject to both natural variability and estimation uncertainty.

The estimation of N and P loading is complicated by spatial variation in concentrations in assessed groundwater and the likelihood of uneven entry of groundwater to the ponds, with higher inflows at the inland ends where the slope of the groundwater table is greater, resulting in faster movement of water through the soil. We have divided the groundwater inflow into two parts for each pond, upgradient (inland) and downgradient (ocean end) components, each adjusted based on contributing land area and water table slope, and applying average N and P values for respective shoreline segments. We have further modified the P loading estimate by removing values from the average where the Fe:P ratio is >10:1, as combination of Fe and P would be expected once the groundwater entered the pond and the P would become part of the sediment by precipitation. That P is likely to figure into internal loading, but is not properly an active part of the groundwater load.

Seawater has not been a factor in water or nutrient loading to Miacomet Pond for over a decade, but past breaching of the bottom barrier has occurred and could occur again. Past breachings may have affected sediment chemistry and groundwater at the ocean end of the pond in lasting ways, or saltwater intrusion into groundwater may be a factor, as the binding of Fe by sulfates in seawater appears to have lowered the Fe:P ratio in groundwater at the ocean end of the pond. But direct entry of seawater to Miacomet Pond is no longer a factor in water or nutrient loading.

Hummock Pond is opened to the ocean twice per year, spring and fall, with varied timing and duration over the years. In general, openings last one to three weeks, lower the pond by about half its volume, and refill it to about the 75% mark. The remaining 25% of pond volume is refilled more gradually by groundwater and direct precipitation, with refill requiring at least a month, longer during dry periods. There is variation in the duration of opening and change in pond volume, and the impact varies along a gradient from ocean to inland, but the scenario listed here appears to approximate the norm.

For 2016, mass balance calculations for salinity suggest that after opening in April the average salinity in May would be 12.6 ppt, while actual measurement in mid-May was 12.2 ppt. Based on monthly estimated inputs of freshwater, the September salinity was calculated at 5 ppt while the actual average salinity was 6 ppt. This gives us some confidence in the general hydrologic assessment for Hummock Pond, but there is considerable variability based on openings and weather. We have no direct measurements for N and P in seawater entering Hummock Pond, but have assumed typical levels in surface seawater as corroborated by data from harbors around Nantucket in estimating loads. The result is a relatively minor portion of the total N and P loads.

Waterfowl can be a significant source of nutrients, and bird counts were made by town staff during 2016 monitoring. We used those counts and literature values for N and P per bird per year as estimates of loading. Many birds will have left in the winter, but we did not reduce the estimate of bird years accordingly; as the estimates of inputs are relatively small, this overestimation is not of any major consequence.

Sediment assessment was another task within this project undertaken to provide specific data. It was not known if anoxia developed near the sediment-water interface and the Fe-P content of the sediment was not known. Both were assessed; anoxia does occur in surficial sediment and Fe-P levels are high enough to support algae blooms when release occurs. With well oxygenated overlying freshwater it is likely that much P recombines with Fe and precipitates out. Yet saltwater additions to Hummock Pond bring sulfates that bind iron and may limit precipitation of P once released into the overlying water. This chemical process may also encourage release of P from sediments under oxic conditions, increasing internal loading. Additionally, decomposition of organic matter releases P into the water column and could be a significant source in these ponds. Where adequate iron is present, it will bind that P, but with the saltwater additions to Hummock, that mechanism may be muted.

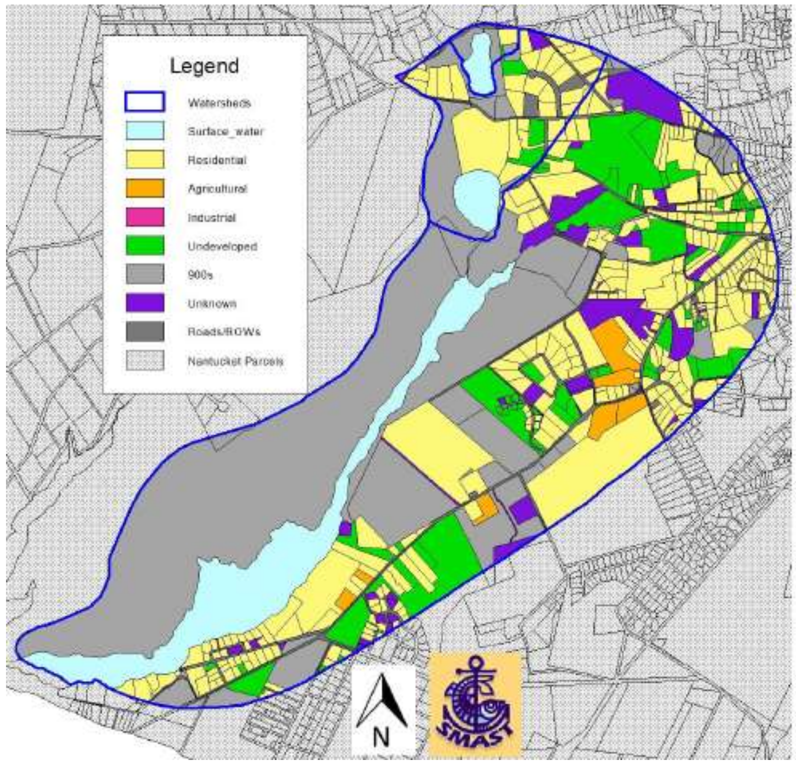
Even if P does recombine with Fe and precipitate from the water column after release, uptake at the sediment-water interface may be important in both Miacomet and Hummock Ponds. With both ponds being shallow, light will penetrate to most of the bottom and algae can grow at the sediment-water interface where the P is released. Such growths often rise into the water column after accumulating substantial biomass and extra P in cells, resulting in surface blooms. Filamentous green algae mats are also generated in this manner, and are observed in both ponds.

We generally find that it is rare for more than 10% of the Fe-P in sediment to be released in a growing season. More P may be released where iron is being bound by sulfur or organic decay is high. We did not conduct core incubations, a lab procedure that can provide direct estimate of P release under controlled conditions, but the estimated release rates based on Fe-P content of the sediment and observed field conditions are 2-4 mg $P/m^2/day$, well within the range normally encountered. Other studies (e.g., Sutherland and Oktay 2010, Sutherland 2013) have suggested that internal loading was a major source of P to these ponds, and our results tend to support that contention, but the estimates of loading are fairly rough and subject to considerable uncertainty.

Overall, the water load for Hummock Pond (Table 3) suggests that the pond is flushed 2.7 times per year (2461 ac-ft of water passing through 923 ac-ft of pond). The estimated average N load is 6134 kg/yr, which is remarkably close to the independently derived MEP estimate of 6023 kg/yr (Howes et al. 2014). About 85% of the N load is attributable to groundwater. The MEP report suggests that 65% of this is from wastewater disposal, but our highest N values in groundwater were associated with large undeveloped areas, mostly *Phragmites* dominated wetland area. That western area is expected to have less actual groundwater flow, so the influence of high N and P concentrations in that groundwater is reduced, but it does suggest potential error in simply assuming that wastewater is the dominant source.

The fairly detailed analysis contained in the MEP report is based on land use and related nutrient load generation, with consideration of attenuation on the way to the pond. The land use map (Figure 29) shows a substantial number of unsewered residential and commercial properties north and east of Hummock Pond (marked as yellow parcels), representing 36% of the watershed. Modeling was used to estimate inputs from all properties. Of particular concern is the area northeast of the pond that would likely drain to the northeast arm of Hummock Pond. The groundwater in that area was not sampled in this study due to access issues, so one potentially large input area may be underrepresented in this study. Still, the estimated total N loads from the MEP and this 604b study are remarkably close, and N concentrations in the sampled groundwater segments toward the northern end of Hummock Pond are not excessive. More investigation with actual measurement of groundwater quality and flow may be needed to gain an understanding of N loading sufficient to support important management decisions like further sewering.

Figure 29. Land use in the Hummock Pond watershed. (From Howes et al. 2014)



Phosphorus loading does not appear to have been previously estimated for Hummock Pond, and this analysis suggests an average annual load of 399 kg P, with about 75% from internal loading from sediments. Using the Lake Loading Response Model (LLRM), it is predicted that the average P concentration in Hummock Pond will be 79 µg/L. Total P has been measured less frequently in recent years, but the average value in available town reports is 84 µg/L, a reasonably close match and certainly within the range of variability indicated by the model. The model further predicts average chlorophyll of about 41 µg/L, while actual chlorophyll measures from recent years average only about 14 µg/L. This is undoubtedly due to P not being the limiting factor for phytoplankton in Hummock Pond; both N and light are likely to be more limiting. However, those conditions favor certain cyanobacteria which can utilize dissolved N gas and grow well under low light; indeed, cyanobacteria blooms are common in Hummock Pond.

Loading of P from wastewater is quite different than for N, as P as phosphate is readily adsorbed to soil particles, even sand, and does not move far beyond leachfields unless they are very old and the soil capacity is exhausted or the groundwater is anoxic and binding of P is reduced. With the observed N concentrations in groundwater downgradient from developed areas of the watershed being low to moderate, we would not expect appreciable P in that groundwater, and indeed the concentrations are fairly low.

The water load to Miacomet Pond (Table 4) suggests that the pond is flushed about 5.8 times per year (1011 ac-ft of water passing through 174 ac-ft of pond). Groundwater is the largest water source, followed by direct precipitation, but surface water inputs may also be substantial. This is an area of some controversy and uncertainty. Flooding has occurred in the Miacomet watershed, but according to town reports and the Woodard and Curran (2014) study, such flooding is mainly a function of high groundwater table and poor drainage systems. The pond has been opened to the ocean to lower it, which then increases the slope of the groundwater table and does increase the rate of drainage for those low-lying areas prone to flooding, but surface connections are limited and the ponds suffers impact just to enhance groundwater flow. Aside from the impact of lowered water level, the increased groundwater flow carries more nutrients into the pond. Opening of Miacomet Pond to the ocean stopped over a decade ago and there is little reason to resume that practice, but there does appear to be some surface flow to the pond that must be addressed in the loading analysis.

One interesting aspect of Miacomet hydrology is that there appears to be a major groundwater input point between stations MIA3 and MIA4 (Figure 22). The temperature near the bottom in only about one meter of water is routinely much colder than at the surface. This apparently uneven input of groundwater may warrant additional investigation. This is an area where potentially substantial sources from the east and west converge and the slope of the groundwater table appears to decline; it may be a major loading point for at least N from the watershed. In response, we adjusted groundwater loading estimates through more partitioning of the drainage area (Table 4), generally following the delineations from the ASA (2001) study.

The estimated average N load to Miacomet Pond is 1163 kg/yr, with groundwater as the largest source. Surface loading has high uncertainty and a wide range, but is potentially a significant source of N. All other sources are relatively minor. The ASA (2001) assessment calculated a total N load of 3376 kg/yr, considerably higher than what this 604b effort derived. The ASA report provides few details of model calculation, but the load of 3376 kg/yr is an input to the mass transport model, which may attenuate this load. Additionally, we suspect that as much as half the groundwater passes under or around Miacomet Pond, which could cut the delivered load in half, making it much closer to the estimate from this 604b study. Mass balance calculations using an input of 1163 kg/yr suggest an average inlake N concentration of 934 µg/L, while the average actual value for Miacomet Pond for the last five years is 990 µg/L. This match is close enough to suggest that the 604b N load estimate is reasonable but probably slightly low. Similar calculation with the ASA N load of 3376 kg/yr suggests an N concentration well over 2 mg/L, more than twice the average value for recent years.

The estimated P load to Miacomet Pond is 98 kg/yr, with internal loading, groundwater and surface water inputs all as significant components. Internal loading is the largest single component, and occurs mainly during the growing season, so it is disproportionately important to summer conditions, but the groundwater and surface water components may be sufficient to support blooms. Application of the P load in LLRM results in a predicted inlake average P concentration of 52 µg/L, while the measured average over the last decade is about 57 µg/L, a reasonable match. The predicted average chlorophyll concentration is 25 µg/L, while the average measured value is 22 µg/L, again a reasonable match. Nutrient limitation appears to fluctuate between P and N, with cyanobacteria blooms seemingly coincident with periods of N limitation. Blooms of golden algae (chrysophytes) are more common when P is limiting, but algae abundance is high most of the summer.

The ASA (2001) assessment estimated a P load of 29 kg/yr, but this did not include internal loading, the largest source identified in this 604b study, and also ignored waterfowl inputs. Summing only the components of this study that are common to the ASA effort, we get an estimated P load of 47 kg/yr, still higher than the ASA (2001) estimate, but justified by the numeric estimations provided here. The ASA report provides little detail of the calculations, but concludes that 76% of the P load comes from the west side of the main body of Miacomet Pond, where the only obvious source is the golf course. Underestimation from sources to the north and east is suspected, along with ignoring internal loading and waterfowl.

Management Needs

For Hummock Pond, control of N and P is desirable, but the current focus on N will not alleviate cyanobacterial blooms. Only by making P the limiting nutrient are we likely to reduce cyanobacteria substantially. If the anoxic release of P is eliminated, LLRM predicts that the P concentration will drop to 49 µg/L, a sizeable decrease from current levels but not enough to prevent blooms. If the anoxic and oxic portions of the internal load could be eliminated, LLRM predicts a P concentration of 20 µg/L; this reduction should be enough to limit blooms and shift composition away from cyanobacteria. Predicted average chlorophyll would be 7.5 µg/L, an acceptable value about half of the current average. No other source of P to Hummock Pond is large enough to provide a substantial decrease if addressed by management. This does not mean that other sources (e.g., wastewater, fertilizer) should not be addressed in a management plan, but the internal load must be addressed if the plan is to be successful.

The situation is similar in Miacomet Pond, but with P sometimes limiting in that pond, where seawater influence has been minimal for over a decade. Elimination of the anoxic component of internal loading in LLRM yields an average inlake P concentration of 35 µg/L, while elimination of both anoxic and oxic internal loads results in a predicted inlake P concentration of 27 µg/L. Neither is low enough to prevent all blooms, although improvement should be marked and there should be fewer cyanobacteria blooms. Additional effort in the watershed may be necessary to further lower the P concentration.

Certainly it would be beneficial to further reduce fertilizer use and revisit golf course management, but Nantucket already has a fertilizer ordinance that calls for a soil test before any P-laden fertilizer can be applied. Additionally, manufacturers are taking excess P out of lawn fertilizers as a result of bans in many USA cities and states. Fertilizer as a P source may already be much lower than many past studies have projected. The breakdown of estimated groundwater inputs suggests that over half of the total input of P is linked to just 10% of inflow in the half of the pond closest to the ocean. Soil capacity to bind P may have been exhausted here by past incidents of saltwater exchange induce by breaching the barrier beach, a practice that only impacted that half of the pond. Further investigation through seepage measurements and groundwater testing is recommended, but it may be possible to “recondition” sediment in this area to better bind P through addition of iron or aluminum.

Reduction in N loading may not be necessary to manage these ponds for recreational use. Miacomet Pond has not been connected to the ocean in over a decade and conversion of N within that pond to organic forms will limit its movement with groundwater out of the pond and into the ocean. Total N values are elevated, but these will produce green algae instead of cyanobacteria if P is reduced, and those algae are more edible within the food web. Certainly N reductions are desirable, and should be pursued with P reductions for watershed inputs, but just reducing N without a greater proportional reduction in P will not reduce blooms of cyanobacteria.

The situation appears similar for Hummock Pond, where reduced P is more important than reduced N for control of cyanobacteria. However, twice annual breaching of the barrier beach connects this pond to the ocean for 6 to 19 days at a time, lowering the N concentration by at least a factor of two and usually resulting in an average total N concentration close to 0.5 µg/L. The breaching adds sulfates from ocean water that preferentially bind with iron and reduce natural P inactivation capacity. This practice effectively shifts the pond into a mode of N limitation with adequate available P, favoring cyanobacteria that can utilize dissolved N gas, an ecological advantage over other algae.

The blooms appear to start in the northern portion of Hummock Pond, especially Head of Hummock, where salinity is lowest and normally freshwater forms of cyanobacteria can still thrive. Those blooms move from the inland end to the ocean end of the pond, finding adequate P to keep the bloom going as long as the salinity is not too high. The pond "freshens" over the summer after the spring breaching and the probability of cyanobacteria blooms increases. If the salinity was kept much higher, such blooms might be avoided, but ongoing fresh water inputs lower salinity, so breaching would have to be more frequent. This would induce considerable fluctuation in water levels that would impair both ecological and recreational functions.

The breaching of the barrier beach at Hummock Pond is practiced to allow flushing of the pond and access by anadromous fish. It is known from monitoring that the flushing function works with regard to N, but it does not effectively reduce P concentrations. It is not known that the breaching supports fish runs that sustain any marine populations. Older surveys suggest that alewife and even striped bass have been found in the pond, but documentation that an opening of a couple of weeks in April and again in October adequately supports marine fisheries is lacking. Town staff is currently working with the Massachusetts Division of Marine Fisheries to investigate fish resources and the utility of the breaching, and such an evaluation is needed to facilitate more informed decisions.

For maximum fishery benefit, the timing of the breaching should match the immigration and emigration timing for herring and allow enough time for adults to spawn and leave in the spring as well as adequate time for young-of-the-year to find their way out in the late summer or early fall. The connection of the pond to the ocean for about one month per year does increase average salinity, but this does not make Hummock Pond a functioning estuarine system, and it impairs freshwater functions. If breaching ceased, the situation would be analogous to Miacomet Pond and P control would be more important than N control to manage algae blooms. Goals and priorities for the management of both ponds need to be set in order to plan appropriately.

Rooted plants are not the subject of this project, but do figure prominently in the management of both ponds. Both ponds are shallow and have a substantial area of fertile bottom sediment. Under these conditions, rooted plant growth is to be expected, and can fill a large portion of the water column. This will provide ecological benefits for some species and negatively impact others, but is routinely a problem for recreational use. Algae blooms reduce light and may reduce plant growth to some degree, but with both ponds being so shallow, nuisance growths are still expected. Control of nutrients to reduce algae blooms may not translate into any plant control, and increased light may actually increase plant density, except where dredging is used to remove nutrient reserves, in which case the substrate in which the plants grow will be altered and growths should be minimized. Some form of rooted plant control is likely to be needed to manage these lakes for maximum recreational benefit and would benefit some ecological functions as well.

In Hummock Pond the submergent plants are virtually all seed producing annual species, as the influx of saltwater twice per year kills perennial freshwater plants. That saltwater influx is not enough, however, to provide control over *Phragmites* (common reed), which has taken over large expanses of shoreline, especially on the west side of Hummock Pond, and encroaches on the pond is some areas, particularly along the narrows and at the northeast end, impairing recreational use and even impeding access for this 604b study. *Phragmites* patches are found along the shoreline of Miacomet Pond, but this invasive plant has not yet achieved the density observed at Hummock Pond. There is an infestation of *Myriophyllum aquaticum* (parrotfeather) in Burchel Pond upstream of Miacomet Pond to the northwest that threatens Miacomet Pond, but a survey in 2016 did not find parrotfeather in Miacomet Pond. Control of this plant upstream of Miacomet Pond is strongly urged.

Management Options

Algae Control

Nutrient management is always the first and best choice for control of algae, but is much easier to understand than to accomplish. If P can be reduced to about 10 µg/L there is minimal potential for algae blooms to develop. At P concentrations up to about 20 µg/L, blooms are not common. Beyond that threshold, the probability of blooms increases and the probability of cyanobacteria blooms also increases. In other words, more P means more algae and likely more cyanobacteria, as has been documented in several excellent studies (e.g., Canfield et al. 1989, Watson et al. 1997).

Elevated nitrogen as nitrate or ammonium in freshwater will often determine the types of algae present, but as many cyanobacteria can utilize dissolved nitrogen gas, control of N in freshwater is unlikely to prevent algae blooms unless P is also reduced. In seawater P tends to be more readily available, particularly where iron is the primary natural P binder (and is complexed by sulfur and made unavailable to bind P), and N-fixing cyanobacteria are uncommon, so N becomes the limiting nutrient in most areas. Managing both N and P is almost always desirable for algae control, and many management actions address both, but the sources of N and P and relative magnitudes are not usually identical in lakes, so what management is applied where can have differential effects on N and P availability.

Watershed management is promoted by many groups, including state and federal governments, as the preferred way to reduce nutrient inputs. Where a lake is in acceptable condition, it is most likely to be kept in that condition by watershed management. Certainly any action taken to minimize the movement of N or P from land into water is protective of downstream lakes and is desirable. However, where damage has been done to a lake, simply reducing continued inputs from its watershed many not be adequate to reverse the damage. The situation is analogous to a leak in a boat; patching the leak will not remove the water already accumulated in the boat. Internal loading can be a dominant P source for kettlehole ponds and other waterbodies in sandy coastal areas of New England with limited surface flows of water. Movement through soil tends to reduce P inputs and most P entering the pond becomes part of the sediment reserve, either as organic matter or as iron-bound P. That sediment P can be released through oxic and anoxic processes. The amount of N released by those same processes is low, leading to low N:P ratios and a propensity to foster cyanobacteria blooms.

In Hummock Pond the estimated internal load of P is the largest P source and no other source is large enough to make a major difference in algae abundance if controlled. Watershed management may be protective, but it will not be restorative. In Miacomet Pond the estimated internal load is the largest source, but both groundwater and possible surface water inputs may be adequate to support blooms if only internal loading is controlled. Some watershed management may be necessary, although the temporal distribution of internal loading (mostly in late spring and summer) makes that source disproportionately important and its control is likely to provide more benefit than a simple annual accounting of loading would indicate.

If internal P loading could be controlled in Hummock Pond, no further action should be necessary to prevent the frequent and severe cyanobacteria blooms currently experienced during summer. Additional watershed management would be desirable mainly as protection to prolong the benefits of internal load control. In Miacomet Pond, it appears that some additional watershed management may be needed to achieve the desired control over cyanobacteria. This is uncertain, as the bulk of the internal loading occurs in summer, so it is the dominant source at the time of blooms, but an additional P load reduction of about 13 kg/yr would lower the total annual load such that the predicted average P concentration would be no more than 20 µg/L. Controls aimed at surface or groundwater sources could provide that level of reduction.

Watershed management can involve source controls or pollutant trapping. Source controls limit activities that generate N and P loads, such as fertilizer application or wastewater disposal, and are highly desirable but difficult and/or expensive to apply in developed areas. Nantucket has a fertilizer ordinance that should limit the use of high P fertilizer, but the level of enforcement is uncertain. Wastewater management could involve additional sewering, a controversial topic on Nantucket that bears considerable cost to implement.

Pollutant trapping relates to methods that keep the N and P from moving off site and reaching the lake, and would include infiltration systems (where soil binds P and denitrification can release N gas), detention basins (where biological processes convert N and P to organic matter that is trapped in the basin), buffer strips (where vegetation limits movement of N and P), and other “trapping” approaches. The fundamental problem with these trapping methods is that they rarely remove enough N or P to maintain pre-development conditions, so some downstream impact is expected. They are appropriate measures, just not completely sufficient in most cases. Where development or agriculture exceeds about 25% of the watershed area, water quality is expected to deteriorate even with best management practices in place, necessitating some inlake maintenance measures if desirable conditions are to be preserved on a regular basis. Both Hummock and Miacomet have >25% of their respective watersheds in non-natural uses.

Wastewater management is a controversial topic on Nantucket, but wastewater has been cited as the primary source of N in groundwater and could be a source of P as well. If an area is not sewered with disposal outside the watershed (which raises issues of its own), the disposal of wastewater on site can be expected to raise background N concentrations (mainly as nitrate or ammonium) and may raise P concentrations over time if binding sites in the soil are exhausted or the groundwater is anoxic. A careful analysis of inputs and movement is beyond the scope of this study, but may be necessary for Miacomet Pond and Hummock Pond. Studies by HWH, ASA and SMAST (MEP program) have all modeled groundwater inputs to Hummock or Miacomet, but results are not in complete agreement and open questions remain. It is clear that sewering would reduce N inputs to each pond, but much less clear that P reductions would result.

Fertilizer use is an issue in most developed areas, but the fertilizer industry has been removing excess P from lawn fertilizers since a number of cities and states have banned use of high P fertilizer as a consequence of documented water quality impact (e.g., Lehman et al. 2013). Nantucket has a fertilizer ordinance that prohibits application of fertilizer with high concentrations of P unless the need is demonstrated through a soil test, so in theory fertilizer P input to ponds should be much reduced over historic levels. Golf course practices may need to be reviewed, as the golf course appears to be a potentially major source of N and P to Miacomet Pond.

Alleviating flooding is a challenge in the Miacomet watershed, and care should be taken not to alter drainage to encourage more surface flow to the pond without also implementing best management practices that maximize the quality of that water. Infiltration should remain the primary stormwater management approach, within the constraints of laws of Nantucket and the Commonwealth of Massachusetts as relates to storm water management.

As watershed management alone is unlikely to provide the P load reduction for either Hummock or Miacomet Pond, inlake measures warrant consideration. The primary means for controlling P already in a waterbody include dredging, oxygenation/circulation and inactivation. Each can be effective, but each has technical and economic drawbacks that limit application or effectiveness.

Dredging is simply the removal of sediment with associated nutrients and many other things, including plant root systems and seeds, algal spores, and oxygen demanding organic matter. As a purely restorative measure, dredging is an outstanding way to set a lake back in time, removing accumulated bottom material and limiting fertility. If cost and permitting were not constraints, this would be the preferred approach for both Hummock and Miacomet Ponds. However, both cost and permitting are serious constraints.

The soft sediment volume in Hummock Pond has not been determined, but assessment of Miacomet Pond as part of a separate WRS project in 2016 indicated a total volume of about 56.6 ac-ft (91,200 cubic yards). At a low end cost of about $30/cy, it would cost $2.7 million to dredge Miacomet Pond to a coarse sandy bottom. The cost to dredge Hummock Pond would undoubtedly be much higher with about three times as much area impacted by organic sediment build-up. Partial dredging is an option and might enhance conditions, but an extensive and expensive process of sediment testing and planning is necessary to get through the permit phase for dredging in Massachusetts. Further examination is beyond the scope of this project, but could be worthwhile if a major restoration process can be afforded. If there is any contamination that would result in the imposition of disposal restrictions, the cost of a dredging program could rise dramatically. It is therefore essential to acquire sediment quality data before further planning.

Oxygenation is the process of adding oxygen to a waterbody, which can be done by direct oxygen (or air) addition or by circulation. With circulation, air or mechanical force is applied to move water. There may be some transfer of oxygen from the air to the water, but the main mode of oxygen addition in circulation is interaction with the atmosphere at the waterbody surface or transfer of oxygenated surface water into deeper areas. In each case, the addition of oxygen suppresses anoxic release of P, potentially controlling algal blooms. However, in very shallow systems like Miacomet or Hummock Ponds, the vertical distance for mixing is short and horizontal water movement is problematic, leading to very inefficient mixing. Circulation and oxygenation can be achieved, but only with an extensive network of points where air or force is applied. The expense and interference of the application network with recreational and ecological functions is generally intolerable, so this approach is unlikely to be appropriate for these ponds.

Inactivation of P has gained popularity with successes over the last two decades. While philosophically less appealing than original source control, it is highly expedient and can be applied flexibly under a variety of circumstances. The three primary applications are:

- Treatment of sediment at relatively large doses to inactivate any P that can be bound to reactive binders (e.g., aluminum, calcium, lanthanum). This tends to greatly depress release of P from iron compounds under anoxic influence and may suppress some oxic release as well. Duration of benefits is years, averaging 11 years in shallow lakes (Huser et al. 2016).
- Treatment of the water column to strip P and limit fertility until that P is replaced. These tend to be lower dose treatments which provide benefits for shorter duration (a season or two), but will also bind some sediment P and over time may provide more lasting benefits.
- Treatment of incoming surface flows to inactivate P. These tend to be short duration, moderate dose treatments that limit P availability in storm flows as needed to keep a lake less fertile. As there are no major surface inflows to Hummock or Miacomet Pond, this approach is not applicable here.

Either the higher dose sediment treatment or lower dose water column treatment could work in Hummock or Miacomet Ponds, but the twice per year addition of seawater to Hummock could reduce the duration of benefits from the sediment treatment. In addition, oxic release of P in Miacomet could be a significant source and may not be strongly affected by a sediment treatment. If Head of Hummock Pond was physically separated from the rest of Hummock Pond (a proposal that has been under consideration on Nantucket for some time), such that seawater no longer reached it, a single sediment treatment with aluminum should provide more than a decade of relief from cyanobacterial blooms. If Hummock Pond was no longer opened to the ocean, a sediment treatment should provide relief once the pond has returned to a freshwater state. As cyanobacterial blooms appear to originate in Head of Hummock, blooms in the rest of Hummock Pond might be reduced by addressing only Head of Hummock Pond, but the algae data are not extensive enough to be certain of this.

The dose necessary to treat sediment depends on the mass of P in the surficial sediments targeted by the treatment. For Head of Hummock Pond, the P mass in the upper 4 cm is just over 4 g/m^2. If aluminum is used as the inactivator, a dose of 40 to 80 g/m^2 would be recommended, at a cost of approximately $3000-6000 per acre. For all of 16 acre Head of Hummock Pond, the treatment would cost $50,000 to $100,000, although it is likely that only about half of Head of Hummock would actually have to be treated (the portion with complete covering by soft sediment). So a cost of $25,000 to $50,000 would be expected, excluding permitting and possibly increased chemical and equipment transportation costs. The average P mass in the upper 4 cm of the rest of Hummock Pond is also close to 4 g/m^2, suggesting a similar dose and cost per unit area. Up to 120 acres might be treated.

The average P mass in the upper 4 cm of Miacomet Pond is close to 2 g/m^2 and about 38 acres of area might be treated. At a dose of 20 to 40 g/m^2, the cost would be about $1500-3000/acre, or $57,000 to $114,000 for the potential maximum treatment area.

The alternative of a low dose water column inactivation is attractive on an experimental basis, as some sediment inactivation is achieved and is additive, so that there is no loss of actual treatment efficiency with sequential lower dose treatments than for a single larger dose treatment. But a low dose (typically 1-3 mg/L) treatment can strip the water column of P and minimize algae blooms for as long as it takes for the water column P to be replaced. With the estimated flushing rates for both ponds, each should avoid blooms for the summer following treatment in May or June. However, the mechanism whereby algae grow at the sediment-water interface then rise into the water column may not be completely counteracted, so the low dose treatment may not provide maximum benefit.

The cost for such a treatment is on the order of $150 to $300 per acre, so an experimental application at Miacomet Pond would cost $6,000 to $12,000, exclusive of permitting costs and any extra transportation cost for chemical and equipment. Additional cost associated with mobilization to Nantucket is difficult to estimate at this point, but this provides a reasonable frame of reference. A similar low dose treatment of 120 acres of Hummock Pond would probably cost on the order of $18,000 to $40,000, depending on dose applied.

If the low dose application provided acceptable results on a seasonal basis, installation of a dosing system could be considered to avoid future labor costs for application. Tubes could be run into the target area with an aeration diffuser with airline and chemical feedline, with a chemical exit port over the diffuser. Pumps would send air and aluminum to the target area, where the air would mix the aluminum with the water column. Such systems exist in multiple lakes and have been very successful on a seasonal basis. The cost of the dosing system depends on the size and shape of the target area, but could be further evaluated if experimental treatments proved useful.

One key aspect of any aluminum application is avoidance of toxicity. Reactive aluminum undergoing the typical hydrolysis reaction in a pond can be toxic to many freshwater organisms above a threshold of about 100 µg/L. Partitioning of aluminum fractions between a pH of 6 and 8 minimizes the toxic fraction, so there is little threat of toxicity as long as the pH remains between 6 and 8 and the total aluminum concentration is not far above 5 mg/L. Treatments are planned with this goal in mind, and proper applications generate lower aluminum concentrations and buffer as needed to keep the pH in the favorable range. It is appropriate to monitor water quality and biological resources before, during and after treatments, adding to treatment cost unless town staff can conduct the monitoring program.

Algaecides can be used to directly kill algae and mitigate blooms. In general, people tend to wait too long to arrange for such treatment, and killing an existing bloom can result in elevated oxygen demand and toxin release in the water column. Proper use of algaecides involves tracking the algae on a weekly basis, then treating when bloom formation is imminent, but before biomass is high. This has been an effective strategy where algal monitoring has been conducted, but requires considerable planning and coordination. Algaecide applications tend to cost $10-50/acre, which is relatively inexpensive. Copper is the most commonly applied algaecide and is toxic to many aquatic organisms, so this approach does carry risk of damage to non-target organisms, although normal target concentrations are low enough to minimize non-target impacts. As an emergency measure it is justifiable in many cases, but is not preferable to nutrient control.

Biological controls offer some interesting theory but less practical appeal. If the biological structure of a pond can be set to encourage consumption of algae by zooplankton and limited consumption of zooplankton by small fish, algal biomass can be maintained at a lower level. However, where nutrients are abundant, algae usually manage to bloom in spite of biological adjustments, and cyanobacteria are particularly adept at avoiding consumption. Shallow, weedy ponds are havens for small fish, increasing predation on zooplankton and minimizing grazing on algae. Biological controls are unlikely to provide an easy answer, and are of limited applicability in Hummock or Miacomet Pond until both nutrients and rooted plant problems are better controlled.

Rooted Plants

Rooted plants are a source of the organic muck that harbors substantial P in both ponds. Dredging would remove the substrate as well as the plants, and regrowth would be limited for many years, making this an attractive albeit expensive approach that has been discussed previously. Beyond dredging, there are really only two alternatives worth considering at the scale necessary in Hummock and Miacomet Ponds: herbicides and harvesting.

Herbicides are chemicals developed to kill target plants. Some are fairly specific to groups of plants, while others are broad spectrum agents. Some are called systemic herbicides, which enter the plant and move throughout it, killing the entire plant. Others are called contact herbicides, killing only the part of the plant which they contact, usually leaves and stems. Systemic herbicides are best used on perennial species, as killing the entire plant will limit regrowth. Contact herbicides are more often used on annual species, since regrowth from seeds is expected in subsequent years and the extra expense of systemic herbicides is not justified.

The dominant plants in both Hummock and Miacomet Ponds are annuals, which sprout from seeds each spring, grow and produce more seeds, die in the fall and start over from seeds in the spring. Those in Hummock Pond must have some salt tolerance as well, and most perennial freshwater plants would be killed by the spring and fall seawater infusion. Consequently, contact herbicides would be most applicable in these ponds, and would need to be applied annually. This is not a favored strategy in many communities, including Nantucket, and it seems doubtful that permits would be granted on an annual basis to apply such herbicides to these ponds. It is a viable strategy from scientific and economic perspectives, but is probably not institutionally acceptable.

Harvesting represents the primary alternative strategy, and has already been demonstrated in Hummock Pond in 2015. Mechanical harvesting machines, functionally aquatic lawnmowers, can be used to keep boating, swimming and fishing lanes open, creating a network of channels and open patches that are both ecologically and recreationally beneficial. Only a portion of each pond would be addressed, but enough can be harvested to enhance appearance and utility each summer. With continued cutting, some patches may remain open or plant density will at least decline, but there is minimal probability that harvesting would not continue to be needed on a seasonal basis. There are issues with bycatch of fish and sometimes other aquatic organisms, but lakes that are routinely harvested are not aquatic deserts and typically have thriving fish, reptile, amphibian and invertebrate communities. Work in shallow water can create turbidity, but both ponds already suffer from elevated turbidity caused by both algae and resuspended sediment. Harvesting would not be expected to cause more turbidity problems than currently experienced.

Removal of plant biomass from a pond represents a removal of N and P as well, but the quantity of nutrients per unit of biomass harvested is rather small. Harvesting programs have not been demonstrated to make a large difference in N or P content of the water column, as most rooted plants get most needed nutrients from the sediment, often well below the surficial layer that interacts with the overlying water. Harvested plant biomass should be disposed of away from the pond, however, to avoid having nutrients released by decay wash back into the pond. The harvesting demonstration program at Hummock Pond in 2015 piled harvested plants near the launch area to dewater, after which they were taken to the Bartlett farm for use as compost and eventual land application.

As the demonstration project showed, the process can be efficient and effective, but is not inexpensive, especially on a contract basis. If there is a desire to maintain open water in Hummock and Miacomet Ponds with mechanical harvesting, the Town of Nantucket or some designated entity within it should consider purchasing a harvester and appropriate accessories at a cost on the order of $200,000 and assuming an annual operating cost of about $50,000.

An alternative form of harvesting is hydroraking, often used to remove heavily rooted plants and emergent growths such as water lilies (*Nymphaea*), cattails (*Typha*) or common reed (*Phragmites*). This is generally not applicable among the submergent annual growths in either pond, as it will create substantial turbidity without providing lasting results. However, this is a valid approach where emergent plant growths are choking off access in shallow areas as with the narrows of Hummock Pond or the far northern arm of Miacomet Pond. In Hummock Pond it seems that the much more extensive common reed problem should be dealt with using systemic herbicides, but hydroraking could provide temporary relief until the larger control project can be permitted and implemented.

The northern arm of Miacomet Pond creates controversy. This was apparently a wetland channel with no appreciable open water some decades ago, but was dredged to create a connection with the main body of the pond as part of a real estate development. As a less open connection, there is more opportunity for biological processes to convert available nutrients into organic matter and protect the main body of the pond. Yet that connection was opened and people bought property with some expectation of access to the main body of the pond. Further, there is open land on the west side that is being considered as a possible park or other public open space; access to open water would seem desirable for that parcel as well.

It is not clear that the channel is providing a major conduit for nutrients to Miacomet Pond, and available data suggest that inputs are larger further south, particularly on the west side, but the loss of wetland treatment functions in the excavated area cannot be considered beneficial to the pond. Certainly elevated N concentrations have been found at the northern end, but there is no indication that P concentrations are higher than elsewhere in the pond. This channel could be hydroraked to maintain access to the pond for bordering properties, but the impact on nutrient loading remains largely unknown. What to do with the narrow northern channel of Miacomet Pond is more of an institutional question than a scientific one at this point. Options exist for its improvement or maintenance, but the goals of such actions require some discussion among responsible and interested parties. Restoration activities under consideration for the northern channel of Miacomet Pond should be discussed with regulatory agencies as well as locally interested parties, as work in this area would fall under the jurisdiction of the Wetlands and Waterways program.

References

Applied Science Associates. 2001. Miacomet Pond Nutrient Loading Model. ASA, Narragansett, RI.

Canfield, D., E. Philps and C.M. Duarte. 1989. Factors influencing the abundance of blue-green algae in Florida Lakes. Can. J. Fish. Aquat. Sci. 46:1232-1237.

Conant, K. 2006. Miacomet Pond Annual Report 2005. Marine and Coastal Resources Department, Town of Nantucket, MA.

Howes, B., R. Samimy, D. Schlezinger, E. Eichner, J. Ramsey and S. Kelley. 2014. Massachusetts Estuaries Project Linked Watershed-Embayment Model to Determine Critical Nitrogen Loading Threshold for the Hummock Pond Estuarine System, Town of Nantucket, MA. SMAST, Dartmouth, MA.

Huser B.J., S. Egemose, H. Harper, M. Hupfer, H. Jensen, K.M. Pilgrim, K. Reitzel, E. Rydin, and M. Futter. 2016. Longevity and effectiveness of aluminum addition to reduce sediment phosphorus release and restore lake water quality. Water Res. 97:122-132.

Lehman, J.T., J.P.Doubek and E.W. Jackson. 2013. Effect of reduced allochthonous P load on biomass and alkaline phosphatase activity of phytoplankton in an urbanized watershed, Michigan. Lake Reserv. Manage. 29:116-125.

NEAR. 2006. Hummock Pond Monitoring Report 2005. NEAR, Mansfield Center, CT.

Sutherland, J. 2013. Head of Hummock Groundwater Wells: The 2011 and 2012 Water Quality Program Final Report. For the Nantucket Land Council, Nantucket, MA.

Sutherland, J. and S. Oktay. 2010. Miacomet Pond Water Quality 2009: A Summary of Physical, Chemical and Biological Monitoring. For the Nantucket Land Council, Nantucket, MA.

Watson, S.B., McCauley, E. and Downing, J.A. 1997. Patterns in phytoplankton taxonomic composition across temperate lakes of differing nutrient status. Limnol. Oceanogr. 42:487-495.

Water Resource Services. 2016a. Plant Survey of Miacomet Pond. WRS, Wilbraham, MA.

Water Resource Services. 2016b. Quality Assurance Project Plant for Study of Phosphorus Sources to Hummock and Miacomet Ponds. Project 2015-04/604. WRS, Wilbraham, MA.

Woodard and Curran. 2014. Miacomet Pond Watershed Study, Nantucket, MA. W&C, Dedham, MA.

Appendix: Data and Related Information

Groundwater Sampling Information

HP Groundwater Sampling Sites				
Sample	DMS Lat	DMS Long	Decimal Lat	Decimal Long
HLIP 1 (A-D)				
A	41 16' 40.3"	70 07' 58.3"	41.277861	-70.132861
B	41 16' 41.3"	70 07' 58.3"	41.278139	-70.132861
C	41 16' 42.2"	70 07' 58.1"	41.278389	-70.132806
D	41 16' 44.1"	70 07' 57.9"	41.278917	-70.13275
Comments: A-C in sand, D in cattails; Shoreline fronting houses				
HLIP 2 (AA-DD)				
AA	41 16' 45.9"	70 07' 57.8"	41.279417	-70.132722
BB	41 16' 47.7"	70 07' 58.4"	41.279917	-70.132889
CC	41 16' 49.3"	70 08' 03.1"	41.280361	-70.134194
DD	41 16' 48.9"	70 08' 05.4"	41.28025	-70.134833
Comments: Red hue on top of sand between CC and DD; One sample collected on shoreline full of duck and goose feces				
HLIP 3 (E-H)				
E	41 16' 44.0"	70 08' 08.8"	41.278889	-70.135778
F	41 16' 42.4"	70 08' 08.2"	41.278444	-70.135611
G	41 16' 40.8"	70 08' 06.6"	41.278	-70.135167
H	41 16' 40.1"	70 08' 05.7"	41.277806	-70.134917
Comments: Three samples taken on sandy shore and one among stand of Iris				
HLIP 4 (EE-GG)				
EE	41 16' 26.4"	70 08' 01.6"	41.274	-70.133778
FF	41 16' 24.8"	70 08' 02.4"	41.273556	-70.134
GG	41 16' 20.0"	70 08' 08.0"	41.272222	-70.135556
Comments: Samples taken in cattail and fern marsh areas				
HLIP 4A* (EE-GG)				
EE	41 16' 26.4"	70 08' 01.6"	41.274	-70.133778
FF	41 16' 24.8"	70 08' 02.4"	41.273556	-70.134
GG	41 16' 20.0"	70 08' 08.0"	41.272222	-70.135556
Comments: Samples taken in cattail and fern marsh areas				
HLIP 5 (I-L)				
I	41 16' 10.8"	70 08' 19.5"	41.269667	-70.13875
J	41 16' 07.8"	70 08' 20.9"	41.268833	-70.139139
K	41 16' 05.8"	70 08' 22.7"	41.268278	-70.139639
L	41 16' 04.3"	70 08' 24.7"	41.267861	-70.140194
Comments: Samples taken behind or between stands of Phragmites				
HLIP 6 (II-KK)				
II	41 16' 01.6"	70 08' 26.9"	41.267111	-70.140806
JJ	41 15' 57.5"	70 08' 30.5"	41.265972	-70.141806
Comments: Sample sites limited due to dense Phragmites; Shoreline is open space				
HLIP BK**				
HLIP 7 (M-Q)				
M	41 15' 40.9"	70 08' 38.1"	41.261361	-70.143917
N	41 15' 39.2"	70 08' 40.9"	41.260889	-70.144694
O	41 15' 36.8"	70 08' 43.1"	41.260222	-70.145306
P	41 15'34.9"	70 08' 44.9"	41.259694	-70.145806
Q	41 15' 33.5"	70 08' 47.3"	41.259306	-70.146472
Comments: Sample at M came out of ground "amber" color				

HP Groundwater Sampling Sites				
HLIP 8 (MM-QQ)				
MM	41 15' 29.7"	70 08' 50.5"	41.25825	-70.147361
NN	41 15' 28.5"	70 08' 53.6"	41.257917	-70.148222
OO	41 15' 27.0"	70 08' 56.8"	41.2575	-70.149111
PP	41 15' 25.9"	70 09' 01.9"	41.257194	-70.150528
QQ	41 15' 24.5"	70 09' 08.5"	41.256806	-70.152361
Comments: Very strong sulfur smell along Segment 8				
HLIP 9 (R-U)				
R	41 15' 18.9"	70 09' 17.2"	41.25525	-70.154778
S	41 15' 19.0"	70 09' 20.9"	41.255278	-70.155806
T	41 15' 17.9"	70 09' 24.3"	41.254972	-70.15675
U	41 15' 16.7"	70 09' 31.8"	41.254639	-70.158833
Comments: Sulfur smell along Segment 9				
HLIP 9A* (R-U)				
R	41 15' 18.9"	70 09' 17.2"	41.25525	-70.154778
S	41 15' 19.0"	70 09' 20.9"	41.255278	-70.155806
T	41 15' 17.9"	70 09' 24.3"	41.254972	-70.15675
U	41 15' 16.7"	70 09' 31.8"	41.254639	-70.158833
Comments: Sulfur smell along Segment 9				
HLIP BK3**				
HLIP 10 (SS)				
SS	41 15' 43.8"	70 08' 54.4"	41.262167	-70.148444
Comments: Only one site on this Segment 10 due to apparent clay layer about 6" below surface; Water very brown				
HLIP 11 (W-X)				
W	41 15' 34.2"	70 09' 10.4"	41.2595	-70.152889
X	41 15' 29.3"	70 09' 13.7"	41.258139	-70.153806
HLIP 12 (WW-XX)				
WW	41 15' 22.9"	70 09' 23.6"	41.256361	-70.156556
XX	41 15' 22.7"	70 09' 38.7"	41.256306	-70.16075
HLIP 13 (A-D)				
A	41 16' 30.0"	70 08' 07.5"	41.275	-70.135417
B	41 16' 20.5"	70 08' 16.6"	41.272361	-70.137944
C	41 16' 13.2"	70 08' 19.7"	41.270333	-70.138806
D	41 15' 56.8"	70 08' 34.6"	41.265778	-70.142944
Comments: Sample A contained orange/brown sediment; Narrower portion of the pond was cloudy with significant surface scum;				
Phyto sample was collected: Bottle #153				
* 4A and 9A are duplicate samples of 4 and 9				
** BK denotes a BLANK sample				

MP Groundwater Sampling Sites				
Sample	DMS Lat	DMS Long	Decimal Lat	Decimal Long
MLIP 1 (A-C)				
A	41 15' 22.1"	70 06' 32.0"	41.256139	-70.108889
B	41 15' 20.0"	70 06' 34.4"	41.255556	-70.109556
C	41 15' 22.9"	70 06' 30.9"	41.256361	-70.108583
MLIP 1A* (A-C)				
A	41 15' 22.1"	70 06' 32.0"	41.256139	-70.108889
B	41 15' 20.0"	70 06' 34.4"	41.255556	-70.109556
C	41 15' 22.9"	70 06' 30.9"	41.256361	-70.108583
MLIP 2 (AA-CC)				
AA	41 15' 23.8"	70 06' 32.6"	41.256611	-70.109056
BB	41 15' 21.4"	70 06' 36.0"	41.255944	-70.11
CC	41 15' 20.8"	70 06' 37.1"	41.255778	-70.110306
MLIP 3 (E-F)				
E	41 15' 12.3"	70 06' 48.2"	41.253417	-70.113389
F	41 15' 09.0"	70 06' 49.9"	41.2525	-70.113861
MLIP 4 (EE-FF)				
EE	41 15' 08.8"	70 06' 46.0"	41.252444	-70.112778
FF	41 15' 06.8"	70 06' 47.4"	41.251889	-70.113167
MLIP 5 (I-J)				
I	41 15' 05.7"	70 06' 53.3"	41.251583	-70.114806
J	41 14' 58.5"	70 06' 56.8"	41.249583	-70.115778
MLIP BK**				
MLIP 6 (II-LL)				
II	41 15' 03.6"	70 06' 49.9"	41.251	-70.113861
JJ	41 15' 02.3"	70 06' 50.7"	41.250639	-70.114083
KK	41 15' 01.1"	70 06' 50.8"	41.250306	-70.114111
LL	41 14' 57.7"	70 06' 51.8"	41.249361	-70.114389
MLIP 7 (M-P)				
M	41 14' 37.3"	70 07' 01.3"	41.243694	-70.117028
N	41 14' 38.9"	70 07' 00.0"	41.244139	-70.116667
O	41 14' 41.3"	70 06' 58.8"	41.244806	-70.116333
P	41 14' 43.7"	70 06' 57.0"	41.245472	-70.115833
MLIP 7A* (M-P)				
M	41 14' 37.3"	70 07' 01.3"	41.243694	-70.117028
N	41 14' 38.9"	70 07' 00.0"	41.244139	-70.116667
O	41 14' 41.3"	70 06' 58.8"	41.244806	-70.116333
P	41 14' 43.7"	70 06' 57.0"	41.245472	-70.115833
MLIP BK2**				
MLIP 8 (MM-PP)				
MM	41 14' 38.5"	70 07' 07.1"	41.244028	-70.118639
NN	41 14' 40.3"	70 07' 06.2"	41.244528	-70.118389
OO	41 14' 42.1"	70 07' 05.4"	41.245028	-70.118167
PP	41 14' 44.4"	70 07' 04.0"	41.245667	-70.117778
MLIP 8A* (MM-PP)				
MM	41 14' 38.5"	70 07' 07.1"	41.244028	-70.118639
NN	41 14' 40.3"	70 07' 06.2"	41.244528	-70.118389
OO	41 14' 42.1"	70 07' 05.4"	41.245028	-70.118167
PP	41 14' 44.4"	70 07' 04.0"	41.245667	-70.117778
MLIP 9 (Q-T)				
Q	41 14' 45.3"	70 07' 03.6"	41.245917	-70.117667
R	41 14' 48.1"	70 07' 02.3"	41.246694	-70.117306
S	41 14' 49.9"	70 07' 01.9"	41.247194	-70.117194
T	41 14' 53.8"	70 07' 01.2"	41.248278	-70.117
MLIP BK4**				
MLIP 10 (QQ-SS)				
QQ	41 14' 51.4"	70 06' 53.4"	41.247611	-70.114833
RR	41 14' 49.6"	70 06' 54.5"	41.247111	-70.115139
SS	41 14' 48.0"	70 06' 55.6"	41.246667	-70.115444
* 1A, 7A and 8A are duplicate samples of 1, 7 and 8				
** BK denotes a BLANK sample				

Groundwater Data

HP Groundwater Data												
Sample	Date	Time	Nitrate-N (mg/L) Reportable Limit		Nitrate-N (mg/L)	Iron Dissolved (mg/L) Reportable Limit		Iron Dissolved (mg/L)	Ammonia-N (mg/L)	Dissolved P (mg/L) Reportable Limit		Dissolved P (mg/L)
HLIP 1 (A-D)	6/16/2016	1200	0.01		0.11	0.01		15.6	0.17	0.005		0.009
HLIP 2 (AA-DD)	6/16/2016	1300	0.01		0.23	0.01		0.36	0.06	0.005		0.016
HLIP 3 (E-H)	6/16/2016	1400	0.01		0.11	0.01		0.03	0.1	0.005		0.067
HLIP 4 (EE-GG)	6/16/2016	1530	0.01		0.06	0.01		0.02	0.02	0.005		0.008
HLIP 4A* (EE-GG)	6/16/2016	1530	0.01		0.06	0.01		0.02	0.05	0.005	BRL	0.0025
HLIP 5 (I-L)	6/16/2016	1630	0.01		0.29	0.01		0.04	0.03	0.005		0.01
HLIP 6 (II-KK)	6/16/2016	1750	0.01		0.15	0.01		0.01	0.04	0.005	BRL	0.0025
HLIP BK**	6/16/2016	1730	0.01	BRL	0.005	0.01	BRL	0.005	0.05	0.005	BRL	0.0025
HLIP 7 (M-Q)	7/13/2016	0900	0.01	BRL	0.005	0.01		8.55	0.07	0.005		0.022
HLIP 8 (MM-QQ)	7/13/2016	1030	0.01	BRL	0.005	0.01		0.31	0.06	0.005		0.044
HLIP 9 (R-U)	7/13/2016	1200	0.01	BRL	0.005	0.01		2.96	0.13	0.005		0.045
HLIP 9A* (R-U)	7/13/2016	1200	0.01		0.01	0.01		2.89	0.09	0.005		0.045
HLIP BK3**	7/13/2016	1200	0.01	BRL	0.005	0.01	BRL	0.005	0.11	0.005	BRL	0.0025
HLIP 10 (SS)	8/3/2016	930	0.01	BRL	0.005	0.01		0.013	21	0.005		0.29
HLIP 11 (W-X)	8/3/2016	1030	0.01		0.15	0.01		0.009	0.14	0.005		0.04
HLIP 12 (WW-XX)	8/3/2016	1130	0.01		0.04	0.01		0.258	19.4	0.005		0.26
HLIP 13 (A-D)	8/9/2016	1100	0.01		0.11	0.01		0.008	13.7	0.005		0.12
Note: Values below the detection limit are expressed as one half the detection limit.												

MP Groundwater Data														
Sample	Date	Time	Nitrate-N (mg/L) Reportable Limit		Nitrate-N (mg/L)	Iron Dissolved (mg/L) Reportable Limit		Iron Dissolved (mg/L)	Ammonia-N (mg/L) Reportable Limit		Ammonia-N (mg/L)	Dissolved P (mg/L) Reportable Limit		Dissolved P (mg/L)
MLIP 1 (A-C)	6/17/2016	1145	0.01	BRL	0.005	0.01		0.04	0.02		0.16	0.005	BRL	0.0025
MLIP 1A* (A-C)	6/17/2016	1145	0.01	BRL	0.005	0.01		0.04	0.02	<	0.02	0.005	BRL	0.0025
MLIP 2 (AA-CC)	6/17/2016	1230	0.01		0.66	0.01		0.11	0.02	<	0.02	0.005		0.007
MLIP 3 (E-F)	6/17/2016	1300	0.01	BRL	0.005	0.01		26.1	0.02		1	0.005		0.02
MLIP 4 (EE-FF)	6/17/2016	1330	0.01	BRL	0.005	0.01		46.6	0.02		0.33	0.005		0.05
MLIP 5 (I-J)	6/17/2016	1615	0.01	BRL	0.005	0.01		47.7	0.02		0.2	0.005		0.058
MLIP BK**	6/17/2016	1615	0.01	BRL	0.005	0.01		0.01	0.02		0.02	0.005	BRL	0.0025
MLIP 6 (II-LL)	7/7/2016	0930	0.01	BRL	0.005	0.01		0.095	0.02		0.31	0.005		0.51
MLIP 7 (M-P)	7/7/2016	1400	0.01	BRL	0.005	0.01		0.087	0.02		0.76	0.005		0.16
MLIP 7A* (M-P)	7/7/2016	1400	0.01	BRL	0.005	0.01		0.079	0.02		0.74	0.005		0.13
MLIP BK2**	7/7/2016	1400	0.01	BRL	0.005	0.01	BRL	0.005	0.02	BRL	0.01	0.005		0.06
MLIP 8 (MM-PP)	7/20/2016	1230	0.01	BRL	0.005	0.01		0.044	0.02		0.4	0.005		0.13
MLIP 8A* (MM-PP)	7/20/2016	1230	0.01	BRL	0.005	0.01		0.048	0.02		0.97	0.005		0.27
MLIP 9 (Q-T)	7/20/2016	1330	0.01	BRL	0.005	0.01		0.071	0.02		1.4	0.005		0.32
MLIP BK4**	7/20/2016	1330	0.01	BRL	0.005	0.01	BRL	0.005	0.02	BRL	0.01	0.005		0.11
MLIP 10 (QQ-SS)	9/1/2016	0830	0.01	BRL	0.005	0.01		0.05	0.02		0.52	0.005		0.22
Note: Values below the detection limit are expressed as one half the detection limit.														

Sediment Data

Hummock and Miacomet Ponds Sediment Data								
Site Name	DMS Lat	DMS Long	Decimal Lat	Decimal Long	Total Solids (%)	Organic Content (%)	Iron Bound P (mg/kg dry weight)	Total P (mg/kg dry weight)
Hummock Pond - 06/16/2016								
HUM 1	41 15' 20.6"	70 09' 29.2"	41.255722	-70.158111	28	6.3	100	263
HUM 2	41 15' 30.6"	70 09' 05.9"	41.2585	-70.151639	28	28.2	373	927
HUM 3	41 15' 40.4"	70 08' 44.3"	41.261222	-70.145639	44	75.7	126	278
HUM 4	41 15' 59.2"	70 08' 31.0"	41.266444	-70.141944	28	30.3	448	672
HUM 4A	41 15' 59.2"	70 08' 31.0"	41.266444	-70.141944	29	6.4	40	2,559
HUM 5	41 16' 10.1"	70 08' 21.8"	41.269472	-70.139389	23	24.9	808	1,110
HUM 6	41 16' 23.6"	70 08' 09.6"	41.273222	-70.136000	12	45.4	1,349	2,250
HUM 7	41 16' 42.9"	70 08' 02.5"	41.278583	-70.134028	6.3	5.6	1,572	3,100
HUM 8	41 16' 30.1"	70 07' 57.4"	41.275028	-70.132611	11	8.3	647	929
Miacomet Pond - 06/17/2016								
MIA 1	41 14' 42.8"	70 07' 01.7"	41.245222	-70.117139	14	13.7	336	643
MIA 2	41 14' 54.4"	70 06' 56.7"	41.248444	-70.11575	11	13.1	423	753
MIA 3	41 15' 05.1"	70 06' 51.5"	41.251417	-70.114306	19	7.5	152	734
MIA 4	41 15' 15.0"	70 06' 43.3"	41.254167	-70.112028	6.3	3.7	703	740
MIA 5	41 15' 29.3"	70 06' 23.5"	41.258139	-70.106528	17	5.4	282	916
MIA 6	41 15' 23.1"	70 06' 32.8"	41.256417	-70.109111	9.4	4.9	293	648
MIA 6A	41 15' 23.1"	70 06' 32.8"	41.256417	-70.109111	8.9	8.6	522	688

Oxygen Profiles

Station	Date	Time	Total Depth (m)	Secchi Depth (m)	Conduct-ivity (µS)	Depth (m)	Temp (°C)	DO (%)	DO (mg/L)
HUM 1 (41 15' 20.9", 70 09'29.9")	6/30/2016	1705	1.53	0.75	14430				
HUM 1	6/30/2016					0.00	27.3	112.2	8.90
HUM 1	6/30/2016					0.50	27.3	112.8	8.94
HUM 1	6/30/2016					1.00	24.7	110.5	9.18
HUM 1	6/30/2016					1.50	24.2	126.0	10.57
HUM 1	6/30/2016					1.53	24.0	114.2	9.61
HUM 3 (41 15' 41.1", 70 08' 41.5")	6/30/2016	1740	2.02	1.06	13830				
HUM 3	6/30/2016					0.00	27.1	118.8	9.45
HUM 3	6/30/2016					0.50	27.2	119.0	9.45
HUM 3	6/30/2016					1.00	27.1	119.5	9.50
HUM 3	6/30/2016					1.50	26.9	120.4	9.62
HUM 3	6/30/2016					2.00	25.0	123.6	10.21
HUM 3	6/30/2016					2.12	24.8	116.8	9.69
HUM 5 (41 16' 08.1", 70 08'23.6")	6/30/2016	1815	2.12	1.04	10970				
HUM 5	6/30/2016					0.00	26.9	136.9	10.93
HUM 5	6/30/2016					0.50	26.9	138.0	11.00
HUM 5	6/30/2016					1.00	24.8	138.9	11.52
HUM 5	6/30/2016					1.50	24.3	121.7	10.19
HUM 5	6/30/2016					2.00	23.4	66.6	5.67
HUM 5	6/30/2016					2.12	23.2	3.5	0.30
HUM 7 (41 16'43.3", 70 08'02.7")	6/30/2016	1910	3.32	1.50	7268				
HUM 7	6/30/2016					0.00	27.1	122.5	9.74
HUM 7	6/30/2016					0.50	27.2	123.2	9.78
HUM 7	6/30/2016					1.00	25.9	159.2	12.99
HUM 7	6/30/2016					1.50	24.9	156.6	12.99
HUM 7	6/30/2016					2.00	23.9	168.2	14.21
HUM 7	6/30/2016					2.50	21.8	123.0	10.79
HUM 7	6/30/2016					3.00	20.9	124.6	11.13
HUM 7	6/30/2016					3.32	19.7	4.0	0.36
HUM 8 (41.16'29.8", 70 07 '57.5")	6/30/2016	1845	1.40	0.57	8815				
HUM 8	6/30/2016					0.00	27.8	131.1	10.28
HUM 8	6/30/2016					0.50	28.0	131.8	10.31
HUM 8	6/30/2016					1.00	27.6	130.0	10.25
HUM 8	6/30/2016					1.40	22.8	3.3	0.28
HUM 1 (41 15'20.7", 70 09'29.7")	7/1/2017	0732	1.66	0.80	14460				
HUM 1	7/1/2017					0.00	23.8	92.8	7.84
HUM 1	7/1/2017					0.50	23.9	91.5	7.72
HUM 1	7/1/2017					1.00	23.9	91.3	7.70
HUM 1	7/1/2017					1.50	23.9	82.7	6.98
HUM 1	7/1/2017					1.66	23.9	68.6	5.78
HUM 1	7/1/2017					3.00	23.6	52.5	4.46
HUM 3 (41 15'41.6", 70 08'41.6")	7/1/2017	0655	2.43	1.11	14090				
HUM 3	7/1/2017					0.00	25.1	103.3	8.52
HUM 3	7/1/2017					0.50	25.1	103.5	8.53
HUM 3	7/1/2017					1.00	25.2	103.5	8.52
HUM 3	7/1/2017					1.50	25.2	104.0	8.56
HUM 3	7/1/2017					2.00	24.9	88.3	7.31
HUM 3	7/1/2017					2.25	24.6	76.1	6.34
HUM 3	7/1/2017					2.43	24.3	58.7	4.91
HUM 3	7/1/2017					3.50	24.4	10.1	0.85
HUM 5 (41 16'08.3", 70 08'23.6")	7/1/2017	0630	2.05	0.83	10980				
HUM 5	7/1/2017					0.00	24.0	115.2	9.70
HUM 5	7/1/2017					0.50	24.1	114.8	9.65
HUM 5	7/1/2017					1.00	24.1	114.2	9.60
HUM 5	7/1/2017					1.50	24.2	106.3	8.94
HUM 5	7/1/2017					2.00	23.2	41.3	3.53
HUM 5	7/1/2017					2.05	23.1	3.5	0.30
HUM 7 (41 16'42.7", 70 08'02.9")	7/1/2017	0535	3.40	1.63	7338				
HUM 7	7/1/2017					0.00	24.5	115.4	9.66
HUM 7	7/1/2017					0.50	24.5	116.2	9.69
HUM 7	7/1/2017					1.00	24.6	116.1	9.67
HUM 7	7/1/2017					1.50	24.6	151.1	12.58
HUM 7	7/1/2017					2.00	23.7	180.0	15.24
HUM 7	7/1/2017					2.50	22.4	165.6	14.32
HUM 7	7/1/2017					3.00	21.3	141.8	12.57
HUM 7	7/1/2017					3.40	19.3	4.6	0.43
HUM 8 (41.16'30.0", 70 07'57.9")	7/1/2017	0600	1.30	0.58	8925				
HUM 8	7/1/2017					0.00	24.6	105.1	8.77
HUM 8	7/1/2017					0.50	24.8	104.2	8.64
HUM 8	7/1/2017					1.00	24.9	102.8	8.51
HUM 8	7/1/2017					1.30	23.9	3.0	0.25
HUM 7 (41 16'43.0", 70 08'03.3")	7/27/2017	0930	3.40	0.37	5132				
HUM 7	7/27/2017					0.00	28.1	163.3	12.81
HUM 7	7/27/2017					0.50	27.2	159.3	12.63
HUM 7	7/27/2017					1.00	26.8	133.2	10.65
HUM 7	7/27/2017					1.50	26.1	121.6	9.85
HUM 7	7/27/2017					2.00	25.1	118.8	9.80
HUM 7	7/27/2017					2.50	23.9	123.9	10.42
HUM 7	7/27/2017					3.00	21.8	46.5	4.08
HUM 7	7/27/2017					3.40	20.3	2.9	0.26

Station	Date	Time	Total Depth (m)	Secchi Depth (m)	Conduct-ivity (µS)	Depth (m)	Temp (°C)	DO (%)	DO (mg/L)
HUM 1 (41 15'20.6", 70 09'30.4")	7/28/2017	0939	2.04	0.87	10780				
HUM 1	7/28/2017					0.00	26.6	93.2	7.50
HUM 1	7/28/2017					0.50	26.5	93.3	7.50
HUM 1	7/28/2017					1.00	26.5	93.3	7.50
HUM 1	7/28/2017					1.50	26.4	96.3	7.76
HUM 1	7/28/2017					2.00	26.1	94.6	7.66
HUM 1	7/28/2017					2.04	26.0	73.2	5.94
HUM 3 (41 15'41.3", 70 08'43.1")	7/28/2017	1011	1.84	1.10	10240				
HUM 3	7/28/2017					0.00	27.7	117.4	9.24
HUM 3	7/28/2017					0.50	27.8	117.5	9.23
HUM 3	7/28/2017					1.00	27.8	126.0	9.90
HUM 3	7/28/2017					1.50	27.8	123.3	9.70
HUM 3	7/28/2017					1.84	26.4	23.7	1.91
HUM 5 (41 16'07.9", 70 08'23.3")	7/28/2017	1039	2.07	0.64	5966				
HUM 5	7/28/2017					0.00	27.0	111.0	8.85
HUM 5	7/28/2017					0.50	26.6	105.2	8.54
HUM 5	7/28/2017					1.00	26.0	90.4	7.33
HUM 5	7/28/2017					1.50	23.9	27.7	2.33
HUM 5	7/28/2017					2.00	22.8	4.6	0.39
HUM 5	7/28/2017					2.07	22.4	1.9	0.16
HUM 7 (41 16'43.2", 70 08'04.1")	7/28/2017	1125	3.23	0.29	5170				
HUM 7	7/28/2017					0.00	29.5	160.8	12.26
HUM 7	7/28/2017					0.50	28.4	180.2	14.03
HUM 7	7/28/2017					1.00	26.9	128.2	10.23
HUM 7	7/28/2017					1.50	26.0	107.2	8.70
HUM 7	7/28/2017					2.00	24.7	94.0	7.81
HUM 7	7/28/2017					2.50	23.4	81.3	6.93
HUM 7	7/28/2017					3.00	21.0	6.5	0.58
HUM 7	7/28/2017					3.23	20.3	2.8	0.26
HUM 8 (41 16'29.0", 70 08'00.5")	7/28/2017	1105	1.57	0.41	4365				
HUM 8	7/28/2017					0.00	27.4	83.0	6.57
HUM 8	7/28/2017					0.50	27.3	82.2	6.51
HUM 8	7/28/2017					1.00	27.2	83.0	6.59
HUM 8	7/28/2017					1.50	24.4	5.1	0.43
HUM 8	7/28/2017					1.57	24.1	2.5	0.21
HUM 1 (41 15'20.2", 70 09'29.5")	8/30/2017	0615	3.00	0.40	8855				
HUM 1	8/30/2017					0.00	25.0	94.7	7.82
HUM 1	8/30/2017					0.50	25.1	94.1	7.76
HUM 1	8/30/2017					1.00	25.1	94.0	7.76
HUM 1	8/30/2017					1.50	25.1	93.9	7.75
HUM 1	8/30/2017					2.00	25.0	91.1	7.53
HUM 1	8/30/2017					2.50	24.9	81.4	6.74
HUM 1	8/30/2017					3.00	24.8	3.2	0.27
HUM 3 (41 15'41.3", 70 08'43.7")	8/30/2017	0643	1.62	0.43	7911				
HUM 3	8/30/2017					0.00	24.6	103.7	8.65
HUM 3	8/30/2017					0.50	24.7	103.5	8.60
HUM 3	8/30/2017					1.00	25.0	98.7	8.15
HUM 3	8/30/2017					1.50	24.9	70.5	5.84
HUM 3	8/30/2017					1.62	24.5	15.5	1.29
HUM 5 (41 16'07.8", 70 '08 24.2")	8/30/2017	0730	1.87	0.32	4054				
HUM 5	8/30/2017					0.00	23.3	90.8	7.75
HUM 5	8/30/2017					0.50	23.5	90.0	7.65
HUM 5	8/30/2017					1.00	23.5	85.7	7.28
HUM 5	8/30/2017					1.50	23.7	25.2	2.13
HUM 5	8/30/2017					1.87	23.3	3.4	0.29
HUM 7 (41 16'43.2", 70 08'03.1")	8/30/2017	0850	3.20	0.36	4531				
HUM 7	8/30/2017					0.00	25.1	141.3	11.65
HUM 7	8/30/2017					0.50	25.0	136.9	11.32
HUM 7	8/30/2017					1.00	24.8	118.5	9.83
HUM 7	8/30/2017					1.50	24.8	113.7	9.43
HUM 7	8/30/2017					2.00	24.6	59.8	4.98
HUM 7	8/30/2017					2.50	23.6	4.0	0.34
HUM 7	8/30/2017					3.00	21.9	2.6	0.22
HUM 7	8/30/2017					3.20	21.1	1.4	0.12
HUM8 (41 16'29.8", 70 07'58.0")	8/30/2017	0753	1.23	0.31	3798				
HUM 8	8/30/2017					0.00	23.8	97.4	8.25
HUM 8	8/30/2017					0.50	23.9	96.4	8.13
HUM 8	8/30/2017					1.00	23.9	90.2	7.60
HUM 8	8/30/2017					1.23	23.5	2.6	0.22

Station	Date	Time	Total Depth (m)	Secchi Depth (m)	Conduct-ivity (µS)	Depth (m)	Temp (°C)	DO (%)	DO (mg/L)
HUM 1 (41 15'20.9", 70 09'28.8")	10/7/2016	0700	1.62	1.20	5952				
HUM 1	10/7/2016					0.00	16.6	110.0	10.74
HUM 1	10/7/2016					0.50	16.8	108.1	10.50
HUM 1	10/7/2016					1.00	16.9	107.3	10.39
HUM 1	10/7/2016					1.50	17.0	105.3	10.17
HUM 1	10/7/2016					1.62	17.0	90.4	8.74
HUM 3 (41 15' 40.7", 70 08' 43.0")	10/7/2016	0730							
HUM 3	10/7/2016					0.00	15.7	97.0	9.66
HUM 3	10/7/2016					0.50	15.8	96.6	9.58
HUM 3	10/7/2016					1.00	16.5	88.0	8.60
HUM 3	10/7/2016					1.50	16.5	79.8	7.80
HUM 3	10/7/2016					1.92	16.6	78.3	7.63
HUM 5 (41 16'07.8", 70 08'23.7")	10/7/2016	0750	2.09	0.81	4575				
HUM 5	10/7/2016					0.00	15.9	91.0	9.01
HUM 5	10/7/2016					0.50	16.0	89.8	8.87
HUM 5	10/7/2016					1.00	16.1	83.2	8.20
HUM 5	10/7/2016					1.50	16.6	82.5	8.04
HUM 5	10/7/2016					2.00	16.7	81.7	7.95
HUM 5	10/7/2016					2.09	16.8	4.0	0.39
HUM 7 (41 16'42.9", 70 08'03.1")	10/7/2016	0830	3.38	0.93	3590				
HUM 7	10/7/2016					0.00	16.7	95.5	9.29
HUM 7	10/7/2016					0.50	16.8	93.0	0.03
HUM 7	10/7/2016					1.00	16.8	91.4	8.87
HUM 7	10/7/2016					1.50	16.8	90.7	8.80
HUM 7	10/7/2016					2.00	16.8	88.4	8.58
HUM 7	10/7/2016					2.50	16.8	87.4	8.48
HUM 7	10/7/2016					3.00	16.8	86.1	8.36
HUM 7	10/7/2016					3.38	17.1	2.9	0.28
HUM 8 (41 16'29.7", 70 07'58.3")	10/7/2016	0815	1.30	0.48	4128				
HUM 8	10/7/2016					0.00	15.3	61.9	6.20
HUM 8	10/7/2016					0.50	15.4	59.3	5.92
HUM 8	10/7/2016					1.00	15.4	57.2	5.72
HUM 8	10/7/2016					1.30	15.6	24.4	2.43

Station	Date	Time	Total Depth (m)	Secchi Depth (m)	Conduct-ivity (µS)	Depth (m)	Temp (°C)	DO (%)	DO (mg/L)
MIA 1 (41 14' 41.5", 70 07' 02.1")	6/28/2016	1655	3.25	1.52	208.9				
MIA 1	6/28/2016					0.00	23.5	95.9	8.14
MIA 1	6/28/2016					0.50	23.6	95.2	8.07
MIA 1	6/28/2016					1.00	23.5	94.5	8.03
MIA 1	6/28/2016					1.50	23.1	92.2	7.90
MIA 1	6/28/2016					2.00	22.9	87.0	7.48
MIA 1	6/28/2016					2.50	22.8	84.6	7.29
MIA 1	6/28/2016					3.00	22.4	69.3	6.02
MIA 1	6/28/2016					3.25	21.8	2.9	0.25
MIA 3 (41 15' 05.3", 70 06' 50.8")	6/28/2016	1745	1.75	1.13	192.4				
MIA 3	6/28/2016					0.00	24.1	110.9	9.32
MIA 3	6/28/2016					0.50	24.1	110.7	9.30
MIA 3	6/28/2016					1.00	23.7	106.7	9.03
MIA 3	6/28/2016					1.50	23.4	99.3	8.47
MIA 3	6/28/2016					1.75	22.9	3.3	0.29
MIA 5 (41 15' 28.1", 70 06' 25.1")	6/28/2016	1815	1.07	1.07	179.2				
MIA 5	6/28/2016					0.00	24.1	98.6	8.29
MIA 5	6/28/2016					0.50	22.0	38.1	3.33
MIA 5	6/28/2016					1.00	18.5	53.5	5.02
MIA 5	6/28/2016					1.07	17.6	10.7	1.02
MIA 1 (41 14' 42.0", 70 07' 02.2")	6/29/2016	0600	3.25	1.65	211.2				
MIA 1	6/29/2016					0.00	22.6	85.8	7.42
MIA 1	6/29/2016					0.50	22.7	85.5	7.38
MIA 1	6/29/2016					1.00	22.7	85.2	7.35
MIA 1	6/29/2016					1.50	22.7	85.1	7.34
MIA 1	6/29/2016					2.00	22.7	84.3	7.27
MIA 1	6/29/2016					2.50	22.5	83.2	7.18
MIA 1	6/29/2016					3.00	22.5	67.5	5.85
MIA 1	6/29/2016					3.25	21.8	3.5	0.30
MIA 3 (41 15' 05.4", 70 06' 50.7")	6/29/2016	0630	1.73	1.19	189.6				
MIA 3	6/29/2016					0.00	23.0	85.6	7.35
MIA 3	6/29/2016					0.50	23.0	84.9	7.28
MIA 3	6/29/2016					1.00	23.0	85.0	7.29
MIA 3	6/29/2016					1.50	23.0	82.4	7.07
MIA 3	6/29/2016					1.73	22.6	3.4	0.29
MIA 5 (41 15' 28.1", 70 06' 24.9")	6/29/2016	0710	0.86		179.9				
MIA 5	6/29/2016					0.00	22.1	45.7	3.99
MIA 5	6/29/2016					0.50	21.4	23.4	2.07
MIA 5	6/29/2016					0.86	17.4	33.9	3.25
MIA 1 (41 14' 41.4", 70 07' 00.7")	7/26/2016	1705	1.84	1.52	197.8				
MIA 1	7/26/2016					0.00	27.4	113.5	8.98
MIA 1	7/26/2016					0.50	27.5	113.8	8.99
MIA 1	7/26/2016					1.00	27.5	114.2	9.02
MIA 1	7/26/2016					1.50	27.5	114.5	9.04
MIA 1	7/26/2016					1.84	27.5	109.3	8.63
MIA 3 (41 15' 05.6", 70 06' 50.2")	7/26/2016	1733	1.72		164.7				
MIA 3	7/26/2016					0.00	28.1	140.1	10.95
MIA 3	7/26/2016					0.50	28.2	141.7	11.06
MIA 3	7/26/2016					1.00	27.8	149.8	11.77
MIA 3	7/26/2016					1.50	27.3	147.4	11.68
MIA 3	7/26/2016					1.72	26.1	3.3	0.27
MIA 5 (41 15' 28.5", 70 06' 24.5")	7/26/2016	1803	1.15	1.15	157.7				
MIA 5	7/26/2016					0.00	26.0	92.1	7.47
MIA 5	7/26/2016					0.50	20.2	52.7	4.71
MIA 5	7/26/2016					1.00	16.6	69.8	6.79
MIA 5	7/26/2016					1.15	13.6	2.1	0.21

Station	Date	Time	Total Depth (m)	Secchi Depth (m)	Conduct-ivity (µS)	Depth (m)	Temp (°C)	DO (%)	DO (mg/L)
MIA 1 (41 14' 41.7", 70 07' 01.7")	9/1/2016	0645	3.09	1.18	175.2				
MIA 1	9/1/2016					0.00	24.4	94.9	7.93
MIA 1	9/1/2016					0.50	24.4	95.0	7.94
MIA 1	9/1/2016					1.00	24.4	94.9	7.93
MIA 1	9/1/2016					1.50	24.4	94.7	7.91
MIA 1	9/1/2016					2.00	24.4	94.7	7.91
MIA 1	9/1/2016					2.50	24.4	94.4	7.89
MIA 1	9/1/2016					3.00	24.4	27.1	2.27
MIA 1	9/1/2016					3.09	24.5	3.0	0.25
MIA 3 (41 15' 06.3", 70 06' 50.0")	9/1/2016	0710	1.55		162.5				
MIA 3	9/1/2016					0.00	24.2	89.6	7.52
MIA 3	9/1/2016					0.50	24.3	89.3	7.48
MIA 3	9/1/2016					1.00	24.3	88.8	7.43
MIA 3	9/1/2016					1.50	24.4	85.1	7.12
MIA 3	9/1/2016					1.55	24.4	3.5	0.29
MIA 5 (41 15' 27.1", 70 06' 26.6")	9/1/2016	0730	1.04		170.6				
MIA 5	9/1/2016					0.00	18.3	22.8	2.12
MIA 5	9/1/2016					0.50	17.7	22.0	2.19
MIA 5	9/1/2016					1.00	15.5	2.5	0.25
MIA 5	9/1/2016					1.04	14.9	1.7	0.17
MIA 1 (41 14' 41.4", 70 07' 01.1")	10/7/2016	1100	2.23	2.10	157.4				
MIA 1	10/7/2016					0.00	17.6	101.0	9.62
MIA 1	10/7/2016					0.50	17.5	101.3	9.69
MIA 1	10/7/2016					1.00	17.3	101.2	9.72
MIA 1	10/7/2016					1.50	17.1	102.3	9.86
MIA 1	10/7/2016					2.00	16.9	99.2	9.61
MIA 1	10/7/2016					2.23	17.1	5.1	0.49
MIA 3 (41 15' 05.4", 70 06' 50.5")	10/7/2016	1038	1.55	1.55	163.3				
MIA 3	10/7/2016					0.00	17.3	102.5	9.84
MIA 3	10/7/2016					0.50	17.2	102.8	9.90
MIA 3	10/7/2016					1.00	16.7	105.1	10.22
MIA 3	10/7/2016					1.50	16.6	105.6	10.29
MIA 3	10/7/2016					1.55	16.9	3.7	0.35
MIA 5 (41 15' 28.0", 70 06' 24.9")	10/7/2016	1015	0.93	0.93	169.3				
MIA 5	10/7/2016					0.00	14.5	27.1	2.77
MIA 5	10/7/2016					0.50	14.1	28.5	2.93
MIA 5	10/7/2016					0.93	13.7	2.5	0.26

Phytoplankton Data

	PHYTOPLANKTON DENSITY (CELLS/ML)									
	Hummock	Hummock	Hummock	Hummock	Hummock	Hummock	Hummock	Hummock	Miacomet	Miacomet
	1	5	7	7	GPS	1	5	7	1	5
TAXON	06/30/16	06/30/16	06/30/16	07/27/16	08/09/16	08/30/16	08/30/16	08/30/16	06/28/16	06/28/16
BACILLARIOPHYTA										
Centric Diatoms										
Cyclotella	0	0	0	0	0	0	28	0	20	0
Araphid Pennate Diatoms										
Synedra	0	20	0	0	0	0	0	0	0	0
Monoraphid Pennate Diatoms										
Biraphid Pennate Diatoms										
Navicula/related taxa	40	20	17	0	0	0	0	0	0	0
Nitzschia	20	20	17	0	0	0	57	0	20	0
CHLOROPHYTA										
Flagellated Chlorophytes										
Chlamydomonas	0	40	17	0	40	37	85	60	0	0
Coccoid/Colonial Chlorophytes										
Coelastrum	0	0	0	0	0	0	0	0	240	559
Crucigenia	0	0	0	0	0	0	0	0	80	0
Elakatothrix	0	0	0	0	0	0	0	0	40	0
Golenkinia	0	0	0	0	0	0	142	0	0	0
Kirchneriella	0	0	0	0	0	0	0	0	200	932
Micractinium	0	0	0	0	0	0	0	0	0	373
Pediastrum	0	0	0	0	0	0	0	0	80	0
Scenedesmus	0	80	66	0	0	0	0	0	80	466
Sphaerocystis	0	0	0	0	0	0	0	0	160	0
Tetraedron	0	0	0	0	0	0	0	0	20	0
Filamentous Chlorophytes										
Desmids										
Closterium	0	0	0	0	0	0	0	0	40	23
Euastrum	0	0	0	0	0	0	0	0	0	23
CHRYSOPHYTA										
Flagellated Classic Chrysophytes										
Dinobryon	0	0	0	0	0	0	0	0	560	2726
Mallomonas	0	0	0	0	0	0	0	0	0	23
Non-Motile Classic Chrysophytes										
Haptophytes										
Tribophytes/Eustigmatophytes										
Raphidophytes										
CRYPTOPHYTA										
Cryptomonas	0	0	0	40	40	37	57	0	40	47
CYANOPHYTA										
Unicellular and Colonial Forms										
Dactylococcopsis	0	0	0	160	0	0	0	0	0	0
Filamentous Nitrogen Fixers										
Anabaenopsis	0	0	0	400	0	1190	5094	5400	0	0
Dolichospermum	200	560	166	54000	64000	54900	135840	139500	0	0
Filamentous Non-Nitrogen Fixers										
EUGLENOPHYTA										
Euglena	0	0	0	0	0	0	0	0	0	466
PYRRHOPHYTA										
Ceratium	0	0	0	0	0	0	0	0	20	0
Peridinium	20	0	17	0	20	0	0	0	20	23
DENSITY (CELLS/ML) SUMMARY										
BACILLARIOPHYTA	**60**	**60**	**33.2**	**0**	**0**	**0**	**84.9**	**0**	**40**	**0**
Centric Diatoms	0	0	0	0	0	0	28.3	0	20	0
Araphid Pennate Diatoms	0	20	0	0	0	0	0	0	0	0
Monoraphid Pennate Diatoms	0	0	0	0	0	0	0	0	0	0
Biraphid Pennate Diatoms	60	40	33.2	0	0	0	56.6	0	20	0
CHLOROPHYTA	**0**	**120**	**83**	**0**	**40**	**36.6**	**226.4**	**60**	**940**	**2376.6**
Flagellated Chlorophytes	0	40	16.6	0	40	36.6	84.9	60	0	0
Coccoid/Colonial Chlorophytes	0	80	66.4	0	0	0	141.5	0	900	2330
Filamentous Chlorophytes	0	0	0	0	0	0	0	0	0	0
Desmids	0	0	0	0	0	0	0	0	40	46.6
CHRYSOPHYTA	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**560**	**2749.4**
Flagellated Classic Chrysophytes	0	0	0	0	0	0	0	0	560	2749.4
Non-Motile Classic Chrysophytes	0	0	0	0	0	0	0	0	0	0
Haptophytes	0	0	0	0	0	0	0	0	0	0
Tribophytes/Eustigmatophytes	0	0	0	0	0	0	0	0	0	0
Raphidophytes	0	0	0	0	0	0	0	0	0	0
CRYPTOPHYTA	**0**	**0**	**0**	**40**	**40**	**36.6**	**56.6**	**0**	**40**	**46.6**
CYANOPHYTA	**200**	**560**	**166**	**54560**	**64000**	**56089.5**	**140934**	**144900**	**0**	**0**
Unicellular and Colonial Forms	0	0	0	160	0	0	0	0	0	0
Filamentous Nitrogen Fixers	200	560	166	54400	64000	56089.5	140934	144900	0	0
Filamentous Non-Nitrogen Fixers	0	0	0	0	0	0	0	0	0	0
EUGLENOPHYTA	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**466**
PYRRHOPHYTA	**20**	**0**	**16.6**	**0**	**20**	**0**	**0**	**0**	**40**	**23.3**
TOTAL	**280**	**740**	**298.8**	**54600**	**64100**	**56162.7**	**141302**	**144960**	**1620**	**5661.9**
CELL DIVERSITY	**0.39**	**0.39**	**0.57**	**0.03**	**0.01**	**0.05**	**0.08**	**0.07**	**0.92**	**0.69**
CELL EVENNESS	**0.65**	**0.50**	**0.73**	**0.05**	**0.01**	**0.08**	**0.09**	**0.15**	**0.79**	**0.67**

	PHYTOPLANKTON BIOMASS (UG/L)									
	Hummock	**Hummock**	**Hummock**	**Hummock**	**Hummock**	**Hummock**	**Hummock**	**Hummock**	**Miacomet**	**Miacomet**
	1	**5**	**7**	**7**	**GPS**	**1**	**5**	**7**	**1**	**5**
TAXON	**06/30/16**	**06/30/16**	**06/30/16**	**07/27/16**	**08/09/16**	**08/30/16**	**08/30/16**	**08/30/16**	**06/28/16**	**06/28/16**
BACILLARIOPHYTA										
Centric Diatoms										
Cyclotella	0.0	0.0	0.0	0.0	0.0	0.0	70.8	0.0	50.0	0.0
Araphid Pennate Diatoms										
Synedra	0.0	16.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Monoraphid Pennate Diatoms										
Biraphid Pennate Diatoms										
Navicula/related taxa	20.0	10.0	8.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Nitzschia	16.0	16.0	13.3	0.0	0.0	0.0	45.3	0.0	16.0	0.0
CHLOROPHYTA										
Flagellated Chlorophytes										
Chlamydomonas	0.0	4.0	1.7	0.0	4.0	3.7	8.5	6.0	0.0	0.0
Coccoid/Colonial Chlorophytes										
Coelastrum	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	48.0	111.8
Crucigenia	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.0	0.0
Elakatothrix	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.0	0.0
Golenkinia	0.0	0.0	0.0	0.0	0.0	0.0	28.3	0.0	0.0	0.0
Kirchneriella	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	20.0	93.2
Micractinium	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1118.4
Pediastrum	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	16.0	0.0
Scenedesmus	0.0	8.0	6.6	0.0	0.0	0.0	0.0	0.0	8.0	46.6
Sphaerocystis	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	32.0	0.0
Tetraedron	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	12.0	0.0
Filamentous Chlorophytes										
Desmids										
Closterium	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	160.0	93.2
Euastrum	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	23.3
CHRYSOPHYTA										
Flagellated Classic Chrysophytes										
Dinobryon	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1680.0	8178.3
Mallomonas	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	11.7
Non-Motile Classic Chrysophytes										
Haptophytes										
Tribophytes/Eustigmatophytes										
Raphidophytes										
CRYPTOPHYTA										
Cryptomonas	0.0	0.0	0.0	8.0	8.0	7.3	11.3	0.0	36.0	41.9
CYANOPHYTA										
Unicellular and Colonial Forms										
Dactylococcopsis	0.0	0.0	0.0	8.0	0.0	0.0	0.0	0.0	0.0	0.0
Filamentous Nitrogen Fixers										
Anabaenopsis	0.0	0.0	0.0	80.0	0.0	237.9	1018.8	1080.0	0.0	0.0
Dolichospermum	40.0	112.0	33.2	10800.0	12800.0	10980.0	27168.0	27900.0	0.0	0.0
Filamentous Non-Nitrogen Fixers										
EUGLENOPHYTA										
Euglena	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	233.0
PYRRHOPHYTA										
Ceratium	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	348.0	0.0
Peridinium	42.0	0.0	34.9	0.0	42.0	0.0	0.0	0.0	42.0	48.9
DENSITY (CELLS/ML) SUMMARY										
BACILLARIOPHYTA	**36.0**	**42.0**	**21.6**	**0.0**	**0.0**	**0.0**	**116.0**	**0.0**	**66.0**	**0.0**
Centric Diatoms	0.0	0.0	0.0	0.0	0.0	0.0	70.8	0.0	50.0	0.0
Araphid Pennate Diatoms	0.0	16.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Monoraphid Pennate Diatoms	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Biraphid Pennate Diatoms	36.0	26.0	21.6	0.0	0.0	0.0	45.3	0.0	16.0	0.0
CHLOROPHYTA	**0.0**	**12.0**	**8.3**	**0.0**	**4.0**	**3.7**	**36.8**	**6.0**	**308.0**	**1486.5**
Flagellated Chlorophytes	0.0	4.0	1.7	0.0	4.0	3.7	8.5	6.0	0.0	0.0
Coccoid/Colonial Chlorophytes	0.0	8.0	6.6	0.0	0.0	0.0	28.3	0.0	148.0	1370.0
Filamentous Chlorophytes	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Desmids	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	160.0	116.5
CHRYSOPHYTA	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**1680.0**	**8190.0**
Flagellated Classic Chrysophytes	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1680.0	8190.0
Non-Motile Classic Chrysophytes	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Haptophytes	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Tribophytes/Eustigmatophytes	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Raphidophytes	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CRYPTOPHYTA	**0.0**	**0.0**	**0.0**	**8.0**	**8.0**	**7.3**	**11.3**	**0.0**	**36.0**	**41.9**
CYANOPHYTA	**40.0**	**112.0**	**33.2**	**10888.0**	**12800.0**	**11217.9**	**28186.8**	**28980.0**	**0.0**	**0.0**
Unicellular and Colonial Forms	0.0	0.0	0.0	8.0	0.0	0.0	0.0	0.0	0.0	0.0
Filamentous Nitrogen Fixers	40.0	112.0	33.2	10880.0	12800.0	11217.9	28186.8	28980.0	0.0	0.0
Filamentous Non-Nitrogen Fixers	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
EUGLENOPHYTA	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**233.0**
PYRRHOPHYTA	**42.0**	**0.0**	**34.9**	**0.0**	**42.0**	**0.0**	**0.0**	**0.0**	**390.0**	**48.9**
TOTAL	**118.0**	**166.0**	**97.9**	**10896.0**	**12854.0**	**11228.9**	**28350.9**	**28986.0**	**2480.0**	**10000.4**
BIOMASS DIVERSITY	**0.57**	**0.49**	**0.64**	**0.02**	**0.01**	**0.05**	**0.09**	**0.07**	**0.54**	**0.32**
BIOMASS EVENNESS	**0.94**	**0.63**	**0.82**	**0.04**	**0.02**	**0.08**	**0.10**	**0.15**	**0.46**	**0.30**