Middle Pond is some portion of the downgradient flow out of the pond and into the Marstons Mills River watershed. The estimated flow through the stream is included in Table 4 as 82,892 m3/yr; this flow is based on the annualized flow of 0.06 mgd, which is discussed above.

Additional description and details of field measurements is contained in the Commission's Water Budget Report (Michaud, *et al.*, 2005).

4. Pond Water Quality

The other major component of this First Order Assessment of the Indian Ponds is a review of water quality in the ponds; this data was coordinated and informed by the preceding water watershed and water budget estimates. In order to begin to characterize the water quality in the system, project staff in coordination with town staff and IPA volunteers developed a sampling plan, ensured adequate volunteer training, reviewed field sampling results as they became available, ensured that proper chain-of-custody procedures were followed for the samples, and reviewed laboratory results. Laboratory and field data results are discussed in this section.

A. Water Quality Sampling Plan

Project staff developed a sampling plan in coordination with the Town of Barnstable and IPA volunteers. Samples to be analyzed in laboratory tests were collected at the following depths in each of the ponds: Mystic (0.5 m, 3 m, 9 m, and one meter off the bottom), Middle (0.5 m, 3 m, and one meter off the bottom), and Hamblin (0.5 m, 3 m, 9 m, and one meter off the bottom). These sampling depths are the same as utilized in the annual Cape Cod Pond and Lake Stewardship (PALS) snapshots, so snapshot results could easily be compared to results from the samples collected during this project. The sampling plan led to water quality sampling on the following dates in 2004: May 19/20, June 9, June 24, July 8, July 22, August 5, August 24, September 7, September 21, and November 2. Samples were collected with Niskin samplers and stored in dark brown acid-washed Nalgene bottles, which were transported in coolers with ice packs. Samples were delivered on the same day as they were collected to the School of Marine Science and Technology (SMAST) water quality lab at the University of Massachusetts, Dartmouth in New Bedford. Laboratory procedures are described in the SMAST Coastal Systems Analytical Facility Laboratory Quality Assurance Plan (2003).

Aside from the samples to be delivered to the SMAST lab, volunteers also collected field readings. These readings were recorded on field sheets; an example is included in Appendix B. Readings included a measurement of Secchi depth and dissolved oxygen and temperature profiles with readings recorded at every meter. Dissolved oxygen and temperature readings were recorded using YSI-55 meters calibrated prior to each sampling event. Laboratory and field data collected, along with detection limits, measurement ranges, and accuracy measurements, are shown in Table 5.

Table 5. Field and laboratory reporting units and detection limits for data collected for the Indian Ponds assessment					
Parameter	**Matrix**	**Reporting Units**	**Detection Limit**	**Accuracy (+\-)**	**Measurement Range**
Field Measurements					
Temperature	Water	ºC	0.5°C	± 0.3 ºC	-5 to 45
Dissolved Oxygen	Water	mg/l	0.5 ppm	± 0.3 mg/l or ± 2% of reading, whichever is greater	0 – 20 mg/l
Secchi Disk Water Clarity	Water	meters	NA	20 cm	Disappearance
Laboratory Measurements - SMAST					
Alkalinity	Water	mg/l as $CaCO_3$	0.5	80-120% Std. Value	NA
Chlorophyll-*a*	Water	µg/l	0.05	80-120% Std. Value	0-145
Nitrogen, Total	Water	µM	0.05	80-120% Std. Value	NA
pH	Water	Standard Units	NA	80-120% Std. Value	0 - 14
Phosphorus, Total	Water	µM	0.1	80-120% Std. Value	NA
Note: All laboratory measurement information from SMAST Coastal Systems Analytical Facility Laboratory Quality Assurance Plan (January, 2003)					

Additional water quality sampling including only the upper portions of the water column was completed in 2005. These results are generally not included or considered in this assessment. Sampling dates during 2005 were: June 28, July 13, July 27, August 11, August 25, September 13, September 27, and October 27 (Mystic Lake only).

B. Field Collected Water Quality Data

i. Dissolved Oxygen and Temperature

Pond and lake ecosystems are controlled by interactions among the physical, chemical, and biological factors within a given lake. The availability of oxygen determines distributions of various species living within a lake; some require higher concentrations, while others are more tolerant of occasional low oxygen concentrations. Oxygen concentrations also determine the solubility of many inorganic elements; higher concentrations of phosphorus, nitrogen, and iron, among other constituents, can occur in the deeper portions of ponds when anoxic conditions convert bound, solid forms in the sediments into soluble forms that are then released into the water column. Temperature is inversely related to dissolved oxygen concentrations (*i.e.*, higher temperature water holds less dissolved oxygen).

Oxygen concentrations are also related to the amount of biological activity in a pond. Since one of the main byproducts of photosynthesis is oxygen, a vigorous algal population can produce DO concentrations that are greater than the concentrations that would be expected based simply on temperature interactions alone. These instances of "supersaturation" usually occur in lakes with high nutrient concentrations, since the algal population would need readily available nutrients in order to produce these conditions. Conversely, as the algal populations die, they fall to the sediments where bacterial populations consume oxygen as they degrade the dead algae. Too much algal growth can thus lead to anoxic conditions and the release of recycled nutrients back into the pond from the sediments.

Shallow Cape Cod ponds [less than 9 meters (29.5 ft) deep] tend to have well mixed water columns because ordinary winds blowing across the Cape have sufficient energy to move deeper waters up to the surface. In these ponds, both temperature and dissolved oxygen readings tend to be constant from surface to bottom; Middle Pond profiles tend to have this characteristic (Figure 10). In deeper ponds on Cape Cod, mixing tends to occur throughout the winter, but rising temperatures in the spring heat upper waters more rapidly than winds can mix the heat throughout the water column. This leads to stratification of the water column with warmer waters continuing to be mixed and warmed throughout the summer and isolating cooler, deeper waters. The upper layer of warmer water is called the epilimnion, while the lower layer is called the hypolimnion; the transitional zone between them is called the metalimnion. Mystic Lake and Hamblin Pond profiles show stratification of temperature and dissolved oxygen (see Figure 10).

Since the lower layer in a stratified pond is cut off from the atmosphere by the epilimnion, there is no mechanism to replenish oxygen consumed by bacterial populations in the sediments as they consume organic matter falling onto the sediments. If there is extensive organic matter falling to the sediments, as one would expect with lakes with higher amounts of nutrients (*i.e.*, eutrophied lakes), the bacterial respiration can consume all of the oxygen before the lake mixes throughout the water column again in the fall. Highly eutrophied lakes can have low oxygen or anoxic conditions set up shortly after stratification occurs (*e.g.*, Eichner, *et al*., 1999). The earliest profile collected on May 20, 2004 for Hamblin Pond shows low oxygen and anoxic conditions deep in the pond (see Figure 10); the conditions rise toward the bottom of the epilimnion as the summer progresses.

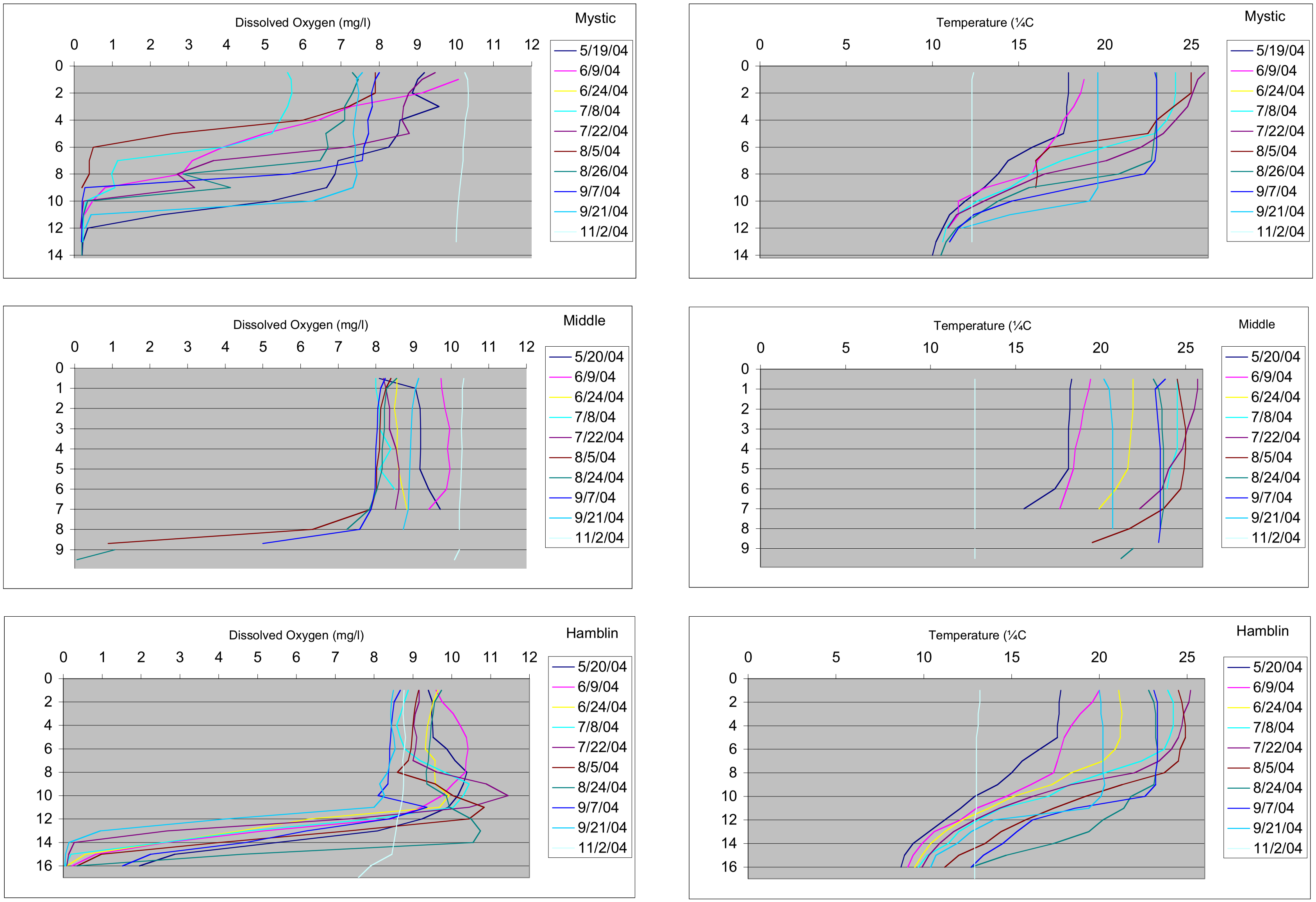


Figure 10. 2004 dissolved oxygen and temperature profiles for Mystic Lake, Middle Pond, and Hamblin Pond.

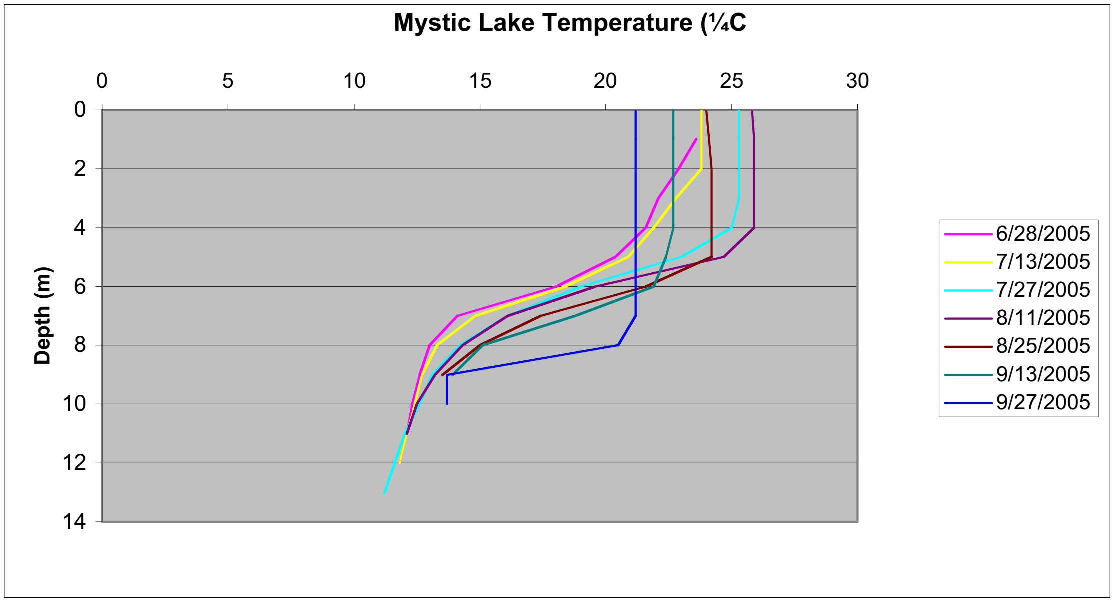
The dissolved oxygen profiles of Hamblin Pond also show what is called a positive heterograde curve with higher concentrations of dissolved oxygen measured near the metalimnion than in the waters above this zone. This metalimnion maximum is usually the result of a high concentration of phytoplankton utilizing light collected in shallower waters and phosphorus seeping from the hypolimnion (Wetzel, 1983).

Since dissolved oxygen and temperature profiles were not collected before the onset of low oxygen conditions in the hypolimnetic waters of Hamblin Pond, a definitive loss of oxygen to sediment demand cannot be determined. However, a reasonable estimate of oxygen demand by the sediments can be made. Staff assumed a March dissolved oxygen concentration of 11 ppm; this is the saturation concentration at 11ºC (temperatures in the November profile were around 13ºC). Based on this assumption, sediment oxygen demand in the hypolimnion ranges between 2,763 and 7,773 kg based on the profiles collected. If these demands are spread over the area of the hypolimnetic sediments (52 ac), which is assumed to be the area below 9 m, the daily oxygen demand varies between 84 and 325 mg/m2 with an average of 219 mg/m2. Similar values are seen in the 2005 data collected by IPA. Baystate Environmental Consultants (1993) estimated a daily sediment oxygen demand based on hypolimnetic concentrations of 860 mg/m2 prior to the alum treatment. This comparison suggests that the alum treatment of Hamblin Pond in 1995 reduced the sediment oxygen demand by approximately 75%

The impact of the oxygen demand in Hamblin Pond can be observed by comparing the November 2004 dissolved oxygen profiles in the three ponds (see Figure 10). Temperature profiles show that temperatures in the three ponds are generally the same and that all three ponds are well mixed, with similar temperatures from top to bottom. Given this, the dissolved oxygen concentrations should also be the same, but Hamblin Pond is approximately 1.5 ppm less than the other two. This difference is likely due to residual oxygen demand in the hypolimnetic waters that was mixed, probably within weeks of the November measurement, into the rest of the water column.

Temperature and dissolved oxygen profiles for Middle Pond show that the pond water column is generally well mixed with occasional slight isolation of waters below 7 m (see Figure 10). For example, the temperature profile from August 5 shows a drop of approximately 5ºC between 6 and 8.5 m; this "bend" in the profile is gone by the next profile measurement on August 24 and the temperature is relatively uniform from top to bottom. The transitory nature of the deep temperature isolation indicates that it is relatively weak and the pond can be fully mixed by normal winds in the area. These isolations may, however, have measurable impact on the amount of phosphorus in the water column. The low dissolved oxygen readings appear to allow phosphorus to be released from the sediments and mixed into the water column; further discussion of this is included in following sections.

The temperature profiles for Mystic Lake are similar to those for Hamblin Pond with a gradual deepening and warming of the epilimnion as the summer progressed (see Figure 10). The dissolved oxygen profiles, however, show a significant amount of variability from reading date to reading date. During the course of the summer, project staff requested clarification of volunteer calibration and sampling activities. Results of this type suggest that the system is notably unstable. Dissolved oxygen profiles collected during 2005 do not show this variability (Figure 11) and suggest that select profiles in the 2004 season should be disregarded.



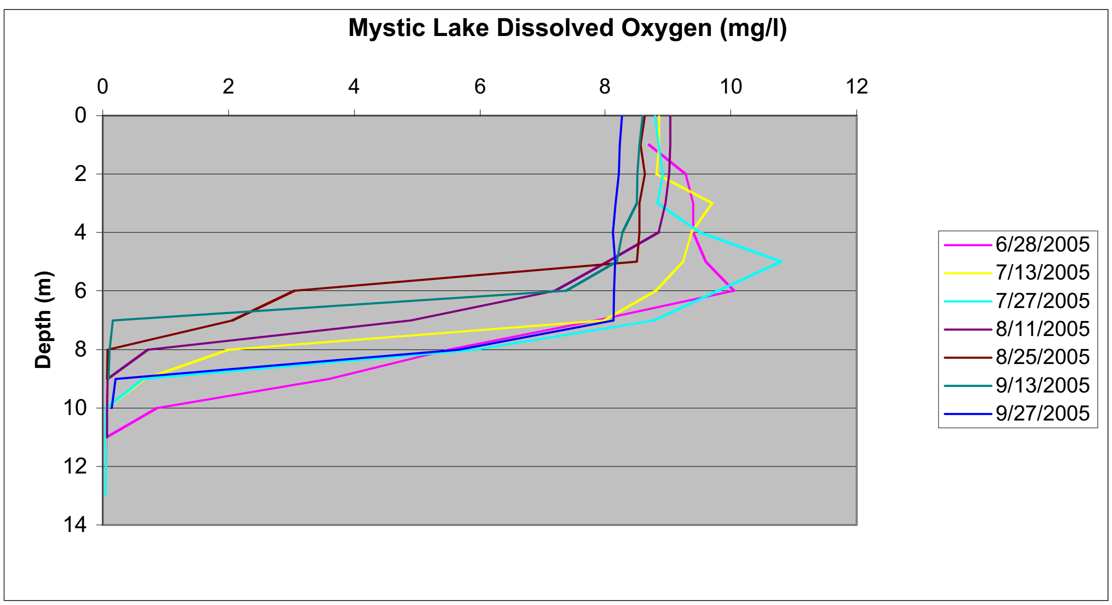


Figure 11. Mystic Lake 2005 Dissolved Oxygen and Temperature Profiles.
Data collected by IPA volunteers using a YSI-55 meter.

Using the 2005 data, Mystic Lake dissolved oxygen and temperature profiles can be used to estimate sediment oxygen demand using the same assumptions used for Hamblin Pond. Staff assumed a March dissolved oxygen concentration of 11 ppm. Based on this assumption, sediment oxygen demand ranges between 6,133 and 9,840 kg based on the profiles collected. If these demands are spread over the area of the hypolimnetic sediments (38 ac), which is assumed to be the area below 9 m, the daily oxygen demand varies between 230 and 424 mg/m2 with an average of 358 mg/m2. This average is 139 mg/m2/d higher than the 2004 average for Hamblin Pond; Hamblin Pond had a 219 mg/m2/d average in 2005 and a 182 mg/m2/d average in 2004. As mentioned previously, BEC (1993) estimated a hypolimnetic oxygen demand of 860 mg/m2/d in Hamlin Pond prior to the alum treatment; Mystic Lake hypolimnetic oxygen demand is roughly half of the pre-alum treatment Hamblin Pond.

ii. Secchi Depth

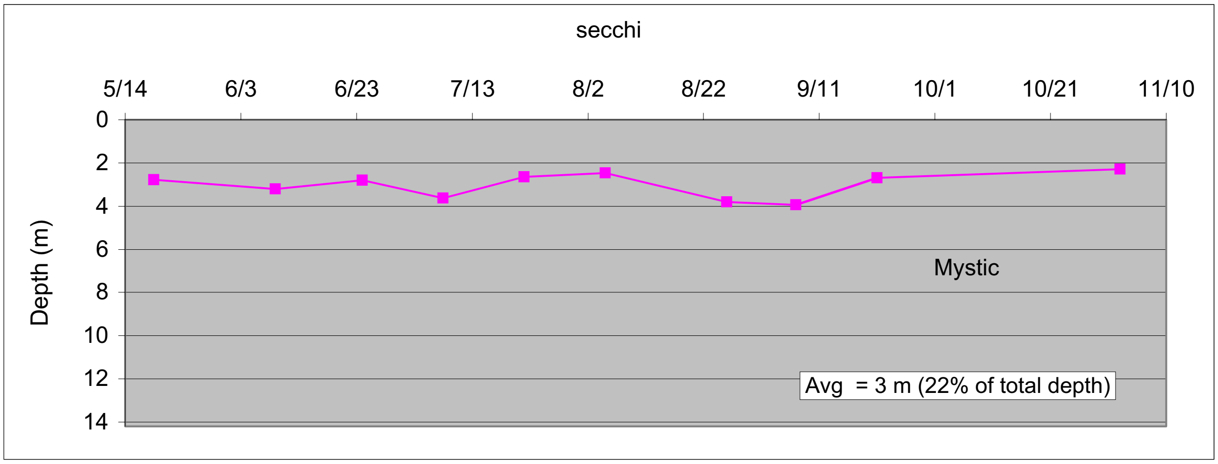
A Secchi disc is used to evaluate transparency, or light penetration, of water. Since fluctuations in Secchi depths are linked to fluctuations in concentrations of plankton or inorganic particles, a Secchi reading is an aggregate general measure of ecosystem condition. Because of this, Secchi readings have been linked through a variety of analyses to trophic status of lakes (*e.g.*, Carlson, 1977). Secchi depth is also related to the overall depth of a pond; if the pond is relatively shallow, the disk may be visible on the bottom even with significant algal densities. Relative Secchi readings compared to total depth of the sampling location have also been used to assess the condition of a pond ecosystem.

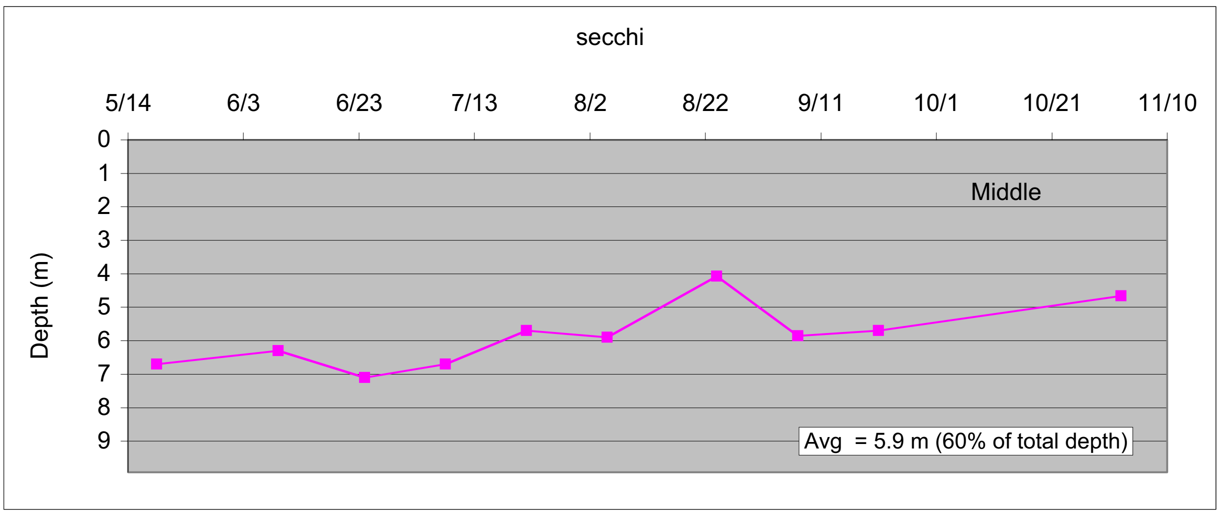
Secchi readings collected for Mystic Lake, Middle Pond, and Hamblin Pond during the 2004 sampling season are relatively stable, although readings from Middle Pond show a bit of an upward trend (Figure 12). Hamblin Pond has the deepest average (6.4 meters), while Middle Pond has the deepest relative average (60% of its total depth). Mystic Lake presents as the most impacted with an average Secchi depth of 3 meters and a relative average of 22% of its total depth. These readings are consistent with a qualitative assessment of the observed dissolved oxygen concentrations.

iii. Historic Field Measurements

Field measurements of Cape Cod ponds have not been extensively collected, but there are a select number of measurements that provide some historical context for readings in the Indian Ponds. A 1948 Massachusetts Division of Fisheries and Game (MADFG) survey of fifty-one Cape Cod lakes and ponds has transparency, dissolved oxygen, and temperature readings. Ahrens and Siver (2000) conducted a survey of sixty Cape Cod lakes and ponds. Hamblin Pond was the focus of a diagnostic feasibility study conducted prior to its 1995 alum application (BEC, 1993). Temperature and dissolved oxygen profiles and Secchi readings are part of the standard sampling protocol for the Cape Cod PALS snapshots that have been annually conducted between 2001 and 2005.

The 1948 MADFG survey includes dissolved oxygen and temperature profiles collected in August for the Indian Ponds (Figure 13). Because the 1948 data is only one profile, comparisons to data collected under this project and the relatively recent PALS data have to be somewhat tentative, but the comparisons present some notable differences. Comparison of the 1948 readings to the PALS readings and August 2004 readings collected under this project (and 2005 for Mystic Lake) show that Mystic Lake appears to have worsened with low dissolved





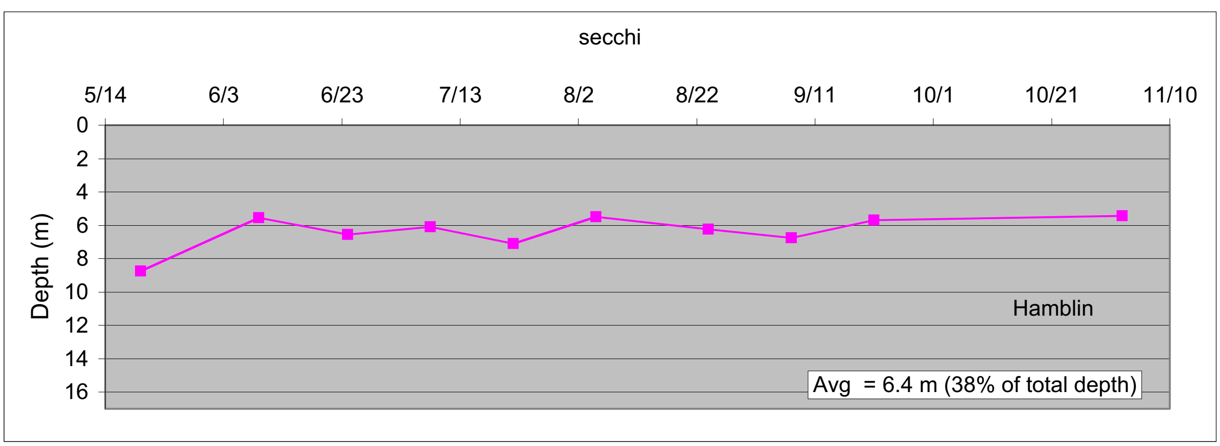


Figure 12. 2004 Secchi Depth readings for Mystic Lake, Middle Pond, and Hamblin Pond

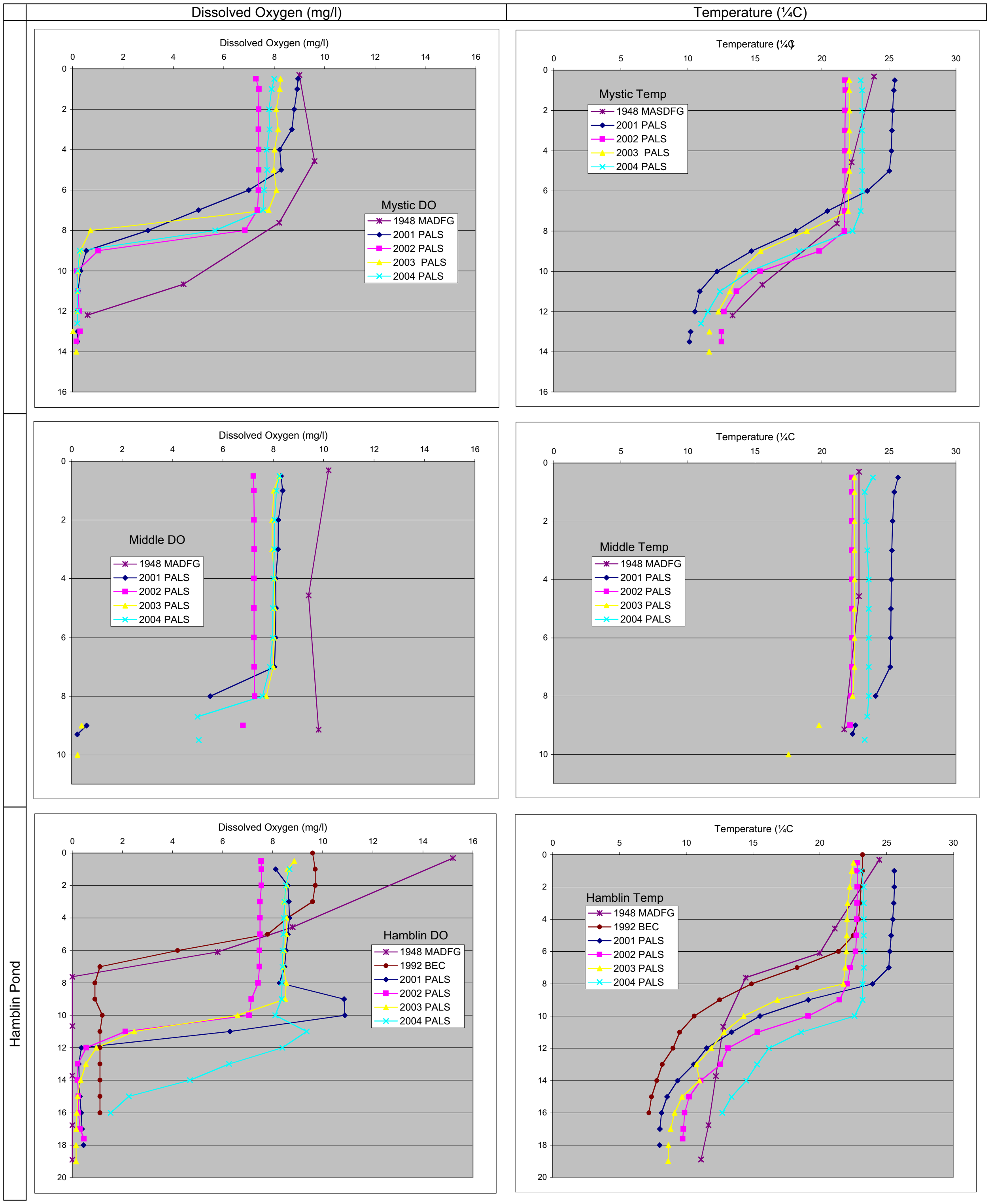


Figure 13. Historic Temperature and Dissolved Oxygen profiles for Indian Ponds. 1948 profile from August reading by MA Division of Fisheries and Game; 2001-2004 profiles from August 15 through September 30 Cape Cod Pond and Lakes Stewardship (PALS) Snapshot.

oxygen readings rising higher in the water column than in 1948 (anoxic conditions were encountered only at 12 m, while they are as shallow as 7 m in 2005) and Hamblin Pond has much improved deep dissolved oxygen concentrations (anoxic conditions existed at 8 m in 1948, while they rose only to 13 m in 2004). Secchi readings show similar effects: Mystic in 1948 was 15 ft (4.57 m), which has declined to 3.5 to 3.8 in readings collected for this study and PALS Snapshots; Hamblin in 1948 was 3 ft (0.91 m) and has improved to 4.2 to 8.1 m in readings collected for this study and PALS Snapshots. Although Middle Pond does not show any significant changes in dissolved oxygen concentrations, comparison of August Secchi readings seem to show some decline; Middle had a reading of 22 ft (6.71 m) in 1948, while readings collected for this study and PALS Snapshots are between 4.1 and 5.9 m.

C. Laboratory Water Quality Data

As mentioned above, unfiltered water samples were collected in the ponds at depths specified under the sampling plan. These depths match the protocols developed for the PALS Snapshot, so comparisons between previous data collected under the Snapshot and data collected as part of this analysis are facilitated. Water samples were analyzed at the SMAST Coastal Systems Analytical Facility Laboratory at UMASS, Dartmouth for the following constituents: pH, total nitrogen (TN), total phosphorus (TP), alkalinity, and chlorophyll *a* (Figure 14).

i. Total Phosphorus (TP)

Phosphorus is the key nutrient in ponds and lakes because it is usually more limited in freshwater systems than nitrogen. Typical plant organic matter contains phosphorous, nitrogen, and carbon in a ratio of 1 P:7 N:40 C per 500 wet weight (Wetzel, 1983). Therefore, if the other constituents are present in excess, phosphorus, as the limiting nutrient, can theoretically produce 500 times its weight in algae. Because it is more limited, 90% or more of the phosphorus occurs in organic forms (plant and animal tissue or plant and animal wastes) and any available inorganic phosphorus [mostly orthophosphate (PO_4^{-3})] is quickly reused by the biota in a lake (Wetzel, 1983). Extensive research has been directed towards trying to determine the most important phosphorus pool for determining the overall productivity of lake ecosystems, but to date, most of the work has found that a measure of total phosphorus is the best predictor of productivity of lake ecosystems (*e.g.*, Vollenweider, 1968). The laboratory analysis techniques for total phosphorus (TP) include ortho-phosphorus and all phosphorus incorporated into organic matter, including algae.

Most Cape Cod lakes have low phosphorus concentrations due to the lack of phosphorus in the surrounding glacially-derived sands. The median surface concentration of TP in 175 Cape Cod ponds sampled during the 2001 Pond and Lake Stewards (PALS) Snapshot is 16 ppb (or µg/l) (Eichner, *et al*., 2003). A more limited sampling of 60 Cape Cod lakes in 1997 and 1998 found a mean TP concentration in surface waters of 14 ppb (Ahrens and Siver, 2000). Using the US Environmental Protection Agency (2000) method for determining a nutrient criteria and the 2001 PALS Snapshot data, the Cape Cod Commission determined that unimpacted ponds on Cape Cod should have a surface TP concentration no higher than 10 ppb).

Mystic Lake has higher TP concentrations at depth, as would be expected due to the anoxic conditions of the sediments. The upper two sampling stations (0.5 and 3 m) are relatively

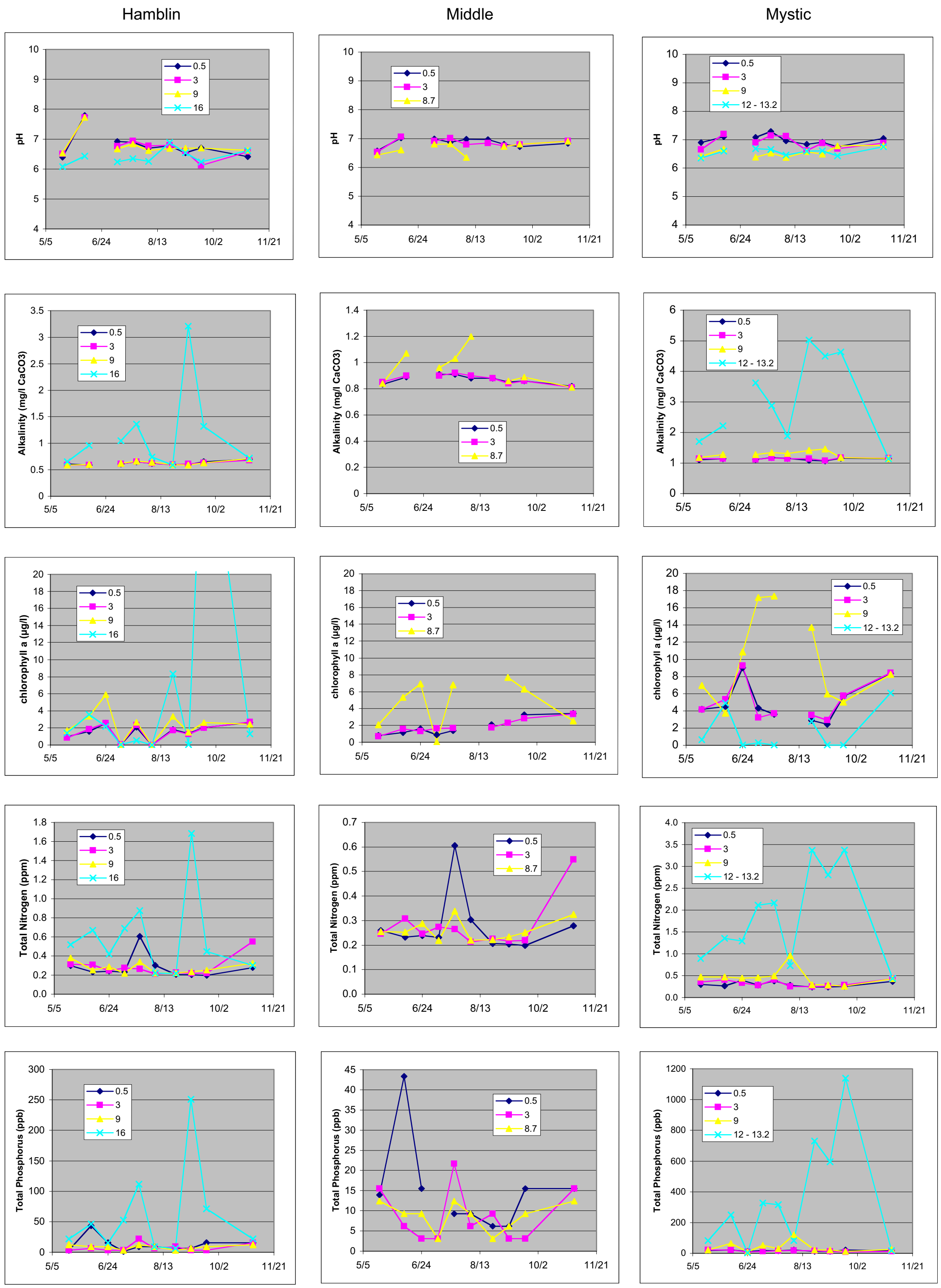


Figure 14. 2004 Laboratory water quality data for Indian Ponds for total phosphorus, total nitrogen, chlorophyll *a*, alkalinity, and pH.

constant and combined have an overall average over the sampling period of 15.9 ppb (Table 6). This is slightly higher than the 12 ppb average of the Mystic Lake PALS Snapshot data from 2001 through 2004 (Figure 15); this is one indication of how more refined data collection can give a better understanding of how conditions develop and fluctuate in a pond. The next deepest (9 m) station has an average concentration in this study of 38 ppb and the deepest station (12-13.2 m) has an average concentration of 355 ppb. Based on bathymetric information and examination of each sampling date, the average amount of TP in Mystic Lake water is 158 kg with a range of 35 to 375 kg.

Hamblin Pond also has higher TP concentrations at depth due to anoxic conditions in the sediments (see Figure 14). The upper concentrations, however, are lower than Mystic Lake with an average TP concentration across the upper three station depths (0.5, 3, and 9 m) of 9.8 ppb (Hamblin Pond PALS data from 2001 through 2004 results in an average of 5.1 ppb). At the deepest station (16 m), the average concentration in this study's data is 61 ppb (see Table 6). Based on bathymetric information and examination of each sampling date, the average amount of TP in Hamblin Pond is 91 kg with a range of 24 to 281 kg.

Table 6. Average Water Quality Concentrations in 2004 in Indian Ponds

	Mystic Lake			Hamblin Pond		Middle Pond	Cape Cod Surface Thresholds[1]	
Depth/ Constituent	0.5 and 3 m	9 m	12-13.2 m	0.5, 3, and 9 m	16 m	0.5, 3, and 8.7 m	All ponds	Unimpacted Ponds
Total Phosphorus (ppb)	15.9	38	355	9.8	61	10.3	10	7.5
Total Nitrogen (ppm)	0.31	0.46	1.85	0.28	0.6	0.27	0.31	0.16
Alkalinity (mg CaCO3/l)	1.1	1.3	3.1	0.6	1.2	0.9		
pH[2]	6.9	6.6	6.6	6.8	6.4	6.8	5.62	5.19
Chlorophyll *a* (µg/l)	5.1	9.9	1.6	2.0	6.6	2.9	1.7	1.0

[1] Thresholds determined based on surface samples collected during the 2001 PALS Snapshot (Eichner, *et al*., 2003); threshold for alkalinity has not been determined
[2] Threshold determination procedures were completed for pH in order to provide some analysis of impacted vs. unimpacted ponds, but the concept of a pH threshold for Cape Cod ponds needs additional analysis.

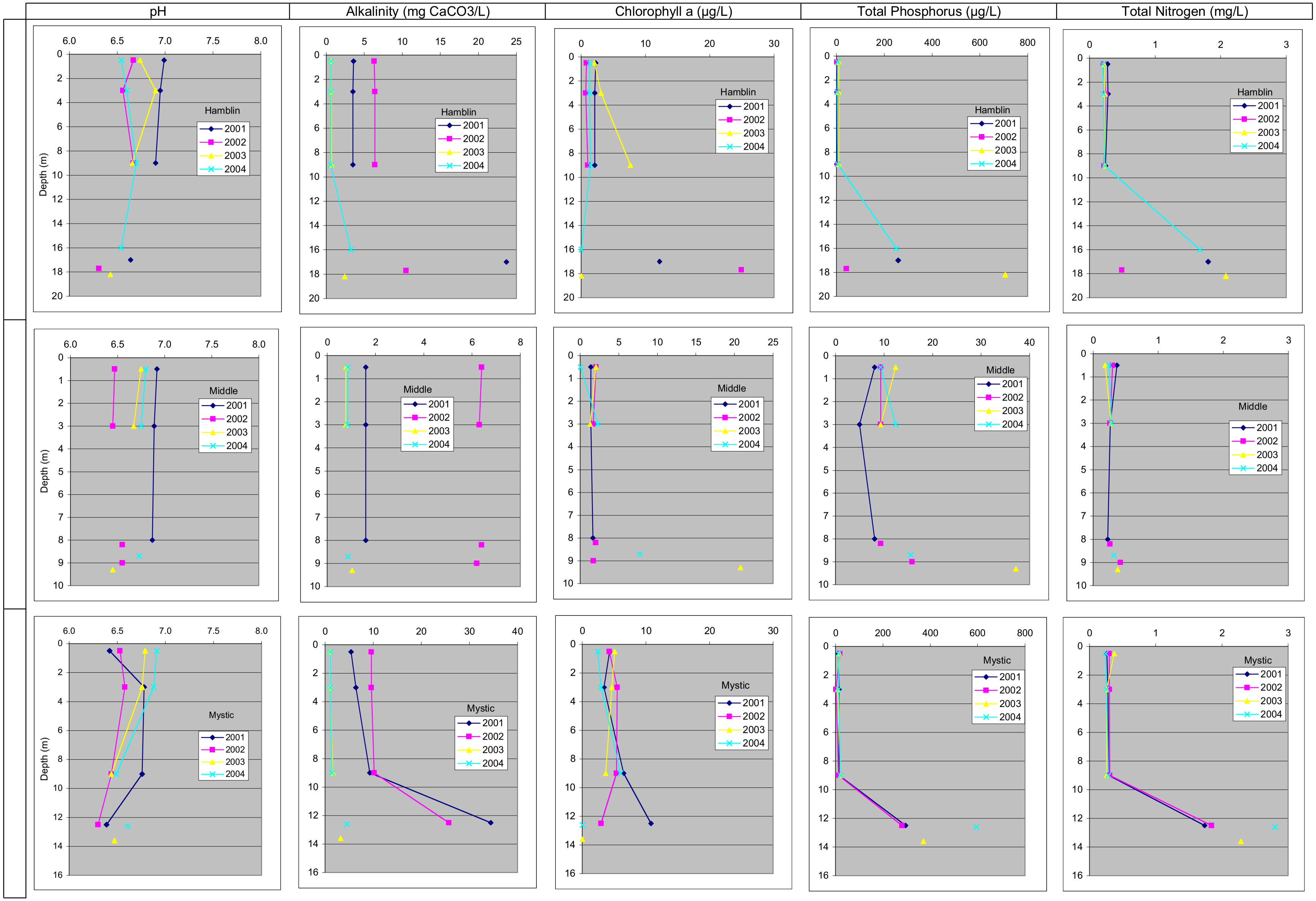


Figure 15. PALS Snapshot Laboratory Data for the Indian Ponds (2001-2004)

Middle Pond does not thermally stratify, so its water column was relatively well mixed throughout the 2004 sampling season and, accordingly, TP concentrations are relatively consistent at all sampling depths (0.5, 3, and 8.7 m) (see Figure 14). The average concentration in Middle Pond is 10.3 ppb, which is essentially the same concentration measured in the upper waters of Hamblin Pond (see Table 6). Middle Pond PALS data from 2001 through 2004 results in an average of 12.4 ppb across all sampling depths (see Figure 15). Based on bathymetric information and examination of each sampling date in this study, the average amount of TP in Middle Pond is 22 kg with a range of 4 to 42 kg.

ii. Total Nitrogen (TN)

Nitrogen is one of the primary nutrients in surface water systems (phosphorus and potassium being the other two). Nitrogen switches between a number of chemical species (nitrate, nitrite, ammonium, nitrogen gas, and organic nitrogen) depending on a number of factors, including dissolved oxygen, pH, and biological uptake (Stumm and Morgan, 1981). Nitrate-nitrogen is the fully oxidized form of nitrogen, while ammonium-nitrogen is the fully reduced (*i.e.*, low oxygen) form. Inorganic nitrogen generally enters ponds in the nitrate-nitrogen form, is incorporated into algae-forming organic nitrogen, and then is converted back to inorganic forms (nitrate- and ammonium-nitrogen) in the waste from algae or organisms higher up the food chain or by bacteria decomposing dead algae in the sediments. Total Kjeldahl nitrogen (TKN) is a measure of organic nitrogen and ammonium forms. Total nitrogen (TN) is generally reported as the addition of TKN and nitrate-nitrogen concentrations.

Nitrogen is not usually the nutrient that limits growth in ponds, but ecosystem changes during the course of a year or excessive phosphorus loads can create conditions where it is the limiting nutrient. In very productive or eutrophic lakes, algae that can extract nitrogen directly from the atmosphere, which is approximately 75% nitrogen gas, often have a strong competitive advantage and tend to dominate the pond ecosystem. These blue-green algae, more technically known as cyanophytes, are generally indicators of excessive nutrient loads.

Nitrogen is a primary pollutant associated with wastewater. Septic systems, the predominant wastewater treatment technology on Cape Cod, generally introduce treated effluent to the groundwater with concentrations between 20 and 40 ppm: Massachusetts Estuaries Project watershed nitrogen loading analyses use 26.25 ppm as an effective TN concentration for septic system wastewater (*e.g.*, Howes, *et al*., 2004). As such, Cape Cod ponds and lakes tend to have relatively high concentrations of nitrogen; the 184 ponds sampled during the 2001 PALS Snapshot had an average surface water TN concentration of 0.58 ppm. Review of these sampling results established that unimpacted ponds have an average concentration of 0.16 ppm (Eichner, *et al*., 2003).

Mystic Lake has higher TN concentrations at depth, as would be expected due to the anoxic conditions of the sediments (see Figure 14). The upper two sampling stations (0.5 and 3 m) are relatively constant and combined have an overall average over the sampling period of 0.31 ppm (see Table 6). The next deepest (9 m) station has an average concentration of 0.46 ppm and the deepest station (12-13.2 m) has an average concentration of 1.85 ppm.

Hamblin Pond also has higher TN concentrations at depth due to anoxic conditions in the sediments (see Figure 14). The upper concentrations, however, are lower than Mystic Lake with an average TN concentration across the upper three station depths (0.5, 3, and 9 m) of 0.28 ppm. At the deepest station (16 m), the average concentration is 0.60 ppm.

Middle Pond does not thermally stratify, so its water column was relatively well mixed throughout the 2004 sampling season and, accordingly, TN concentrations are relatively consistent at all sampling depths (0.5, 3, and 8.7 m) (see Figure 14). The average concentration in Middle Pond is 0.27 ppm, which is essentially the same concentration measured in the upper waters of Hamblin Pond.

iii. Alkalinity and pH

pH is a measure of acidity; pH values less than 7 are considered acidic, while pH values greater than 7 are considered basic. pH is the negative log of the hydrogen ion concentration in water (*e.g.*, water with a H^+ concentration = $10^{-6.5}$ has a pH of 6.5). pH is determined by the interaction of all of the ions with carbon species, like carbon dioxide, carbonate, and bicarbonate, having the most direct effect (Stumm and Morgan, 1981). The pH of rainwater, in equilibrium with carbon dioxide in the atmosphere, is 5.65. Photosynthesis takes carbon dioxide and hydrogen ions out of the water causing pH to increase, so more productive lakes will tend to have higher pH measurements. Alkalinity is a measure of the compounds that shift pH toward more basic values, is mostly determined by the concentrations of bicarbonate, carbonates, and hydroxides, and is a measure of the capacity of waters to buffer acidic inputs. Consequently, pH and alkalinity are linked values.

Since the sand deposited as Cape Cod during the last glacial period does not have carbonate minerals, Cape soils have low alkalinity and little capacity to buffer the naturally acidic rainwater that falls on the Cape. Available groundwater data generally shows pH on Cape Cod between 6 and 6.5; Frimpter and Gay (1979) sampled groundwater from 202 wells on Cape Cod and found a median pH of 6.1. The average surface pH of 193 ponds sampled in the 2001 PALS Snapshot is 6.16 with a range of 4.38 to 8.92, while the average alkalinity is 7.21 mg/L as $CaCO_3$ with a range of 0 to 92.1 (Eichner, *et al*., 2003).

The three ponds all show relatively high pHs compared to most Cape Cod ponds (see Figure 14); Hamblin Pond has an average pH of 6.7, Middle Pond is 6.8, and Mystic is 6.8. Readings tend to drop slightly in all three ponds with increasing depth, likely due to the lower photosynthetic activity.

Average alkalinity in shallow waters of Mystic and Middle are similar (1.1 mg/L as $CaCO_3$ in Mystic and 0.9 mg/L as $CaCO_3$ in Middle), while Hamblin has a slightly lower average concentration (0.6 mg/L as $CaCO_3$) (see Table 6). Hamblin and Mystic have increased average concentrations at the deepest sampling locations (1.2 mg/L as $CaCO_3$ in Hamblin and 3.1 mg/L as $CaCO_3$ in Mystic). These increases are consistent with the anoxic conditions measured; lack of oxygen causes a number of elements to convert from insoluble to soluble forms and many of these soluble forms will increase buffering capacity (Stumm and Morgan, 1981).

iv. Chlorophyll *a* (CHL-a)

Chlorophyll is the primary photosynthetic pigment in plants, both algae and macrophytes (*i.e.*, any aquatic plants larger than microscopic algae, including rooted aquatic plants). Because of its prevalence, measurement of chlorophyll can be used to estimate how much algae is present in collected water samples. Chlorophyll *a* (CHL-a) is a specific pigment in the chlorophyll family and plays a primary role in photosynthesis (USEPA, 2000).

During the 2001 PALS Snapshot sampling, 191 ponds had surface CHL-a samples. The average of concentration of these samples is 8.44 µg/l with a range from 0.01 to 102.9 µg/l. Ahrens and Siver (2000) survey of sixty Cape Cod lakes and ponds found the mean CHL-a concentration to be 3.07 µg/l with a range of 0.51 to 19.25 µg/l. Review of the PALS 2001 sampling results established that unimpacted ponds have an average CHL-a concentration of 1.0 µg/l (Eichner, *et al*., 2003).

Hamblin and Middle Ponds have similar CHL-a profiles (see Figure 14). Both have average surface concentrations in the 1.7-1.9 µg/l range with higher concentrations deeper in the ponds; Hamblin's 16 m station has an average CHL-a concentration of 8.5 µg/l, while Middle's 8.5 m station has an average of 5.4 µg/l (see Table 6). While Hamblin concentrations do not have significant trends over the course of the sampling season, Middle Pond shallow water concentrations significantly increase ($R^2 = 0.87$ at the 0.5 m station and $R^2 = 0.89$ at the 3 m station).

Mystic Lake has a much higher average shallow CHL-a concentration than the other two ponds (5 µg/l at 0.5 m station and 5.2 µg/l at the 3 m station)(see Figure 13). These concentrations are similar to the concentration observed at the deepest sampling station in Middle Pond. The 9 m sampling station in Mystic Lake has an average concentration of 9.9 µg/l, while the deepest station (12-13.2 m) has an average concentration of 1.6 µg/l.

5. Overall Assessment: Ecosystem Status and Phosphorus Budget

A. Ecosystem Status Factors

Assessing the ecosystem status of a lake or pond usually starts from trying to develop an understanding what the system would be like if it did not have the impacts of watershed and surrounding land uses. This understanding usually has to be developed by looking at similar, unimpacted ponds and historic water quality measurements. On Cape Cod, developing this understanding is hindered a bit more than in other portions of the country since the Cape's geology and climatic environment are relatively unique.

Carlson (1977) developed a trophic status index based on water quality monitoring available at the time, mostly for ponds in Wisconsin and Minnesota. The trophic state of a pond is the total amount of living biological material (*i.e.*, biomass) in the ecosystem and Carlson's index uses various measures to provide a single index number that places ponds in various trophic categories (Table 7). Carlson designed the system to utilize one or another of the measures to classify the trophic state index (TSI) of a pond or lake on a scale of 0 to 100 (Carlson and Simpson, 1996). Although the Carlson indices were developed for use in northern temperate lakes and do not work well in lakes where macrophytes (i.e., rooted aquatic plants)