

is based on existing conditions. The watershed budget is based on steady state conditions and does not include modification to account for phosphorus time of travel.

In summary, the apportionment of the watershed load into the various categories could require some additional work to refine and confirm, but the overall budget compares reasonably with the water quality data. This comparison also supports the assessment that deeper, hypolimnetic sediment regeneration of TP is not significantly impacting the upper, epilimnetic waters of Hamblin Pond.

6. Conclusions

After reviewing the water quality data, it is clear that Mystic Lake is impaired. Water quality in the other two ponds shows some issues of concern, but water quality conditions are generally good.

Mystic Lake's impairments are the result of total phosphorous entering the lake from its watershed and being regenerated from its sediments. Anoxic conditions in the hypolimnion that have occurred over the last 50 years allow TP to be released from the sediments back into the water; TP in the sediments originally came from the watershed, was utilized by phytoplankton in the lake, and fell to the sediments when the phytoplankton died. So much TP is being released from the sediments that it is leaking through the bottom of the epilimnion and prompting higher TP and chlorophyll *a* concentrations in this upper layer, as well as lower Secchi readings. Current phosphorus loading from the lake's watershed is approximately 35 kg/yr, while sediment regeneration is estimated as 12 kg/yr. Watershed loads are projected to increase to 47 kg/yr at steady state without any additional development along the shoreline and 50 kg/yr at full buildout. TP management activities should address the sediment regeneration and the existing and future watershed sources.

Middle Pond has surface water phosphorus concentrations that are just above the impacted threshold of 10 ppb determined by the Cape Cod Commission (Eichner, *et al.*, 2003). Chlorophyll *a* concentrations and Secchi depth readings have significant summer-long trends indicating worsening conditions in the pond. Current watershed phosphorus loading is approximately 23 kg/yr plus an additional ~14 kg/yr from sediment regeneration and/or direct input from Mystic Lake. Watershed loads are projected to increase to 40 kg/yr at steady state without any additional development along the shoreline and two additional lots at buildout will increase this load less than one additional kilogram per year.

Hamblin Pond has surface water phosphorus concentrations that are just below the 10 ppb threshold, but anoxic conditions that allow sediment regeneration of phosphorus exist deeper in the pond. Fortunately, the 1995 alum treatment reduced sediment oxygen demand sufficiently to reestablish a fully oxygenated layer within the hypolimnion. The above analysis indicates that this oxygenated layer is preventing regenerated phosphorus from prompting phytoplankton growth in the epilimnion. Current watershed phosphorus loading is approximately 24 kg/yr. Watershed loads are projected to increase to 29 kg/yr at steady state without any additional development along the shoreline and there are no projected additions at buildout.

7. Recommendations for Future Activities

A. Mystic Lake

The sum of the above analysis indicates that the high phosphorus and low Secchi depth readings in Mystic Lake are the result of phosphorus loading from both its watershed and regeneration from its sediments. If the 10 ppb TP threshold in the epilimnion is used as a planning target, ~35 kg/yr would be the acceptable load to this layer. Attaining this target would require reductions in both watershed and sediment regeneration loading.

If a phosphorus reduction similar to that achieved in Hamblin Pond by the alum treatment occurred, a layer of well-oxygenated water in the hypolimnion would effectively isolate the phosphorus regenerated by the sediments and remove this load from the epilimnion. This would reduce the epilimnion mass to the 35 kg/yr target. While this is the projected current load, it is estimated that an additional 12 kg/yr are already in the groundwater from existing development and an additional 3 kg at buildout within the 300 ft buffer around the shoreline, so additional phosphorus reduction steps in the watershed will be necessary to accommodate the steady state loading and loading that is already coming from existing development, as well as buildout additions.

Project staff recommends that the IPA and the Town consider a series of three parallel steps to remediate Mystic Lake. The first step would be to address the phosphorus regenerated from the sediments; this can be done a number of ways (*e.g.*, alum application, hypolimnetic aeration, etc.); a complete list of remedial options is available in the state's Final Generic Environmental Impact Report on Eutrophication and Aquatic Plant Management (Mattson, *et al.*, 2003). Interim steps to determine the appropriate activity should include sampling of the sediments, analysis of their phosphorus content, and evaluation of various phosphorus forms to identify likely maximum regeneration. Whatever remedial activity is chosen will likely require a permit and associated public hearings from the town Conservation Commission.

The second step would be a number of activities to address the watershed loading; the two largest sources in the watershed portion of the phosphorus budget are wastewater (19.5 kg at steady state) and waterfowl (12.2 kg at steady state). Based on the phosphorus budget, 15 kg of TP would have to be removed. As mentioned previously, in order to better quantify the waterfowl loading, the town and/or IPA would need to initiate a site-specific waterfowl phosphorus loading project on Mystic Lake. The wastewater loading would require an evaluation of options to remove or reduce this component.

Reducing the wastewater component could be addressed by removing this source from the watershed via sewers; since this is likely a high cost proposition, additional analysis is warranted. Additional analysis should include review of: 1) alternative treatments that utilize existing or upgraded septic systems, 2) issues associated with design of a collection system, selection of a wastewater discharge site and evaluation of impacts of effluent discharge on other downgradient resources, and 3) cost evaluation of management, design, and financing of the various options.

A third step would be to review existing regulatory programs (*i.e.*, board of health, conservation commission, and planning board) and their regulations and bylaws to evaluate

potential changes that would better protect water quality and preserve the benefits of whatever investment is made to reduce the sediment phosphorus regeneration. One recent example of this was the bylaw and regulation evaluation completed by the Cape Cod Commission staff at the request of the Brewster Board of Selectmen; this evaluation included recommendations to increase the minimum septic system leachfield setbacks from ponds and to enhance and better utilize existing requirements such as real estate transfer upgrades and required water quality reports (1/30/04 memo from Ed Eichner to Brewster Board of Health and Conservation Commission).

During the course of these activities, it is further recommended that the town and/or the IPA continue to monitor Mystic Lake. This monitoring program should include, at a minimum, the same parameters, detection limits, depths, and sampling procedures utilized during this project; sampling should occur, at a minimum, in early April and late August. The late August sampling could occur via the regular PALS Snapshot, if this project is still occurring.

B. Middle Pond

The sum of the above analysis indicates that Middle Pond has generally good water quality, but the summer-long upward trends for chlorophyll a concentrations and decrease in Secchi transparency and the late summer anoxia deep in the pond raise some concerns. These concerns have developed over the last 50 years.

Current average TP concentrations are just above the 10 ppb TP threshold for Cape Cod ponds; existing and buildout loads will increase this concentration by ~1.5 ppb. The total load into the pond needed to balance the observed water quality concentrations includes an addition from an undefined source. Based on the physical connection to Mystic Lake and the observed deep anoxia, this undefined source could be loads from Mystic Lake, sediment regeneration or a combination of the two sources.

If the recommended target of 10 ppb TP is met in Mystic Lake, as discussed above, and it is assumed that Mystic Lake contributes half of the undefined load, the resulting improvements in Mystic Lake would cause average existing Middle Pond TP concentrations to drop to 7.7 ppb and the average buildout TP concentration to drop to 9.8 ppb. This analysis indicates that if Mystic Lake is the undefined source needed to balance the TP budget in Middle Pond, effectively addressing Mystic Lake's TP concentrations would also address Middle Pond's water quality concerns.

If, on the other hand, internal sediment regeneration is the predominant source of the undefined TP, similar protections of Middle Pond would require activities to address the phosphorus or the sediment oxygen demand. Given that Middle Pond is shallower than Mystic Lake or Hamblin Pond and does not thermally stratify, there are additional options available. These options might include removal of the sediments, enhanced aeration near the sediments, or a phosphorus inactivation (*e.g.*, alum application); a complete list of potential options is available in the state's Final Generic Environmental Impact Report on Eutrophication and Aquatic Plant Management (Mattson, *et al.*, 2003).

Given that Middle Pond has generally good water quality, it is recommended that the IPA and the town focus on addressing the water quality problems in Mystic Lake while continuing to monitor water quality conditions in Middle Pond. The impact of implementing remedial activities in Mystic Lake should be observed in Middle Pond within five years if Mystic Lake is the undefined source of TP to Middle Pond. If monitoring does not show improvement after five years, the town and IPA should consider proceeding with remedial activities for the sediments in Middle Pond.

Since water quality monitoring is the key to realizing this recommended adaptive management strategy, a monitoring program should include, at a minimum, the same parameters, detection limits, depths, and sampling procedures utilized during this project. Sampling should occur, at a minimum, in early April and late August. The late August sampling could occur via the regular PALS Snapshot, if this project is still occurring.

C. Hamblin Pond

The sum of the above analysis indicates that Hamblin Pond has generally good surface water quality, including the best average TP concentrations among the Indian Ponds. The 1995 alum treatment has significantly improved all water quality measures and has created a layer of cold, well-oxygenated water that essentially isolates the persistent low dissolved oxygen and sediment TP regeneration found deeper in the pond. Water quality data and the phosphorus budget indicate that there is no significant leakage of high TP concentrations into the upper waters.

The phosphorus budget and water quality data indicates that the arrival of all phosphorus coming from existing development within the 300 ft buffer has not arrived at the pond. Once all of this arrives and steady-state is achieved, average TP concentrations should rise ~1.8 ppb and exceed the 10 ppb Cape Cod impacted threshold. Given that the pond has some concerns regarding chlorophyll *a* concentrations and Secchi transparency, this slight rise above the threshold should be closely watched.

It is recommended, therefore, that the town and IPA continue monitoring Hamblin Pond. This monitoring program should include, at a minimum, the same parameters, detection limits, depths, and sampling procedures utilized during this project. Sampling should occur, at a minimum, in early April and late August. The late August sampling could occur via the regular PALS Snapshot, if this project is still occurring. Monitoring data should be reviewed every five years; if additional concerns arise, remedial options to address the concerns should be reviewed at that time.

8. References

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Appendix A

Water-level information from May to October 2004
collected at sites in Figure 4

Pond Water Level Measurements

Gauge	Location	Elevation of Benchmark (feet NGVD)	Elevation of Measuring Point (feet NGVD)		Measurement (feet)	Date	Pond Elevation (feet NGVD)	Data Recorded by	Notes
			original gauge (June 1, 2004)	replacement gauge (Sept. 1, 2004)					
Mystic Lake	1139 Race Lane	47.99	46.11	N/A	2.2	6/23/2004	45.0	N.Dawson, resident volunteer	Z
					2.1	7/7/2004	44.9		Z
					1.9	7/16/2004	44.7		Z
					1.8	8/25/2004	44.6		Z
					1.7	9/1/2004	44.5		Z
					1.7	9/7/2004	44.5		Z
					1.5	9/14/2004	44.3		Z
					1.5	10/2/2004	44.3		Z
					1.4	10/12/2004	44.2		Z
					0.8	7/8/2004	44.8		Z
Middle Pond (north)	380 Wheeler Road	49.32	45.56	46.66	1.1	8/2/2004	44.5	R. Frazee/A.Frazee, resident volunteer	Z
					2.2	9/1/2004	44.5		Z
					2.3	9/5/2004	44.4		Z
					2.5	9/17/2004	44.2		Z
					2.3	9/19/2004	44.3		Z
					1.4	10/18/2004	44.2		confirmation measurement
					2.5	10/18/2004	44.2		
Hamblin Pond	335 Hollidge Hill Road	46.27	45.67	N/A	1.6	10/21/2004	44.0	S.Sawyer, resident volunteer	Z
					45.4	5/18/2004	45.4		Z
Middle Pond (herring run)	Flume Avenue	-	-	N/A	45.4	5/27/2004	45.4	S.Michaud, CCC	Z
					45.3	6/11/2004	45.3		Z
					45.3	6/21/2004	45.3		Z
					44.9	7/19/2004	44.9		Z
					44.6	8/26/2004	44.6		Z
					43.4	10/21/2004	-		Channel between herring run and Middle Pond sandbagged

Appendix B

Indian Ponds Water Quality/Sampling Field Sheet



LAKE AND POND SAMPLING DATA SHEET
2004 Indian Ponds Sampling Project

LAKE/POND NAME: _____
TOWN: _____ **Sample Collector:** _____
Date: _____ **Time:** _____ (AM or PM)

Observations (write in or circle as appropriate):
Water Color: _____ (blue, brown, green, blue/green, red/orange, white, etc)
Weather (circle):
 1. Cloudless, 2. Pt. Cloudy, 3 Overcast, 4. Rain, 5. Fog/Haze, 6. Drizzle, 7. Intermit. Rain
Wind (circle): 1. Calm, 2. Light Breeze, 3. Steady Wind, 4. Strong Wind

Plants on Pond (check conditions):	Over 50%	25% to 50%	10% to 25%	up to 10%	less than 1% or None
Waterlilies coverage of pond surface:					
Floating Algae on pond surface:					
Emergent Grasses/Sedges of surface:					
Other plant #1 _____:					
Other plant #2 _____:					
Other Notes:					

TOTAL DEPTH: _____ meter

SECCHI READING: Disappearing: _____ meter Reappearing: _____ meter

DISSOLVED OXYGEN/TEMPERATURE PROFILE

Meter Manufacturer: _____ Model# _____

Record DO/Temp profile in one-meter increments except for the first surface reading which is taken at 0.5 m. If the pond is very shallow (3 meters or less), record readings at 0.5 meter increments.

Depth (m)	Temp (°C)	Dissolved Oxygen (mg/l)	Depth (m)	Temp (°C)	Dissolved Oxygen (mg/l)	Depth (m)	Temp (°C)	Dissolved Oxygen (mg/l)

LAKE/POND NAME: _____

TOWN: _____ Sample Collector: _____

WATER QUALITY SAMPLING

!! FILL BOTTLE TO TOP and RECORD BOTTLE #'s !!

Hamblin Pond or Mystic Lake	
Sampling Depth	Bottle Number/Label
a. just below the surface	
b. 3 m down	
c. 9 m down	
d. 1 m above the bottom	

Middle Pond	
Sampling Depth	Bottle Number/Label
a. just below the surface	
b. 3 m down	
c. 1 m above the bottom	

TIME SAMPLING COMPLETED: _____ (AM or PM)

SAMPLE SIGNOFFS

	Signature	Received Date/Time	Delivered Date/Time
Pond Monitor			
Sampling Coordinator			
SMAST			

Appendix C

Glossary of Pond and Lake Terms and List of Acronyms

Glossary and List of Acronyms

Aerobic:

Processes requiring oxygen.

Algae:

microscopic organisms/aquatic plants that use sunlight as an energy source (*e.g.*, diatoms, kelp, seaweed). One-celled (phytoplankton) or multicellular plants either suspended in water (Plankton) or attached to rocks and other substrates (periphyton). Their abundance, as measured by the amount of chlorophyll *a* (green pigment) in an open water sample, is commonly used to classify the trophic status of a lake. Numerous species occur. Algae are an essential part of the lake ecosystem and provide the food base for most pond and lake organisms, including fish. Phytoplankton populations vary widely from day to day, as life cycles are short.

Alkalinity:

The ability of water, or other substances, to absorb high concentrations of hydrogen ions. A measure of the amount of carbonates, bicarbonates, and hydroxide present in water. Increasing alkalinity is often related to increased algae productivity. Often expressed as milligrams per liter (mg/l) of calcium carbonate (CaCO₃).

Anoxic:

Lacking oxygen

CCC:

Cape Cod Commission

Chlorophyll *a*:

Green pigment present in all plant life and necessary for photosynthesis. The amount present in lake water depends on the amount of algae and is therefore used as a common indicator of water quality.

Chlorophyll:

a green pigment found in plants that is essential for the process of photosynthesis.

Concentration:

The amount of solute present in proportion to the total solution. More specifically, a measure of the average density of pollutants or other constituents, usually specified in terms of mass per unit volume of water or other Solvent (*e.g.*, milligrams per liter) or in terms of relative volume of solute per unit volume of water (*e.g.*, parts per million). Other common units of concentration are: parts per billion (ppb), micrograms per liter (µg/l), and micromoles per liter (µM).

Decompose:

breakdown of organic materials to inorganic materials.

Detritus:

partially decomposed (dead) organic matter.

Dissolved Oxygen (DO):

the amount of free oxygen absorbed by the water and available to aquatic organisms for respiration; amount of oxygen dissolved in a certain amount of water at a particular temperature and pressure, often expressed as a concentration in parts of oxygen per million parts of water.

Ecosystem:

a system formed by the interaction of a community of organisms with each other and with the chemical and physical factors making up their environment.

Epilimnion:

The upper layer of water during stratification. Stratification is caused by water's temperature-related density differences. Water's greatest density occurs at 39 °F (4 °C). As water warms during the summer, it remains near the surface while colder water remains near the bottom. Wind mixing determines the thickness of the warm surface water layer (epilimnion), which on Cape Cod usually extends to a depth of about 9 m (29 ft).

Eutrophication:

the process by which surface waters are enriched by nutrients, and the resulting increase in plant and algae growth. The extent to which this process has occurred is reflected in a lake's trophic classification: oligotrophic (nutrient poor), mesotrophic (moderately productive), and eutrophic (very productive and fertile).

Flushing Rate/Residence Time:

The average length of time water resides in a pond or lake, ranging from several days in small ponds to many years in large lakes. Residence time is important in determining the impact of nutrient inputs. Long retention times result in recycling and greater nutrient retention in most lakes. Calculate retention time by dividing the annual volume of water passing through a pond by the pond volume.

Hypolimnion:

The lower layer of water during stratification. Stratification is caused by water's temperature-related density differences. Water's greatest density occurs at 39 °F (4 °C). As water warms during the summer, it remains near the surface while colder water remains near the bottom. The cold bottom water is the hypolimnion.

IPA:

Indian Ponds Association

Insoluble:

incapable of dissolving in water.

Limiting nutrient/factor:

The nutrient or condition in shortest supply relative to plant growth requirements. Plants will grow until stopped by this limitation; for example, phosphorus in summer, temperature or light in fall or winter.

Limnology:

the study of inland lakes and waters.

Metalimnion:

The middle layer of water during stratification. Stratification is caused by water's temperature-related density differences. Water's greatest density occurs at 39 °F (4 °C). As water warms during the summer, it remains near the surface while colder water remains near the bottom. Wind mixing determines the thickness of the warm surface water layer (epilimnion), which on Cape Cod usually extends to a depth of about 9 m (29 ft). The narrow transition zone between the epilimnion and cold bottom water (hypolimnion) is called the metalimnion or thermocline.

Nitrogen:

Essential element for plant growth, comprising 78 percent of the atmosphere in gaseous (N₂) form, which is quite inert and unavailable to most plants in its natural form. Dissolved in water in ammonia (NH₄⁺), nitrate or nitrite or elemental forms. Nitrate is an inorganic form that is the stable form when oxygen is present. Nitrate often contaminates groundwater when water originates from lawns or septic systems. Nitrite (NO₂⁻) is rapidly converted to nitrate (NO₃⁻) and is usually included in the NO₃⁻ analysis. Total Kjeldahl Nitrogen (TKN) is a measure of all organic and ammonium forms. Total Nitrogen (TN) is generally reported as TKN plus nitrate-nitrogen.

Nitrogen Cycle:

cyclic movement of nitrogen in different chemical forms from the environment to organisms and then back to the environment.

Nutrients:

elements or substances such as nitrogen and phosphorus that are necessary for plant growth. Large amounts of these substances can become a nuisance by promoting excessive aquatic plant growth.

Organic Matter:

elements or material containing carbon, a basic component of all living matter.

Destratification/Turnover:

Fall cooling of surface water on Cape Cod increases density, and gradually makes temperature and density uniform from top to bottom. This allows wind and wave action to mix the entire lake. Mixing allows bottom waters to contact the atmosphere, raising the water's oxygen content.

PALS:

Pond and Lake Stewards or Pond and Lake Stewardship program. Umbrella association of all organizations, groups, and individuals concerned with pond and lake issues on Cape Cod.

pH:

the numerical value used to indicate how acid or alkaline a solution is. The number is a measure of the concentration of hydrogen ions in the solution. The pH scale ranges from 1 to 14 with 7.0 being neutral; solutions with pH below 7 are acidic, while solutions with pH above 7 are alkaline.

Phosphorus:

Key nutrient influencing plant growth in Cape Cod ponds and lakes. Soluble reactive phosphorus is the amount of phosphorus in solution that is readily available to plants. Total phosphorus (TP) includes the amount of phosphorus in solution (reactive) and in particulate form.

Photosynthesis:

the process by which green plants convert carbon dioxide (CO₂) dissolved in water to sugar and oxygen using sunlight for energy. Photosynthesis is essential in producing a lake's food base, and is an important source of oxygen for many lakes.

Phytoplankton:

microscopic plants found in the water. Algae or one-celled (phytoplankton) or multicellular plants either suspended in water (plankton) or attached to rocks and other substrates (periphyton). Their abundance, as measured by the amount of chlorophyll *a* (green pigment) in an open water sample, is commonly used to classify the trophic status of a lake. Numerous species occur. Algae are an essential part of the lake ecosystem and provide the food base for most lake organisms, including fish. Phytoplankton populations vary widely from day to day, as life cycles are short.

Plankton:

small plant organisms (phytoplankton and nanoplankton) and animal organisms (zooplankton) that float or swim weakly through the water.

ppm:

parts per million; units per equivalent million units; equal to milligrams per liter (mg/l)

Precipitate:

A solid material which forms and settles out of water as a result of certain negative ions (anions) combining with positive ions (cations).

Secchi Disc:

An 8-inch diameter plate with alternating quadrants painted black and white that is used to measure water clarity (light penetration).

Sediments:

Accumulated organic and inorganic matter on the lake bottom. Sediment includes decaying algae and other organic matter collected from the lake and its watershed.

SMAST

School of Marine Science and Technology, University of Massachusetts, Dartmouth

Soluble:

capable of being dissolved.

Species:

A group of animals or plants that share similar characteristics such as can reproduce.

Stratification:

The layering of water due to differences in density. Stratification is caused by water's temperature-related density differences. Water's greatest density occurs at 39 °F (4 °C). As water warms during the summer, it remains near the surface while colder water remains near the bottom. Wind mixing determines the thickness of the warm surface water layer (epilimnion), which on Cape Cod usually extends to a depth of about 9 m (29 ft). The narrow transition zone between the epilimnion and cold bottom water (hypolimnion) is called the metalimnion or thermocline.

Trophic State:

Eutrophication is the process by which ponds and lakes are enriched with nutrients, increasing the production of rooted aquatic plants and algae. The extent to which this process has occurred is reflected in a pond's trophic classification or state: oligotrophic (nutrient poor), mesotrophic (moderately productive), and eutrophic (very productive and fertile).

USGS:

United States Geological Survey

Watershed:

the land area draining into a specific stream, river, lake, estuary or other body of water. On Cape Cod, these areas are determined largely by the topography of the top of the groundwater system, known as the water table.

Zooplankton:

Microscopic or barely visible animals that eat algae. These suspended plankton are an important component of a pond or lake food chain and ecosystem. For many fish, they are the primary source of food.

Adapted from the following sources:

1. Libby McCann and "Understanding Lake Data" by Byron Shaw, Christine Mechenich and Lowell Klessig (<http://dnr.wi.gov/org/water/fhp/lakes/laketerm.htm>)
2. North American Lake Management Society Lake and Water Word Glossary (<http://www.nalms.org/glossary/glossary.htm>)