Eastham Freshwater Ponds: Water Quality Status and Recommendations for Future Activities

draft FINAL REPORT

December 2008

for the

Town of Eastham
and
Barnstable County

Prepared by:

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CAPE COD COMMISSION

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Prepared By

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Cover photo: samplers on Muddy Pond (Sandy Bayne, August 2008)

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Executive Summary

Eastham Freshwater Ponds: Water Quality Status and Recommendations for Future Activities

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The Coastal Systems Program at the School of Marine Science and Technology (SMAST), University of Massachusetts Dartmouth has completed a review of pond monitoring data collected by Town of Eastham volunteers from 10 ponds between 2001 and 2006. This review includes a detailed review of six ponds selected by the Eastham Water Resources Advisory Board: Great, Herring, Muddy, Long, Minister, and Schoolhouse. The detailed review includes delineation of pond watersheds, development of water and phosphorus budgets, characterization of the ponds ecological status, and review of pertinent data within the context of this additional information. This review also includes use of revised bathymetric maps that were developed by Cape Cod Commission staff for all of the ponds except Great and Herring based on data collected by town volunteers. The overall project was completed using funding to the Pond and Lake Stewardship (PALS) program from Barnstable County's Growth Management Initiative.

The review of all the volunteer data from 10 ponds monitored in Eastham indicates that eight of the ponds have average dissolved oxygen concentrations that fail to attain minimum thresholds in the state surface water regulations. Jemima and Muddy are the two ponds that meet state dissolved oxygen standards. Review of nitrogen and phosphorus concentrations finds that all ponds are phosphorus limited, which means that water quality in all of the ponds is determined by phosphorus loads. Review of average total phosphorus concentrations also shows that all of the ponds exceed the 10 ppb "healthy" threshold that was developed by the Cape Cod Commission specifically for Cape Cod ponds (Eichner and others, 2003).

Six ponds were selected by the town for more detailed review by SMAST staff. These reviews allow the water quality data review to be enhanced by incorporating watershed delineation and development of water and phosphorus budgets. Development of the watersheds allowed project staff to determine how the ponds interact with the surrounding aquifer. Staff also developed estimates of current and future sources of phosphorus loads, which can then be compared to the average measured mass in each of the ponds to assess delays in phosphorus transport from the pond watersheds and likely future steady-state conditions. Because phosphorus moves very slowly in Cape Cod aquifer conditions, it can take decades in some cases for loads from a nearby sources, such as septic systems, to reach a pond shoreline and discharge into the pond. Comparison of existing conditions to projected future loads in the six ponds show that only a fraction of the steady-state watershed nutrient loads have reached the ponds; water quality will worsen in time as systems move closer to steady state.

The detailed review of the six individual ponds also shows that all but Muddy have both ecological and regulatory impairments. Development of appropriate and cost-effective water quality restoration strategies for all these ponds will require collection of some additional information. All ponds require sampling of their sediments to directly measure current and future potential phosphorus loading from the sediments to the overall load within each pond. Review of the phosphorus budgets also indicates that development of pond-specific information about stormwater inputs and aquatic bird populations is important for effectively targeting restoration strategies. Collection of this information, along with other recommended pond-specific data, will refine the phosphorus budgets and ensure that management and restoration strategies accurately target the sources of the impairments in these ponds.

In addition to addressing these data needs for effective restoration plans, additional information is also necessary to resolve some inconsistencies in the existing datasets. Great, Long, and Minister/Schoolhouse have inconsistencies between total phosphorus results and dissolved oxygen readings. It appears that some of the shallow and deep phosphorus concentration results may have been transposed. It is recommended that additional water quality sampling be paired with the recommended sediment sampling to ensure that these inconsistencies are resolved and the restoration strategies are well-defined.

Since the results from the detailed and town-wide data reviews consistently show impairments in almost all of Eastham's ponds and restoration activities will require significant coordination and guidance, it is further recommended that the Town of Eastham consider development of an integrated pond remediation and monitoring program. This program would be tasked with: a) addressing the existing impairments each pond, b) developing ways to ensure the future long term health of these ecosystems, and c) integrating on-going monitoring to assess long term water quality trends and efficacy of remedial projects. The suggested details of such a program are described in a series of recommendations and it is further suggested that such a program could be jointly managed by SMAST and the Town of Eastham.

These recommendations and others are described in more detail in this report. SMAST staff are available to assist the town in discussion of these types of activities, the pond analysis results, and recommendations contained in the report.

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Eastham Freshwater Ponds: Water Quality Status and Recommendations for Future Activities

I. Introduction

The Town of Eastham has 23 ponds that collectively occupy 258 acres (Eichner and others, 2003). Of these ponds, 16 of them are greater than one acre and five of them are greater than ten acres: Great, Herring, Long/Depot, Muddy, and Minister. Local concerns about the water quality of these ponds have grown as impacts from population growth have been measured in other water resources.

Local pond concerns mirror pond concerns that are being raised Cape-wide. The Cape Cod Commission (CCC) and other community partners, including the Community Foundation of Cape Cod, the state Executive Office of Environmental Affairs, and the University of Massachusetts Dartmouth School of Marine Science and Technology (SMAST), developed the Pond and Lake Stewards (PALS) program in 2000 to respond to these concerns. Initial PALS activities included the production of the Cape Cod Pond and Lake Atlas (Eichner and others, 2003), a number of "Ponds in Peril" workshops where pond concerns and solutions could be shared among all towns and volunteers, and participation of volunteers in the National Secchi Dip-In using Secchi disks provided by the CCC to measure transparency in their ponds. Volunteers who participated in the Dip-In wanted to know more about the water quality in their ponds and, with SMAST's offer of free laboratory analysis of water samples, the CCC, SMAST, and the towns created the first PALS Snapshot of pond water quality sampling in 2001.

Many towns, including Eastham, took the opportunities presented by the annual PALS Snapshots, which have continued from 2001 through 2008, to create larger, more intensive volunteer pond monitoring programs. Eastham's monitoring program has included getting funding for laboratory analysis of water samples, training of volunteers, sampling throughout select summers, and coordination through town staff. The Eastham program uses the PALS sampling protocol as guidance and has included the collection of samples from 10 of the town's ponds (Figure I-1). Over the years, results from the sampling program have been presented at a number of Ponds in Peril workshops and meetings of various town boards.

In 2005, Barnstable County asked the towns for proposals to use county services to help address impacts from growth. A number of towns, including Eastham, requested CCC assistance to provide interpretation of volunteer-collected pond water quality data. The project scope developed by Eastham and CCC staff for this effort included an overall review and interpretation of all volunteer-collected pond water quality data, as well as detailed reviews, including water and phosphorus budgets, of six ponds selected by the Town. Staff from the Coastal Systems Program at the University of Massachusetts Dartmouth School of Marine Science and Technology (SMAST) are now working with the CCC to complete this project.

With the assistance of a number of core town volunteers, all of the volunteer data was compiled, organized, and reviewed by SMAST and CCC water resources staff. A preliminary summary of this review was presented at a combined town Water Resources Advisory Board and Waste Water Management Planning Committee meeting on June 13, 2006. At that meeting, the boards, in consultation with other concerned citizens and staff, selected the following ponds for the more detailed review: Great, Herring, Long/Depot, Muddy, and Minister/Schoolhouse (see Figure I-1). The information presented below details the overall review of the volunteer monitoring data, followed by the detailed review of the selected ponds.

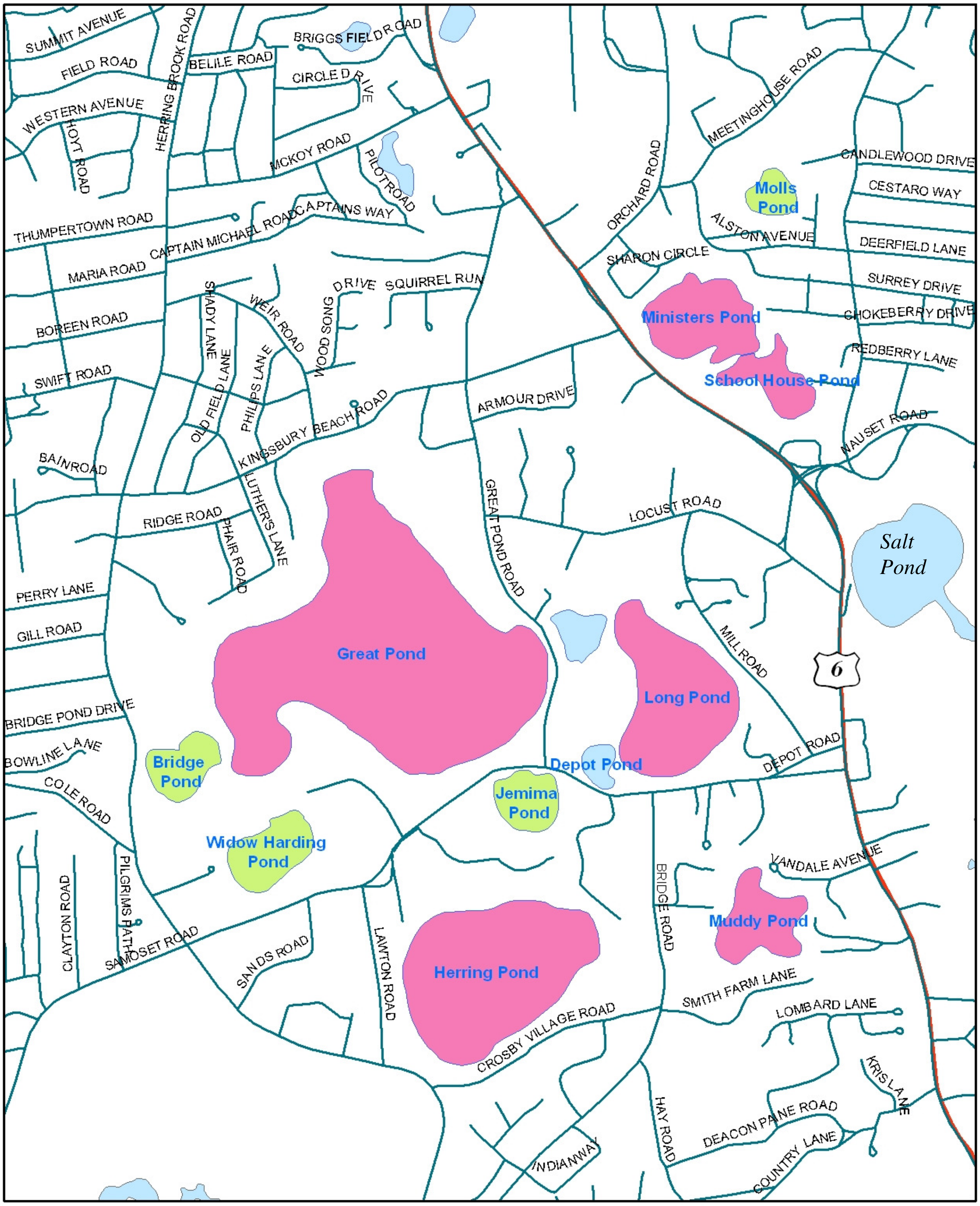

Figure I-1. Ponds regularly sampled by Eastham volunteers
Ponds colored pink have been regularly sampled by Eastham volunteers and their water quality and watershed information is reviewed in detail in this report. Ponds colored green are regularly sampled and their data is included in this report, but they are not subject to detailed review.

II. Pond Data Sources

During the initial 2001 PALS Snapshot, Eastham volunteers collected data from 10 ponds. Field data was collected along with water quality samples that were analyzed by the Coastal Systems Program Laboratory, School of Marine Science and Technology (SMAST), University of Massachusetts Dartmouth. All subsequent PALS Snapshot samples were also analyzed at the SMAST lab. Pond samples collected throughout the summer have been analyzed at the North Atlantic Coastal Laboratory at Cape Cod National Seashore (CCNS).

PALS Snapshots were completed every year between 2001 and 2008 and all data except for 2007 and 2008 is included in the following analysis; 2007 data was not available during the analysis phase of this project and 2008 Snapshot is just getting underway at the time this report was written. The PALS Snapshot collection window is between August 15 and the end of September and is designed to capture the worst water quality conditions. The PALS Snapshots are supported by free laboratory analyses from the SMAST Coastal Systems Analytical Facility Laboratory and are coordinated in conjunction with the Cape Cod Commission. The PALS pond water sampling protocol calls for a shallow (0.5 m) sample and then generally a deep sample 1 m off the bottom for all ponds of 9 m total depth or less; ponds less than 1.5 m should have two samples from the surface collected. Ponds that are deeper than 5 m will have a third sample collected at 3 m (*i.e.*, 0.5 m, 3 m, and one meter off the bottom) and ponds greater than 10 m will have a fourth sample collected at 9 m (*i.e.*, 0.5 m, 3 m, 9 m, and one meter off the bottom). Samples are collected as whole water, stored at 4°C, and transferred to the SMAST lab within 24 hours. Field sampling procedures under the PALS Snapshot protocol include water column profile measurements of dissolved oxygen and temperature, and Secchi disk transparency.

Laboratory analysis and sample handling procedures used for the PALS Snapshot samples are described in the SMAST Coastal Systems Analytical Facility Laboratory Quality Assurance Plan (2003), which is approved by the Massachusetts Department of Environmental Protection. Laboratory analysis of PALS Snapshot samples include the following parameters: total nitrogen, total phosphorus, chlorophyll-*a*, pH, and alkalinity. Detection limits for laboratory analytes and field data collection are listed in Table II-1.

In addition to the PALS Snapshots, the Eastham volunteers also benefited from laboratory services provided by the North Atlantic Coastal Laboratory at Cape Cod National Seashore (CCNS). Analysis of samples taken to the CCNS lab includes the following parameters: total nitrogen, total phosphorus, chlorophyll-*a*, nitrate-nitrogen, ammonia-nitrogen, and ortho-phosphate. These laboratory services were funded through grants and allowed monthly and bimonthly sampling during the summers of 2002 and 2003 and more limited analyses during 2005 and 2006. No samples were analyzed by the CCNS lab in 2004. Sampling depths and field data collection procedures generally followed PALS protocols so data could be compared. Laboratory methods used at the CCNS lab are listed in Table II-2.

Table II-3 shows the ponds sampled and the frequency of sampling events for all the Eastham ponds between 2001 and 2006, including both SMAST and CCNS-supported lab analyses. The data collected during this time period was used for the initial overview of all the ponds that is discussed in Section III. Data collected prior to this period is included in the analyses of the ponds selected for more detail review as discussed in Section V.

Table II-1. Field and laboratory reporting units and detection limits for data collected for the Eastham Ponds under the PALS Snapshots

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	± 0.3 mg/l or ± 2% of reading, whichever is greater	0 – 20
Secchi Disk Water Clarity	Water	meters	NA	20 cm	Disappearance
Laboratory Measurements – School of Marine Science and Technology, University of Massachusetts Dartmouth					
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)

Table II-2. Laboratory methods and detection limits pond water samples analyzed by the Cape Cod National Seashore lab.

Parameter	Unit	Range	MDL	Method	Matrix	Ref
Dissolved Ammonium	µg/L	4 to 400	4	Lachat QC FIA+ 8000 Method #10-107-06-1-C (Diamond, D., & Switala, K., 9 October 2000 Revision)	waters (Salinity=0 to 35 ppt) (field filtered and acidified	A
Dissolved Orthophosphate	µg/L	0.62 to 310	0.62	Lachat QC FIA+ 8000 Method #31-115-01-1-G (Diamond, D., 30 December 1998 Revision)	waters (Salinity=0 to 35 ppt) (field filtered and acidified	B
Dissolved Nitrate/Nitrite	µg/L	1.68 to 700	1.68	Lachat QC FIA+ 8000 Method #31-107-04-1-C (Diamond, D., 27 June 2000 Revision)	waters (Salinity=0 to 35 ppt) (field filtered and acidified	C
total phosphorus-persulfate digestions	µg/L	1 to 200	1	Lachat QC FIA+ 8000 Method #10-115-01-1-F (Diamond, D., 14 October 1994 Revision)	waters (Salinity=0 to 35 ppt)	D
TP/TN-persulfate digestions (simultaneous						
Total phosphorus	µg/L	0.62 to 310	0.62	Lachat QC FIA+ 8000 Method #31-115-01-1-G	waters (Salinity=0 to 35 ppt)	E
Total nitrogen	µg/L	1.68 to 700	1.68	Lachat QC FIA+ 8000 Method #31-107-04-1-C		
Particulate Carbon/Nitrogen	µg/L			CarloErba CHNS Elemental Analyzer (Beach, R., MERL Manual, 1986)	waters	F
Chlorophyll-a & Pheopigments	µg/L			90% Acetone Extraction (Godfrey, P., et al. 1999)	waters	G

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G. Godfrey, P.J. and P. Kerr. 1999. A new method of preserving Chlorophyll on Glass Fiber Filters for use by Professional Lake Managers and Volunteer Monitors. Submitted to Lake and Reserv. Manage. UMASS-Amherst, Massachusetts Water Resources Research Center/

Note: Information provided by Krista Lee, CCNS (personal communication, 2002). MDL = method detection limit.

Table II-3. Ponds sampled for laboratory samples and number of sampling events for Eastham Ponds (2001-2006)

	2001	2002						2003						2004			2005							2006								01-06
POND	Sep	Jun	Jul	Aug	Sep	Oct	SUM	Jun	Jul	Aug	Sep	Oct	SUM	Aug	Sep	SUM	Apr	May	Aug	Sep	Oct	Nov	SUM	Apr	May	Jul	Aug	Sep	Oct	Nov	SUM	TOTAL
Bridge	1	1	1	1	2		5				2		2			0							0								0	8
Deborah	1						0						0			0							0								0	1
Long	1	1	1	1	2		5		2	3	1	1	7	1		1	1		1	1			3	1		1	1			1	4	21
Great	2	1	1	1	2		5		2	2	3	1	8		2	2			1	1		1	3	1		1	1			1	4	24
Herring	1	1	1	1	2	1	6	1	2	2	3	2	10	1	1	2	1		2	1	1		5	1		1	1			1	4	28
Jemima	1	1	1	1	2	1	6		2	2	3		7	1		1		1	1	1	1		4	1		1	1	1			4	23
Minister	1	1	1	1	2		5		2	1	3	2	8	1	1	2	1		1	1	1		4	1		1		1	1		4	24
Molls	1	1	1	1	2		5	1	1	2	3		7		1	1	1		1	1		1	4	1		1		2			4	22
Muddy	1	2	2	2	2	1	9	1	1	2	2	1	7	1		1		1	1	1	1		4		1	1	1	1			4	26
Schoolhouse		1	1	1			3		2	1	3	2	8	1	1	2	1		1	1	1		4	1		1		1	1		4	21
Widow Harding	1	1	1	1	2		5		2	2	2		6	1		1	1		1	1	1		4	1		1		2			4	21
# of ponds	10	10	10	10	9	3	54	3	9	9	10	6	70	7	5	13	6	2	9	9	6	2	35	8	1	9	5	6	2	3	36	219

Note: Number of ponds sampled each month is shown in the bottom row, while the number of yearly sampling runs for each pond is shown in the sum column. Only sampling runs that resulted in laboratory samples are shown; some ponds had more frequent collections of field data, such as dissolved oxygen and Secchi readings. Cape Cod PALS Snapshot data is included; in 2001 and 2004 only PALS data was collected. Two laboratories were utilized for the analyses: Coastal Systems Laboratory, School of Marine Science and Technology, University of Massachusetts Dartmouth and Cape Cod National Seashore, North Atlantic Coastal Laboratory.

III. Town-wide Water Quality Data

In order to complete the town-wide data review, SMAST and Commission staff organized the data by pond and sampling depth. Since all sampling is based to the PALS sampling protocol, sampling runs, regardless of lab used, generally are sampled at the same depth. Thus, a pond like Molls Pond that is approximately 4 m deep would have a shallow sampling station at 0.5 m and a deep sampling station that is one meter off the bottom. Deep stations depths vary due to slight changes in the sampling location and fluctuations in the pond's water level. The analysis also generally focuses on average concentrations between June through September. Data outside of this period helps in understanding how the ecosystems are set prior to the primary period of ecosystem activity or how they reset following this period, but June through September is the most ecological significant time period, as well as the period when most residents spend recreational time in or on Cape Cod ponds.

III.1. Field Collected Water Quality Data

III.1.1 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 species 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 potentially leading to more algal growth.

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 circulate water within a pond and move deeper waters up to the surface. In these ponds, both temperature and dissolved oxygen readings tend to be relatively constant from surface to bottom; this would be the expected condition in most of the Eastham ponds reviewed in this report.

In deeper Cape Cod ponds, mixing of the water column 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, upper waters continuing to be mixed and warmed throughout the summer and the isolation of cooler, deeper waters. The upper layer is called the epilimnion, while the lower layer is called the hypolimnion; the transitional zone between them is called the metalimnion. Among the Eastham Ponds, Great, Herring, and Long are deep enough to have these layers.

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 sediment bacterial populations. These populations respire (consume oxygen and produce carbon dioxide) as they consume organic matter (*e.g.*, algae/phytoplankton, fish) that has sunk to the bottom. If there is extensive organic matter falling to the sediments, as one would expect with lakes with higher amounts of nutrients, the bacterial respiration can consume all of the oxygen before the lake mixes throughout the water column again in the fall. All three of the deepest Eastham ponds have low oxygen or anoxic conditions in their deepest layer.

State surface water regulations (314 CMR 4) have numeric standards for both dissolved oxygen and temperature. Under these regulations, ponds that are not drinking water supplies are required to have a dissolved oxygen concentration of not less than 6.0 mg/l in cold water fisheries (*e.g.*, Great) and not less than 5.0 mg/l in warm water fisheries (*e.g.*, Molls). These regulations require that temperature not exceed 68^0F (20^0C) in cold-water fisheries or 83^0F (28.3^0C) in warm water fisheries. There are additional provisions in the regulations that allow lower oxygen concentrations or higher temperatures if those are natural background conditions.

The occurrence of concentrations less than the Massachusetts regulatory thresholds can have profound impacts on fish and other animals in a pond ecosystem if they occur even once. Studies of fish populations have shown decreased diversity, totals, fecundity, and survival at low dissolved oxygen concentrations (*e.g.*, Killgore and Hoover, 2001; Fontenot and others, 2001, Thurston and others, 1981; Elliot, 2000). Concentrations of less than 1 ppm are generally lethal, even on a temporary basis, for most species (Wetzel, 1983; Matthews and Berg, 1997).

Dissolved oxygen and temperature concentrations are the most extensive dataset collected by volunteers for the Eastham ponds. Readings were generally collected following the PALS protocol with an initial reading at a depth of 0.5 meter and then 1 m increments below that (*e.g.*, 0.5 m, 1 m, 2 m, etc.). For the initial town-wide overview, staff reviewed dissolved oxygen concentrations at the water sample collection depths specified by the PALS protocol. More refined review of the dissolved oxygen and temperature concentrations are detailed for the ponds selected for more in-depth review (see Section V).

Among the 10 ponds in Eastham with volunteer data selected for the town-wide overview, there are 74 station depths where dissolved oxygen concentrations were measured between 2001 and 2006. These station depths have between 3 (Bridge) and 36 (Herring) dissolved oxygen readings. Based on an initial review, Great, Herring, and Long would be classified as cold water fisheries, while the rest of the ponds would be considered warm water fisheries.

Five of the seven warm water ponds have at least one station depth, usually the deepest ones, which has an average dissolved oxygen concentration less than the state standard. Jemima and Muddy are the two warm water ponds that have average dissolved oxygen concentrations greater than the 5 ppm state standard at all depths. Of the 35 station depths in the seven warm water fishery ponds, 10 had average concentrations between June and September less than the state 5 ppm standard for warm water fisheries (Figure III-1a).

All three of the deeper, cold water fishery ponds have station depths that have average dissolved oxygen concentrations less than the state 6 ppm standard (Figure III-1b). Of the 39 station depths in the cold water fishery ponds, 19 (or 49%) had average dissolved oxygen concentrations less than 6 ppm.

Project staff also identified stations where dissolved oxygen concentrations of 1 ppm or less had been measured. Of the 29 depth stations in Eastham ponds that have averages less than the state standards, all but the deepest station in Bridge, also have dissolved oxygen minima of less than 1 ppm; no other stations have minima less than 1 ppm (see Figures III-1a and III-1b).

III.1.2 Secchi Depth

A Secchi disc is an eight-inch disk with black and white quadrants that is used to evaluate water transparency. Since transparency fluctuations 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 or nutrient levels 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. Secchi readings comparing the Secchi depth to total depth of the sampling location, also known as relative Secchi readings, have also been used to assess the condition of a pond ecosystem. Although there is no state regulatory standard for Secchi depth, there is a state safe swimming clarity limit of 4 feet (105 CMR 435).

Secchi readings were generally collected by Eastham volunteers each time dissolved oxygen and temperature readings were collected; the number of readings between 2001 and 2006 ranged between 3 (Bridge) and 38 (Herring). As shown in Figure III-2, all the ponds except for Muddy have average Secchi readings deeper than the state safe swimming clarity limit of 4 feet. Since Muddy has an average depth of 5.2 ft, a relatively small decrease in clarity will take it below the 4 ft limit. Minister, Schoolhouse and Herring have had at least one reading (*i.e.*, minimum reading) less than 4 feet. Average relative readings varied between 28% (Great) and 81% (Jemima).

III.2 Laboratory Water Quality Data

As mentioned above, water samples were collected in the ponds at depths generally specified by the PALS Snapshot protocol. The PALS Snapshot protocol specifies a 0.5 m sampling depth in all ponds and a deep sampling depth (1 m off the bottom) for any pond greater than 2 m deep. Additional sampling depths of 3 m and 9 m are added as the depth of the pond increases. This protocol anticipates that there should be some variability in the sampling depth, especially the deepest station, because of fluctuations in the water table/surface of the pond. Water samples were generally analyzed at the School of Marine Science and Technology (SMAST) Coastal Systems Analytical Facility Laboratory, University of Massachusetts Dartmouth or at the North Atlantic Coastal Laboratory at Cape Cod National Seashore. Data reviewed below is based on 2001 through 2006 data; data from pre-2001 samples, which are discussed for the ponds selected for detailed review, used a variety of sampling protocols and

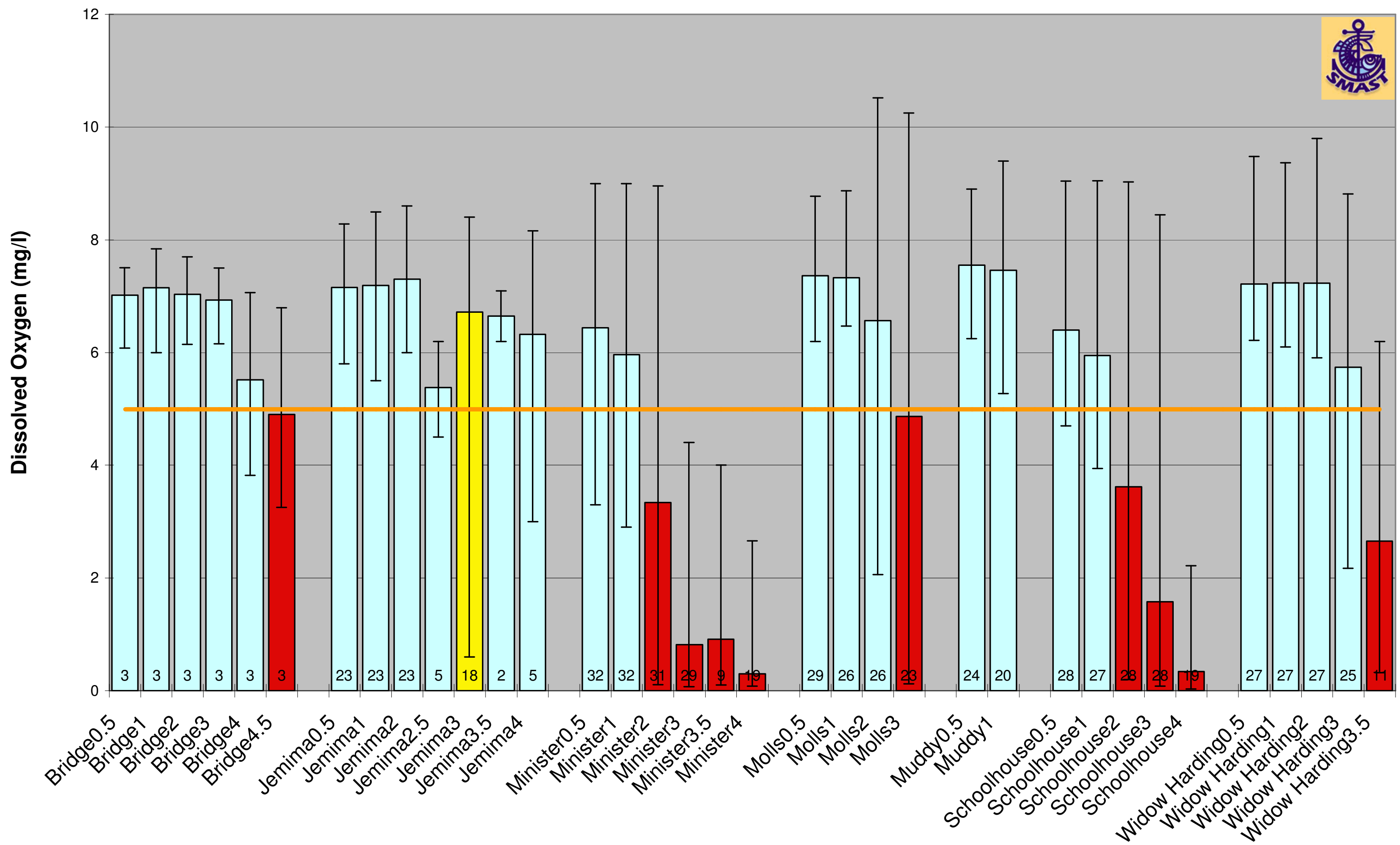


Figure III-1a. Average Dissolved Oxygen Concentrations in shallow Eastham Ponds 2001-2006

Source data is field measurements collected by Eastham volunteers. Pond names have the depths in meters at which readings were collected (*e.g.*, “Molls0.5” is Molls Pond readings collected at 0.5 m). Error bars show maximum and minimum recorded concentrations; all values are corrected for outliers (>±two standard deviations). The orange line is the MassDEP regulatory threshold (5 milligrams per liter of dissolved oxygen) for warm water fisheries (314 CMR 4). Bars indicating average concentrations less than the state threshold are colored red, while stations with an average above the threshold, but with a minimum of less than 1 ppm are colored yellow. Numbers shown at the base of each bar indicate the number of readings used to calculate the average concentration.

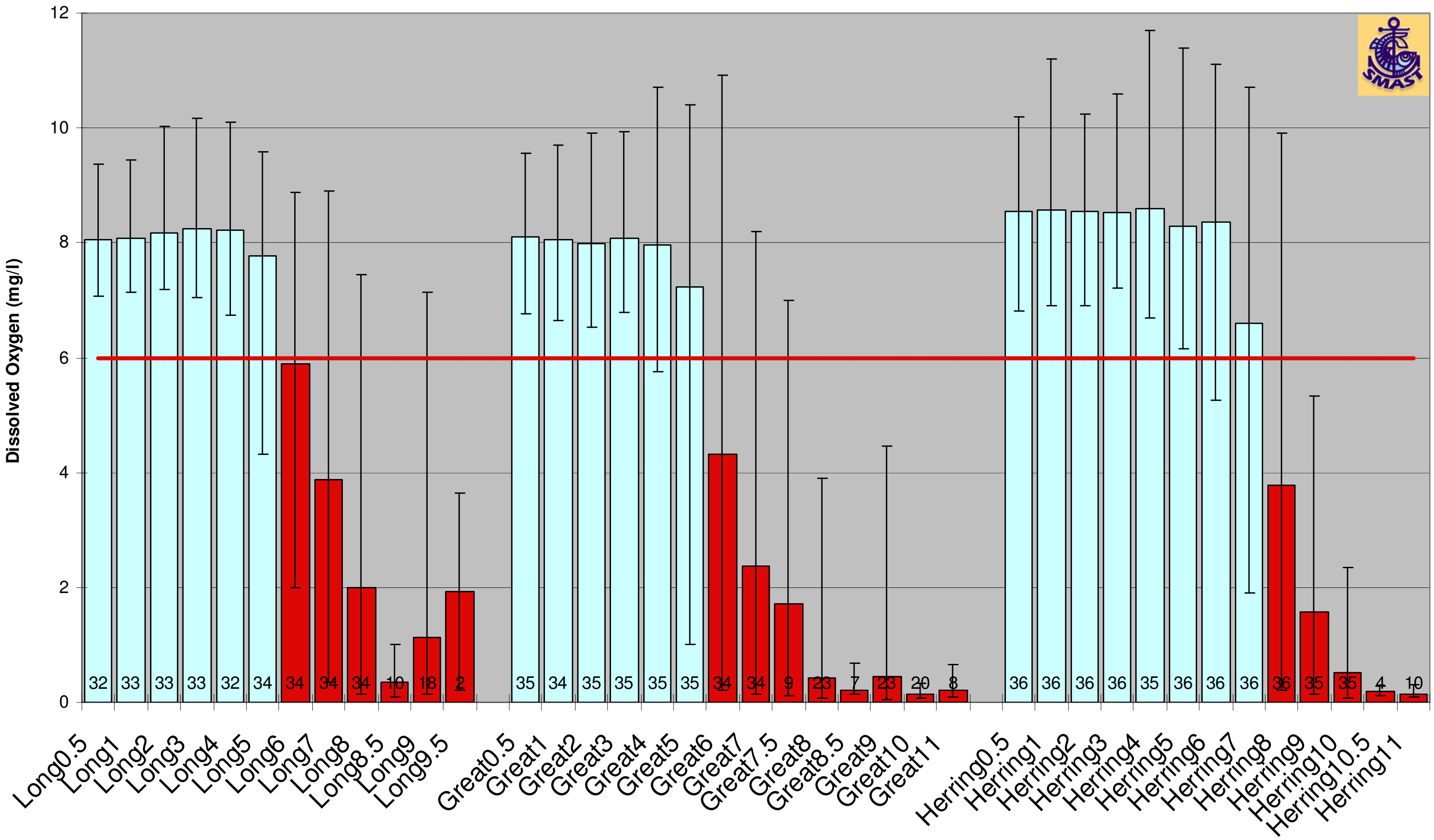


Figure III-1b. Average Dissolved Oxygen Concentrations in deep Eastham Ponds 2001-2006
Source data is field measurements collected by Eastham volunteers. Pond names have the depths in meters at which readings were collected (*e.g.*, "Long0.5" is Long Pond readings collected at 0.5 m). Error bars show maximum and minimum recorded concentrations; all values are corrected for outliers (>±two standard deviations). The red line is the MassDEP regulatory threshold (6 milligrams per liter of dissolved oxygen) for cold water fisheries (314 CMR 4). Bars indicating average concentrations less than the state threshold are colored red. Numbers shown at the base of each bar indicate the number of readings used to calculate the average concentration.

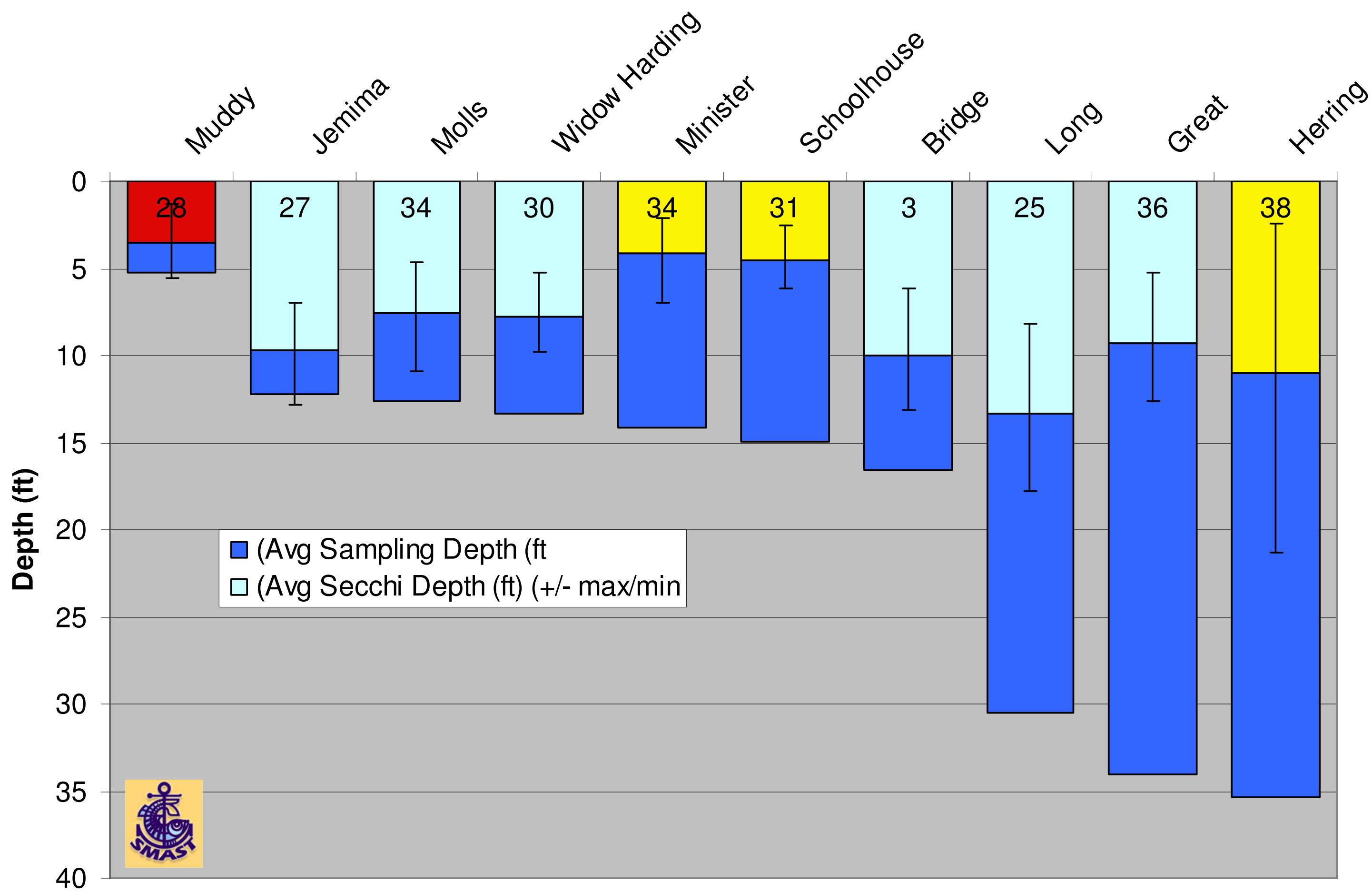


Figure III-2. Average Secchi Transparency Readings in Eastham Ponds 2001-2006
Source data is field measurements collected by Eastham volunteers. Error bars show maximum and minimum recorded depths; all values are corrected for outliers (>±two standard deviations). Numbers shown near the base of each bar indicate the number of readings used to calculate the averages for each pond. Ponds with red bars have average Secchi depths that are less than the state safe swimming clarity limit of four feet (105 CMR 435), while ponds with yellow bars have minimum recorded readings that are less than the four foot limit.

labs. Review of water quality laboratory results focused on the following constituents: pH, total nitrogen (TN), total phosphorus (TP), alkalinity, and chlorophyll *a*.

III.2.1 Total Phosphorus (TP)

Phosphorus is the key nutrient in ponds and lakes because it is usually more limited in freshwater systems than nitrogen, which is also crucial for growth. 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 or phytoplankton. 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 in the orthophosphate (PO_4^{-3}) form] 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) provide a measure of all phosphorus in a water sample, including ortho-phosphorus and all phosphorus incorporated into organic matter, including algae.

Most Cape Cod lakes have relatively low phosphorus concentrations due to the lack of phosphorus in the surrounding glacially-derived sands; most of the phosphorus in Cape Cod ponds is due to additions from the watershed and regeneration of past watershed additions from the pond sediments. 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 and others, 2003). Using the US Environmental Protection Agency (2000) method for determining a nutrient threshold criteria and the 2001 PALS Snapshot data, the Cape Cod Commission determined that "healthy" pond ecosystems on Cape Cod should have a surface TP concentration no higher than 10 ppb, while "unimpacted" ponds should have a surface TP concentration no higher than 7.5 ppb (Eichner and others, 2003).

Average TP concentrations at the 25 Eastham pond water quality sampling depths range between 8.0 ppb (3 m station in Long) and 56.4 ppb (deep station in Herring) (Figure III-3). Average surface concentrations in 9 of the 10 ponds exceed the 10 ppb TP regional limit; the only pond with average surface concentration less than 10 ppb TP is Bridge. No stations have an average concentration less than 7.5 ppb. Among the deepest ponds, Long concentrations at all depths are either slightly above or slightly below the 10 ppb threshold, while Great and Herring have generally have increasing averages with increasing depth. Overall, among all 10 ponds, 23 of the 25 sampling stations have average TP concentrations exceeding 10 ppb.

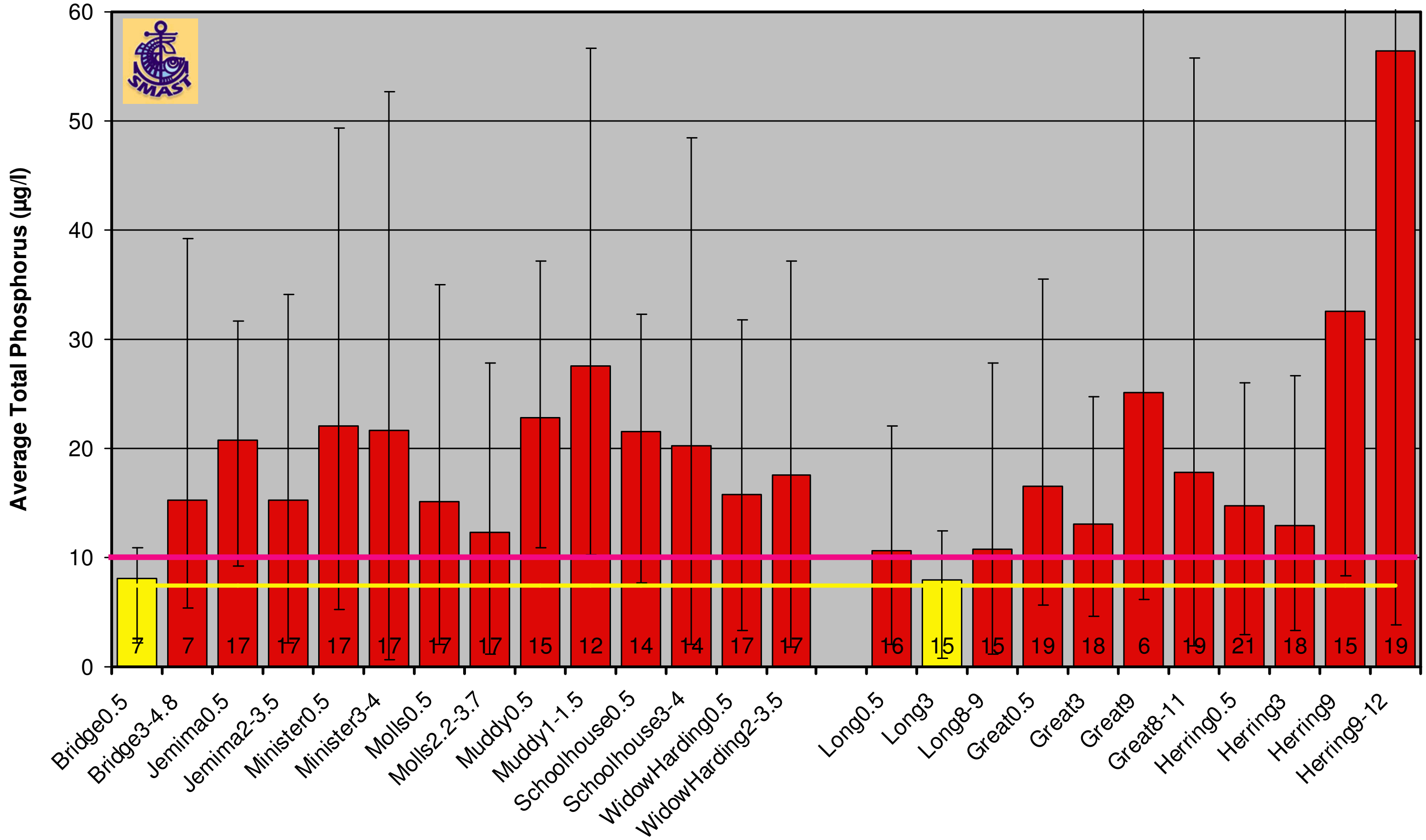


Figure III-3. Average Total Phosphorus Concentrations in Eastham Ponds 2001-2006

Average total phosphorus concentrations based on available pond data between June and September. Pond names have the depths in meters at which readings were collected (*e.g.*, "Bridge0.5" is Bridge Pond readings collected at 0.5 m). Error bars show maximum and minimum recorded concentrations; all values are corrected for outliers (>±two standard deviations). The pink line is the Cape Cod threshold for healthy pond ecosystems (10 micrograms per liter of TP from Eichner and others, 2003); bars for ponds with an average TP concentration greater than 10 µg/l are colored red. Bars colored yellow identify depth stations with average concentrations greater than the Cape Cod 7.5 µg/l "impacted" threshold, which is also indicated with a yellow line, but less than the 10 µg/l TP threshold. Numbers shown at the base of each bar indicate the number of readings used to calculate the average concentration for each pond. Great Pond 9 m station maximum is 61 µg/l, while Herring deepest station maximum is 176 µg/l; scale is reduced to better show results from other ponds.

III.2.2 Total Nitrogen (TN)

Nitrogen is one of the primary nutrients that prompt plant growth 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 Cape Cod ponds from the surrounding aquifer in the nitrate-nitrogen form, is incorporated into the tissues of phytoplankton forming organic nitrogen, and then is converted back to inorganic forms (nitrate- and ammonium-nitrogen) in the waste from 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, blue-green 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 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 nitrogen 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 and others, 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 concentration limit of 0.16 ppm, while the "healthy" threshold concentration is 0.31 ppm (Eichner and others, 2003).

Average TN concentrations at the 25 Eastham pond depth stations range between 0.27 ppm (the deep station in Molls) and 1.3 ppm (the deep station in Herring) (Figure III-4). The number of surface TN samples among the ponds range from 7 (Bridge) to 20 (Herring); surface stations have an average of 16 readings available in the June to September analysis period. Average surface concentrations in 8 of the 10 ponds exceed the 0.31 ppm threshold; Molls average is at the threshold, while only Long has an average TN concentration less than the "healthy" limit. The two next deepest stations in Molls and Long also have average TN concentrations less than 0.31 ppm. None of the station depths have an average concentration less than the 0.16-ppm TN "unimpacted" threshold. Overall, average concentrations at 21 of the 25 station depths exceed the "healthy" 0.31-ppm TN limit.

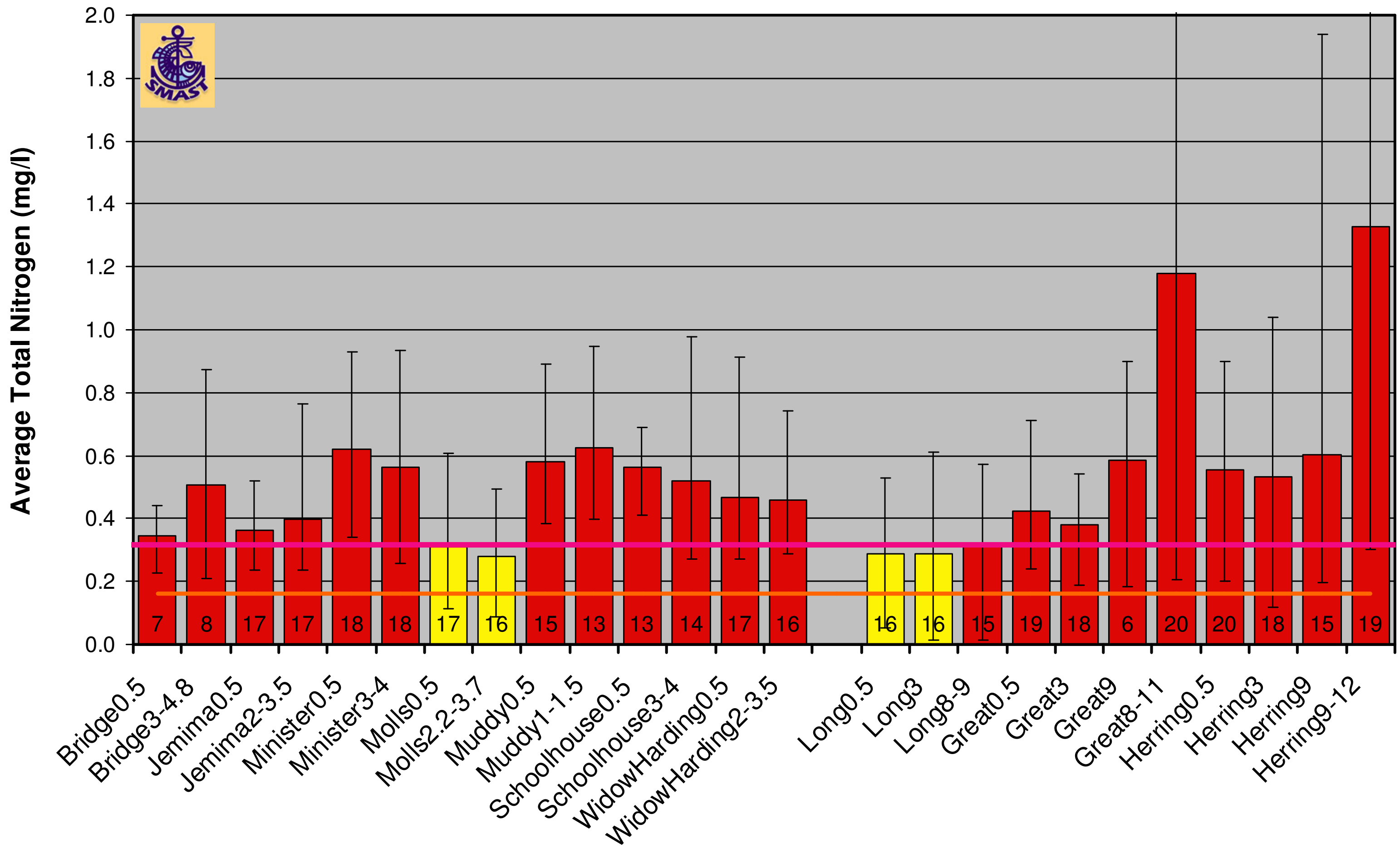


Figure III-4. Average Total Nitrogen Concentrations in Eastham Ponds 2001-2006

Average total nitrogen concentrations based on available pond data between June and September. Pond names have the depths in meters at which readings were collected (*e.g.*, "Bridge0.5" is Bridge Pond readings collected at 0.5 m). Error bars show maximum and minimum recorded concentrations; all values are corrected for outliers (>±two standard deviations). The pink line is the Cape Cod threshold for healthy pond ecosystems (0.31 milligrams per liter of TN from Eichner and others, 2003); bars for ponds with an average TN concentration greater than 0.31 mg/l are colored red. Bars colored yellow identify depth stations with average concentrations greater than the Cape Cod 0.16 mg/l "impacted" threshold, which is also indicated with a yellow line, but less than the 0.31 mg/l TN threshold. Numbers shown at the base of each bar indicate the number of readings used to calculate the average concentration for each pond. Great Pond deep station maximum is 2.45 mg/l, while Herring deepest station maximum is 3.68 mg/l; scale is reduced to better show results from other ponds.

III.2.3 Alkalinity and pH

pH is a measure of acidity; pH values less than 7 are acidic, while pH values greater than 7 are basic. pH is the negative log of the hydrogen ion concentration in water (*e.g.*, water with an H^+ concentration = $10^{-6.5}$ has a pH of 6.5). The general 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 (Stumm and Morgan, 1981). Because pH and alkalinity are influenced by shared constituents, they are linked values.

Since the sand deposited as Cape Cod during the last glacial period does not have carbonate minerals, Cape soils generally have low alkalinity and little capacity to buffer the naturally acidic rainwater that falls on the Cape. Groundwater data collected throughout the Cape generally shows pH 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. As might be expected because of their interconnection with the surrounding aquifer, Cape Cod ponds tend to have pH readings close to the groundwater average, while the least impacted ponds have pH close to average rain pH of 5.65. 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 and others, 2003). The lower 25th percentile among pH readings from the 2001 Snapshot, or the least impacted ponds, is 5.62.

Average pH readings at the 25 Eastham pond depth stations range between 5.5 (deep station in Molls) and 9.0 (two shallowest stations in Herring) (Figure III-5). Since pH readings tended to only be measured in samples taken to the SMAST lab during the PALS Snapshots, the number of readings tend to be smaller than readings reported for other water quality constituents; the number of surface pH readings among the ponds range from 1 (Muddy, deepest station) to 8 (Great, deepest station). Average surface pH readings in 8 of the 10 ponds exceed 5.62; average surface pH readings below 5.62 are in Jemima and Molls. Overall 21 of the 25 stations have pH averages exceeding 5.62.

The high average pH readings at Herring's two shallow stations are notable. Readings at the 0.5 m and 3 m depths have been consistently high during each PALS Snapshot, except for the 2007 Snapshot when the readings fell to somewhat less elevated 7.4. Review of historic information from the BEC (1991) shows average pH of 6.6 during the comparable time of year. These consistently and anomalous elevated readings suggest that something is being regularly added to the pond and that this addition began sometime after 1989.

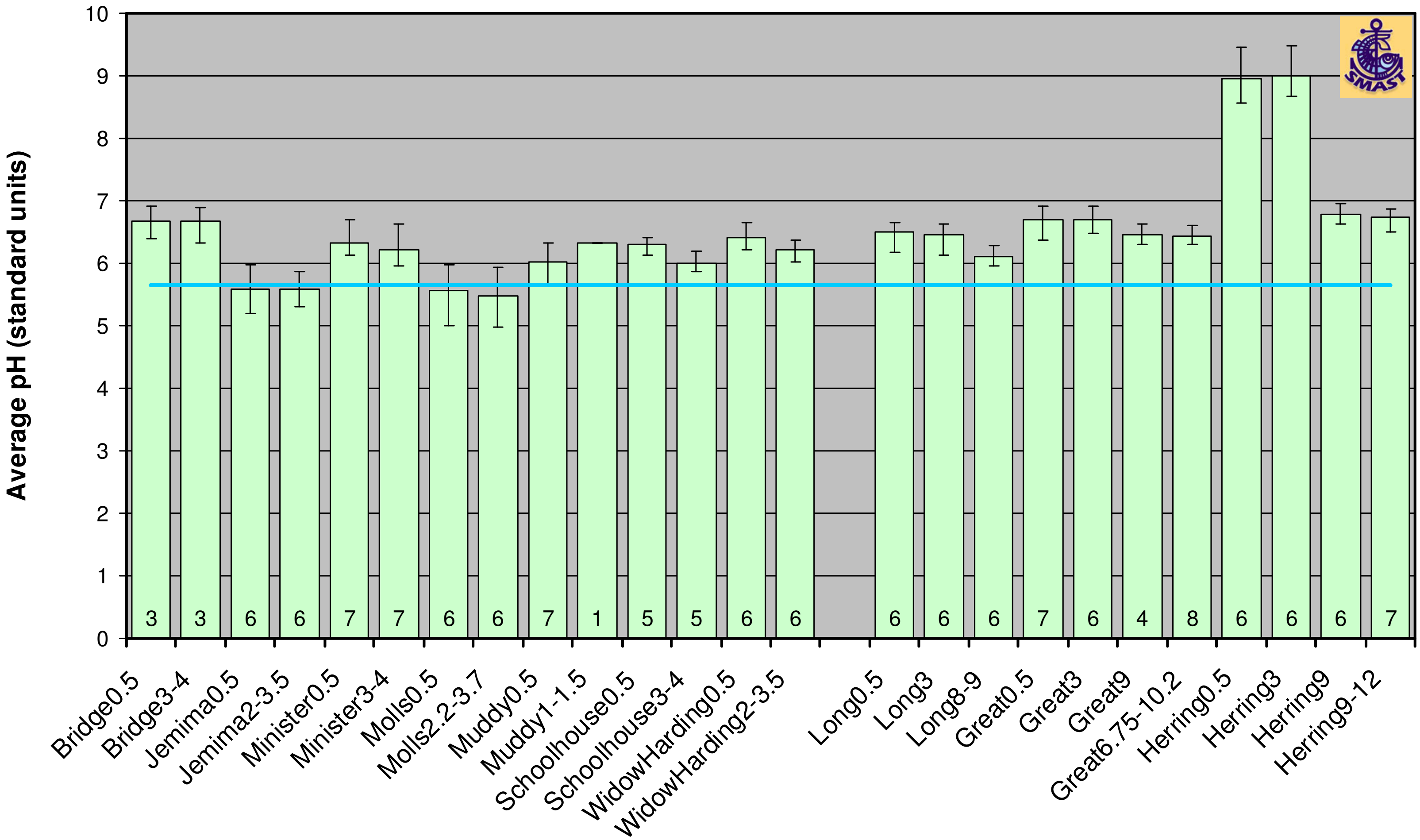


Figure III-5. Average pH in Eastham Ponds 2001-2006

Average pH readings based on available pond data between June and September. Pond names have the depths in meters at which readings were collected (e.g., "Bridge0.5" is Bridge Pond readings collected at 0.5 m). Error bars show maximum and minimum recorded readings; all values are corrected for outliers (>±two standard deviations). The blue line is 5.65, which is the pH of natural rainwater in equilibrium with carbon dioxide in the atmosphere. Numbers shown at the base of each bar indicate the number of readings used to calculate the average pH for each pond. Elevated average readings in the shallow station of Herring are consistent among the 2001 through 2006 PALS Snapshots; readings more consistent with other ponds were measured in 1988 and 1989 (BEC, 1991).

III.2.4 Chlorophyll *a* (CHL-a)

Chlorophyll is a family of primary photosynthetic pigments in plants, both phytoplankton or 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 planktonic algae, or floating microscopic plants, are 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).

Because phosphorus, the limiting nutrient in most Cape Cod ponds, is needed for the growth of both algae and macrophytes, the available phosphorus pool can be divided unequally between these two groups of plants. Because of this relationship, the relationship between chlorophyll *a* and phosphorus measurements can sometimes be slightly askew, especially in ponds where the dominant plant community is macrophytes. Anecdotal evidence from Cape Cod ponds with undeveloped land around them suggests that “natural” Cape ponds are algal dominated and, therefore, should have a strong relationship between chlorophyll a and total phosphorus concentrations. Ponds, such as Long in Centerville, where extensive rooted macrophyte growth exists (IEP and KVA, 1989), appear to be the product of excessive nutrient loads and largely unrepresentative of the ecology in most Cape Cod ponds.

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. Review of the PALS 2001 sampling results established that unimpacted Cape Cod ponds have a CHL-a threshold concentration of 1.0 µg/l, while the “healthy” threshold concentration is 1.7 µg/l (Eichner and others, 2003).

Average CHL-a concentrations at the 25 Eastham pond depth stations range between 2.5 ppb (0.5 m station in Long) and 72 ppb (deep station in Schoolhouse) (Figure III-6). The number of surface CHL-a samples among the ponds range from 4 (Bridge) to 11 (Muddy); surface stations have an average of 8 readings available for the June to September analysis period between 2001 and 2006. Average surface concentrations in all 10 monitored ponds exceed the “healthy” threshold concentration of 1.7 µg/l. Overall all 25 depth stations have average CHL-a concentrations greater than the Cape Cod-specific 1.7 µg/l “healthy” threshold concentration.

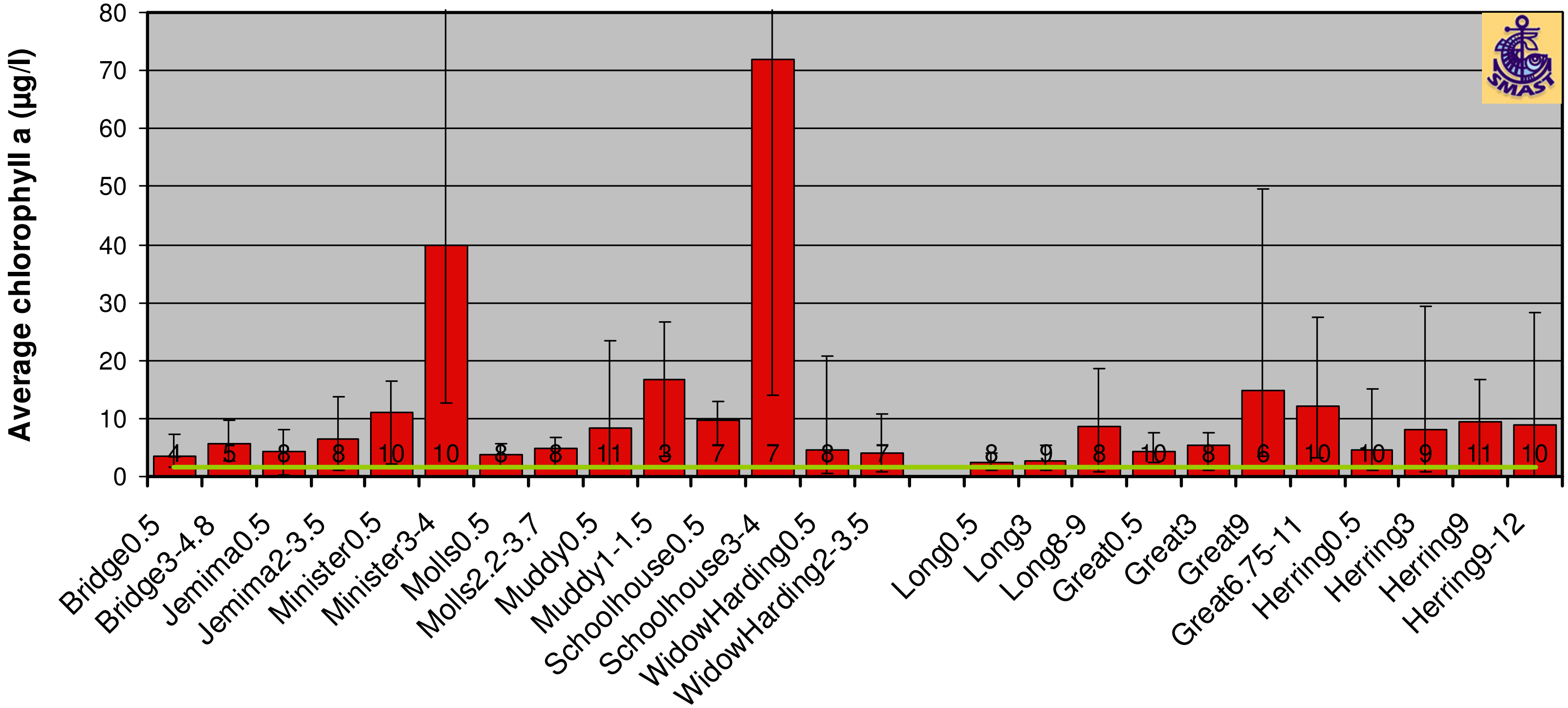


Figure III-6. Average Chlorophyll-a Concentrations in Eastham Ponds 2001-2006

Average chlorophyll *a* concentrations based on available pond data between June and September. Pond names have the depths in meters at which readings were collected (*e.g.*, "Bridge0.5" is Bridge Pond average of readings collected at 0.5 m). Error bars show maximum and minimum recorded concentrations; all values are corrected for outliers (>±two standard deviations). The green line is the Cape Cod threshold for healthy pond ecosystems (1.7 micrograms per liter of chlorophyll *a* from Eichner and others, 2003); bars for ponds with an average CHL-a concentration greater than this threshold are colored red. Numbers shown near the base of each bar indicate the number of readings used to calculate the average concentration for each pond. The maximum concentrations for the deepest stations in Minister and Schoolhouse are 80.9 and 206 µg/l, respectively. Scale on the y-axis is adjusted to better show detail.

IV. Water Quality Town-wide Overview

IV.1 Trophic Status

The trophic status of a surface water body is generally based on the amount of biomass (or more generally "life") that is contained in the lake or pond. Developing a trophic index usually incorporates an understanding of the regional geologic or climate setting, including what constitutes a "healthy" pond, and some proxy measure or measures of the biomass. One of the better known pond trophic classification strategies is the one developed by Carlson (1977) that is largely based on data from Wisconsin and Minnesota lakes, but has been applied world-wide. Carlson's strategy looks at algal biomass and relates it to separate measures of total phosphorus, chlorophyll *a*, and Secchi disk depth. 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). The equations for producing the various TSI values and the likely ecosystem characteristics are presented in Table IV-1.

Table IV-1. – Carlson Trophic State Index (TSI)

TSI Calculations	
TSI(SD) = 60 - 14.41 ln(SD)	SD = Secchi disk depth (meters)
TSI(CHL) = 9.81 ln(CHL) + 30.6	CHL = Chlorophyll a concentration (µg/L)
TSI(TP) = 14.42 ln(TP) + 4.15	TP = Total phosphorus concentration (µg/L)

TSI values and likely pond attributes

TSI Values	Chl a (µg/L)	SD (m)	TP (µg/L)	Attributes	Fisheries & Recreation
<30	<0.95	>8	<6	Oligotrophy: Clear water, oxygen throughout the year in the hypolimnion	Salmonid fisheries dominate
30-40	0.95-2.6	8-4	6-12	Hypolimnia of shallower lakes may become anoxic	Salmonid fisheries in deep lakes only
40-50	2.6-7.3	4-2	12-24	Mesotrophy: Water moderately clear; increasing probability of hypolimnetic anoxia during summer	Hypolimnetic anoxia results in loss of salmonids.
50-60	7.3-20	2-1	24-48	Eutrophy: Anoxic hypolimnia, macrophyte problems possible	Warm-water fisheries only. Bass may dominate.
60-70	20-56	0.5-1	48-96	Blue-green algae dominate, algal scums and macrophyte problems	Nuisance macrophytes, algal scums, and low transparency may discourage swimming and boating.
70-80	56-155	0.25-0.5	96-192	Hypereutrophy: (light limited productivity). Dense algae and macrophytes	
>80	>155	<0.25	192-384	Algal scums, few macrophytes	Rough fish dominate; summer fish kills possible

after Carlson and Simpson (1996);
Carlson TSI developed in algal dominated, northern temperate lakes

Subsequent evaluation of Carlson's Index has found that one measure or another is better for use at various times of year (*e.g.*, total phosphorus may be better than chlorophyll at predicting summer trophic state), but the best overall predictor of algal biomass is chlorophyll *a* concentrations (Carlson, 1983). Subsequent uses of the Carlson Index by other investigators have included combining and averaging the various TSI values. Carlson (1983) regards this as a misuse of the indices and states "There is no logic in combining a good predictor with two that are not."

Trophic indices are appropriate for first order comparison among ponds, especially when data is limited; further detailed pond by pond analysis of individualized measures (*e.g*., total phosphorus, dissolved oxygen, macrophyte cover, etc.) should be evaluated to assess the "health" of a particular lake. It should also be further noted that higher Carlson values do not necessarily mean that the water quality in a pond is "poor"; although water quality and biomass levels are linked, higher biomass levels are valuable for warm water fisheries (*e.g*., bass) and may be appropriate for shallow, more naturally productive pond ecosystems.

Figure IV-1 shows the trophic categories based on the average surface chlorophyll *a* concentrations in the Eastham ponds, as well as error bars showing maximum and minimum readings. The length of the error bars show the variability in the data and how much conditions fluctuate within individual ponds. For example, Minister Pond on average is classified under this index as a eutrophic pond, but chlorophyll concentrations fluctuate enough to place it on occasion in the oligotrophic or mesotrophic categories.

Data from the 2001 PALS Snapshot indicated that a "healthy" freshwater pond on Cape Cod would have a threshold concentration of 1.7 µg/l for chlorophyll *a*, which translates to a TSI of 35.8, while the cleanest, and presumably pristine, Cape Cod ponds have a TSI of 30.6 (Eichner and others, 2003). Either of these TSIs is classified as oligotrophic on the Carlson index (see Table 4 for generalized conditions). Based on the average TSIs from sampling between 2001 and 2006, none of the Eastham ponds are oligotrophic. All of the ponds are classified as either mesotrophic or eutrophic.

IV.2. Comparison of Key Data: Selection of Ponds for Detailed Review

In June 2006, CCC staff presented a preliminary overview of town-wide data at a regular meeting of the Eastham Water Resources Advisory Board. This presentation included a review of data available at that time, much of which is discussed in the previous section, as well as a comparison among the ponds in order to provide some guidance for the selection of the six ponds that would be subject to more detailed analysis.

The comparison among the ponds included a review of each of the parameters above and a weighting scheme based on whether the average concentrations exceed the parameter-specific Cape Cod thresholds in the Pond and Lake Atlas (Eichner and others, 2003). The primary criterion for each of these measures (*e.g.*, average TP concentration greater than 10 ppb) was assigned a value of two in the weighting scheme, while the secondary criterion (*e.g.*, average TP concentration greater than 7.5 ppb) was assigned a value of one. The criteria were reviewed for each sampling station depth and resulting values were summed. Because deeper ponds have

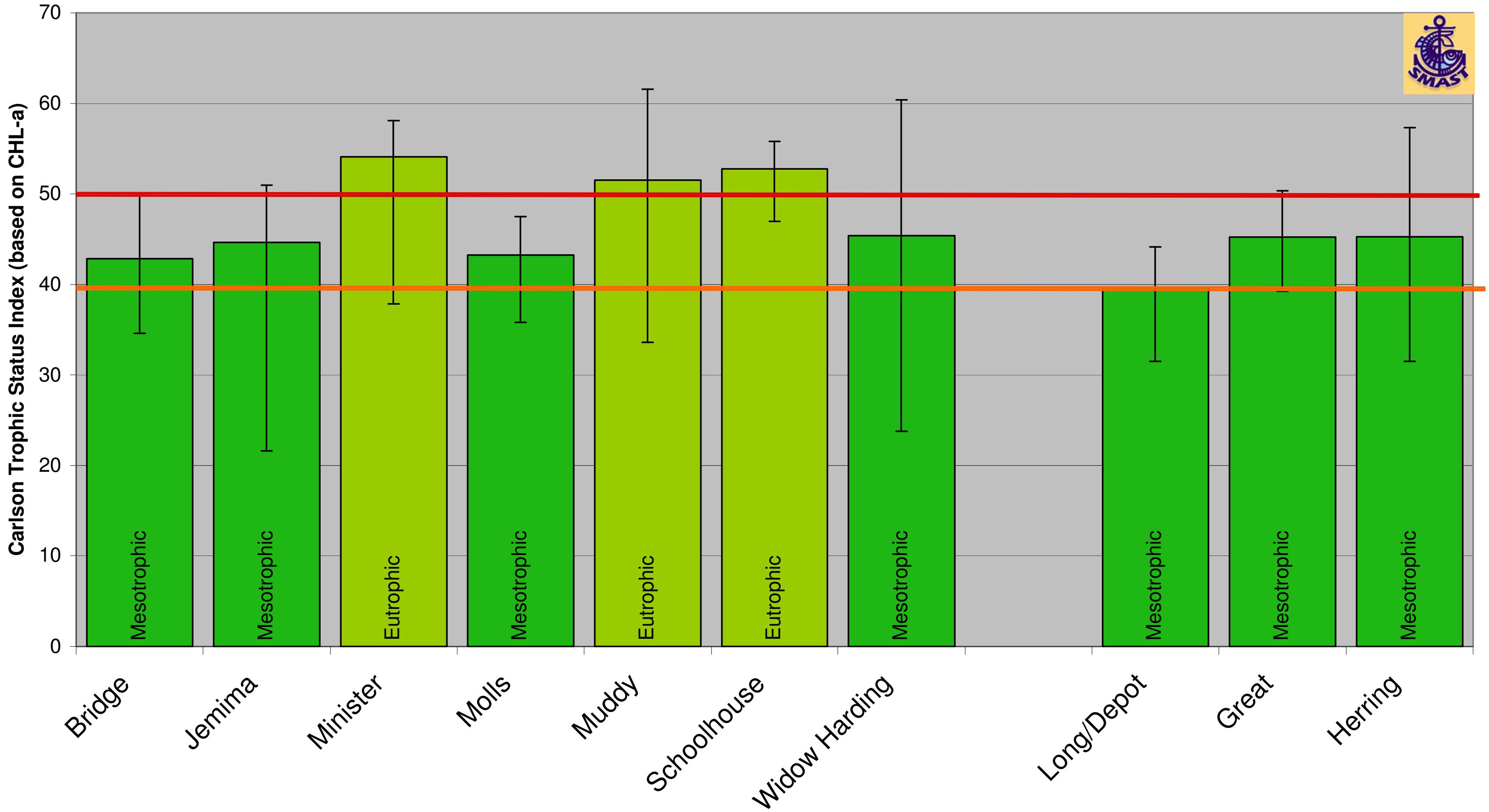


Figure IV-1. Trophic Status Index (TSI) in Eastham Ponds 2001-2006

TSI value is based on average chlorophyll *a* concentrations from data collected between June and September that are corrected for outliers (>±2 std dev); error bars show TSI based on maximum and minimum readings for each pond. Classification at base of each bar is based on TSI ranges in Carlson and Simpson (1996) for chlorophyll *a,* which are detailed in Table IV-1. Orange line is boundary between oligotrophic and mesotrophic classifications; red line is boundary between mesotrophic and eutrophic classifications.

more depth stations, this scheme assigns higher potential scores to deeper ponds than shallow ponds.

This analysis indicated that most of Herring's concentrations exceed the respective thresholds, but the results from the rest of the ponds were grouped in a relatively small range. The limited difference among most of the ponds is largely because so many of the average concentrations exceed the parameter thresholds. The results of this analysis reinforced the conclusion that all of the ponds are impacted. Total phosphorus, total nitrogen, and chlorophyll *a* concentrations show that all of the ponds are impacted. Secchi disk results show that visibility has been a concern for swimming in four of the ten ponds at one time or another. Close review of the dissolved oxygen results show that average conditions in the deep portion of almost every pond are lower than state limits and have regular occurrences of anoxic conditions.

Since most of the ponds are impaired in one way or another, the selection of six ponds for more detailed evaluation could not be based strictly on water quality criteria. Since the Water Resources Advisory Board and other Eastham residents could bring additional insights into selection of the ponds, CCC staff discussed the preliminary results at the June 2006 Board meeting. The Board, with additional public input from those attending the meeting, selected six ponds for more detailed evaluation: Long/Depot, Great, Herring, Minister, Muddy, and Schoolhouse (see Figure I-1).

V. Detailed Pond Evaluations

The detailed evaluations for the selected ponds include delineation of watersheds, incorporation of historic water quality data, development of phosphorus and water budgets, and more refined interpretation of the available water quality data. These evaluations are described in the following sections.

V.1. Location and Physical Characteristics of Long/Depot, Great, Herring, Minister, Muddy, and Schoolhouse ponds

The six ponds selected for more detailed review are located in glacial outwash plain deposits referred to as the Eastham Plain Deposits (Oldale and Barlow, 1986). The outwash plain is mostly sand and gravel. The glacial sediments were deposited during the last deglaciation of Wisconsinan Stage of the Pleistocene Epoch that occurred in New England approximately 15,000 years ago.

The ponds are groundwater-flooded kettle holes. As the glacial ice sheets melted and receded from southern New England, remnant "dead" ice blocks were buried beneath the sandy outwash deposits derived from glacial melt water (Strahler, 1966). When these buried ice blocks later melted, the overlying sediments collapsed and left large depressions in the landscape. Groundwater levels rose in response to a post-glacial rise in sea level, which is estimated to have attained its modern level approximately 6,000 years ago, (Ziegler and others, 1965), filled the depressions and created the ponds. Pollen records from ponds on outer Cape Cod show lake sediments were forming approximately 12,000 years ago (Winkler, 1985), so water existed in these depressions at that time.

The Eastham ponds are located in the Nauset Lens, the third largest of six independent groundwater flow cells that comprise the Cape Cod aquifer. The Cape's groundwater system was designated as the Cape Cod Sole Source Aquifer, by the U.S. Environmental Protection Agency; this designation explicitly acknowledges that the aquifer system is Cape Cod's only source of potable water and somewhat implicitly indicates how all water on the Cape is linked together. The Nauset Lens freshwater aquifer system is bounded by the water table at its surface and is surrounded at its margins and underneath by marine waters; bedrock is located beneath the freshwater/saltwater interface (LeBlanc and others, 1986). The freshwater aquifer in the area of the five Eastham ponds is approximately 250 feet thick (Masterson, 2004).

Great Pond is the largest (109.7 acres) of the six ponds selected for detailed review (Table V-1). It is situated to the west of Route 6 and Long/Depot Pond and directly to the north of Jemima and Widow Harding ponds. Great is also the deepest of the six ponds at 13 m, while Herring is the next deepest at 12 m. Herring is the second largest of the ponds (44.2 acres), followed by Long/Depot at 27.9 acres, Ministers at 14.6 acres, Muddy at 10.5 acres, and Schoolhouse at 6.8 acres. Minister and Schoolhouse are separated basins within the same pond; although the extent of the connection appears to fluctuate based on groundwater elevations.

New bathymetric information was collected during 2005-2006 by volunteer Carolyn Kennedy and others, with guidance from Henry Lind, Eastham Natural Resource Officer, for all ponds except Great and Herring using integrated depth and GPS recording. The raw depth and GPS data were forwarded to the Cape Cod Commission and refined by staff using GIS techniques and Surfer graphing software to develop depth contours. These depth contours are the basis for the pond volumes shown in Table V-1 and the bathymetric maps included in Appendix A. Herring and Great volume calculations are based on bathymetric information available from their respective diagnostic/feasibility studies (BEC, 1991 and BEC, 1987).

Table V-1. Physical Characteristics of Long/Depot, Great, Herring, Minister, Muddy, and Schoolhouse ponds

Pond	PALS Pond unique ID	Area	Volume	Residence Time	Deepest Point
		Acres	Cubic meters	Years	Feet
Long/Depot	EA-96	27.9	600,450	3.0	33
Great	EA-95	109.7	1,632,139	1.0/2.2	43
Herring	EA-103	44.2	889,138	2.8	39
Minister	EA-92	14.6	126,181	0.3	13
Muddy	EA-102	10.5	44,623	0.4	5
Schoolhouse	EA-92	6.8	36,170	1.5	13

Notes: 1) Volume for all but Great and Herring developed by Cape Cod Commission staff based on data collected by Eastham volunteers using integrated depth and GPS, 2) volumes for Herring and Great based on bathymetric maps from BEC (1991) and BEC (1987), respectively, 3) PALS ID is a unique identification assigned to each pond by the Cape Cod Commission under the Pond and Lake Stewardship (PALS) program during the preparation of the Cape Cod Pond and Lake Atlas (Eichner and others, 2003), which is also the source of all area values, and 4) Minister and Schoolhouse are usually linked during normal groundwater conditions and do not have separate PALS IDs, 5) Two residence times are presented for Great: 1.0 years is the residence time using available stream outflow data from BEC (1987), while 2.2 years is the residence time if all outflow occurred via groundwater seepage along the downgradient shoreline.

V.2. Watershed Delineation and Water Budgets

A water budget accounts for the volume of water in a pond and the flows of water entering and leaving the pond. In kettle hole ponds, groundwater flows through the pond, typically entering the pond along one shoreline (*i.e.*, the upgradient side), while an equal amount of pond water reenters the aquifer system along the opposite shoreline (*i.e.*, the downgradient side). Muddy Pond functions in this way. In some cases, kettle ponds have small streams entering or leaving them; Great Pond has a stream that discharges from it into Bridge Pond on its downgradient side and streams that discharge into it from Deborah Pond and another along the northern side. Even with stream flows, a pond surface on Cape Cod is generally a reflection of the level of the water table of the surrounding aquifer (Eichner and others, 1998). Groundwater flows from higher hydraulic heads on the upgradient side to lower heads on the downgradient side, sort of like water flowing downhill. In Eastham, the highest groundwater elevations are at the top of the Nauset Lens near Helm Road and Sparrowhawk Lane, where the water table elevation is approximately 16 feet above mean sea level. Groundwater flows radially toward Great Pond where it is approximately 10 feet above mean sea level and Minister/Schoolhouse Pond, where it is approximately 12 feet above mean sea level (Masterson, 2004).

On Cape Cod, groundwater flow lines may be projected upgradient from ponds, perpendicular to water table contours (or lines of the same groundwater elevation), to delineate recharge areas to the ponds or estuaries (*e.g.*, Cambareri and Eichner, 1998). Assuming uniformly distributed recharge from precipitation across watersheds, watershed areas are directly proportional to the flux of water through those watersheds and, consequently, the amount of groundwater entering a given pond. Using these basic understandings of the aquifer system, hydrologists can organize site-specific information in a groundwater model of the system to help develop a more refined understanding of interactions between ponds, estuaries, public water supplies, and the groundwater system.

The United States Geological Survey (USGS) has recently released a revised version of a regional Cape Cod groundwater model that extends from Eastham to Provincetown and encompasses the Nauset Lens, where the Eastham ponds are located (Masterson, 2004). This model incorporates information characterizing groundwater levels, municipal drinking water supply pumping, stream flow measurements, and hydrogeologic information developed over a number of decades. The model relies on the USGS computer model SEAWAT (Guo and Langevin, 2002), which can simulate variable density, transient groundwater flow in three dimensions, and the USGS particle-tracking program MODPATH4 (Pollock, 1994). MODPATH4 uses output files from SEAWAT to track the simulated movement of water in the aquifer and was used to delineate the recharge areas to wells, streams, ponds, and estuaries. The model simulates steady state, or long-term average, hydrologic conditions using a number of factors including a long-term average recharge rate of 24 inches/year and a 15% consumptive loss from developed properties. The loss factor is applied geographically within the model and, in Eastham, is determined by using the distribution of buildings, since on-site wells are the primary drinking water source in Eastham.

This USGS regional groundwater model incorporates selected ponds, including approximations of their depths, and can reasonably model their “flow-through” interactions with the aquifer. With this in mind, the USGS model was used to delineate watersheds to the six ponds selected for more detailed review. Model outputs were then refined to better reflect shoreline configuration and measured streamflow information (Figure V-1).

As indicated in Figure V-1, there are a number of ponds clustered together where the six ponds selected for more detailed review are located. This clustering is relatively common on the Cape and adds additional complexities to understanding how groundwater flows through ponds and, in some cases, into others. Ponds closer to the edge of the aquifer (*e.g.*, Cape Cod Bay or Salt Pond) are the most likely to receive flow from an upgradient pond. A portion of the outflow from an upgradient pond (*e.g.*, Great) can discharge into the watershed of a downgradient pond (*e.g.*, Jemima), while another portion can flow into another pond watershed or directly toward the ocean or bay. In order to calculate the amount of recharge or annual flow out of each pond, project staff determined the length of the downgradient shoreline of each pond based on the model results. Discharge out of the pond was then split among all the downgradient watersheds receiving flow based on the percentage of the total shoreline length. This information was also compared to streamflow information for those ponds that have surface water inlets and outlets.

Since recharge drives movement of groundwater and surface water within the aquifer system, annual recharge within each watershed is equivalent to the water discharge (both streamflow and groundwater) out of each watershed. This recharge was then compared with the volume of each pond and a residence time for water within each of the ponds was determined. This data is then compared to observed nutrient concentrations as a check on its reliability.

The preceding analyses are based on output from the USGS groundwater flow model as it is currently configured. Parameters and assumptions imposed on the model result in a simulation that suggests that water from the top of the aquifer does not underflow Great or Minister/Schoolhouse. This means that groundwater from the bottom of the lens, approximately 200 feet below the water table, would eventually surface into the ponds. Of course, water that takes this path may take decades to arrive at the pond. Since the watersheds are determined by groundwater elevations, changes in the elevations, by addition of large-volume water supply well, for example, would have the potential to alter watershed delineations. These alterations could be evaluated using the model. Additional water table monitoring wells in the area or better streamflow information would also add additional site-specific data that could be used to refine the watershed delineations presented in this report.

This report's revision of the Great Pond watershed is an example of how new data can alter the understanding of these systems. The BEC (1987) watershed was completed using water table contours developed by the county's Cape Cod Planning and Economic Development Commission. These contours were based on a limited number of water table measurements, the hydrogeology known at the time, and a very limited knowledge of the freshwater/saltwater interface at the bottom of the lens. The delineation shown in Figure V-1 incorporates all of this previous information and adds additional data collected over the last 20 years, including monthly water table measurements and geologic data developed in support of the USGS modeling project. The USGS groundwater model is used to organize all of this data and allows a better definition of the top of the Nauset Lens under average conditions, as well as better understanding of subsurface groundwater flow (Masterson, 2004). Additional site-specific hydrogeologic data collection would be necessary to further refine groundwater flowpaths in this area.

A pond water budget summarizes all the water inputs and outputs and, because the pond volume is relatively stable, makes sure that the inputs and outputs balance. In the case of Eastham Ponds selected for more detailed evaluation, groundwater is generally the predominant input and output with additional inputs from precipitation and additional outputs from evaporation. Streamflow is an additional component for selected ponds (*e.g.*, Great), but estimated quantities have to be based on historic information because this has not been part of regular data collection strategies. In equation form, a water budget is typically represented as:

$$GW_{in} + \text{Precipitation} + \text{streamflow}_{in} = GW_{out} + \text{evaporation} + \text{streamflow}_{out} + \Delta S \qquad (1)$$

Where,

GW_{in} = groundwater inflow

streamflow_{in} = stream water inflow

GW_{out} = groundwater discharge

streamflow_{out} = stream water outflow

ΔS = change in water storage as water levels increase or decrease

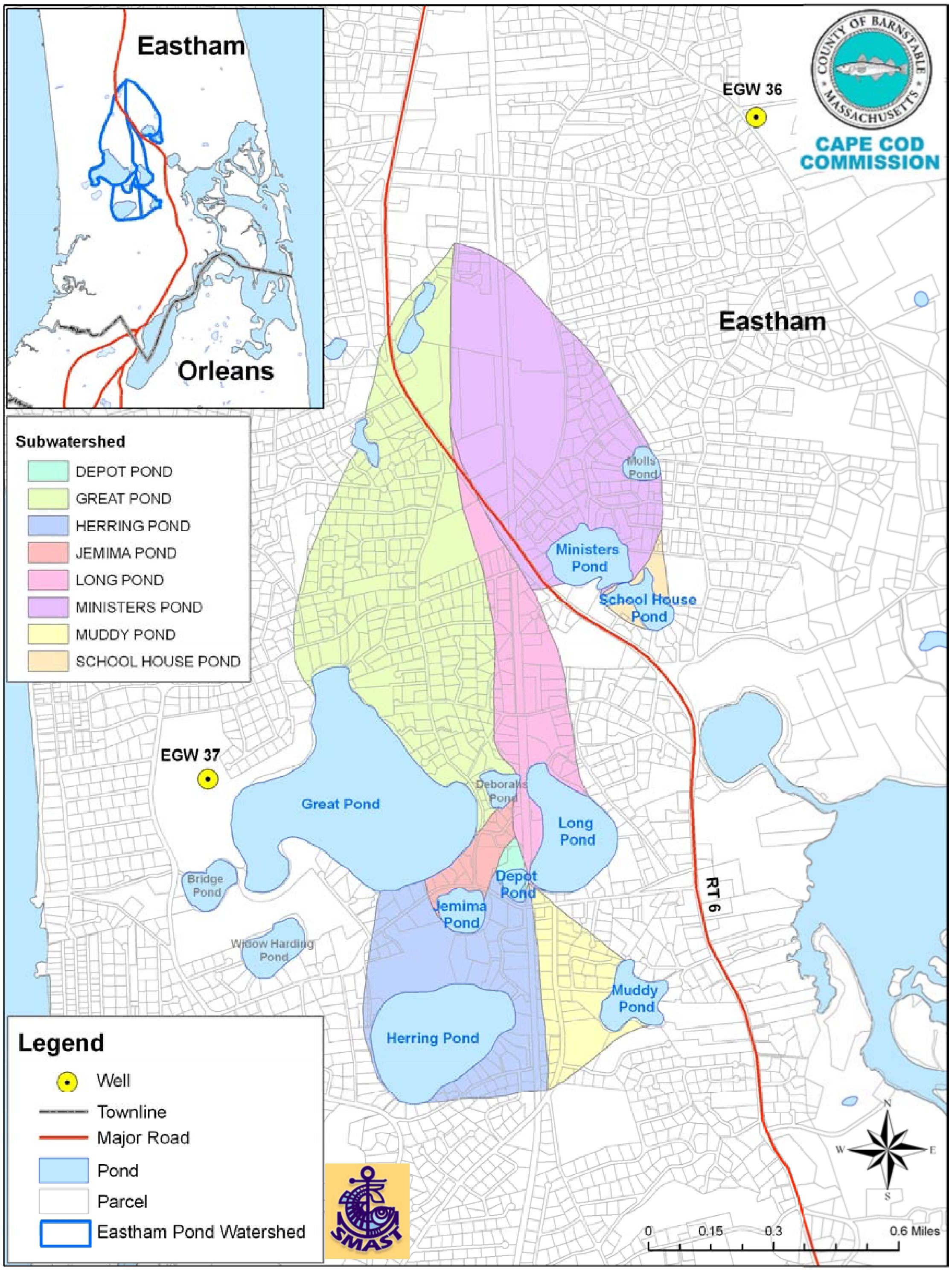


Figure V-1. Pond Watersheds to Eastham Ponds selected for detailed review: Long, Great, Herring, Minister/Schoolhouse, and Muddy

Watersheds to ponds based on SMAST staff refinements to recharge areas from US Geological Survey model outputs (Masterson, 2004). Also shown are locations of monitoring wells that have long term groundwater level data collected by the Cape Cod Commission.

As mentioned above, groundwater levels and pond levels of Cape Cod ponds tend to fluctuate together; so long-term changes in the volume of a pond tend to be accompanied by equivalent changes in the amount of groundwater inflow and outflow. Shorter term events, such as high volume rainstorms, can change the storage/volume, but these are quickly assimilated by the aquifer and have little impact on an annual water budget (*e.g.*, Eichner and others, 1998). Because of this relationship and the absence of streamflow in or out of most Cape Cod ponds, the storage component of the water budget equation is typically removed and equation (1) is simplified to:

$$GW_{in} + \text{Precipitation} = GW_{out} + \text{evaporation} \qquad (2)$$

In Eastham's ponds selected for more detailed review, groundwater is generally the majority of the inflow portion of the water budget in all ponds except for Schoolhouse (Table V-2). For all these ponds, the "IN" portion of the budget is determined by the recharge within the watersheds shown in Figure V-1 and precipitation on the surface of the ponds. In order to account for likely road runoff, project staff have also included precipitation on road surfaces that are inside a 300 ft buffer to the pond regardless of whether the roads are in the watershed or not. The precipitation on roads, even those outside of the watershed, are included because most road drainage systems are designed to discharge to the lowest elevation point, which, in the area of these ponds, is likely the pond surface (*e.g*., Town of Orleans, 2003).

Recharge and precipitation rates for the water budget are based on recent USGS reviews completed in support of the regional groundwater model development (Masterson, 2004). This evaluation showed annual precipitation in Provincetown (1948 to 1992) and South Truro (1980 to 2000) averaged 42 inches. Using available hydrogeologic data, Masterson (2004) estimated annual recharge to groundwater through land surfaces to be 24 inches and through ponds to be 14 inches. Ponds have a lower recharge rate because of higher evapotranspiration due to exposure of the water surface to sunlight and wind, as well as plant biota transpiration.

In the preparation of the "OUT" portion of the budget, the difference between precipitation (42 inches per year) and the net pond recharge (14 in/y) is the amount of evapotranspiration. Stream outflow readings in Table V-2 are based on historic measurements for Great (BEC, 1987) and Herring (BEC, 1991). Groundwater outflow is determined by subtracting the sum of evaporation and streamflows from the sum of the "IN" portions of the budget.

The streamflow information included in the water budgets for Great and Herring are based on data collected during the preparation of diagnostic/feasibility studies in 1985/86 and 1988/89, respectively. Since stream outflows and groundwater levels tend to be related in ponds on Cape Cod (*e.g.*, Eichner and others, 1998), project staff compared water level readings during the 1985/86 and 1988/89 periods to water level readings during the 2002/2004 period when most of the pond water quality data that is discussed in this report was collected. Groundwater elevations are from two water level monitoring wells located in Eastham that are measured monthly by the Cape Cod Commission.

Table V-2. Water budgets for Eastham Ponds selected for detailed review.

Inflow is composed of groundwater inflow based on annual recharge within the pond watershed, precipitation on the surface of the pond, and road precipitation. Road precipitation of the "IN" budget is based on estimated annual runoff from road areas within 300 ft of each pond. Outflow is based on streamflow out of the pond, evaporation off its surface, and groundwater outflow. Streamflow information is based on median flows recorded for Great and Herring during May 1985 to April 1986 (BEC, 1987) and April 1988 to March 1989 (BEC, 1991), respectively. Evaporation is based on USGS groundwater model assumptions (Masterson, 2004), while groundwater outflow is based on the remaining difference after accounting for evaporation and stream outflow. Herring groundwater inflow includes recharge from Jemima and Long pond watersheds. PALS# is unique identifier developed for each pond by the Cape Cod Commission under the Cape Cod Pond and Lake Stewardship (PALS) program.

Pond	PALS #	Pond Area	IN				OUT				Storage Volume
			GW	Pond Surface Precipitation	Road Precipitation	TOTAL	GW	Evaporation	Stream	TOTAL	
		ac	m3/y	m3/y	m3/y	m3/y	m3/y	m3/y	m3/y	m3/y	m3
Ministers	EA-92	15	420,950	63,153	17,752	501,855	442,001	42,102		484,104	126,181
Schoolhouse	EA-93	7	20,788	29,525	6,639	56,953	30,630	19,683		50,313	36,170
Great	EA-95	110	587,395	473,781	19,040	1,080,216	(58,846)	315,854	804,168	1,061,176	1,632,139
Long/Depot	EA-96	28	171,594	120,371	10,791	302,755	211,717	80,247		291,964	600,450
Muddy	EA-102	10	108,144	45,199	9,629	162,972	123,211	30,133		153,343	44,623
Herring	EA-103	44	211,250	191,021	15,229	417,500	274,923	127,347	-	402,271	889,138

Pond	PALS #	Pond Area	IN			OUT		
			GW	Pond Surface Precipitation	Road Precipitation	GW	Evaporation	Stream
		m2	m3/y	m3/y	m3/y	m3/y	m3/y	m3/y
Ministers	EA-92	59,199	84%	13%	4%	91%	9%	-
Schoolhouse	EA-93	27,676	37%	52%	12%	61%	39%	-
Great	EA-95	444,114	54%	44%	2%	-6%	30%	76%
Long/Depot	EA-96	112,833	57%	40%	4%	73%	27%	-
Muddy	EA-102	42,369	66%	28%	6%	80%	20%	-
Herring	EA-103	179,060	51%	46%	4%	68%	32%	0%

Groundwater monitoring well EGW36 is located near the top of the Nauset Lens (see Figure V-1). Because it is located near the top of the lens, it will have the greatest fluctuation in water levels and be most responsive to precipitation events. Water levels at EGW36 between 1978 and 2005 have a range of 8.1 feet between the highest and lowest levels and an average elevation of 13.37 feet above mean sea level. Well EGW37 is located just to the north of Great Pond and closer to the coast (see Figure V-1). Because it is at a lower elevation in the aquifer, the fluctuation range at EGW36 is 5 feet with an average elevation of 8.38 feet above mean sea level.

Since EGW36 is closest to Great and Herring, project staff compared water levels from the two BEC streamflow measurement periods and water levels during the 2002/2004 period. As shown in Figure V-2, water levels during 1988/89 (Herring) and 2002 are very similar, while 1985/86 (Great) water levels are approximately one foot higher. Water levels spiked a bit higher than average during the early spring of 2003 and 2004, but during the primary June through September pond water quality sampling period, water levels during the three year period are generally within one foot of the long term average (8.38 feet above mean sea level). Average water levels during the 1988/89 Herring streamflow period are slightly lower (8.0 ft above msl) than average, while average water levels during the 1985/85 Great streamflow period are 8.4 ft above msl or consistent with the long term average at EGW36. This review of water levels would seem to indicate that the BEC streamflow data can be considered as being reasonably representative of average conditions.

The outflow stream data for Great from May 8, 1985 to April 16, 1986 has an average, median, maximum and minimum flow readings of 1.65, 1.53, 3.74, and 0.34 m3/min, respectively (Figure V-3). Use of the median or average streamflows results in an annual water budget that generally shows that the stream is draining out all the water that is coming into the pond from the watershed. This also means that little or no pond water is discharging back into the aquifer along the downgradient shoreline; there is no flow from Great into the pond watersheds to Jemima, Long or Herring. Streams discharging the majority of pond outflow has been observed in other Cape ponds (Eichner, 2008; Howes and others, 2003).

The Great Pond water budget in this report is different than the water budget that was estimated by BEC (1987). BEC estimated groundwater outflow constituted 70% of the pond outflow and that the groundwater inflow was six times greater than the estimates shown in Table V-2. The BEC groundwater inflow estimate is larger mostly due to differences in the pond watershed delineation; the BEC watershed is approximately 1,000 acres greater than the one shown in Figure V-1. The eastern boundary of the BEC Great Pond watershed delineation extends through Minister Pond and the northern boundary extends to Brackett Road. The smaller watershed developed for this report results in less recharge being captured and, thus, less groundwater flow into the pond.

In contrast to Great Pond outflow, Herring Pond outflow stream data from April 5, 1988 to March 15, 1989 shows very little water leaving the pond through the stream. Average, median, maximum, and minimum outflow readings from Herring are 0.06, 0, 0.17, and 0 m3/min (see Figure V-3). Because streamflow is relatively small, groundwater is the predominant source of inflow and outflow in Herring.

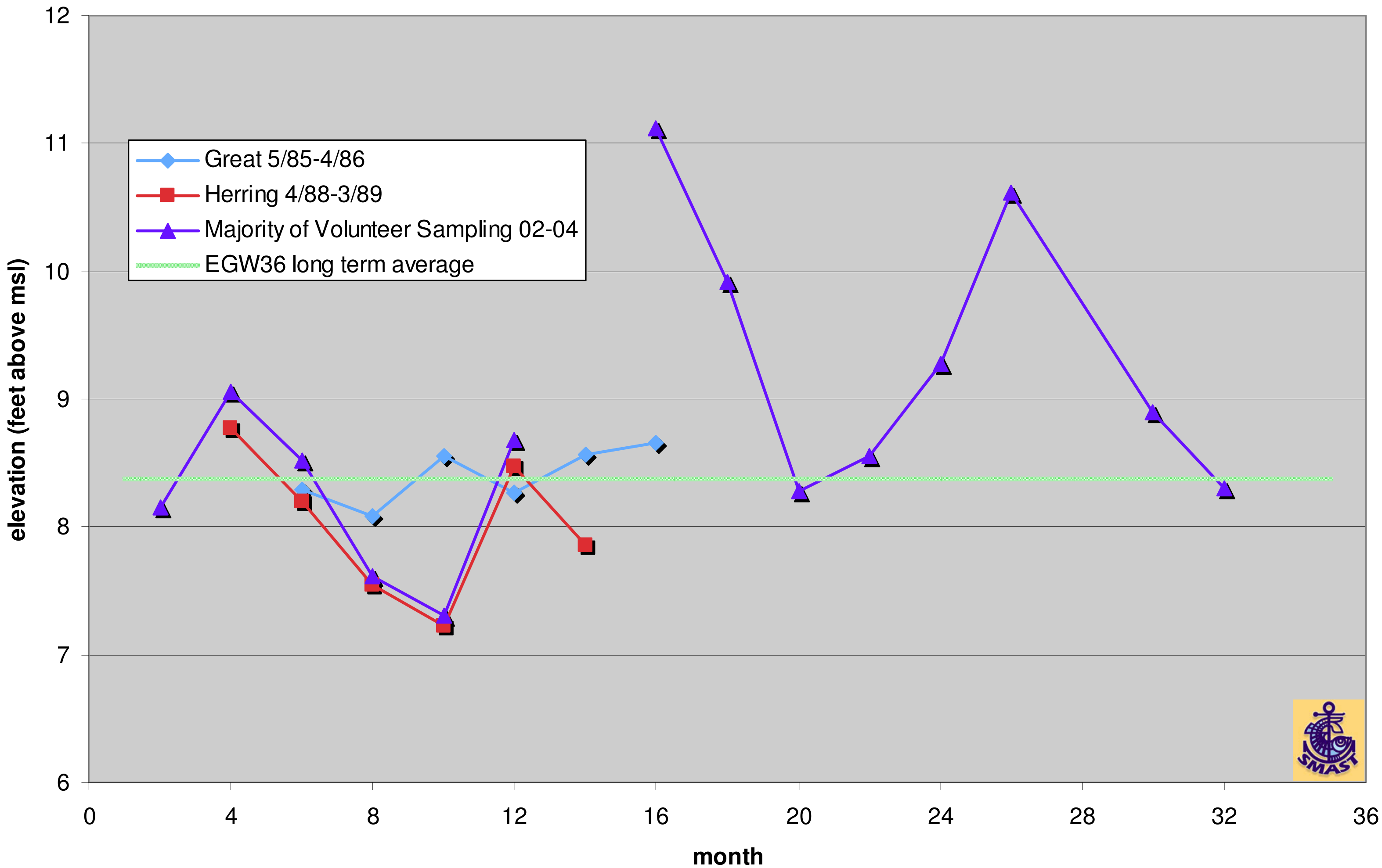
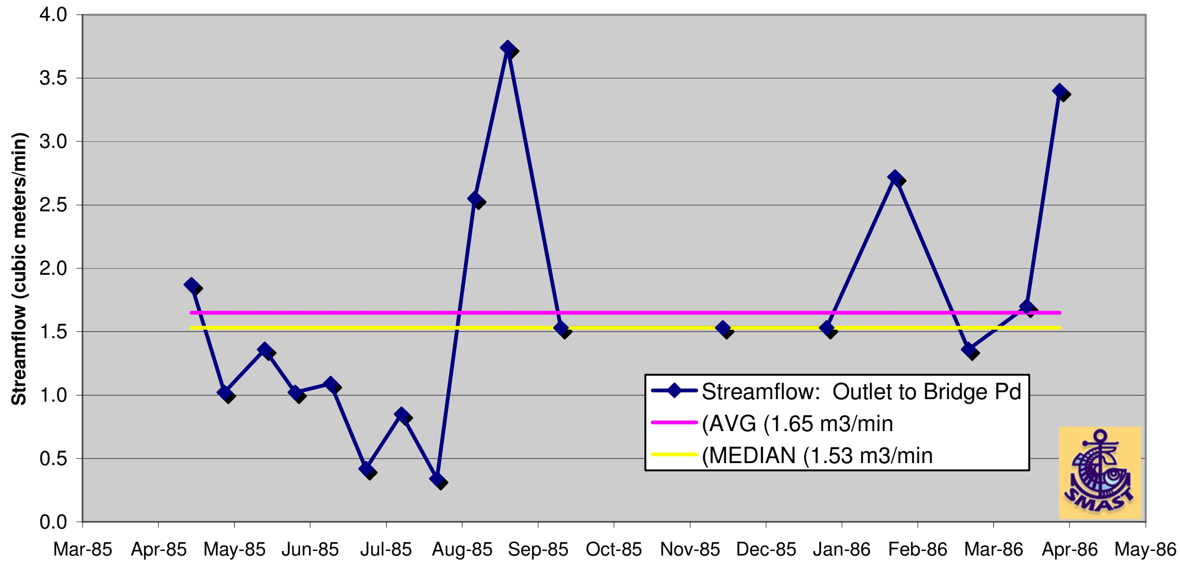


Figure V-2. Groundwater Elevations at EGW36 during pond sampling periods
Groundwater elevations in feet above mean sea level at EGW36 during the water quality sampling periods for Great (BEC, 1987), Herring (BEC, 1991), and the majority of the volunteer pond sampling discussed in this report (2002-2004). Data is arranged to match months (1 = January, 2 = February, etc.). Dates of the sampling periods are shown in the legend. The green line is the long term average (8.38 ft above mean sea level) for EGW36 between July 1978 and November 2005. All water level data are from Cape Cod Commission files.

a. Great Pond: Outlet to Bridge Pd



b. Herring Pond: Outlet sluiceway at Town Landing

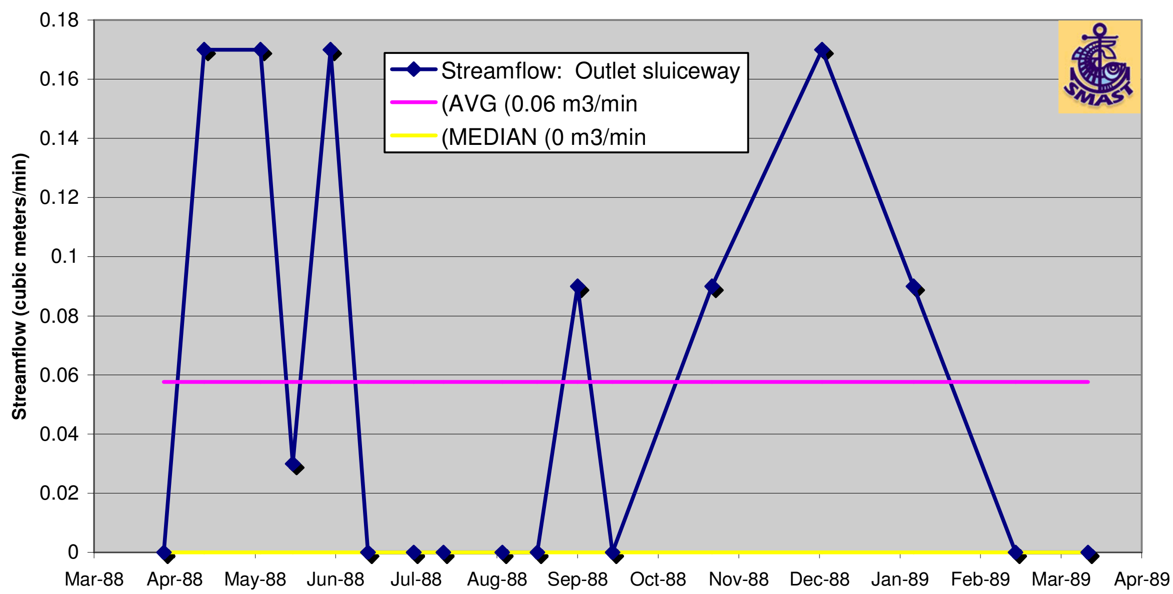


Figure V-3. Historic Outlet Streamflow from Great Pond and Herring Pond
a. Great Pond outflow streamflow data from BEC (1987). b. Herring Pond outflow streamflow data from BEC (1991).

Aside from the streamflows in Great and Herring, most of the other ponds have groundwater dominated water budgets except for Schoolhouse, which has a high percentage of its inflow from surface precipitation. This is largely the result of its proximity and connection to Minister. Minister is directly above Schoolhouse in the same groundwater flowpath, so the groundwater model results show that Minister focuses and captures all of the upgradient flow and leaves only a very small area for groundwater recharge capture by Schoolhouse. Further discussion of the likely seasonal aspects of the water budget is discussed in the water quality sections below.

V.3. Phosphorus Budget Factors

Just as a water budget accounts for all the water coming into and leaving a pond, a phosphorus budget does the same for phosphorus. Biomass in pond and lake ecosystems is usually limited by a key nutrient; if more of this key nutrient is available, the biomass will increase. In ponds and lakes, the key nutrient is usually phosphorus. Diminishing water quality in ponds and lakes generally follow a relatively simple progression that begins with higher phosphorus concentrations and ends with low oxygen conditions: more nutrients create more plants (either phytoplankton or rooted plants), which in turn create more decaying material falling to the pond bottom, where bacteria consume oxygen while decomposing the dead plants. Low oxygen conditions produces chemical changes in the sediment materials that allow phosphorus in the sediments to be regenerated back into the water, creating the opportunity to enhance the growth cycle with additional nutrients. Of course this general description often becomes more complex as the details that are specific to each pond are considered. However, because water quality impacts follow this progression, regular low dissolved oxygen conditions are generally more of a terminal state, while diminishing clarity/Secchi depth and elevated phosphorus concentrations are generally the initial stages. The status of a pond on this progression generally provides some sense of the level of impacts it is receiving.

One way to assess whether a lake is limited by phosphorus is to review the balance between phosphorus and nitrogen; as a rule of thumb, if the ratio between nitrogen and phosphorus is greater than 16, phosphorus is the limiting nutrient (Redfield and others, 1963). Because phosphorus is usually the key nutrient, lake scientists usually develop a phosphorus budget to quantify the primary sources and, if there are water quality problems, to develop targeted strategies to reduce the phosphorus loads from these sources.

As groundwater flows into Cape Cod ponds along the upgradient shoreline, it brings with it contaminants from the pond watershed, including phosphorus. Phosphorus is chemically more stable and biologically unavailable in well-oxygenated waters if it is bound with iron (Stumm and Morgan, 1981). Because of this, sandy aquifer systems, like the Cape, where iron coats the sand particles within the aquifer, cause groundwater phosphorus from small sources, like septic systems, to move very slowly (1.1-2.6 m/yr) (Robertson, 2008). In contrast, nitrogen, which is generally present in the Cape's groundwater system in its fully-oxidized, nitrate form, flows with the groundwater, which generally moves 1 ft/d (or 111 m/yr). Because of the slow movement of phosphorus, most of the sources of phosphorus entering Cape Cod ponds is from properties abutting the pond shoreline; previous analysis of Cape Cod ponds have focused on properties within 250 to 300 ft of the shoreline (*e.g.*, Eichner and others, 2006; Eichner, 2007; Eichner, 2008).

For the six Eastham ponds selected for more detailed review, project staff began the development of the watershed portion of the phosphorus budget by asking Eastham Water Resources Advisory Board members and other volunteers to review town Board of Health records to determine the distance from the pond shorelines to septic system leachfields, pits and cesspools on properties within 300 ft of the pond shorelines. During this review, information on the age of the wastewater systems and the age of the buildings connected to these systems were also collected. SMAST and Town staff assisted the volunteers during the review of the records by preparing maps and accompanying spreadsheets listing all parcels within or partially within the 300 ft buffer. Project staff also encouraged volunteers to note large potential nutrient sources outside of the 300 ft buffer area, as well as seeking out historic information on past land uses that might still have some impacts on the currently observed water quality in the six selected ponds.

The lists of properties within 300 ft of the shorelines were then adjusted to focus on properties on the upgradient sides of the ponds (Figure V-4). Aerial photographs of the properties were reviewed and non-wastewater loads were only assigned to developed properties with houses or other structures within the 300 ft buffer and upgradient, or within the watersheds, to the ponds. For the purposes of reviewing wastewater sources, all septic system discharge structures on upgradient properties within or partially within the 300 ft buffer were included in the calculations. Properties included in the loading calculations were adjusted, as described below, based on best professional judgment of likely groundwater flow characteristics near the ponds. Phosphorus loads were developed based on the factors in Table V-3. Review of selected loading factors and the details of the loads to the individual ponds are discussed below.

Table V-3. Watershed Loading Factors for Phosphorus Budget

Listed below are factors used in the development of the watershed phosphorus loading estimates for the Eastham ponds selected for more detailed review.

Factor	Value	Units	Source
Wastewater P load	1	lb P/septic system	MEDEP, 1989
Road surface P load	5.3	lb P/ac	MEDEP, 1989
Roof surface P load	3.5	lb P/ac	MEDEP, 1989
Natural Areas P conc.	0.014	mg P/l	BEC, 1993
Recharge Rate	24	in/yr	Masterson, 2004
Precipitation Rate	42	in/yr	Masterson, 2004
Building Area	2,000	ft2	Eichner and Cambareri, 1992
Road Area	Actual value	ft2	Mass. Highway Information
Lawn Factors			
Area per residence	5,000	ft2	Eichner and Cambareri, 1992
Fertilizer lawn load	0.3	lb P/ac	MEDEP, 1989
Waterfowl Factors			
P load	0.156	g/m2/yr	Scherer, *et al.*, 1995
New P load	13	%	Scherer, *et al.*, 1995
Alt external P load	0.5 – 1.3	kg/yr	Non-areal load based on Cape Cod bird counts

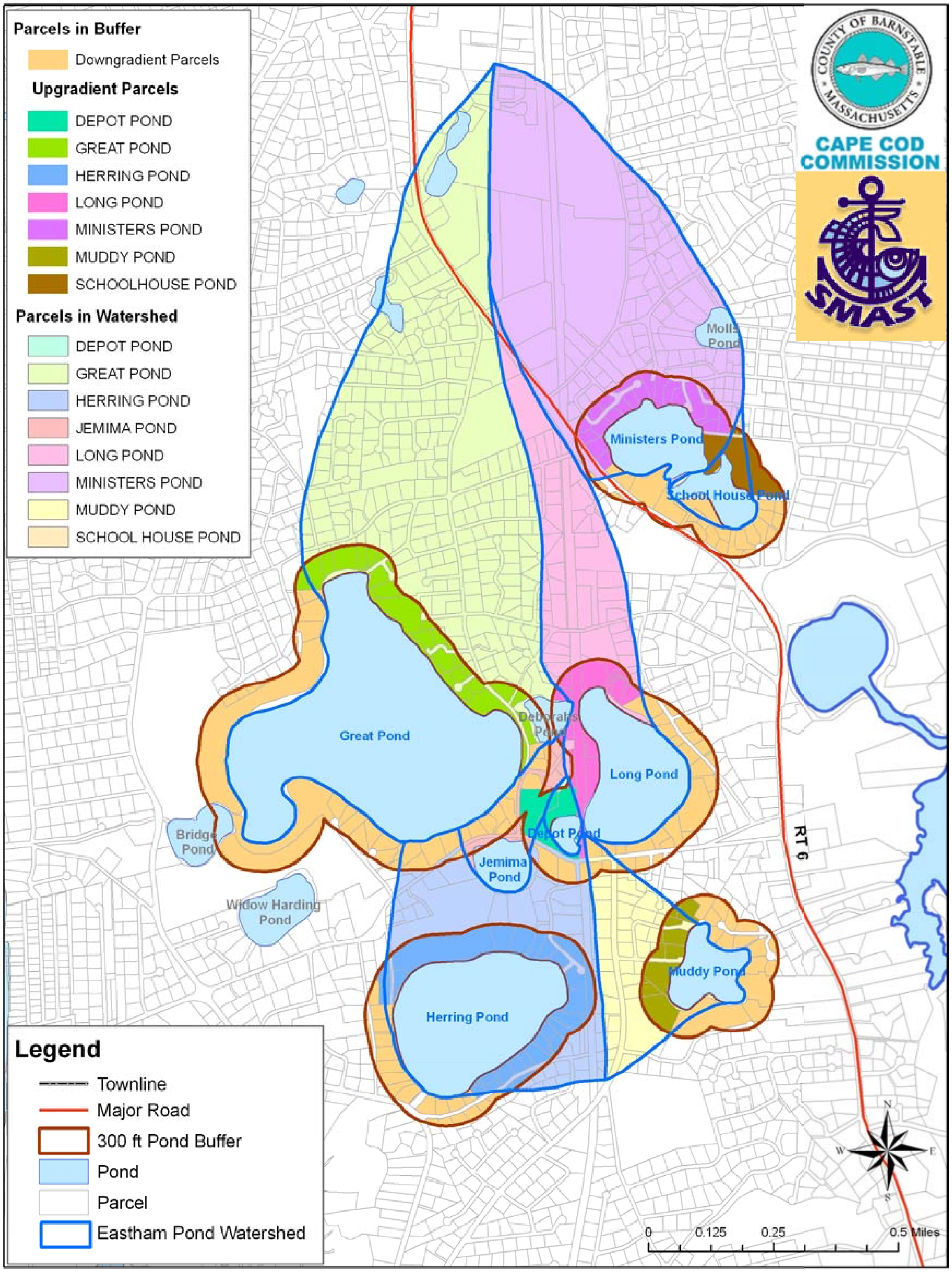


Figure V-4. Parcels reviewed in pond watershed phosphorus loading estimates. Phosphorus loads are developed for parcels within 300 ft that are also within the pond watersheds; these parcels are colored darker within the watersheds. Watershed parcels outside of the 300 ft buffer are not assigned a phosphorus load except for road areas. Phosphorus loads are based on factors shown in Table V-3. Parcel data is based on Town Assessor data and review of Board of Health records.

V.3.1 Wastewater Phosphorus Loading Factor

Given that wastewater is usually a significant component of the overall phosphorus load to a pond, staff reviewed the factors traditionally used for phosphorus loading analysis on Cape Cod. For wastewater, previous analyses typically used the septic system loading rate developed by the Maine Department of Environmental Protection (MEDEP, 1989). The MEDEP uses a phosphorus loading methodology for assessing the potential impact of development on pond and lake water quality. Among the factors used is one pound of phosphorus annually for each septic system bordering a pond or lake and located in sandy soils.

Because of phosphorus' chemical characteristics, field studies of phosphorus loads have typically had varied results that are very dependent on the individual characteristics of the resource being evaluated. Evaluation of available studies have shown that annual per capita phosphorus loads range from 1.1 (*e.g.*, Reckhow and others, 1980; Panuska and Kreider, 2002) to 1.8 pounds (*e.g.*, Garn and others, 1996). When the soil range of potential phosphorus soil retention factors (0.5 to 0.9) are applied (Robertson and others, 2003), the resulting annual per capita load ranges between 0.11 and 0.9 lb. As a point of comparison, KV/IEP (1989) assumed an annual per capita load of 0.25 lb and a per house load of 0.75 lbs in their buildout calculations. If one uses the average occupancy in the Town of Eastham during the 2000 Census (2.28 people per house), the per capita range results in an average septic system load range of 0.3 to 2.1 lbs. Given that the MEDEP load falls into the range, project staff proceeded with this factor as the initial wastewater phosphorus load from septic systems.

V.3.2. Lawn Fertilizer Phosphorus Loading Factor

Lawn fertilizers are nutrients designed to prompt growth from the plants that make up a lawn. Reviews of fertilizer application rates on Cape Cod have generally found that homeowners do not fertilize lawns as frequently as recommended by lawn care guidelines unless commercial companies tend the lawns [see Howes and others (2007) for summary]. In addition, multi-town surveys have found that approximately half of Cape Codders do not use lawn fertilizers at all (White, 2003). Because of some the uncertainty exposed by these findings, project staff continued to use the standard phosphorus loading factors listed in Table V-3.

V.3.3. Bird Phosphorus Loading Factor

Phosphorus loading from birds has been a difficult factor to resolve for Cape Cod ponds. Previous analyses completed by SMAST staff have relied on the factors shown in Table V-3 that are derived from a highly detailed study of birds and pond water quality from Seattle, Washington (Scherer and others, 1995). This study evaluated bird counts for a large pond (259 acres), determined the load per species, and the percentage of the phosphorus load from each species that was new addition to the pond and how much was reworking of existing phosphorus sources already in the pond. The results from Scherer and others (1995) found that the annual average phosphorus load from birds is 0.156 grams of P per square meter of lake surface with 13% of the load as new P additions to the lake. Because this load is determined by the area of the pond, applying this factor would result in larger ponds having greater bird loading.

In order to provide some sense of how well the Scherer and others (1995) study might apply to Cape Cod, project staff reviewed bird counts from the annual Cape Cod Bird Club surveys (www.capecodbirds.org/waterfowl.htm). These surveys are usually conducted during the first week of December, have been done since 1984, and generally collect data from over 300 ponds. In 2007, an average of 36 birds per pond was recorded on the 313 ponds surveyed. The average for all surveys since 1984 is 33 birds per pond. If pertinent factors from Scherer and others (1995) (*e.g.*, phosphorus content of droppings) are used with the Cape Cod bird counts and it is further assumed that December counts are representative of year-round populations, the resulting average load of new phosphorus per Cape Cod pond is 0.9 kg/y.

VI. Individual Pond Reviews
VI.1. Great Pond
VI.1.1. Great Pond Review and Discussion

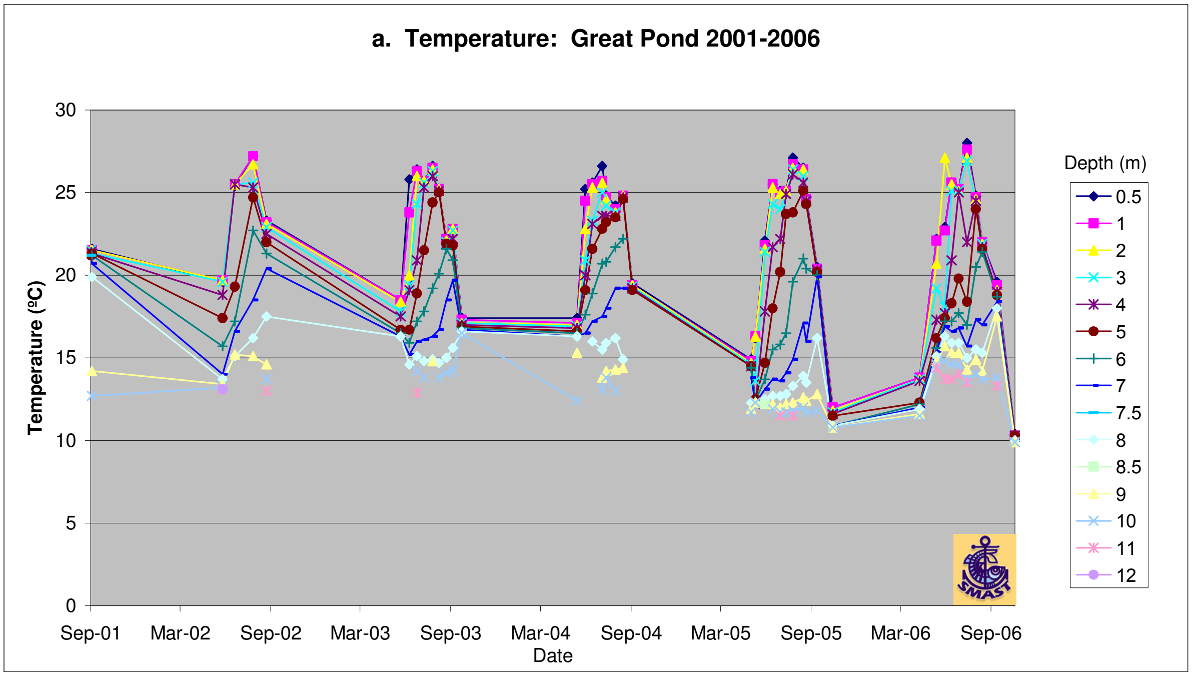
Great Pond is a 110-acre pond that is located to the west of Route 6 (see Figure V-1). It is the deepest of the ponds selected from detailed review; its deepest point is 13 m (~43 ft). Water quality in Great was reviewed as part of a diagnostic/feasibility study (BEC, 1987) and field readings were collected once in 1948 (MADFG, 1948). Given its depth, it thermally stratifies usually starting in late May/early June with deepest temperatures during the summer between 12 and 15°C (Figure VI-1). The upper layer continues to warm throughout the summer, generally reaching 26 to 28°C, and this warmth is mixed throughout the upper layer (*i.e.*, the epilimnion). This warmer layer gradually thickens and deepens, generally starting with the upper 3 to 4 m in June and extending to 5 or 6 m by September. Once stratification layers set up, oxygen consumption from the bottom sediments regularly creates anoxic (<1 ppm) conditions in the lower layer (*i.e.*, the hypolimnion). By the end of September/early October, when thermal stratification begins to break down, anoxic conditions can reach as high as 6 m in depth or to the bottom of the epilimnion.

Since Great Pond thermally stratifies and has a portion of the water column with an average summer temperature below 20ºC, it has the potential to sustain a state-defined, cold-water fishery. State surface water regulations (314 CMR 4) require cold-water fisheries to attain a 6 ppm dissolved oxygen standard and have temperatures less than 20ºC.

Based on average conditions for June through September on data collected between 2001 and 2006, the state 6-ppm standard is usually met down to a depth of 5 m (Figure VI-2). Waters 5 m and deeper have dissolved concentrations that are less than the 6 ppm standard the majority of the time between June and September. On average, approximately 19% of the pond volume fails to meet the 6-ppm DO standard (Figure VI-3). Since temperatures on average exceed 20ºC at depths at 5 m and above, the potential cold water fishery is below 5 m. Because the entire volume of the potential cold water fishery has average dissolved oxygen concentrations that are less than the state 6 ppm standard, this pond would be classified as impaired under state regulations and would be required to have a TMDL (Total Maximum Daily Load) developed.

The dissolved oxygen profile collected by the Massachusetts Division of Fisheries and Game shows that similar low oxygen conditions existed on August 20, 1948 (see Figure VI-2). Since the profile is the only one available that year and it is collected during the time of year when the worst water quality conditions are expected, it is impossible to draw definitive conclusions comparing current results to this single profile. Comparison of current water quality conditions to MADFG (1948) monitoring data from other Cape ponds generally shows worsening conditions in ponds across Cape Cod (Eichner and others, 2003).

Dissolved oxygen data collected during the diagnostic/feasibility study of Great (BEC, 1987), generally agree with the average conditions shown in Figure VI-2, although the average DO concentration at 5 m is above the 6 ppm standard in the volunteer collected data. This difference is likely due to a better evaluation of average conditions that is provided by the multi-year data collected by the volunteers. Year to year fluctuations in precipitation, cloud cover, and temperatures can have a significant impact on individual readings collected over a single year.



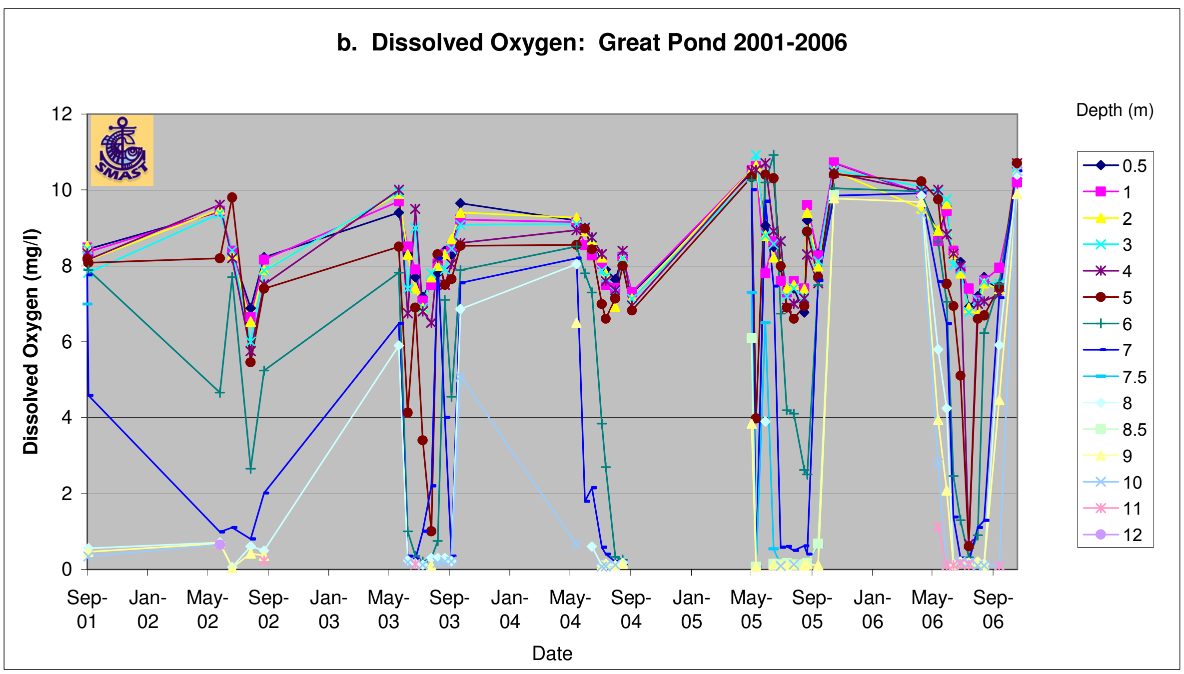


Figure VI-1. Great Pond Temperature and DO Readings 2001-2006
Temperature data shows that the upper water column is well mixed with temperatures increasing during summers, while the deeper waters get colder with increasing depth. During early spring and late fall, water temperatures are relatively constant throughout the water column. Dissolved oxygen concentrations show lower concentrations with increasing depth and regular anoxic (<1 ppm) concentrations during the summer. All data collected by Eastham volunteers using DO/Temp meters. These graphs include data documented in Eichner and others (2001) and PALS Snapshots from 2001 to 2006.

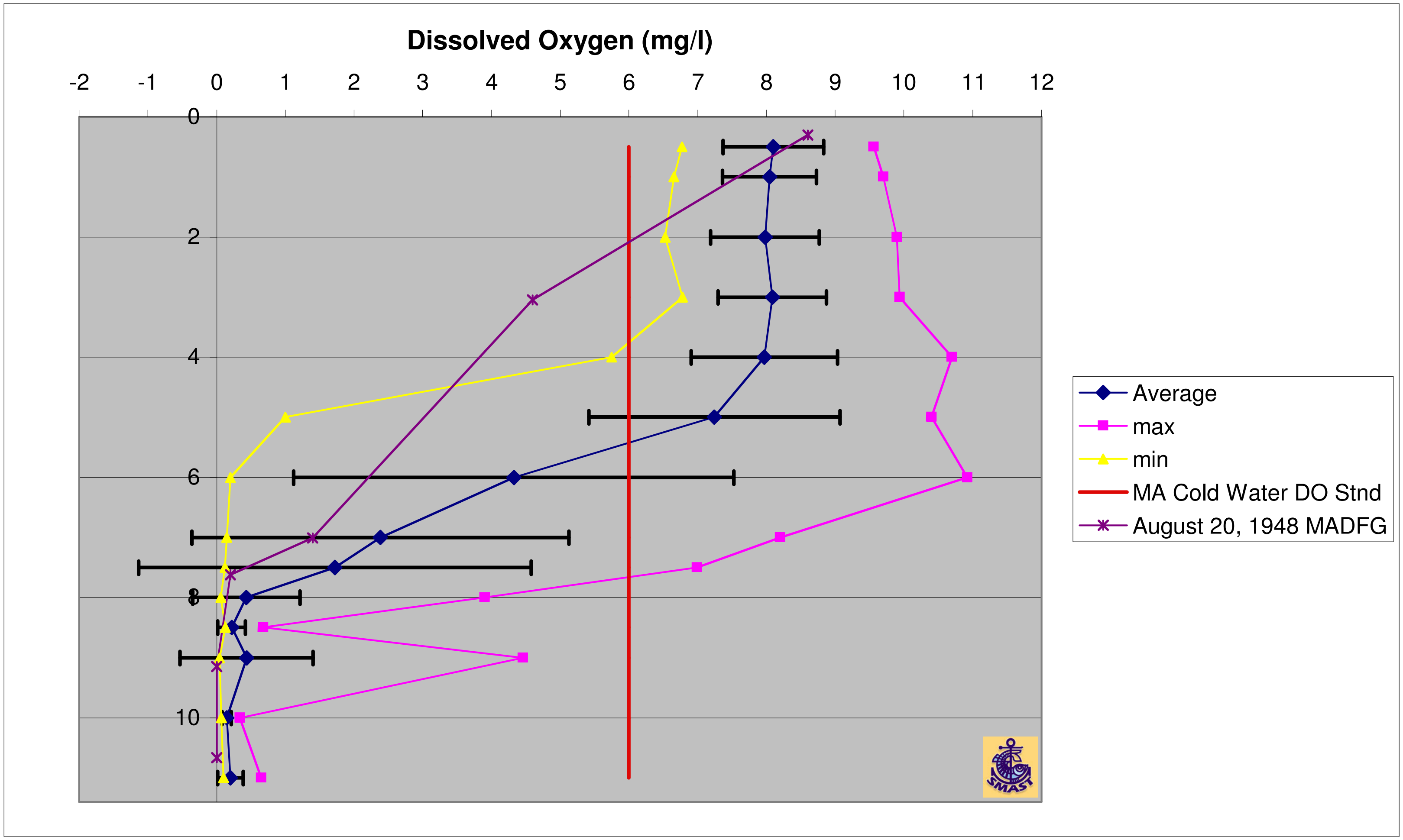


Figure VI-2. Average dissolved oxygen concentrations in Great Pond (June through September, 2001-2006)
Graph shows average DO profile based on data collected by town volunteers between 2001 and 2006 with error bars (±1 standard deviation) plus profiles based on maximum and minimum readings for each depth. Also shown is August 20, 1948 profile (MADFG, 1948) and the state surface water 6-ppm DO standard for cold water fisheries (310 CMR 4). Most depths have 46 readings collected between 2001 and 2006.

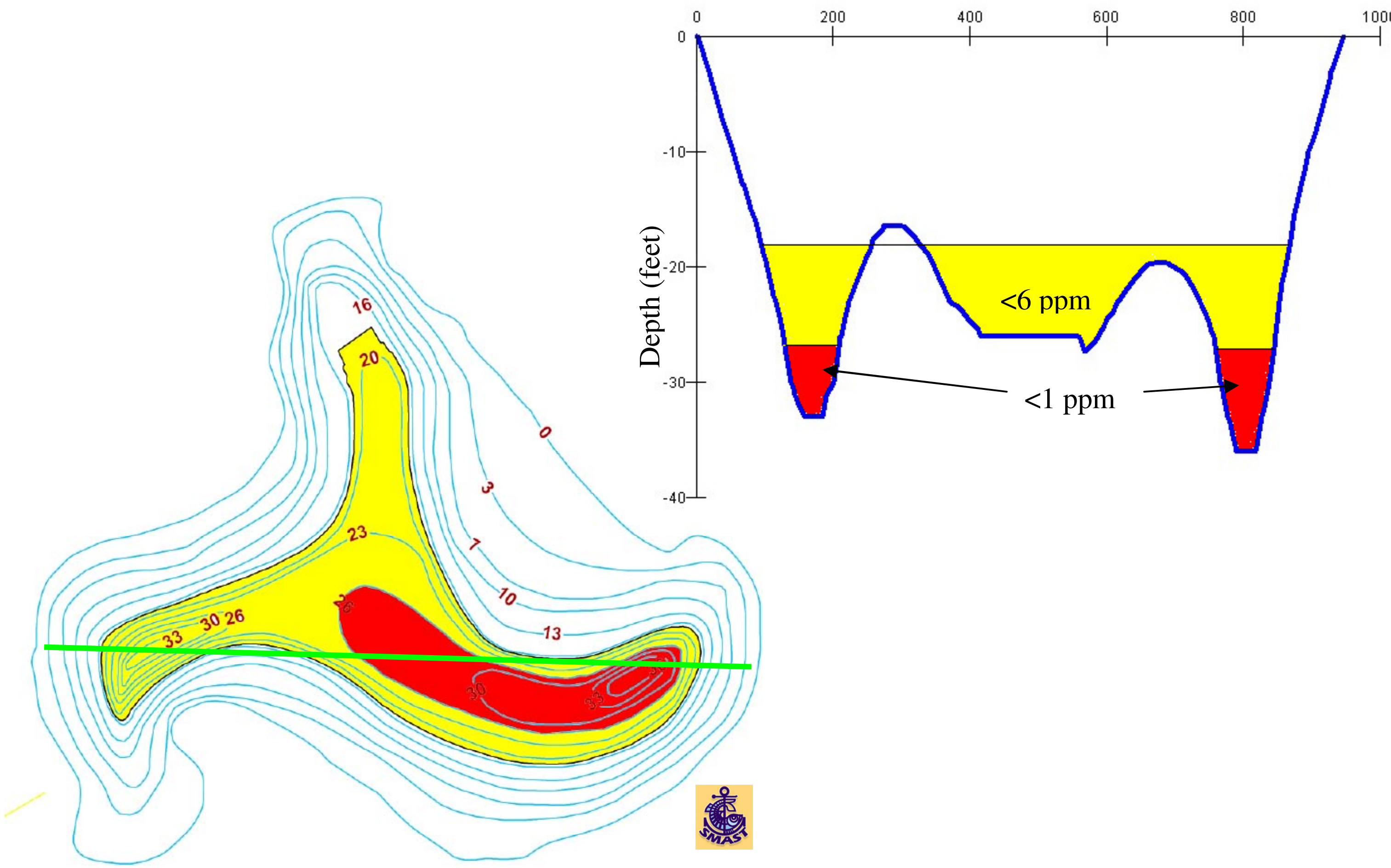


Figure VI-3. Great Pond: Average dissolved oxygen (June through September) and state surface water standards
Depth profile and bathymetric map showing volume and area of Great Pond that has average dissolved oxygen concentration between June and September that is less than state regulatory limit of 6-ppm DO standard for cold water fisheries (shaded yellow) and areas that are anoxic (<1 ppm) (shaded red). Green line on map shows depth profile track through the pond that corresponds to cross-section. Bathymetry is from BEC (1987).

Secchi readings in Great average 2.8 m between June and September (n=36) in the 2001-2006 dataset (Figure VI-4). Average sampling station depth is 10.4 m and on average 28% of the overall water depth is clear enough at the sampling station to see a Secchi disk. Station depth readings have an upward trend; this trend matches the increasing trend measured in local groundwater levels during the same time (Cape Cod Commission files). Increasing groundwater levels would tend to increase the pond volume, dilute phosphorus loads and algal populations, and lead to greater transparency. Secchi readings do not demonstrate any trend, which suggests that transparency is worsening; this is also seen in the downward trend in the relative Secchi readings (% of total depth). Secchi readings have an overall range from 1.60 to 3.85 m.

The average Secchi readings from the 2001-2006 dataset are significantly less than the readings during the diagnostic/feasibility study (BEC, 1987). The average Secchi reading for all data collected by volunteers is 2.85 m, while the average collected by BEC was 3.85 m. This difference is statistically significant using a t-test ($p<0.001$). For comparison, the Secchi reading on August 20, 1948 was 3.66 m (MADFG, 1948).

Average total phosphorus (TP) concentrations in Great Pond between June and September are greater than both Cape Cod-specific pond thresholds (7.5 ppb "unimpacted" and 10 ppb "healthy") at all four sampling depth stations: 16.6 ppb at 0.5 m (n=19), 13.0 ppb at 3 m (n=18), 25.1 ppb at 9 m (n=7), and 17.8 ppb at the deepest station (n=19). The average depth of the deepest station, which sampling protocol requires be 1 m off the bottom, is 9.35 m (n=18). Because of the low DO conditions in the deeper portions of the pond, one would expect that TP concentrations closer to the sediments would be higher and reflect regeneration of phosphorus from the sediments caused by the depressed DO concentrations.

As laboratory data became available during the earlier years of the 2001 to 2006 dataset, preliminary review raised concerns that sample bottles may have been transposed and data from the deepest samples were actually from the shallowest samples. If data is transposed from a total of seven selected sampling runs in 2002/03 where this appears to be the case, the concentrations at the various depths match better with what would be expected based on the measured dissolved oxygen concentrations. Transposed average TP concentrations are still above both Cape Cod TP thresholds, but the shallowest average concentration is lower and the deepest concentration is higher: 11.9 ppb at 0.5 m (n=19), 12.7 ppb at 3 m (n=18), 25.9 ppb at 9 m (n=7), and 22.4 ppb at the deepest station (n=19). Because of the uncertainty related to the results, project staff carried both sets of averages through the rest of the analysis.

BEC (1987) observed only a slight gradient between surface and bottom TP concentrations, although the average concentrations between June and September were much higher: 27.3 ppb (n=8) at the surface, 35.1 ppb (n=8) at 3 m, and 30.4 ppb (n=8) at the deepest station. Higher concentrations during the BEC analysis suggest some issues with differences in lab methods; more refined techniques are commonly available now. However, the pattern of only slightly elevated deep concentrations suggests that the current averages from the non-transposed dataset may be accurate.

Total nitrogen to total phosphorus ratios average 63 in the upper waters for non-transposed readings between June and September, while the transposed data has an average ratio

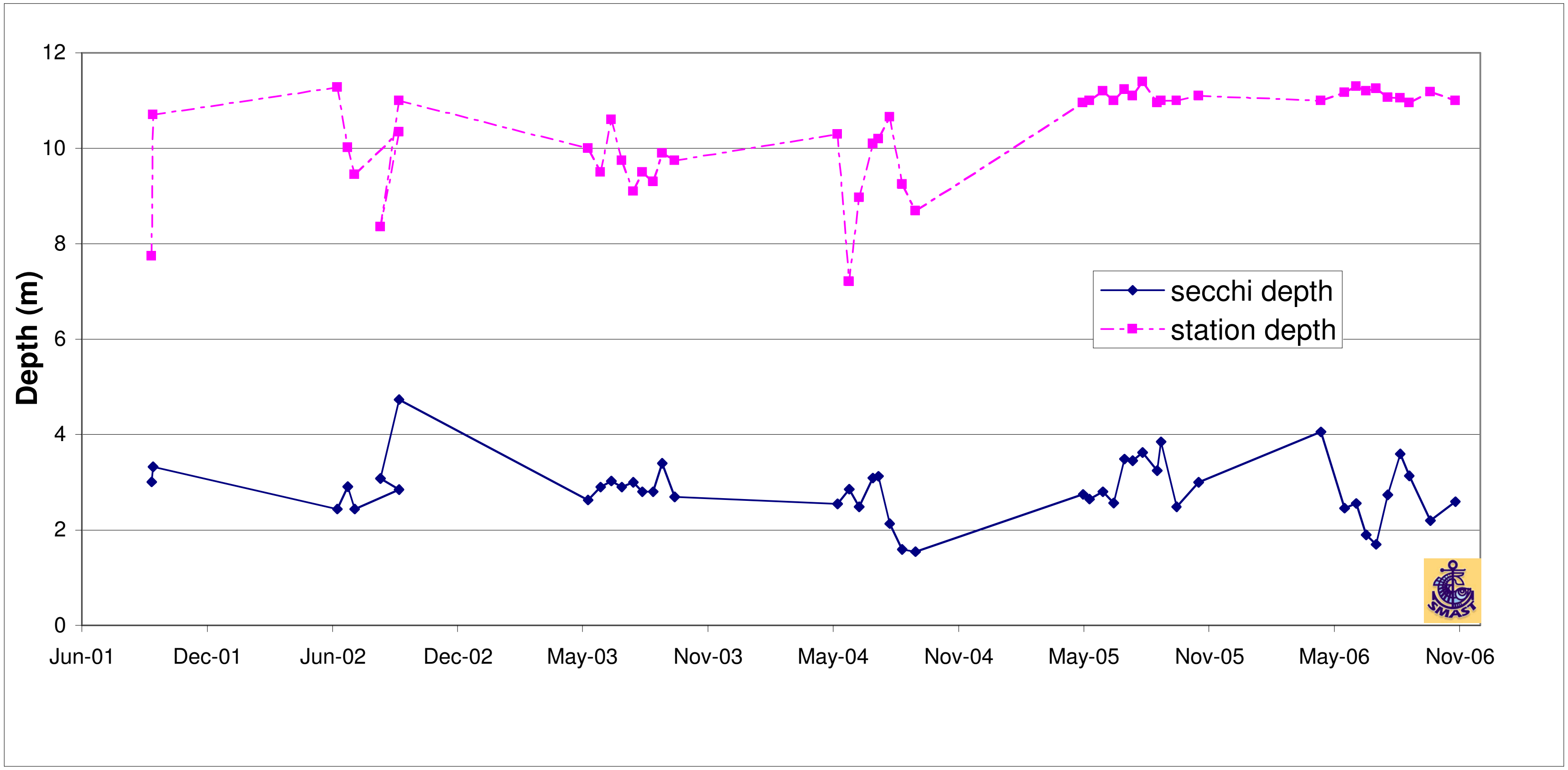


Figure VI-4. Secchi transparency readings in Great Pond 2001-2006

Blue data points are Secchi depth readings, while station depth measurements are shown in pink. All data collected by Eastham volunteers. Station depth has an increasing trend over the sampling period, while Secchi readings are relatively constant. The increasing station depth trend matches the trend in local groundwater elevations experienced during this same period. Since Secchi reading would be expected to also match this trend, the comparison suggests that transparency is worsening in the pond.

of 117. Use of all non-transposed surface water data, including readings outside of the primary June to September analysis window, also has an average of 63, while transposed data has an average ratio of 110. BEC (1987) also had an average TN:TP ratio of 63 in the surface waters for readings between June and September and had an average ratio of 47 for all surface data collected during the study. Since most of these average ratios are multiples of the Redfield ratio of 16, on average during the summer the pond is phosphorus limited and phosphorus should be the target nutrient for managing water quality in Great Pond.

In order to begin to frame an appropriate water quality management strategy, all the sources of phosphorus should be identified and this is usually done through the development of a phosphorus budget. Results from the phosphorus budget are then compared to the mass of phosphorus in the pond to assess the assumptions in the loading factors and develop a better understanding of the functions within an individual pond. To begin to develop a watershed phosphorus budget for Great Pond, town volunteers reviewed Board of Health (BOH) records to determine the distance between the pond and septic system leachfields for all properties within 300 feet of the pond (see Figure V-4), the age of the septic systems, and the age of the houses. Volunteers also noted any large lawn areas or any other notable potential sources of phosphorus close to the pond. Once this information was developed, project staff narrowed the list to the properties that are upgradient of the pond (*i.e.*, in the watershed) and used the factors in Table V-3 to estimate a watershed phosphorus load to Great Pond.

As mentioned previously, phosphorus travel through an iron-rich aquifer, like Cape Cod's, is slower than groundwater, and is estimated to take 35 to 81 years to travel 300 feet (Robertson, 2007). Project staff compared this range of times to the septic system information developed by the town volunteers and determined whether it was likely that a septic system or a house is currently contributing phosphorus to the pond or whether the phosphorus from the property is still in transit in the aquifer.

Based on the land use review, there are 22 properties within the 300 ft buffer upgradient of Great Pond. Sixteen of the properties have residences with an average age of 73 years old and a range of years built from 1820 to 2001. There are two additional properties classified by the town's Assessor as developable and two more that are classified as undevelopable. The average age of the septic systems is 17 years old with year of installation ranging between 1959 (assumed based on year built and lack of BOH record) and 2006. The average distance to the pond for the fourteen properties with leachfield plans in their BOH records is 150 feet with a range of 50 to 350 feet.

Based on the age of the houses on the 16 developed properties, 15 of them have existed long enough to contribute phosphorus to the pond if one assumes that it takes 35 years for phosphorus to travel 300 ft, while 13 contribute phosphorus if it is assumed that the phosphorus travel time is 81 years. Since the septic systems are usually younger than the houses, the expected contributions are lower if these are considered: the respective numbers are 7 are contributing phosphorus to the pond if the time of travel is 35 years and 5 are contributing phosphorus to the pond if the time of travel is 81 years.

Using the factors in Table V-3 and accounting for the range of groundwater lag times**,** the watershed load to Great Pond is estimated to be between 14.2 and 27.2 kg/yr. Of this, wastewater from septic systems is 2.3 and 6.8 kg/yr (16 to 35 %) of the annual external phosphorus load. Other portions of external loads into the pond include precipitation (22 to 43%), lawns (2 to 4%), roof runoff (4 to 8%), birds based on the areal loading rate (33 to 40%), birds based on the per pond load (3 to 9%), and roads (13 to 26%) (Figure VI-5). Steady state load under current conditions is calculated as 19.1 to 27.6 kg/yr and buildout loading is projected to be 21.2 to 29.7 kg/yr. Uncertainties associated with the loading factors are discussed in the phosphorus budget factors section (see Section V.3.).

Of these loading sources, bird loading has the widest range and is the most uncertain. Given how this could impact management strategies, it is recommended that the bird contribution should be clarified by regular counts (daily or monthly) of bird species and numbers on Great Pond throughout a whole year. Such a study, which is beyond the scope of the current analysis, would be required to detail this in a more definitive fashion. This type of effort could be accomplished by volunteers who are trained or have training to identify the likely bird species and have the ability to view the entire lake. SMAST staff can provide guidance to the town for resolving this issue.

Given that water budget estimates indicate that the outflowing stream releases approximately the same amount of flow as the external water inputs, the residence time of the pond is 1.0 year. This residence time means that the average mass of phosphorus measured in the pond should balance annual external loads from the watershed and precipitation plus any phosphorus regenerated from the sediments. The total mass of phosphorus in the pond based on water quality measurements between June and September averages 24.2 kg (n=19) using the non-transposed data and 21.6 kg (n=19) using the transposed data. Of this mass, 88% or 82%, respectively, is contained in the well-mixed upper layer. Based on this residence time and the 10 ppb TP Cape Cod-specific threshold, the target phosphorus mass in the Great would be 12.4 kg.

An additional factor to consider is the amount of phosphorus flowing out of the pond. Using the BEC streamflow measurements and the average pond concentrations, the stream is annually releasing between 10.6 to 14.7 kg from Great Pond. If this flow is accurate for current conditions, the pond is capturing 6.9 to 13.6 kg (approximately 30-60%) of its annual phosphorus load. Other studies on the Cape have found that ponds capture approximately 50% of their external phosphorus loads (*e.g.*, Eichner, 2008). Analysis of the sediments would provide some clarification about how this captured load is stored.

The results from the phosphorus budget require some additional clarification before management strategies are adopted and implemented. The higher annual loading estimates from the phosphorus budget analysis approximate the measured mass in the pond. If this is accurate, the mass in the pond is largely determined by external/watershed inputs and any management strategies should target these sources. This hypothesis is generally supported by the non-transposed results.

However, the lower annual loading estimates from the phosphorus budget analysis suggest that there is an internal, sediment source of phosphorus that is necessary to match the

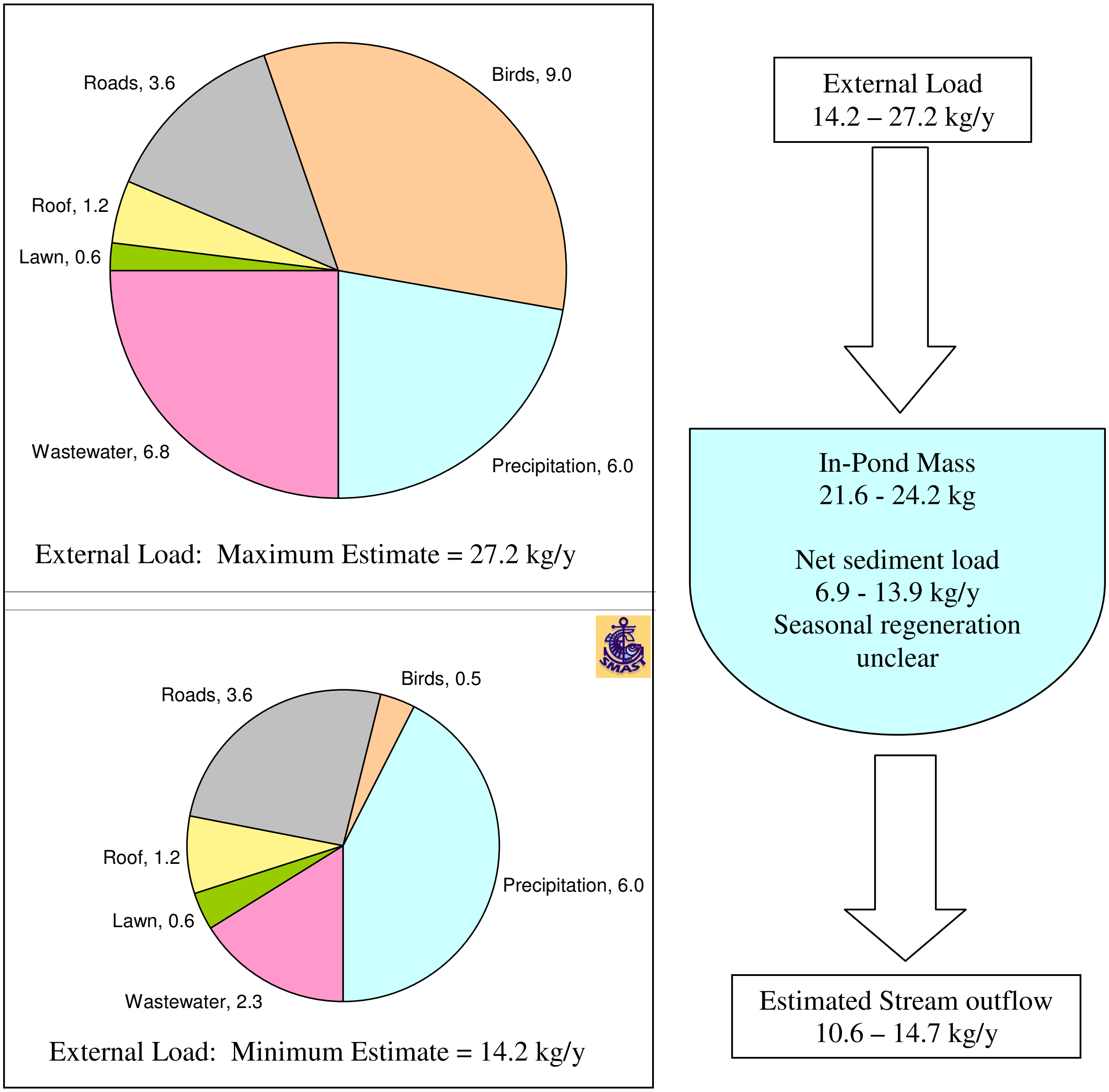


Figure VI-5. Estimated phosphorus budget for Great Pond

In -lake mass is based on collected 2001-2006 water quality data. Wastewater load from upgradient properties within the 300 ft buffer based on septic load travel time of 35 to 81 years. Road loads include all areas within 300 ft buffer. Bird loading has the largest range (depending on an areal or per pond estimate) and it is recommended that a bird survey be conducted to provide a Great Pond-specific estimate. Other loads based on factors from Table V-3. Stream outflow load based on BEC (1987) streamflow and 2001-2006 average surface total phosphorus concentrations. Net annual sediment load is estimated based on comparison of external load and stream outflow and is all captured by sediments. Contribution of seasonal phosphorus regeneration from the sediments is not clear from available data; it is recommended that this be measured directly through collection and testing of sediment cores.

measured concentrations in the pond. This hypothesis is supported by the transposed TP results, as well as the measured low dissolved oxygen concentrations in the hypolimnion. It is recommended that the town consider collecting sediment cores and testing the cores to see what dissolved oxygen concentrations are required to mobilize available sediment phosphorus and how much can be released. Completion of this task would help the town to clarify the phosphorus budget and, thus, accurately target water quality management activities.

Given the relative importance of streamflow in the overall phosphorus budget and the relatively impaired conditions in the pond, the budget analysis suggests that a drop in the average streamflow could make conditions in Great much worse without any increases in watershed or sediment loads. If the streamflow were somehow stopped either due to decreasing water levels or obstruction of the stream, the residence time of water in the pond could double, which would cause phosphorus concentrations to at least double and would likely lead to increased algal growth and decreased Secchi readings. Increased residence time might also cause a greater release of phosphorus from the sediments. These conditions have not been documented in Great Pond, but regular collection of streamflow readings with water quality data in the pond is recommended to better understand the relationships involved and the impact of lower water table conditions.

VI.1.2. Great Pond Conclusions and Recommendations

Great Pond is a 110-acre pond that is the largest and deepest of Eastham's ponds. Great Pond has impaired water quality according to state regulations and as such will eventually require a TMDL. Average dissolved oxygen concentrations between June and September are below state surface water standards throughout the available cold water fishery and up to the bottom of the warmer upper layer. These conditions would allow any nutrients regenerated from the sediments to mix into the warmer upper waters on a regular basis.

There are some inconsistencies among the various datasets. Some of the data (*i.e.,* Secchi readings) suggest that water quality is worsening, but TP concentrations suggest that conditions are relatively stable. Some of the shallow and deep TP concentrations appear to be transposed, but there is no definitive way to resolve this without additional data to help clarify. Streamflow out of the pond to Bridge Pond cuts the residence time of the pond in half, and keeps the TP concentrations lower than if this drain did not exist. Comparison of nitrogen and phosphorus concentrations shows that phosphorus management is the key to water quality conditions in Great Pond.

The phosphorus budget analysis does not provide a clear picture for the development of water quality management strategies unless additional information is developed. Sediment sources have the potential to be a significant portion of the phosphorus load to the pond, but the lack of consistency among the available datasets suggests that the sediment conditions and phosphorus concentrations should be betters characterized. In addition, additional evaluation of bird loading is also recommended to clarify its role in the phosphorus budget. Once sediment and bird loadings are better defined, management activities can be developed to target the phosphorus sources that are the most cost effective and achieve the largest reductions.

In order to comprehensively address the questions raised by the above review of the data, develop a TMDL, and be able to appropriately target water quality management activities, it is recommended that the town consider a targeted data collection to address the management uncertainties. This study could build on the results discussed here with simultaneous data collected from the pond, sediments, and the stream. It is recommended that streamflow be measured at least monthly with water quality analysis using at least the PALS constituents. This sampling would be accompanied by pond samples and readings using the standard PALS protocols. It is also recommended that this study should include coincident sediment core analysis and bird evaluation recommended above so a more complete evaluation of conditions throughout the pond occurs. SMAST staff are available to discuss development of a scope for such a study with town officials.

The results of this study would provide more definitive management guidance for water quality in Great Pond, but the above analysis also shows that there are existing management steps that should be pursued now: a) maintaining the stream outflow and b) pursuing best management practices for properties around the pond. Maintaining streamflow out of the pond is an essential management activity in the short term to ensure that water quality does not worsen in the pond; even a partial obstruction of the outflow will worsen water quality . In addition, although the target watershed reductions are not clear at this point, application of relatively low cost, best management practices around the pond shoreline would help to reduce external loads. These practices would include: 1) maintaining, planting, or allowing regrowth of natural buffer areas between the pond and lawns/yards/houses, 2) installing treatment for or redirecting any direct stormwater runoff, and 3) ensuring that all new or upgraded septic system leachfields have an adequate setback from the pond (at least 300 feet or the maximum possible on a lot). The Brewster Board of Health approved a 300 ft or maximum available setback regulation that could provide some guidance if Eastham wishes to explore this option. Review of the potential benefits and costs of the various options could be evaluated as part of a slight expansion of the recommended targeted study.

During the course of deliberations about remedial options and prior to further study, it is further recommended that the town continue to maintain a volunteer pond water quality monitoring program and that Great should be part of it. Given the amount of volunteer data that has already been collected from Great, it is recommended that this sampling be limited to a minimum of two sampling runs conducted each year using the PALS sampling protocol and the parameters measured. It is suggested that these runs be completed during April and August/September (the latter being the usual PALS Snapshot period). This type of in-lake sampling schedule would create annual data to assess how the ecosystem is set prior to the active summer period (the April run) and then measure conditions during the likely worst-case water quality conditions (the August/September run). Comparison of this data to prior data would provide a better sense of interannual ecosystem fluctuations, measures to assess the benefits of any remedial activities that are undertaken, and provide an "early warning" if conditions worsen significantly. It is further recommended that collected data be reviewed and interpreted at least every five years in order to provide regular feedback and assessment of pond conditions.

SMAST staff are available to assist the town with the completion of any of the actions recommended for consideration and can provide a detailed cost proposal if requested.

VI.2. Herring Pond

VI.2.1. Herring Pond Review and Discussion

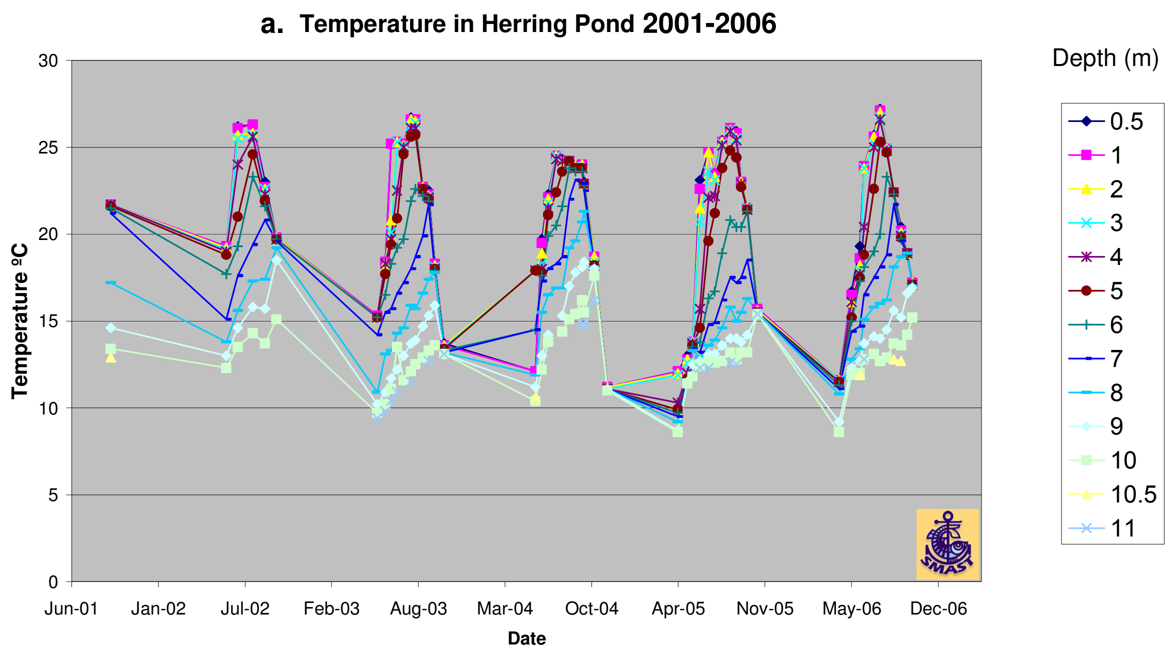
Herring Pond is a 44-acre pond that is the second largest and second deepest pond in the Town of Eastham after Great Pond. It is located to the south of Great and west of Route 6 (see Figure V-1). Herring's deepest point is 35 ft (10.7 m). Water quality in Herring was reviewed as part of a diagnostic/feasibility study (BEC, 1991) and field readings were also collected once in 1948 (MADFG, 1948). Given its depth, it thermally stratifies usually starting in late May/early June (Figure VI-6). The upper layer continues to warm throughout the summer and this warmth is mixed throughout the upper layer (*i.e.*, the epilimnion). This warmer layer gradually thickens throughout the summer, generally starting with the upper 3 to 4 m in June and deepening to 5 or 6 m by September. Once stratification sets up, oxygen consumption from the sediments regularly creates anoxic (<1 ppm) conditions in the deepest portions of the pond with concentrations generally less than state standards in waters 8 m and below. By the end of September/early October, when thermal stratification begins to breakdown, anoxic conditions can reach as high as 7 m in depth.

Since Herring Pond thermally stratifies and has a portion of the water column with an average summer temperature below 20ºC, it has the potential to sustain a state-defined, cold-water fishery. State surface water regulations (314 CMR 4) require cold-water fisheries to attain a 6 ppm dissolved oxygen standard and have temperatures less than 20ºC.

Based on average conditions for June through September from data collected between 2001 and 2006, the 6-ppm dissolved oxygen standard is usually met in Herring Pond down to a depth of 7 m (Figure VI-7). Waters 8 m and deeper are less than the state 6 ppm dissolved oxygen standard the majority of the time between June and September; these waters are 8% of the pond volume (Figure VI-8). Since average temperatures exceed 20ºC at depths at 6 m and above, the potential cold water fishery is below this depth. Comparisons of the dissolved oxygen and temperature readings means that average summer conditions have approximately 1 meter (between 7 and 8 meters in depth) worth of acceptable cold water fishery in Herring Pond.

Review of the minimum dissolved oxygen readings show that even this relatively thin cold fishery is regularly lost during the summer. The minimum dissolved oxygen reading at 7 m is 0.6 ppm, which is anoxic, and 35% of the readings at 7 m are less than the state 6 ppm standard. Anoxic conditions, which are usually lethal to fish even on a temporary basis, reached as shallow as 6 m. The regular lack of sufficient oxygen and occasional anoxic conditions suggests that Herring's cold water fishery is not sustainable and reinforces the classification of Herring as impaired under state surface water regulations.

A single dissolved oxygen profile collected by the Massachusetts Division of Fisheries and Game on August 26, 1948 suggests that conditions have worsened since 1948. Deep water anoxia similar to the 2001-2006 average conditions existed in 1948, however since August conditions are generally among the worst case conditions, comparison of the 1948 profile and the minimum readings between 2001-2006 show that approximately 2 m more of the water column is anoxic now (see Figure VI-7). Comparison of other monitoring from MADFG (1948) to 2001 PALS Snapshot results generally shows worsening conditions in ponds across Cape Cod (Eichner and others, 2003).



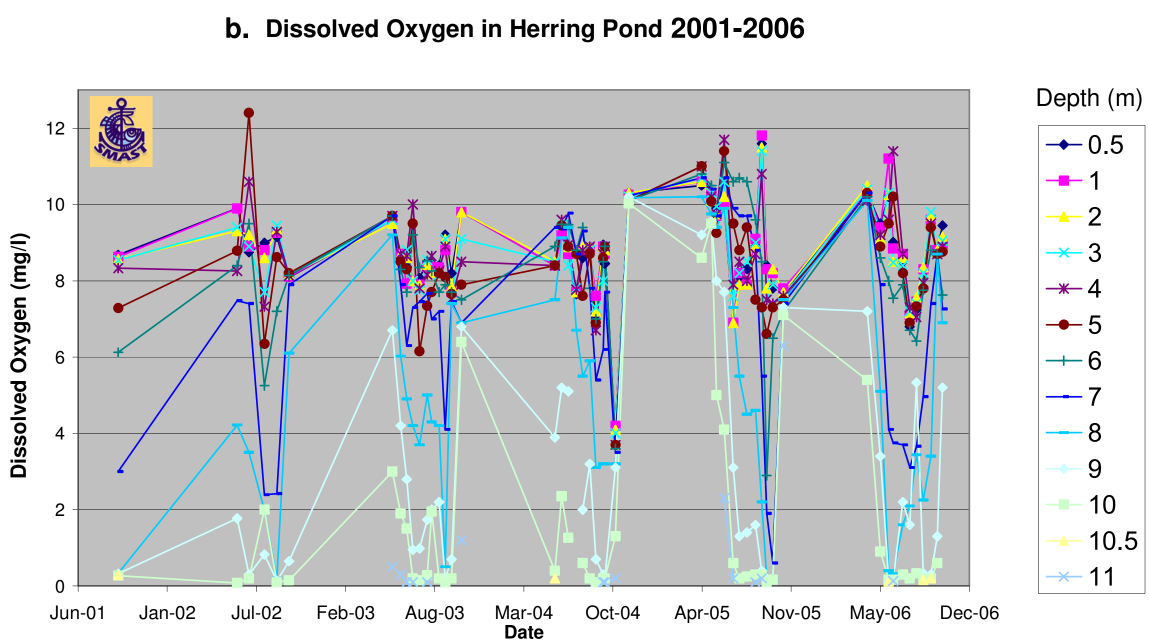


Figure VI-6. Herring Pond Temperature and DO Readings 2001-2006
Temperature data shows that the upper water column is well mixed with temperatures increasing during summers, while the deeper waters get colder with increasing depth. During early spring and late fall, water temperatures are relatively constant throughout the water column. Dissolved oxygen concentrations show lower concentrations with increasing depth and regular anoxic (<1 ppm) concentrations during the summer. Data collected by Eastham volunteers using DO/Temp meters. These graphs include data documented in Eichner and others (2003) and PALS Snapshots from 2001 to 2006.

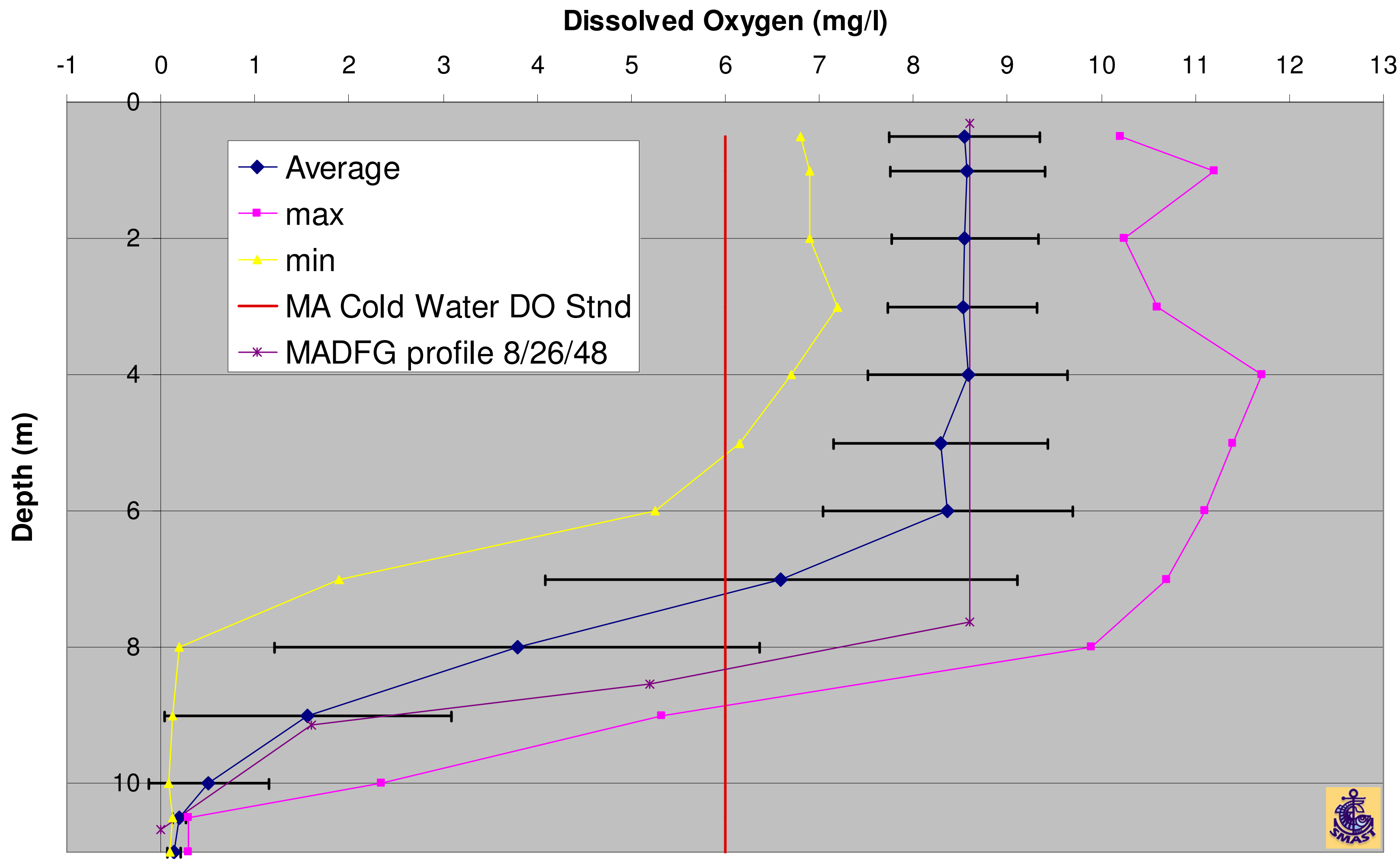


Figure VI-7. Average dissolved oxygen concentrations in Herring Pond (June through September, 2001-2006)
Graph shows average DO profile based on data collected by town volunteers between 2001 and 2006 with error bars (±1 standard deviation) plus maximum and minimum readings for each depth. Also shown is August 26, 1948 profile (MADFG, 1948) and the state surface water 6-ppm DO standard for cold water fisheries (310 CMR 4). Average concentrations at most depths are based on 35 readings collected between 2001 and 2006.

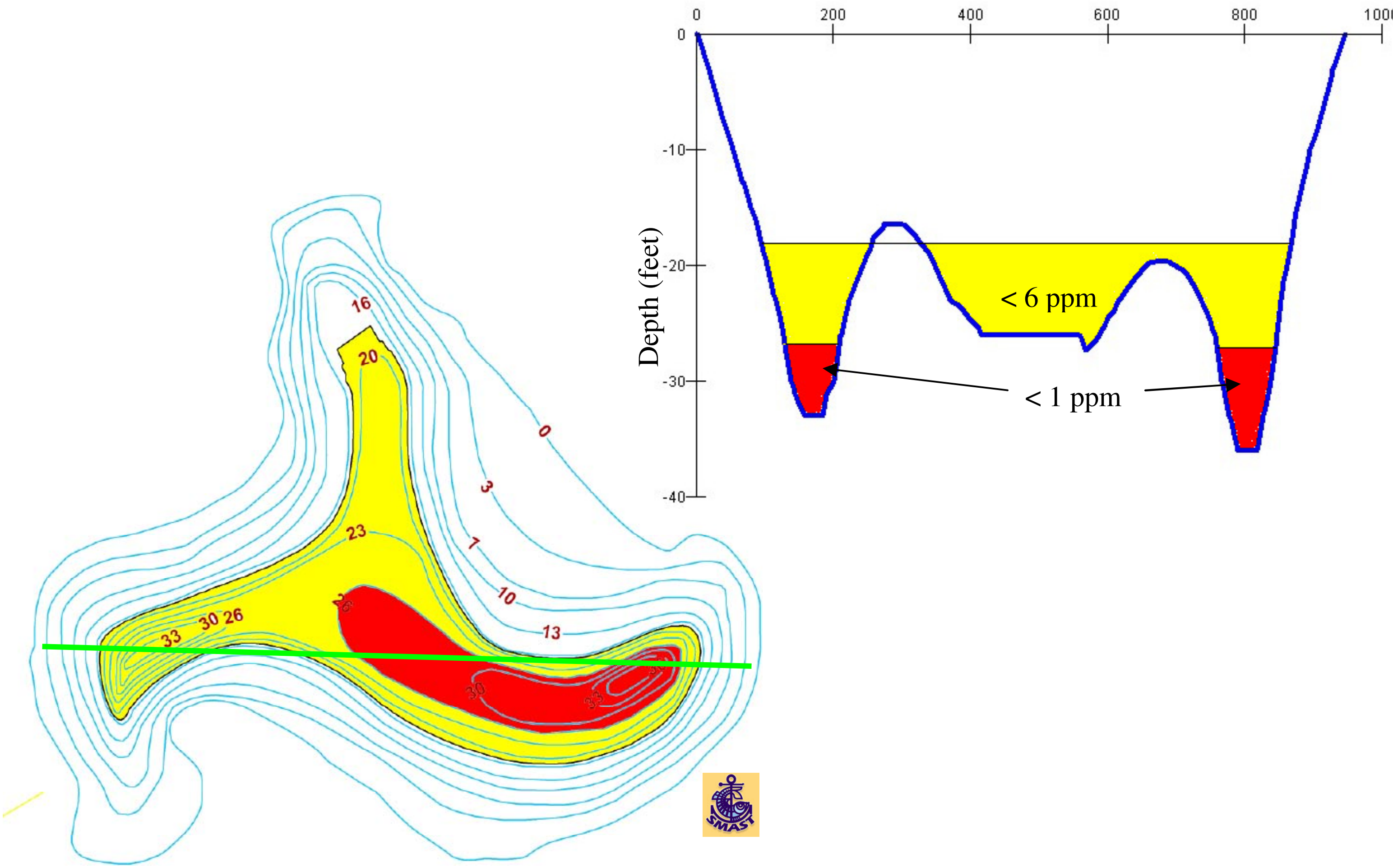


Figure VI-8. Herring Pond: Comparison of average dissolved oxygen (June through September) and state surface water standards

Depth profile and bathymetric map showing volume and area of Herring Pond that has an average dissolved oxygen concentration between June and September that is less than surface water 6-ppm DO standard for cold water fisheries (shaded yellow) and areas that are anoxic (<1 ppm) (shaded red). Green line on map shows depth profile track that corresponds to the cross-section. Bathymetry is from BEC (1991).

Dissolved oxygen data collected during the diagnostic/feasibility study of Herring (BEC, 1991) generally agree with the average conditions shown in Figure VI-7. BEC (1991) also found that deep dissolved oxygen concentrations during the 1988 winter did not meet the state 6 ppm standard, while during the 1989 winter they did. Volunteer data between 2001 and 2006 found that bottom dissolved oxygen concentration met the 6 ppm standard during 4 of the 5 winters. These results reinforce the need to monitor water quality over longer periods in order to account for year to year fluctuations and also suggest that sediment oxygen demand in Herring is strong enough to have influence on the pond water quality throughout the year.

Secchi readings average 3.4 m between June and September (n=38) during the 2001-2006 dataset (Figure VI-9). Average sampling station depth is 10.8 m and on average 32% of the overall water depth is clear enough at the sampling station to see a Secchi disk. Both station depth and Secchi readings have very small downward trends (0.1-0.2 m/yr) between 2001 and 2006, but both are insignificant. The direction of the trend is surprising for the depth readings given that groundwater levels generally increased during the sampling period and Cape Cod pond levels tend to match groundwater level movements. This relative lack of trend for station depth readings may be due to Herring's close proximity to the coast; water levels close to the coast tend to fluctuate within a smaller range than those closer to the peak of the aquifer lens (Frimpter and Belfit, 1992). Secchi readings do fluctuate significantly; the coefficient of variation for Herring is 44% as opposed to an 18% coefficient of variation for Secchi readings in Great. This high variability suggests that the pond ecosystem is unstable and more unstable systems tend to be impaired (*e.g.*, Eichner, 2004). Secchi readings have an overall range from 0.73 to 6.5 m. As mentioned previously, the lower end of this range fails to meet the clarity requirements for safe swimming in Herring (see Figure III-2).

The average Secchi readings during 2001 through 2006 are less than the readings during the diagnostic/feasibility study (BEC, 1991), but it is not statistically significant difference (t-test $\rho<0.52$). The lack of significant difference is likely due to the high variability in the readings. The June through September average Secchi reading from the BEC (1991) study, which is based on data gathered between April 1988 and March 1989, is 4.1 m (n=8), as opposed to the 2001 to 2006 data average of 3.4 m (n=38). For comparison, the Secchi reading on August 20, 1948 was 5.49 m (MADFG, 1948).

Average total phosphorus (TP) concentrations in Herring Pond between June and September are greater than both the Cape Cod-specific pond thresholds (7.5 ppb "unimpacted" and 10 ppb "healthy") at all four sampling depth stations: 14.8 ppb at 0.5 m (n=21), 12.9 ppb at 3 m (n=18), 32.6 ppb at 9 m (n=15), and 56.4 ppb at the deepest station (n=18). The average depth of the deepest station, which sampling protocol requires be 1 m off the bottom, is 10.0 m (n=18). The gradient of increasing TP concentrations with increasing depth are consistent with the measured low DO conditions; low dissolved oxygen mobilizes iron-bound forms of phosphorus and allows regeneration of phosphorus from the pond sediments into the overlying water.

As with Great Pond, average TP concentrations from volunteer data from Herring are much lower than corresponding BEC (1991) averages; average concentrations are 58-66% lower in the 2001-2006 dataset. There is also a larger difference in shallow and deep concentrations in

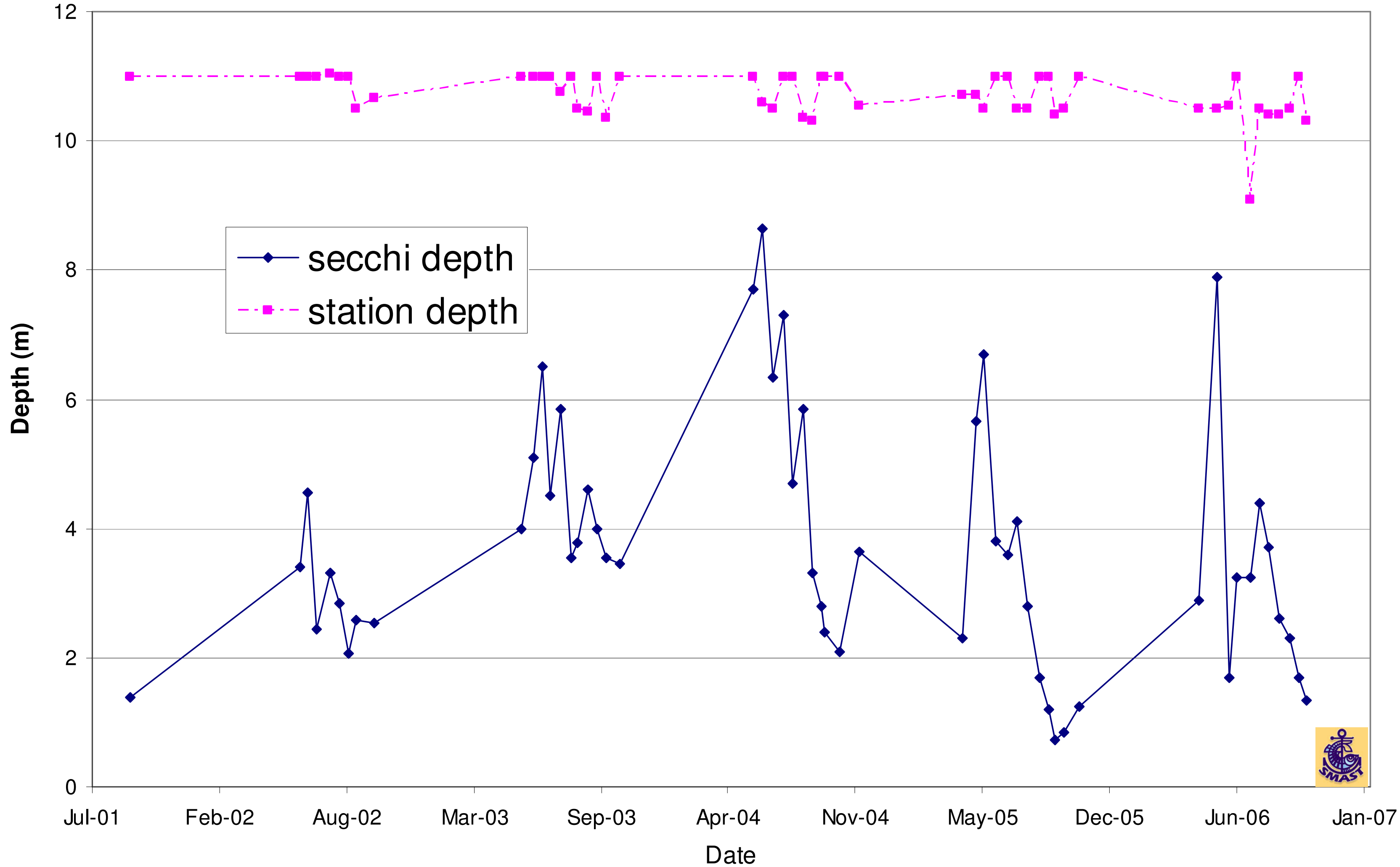


Figure VI-9. Secchi transparency readings in Herring Pond 2001-2006
Blue data points are Secchi depth readings, while station depth measurement are shown in pink. All data collected by Eastham volunteers. Station depth and Secchi depth have insignificant downward trends over the sampling period. Secchi readings are extremely variable (coefficient of variation = 44%).

the newer dataset: the shallow average TP concentration is 26% of the deeper average, while the corresponding percentage for the BEC (1991) dataset is 71%. As with the data from Great, these differences suggest that there are some issues with differences in lab methods (*i.e.*, more refined techniques are commonly available now).

Ratios of total nitrogen to total phosphorus in June and September average 90 in the upper waters and average 89 for all surface data. BEC (1991) had an average of TN:TP ratio of 57 in the surface waters for readings between June and September and an average ratio of 62 for all surface data collected during the study period. Since all of these average ratios are multiples of the Redfield ratio of 16, on average during the summer and throughout the year the pond is phosphorus limited and, as such, phosphorus should be the target nutrient for managing water quality in Herring Pond.

The total mass of phosphorus in Herring between June and September averages 21.9 kg (n=19) and 20.4 kg (n=25) for all available data. Of this mass, 55% and 59%, respectively, is contained in the well-mixed upper layer. Based on the water quality data, the range of phosphorus mass in the pond between June and September is 5.9 to 48.2 kg, while the range of all the data is between 3.6 and 48.2 kg. Although the concentrations differences between the BEC data and the current dataset make direct comparisons awkward, the percentage of phosphorus in the well-mixed upper layer during 1988-89 was 70% in June through September and 76% for all the BEC (1991) data. This comparison suggests that the sediments are an increasing source of the phosphorus in the pond.

In order to begin to frame an appropriate water quality management strategy, all the sources of phosphorus should be identified and this is usually done through the development of a phosphorus budget. Results from the phosphorus budget are then compared to the mass of phosphorus in the pond to assess the assumptions in the loading factors and develop a better understanding of the functions within an individual pond. In order to begin to develop a watershed phosphorus budget for Herring, town volunteers reviewed Board of Health (BOH) records to determine the distance between the pond and septic system leachfields for all properties within 300 feet of the pond (see Figure V-4), the age of the septic systems, and the age of the houses. Volunteers also noted any large lawn areas or any other notable potential sources of phosphorus close to the pond. Once this information was developed, project staff narrowed the list to the properties that are upgradient of the pond (*i.e.*, in the watershed) and used the factors in Table V-3 to estimate a watershed phosphorus load to Herring Pond.

As mentioned previously, phosphorus travel through an iron-rich aquifer, like Cape Cod's, is slower than groundwater, and is estimated to take 35 to 81 years to travel 300 feet (Robertson, 2007). Project staff compared this range of times to the septic system information developed by the town volunteers and determined whether it was likely that a septic system or a house is currently contributing phosphorus to the pond or whether the phosphorus from the property is still in transit in the aquifer.

Based on the land use review, there are 26 properties within the 300 ft buffer upgradient of Herring Pond. Twenty of the properties have residential development (19 are single family residences) with an average age of 40 years old and a range of years built from 1924 to 2004.

There is one property classified by the town's Assessor as developable residential and one more that is classified as undevelopable residential. The average age of the septic systems on the developed lots is 12 years old with year of installation ranging between 1967 and 2004. The average distance to the pond for the nineteen properties with leachfield plans filed with the BOH is 171 feet with a range of 105 to 300 feet.

Based on the age of the houses on the 20 developed properties, 15 of them have existed long enough to contribute phosphorus to the pond if one assumes that it takes 35 years for phosphorus to travel 300 ft, while 10 contribute phosphorus if it is assumed that the phosphorus travel time is 81 years. Since the septic systems are usually younger than the houses, the expected contributions are lower if these are considered: four are contributing phosphorus to the pond if the time of travel is 35 years and none are contributing phosphorus to the pond if the time of travel is 81 years.

Using the factors in Table V-3 and accounting for the range of groundwater lag times, the current external/watershed load to Herring is estimated to be between 7.7 and 17.6 kg/yr. Of this, wastewater from septic systems is between 0 and 6.8 kg/yr (0 to 47%) of the watershed load. Other portions of external loads into the pond are lawns (4 to 8%), roof runoff (8 to 18%), birds based on an areal loading rate (21 to 33%), birds based on the per pond load (3 to 15%), and roads (15 to 35%) (Figure VI-10). Steady state load under current conditions is calculated as 16.3 to 19.4 kg/yr and buildout loading is projected to be 18.4 to 21.5 kg/yr. Uncertainties associated with the loading factors are discussed in the phosphorus budget factors section (see Section V.3.).

Of these loading sources, bird loading is the most uncertain. Given how this could impact management strategies, it is recommended that the bird contribution should be clarified by regular counts (daily or monthly) of bird species and numbers on Herring Pond throughout a whole year. Such a study, which is beyond the scope of the current analysis, would be necessary to provide a better understanding of this component of the phosphorus budget . This type of effort could be accomplished by volunteers who are trained or have training to identify the likely bird species and have the ability to view the entire lake. SMAST staff can provide guidance to the town for resolving this issue.

The residence time for Herring is 2.7 years. As noted in the water budget calculations this includes flow from the watersheds to Jemima, Long, and Herring, but no flow from Great since the stream to Bridge drains all of Great's inflows. Herring's residence time means that the average mass of phosphorus measured in the pond should be approximately 2.7 times the annual external loads from the watershed and precipitation plus any phosphorus regenerated from the sediments. The total mass of phosphorus in the pond based on water quality measurements between June and September averages 21.9 kg (n=19) and 20.4 kg (n=25) if all data is considered. Of this mass, 55% or 59%, respectively, is contained in the well-mixed upper layer. Based on this residence time and the 10 ppb TP Cape Cod-specific threshold, the target phosphorus mass in the Herring would be 8.9 kg.

Based on a residence time of 2.7 years and the average surface total phosphorus concentration of 14.8 ppb, the annual load that is projected to enter Herring Pond from external

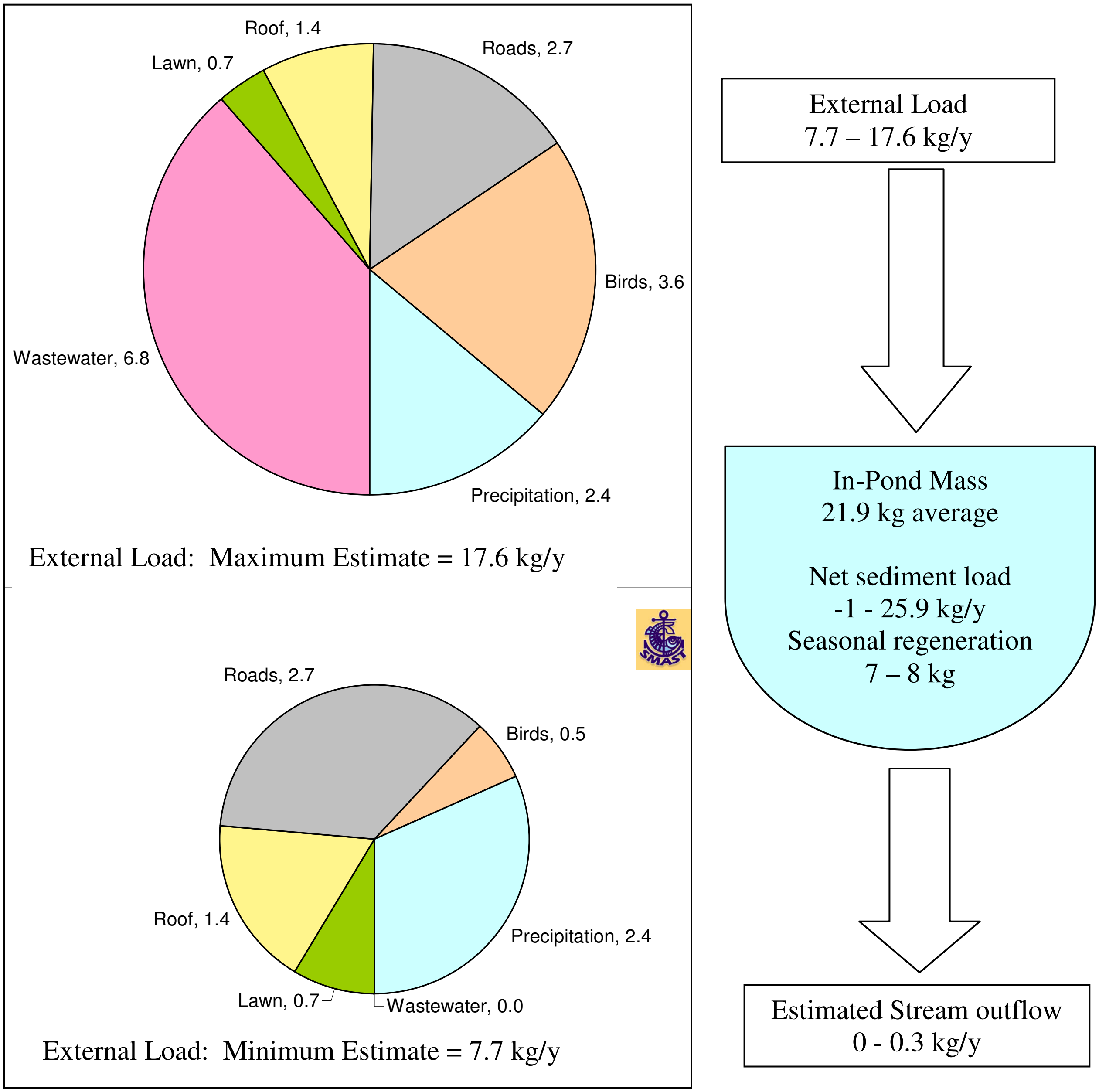


Figure VI-10. Estimated phosphorus budget for Herring Pond
In-lake mass is based on collected 2001-2006 water quality data. Wastewater load from upgradient properties within the 300 ft buffer based on septic load travel time of 35 to 81 years. Road loads include all areas within 300 ft buffer. Wastewater and bird loading have the largest range. Bird loading depends on an areal or per pond estimate and it is recommended that a bird survey be conducted to provide a Herring Pond-specific estimate. Wastewater factors loading factors are reasonably well understood, so time of travel is likely the key variable in the estimate of wastewater load; steady-state wastewater load is projected to be 8.6 kg/y. Other loads based on factors from Table V-3. Stream outflow load based on BEC (1991) streamflow and 2001-2006 average surface total phosphorus concentrations. Net sediment load is based on comparison of external load and stream outflow. Contribution of seasonal phosphorus regeneration from the sediments is estimated from available data; it is recommended that this be measured directly through collection and testing of sediment cores.

sources would be 4.9 kg. This estimate assumes that sediment loads are not impacting surface concentrations, but it suggests that 7 to 8 kg of total phosphorus mass measured in the pond at any given time is due to sediment regeneration. Most of this regeneration appears to occur later in the summer (Figure VI-11). Comparison of this result to the phosphorus loading estimates also suggests that unless watershed management activities to reduce phosphorus are implemented, the mass in the pond will significantly increase as more watershed sources eventually reach the pond.

Even with significant fluctuations throughout the summer, review of the trends for the mass of phosphorus in Herring show that the mass in the pond water increased significantly ($\rho<0.05$) between 2001 and 2006 (Figure VI-12). The rate of increase is 2.2 kg/y or 9% of the average total mass. This finding suggests that regeneration of phosphorus from the sediments is increasing and/or delayed wastewater loads are finally beginning to reach the pond.

Evaluating which of these is the primary source is beyond the scope of this current project, but resolving their impacts is very important for planning future management activities. Gaining an understanding of the sediment release will be the lowest cost alternative, so it is recommended that the town consider a targeted data collection that includes collection of sediment cores and testing of the cores to gauge the maximum amount of expected phosphorus release from the sediments and the dissolved oxygen conditions that would cause this release to occur. Sediment sampling would involve collecting sediment cores at three or more locations in the pond and incubating these cores using a set of criteria to evaluate phosphorus regeneration.

While the data available at this point suggest that the sediment interaction is the key for effective management in Herring Pond, the town may want to consider a couple of additional steps to provide a more comprehensive basis for developing and implementing management strategies. A recently completed study of Lake Wequaquet in Barnstable suggested that a rise in phosphorus might also be due to a significant loss of rooted plants around the shoreline of the lake (Eichner, 2008). Loss of the rooted plants would allow phosphorus that was otherwise stored in their tissues to be released back to the water column and lead to additional phytoplankton growth. Herring's average surface chlorophyll *a* concentration from the 2001-2006 dataset is double the BEC dataset average. To help address this issue, it is recommended that the town consider evaluation of the plant community (rooted plants, epiphytes, and phytoplankton). In addition, review and testing of shoreline stormwater inputs and more frequent measurement and testing of the stream outflow would allow the town to refine these portions of the phosphorus budget and allow the over all management based on the budget to be more clearly defined.

SMAST staff are available to assist the town with the completion of any of the actions recommended for consideration and can provide a detailed cost proposal if requested.

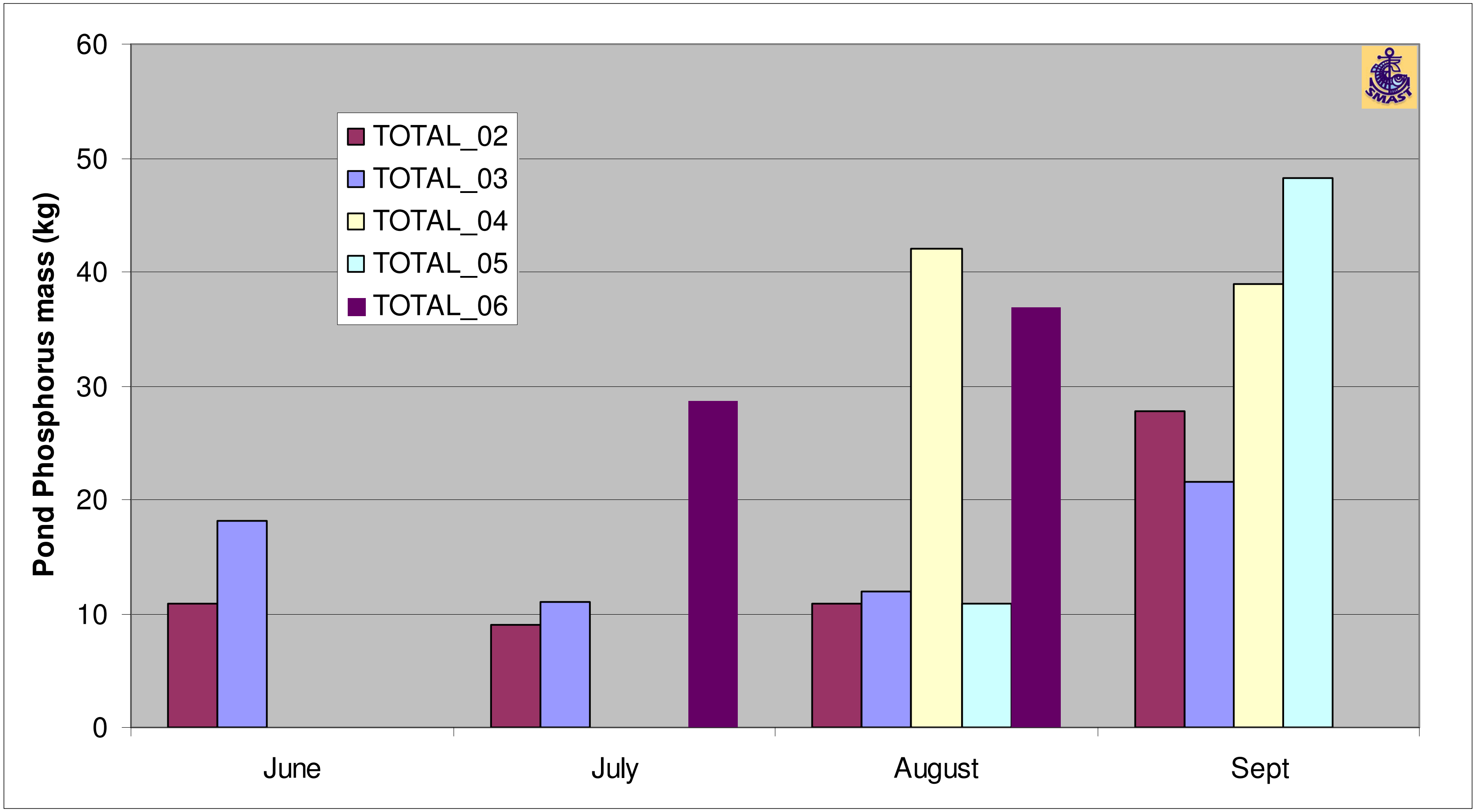


Figure VI-11. Monthly mass of phosphorus in Herring Pond June through September 2002 to 2006
Mass of phosphorus based on laboratory concentrations and volumes for various depths. Samples taken at surface (0.5 m), 3 m, 9 m, and deep (1 m off bottom); 0.5 m concentration assigned to upper volume (0-2 m), 3 m concentration to 3-5 m volume, and average of 9 m and deep concentration to 6 m to bottom volume. Results generally show increase in mass of phosphorus in pond as summer progresses likely due to sediment regeneration.

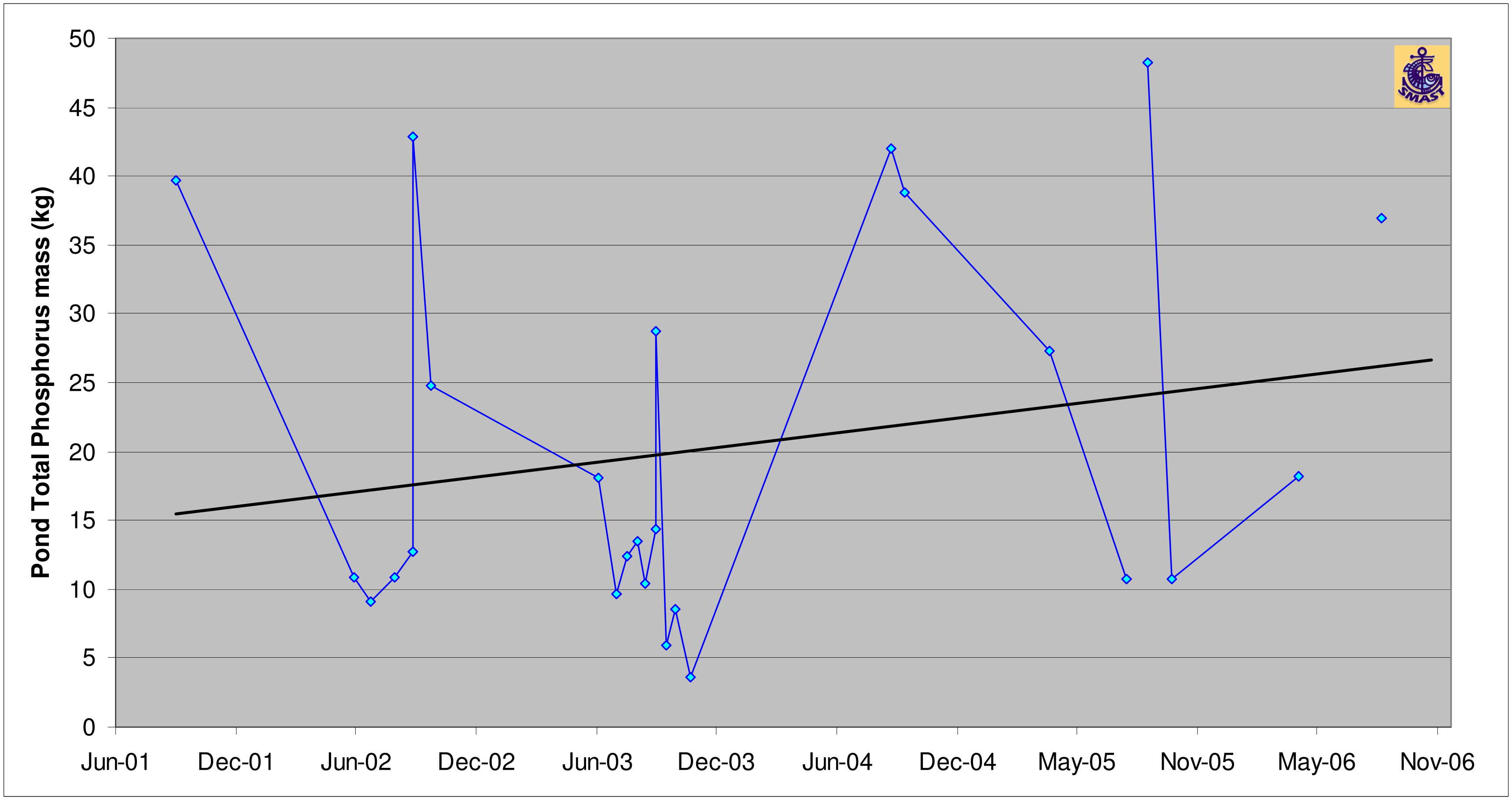


Figure VI-12. Mass of phosphorus in Herring Pond 2001 to 2006

Mass of phosphorus based on laboratory concentrations and volumes for various depths. Samples taken at surface (0.5 m), 3 m, 9 m, and deep (1 m off bottom); 0.5 m concentration assigned to upper volume (0-2 m), 3 m concentration to 3-5 m volume, and average of 9 m and deep concentration to 6 m to bottom volume. Total mass fluctuates significantly likely due to inconsistent sediment releases. These fluctuations result in a relationship with a fairly low r^2, but with an upward trend of 2.2 kg/y.

VI.2.2. Herring Pond Conclusions and Recommendations

Herring Pond is the second largest (44 acres) and second deepest (12 m) pond in Eastham. Based on a review of the available data, Herring Pond has impaired water quality and does not meet the state's regulatory thresholds under the surface water regulations and, as such, will eventually require a TMDL. Although the pond supports a limited cold water fishery based on average conditions, the high frequency of unacceptable low dissolved oxygen throughout these waters means that this fishery is unsustainable.

Water column measurements show that low dissolved oxygen conditions are causing the release of phosphorus from the sediments, in some cases doubling the phosphorus mass in the pond by the end of the summer. Annual phosphorus budget calculations indicate that the pond is an efficient trap for phosphorus, but water quality readings show that an increasing mass of collected phosphorus is making its way back into the water column during the summer . Secchi readings suggest that the pond ecosystem is highly unstable, which would be consistent with a pond that has a significant internal source of phosphorus readily available from the sediments.

The increasing phosphorus in the water column appears to due a combination of wastewater phosphorus beginning to reach the pond and increasing sediment regeneration, but available data is insufficient to determine which is the predominant source. Direct measurement of sediment regeneration is the lowest cost option to provide better assessment of management strategies and can be accomplished by SMAST staff. It is recommended that this should be pursued at a minimum.

In order to move water quality management for Herring forward in a more comprehensive fashion and provide the basis for development of a TMDL, it is also recommended that sediment regeneration analysis be paired with a targeted measurement of some of the other key factors in the phosphorus load. In addition to sediment phosphorus regeneration, these would include: 1) evaluation of the plant community to gauge whether there have been significant changes since the BEC (1991) study and whether loss of rooted plants might also be a cause of increasing phosphorus loads, 2) direct evaluation and measurement of stormwater phosphorus inputs to accurately gauge this source, and 3) concurrent stream gauging and water quality measurement to assess phosphorus outflows. This targeted study would also be complemented by a year-long bird counting and identification study, which could be developed as a volunteer activity and would help to refine this portion of the phosphorus budget.

Even with the uncertainties in the sources and their magnitudes, it is clear that future management activities will have to address phosphorus from both sediment sources and watershed loads. Sediment sources are typically addressed either by: 1) adding oxygen to the near-sediment waters that keeps the phosphorus bound to iron or 2) through addition of a chemical, such as alum, that binds the phosphorus. Alum applications on Cape Cod has been completed in Hamblin Pond in Barnstable and Long Pond in Brewster/Harwich and another is planned for Mystic Lake in Barnstable. Hypolimnetic aeration has not been permanently installed on the Cape although a number of communities have used smaller systems and a whole lake aeration effort is currently underway in Skinequit Pond in Harwich. Review of potential sediment treatment options that have been completed in Massachusetts is contained in a state Generic Environmental Impact Report (Mattson and others, 2004) . Typically an analysis all potential sediment treatment options and costs is completed following a complete review of the individual pond's physical characteristics and water quality conditions. The targeted data collection recommended above will complete such a review and provide the basis for developing treatment costs.

Watershed loads are typically addressed through the implementation of best management practices, which are also usually the lowest cost alternatives. These practices include: 1) maintaining, planting, or allowing regrowth of natural buffer areas between the pond and lawns/yards/houses, 2) installing treatment for or redirecting any direct stormwater runoff, and 3) ensuring that all new septic system leachfields have an adequate setback from the pond (at least 300 feet or the maximum possible on a lot). If the town pursues sewering in this area as a result of current wastewater planning, this would remove the wastewater portion of the watershed load. The Brewster Board of Health approved a 300 ft or maximum available setback regulation that could provide some guidance if Eastham wishes to explore this option. Review of the potential benefits and costs of the various options could be evaluated as part of a slight expansion of the recommended targeted study.

Finally, it is further recommended that the town continue to maintain a volunteer pond water quality monitoring program and that Herring should continue to be part of it. Given the amount of volunteer data that has already been collected in Herring, it is recommended that this sampling be limited to a minimum of two sampling runs conducted each year using the PALS sampling protocol and the parameters measured. It is suggested that these runs be completed during April and August/September (the latter being the usual PALS Snapshot period). This type of in-lake sampling schedule would create annual data to assess how the ecosystem is set prior to the active summer period (the April run) and then measure conditions during the likely worst-case water quality conditions (the August/September run). Comparison of this data to prior data would provide a better sense of interannual ecosystem fluctuations, measures to assess the benefits of any remedial activities that are undertaken, and provide an "early warning" if conditions worsen significantly. It is further recommended that collected data be reviewed and interpreted at least every five years in order to provide regular feedback and assessment of pond conditions.

SMAST staff are available to assist the town with the completion of any of the actions recommended for consideration and can provide a detailed cost proposal if requested.

VI.3. Muddy Pond

VI.3.1. Muddy Pond Review and Discussion

Muddy Pond is a 10.5-acre pond located to the east of Herring Pond and west of Route 6 (see Figure V-2). It is the shallowest of the ponds selected from detailed review with a deepest point of 1.6 meters (5.2 feet). The citizen collected data reviewed in this report appears to be the only available water quality data for Muddy Pond; project staff reviewed available Cape Cod Commission, state, and federal pond water quality data sources and found no other Muddy Pond water quality data.

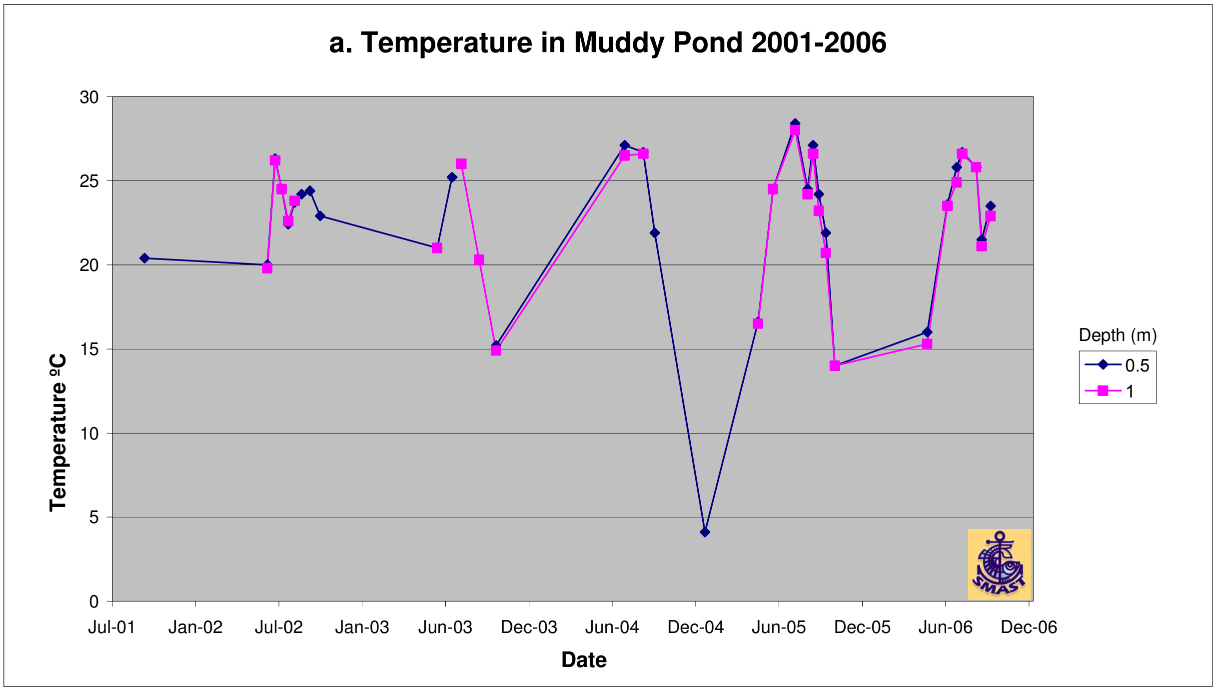
Since Muddy Pond is shallow, the water column temperatures should be consistent from the surface to the bottom; temperature data collected between 2001 and 2006 generally shows the same temperatures at 0.5 m and 1 m (Figure VI-13). Given its temperatures and shallow depth, Muddy Pond would be classified as a warm-water fishery by the state. State surface water regulations generally define warm-water fisheries as having maximum mean monthly temperature exceeding 68°F (20°C) during the summer months and are not capable of sustaining a year-round population of cold water fisheries (314 CMR 4). Average Muddy Pond temperatures in the 2001 to 2006 dataset between June and September are 24.2°C at 0.5 m (n=25) and 24.1°C at 1 m (n=22).

Muddy Pond meets the state dissolved oxygen standard for the best water quality. The best quality warm water fisheries are required under state surface water regulations to have dissolved oxygen concentrations of 5 milligram per liter or greater; 5 mg/l is equivalent to 5 parts per million (ppm). Average dissolved oxygen concentrations in the 2001 to 2006 dataset between June through September are 7.5 ppm at both the 0.5 and 1 m depth stations. Only one reading of 20 at the deepest station was below the state 5 ppm standard (see Figure VI-13).

Although Muddy Pond meets the state dissolved oxygen standards, readings that would indicate impacts before dissolved oxygen thresholds are crossed, such as Secchi depth or nutrient concentrations, should also be considered. Secchi readings average 1.1 m between June and September (n=28) during the 2001-2006 dataset (Figure VI-14). Average sampling station depth is 1.6 m and on average 71% of the overall water depth is clear enough at the sampling station to see a Secchi disk.

Both station depth and Secchi readings have increasing trends between 2001 and 2006. These trends are larger than the increasing trend observed in water levels at EGW37 (see Figure V-1 for well location), but that might be expected given that Muddy is closer to the groundwater divide between Nauset Marsh and Cape Cod Bay and greater fluctuations are generally seen at the top of the Cape's groundwater lens (Frimpter and Belfit, 1992). Review of the relative Secchi readings, or the percentage of total depth for each Secchi reading, generally indicate that the increasing trends for station depth and Secchi depth are similar. The variation in the Secchi readings is relatively high (COV=32%), which indicates conditions affecting clarity fluctuate significantly in Muddy Pond.

Average total phosphorus (TP) concentrations in Muddy Pond between June and September are greater than both the pertinent Cape Cod-specific thresholds (7.5 ppb "unimpacted" and 10 ppb "healthy") at both sampling depth stations: 22.9 ppb at 0.5 m (n=15)



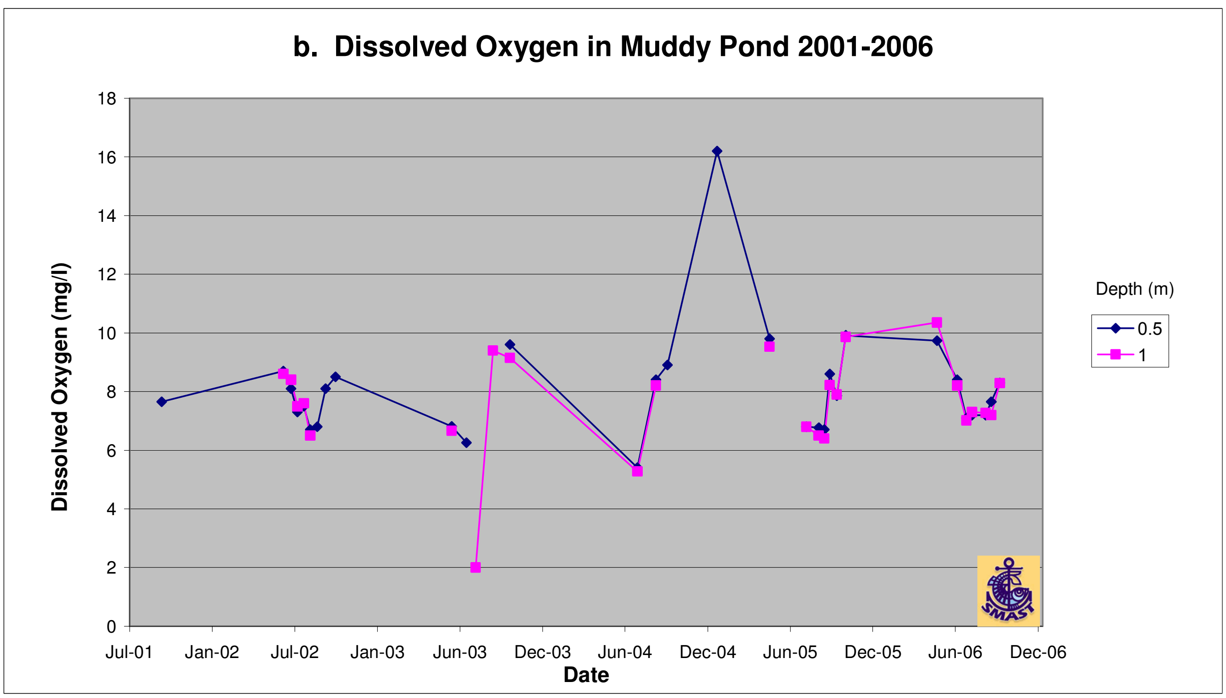


Figure VI-13. Muddy Pond Temperature and DO Readings 2001-2006
Temperature data shows that the water column is well mixed with the same temperature at the both depth stations throughout the year. Dissolved oxygen concentrations generally follow the same pattern. Data collected by Eastham volunteers using Dissolved Oxygen/Temperature meters. These graphs include data documented in Eichner and others (2003) and PALS Snapshots from 2001 to 2006.

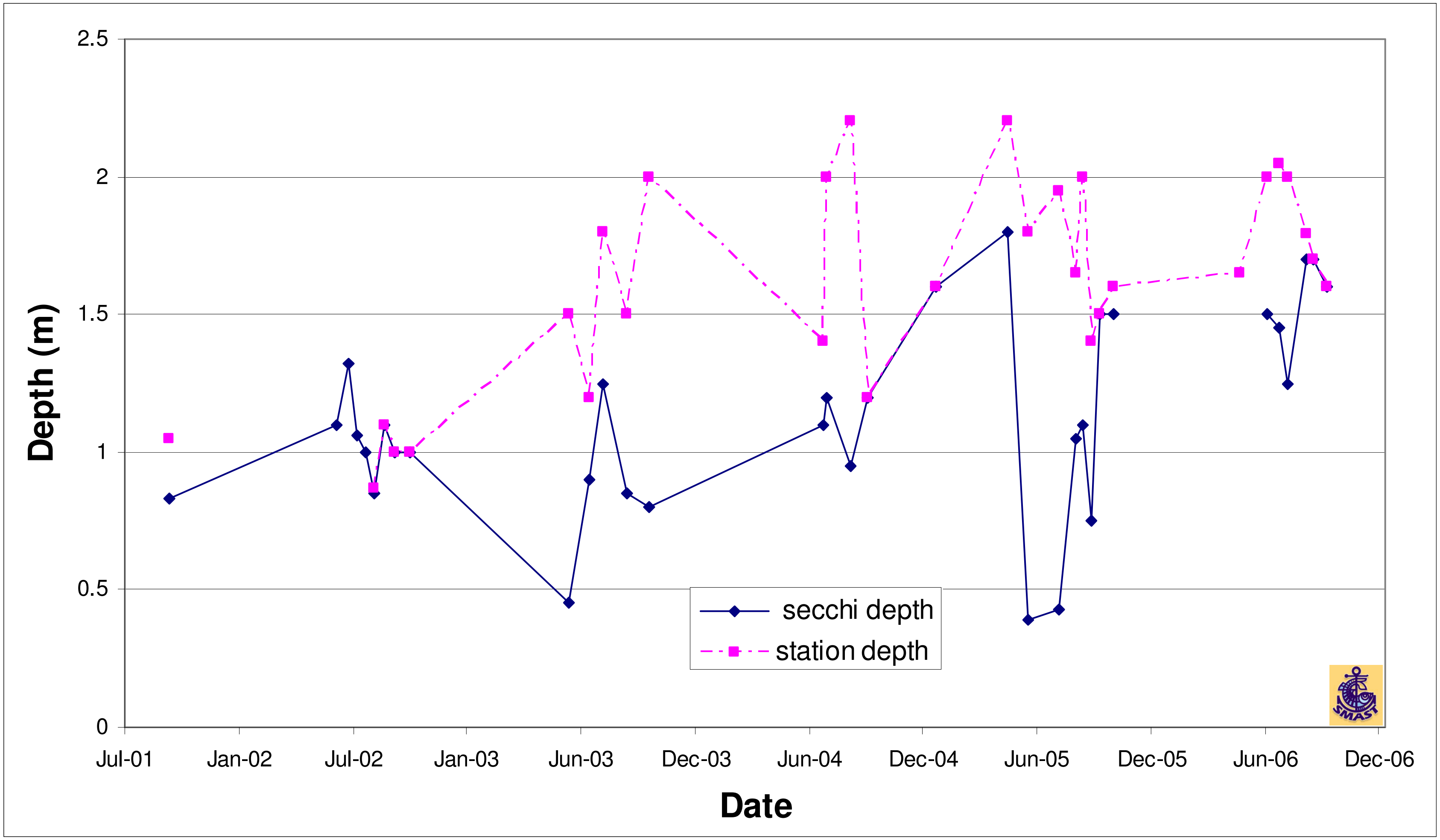


Figure VI-14. Secchi transparency readings in Muddy Pond 2001-2006

Blue data points are Secchi depth readings, while station depth measurement are shown in pink. All data collected by Eastham volunteers. Station depth and Secchi depth both have slight increasing trends over the sampling period, although neither is statistically significant. Review of relative Secchi readings show that Secchi depth and station depth are generally increasing at the same rate and that water clarity in Muddy Pond is relatively stable during the 2001 to 2006 dataset.

and 27.5 ppb at 1 m (n=12). The slightly higher TP concentrations at 1 m suggest some sediment regeneration, but the difference between the concentrations is not statistically significant and well oxygenated conditions at 1 m would not tend to support sediment regeneration of phosphorus. The total mass of phosphorus in Muddy between June and September averages 1.2 kg (n=21) and 1.1 kg (n=25) for all available data.

Ratios of total nitrogen to total phosphorus in Muddy between June and September average 57 at the 0.5 m station, 52 at the 1 m station, and 54 for all data. Since all of these average ratios are multiples of the Redfield ratio of 16, on average during the summer and throughout the year the pond is phosphorus limited and, as such, any water quality management strategies for Muddy Pond should target phosphorus.

In order to begin to frame an appropriate water quality management strategy, all the sources of phosphorus should be identified and this is usually done through the development of a phosphorus budget. Results from the phosphorus budget are then compared to the mass of phosphorus in the pond to assess the assumptions in the loading factors and develop a better understanding of the functions within an individual pond. In order to begin to develop a watershed phosphorus budget for Muddy, town volunteers reviewed Board of Health (BOH) records to determine the distance between the pond and septic system leachfields for all properties within 300 feet of the pond (see Figure V-4), the age of the septic systems, and the age of the houses. Volunteers also noted any large lawn areas or any other notable potential sources of phosphorus close to the pond. Once this information was developed, project staff narrowed the list to the properties that are upgradient of the pond (*i.e.*, in the watershed) and used the factors in Table V-3 to estimate a watershed phosphorus load to Muddy Pond.

As mentioned previously, phosphorus travel through an iron-rich aquifer, like Cape Cod’s, is slower than groundwater, and is estimated to take 35 to 81 years to travel 300 feet (Robertson, 2007). Project staff compared this range of times to the septic system information developed by the town volunteers and determined whether it was likely that a septic system or a house is currently contributing phosphorus to the pond or whether the phosphorus from the property is still in transit in the aquifer.

Based on the land use review, there are five properties within the 300 ft buffer to Muddy Pond that are also upgradient of Muddy Pond. All five are single family residences with an average age of 36 years old and a range of years built from 1968 to 1977. There are no other developable parcels, so any additional development would have to occur via intensification on the existing developed lots. The average age of the septic systems on these five properties is 17 years old with year of installation ranging between 1968 and 2003. The average distance to the pond for the septic system leachfields on these properties is 163 feet with a range of 100 to 300 feet.

Based on the age of the five residences, all five of them have existed long enough to contribute phosphorus to the pond if one assumes that it takes 35 years for phosphorus to travel 300 ft, while two contribute phosphorus if it is assumed that the phosphorus travel time is 81 years. Since the septic systems are usually younger than the houses, the expected contributions are lower if these are considered: the respective numbers are two are contributing phosphorus to the pond if the time of travel is 35 years and none are contributing phosphorus to the pond if the time of travel is 81 years.

Using the factors in Table V-3 and accounting for the range of groundwater lag times, the current external/watershed load to Muddy is estimated to be between 2.9 and 6.0 kg/yr. Of this, wastewater from septic systems is between 0 and 2.3 kg/yr (0 to 41%) of the watershed load. Other portions of external loads into the pond are lawns (3 to 5%), roof runoff (7 to 11%), birds based on an areal loading rate (15 to 26%), birds based on the per pond load (8 to 45%), and roads (23 to 39%) (Figure VI-15). Steady-state load under current conditions is calculated as 5.2 to 6.0 kg/yr and buildout loading is the same as steady state since there are no developable lots within the 300 ft upgradient buffer. Uncertainties associated with the loading factors are discussed in the phosphorus budget factors section (see Section V.3.).

Of these loading sources, bird loading is the most uncertain. Given how this could impact management strategies, it is recommended that the bird contribution should be clarified by regular counts (daily or monthly) of bird species and numbers on Muddy Pond throughout a whole year. Such a study, which is beyond the scope of the current analysis, would be required to detail this in a more definitive fashion. This type of effort could be accomplished by volunteers who are trained or have training to identify the likely bird species and have the ability to view the entire lake. SMAST staff can provide guidance to the town for resolving this issue.

The residence time for Muddy is 0.4 years (132 days). Muddy's residence time means that the average mass of phosphorus measured in the pond should be approximately 0.4 times the annual external loads from the watershed and precipitation plus any phosphorus regenerated from the sediments. The total mass of phosphorus in the pond based on water quality measurements between June and September averages 1.2 kg (n=21) and 1.1 kg (n=25) if all data is considered. Based on this residence time and the 10 ppb TP Cape Cod-specific threshold, the target phosphorus mass in the Muddy would be 0.4 kg.

If the lower annual phosphorus loading estimates are considered, the phosphorus budget appears to be in relative balance with observed concentrations. Using the low estimate from the phosphorus loading analysis (2.9 kg/y), the resulting estimated phosphorus mass in the pond is 1.1 kg with an estimated TP concentration of 23.5 ppb as compared to the 1.1-1.2 kg in the pond based on water quality data and average surface TP concentrations of 22.9 ppb. Based on the rate of increase observed in the mass of phosphorus per year (0.2 kg/y) in Muddy, it is estimated that it will take approximately 10 years for the pond to attain the estimated steady state mass (Figure VI-16).

This simple comparison does not account for an attenuation of the phosphorus entering Muddy Pond and, therefore, suggests that external loading must be higher than 2.9 kg/y. If it is conservatively assumed that Muddy is attenuating 50% of the external load that is entering, the estimated external loading would be 5.8 kg/y or very close to the highest estimate from the phosphorus loading analysis. The fairly rapid residence time suggests that the phosphorus attenuation in Muddy should be relatively low, but the slightly higher TP concentrations in the deeper station suggest that the sediments are gathering phosphorus and that sediments are regenerating some of that load. By incorporating a 50% internal attenuation rate, only a small

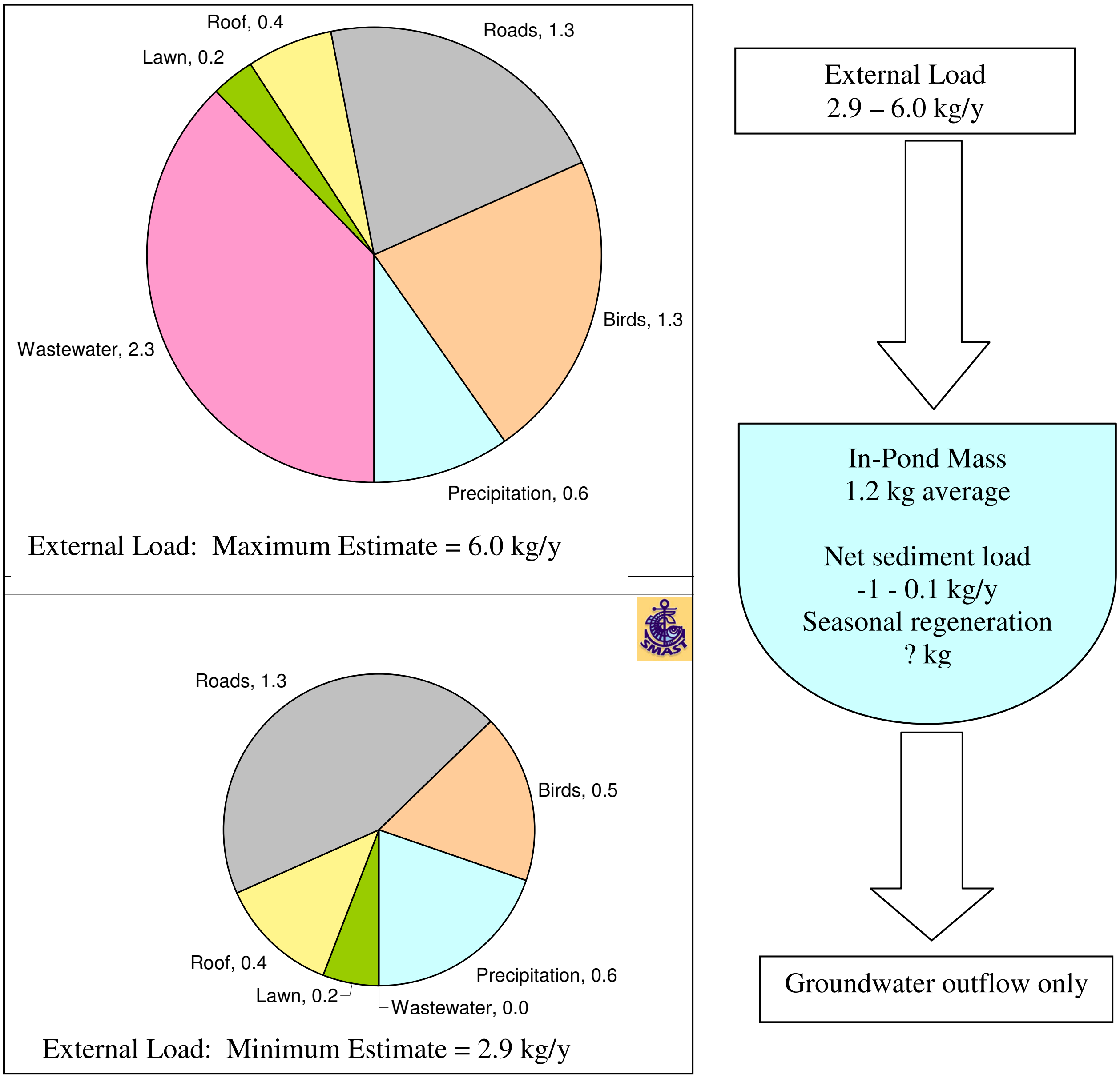


Figure VI-15. Estimated phosphorus budget for Muddy Pond
In-lake mass is based on collected 2001-2006 water quality data. Wastewater load from upgradient properties within the 300 ft buffer based on septic load travel time of 35 to 81 years. Road loads include all areas within 300 ft buffer. Wastewater has the largest range, but bird loading is the most uncertain. Bird loading depends on an areal or per pond estimate and it is recommended that a bird survey be conducted to provide a Muddy Pond-specific estimate. Wastewater factors loading factors are reasonably well understood, so time of travel is likely the key variable in the estimate of wastewater load; steady-state wastewater load is projected to be the same as the upper end of the current projected range (6.0 kg/y). Other loads based on factors from Table V-3. Groundwater outflow is the only potential discharge of phosphorus from the pond. Net sediment load is based on comparison of external load and in-lake mass. Determination of sediment regeneration would require direct measurement through collection and testing of sediment cores.

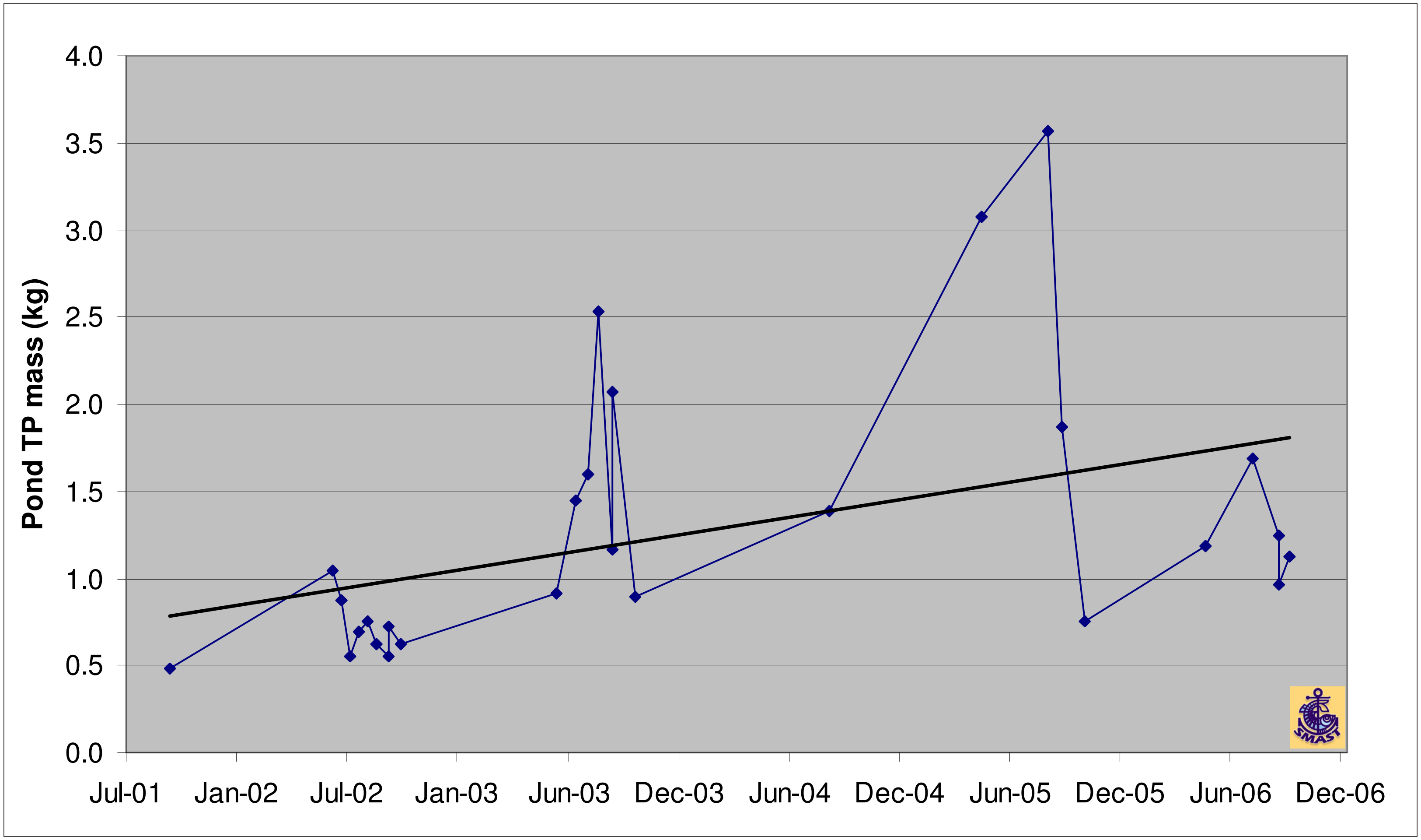


Figure VI-16. Mass of phosphorus in Muddy Pond 2001 to 2006

Mass of phosphorus based on average total phosphorus concentrations at 0.5 and 1 m depth stations and total volume of Muddy Pond. Total mass fluctuates seasonally with higher mass during the summer and lower mass in the spring and fall. These fluctuations result relationship with a low r^2, but with an upward trend of 0.2 kg per year.

amount of additional phosphorus loads from within the buffer zone are still in transit toward the pond and projected average total phosphorus concentrations will reach a maximum of approximately 25 ppb. Additional clarification of these relationships including the observed increasing mass in the pond (see Figure VI-16) could be determined by collecting more refined data on sediment accretion rates and phosphorus regeneration. SMAST staff are available to assist the town in detailing the tasks and accompanying cost estimates for such a study if requested.

VI.3.2. Muddy Pond Conclusions and Recommendations

Muddy Pond is a 10.5 acre pond with a maximum depth of 1.5 m. Based on a review of the available data, water quality in Muddy Pond is not impaired according to state surface water regulations and, therefore, will not require a TMDL. Review of criteria that would show more immediate response to excessive nutrient inputs show higher than healthy total phosphorus concentrations, but relatively stable Secchi clarity readings during the 2001 to 2006 dataset. Development and review of phosphorus loading estimates show that total phosphorus concentrations may be close to steady-state conditions depending on sediment regeneration and accretion rates. Review of nitrogen to phosphorus ratios show that management of phosphorus is the key to managing water quality in Muddy Pond.

Given that Muddy Pond is relatively shallow, it is unlikely that it will ever fail to meet state dissolved oxygen limits. Even if oxygen consumption by the sediments increases significantly, available wind energy across the surface will mix in atmospheric oxygen to address any oxygen deficits that might arise. Since dissolved oxygen concentrations are the primary state water quality standard, it is unlikely that the town would be required to address water quality management by state regulators unless excessive algal blooms occur. Future management of Muddy, therefore, is likely to be directed by local concerns about aesthetics and ecosystem function. One additional consideration might be if nitrogen reductions are identified as a need for Nauset Marsh by the Massachusetts Estuaries Project; if this occurs there may be opportunities to enhance natural nitrogen attenuation in Muddy Pond via deepening or better management of its sediments.

The biggest concerns for future management of aesthetics and ecosystem function are the high phosphorus concentrations and the increasing mass of phosphorus in the pond. Since existing total phosphorus concentrations are already higher than would be considered healthy for a Cape Cod freshwater pond ecosystem, the potential for spontaneous algal blooms and accompanying decreases in clarity is relatively high. The key for providing a better assessment of the likelihood of these events is a better understanding of the sediments. The available data suggests that the sediments play a relatively minor role in the observed in-pond phosphorus concentrations, but a significant role in capturing phosphorus entering the pond. If phosphorus in these sediments is relatively labile and easily converted to soluble forms in low oxygen conditions, the sediments may prove to be a ready source of phosphorus in the future that could prompt algal blooms or, over the longer term, create worse water quality conditions. In order to address this, it is recommended that the town consider collection of sediment cores and testing of the cores to gauge the maximum amount of expected phosphorus release from the sediments and the dissolved oxygen conditions that would cause this release to occur.

In addition, observation of other Cape Cod ponds with high phosphorus concentrations suggests that these ponds may be more susceptible to shifting from a phytoplankton-dominant plant community to one dominated by rooted plants. In the later case, Secchi clarity will initially improve, but over the longer term, the surface of the pond may slowly be covered by plants and recreational options will become more limited. With this in mind, it is further recommended that the town consider completing a current baseline evaluation of rooted plants in Muddy Pond. This evaluation should include identification of species and percentage of plant coverage throughout the pond.

Since the mass of phosphorus in the pond appears to be predominately determined by external, watershed sources, addressing these sources through best management practices can slowly reduce the mass of phosphorus in Muddy Pond and return it to a more typical and sustainable phosphorus concentration relatively inexpensively. These practices include: 1) maintaining, planting, or allowing regrowth of natural buffer areas between the pond and lawns/yards/houses, 2) installing treatment for or redirecting any direct stormwater runoff, and 3) ensuring that all new septic system leachfields have an adequate setback from the pond (at least 300 feet or the maximum possible on a lot). If the town pursues sewering in this area as a result of current wastewater planning, this would remove the phosphorus wastewater component. Review of the potential benefits and costs of the various options could be addressed as a supplemental task paired with the recommended plant survey and sediment characterization. SMAST staff are available to provide further guidance to the town in addressing this issue.

Finally, it is further recommended that the town continue to maintain a volunteer pond water quality monitoring program and that Muddy should continue to be part of it. Given the amount of volunteer data that has already been collected in Muddy, it is recommended that this sampling be limited to a minimum of two sampling runs conducted each year using the PALS sampling protocol and the parameters measured. It is suggested that these runs be completed during April and August/September (the latter being the usual PALS Snapshot period). This type of in-lake sampling schedule would create annual data to assess how the ecosystem is set prior to the active summer period (the April run) and then measure conditions during the likely worst-case water quality conditions (the August/September run). Comparison of this data to prior data would provide a better sense of interannual ecosystem fluctuations, measures to assess the benefits of any remedial activities that are undertaken, and provide an “early warning” if conditions worsen significantly. It is further recommended that collected data be reviewed and interpreted at least every five years in order to provide regular feedback and assessment of pond conditions.

SMAST staff are available to assist the town with the completion of any of the actions recommended for consideration and can provide a detailed cost proposal if requested.

VI.4. Long/Depot Pond

VI.4.1. Long/Depot Pond Review and Discussion

Long Pond is a 27.9-acre pond that is located to the east of Great Pond, west of Route 6, and to the north of Muddy Pond (see Figure V-2). Long is the third deepest of the ponds selected for detailed review after Great and Herring; its deepest point is 10 meters (~33 feet). Long is referred to on some historic and current maps as Depot Pond, which is also ascribed to the small pond off the southwestern lobe of Long. In this report, the larger pond is referred to as Long Pond.

Depot Pond is separated from Long by the Cape Cod Rail Trail. A 1893 US Geological Survey quadrangle suggests that the construction of the railroad separated Depot from the rest of Long Pond; the quad shows an intact pond with railroad line symbol drawn over the area where the Rail Trail exits today (Figure VI-17). A 1944 USGS quadrangle of the same area shows the two separate ponds with Long Pond named Depot Pond.

Ponds of 9 m or more on Cape Cod typically thermally stratify during the summer with a warm, well mixed upper layer or epilimnion and a colder, deeper layer called the hypolimnion. Great stratifies like this. Ponds with maximum depths close to 9 m, such as Long Pond, can be strongly or weakly stratified into temperature layers depending on how much protection from the winds is provided by surrounding topography and even this can vary from year to year depending on temperatures and wind intensity during a given summer.

Temperature data collected by volunteers between 2001 and 2006 shows that Long Pond regularly stratifies with an average difference of 11°C (~20°F) between summer surface temperatures and temperatures at 9 m. This stratification typically starts in late May/early June (Figure VI-18). The upper layer continues to warm throughout the summer and this warmth is mixed throughout the upper layer. This warmer layer gradually thickens and deepens, generally starting with the upper 2 m at the start of the stratification cycle, deepens to 3 m in June and extends to 4 or 5 m by September. The deeper waters generally get colder with increasing depth, which suggests that these waters are generally not well mixed.

Dissolved oxygen data from the same dataset shows that there is on-going oxygen consumption from the sediments from the first profile of the summer season through the season's last one (see Figure VI-18). Once the thermal layers are established and the lower layer is cut off from oxygen replenishment from the upper waters, oxygen consumption from the sediments creates regular anoxic (<1 ppm) conditions in the deepest portions of the pond. Anoxic conditions have been measured as shallow as 7 m from the surface.

Since Long Pond thermally stratifies, it has the potential to sustain a cold-water fishery. State surface water regulations define cold-water fisheries as having temperatures less than 20ºC and require cold-water fisheries to attain a 6 ppm dissolved oxygen standard (314 CMR 4) . Readings show that Long Pond has average temperatures less than the 20ºC cold-water fishery level at 6 m and deeper between June and September.

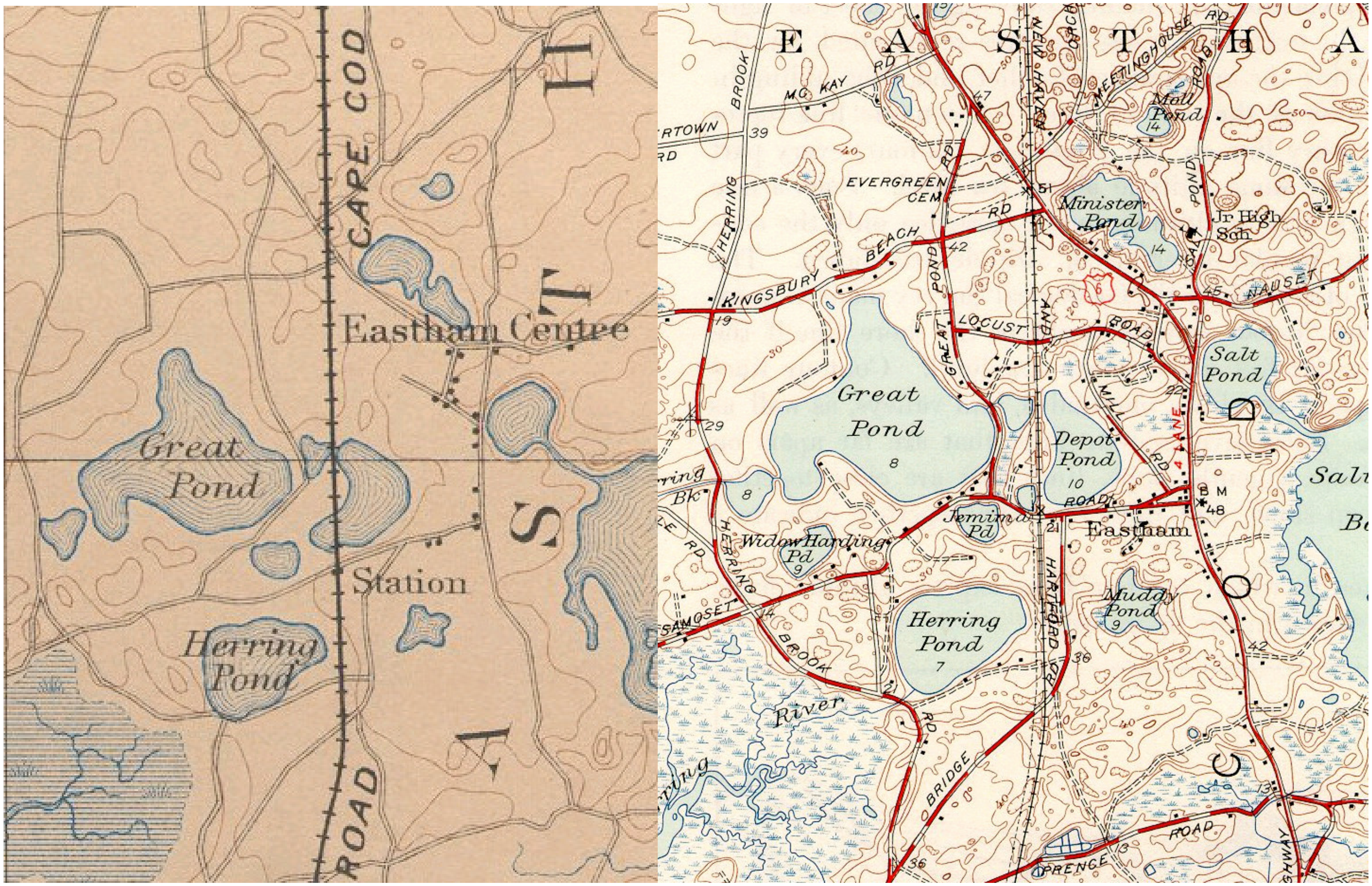
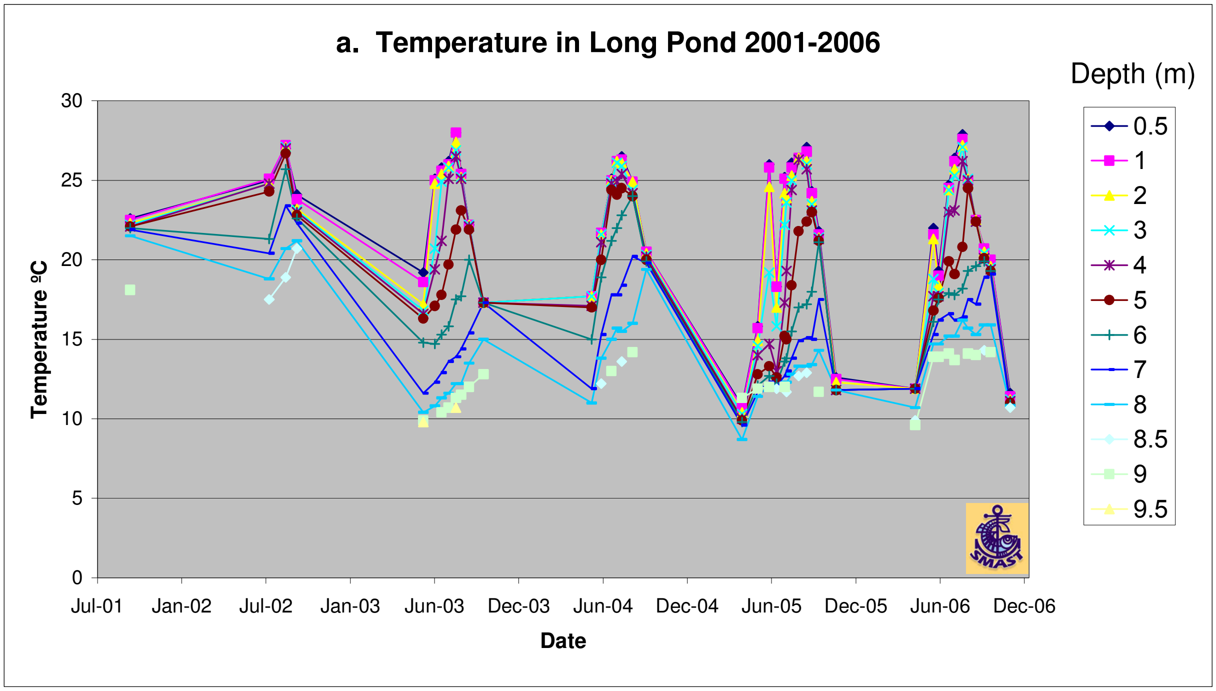


Figure VI-17. Historic US Geological Survey Quadrangles of Long/Depot Pond

Left side is excerpt of 1893 Wellfleet, MA Quadrangle 15 Minute Series, while the right side is excerpt from 1944 Orleans, MA Quadrangle 7.5 Minute Series. Both maps are from the University of New Hampshire, Dimond Library, Documents Department and Data Center collection of Historic USGS Maps of New England and New York (http://docs.unh.edu/nhtopos/nhtopos.htm). 1893 quad appears to show that Long Pond included Depot Pond prior to construction of a railroad, while Long Pond is named Depot Pond in the 1944 quad.



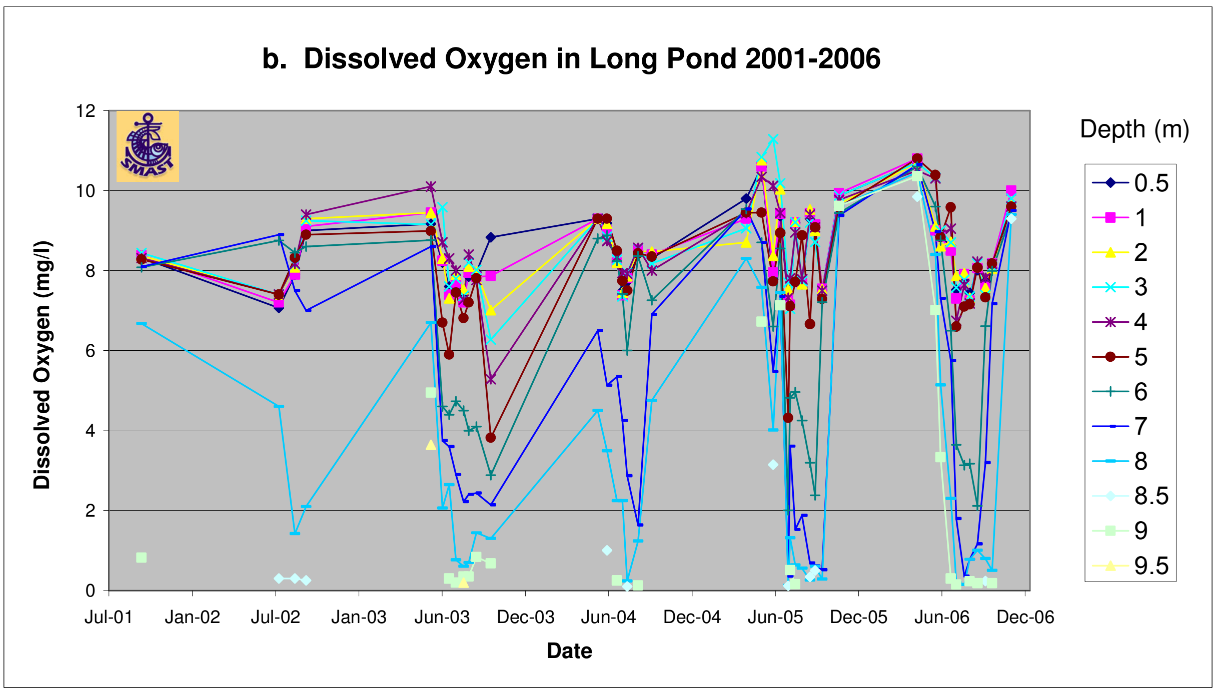


Figure VI-18. Long Pond Temperature and DO Readings 2001-2006
Temperature data shows that the upper water column is well mixed with temperatures increasing during summers, while the deeper waters get colder with increasing depth. During spring and fall, water temperatures are relatively constant throughout the water column. Dissolved oxygen concentrations show lower concentrations with increasing depth and regular anoxic (<1 ppm) concentrations during the summer. Data collected by Eastham volunteers using DO/Temp meters between 2001 and 2006 and includes data from Cape Cod PALS Snapshots.

Based on average conditions for June through September from data collected between 2001 and 2006, the 6-ppm dissolved oxygen standard is usually met in Long Pond down to a depth of 5 m (Figure VI-19). Water at 6 m has an average DO concentration of 5.9 ppm, while waters at 7 m and deeper have average DO concentrations less than 4 ppm. Since the potential cold water fishery in Long Pond is at 6 m and deeper and waters with adequate DO concentrations for cold water fish are at 5 m and shallower, Long Pond cannot sustain a cold water fishery. Overall, 100% of the available cold water fishery and 21% of the total pond volume fail to meet state dissolved oxygen limits (Figure VI-20). Based on state surface water regulations, Long Pond would be classified as having impaired water quality and, as such, would eventually be required to have a TMDL.

Aside from the state fisheries definition, the average dissolved oxygen conditions in deep waters of Long Pond are clearly ecologically impaired. Anoxic concentrations (<1 ppm DO) are usually lethal to fish even on a temporary basis. Anoxic concentrations are regularly measured in Long Pond at 8 and 9 meter depth (15 of 33 readings at both depths) and have been measured as shallow as 7 m. Average concentrations are generally are slightly greater than 1 ppm [*e.g.*, 9 m average concentration is 1.1 ppm (n=18)]

Secchi readings average 4.0 m between June and September (n=25) during the 2001-2006 dataset (Figure VI-21). Average sampling station depth is 9.3 m and on average 43% of the overall water depth is clear enough at the sampling station to see a Secchi disk. Both station depth and Secchi readings have very small upward trends (~0.1 m per year) between 2001 and 2006, but both are insignificant. The direction of the trend is the same as regional groundwater levels during the sampling period, but the magnitude is approximately half the rate at EGW36 (CCC water level records).

The Secchi readings do not show significant fluctuation either. The coefficient of variation for Secchi readings is 22%, which closely approximates the 18% for Secchi readings in Great and is much more stable than the 44% in Herring's readings. It should also be noted that the minimum Secchi reading (1.88 m or 6.1 ft) is well above the state safe swimming clarity limit of 4 feet (see Figure III-2).

Average total phosphorus (TP) concentrations in Long Pond between June and September are generally only slightly higher than the Cape Cod 10 ppb "healthy" threshold, although all depths exceed the 7.5 ppb "unimpacted" threshold: 10.6 ppb at 0.5 m (n=16), 8.0 ppb at 3 m (n=15), and 10.8 ppb at the deepest station (n=15). The average depth of the deepest sampling station is 8.6 m (n=15).

Based on measured TP concentrations, the total mass of phosphorus in Long Pond between June and September averages 6.0 kg (n=15) and 7.7 kg (n=21) for all available data. Of this mass, 86% and 85%, respectively, is contained in the well-mixed upper layer (above 6 m). Based on the water quality data, the range of phosphorus mass in the pond between June and September is 1.3 to 11.0 kg, while the range of all the data is between 1.3 and 28.3 kg.

Based on the consistently low dissolved oxygen readings at depth within Long Pond, one would expect that TP concentrations at the deepest station should be much higher. Staff

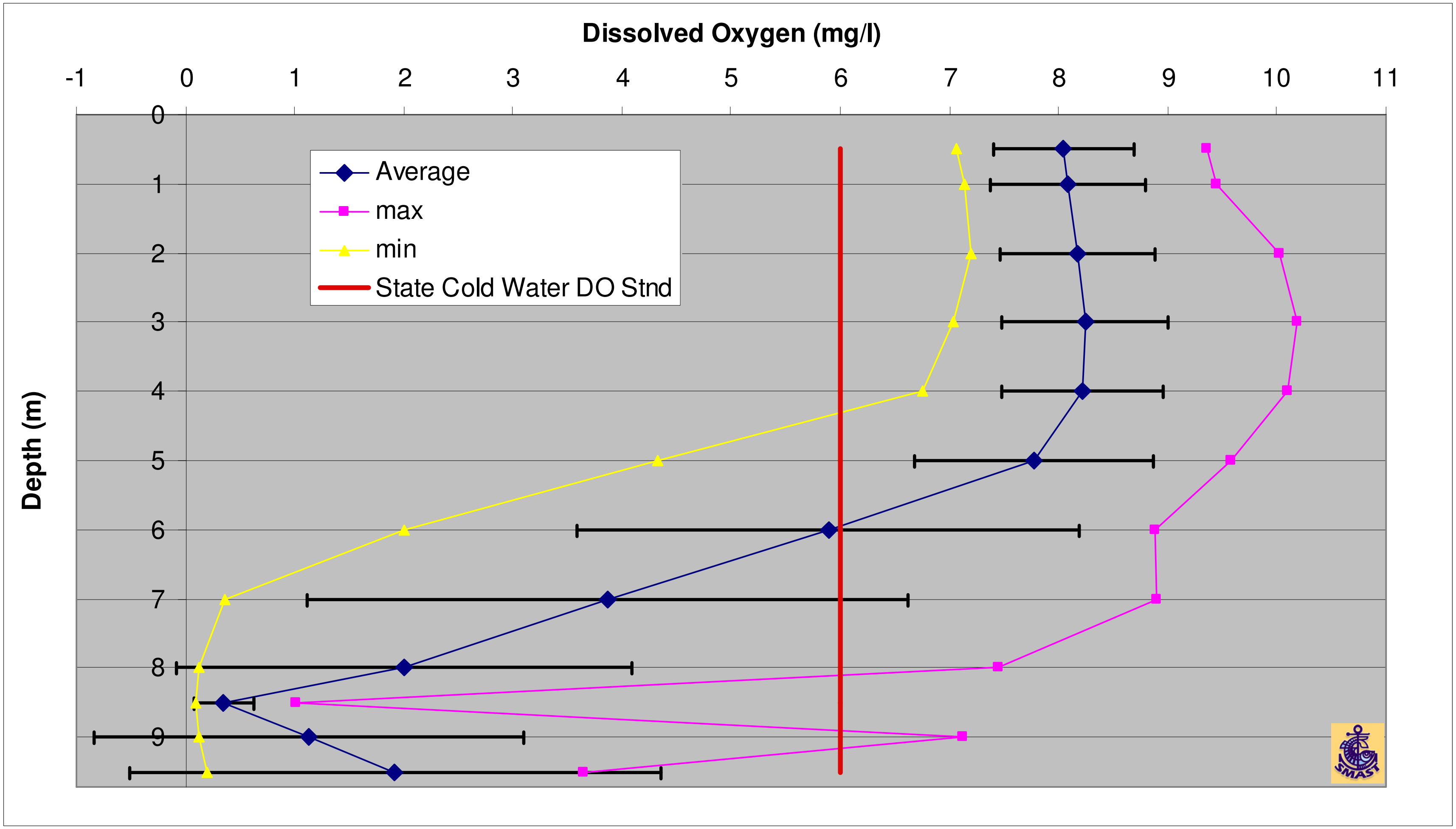


Figure VI-19. Average dissolved oxygen concentrations in Long Pond (June through September, 2001-2006)
Graph shows average DO profile (blue line) based on data collected by town volunteers between 2001 and 2006 with error bars (±1 standard deviation) plus maximum (pink line) and minimum (yellow line) readings for each depth. Also shown by the red line is the state surface water 6-ppm DO standard for cold water fisheries (310 CMR 4). Most depths have 32-34 readings collected between 2001 and 2006.

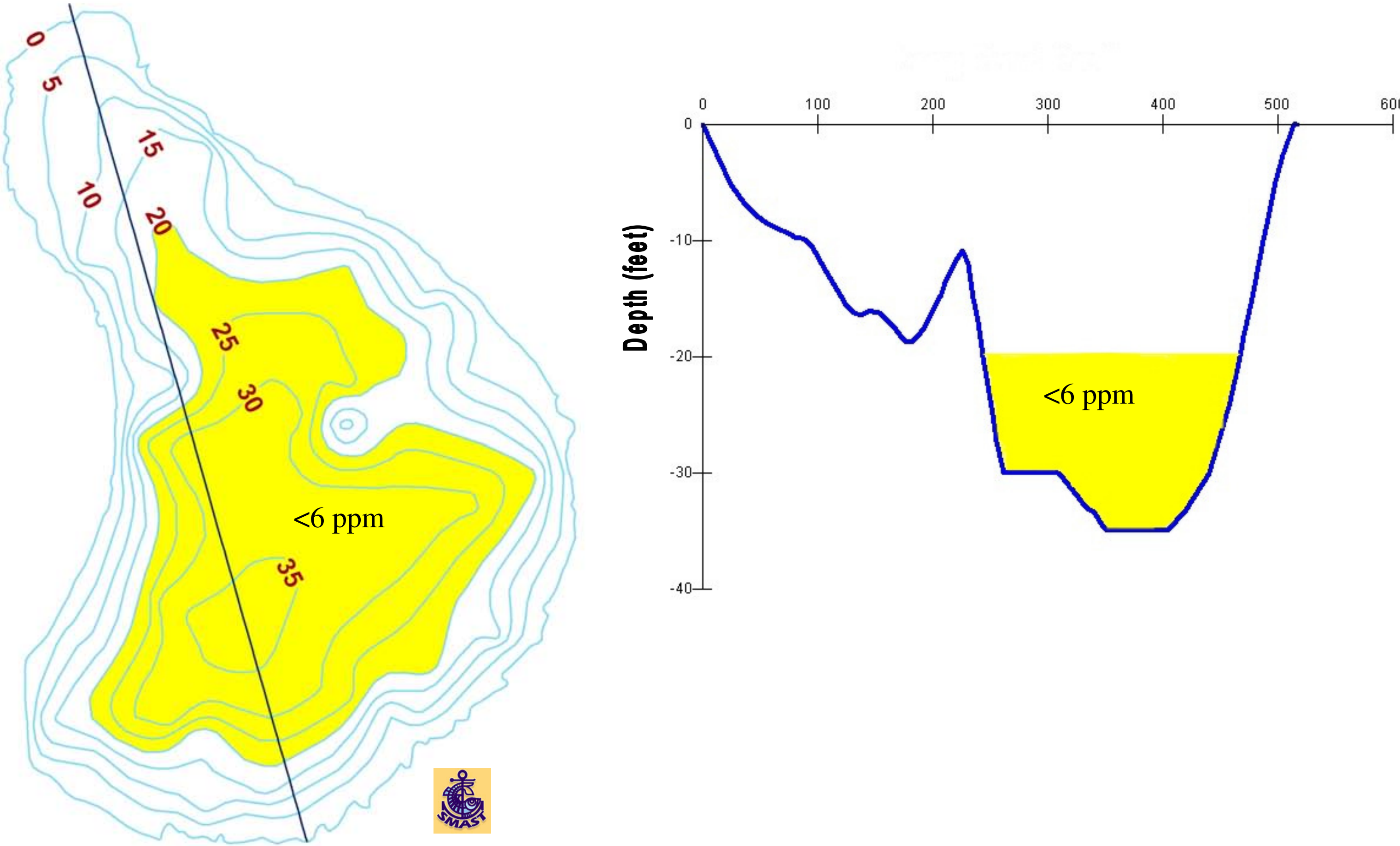


Figure VI-20. Long Pond: Comparison of average dissolved oxygen (June through September) and state surface water standards

Depth profile cross-section and bathymetric map showing volume and area of Long Pond with average dissolved oxygen concentration less than surface water 6-ppm DO standard for cold water fisheries (shaded yellow). Blue line on the bathymetric map shows depth profile track through the pond that corresponds to cross-section. 100% of the available cold water fishery and 21% of the total pond volume fail to meet state dissolved oxygen limit.

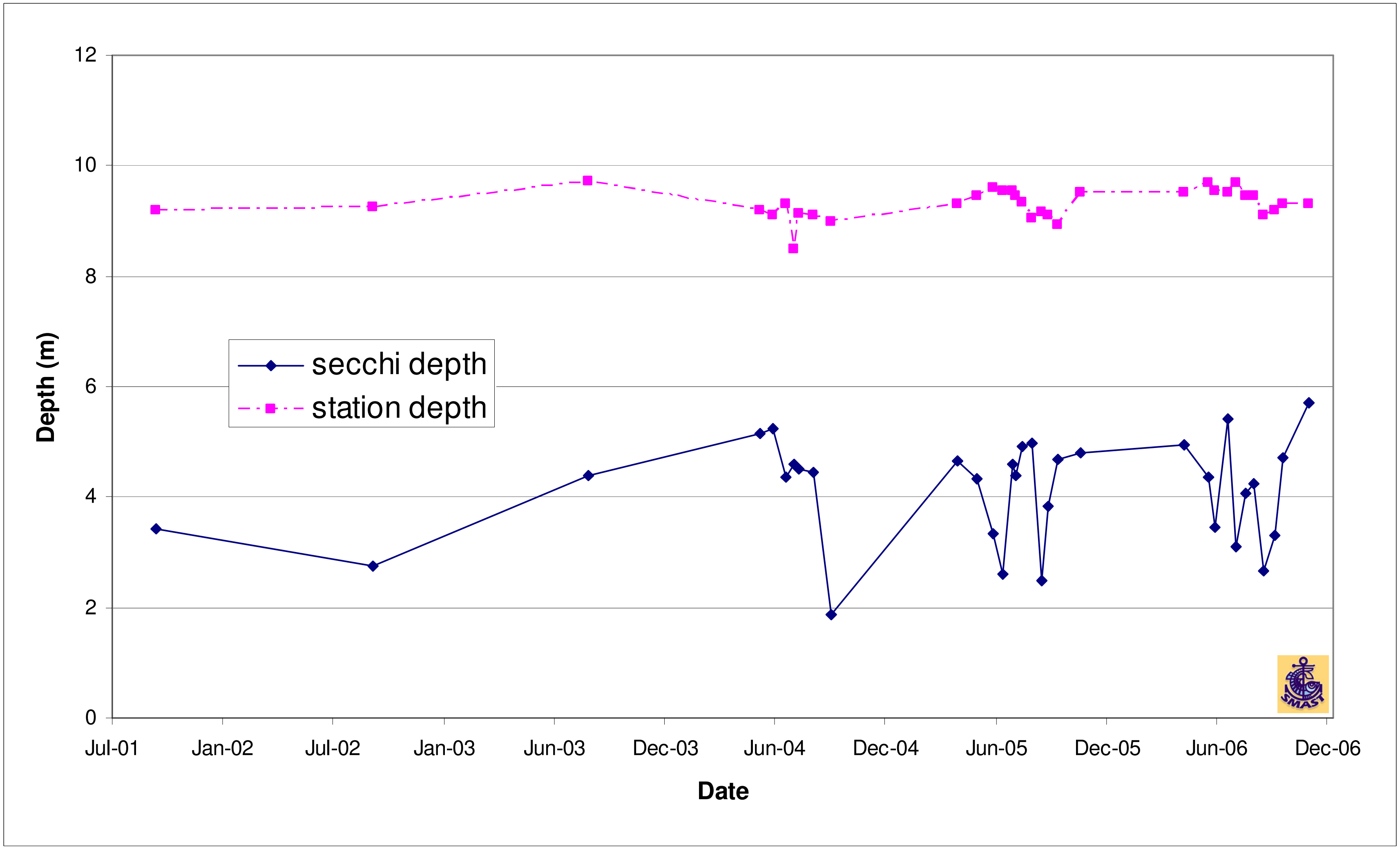


Figure VI-21. Secchi transparency readings in Long Pond 2001-2006

Blue data points are Secchi depth readings, while station depth measurement are shown in pink. All data collected by Eastham volunteers. Station depth and Secchi depth have no definitive trend over the sampling period. Average Secchi depth reading is 4.0 m (n=25), while the average station sampling depth is 9.3 m (n=25).

reviewed the dissolved oxygen concentrations and found that these profiles were relatively consistent throughout each of the summers and from year to year. Next, project staff reviewed the TP concentrations and found there are a number of individual sampling runs with the expected results, *i.e.*, relatively low surface TP concentrations with increasing concentrations with depth, but there are more samples with similar concentrations at all the depth stations. This inconsistency between the two dataset should be resolved prior to the development of definitive management strategies for Long Pond.

Ratios of total nitrogen to total phosphorus in Long Pond between June and September average 75 in the surface waters, 86 at 3 m, and 73 at the deepest station. If all data, including samples collected between October and May, are included, the respective ratios are 84, 129, and 101. Since all of these average ratios are multiples of the Redfield ratio of 16, on average during the summer and throughout the year the pond is phosphorus limited and, as such, any water quality management strategies for Long Pond should target controls for phosphorus..

In order to begin to frame an appropriate water quality management strategy, all the sources of phosphorus should be identified and this is usually done through the development of a phosphorus budget. Results from the phosphorus budget are then compared to the mass of phosphorus in the pond to assess the assumptions in the loading factors and develop a better understanding of the functions within an individual pond. In order to begin to develop a watershed phosphorus budget for Long, town volunteers reviewed Board of Health (BOH) records to determine the distance between the pond and septic system leachfields for all properties within 300 feet of the pond (see Figure V-4), the age of the septic systems, and the age of the houses. Volunteers also noted any large lawn areas or any other notable potential sources of phosphorus close to the pond. Once this information was developed, project staff narrowed the list to the properties that are upgradient of the pond (*i.e.*, in the watershed) and used the factors in Table V-3 to estimate a watershed phosphorus load to Long Pond.

As mentioned previously, phosphorus travel through an iron-rich aquifer, like Cape Cod's, is slower than groundwater, and is estimated to take 35 to 81 years to travel 300 feet (Robertson, 2007). Project staff compared this range of times to the septic system information developed by the town volunteers and determined whether it was likely that a given septic system or a house is currently contributing phosphorus to the pond or whether the phosphorus from the property is still in transit in the aquifer.

Based on the land use review, there are 11 properties within the 300 ft buffer that are also upgradient of Long Pond. Of these, nine are fully in the watershed with six of these classified by the town Assessor as residential. Of the six residential properties, four are single family residences and the other two are multi-family dwellings. The average age of the six residences is 43 years old and the year built ranges between 1950 and 1983. There is one property classified by the town's Assessor as developable residential and one more that is classified as having accessory buildings but no residence. The average age of the septic systems on the developed lots is 21 years old with year of installation ranging between 1960 and 2004. The average distance to the pond for the six residences based on leachfield plans filed with the BOH is 151 feet with a range of 60 to 350 feet.

Based on the age of the six residences, all six of them have existed long enough to contribute phosphorus to the pond if one assumes that it takes 35 years for phosphorus to travel 300 ft, while three contribute phosphorus if it is assumed that the phosphorus travel time is 81 years. Since the septic systems are usually younger than the houses, the expected contributions are lower if these are considered: five are contributing phosphorus to the pond if the time of travel is 35 years and none are contributing phosphorus to the pond if the time of travel is 81 years.

Using the factors in Table V-3 and accounting for groundwater lag times, the current total external/watershed load to Long is estimated to be between 1.6 and 6.1 kg/yr. Of this, wastewater from septic systems is between 0 and 2.7 kg/yr (0 to 44%) of the watershed load. Other portions of external loads into the pond are lawns (3 to 6%), roof runoff (9 to 13%), birds based on an areal loading rate (37 to 67%), birds based on the per pond load (8 to 81%), and roads (6 to 10%) (Figure VI-22). Steady-state load under current conditions is calculated as 4.3 to 6.1 kg/yr and buildout loading is calculated as 5.4 to 7.2 kg/yr. Uncertainties associated with the loading factors are discussed in the phosphorus budget factors section (see Section V.3.)

Of these loading sources, bird loading is the most uncertain. Given how this could impact management strategies, it is recommended that the bird contribution should be clarified by regular counts (daily or monthly) of bird species and numbers on Long Pond throughout a whole year. Such a study, which is beyond the scope of the current analysis, would be required to detail this in a more definitive fashion. This type of effort could be accomplished by volunteers who are trained or have training to identify the likely bird species and have the ability to view the entire lake. SMAST staff can provide guidance to the town for resolving this issue.

The residence time for water in Long Pond is 2.8 years. This residence time means that the average mass of phosphorus measured in the Long should be approximately 2.8 times the annual external loads from the watershed and precipitation plus any phosphorus regenerated from the sediments. As mentioned previously, the total mass of phosphorus in the pond based on water quality measurements between June and September averages 6.0 kg (n=15) and 7.7 kg (n=21) if all data is considered. Based on this residence time and the 10 ppb TP Cape Cod-specific threshold, the target phosphorus mass in the Long would be 6.0 kg.

The water quality data seems to show that existing loading to Long is likely to be toward the higher end of estimated loading range. Based on a residence time of 2.8 years and the average surface total phosphorus concentration of 10.6 ppb, the annual load that is projected to enter Long Pond from external and internal sources would be 2.5 kg without considering any attenuation. If it is assumed that Long is attenuating 50% of the external load that is entering, the estimated external loading would be 5.0 kg/y or 82% of the highest estimate from the phosphorus loading analysis. A large portion of the maximum wastewater phosphorus load must be reaching pond, since this rate cannot be attained without significant wastewater input (see Figure VI-22).

Based on this comparison, additional phosphorus loads from within the buffer zone are still in transit toward the pond and, if the loading rates are correct, total phosphorus concentrations could increase to approximately 15 ppb. Based on the rate of increase observed

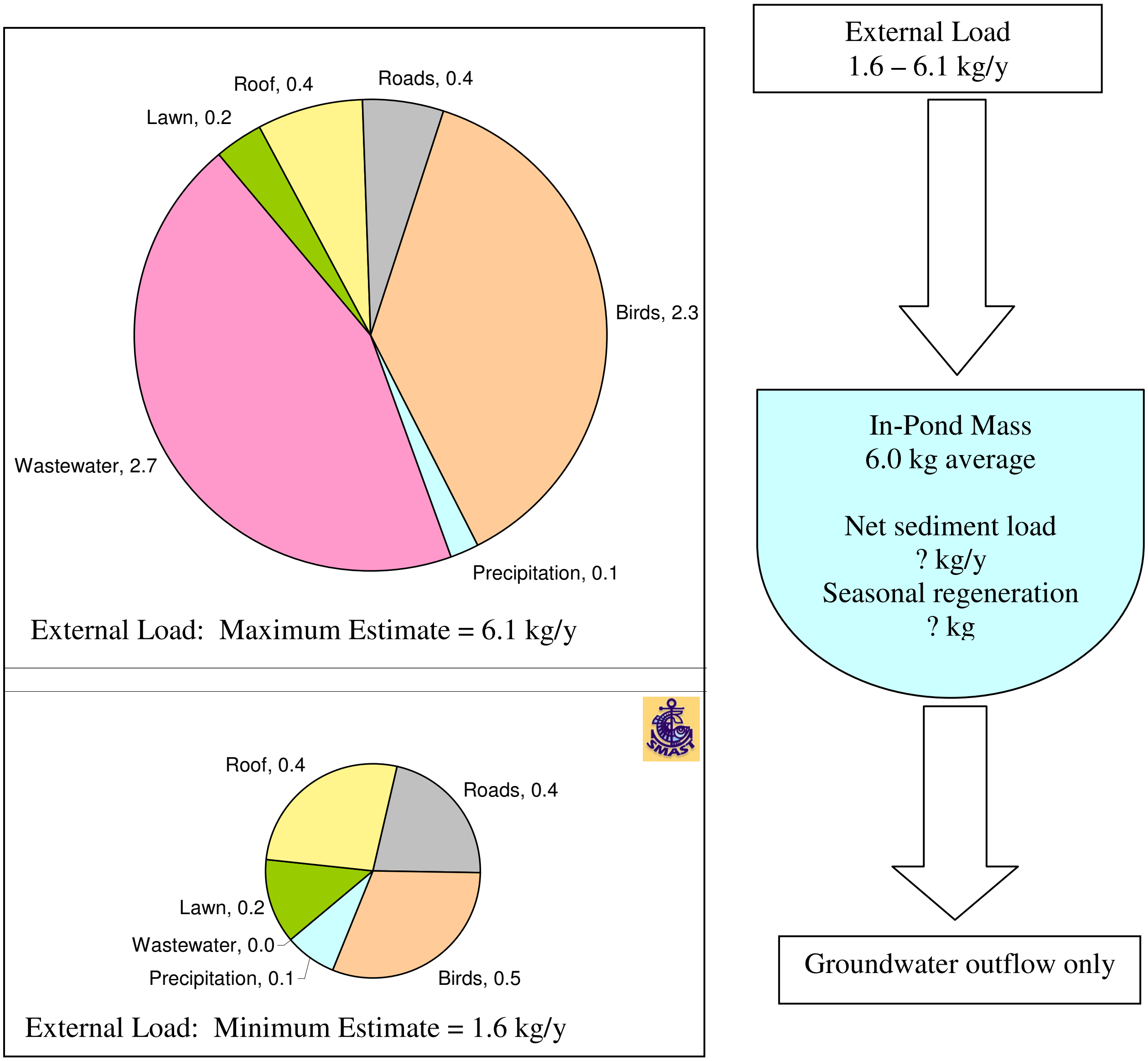


Figure VI-22. Estimated phosphorus budget for Long Pond
In-lake mass is based on collected 2001-2006 water quality data. Wastewater load from upgradient properties within the 300 ft buffer based on septic load travel time of 35 to 81 years. Road loads include all areas within 300 ft buffer. Wastewater and bird loading have the largest ranges, but bird loading is the most uncertain. Bird loading depends on an areal or per pond estimate and it is recommended that a bird survey be conducted to provide a Long Pond-specific estimate. Wastewater factors loading factors are reasonably well understood, so time of travel is likely the key variable in the estimate of wastewater load. Other phosphorus loads are based on factors from Table V-3. Groundwater outflow is the only potential discharge of phosphorus from the pond. Sediment sources are not well understood, due to apparent inconsistencies between dissolved oxygen and total phosphorus concentrations. Determination of sediment regeneration would require direct measurement through collection and testing of sediment cores.

in the mass of phosphorus per year (0.8 kg/y), it is estimated that steady-state current conditions will be attained within the next few years. Review of the data does, however, show significant fluctuation, largely resulting from the TP fluctuating between results that look like there is significant phosphorus regeneration and results that seem to indicate relatively consistent concentrations throughout the water column. These results again reinforce the need to complete some additional refined sampling of the sediments with some coincident water sampling.

VI.4.2. Long Pond Conclusions and Recommendations

Long Pond is 28 acres with a maximum depth of 10 meters. Based on a review of the available data, Long Pond has impaired water quality according to state regulatory thresholds and will eventually require a TMDL. Although the pond temperatures indicate that the pond could sustain a cold water fishery at 6 m depth and deeper, average dissolved oxygen concentrations throughout this portion of the water column do not meet the required state regulatory limit of 6 ppm and are less than 2 ppm near the sediments. Review of nitrogen to phosphorus ratios show that management of phosphorus is the key to managing water quality in Long Pond.

There is, however, inconsistencies among the datasets about how to move forward with addressing phosphorus controls. Average total phosphorus concentrations generally do not show significant impairment and results from sampling stations closest to the bottom sediments do not suggest significant regeneration of phosphorus from the sediments. The lack of higher concentrations in deep samples appears to be inconsistent with the relatively consistent low dissolved oxygen concentrations. Review of individual sampling runs show a small number of sampling runs (3-4) with significantly higher surface concentrations, which would be consistent with transposed sample bottles. Switching these results, however, does not result in increased surface concentrations even though a concentration gradient becomes more consistent with the low dissolved oxygen concentrations. These results suggest that there are other factors, perhaps a significant rooted plant population, that is impacting phosphorus concentrations, but continuing to provide excessive biomass to depress sediment oxygen concentrations.

To help resolve these apparent inconsistencies and move forward with appropriate management strategies, it is recommended that the town complete a one year, targeted pond characterization study. This study would include 1) collection of sediment cores and testing of the cores to gauge the maximum amount of expected and potential phosphorus release from the sediments, 2) coincident collection of water quality samples and field data, 3) a plant survey, and 4) identification and counts of birds on the pond throughout a year. Analysis of the samples should include evaluation of constituents that might be providing oxygen and suppressing phosphorus release from the sediments. This type of study will allow the town to better understand phosphorus dynamics in the pond and how low dissolved oxygen concentrations are apparently having little impact on sediment regeneration of phosphorus. It will also allow the town to establish a dissolved oxygen threshold for significant release of phosphorus from the sediments. This type of study will adequately characterize the system and will result in water quality management strategies that will be more definitively supported. SMAST staff can provide a detailed scope and anticipated cost for such a study if requested by the Town.

Although there are inconsistencies among the various datasets, it is clear that dissolved oxygen conditions do not meet state surface water regulatory standards and phosphorus reductions will be necessary. Since phosphorus is clearly the controlling nutrient for Long Pond, implementation of best management practices to reduce phosphorus loads can only help to improve water quality conditions in the pond. Given that the predominant land use in the Long Pond watershed is single-family residences, best management practices (BMPs) focused on uses along the pond shoreline are likely the lowest cost alternatives for decreasing watershed phosphorus loading. These BMPs would include: 1) maintaining, planting, or allowing regrowth of natural buffer areas between the pond and lawns/yards/houses, 2) installing treatment for or redirecting any direct stormwater runoff, and 3) ensuring that all new septic system leachfields have an adequate setback from the pond (at least 300 feet or the maximum possible on a lot). If the town pursues sewering in this area as a result of current wastewater planning, this would remove the phosphorus wastewater component. Review of the potential benefits and costs of the various options could be addressed as a supplemental task paired with the recommended plant survey and sediment characterization. SMAST staff are available to provide further guidance to the town in addressing this issue.

It is further recommended that the town continue to maintain a volunteer pond water quality monitoring program and that Long should continue to be part of it. Given the amount of volunteer data that has already been collected in Long, it is recommended that this sampling be limited to a minimum of two sampling runs conducted each year using the PALS sampling protocol and the parameters measured. It is suggested that these runs be completed during April and August/September (the latter being the usual PALS Snapshot period). This type of in-lake sampling schedule would create annual data to assess how the ecosystem is set prior to the active summer period (the April run) and then measure conditions during the likely worst-case water quality conditions (the August/September run). Comparison of this data to prior data would provide a better sense of interannual ecosystem fluctuations, measures to assess the benefits of any remedial activities that are undertaken, and provide an “early warning” if conditions worsen significantly. It is further recommended that collected data be reviewed and interpreted at least every five years in order to provide regular feedback and assessment of pond conditions.

SMAST staff are available to assist the town with the completion of any of the actions recommended for consideration and can provide a detailed cost proposal if requested.

VI.5. Minister and Schoolhouse Ponds

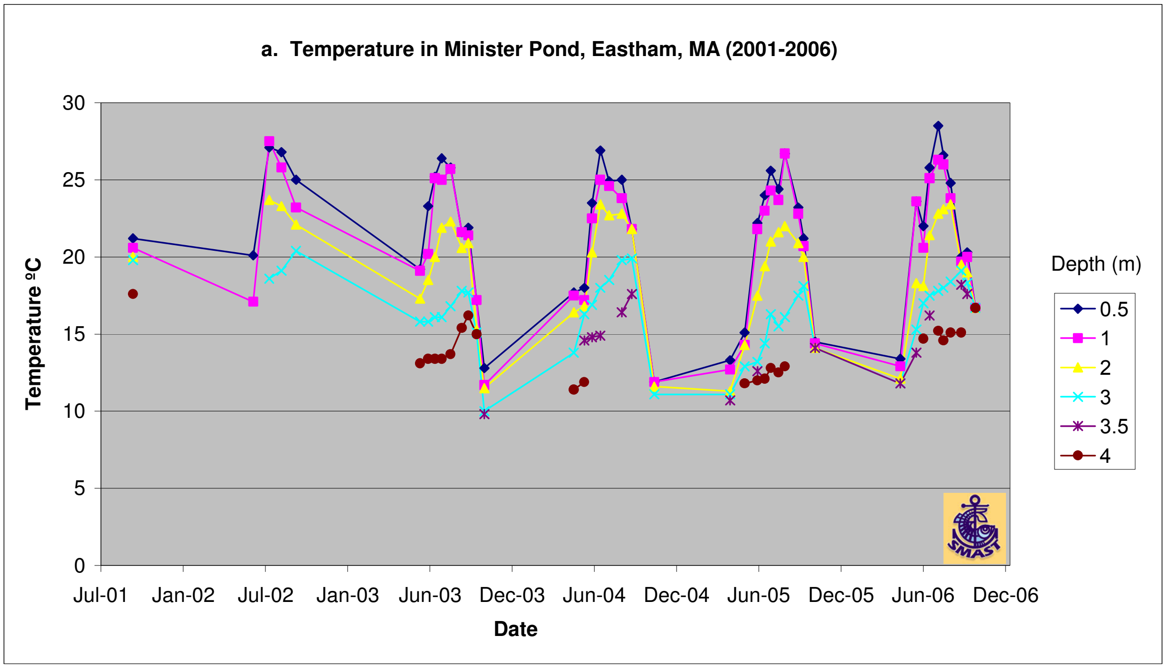
VI.5.1. Minister and Schoolhouse Ponds Review and Discussion

Minister Pond is a 22.3 acre pond located to the east of Route 6 and to the north of Salt Pond (see Figure V-2). Minister Pond has two basins: the northernmost 16.8 acre basin which is usually called Minister Pond and a 5.6 acre southern basin that is usually called Schoolhouse Pond. The two basins will be referred to by these names in this report and are separated by isthmus that is usually submerged, but can become exposed during low water table conditions. Historic US Geological Survey maps of the pond usually show the ponds as one merged pond labeled Minister Pond (University of New Hampshire Library Digital Collections Initiative, http://docs.unh.edu/nhtopos/nhtopos.htm).

Minister is 4.3 meters (14.1 feet) deep, while Schoolhouse is slightly deeper (4.5 meters; 14.9 feet). Given that they are situated along the same groundwater flowpath, Minister and Schoolhouse essentially share the same watershed, although Minister receives the bulk of the watershed-derived groundwater discharge and likely discharges most of this flow to Schoolhouse via their hydroconnection over the submerged isthmus. Similar situations exist in Mashpee-Wakeby pond in Mashpee/Sandwich, the Indian Ponds in Barnstable (Eichner and others, 2006), and between the basins of Lake Wequaquet in Barnstable (Eichner, 2008). Hydrologic pressure differences pull groundwater up into the first pond with very little flow bypassing this pond and making it to the second.

Typically Cape Cod ponds with depths less than 9 meters do not thermally stratify during the summer because there is sufficient wind energy sweeping across their surface to keep the water column well mixed. Both Minister and Schoolhouse appear to be an exceptions to this general rule since average conditions in both ponds have approximately a 10°C difference between surface and bottom waters between June and September (Figures VI-23 and VI-24, respectively). This difference is roughly equivalent to the difference measured in Herring and Great, but because of their relatively shallow depths, Minister and Schoolhouse have very thin (1-1.5 m) layers of warm and cold water at the top and bottom, respectively, separated by transitional zone. A similar temperature regime was measured in Boland Pond, which is a shallow pond in Orleans (Eichner, 2007). Boland's regime was hypothesized to be due to Boland receiving deeper groundwater flow because it is close to the edge of the groundwater lens; this might also be the case of Minister/Schoolhouse, especially given that its longest axis is oriented in the same direction as groundwater flow and this would serve to pull even the deepest, groundwater up into the ponds.

Both Minister and Schoolhouse appear to have extensive internal sediment oxygen demand. Dissolved oxygen concentrations average approximate 6.5 ppm at the surface between June and September; this is 74% saturation; most ponds on Cape Cod typically have 90-100% saturation in their upper waters. Near perfect oxygen saturation in surface waters should be expected since these waters are in direct contact with the atmosphere. Both ponds show surface water dissolved oxygen concentrations declining to below 5 ppm, the lowest state surface water regulatory standard (see Figures VI-23 and VI-24). Average concentrations in the bottom waters between June and September in both ponds are anoxic (<1 ppm); maximum concentrations at these depths during the summer do not attain 5 ppm. Anoxic conditions rise as high as 2 m below the surface in both ponds (Figure VI-25).



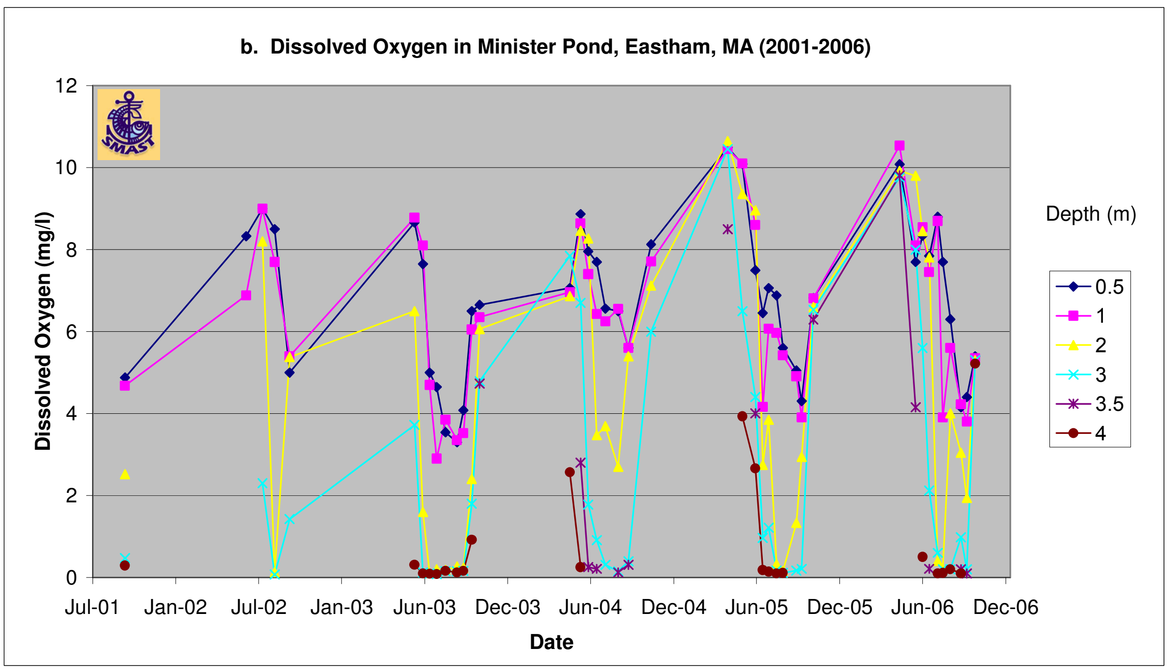
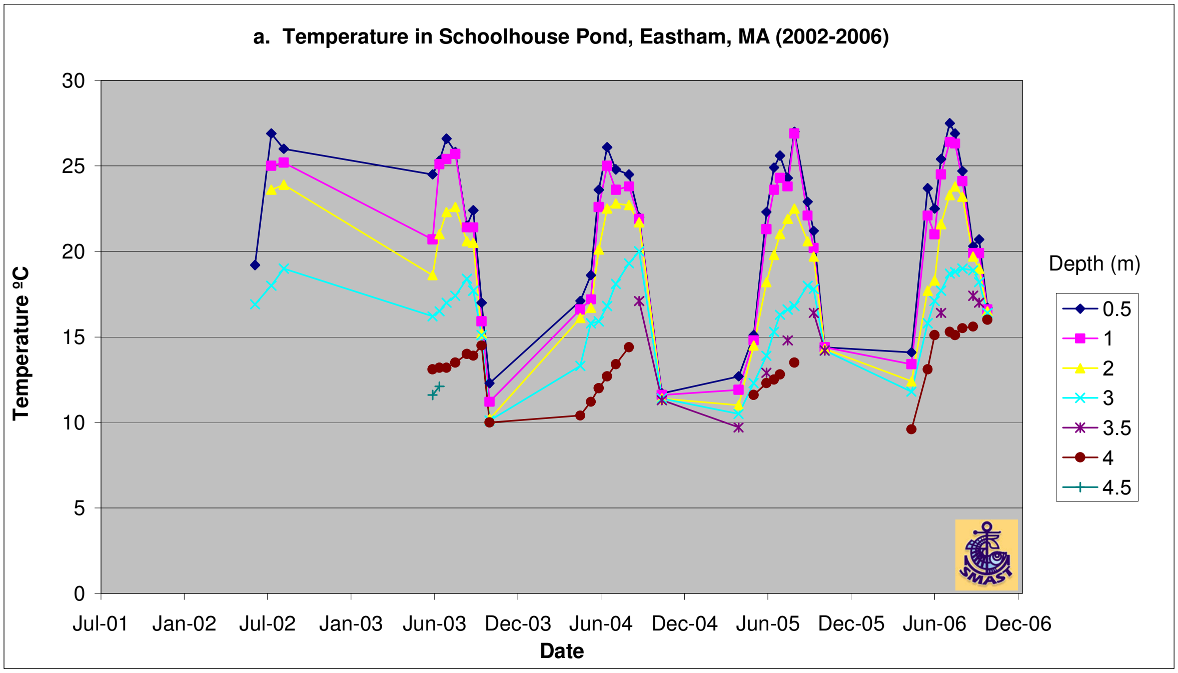


Figure VI-23. Minister Pond Temperature and DO Readings 2001-2006
Temperature data shows that the upper 1 m of the water column is well mixed with temperatures getting colder with increasing depth. Waters below 3 m consistently meet the 20°C regulatory threshold listed by the state for cold water fisheries (314 CMR 4). During early spring and late fall, water temperatures are relatively constant throughout the water column. Dissolved oxygen concentrations show lower concentrations with increasing depth and regular anoxic (<1 ppm) concentrations during the summer, which reach as high as 2 m below the surface. All data collected by Eastham volunteers using DO/Temperature meters between 2001 and 2006 and includes data from Cape Cod PALS Snapshots.



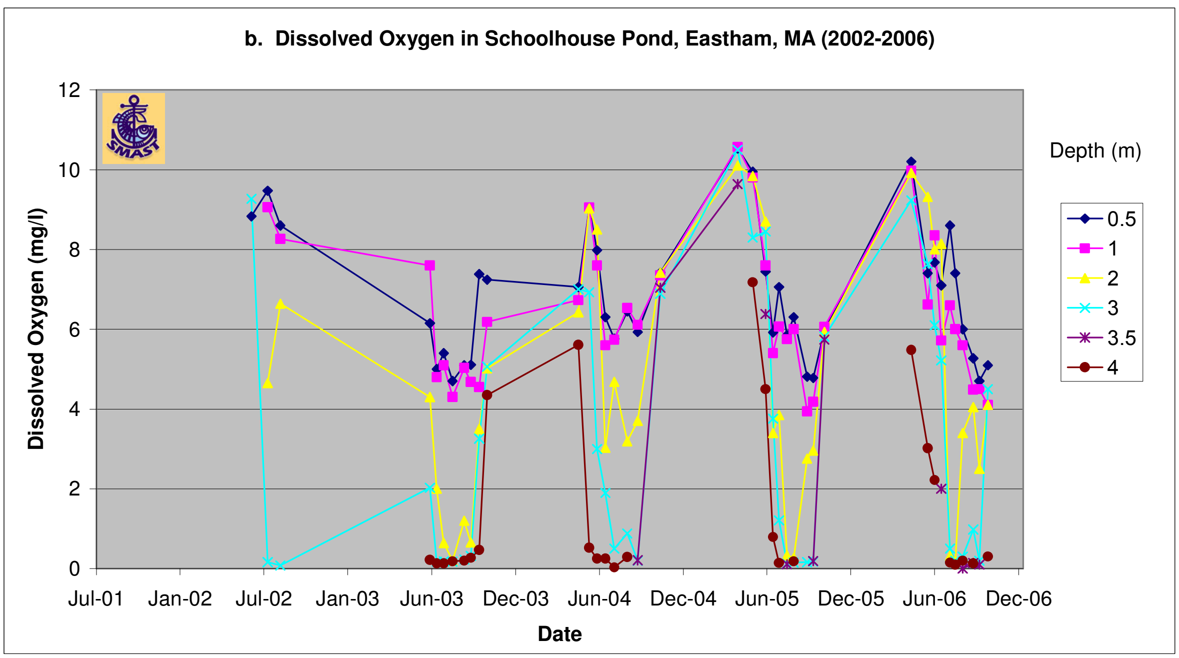
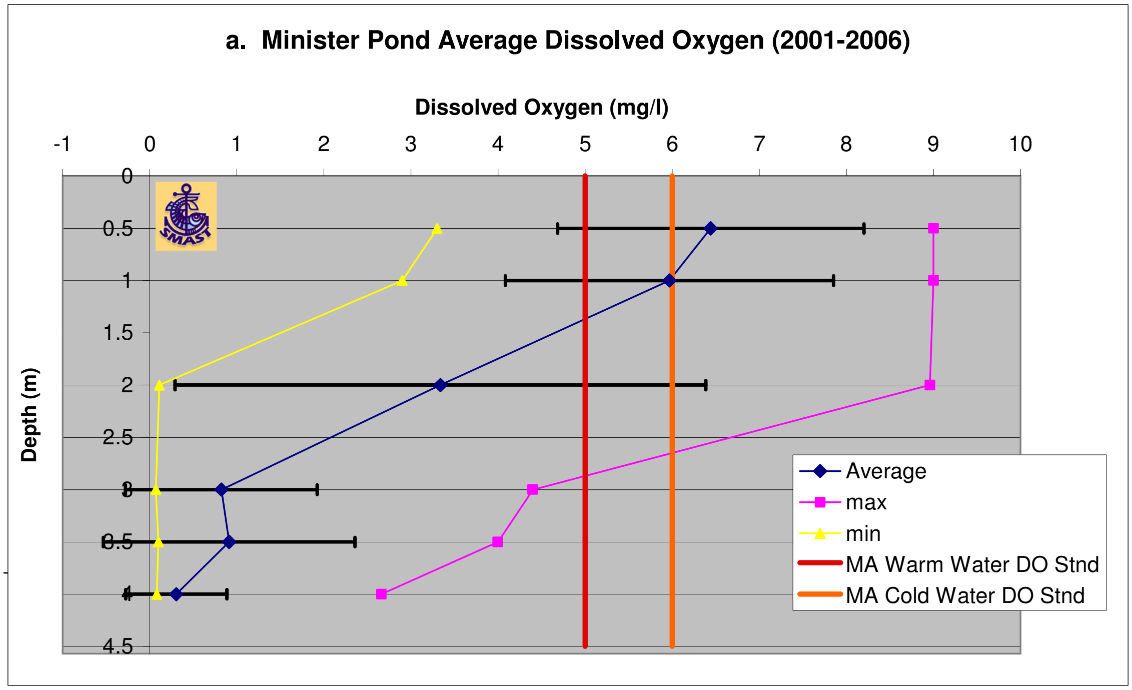


Figure VI-24. Schoolhouse Pond Temperature and DO Readings 2002-2006
Temperature data shows that the upper 1 m of the water column is well mixed with temperatures getting colder with increasing depth. Waters below 3 m consistently meet the 20°C regulatory threshold listed by the state for cold water fisheries (314 CMR 4). During early spring and late fall, water temperatures are relatively constant throughout the water column. Dissolved oxygen concentrations show lower concentrations with increasing depth and regular anoxic (<1 ppm) concentrations during the summer, which reach as high as 2 m below the surface. All data collected by Eastham volunteers using DO/Temperature meters between 2001 and 2006 and includes data from Cape Cod PALS Snapshots.



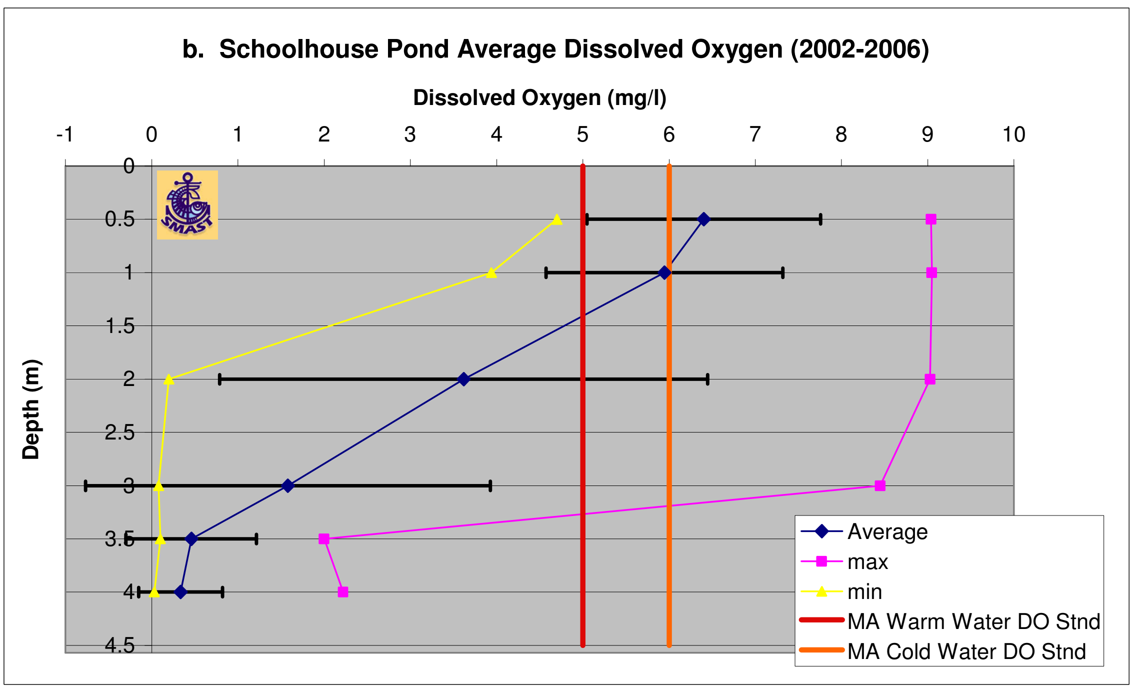


Figure VI-25. Minister and Schoolhouse Ponds Average DO Readings
Graph shows average DO profile (blue lines) based on data collected by town volunteers between 2001 and 2006 with error bars (±1 standard deviation) plus maximum (pink lines) and minimum (yellow lines) readings for each depth for (a) Minister (2001-2006) and (b) Schoolhouse (2002-2006) . Also shown by the orange line is the state surface water regulatory standard (6-ppm DO) for cold water fisheries and by the red line, the state surface water regulatory standard (5-ppm DO) for warm water fisheries (310 CMR 4). Most depths have 27-32 readings.

It is unclear what the appropriate state regulatory dissolved oxygen standard should be for Minister and Schoolhouse. Both ponds have average summer temperatures below 3 meters that are less than the 20ºC threshold that the state regulations use for defining cold-water fisheries (314 CMR 4). But both have a relatively small volume of cold water compared to larger, traditionally-stocked, cold water ponds like Great Pond. Conversely, the percentage of their volume meeting the temperature threshold is approximately the same as Great; waters greater than 3 m are 10% of Minister's volume and 6% of Schoolhouse's volume, while waters averaging less than 20ºC are 11% of Great's volume.

Regardless of the selection of the state regulatory dissolved oxygen standard, however, current average conditions in Minister and Schoolhouse fail to meet either standard and are clearly impaired under the state regulatory definition. Impaired waters are required to have a TMDL prepared. Waters with average dissolved oxygen below both state standards are 25% of Minister's entire volume and 20% of Schoolhouse's entire volume; if one uses the 6 ppm DO state standard, 46% of Minister and 42% of Schoolhouse volumes fails to meet the standard (Figures VI-26 and VI-27, respectively). If one looks at the waters in either lake with average temperatures less than the cold water fishery standard (20ºC), 100% of the volume of those waters fails to meet state dissolved oxygen standards.

Secchi readings in Minister average 1.3 m between June and September (n=34) during the 2001-2006 dataset (Figure VI-28). Average station depth is 4.3 m and on average 29% of the overall water depth is clear enough at the sampling station to see a Secchi disk. Station depth and Secchi readings have opposite trends of approximately the same magnitude (0.07 m per year); station depth have an increasing trend, while Secchi readings have a decreasing trend. The station depth trend is consistent with the increasing trend in groundwater levels at EGW36 (CCC water level records), but is approximately half the magnitude. Fluctuations in the Secchi readings are relatively small (COV=25%) and the trends are relatively insignificant. Secchi measurements are generally the highest during the early spring (April/May), followed by a drop of approximately 1.0 m with fluctuations within a 0.5 m range throughout the summer. Typically, the lowest reading is recorded in late July/early August. Minister is the only pond of those evaluated in detail that has a decreasing Secchi trend and its average relative Secchi reading (29%) is the lowest among all the ponds in Eastham (see Figure III-2).

Secchi readings in Schoolhouse average 1.4 m between June and September (n=31) during the 2002-2006 dataset (see Figure VI-28). Average sampling station depth is 4.6 m and on average 32% of the overall water depth is clear enough at the sampling station to see a Secchi disk. Station depth and Secchi readings have slight increasing trends 2002 and 2006; station depth is increasing at 0.02 m/y, while Secchi readings are increasing at 0.07 m/y. Neither trend is significant, but it is notable that the station depth is increasing at a rate that is smaller than the Minister. This difference is likely due to the close proximity of Minister and its likely dampening of water level changes because of its upgradient position. Secchi readings in Schoolhouse generally follow the same yearly pattern as Minister, although the initial drop from the early spring high is approximately 1.5 m. The relative Secchi reading (32%) is tied with Herring for the second lowest among all the ponds in Eastham (see Figure III-2). The variability of Secchi readings in both ponds is similar; coefficient of variation is 25% in Minister and 23% in Schoolhouse. It should also be noted that water clarity in both Minister and

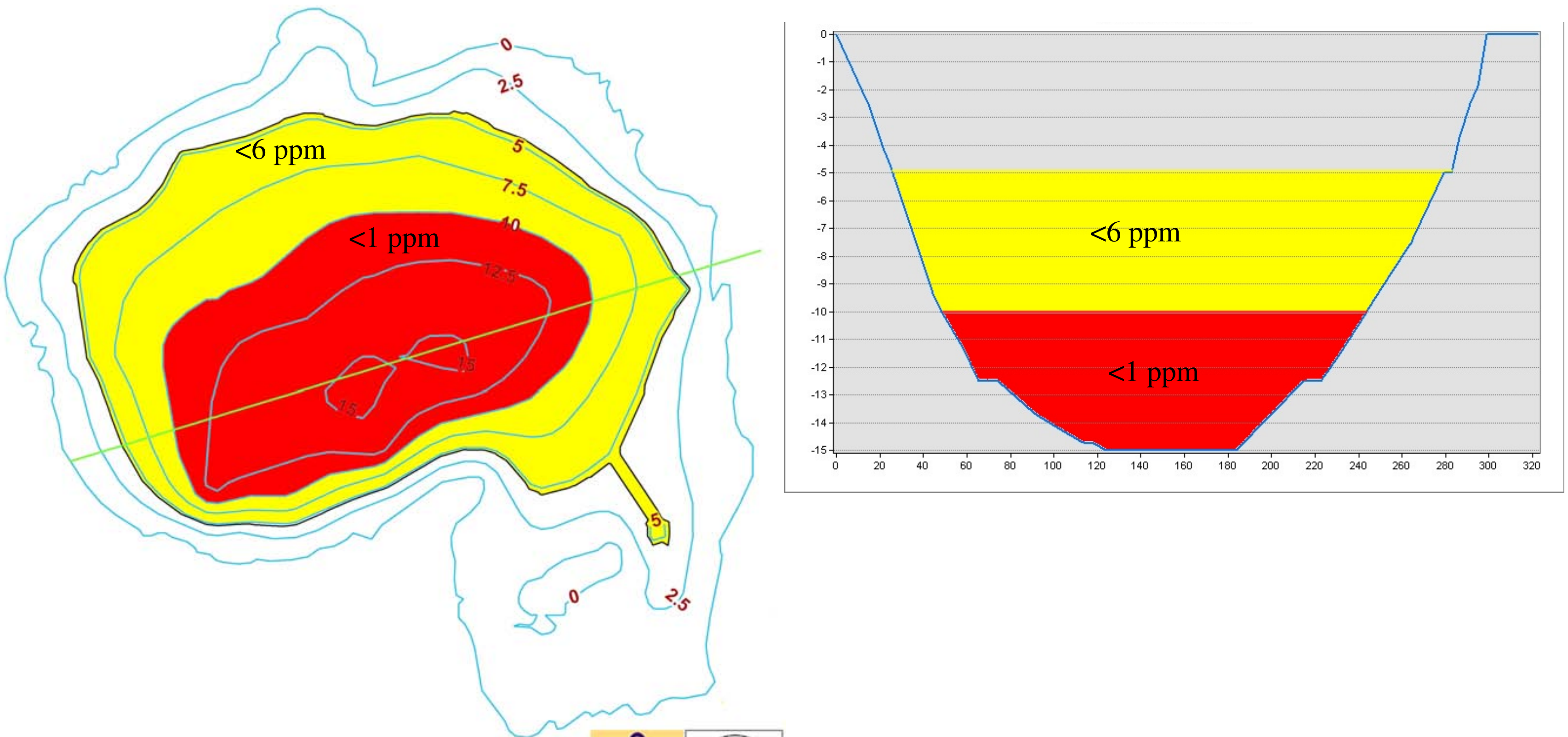


Figure VI-26. Minister Pond: Comparison of average dissolved oxygen (June through September) and state surface water regulatory standards

Depth profile and bathymetric map showing volume and area of Minister Pond with average dissolved oxygen (DO) concentration less than 6-ppm DO standard for cold water fisheries (shaded yellow) and area with average concentration less than 1 ppm (anoxic), which is shaded red. Green line on map shows depth profile track through the pond that corresponds to cross-section. 100% of the available cold water fishery and 46% of the total pond volume fail to meet the 6 ppm state DO limit. All bathymetry values are in feet.

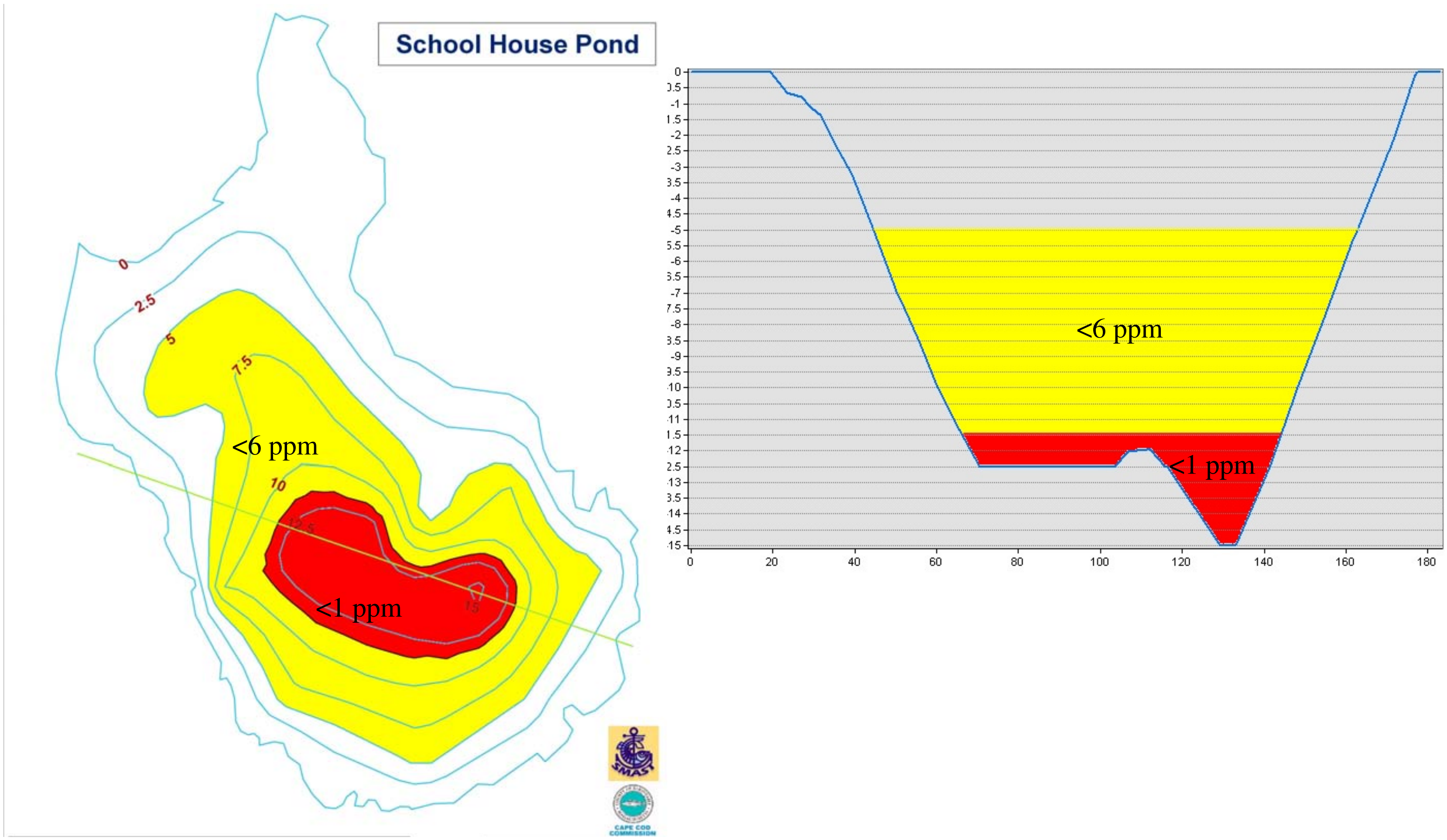
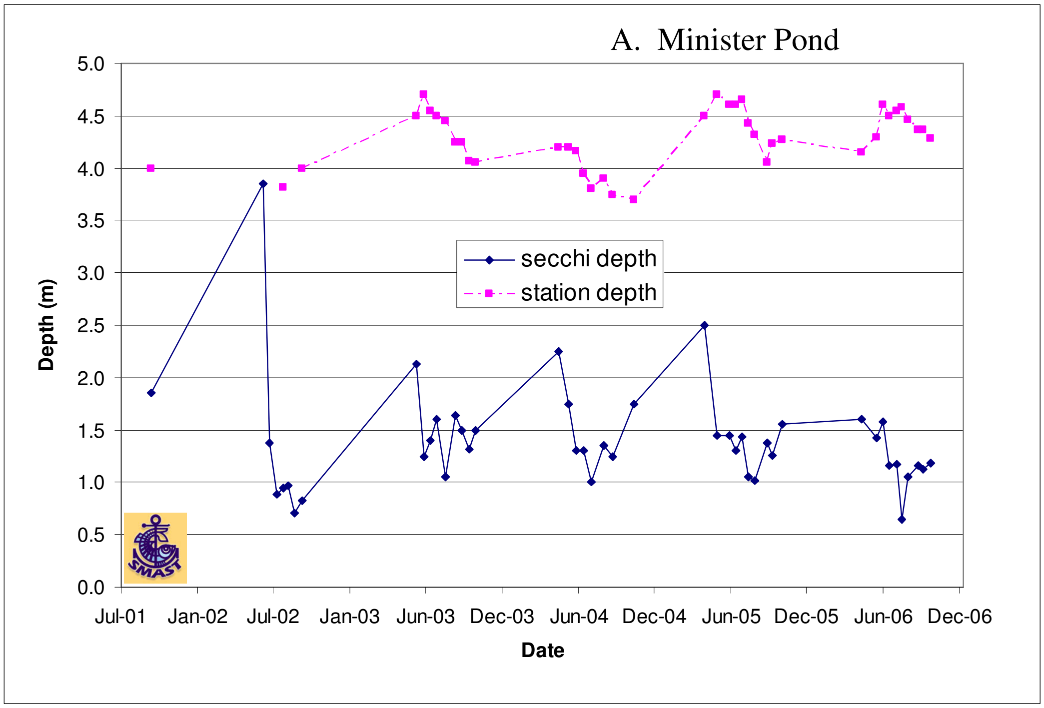


Figure VI-27. Schoolhouse Pond: Comparison of average dissolved oxygen (June through September) and state surface water regulatory standards

Depth profile and bathymetric map showing volume and area of Schoolhouse Pond with average dissolved oxygen (DO) concentration less than 6-ppm DO standard for cold water fisheries (shaded yellow) and area with average concentration less than 1 ppm (anoxic), which is shaded red. Green line on map shows depth profile track through the pond that corresponds to cross-section. 100% of the available cold water fishery and 41% of the total pond volume fail to meet the 6 ppm state DO limit. All bathymetry values are in feet.



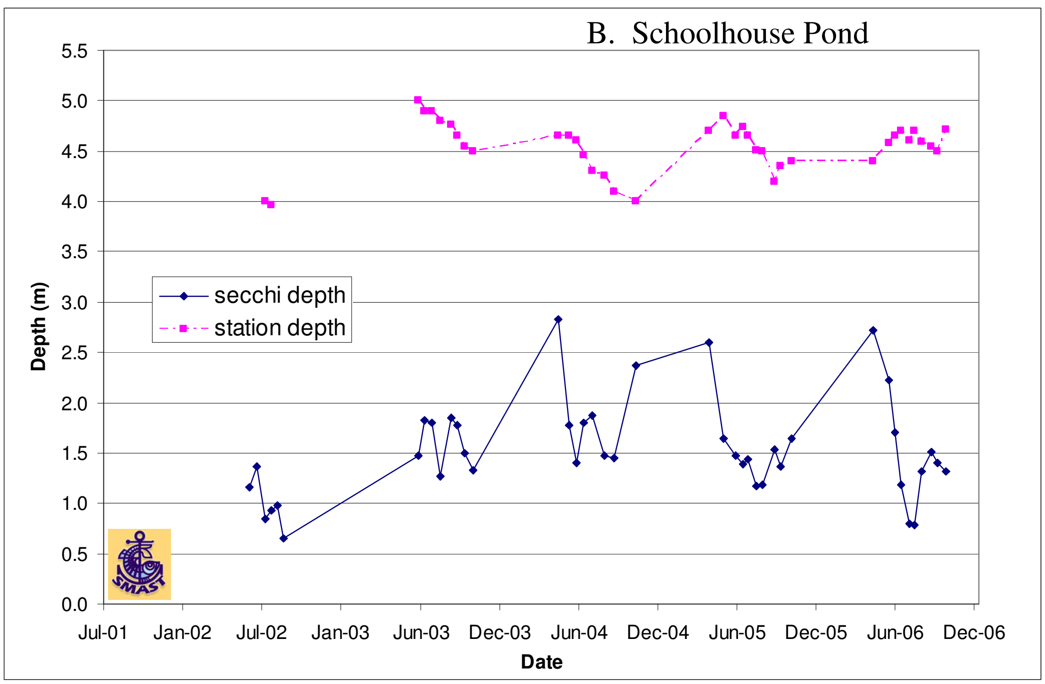


Figure VI-28. Secchi transparency readings in Minister Pond and Schoolhouse Pond 2001-2006

Blue data points are Secchi depth readings, while station depth measurement are shown in pink. All data collected by Eastham volunteers. Station depth and Secchi depth have no definitive trend over the sampling period. Average Secchi depth reading in Minister Pond is 1.26 m (n=34), while the average station depth is 4.3 m (n=30). Average Secchi depth reading in Schoolhouse Pond is 1.40 m (n=31), while the average station depth is 4.57 m (n=27).

Schoolhouse occasionally fail to attain the state standard for safe swimming of 4 ft (105 CMR 435).

Average total phosphorus (TP) concentrations between June and September in both Schoolhouse and Minister are more than double the Cape Cod 10 ppb "healthy" threshold. Schoolhouse average TP is 21.6 ppb at 0.5 m (n=14) and 20.3 ppb at the deepest station (n=14). Minister average TP is 22.0 ppb at 0.5 m (n=17) and 21.6 ppb at the deepest station (n=17). The average depth of the deepest station, which sampling protocol requires be 1 m off the bottom, is 3.2 m (n=14) in Schoolhouse and 3.1 m (n=18) in Minister.

The total mass of phosphorus in each pond is consistent with Minister acting as an initial "cleansing" basin and the recipient of most of the loads from the watershed. Minister has an average total mass of phosphorus between June and September of 3.0 kg (n=18); the average of all the data (n=24) is also 3 kg. Schoolhouse, on the other hand, has an average total mass of phosphorus of less than a third of Minister: 0.8 kg (n=15) between June and September and 0.9 kg (n=21) for all available data.

Based on the consistently low dissolved oxygen readings near the sediments in both Minister and Schoolhouse, one would expect that contrary to the measured concentrations that there would be elevated TP concentrations at the deepest station in both ponds. Low dissolved oxygen typically mobilizes iron-bound forms of phosphorus and allows regeneration of phosphorus from the pond sediments into the overlying water. Staff reviewed the dissolved oxygen concentrations and found that individual sampling profiles were relatively consistent throughout each of the summers and from year to year.

In order to explore this inconsistency further, project staff next reviewed the TP concentrations and found there are a number of individual sampling runs with the expected results, *i.e.*, relatively low surface TP concentrations with increasing concentrations with depth (7 of 18 runs in Minister), but there are more sampling runs with significantly higher concentrations in the shallow sample (11 of 18 in Minister). All of the 2003 data in Minister, which has the most samples of any of the years in the dataset, have significantly different ($\rho<0.02$) concentrations at shallow and deep stations. This kind of difference is usually seen when the deep station is influenced by sediment regeneration, but in this case, the higher concentration is measured in the surface samples. Flipping the 11 questionable samples in Minister results in an average surface TP concentration of 16 ppb and an average deep TP concentration of 29 ppb, which again raises the issue of transposed sample bottles or sampling results, which arose initially when these results were first made available. Similar changes are seen in the Schoolhouse concentrations. Previous discussions with CCNS lab staff have indicated that there is no way to clarify this issue further without additional sampling.

Ratios of total nitrogen to total phosphorus in both ponds between June and September show that the ponds are phosphorus limited. Minister has an average ratio of 78 in the surface waters and 206 at the deepest station, while Schoolhouse has an average ratios of 57 and 82, respectively. The higher ratios in Minister suggest that it is receiving a relatively higher nitrogen load than Schoolhouse. As would be expected, the transposed TP dataset increases the surface average ratios and decreases the bottom ratios in both ponds. Since all of these average ratios are multiples of the Redfield ratio of 16, regardless of whether the dataset is transposed or not, on average during the summer and throughout the year the pond is phosphorus limited. Review of nitrogen to phosphorus ratios show that management of phosphorus is the key to managing water quality in both Minister and Schoolhouse ponds.

In order to begin to frame appropriate water quality management strategy for both basins, all the sources of phosphorus that determine the mass of phosphorus in the ponds should be identified and this is usually done through the development of a phosphorus budget. Results from the phosphorus budget are then compared to the mass of phosphorus measured in the ponds to assess the assumptions in the loading factors and develop a better understanding of the functions within each basin. In order to begin to develop a watershed phosphorus budget for Minister and Schoolhouse, town volunteers reviewed Board of Health (BOH) records to determine the distance between the pond shoreline and septic system leachfields for all properties within 300 feet of the ponds (see Figure V-4), the age of the septic systems, and the age of the houses. Volunteers also noted any large lawn areas or any other notable potential sources of phosphorus close to the ponds. Once this information was developed, project staff narrowed the list to the properties that are upgradient of the ponds (*i.e.*, in the watershed) and used the factors in Table V-3 to estimate a watershed phosphorus load to both ponds.

As mentioned previously, phosphorus travel through an iron-rich aquifer, like Cape Cod's, is slower than groundwater, and is estimated to take 35 to 81 years to travel 300 feet (Robertson, 2007). Project staff compared this range of times to the septic system information developed by the town volunteers and determined whether it was likely that a given septic system or a house is currently contributing phosphorus to the pond or whether the phosphorus from the property is still in transit in the aquifer.

Based on the land use review, there are 23 properties within the 300 ft buffer upgradient of Minister Pond. Of these, 20 are developed and are classified by the town Assessor as residential; 16 are single family residences. Two parcels are classified as being available for single-family residential development, while the other parcel is a portion of the Eastham Elementary School parcel. Schoolhouse only has two developed properties within its relatively small watershed; one is a mixed use building and the other is another portion of the Eastham Elementary School parcel. Review of the elementary school's septic system layout indicates that it is not within the watershed to either Minister or Schoolhouse Pond.

The average age of the 20 existing residences upgradient of Minister and within the 300 ft buffer is 43 years old and a range of years built from 1910 to 1988. The one building in the Schoolhouse watershed is 61 years old with a septic system estimated to be 50 years old that has a leachfield that is estimated to be 250 feet from the pond shore. The average age of the septic systems on the developed lots upgradient of Minister is 13 years old with year of installation ranging between 1980 and 2005. The average distance to Minister for these residences' septic system leachfields, based on a review of BOH records, is 209 feet with a range of 82 to 350 feet.

Based on the age of the Minister residences, 17 of the 20 have existed long enough to contribute phosphorus to the pond if one assumes that it takes 35 years for phosphorus to travel 300 ft, while only four contribute phosphorus if it takes 81 years. Based on the age of the septic systems, the respective numbers are five and zero systems contributing to the pond. The single Schoolhouse developed property is contributing phosphorus to the pond based on a 35 year time-of-travel and is not if an 81 year time-of-travel is assumed.

Using the factors in Table V-3 and accounting for groundwater lag times, the current total external/watershed phosphorus load to Minister is estimated to be between 8.4 and 17 kg/yr with an existing steady state loading range of 17.5 to 18.3 kg/y. Of this total load, wastewater from septic systems is between 0 and 7.7 kg/yr (0 to 46%) of the external load. Other portions of external loads into the pond are lawns (4 to 8%), roof runoff (9 to 18%), birds based on an areal loading rate (7 to 14%), birds based on the per pond load (3 to 15%),and roads (30 to 60%) (Figure VI-29). The areal bird loading rate (1.2 kg/y) for Minister is roughly equivalent to the high end of the per pond bird loading rate (1.3 kg/y), so difference between these two estimates is captured within the overall pond loading estimate. Buildout of the two undeveloped lots within the 300 ft buffer is projected to the increase the steady-state loading range to 19.6 to 20.4 kg/y. Uncertainties associated with the loading factors are discussed in the phosphorus budget factors section (see Section V.3.).

Given that Minister occupies most of their shared watershed, the estimated total external/watershed phosphorus load to Schoolhouse is much smaller: between 1.5 and 2.8 kg/yr using the factors in Table V-3 and accounting for groundwater lag times. The existing steady-state annual loading range is 1.9 to 2.8 kg. Of this total load, wastewater from septic systems is between 0 and 0.5 kg/yr (0 to 18%) of the external load. Other portions of external loads into the pond are lawns (1 to 2%), roof runoff (3 to 5%), birds based on an areal loading rate (20 to 38%), birds based on the per pond load (18 to 48%),and roads (18 to 34%) (Figure VI-30). The areal bird loading rate (0.6 kg/y) for Minister is roughly equivalent to the low end of the per pond bird loading rate (0.5 kg/y), so difference between these two estimates is captured within the overall pond loading estimate. Since there are not any additional lots available for development in the watershed, the buildout steady-state phosphorus loading range for Schoolhouse increases only slightly to 1.9 to 2.8 kg/y to account for the remaining fraction of groundwater phosphorus delay.

Although the bird loading source is relatively constrained by the available estimates, it is recommended that the bird contribution to both ponds should be clarified by regular counts (daily or monthly) of bird species and numbers throughout a whole year. Such a study, which is beyond the scope of the current analysis, would be required to detail this in a more definitive fashion and would provide pond-specific information. This type of effort could be accomplished by volunteers who are trained or have training to identify the likely bird species and have the ability to view the entire lake. SMAST staff can provide guidance to the town for resolving this issue.

In addition, it is also recommended that the town consider evaluating stormwater runoff around both ponds. Based on the assumptions in Table V-3, road runoff accounts for a significant portion of the total phosphorus budget for both ponds. Developing more refined measurements of actual loads would help to refine the phosphorus budget and the better target phosphorus management strategies.

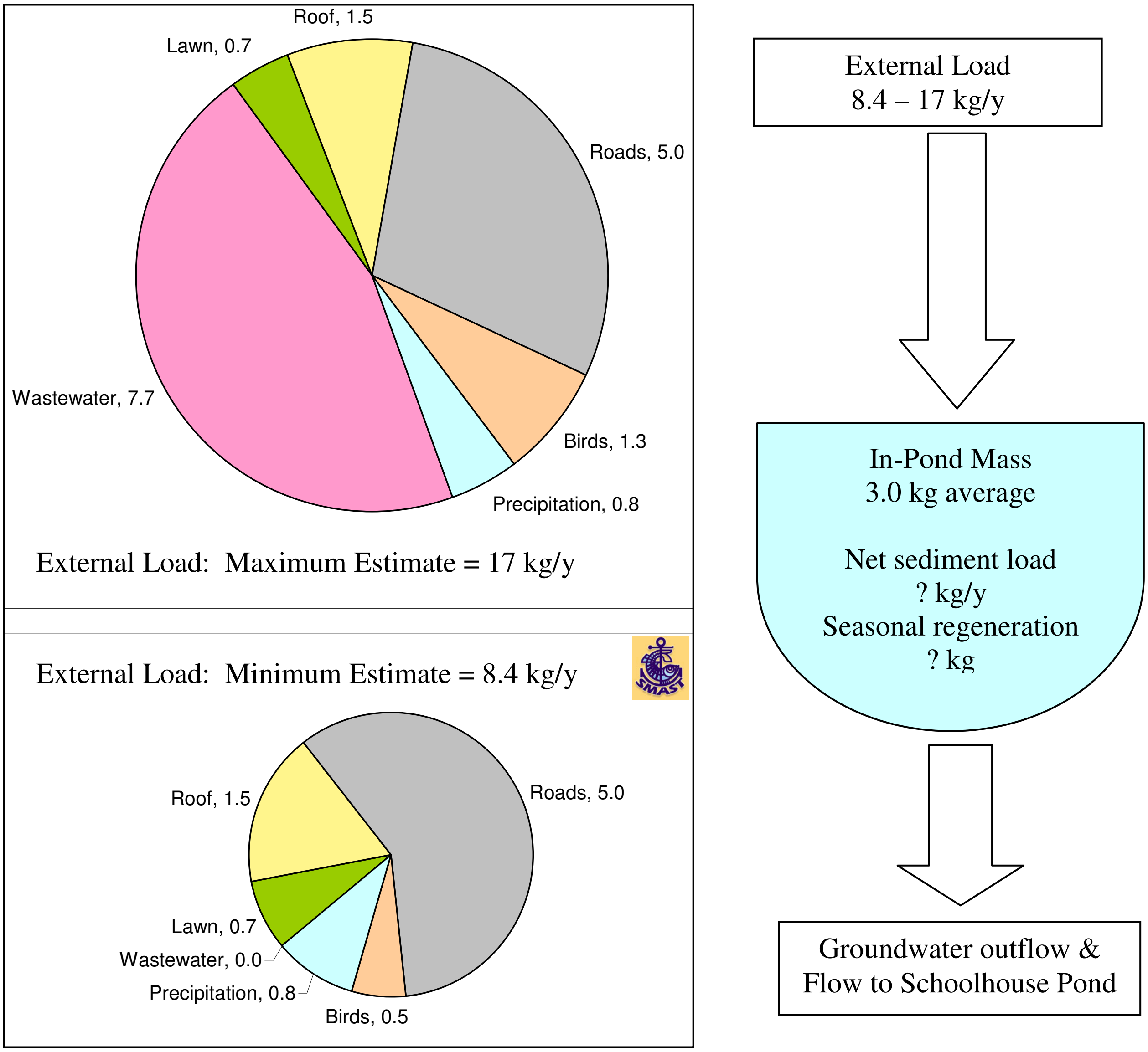


Figure VI-29. Estimated phosphorus budget for Minister Pond

In-lake mass is based on collected 2001-2006 water quality data. Wastewater load from upgradient properties within the 300 ft buffer based on septic load travel time of 35 to 81 years. Road loads include all areas within 300 ft buffer. Among these loads, bird loading is the most uncertain, although gathering additional information on road runoff is also recommended, as is further evaluation of outflow of phosphorus to Schoolhouse Pond. Wastewater factors loading factors are reasonably well understood, so time of travel is likely the key variable in the estimate of wastewater load. Other phosphorus loads are based on factors from Table V-3. Groundwater outflow and flow to Schoolhouse Pond are the potential discharge routes for phosphorus from Minister. Sediment sources are also not well understood, due to apparent inconsistencies between dissolved oxygen and total phosphorus concentrations. Determination of sediment regeneration to help resolve these inconsistencies would require direct measurement through collection and testing of sediment cores.

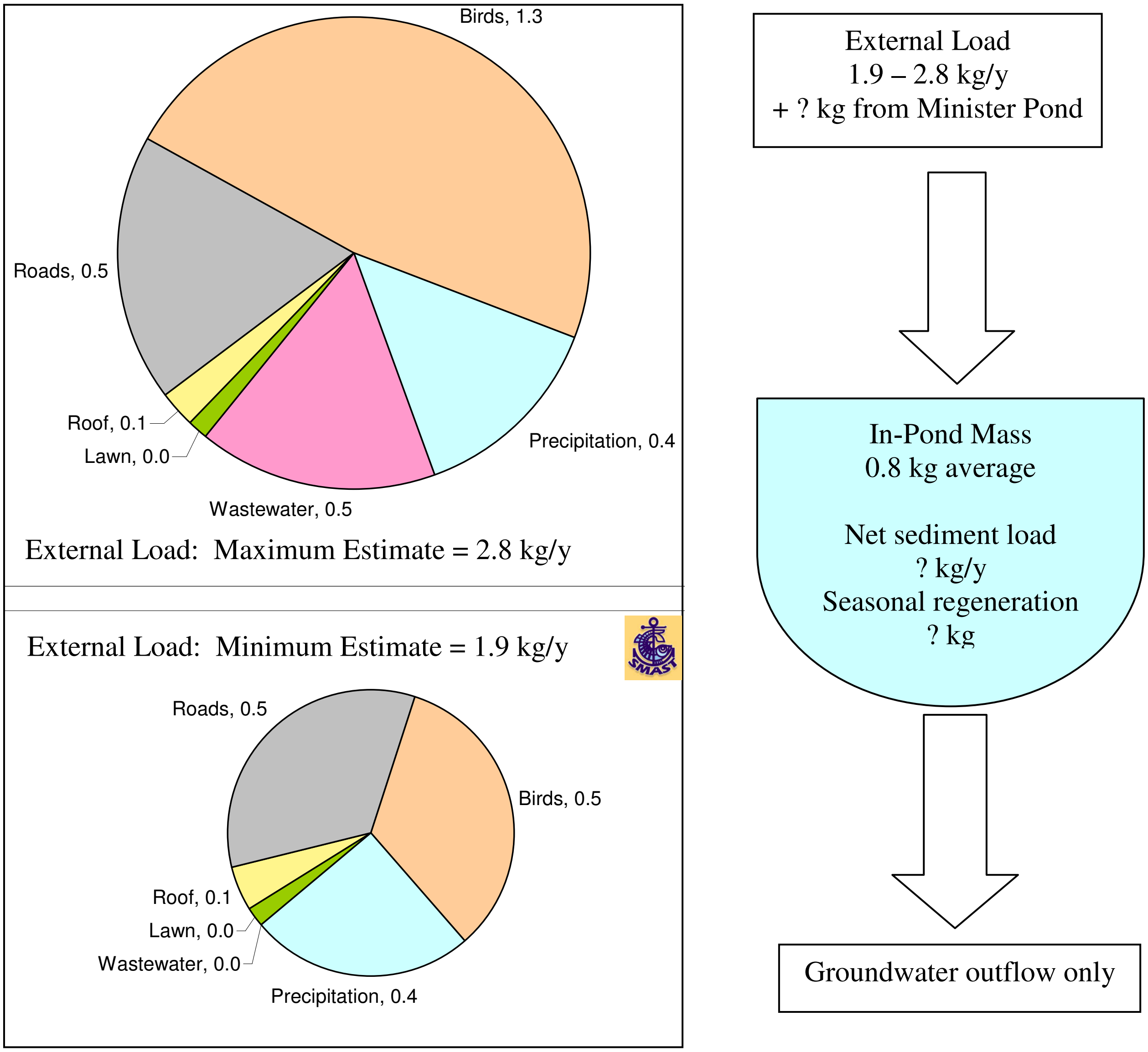


Figure VI-30. Estimated phosphorus budget for Schoolhouse Pond

In-lake mass is based on collected 2001-2006 water quality data. Wastewater load from upgradient properties within the 300 ft buffer based on septic load travel time of 35 to 81 years. Road loads include all areas within 300 ft buffer. Among these loads, bird loading is the most uncertain, although additional information on road runoff is also recommended, as is further evaluation of influx of phosphorus from Minister Pond. Wastewater factors loading factors are reasonably well understood, so time of travel is likely the key variable in the estimate of wastewater load. Other phosphorus loads are based on factors from Table V-3. Groundwater outflow is the only potential discharge of phosphorus from the pond. Sediment sources are not well understood, due to apparent inconsistencies between dissolved oxygen and total phosphorus concentrations. Determination of sediment regeneration to help resolve these inconsistencies would require direct measurement through collection and testing of sediment cores.

The residence time for water in Minister Pond is 0.3 years, while Schoolhouse's is 1.2 years. Residence time means that the average mass of phosphorus measured in the pond without accounting for any phosphorus regenerated from the sediments should be approximately the same as annual external loads from the watershed and precipitation times the residence time. As mentioned previously, the total mass of phosphorus in the Minister based on water quality measurements between June and September averages 3.0 kg (n=18) and also 3.0 kg (n=24) if all data is considered. Schoolhouse average total mass is 0.8 kg (n=14) and 0.9 kg (n=24) if all data is considered. Based on the residence times and the 10 ppb TP Cape Cod-specific threshold, the target phosphorus mass in Minister is 1.3 kg, while the target phosphorus mass in Schoolhouse is 0.4 kg.

Based on the respective residence times and the average surface total phosphorus concentrations, the annual load that is projected to enter Minister Pond from external and internal sources would be 9.7 kg, while the Schoolhouse load would be 0.7 kg. If the transposed concentrations are used, the respective annual loads are 7 and 0.46 kg. None of the estimates consider any in-pond attenuation.

The non-transposed water quality data seems to show that existing loading to Minister is likely to be toward the lower end of estimated phosphorus loading range, while Schoolhouse is less than the lowest estimated annual load. The non-transposed Minister loading rate is slightly higher than the 8.4 kg/y minimum assumed from the phosphorus loading estimates, while the Schoolhouse loading rate is approximately half of the lowest estimate phosphorus loading estimate (1.5 kg/y). The transposed values are both lower than the lowest loading estimates, which would be consistent with the sediments being a more significant source.

Given a phosphorus attenuation rate of 50%, the annual loads into Minister would have to be double the loading rate. Incorporating this attenuation rate results in a phosphorus loading rate of 19.4 kg/y for the non-transposed concentrations and 14 kg/y for the transposed concentrations. Both of these are near the high end of the estimated phosphorus loading rate based on the factors in Table V-3. This analysis reinforces the need to better characterize the sediments and whether they need to be addressed in water quality management strategies.

Since the Schoolhouse loading rate is lower than the estimated rates for both transposed and non-transposed data and the loading sources are so limited, it raises the question of how much of Schoolhouse's load is contributed by the direct connection to Minister. The 0.46 or 0.7 kg/y phosphorus in Schoolhouse suggests that the only significant loads to the pond are precipitation, road runoff, and birds. If estimated loads of these sources are added together and a phosphorus retention rate of 50% is applied, this approximates 0.7 kg/y, but this does not account for any flow from Minister. Evaluation of other connected basins in ponds on Cape Cod have shown that transfer between the basins is likely, especially when one of the basins is the primary discharge location (Eichner, 2008). Further evaluation of potential phosphorus sources, including measurements at the connection between Minister and Schoolhouse, would be necessary to establish the relative contribution of all sources.

VI.4.2. Minister and Schoolhouse Conclusions and Recommendations

Minister and Schoolhouse Ponds are two basins within a combined 21 acre pond. Based on a review of the available data, both Minister Pond and Schoolhouse Pond have impaired water quality according to state regulatory thresholds and, thus, will eventually require a TMDL. Although the temperature data suggest that the combined pond could sustain a small cold water fishery in both basins, average dissolved oxygen concentrations throughout this portion of the water column in either basins do not meet the required state regulatory limit of 6 ppm, and are generally lethal to fish because they are anoxic. Review of nitrogen to phosphorus ratios show that management of phosphorus is the key to managing water quality in both Minister and Schoolhouse.

Average total phosphorus concentrations are not consistent with these anoxic conditions having similar concentrations at both the surface and deep stations in both ponds. Transposing shallow and deep concentrations measured mostly during the 2003 sampling year do, however, establish a consistency between these two dataset and raises the issue of whether samples or data were consistently transposed. Regardless of whether transposed or non-transposed datasets are used, average surface TP concentrations are elevated above Cape Cod-specific standards.

In order to manage phosphorus, better definition of its sources is required. The dissolved oxygen data and the transposed phosphorus data suggests that the sediments need to be a target for management, while the non-transposed phosphorus data suggests that the primary target for management should be the watershed loading. Review of the phosphorus loading information suggests resolving the role of the sediments is important, as well as developing more refined, pond-specific information on some of the watershed sources.

To help resolve these apparent inconsistencies and move forward with appropriate management strategies, it is recommended that the town complete a one year, targeted pond characterization study of both basins. This study would include, at a minimum: 1) collection of sediment cores from both basins and testing of the cores to gauge the maximum amount of expected and potential phosphorus release from the sediments, 2) coincident collection of water quality samples and field data, 3) characterization of the internal movement of water and nutrients between Minister and Schoolhouse, 4) identification and measurement of stormwater inputs into Minister and Schoolhouse, and 5) identification and counts of birds on the ponds throughout a year. Analysis of the samples should include evaluation of constituents that might be providing oxygen and suppressing phosphorus release from the sediments. This type of study will allow the town to better understand phosphorus dynamics throughout the ponds and how low dissolved oxygen concentrations are apparently having little impact on sediment regeneration of phosphorus. It will also allow the town to establish a dissolved oxygen threshold for significant release of phosphorus from each basin’s sediments. This type of study will adequately characterize the system and will result in water quality management strategies that will be more definitively supported. SMAST staff can provide a detailed scope and anticipated cost for such a study if requested by the Town.

Although there are inconsistencies among the various datasets, it is clear that dissolved oxygen conditions do not meet state surface water regulatory standards. In addition, since phosphorus is clearly the controlling nutrient for Minister and Schoolhouse ponds, implementation of best management practices to reduce phosphorus loads can only help to improve water quality conditions in the pond. Given that the majority of the land uses are in the Minister watershed and these are predominantly residences, best management practices (BMPs) focused on uses along the pond shoreline are likely the lowest cost alternatives for decreasing watershed phosphorus loading. These BMPs would include: 1) maintaining, planting, or allowing regrowth of natural buffer areas between the pond and lawns/yards/houses, 2) installing treatment for or redirecting any direct stormwater runoff, and 3) ensuring that all new septic system leachfields have an adequate setback from the pond (at least 300 feet or the maximum possible on a lot). If the town pursues sewering in this area as a result of current wastewater planning, this would remove the phosphorus wastewater component. Review of the potential benefits and costs of the various options could be addressed as a supplemental task paired with the recommended plant survey and sediment characterization. SMAST staff are available to provide further guidance to the town in addressing this issue.

It is further recommended that the town continue to maintain a volunteer pond water quality monitoring program and that Minister and Schoolhouse should continue to be part of it. Given the amount of volunteer data that has already been collected in the ponds, it is recommended that this sampling be limited to a minimum of two sampling runs conducted each year using the PALS sampling protocol and the parameters measured. It is suggested that these runs be completed during April and August/September (the latter being the usual PALS Snapshot period). This type of in-lake sampling schedule would create annual data to assess how the ecosystem is set prior to the active summer period (the April run) and then measure conditions during the likely worst-case water quality conditions (the August/September run). Comparison of this data to prior data would provide a better sense of interannual ecosystem fluctuations, measures to assess the benefits of any remedial activities that are undertaken, and provide an "early warning" if conditions worsen significantly. It is further recommended that collected data be reviewed and interpreted at least every five years in order to provide regular feedback and assessment of pond conditions.

SMAST staff are available to assist the town with the completion of any of the actions recommended for consideration and can provide a detailed cost proposal if requested.

VII. Recommendations

VII.1. Town-wide Monitoring Recommendations

On April 3, 2007, the author prepared a memo to the town describing pond monitoring recommendations for summer 2007. The recommendations in the memo are generally consistent with the enhanced recommendations that are included in this report, notably: 1) continuing the volunteer monitoring program at a reduced sampling frequency on the 9 of 10 ponds that have been regularly sampled, 2) reviewing whether sampling is supported or desired for the other 13 ponds that have not been sampled, and 3) preparing for targeted sampling of other pond components, such as the sediments, but waiting until the review of the data (*i.e.*, this report) is completed. Bridge Pond was the one pond that is not recommended for reduced sampling since it had only been sampled three times and only through the PALS Snapshots. The 2007 recommendations memo is included in Appendix B. These recommendations are reinforced and expanded on in the following discussion.

Eastham volunteers under the guidance of the town Water Resources Advisory Board (WRAB) have regularly collected data from nine ponds. The majority of laboratory water quality datasets for most ponds generally consist of monthly to biweekly water quality samples collected during four summers (2002-2003 and 2005-2006). This data is supplemented with additional once-a-year PALS snapshot data from 2001-2006. A number of the ponds have Secchi transparency readings and dissolved oxygen and temperature profiles collected on a monthly to biweekly basis between May and October from 2002 through 2006, but some were not sampled at this rate throughout this period.

In general, most of the ponds have between 15-20 total phosphorus (TP) readings and 25-35 dissolved oxygen profiles and Secchi readings. Since Secchi and DO readings can be collected in the field and do not require laboratory analysis costs, their collection is relatively less expensive and generally depends on volunteer time and access to field equipment. Since the upper portions of the water columns in most of the ponds are well mixed by normal Cape Cod winds, the upper DO readings tend to be relatively stable. Deeper in these ponds, where the impact of sediment oxygen demand can reduce DO concentration, readings are consistently more unstable. Total phosphorus, total nitrogen and chlorophyll all follow a similar stability pattern, except for those ponds where deep and shallow concentrations may have been transposed. The review of the data and the detailed analysis of selected ponds indicate that this increased variability is generally a reflection of ecosystem impairment. This finding also suggests that sufficient volunteer monitoring data has generally been gathered in the nine ponds regularly monitored and it is now time to turn toward less intensive long-term volunteer monitoring and more refined targeted or focused monitoring of selected parameters identified through the detailed review of Great, Herring, Muddy, Long, Schoolhouse, and Minister.

It is recommended that the volunteer pond monitoring program should be refocused into a tiered effort to address additional data needs for ponds in the Town. It is suggested that this effort focus on 1) sampling and assessment of ponds that have not been monitored, 2), collection of targeted data from the well-monitored ponds that will help to better define remedial and protection strategies, 3) long-term monitoring and review to assess longer term trends and provide an "early warning" system for yearly conditions that warrant additional attention, and 4) provisions to monitor and review the benefits of any remedial or protection strategies that are implemented. Each of these recommendations is briefly discussed below.

The above review has shown some of the limitations of the available data and, more importantly, the fluctuations in year to year results. Although targeted sampling will resolve some of the apparent inconsistencies, it is clear that conditions in these ponds are continuing to change and fluctuate. With this in mind, it is recommended that these ponds should continue to be regularly monitored, but with reduced frequency, in order to assess whether the systems have longer-term trends that should be addressed, as well as providing a year-to-year review of changes that are exceptional and outside of the ranges established by the current dataset. It is recommended that the town consider changing the monitoring program for the nine ponds with extensive datasets to a twice-annual sampling strategy. Water samples and field readings would be collected in April and August/September, while continuing to use the PALS sampling protocols and parameters. The August/September sampling for long-term trend analysis could continue to be funded through the PALS Snapshot as long as it continues to be supported by UMASS Dartmouth, School of Marine Science and Technology and the Cape Cod Commission. A brief review at the end of each sampling season should be conducted to identify training needs for the next season and identify any other potential concerns. Every five years, gathered data should be reviewed for trend analysis and long term monitoring concerns including comparison to past data. It is estimated that the annual cost for samples without PALS funding and with a simple annual review would be $5,000 to $7,000. The review of five years worth of data and comparison to past data would have an estimated cost range of $10,000 to $15,000.

In addition, it is recommended that monitoring frequency would then be increased to at least once a month between April and November for at least one year or longer at the time any remedial water quality activities are initiated either in a watershed or within a pond. The overall length of monitoring would depend on projected groundwater flow times and/or pond residence times to assess whether projected benefits are realized. Details regarding the parameters to be measured could be worked out at the time the increased frequency and remedial activities are planned.

The reduced frequency of sampling recommended for the other ponds that have been monitored would allow volunteers to focus efforts on the approximately 13 other ponds in Eastham that have not been monitored plus Bridge. It is recommended that the Town WRAB consider adding additional ponds to the sampling program. The Cape Cod Pond and Lake Atlas (Eichner and others 2003) lists Eastham as having 23 ponds, while 10 are currently sampled. It would be useful to determine what is known about the ponds that have not been sampled and assess whether monitoring and/or physical characterization (*e.g.*, bathymetry) is desired. Since it is estimated that most of these ponds are relatively shallow and would only require two samples under the PALS sampling protocol, the estimated cost per sampling run of all 13 ponds would be approximately $2,000 to $2,750 if volunteers collected all of the samples. It is recommended that the WRAB initiate a process to evaluate the interest and desirability of sampling or gathering other information for the ponds that have not been monitored.

Targeted additional data from the ponds that have been monitored will be necessary prior to the final development of remedial or protective strategies. This need has been identified as a priority from the detailed reviews of all six ponds discussed above, but it is likely to be an issue for all the other ponds that already have extensive datasets. Additional data to be collected would include evaluation of sediment nutrient (and potentially metals) concentrations and potential nutrient regeneration rates, measurement of stormwater nutrient loads, pond-specific bird counts, and better measurement of stream inputs and outputs from selected ponds. Some of these data needs can be collected by volunteers, but others will require data collection by professionals. Further discussion of this issue will be derived from review of information on the individual ponds and, accordingly, is discussed below for the ponds that were selected for detailed review.

Of course, all of the above recommendations are dependent on adequate funding to complete the recommended work. Volunteers provide savings for labor costs and the town has made investments in equipment costs, but implementation of the above refocusing will require additional funding for laboratory analysis and professional staff time. SMAST staff are available to help the town evaluate potential costs for all the monitoring options.

In summary, data from the completed volunteer monitoring is sufficient to identify additional data needs and eventually potential remedial/protective strategies for: Great, Herring, Jemima, Long, Minister, Molls, Muddy, Schoolhouse, and Widow Harding. Plans should be considered to conduct detailed reviews of Jemima, Molls, and Widow Harding The town should consider expanding the scope of these reviews to incorporate all of the available data, including chlorophyll *a* and nitrogen. It is further recommended that existing volunteer monitoring be refocused into a reduced frequency, longer-term schedule for all nine ponds listed until management activities are implemented and consideration should be given to extending monitoring to other ponds in Eastham that have not been monitored.

VII.2. Recommendations for Next Steps for Great, Herring, Long/Depot, Muddy, and Minister/Schoolhouse

The review of data contained in this report indicates that sufficient basic volunteer data has been gathered from Great, Herring, Long/Depot, Muddy, and Minister/Schoolhouse ponds to identify targeted data needs and begin down the path toward the development of remedial/management activities to address their impairments. Each of these ponds has unique characteristics that suggest that the next steps will require pond-specific tailoring of these activities. Project staff have developed approximate cost ranges for each of these recommendations based on School of Marine Science and Technology (SMAST) staff completing these tasks; there are likely to be cost savings associated with completing a number of tasks together. SMAST staff are available to discuss these recommendations with town staff and can develop refined cost proposals that will detail the tasks, appropriate schedules and the resulting reports.

VII.2.1. Great Pond Recommendations

Great Pond is the deepest (13 m) and largest (110 acres) of Eastham's ponds. Great is classified as a mesotrophic pond, is impaired according to state surface water regulations, and thus, will eventually require preparation of a TMDL. Average summer dissolved oxygen concentrations throughout the bottom waters fail to attain the state cold water fishery standard of 6 ppm and the deepest waters are anoxic (*i.e.*, lacking oxygen). These conditions would allow any nutrients regenerated from the sediments to mix into the warmer upper waters on a regular basis and prompt additional phytoplankton growth.

Phosphorus is the key nutrient to manage water quality in Great Pond, but additional information about internal sediment regeneration, loading from birds, and updated stream outflow is recommended before development of definitive management strategies. Collection of this data will also help to resolve some inconsistencies among the available datasets. Once the recommended information is provided, management activities can be crafted to address the phosphorus sources that are the most cost effective and achieve the largest reductions.

In order to develop the recommended information and incorporate it into a revised evaluation of Great Pond, it is recommended that the town consider a targeted one year analysis of select phosphorus components in order to develop management strategies that can be confidently pursued, resolve the inconsistencies in the various datasets, and lay the groundwork for preparation of a TMDL. This study would build on the results in this current report and answer the questions that have been raised, but left unanswered, by the currently available data. SMAST staff recommend that this study include the following at a minimum: 1) collection and incubation of three sediment sample cores to determine phosphorus content, regeneration potential, and dissolved oxygen thresholds, 2) a whole year of observation of bird populations on the pond, including identification of species, 3) at least monthly measurement of stream outflow and analysis of accompanying water quality samples, and 4) at least monthly collection of water quality samples in the pond using the standard PALS procedures including dissolved oxygen and temperature profiles and standard laboratory analysis plus other chemical constituents that might influence phosphorus regeneration. Development of this information could then be used to develop recommendations and costs for management strategies. SMAST staff have estimated that the cost of a stand alone project with these recommended activities at between $25,000 and $30,000 with another $11,000 to $13,000 for combining this information with past information and developing water quality management strategies and a recommended TMDL. Additional analysis that should be considered and would help to clarify interactions in the pond and potential management activities would include a survey of rooted plants, phytoplankton and epiphytic algae, an updated bathymetric map, a survey and map of sediment thickness, and evaluation of stormwater structures around the pond. SMAST staff can discuss strategies with town staff and can provide the town with a detailed scope of work if requested.

VII.2.2. Herring Pond Recommendations

Herring Pond is the second deepest (12 m) and second largest (44 acres) of Eastham's ponds. Herring is classified as a mesotrophic pond, is impaired according to state surface water regulations, and thus, will eventually require preparation of a TMDL. Although the pond has on average approximately 1 m of cold waters that meet the state minimum dissolved oxygen standard, the high frequency of unacceptable low dissolved oxygen in these waters means that the fishery is unsustainable. Average summer dissolved oxygen concentrations deeper than this unstable layer are less than the state 6 ppm standard and the deepest waters are anoxic (*i.e.*, lacking oxygen). These impaired oxygen conditions are causing the release of phosphorus from the sediments, in some cases doubling the phosphorus mass in the pond by the end of the summer and creating conditions that cause water clarity to fluctuate more than any of the other ponds that were looked at in detail.

Phosphorus is the key nutrient to manage water quality in Herring Pond, but additional information about internal sediment regeneration, loading from birds, a plant community assessment, and updated stream outflow are recommended before development of definitive management strategies. Once the recommended information is provided, management activities can target the phosphorus sources that are the most cost effective and achieve the largest reductions.

In order to develop the recommended information and incorporate it into a revised evaluation of Herring Pond, it is recommended that the town consider a targeted, one year data collection. This study would build on the results in this current report and answer the questions that have been raised, but left unanswered, by the currently available data, and lay the groundwork for preparation of a TMDL. SMAST staff recommend that this study include the following at a minimum: 1) collection and incubation of three sediment sample cores to determine phosphorus content, regeneration potential, and dissolved oxygen thresholds, 2) a whole year of observation of bird populations on the pond, including identification of species, 3) at least monthly measurement of stream outflow and analysis of accompanying water quality samples, 4) at least monthly collection of water quality samples in the pond using the standard PALS procedures including dissolved oxygen and temperature profiles and standard laboratory analysis plus other chemical constituents that might influence phosphorus regeneration, and 5) evaluation of the plant community (rooted plants, phytoplankton, and epiphytes) to gauge whether there have been significant changes since the BEC (1991) study. Development of this information could then be used to develop recommendations and costs for management strategies. SMAST staff have estimated that the cost of a stand alone project for these recommended activities between $32,000 and $35,000 with another $11,000 to $13,000 for combining this information with past information and developing water quality management strategies and a recommended TMDL. Additional analysis that should be also be considered would be an updated bathymetric map, a survey and map of sediment thickness, and an evaluation of stormwater structures around the pond. SMAST staff can discuss strategies with town staff and can provide the town with a detailed scope of work if requested.

VII.2.3. Muddy Pond Recommendations

Muddy Pond is 10.5 acres with a maximum depth of 1.5 m. Muddy is classified as eutrophic and is not impaired according to state surface water regulations. Given its relatively shallow depth, it is unlikely that Muddy will ever fail to meet state dissolved oxygen limits. Even if oxygen consumption by the sediments increases significantly, it is likely available wind energy across the surface will mix in atmospheric oxygen to address any oxygen deficits that might arise. Since dissolved oxygen concentrations are the primary state water quality standard, it is unlikely that the town would be required to address water quality management by state regulators.

Future management of Muddy, therefore, is likely to be directed by local concerns about aesthetics and ecosystem function, with the function also potentially being linked to future management of nitrogen loads to Nauset Marsh. The key nutrient for management of water quality in Muddy is phosphorus. Since existing total phosphorus concentrations are already higher than would be considered healthy for a Cape Cod freshwater pond ecosystem, the potential for spontaneous algal blooms and accompanying decreases in clarity is relatively high.

The key for managing future water quality in Muddy is understanding the characteristics of the pond sediments. The available data suggests that the sediments play a relatively minor role in the observed in-pond phosphorus concentrations, but are a significant sink for capturing phosphorus that enters the pond. It is recommended that the town consider targeted collection of sediment cores and testing of the cores to gauge the maximum amount of expected phosphorus release from the sediments and to establish the dissolved oxygen conditions that would cause this release to occur. If phosphorus in these sediments is relatively labile and easily converted to soluble forms in low oxygen conditions, the sediments may prove to be a ready source of phosphorus and worse water quality conditions. SMAST staff have estimated that a stand alone project for the cost of the collection, analysis, interpretation of this sediment data and updating management strategies at between $8,000 and $10,000. SMAST staff can discuss strategies with town staff and can provide the town with a detailed scope of work if requested.

It is further recommended that the town consider completing a current baseline evaluation of rooted plants in Muddy Pond. Observation of other shallow Cape Cod ponds with high phosphorus concentrations suggests that these ponds may be more susceptible to shifting from a phytoplankton-dominant plant community to one dominated by rooted plants. In the later case, the surface of the pond may slowly be covered by plants and recreational options will become more limited. This evaluation should include identification of species and percentage of plant coverage throughout the pond. SMAST staff have estimated that a stand alone project for the cost of the collection, analysis, interpretation of this plant data at between $8,000 and $10,000.

SMAST staff are available to assist the town with the completion of any of the actions recommended for consideration and can provide a detailed cost proposal if requested. There would be cost savings in pursuing a number of activities at the same time.

VII.2.4. Long/Depot Pond Recommendations

Long Pond is the third largest (28 acres) of the Eastham ponds and is 10 m deep. Long is classified as mesotrophic, is impaired according to state surface water regulations, and thus, will eventually require preparation of a TMDL. Temperatures suggest that Long could support a cold water fishery, but average summer dissolved oxygen concentrations throughout the bottom waters fail to attain the state standard of 6 ppm and the deepest waters are nearly anoxic.

Phosphorus is the key nutrient to manage water quality in Long Pond, but additional information about internal sediment regeneration, loading from birds, and updated stream outflow is recommended before development of definitive management strategies. Collection of this data will also help to resolve some inconsistencies among the phosphorus and dissolved oxygen datasets. Once the recommended information is provided, management activities can be crafted to address the phosphorus sources that are the most cost effective and achieve the largest reductions.

In order to develop the recommended information and incorporate it into a revised evaluation of Long Pond, it is recommended that the town consider a targeted one year analysis of select phosphorus components in order to develop management strategies that can be confidently pursued, resolve the inconsistencies in the various datasets, and lay the groundwork for preparation of a TMDL. This study would build on the results in this current report and answer the questions that have been raised, but left unanswered, by the currently available data. SMAST staff recommend that this study include the following at a minimum: 1) collection and incubation of three sediment sample cores to determine phosphorus content, regeneration potential, and dissolved oxygen thresholds, 2) a plant survey, 3) a whole year of observation of bird populations on the pond, including identification of species, and 4) at least monthly collection of water quality samples in the pond using the standard PALS procedures including dissolved oxygen and temperature profiles and standard laboratory analysis plus other chemical constituents that might influence phosphorus regeneration. Development of this information could then be used to develop recommendations and costs for management strategies. SMAST staff have estimated that the cost of a stand alone project for these recommended activities between $32,000 and $35,000 with another $11,000 to $13,000 for combining this information with past information and developing water quality management strategies and a recommended TMDL. Additional analysis that should be considered and would help to clarify interactions in the pond and potential management activities would include an evaluation of stormwater structures around the pond. SMAST staff can discuss strategies with town staff and provide the town with a detailed scope of work if requested.

VII.2.5. Minister/Schoolhouse Pond Recommendations

Minister and Schoolhouse ponds are two four meter deep basins of a combined 21 acre pond. Both basins are classified as eutrophic and have impaired water quality according to state regulatory thresholds. Temperature data suggest that the combined pond could sustain a small cold water fishery in both basins, average dissolved oxygen concentrations throughout this portion of the water column in either basins do not meet the required state regulatory limit of 6 ppm, and are generally lethal to fish because they are anoxic.

Phosphorus is the key nutrient to manage water quality in Minister and Schoolhouse Ponds, but additional information about internal sediment regeneration, loading from birds, and updated stream outflow is recommended before development of definitive management strategies. Collection of this data will also help to resolve some inconsistencies among the phosphorus and dissolved oxygen datasets. Once the recommended information is provided, management activities can be crafted to address the phosphorus sources that are the most cost effective and achieve the largest reductions.

In order to develop the recommended information and incorporate it into a revised evaluation of Minister and Schoolhouse ponds, it is recommended that the town consider a targeted one year analysis of select phosphorus components in both ponds in order to develop management strategies that can be confidently pursued, resolve the inconsistencies in the various datasets, and lay the groundwork for preparation of a TMDL. This study would build on the results in this current report and answer the questions that have been raised, but left unanswered, by the currently available data. SMAST staff recommend that this study include the following at a minimum: 1) collection and incubation of three sediment sample cores in each basin to characterize the amount of available phosphorus and the dissolved oxygen conditions that prompt its release, 2) concurrent monthly water quality sampling in each basin between April and November to resolve the apparent inconsistencies in the phosphorus and dissolved oxygen data, 3) characterization of the internal movement of water and nutrients between Minister and Schoolhouse, 4) identification of stormwater structures and measurement of any stormwater inputs into Minister and Schoolhouse, and 5) identification and counts of birds on the two ponds throughout a year. Development of this information could then be used to develop recommendations and costs for management strategies. SMAST staff have estimated that the cost of a stand alone project for these recommended activities between $35,000 and $40,000 with another $11,000 to $13,000 for combining this information with past information and developing water quality management strategies.

VII.3. Recommendations for Town-wide Water Quality Management Activities

All six of the ponds reviewed in detail have water quality concerns related to the land uses within their watershed. Five of the six have impaired water quality that impacts the ecosystem of these ponds to varying degrees, some in highly significant ways. It is clear from the town-wide overview of the ponds that every pond with available data has excessive nutrients and almost all ponds fail to meet state surface water dissolved oxygen standards. What is not clear is how management activities should be targeted in a cost-effective way for each pond, how the recommended monitoring will be prioritized and funded, and how water quality in should be ensured in the long term.

In order to organize all of these needs, it is recommended that the Town of Eastham consider development of a pond remediation program. This program would begin by completing watershed loading, water and nutrient budget development and water quality review for the three remaining ponds with adequate data that were not selected for detailed review. This program would also incorporate the implementation of the recommendations discussed above for the six ponds that have detailed reviews in this report. This program could also be the central focus for development of the required funding for remedial in-lake activities such as alum treatments and aeration, which are likely to be necessary for many of these ponds in the future, as well as implementation of best management practices, such as removing or minimizing stormwater discharge into the ponds. The town could also consider expanding this program to deal with other management issues such as watersheet planning, fish stocking issues, and on-going questions of access. Town of Eastham and SMAST staff could discuss opportunities to jointly manage such a program.

Included under the umbrella of this program, it is also recommended that the town begin the implementation of best management practices for shoreline properties. Given that all the ponds have excessive phosphorus concentrations and any in-lake remedial steps will have to also include watershed reductions in order to sustain them, these steps are recommended throughout the town. These practices can slowly reduce the mass of phosphorus entering the ponds and are all relatively inexpensive to implement. As mentioned previously, these practices include: 1) maintaining, planting, or allowing regrowth of natural buffer areas between the pond and lawns/yards/houses, 2) installing treatment for or redirecting any direct stormwater runoff, and 3) ensuring that all new septic system leachfields have an adequate setback from the pond (at least 300 feet or the maximum possible on a lot).

These best management practices could be implemented through both changes in town regulations and local educational efforts. Review of existing town regulations (*i.e.,*, subdivision rules, conservation commission regulations, board of health regulations) for opportunities to better protect pond water quality could be a first step. Implementation of any changes could occur when properties change ownership. The town may also want to consider combining all of these activities with monitoring programs, so all pond-related activities are coordinated and mutually supportive.

SMAST staff are available to assist the town in discussion of all these activities.

VIII. Conclusions

As part of Barnstable County's Growth Management Initiative and the Pond and Lake Stewardship (PALS) program and in partnership with the Cape Cod Commission, the Coastal Systems Program at the School of Marine Science and Technology (SMAST), University of Massachusetts Dartmouth has completed a review of pond monitoring data collected by Town of Eastham monitoring volunteers from 10 ponds between 2001 and 2006, as well as detailed evaluations of selected ponds. Preliminary results from an initial review of the data from the 10 ponds were presented before the Eastham Water Resources Advisory Board (WRAB) and Waste Water Management Planning Committee on June 13, 2006. At that meeting, the town was asked to select six ponds for more detailed evaluation. Through the WRAB, the town selected Great, Herring, Muddy, Long, Minister, and Schoolhouse for detailed review.

The completed review of the data from the 10 Eastham ponds shows that eight of the ponds have average dissolved oxygen concentrations during June through September that fail to meet state surface water standards. Review of phosphorus data show that all 10 of the ponds have average concentrations that exceed the "healthy" pond threshold developed by the Cape Cod Commission (Eichner and others, 2003).

The detailed review completed for the six selected ponds more thoroughly defined and quantified the extent of the impairments found in the initial review. Detailed review included delineation of watersheds and review of phosphorus loading, as well as more refined reviews of dissolved oxygen and temperature profiles, Secchi transparency readings, and phosphorus concentrations. Development of the watersheds allowed SMAST staff to review current and future sources of phosphorus loads. Because phosphorus becomes bound to sand as it travels through the aquifer, phosphorus does not reach a pond until all binding sites are between its source and the pond are used. Therefore, it can take decades for watershed loads, such as those from shoreline septic system to discharge into a given pond.

The detailed review of the six individual ponds shows all but Muddy fail to meet dissolved oxygen thresholds in state surface water regulations and, therefore, are classified as "impaired" ponds and will eventually require the preparation of state-approved Total Maximum Daily Load (TMDL) reports. All of the impaired ponds have some temperature stratification or layering during summer with cold waters near the bottom sediments separated from warmer, well-mixed surface waters. The deepest waters in these ponds tend to have average conditions that are anoxic or lacking oxygen; these types of conditions are lethal to fish.

Review of other available data for all six of the ponds show that management of phosphorus is the key to managing their water quality and that reductions in phosphorus loads are the key to restoring the impaired ponds. All six of the ponds exceed Cape Cod-specific total phosphorus thresholds to varying degrees and the watershed and phosphorus loading analyses indicate that all ponds will receive higher phosphorus loads in the future.

Development of appropriate and cost-effective water quality restoration strategies for these ponds will require some additional information. All ponds require sampling of their sediments to directly measure their current and future potential contribution to the overall phosphorus load in each pond. Review of the phosphorus budgets also indicated that development of pond-specific information about stormwater inputs and aquatic bird populations is important for effectively targeting restoration strategies. Collection of this information, along with other recommended pond-specific data, will refine the phosphorus budgets and ensure that management and restoration strategies will remediate these impaired ponds.

In addition to these needs, Great, Long, and Minister/Schoolhouse have inconsistencies between total phosphorus sampling results and dissolved oxygen readings. It appears that some of the shallow and deep phosphorus concentration results have been transposed. It is recommended that the sediment sampling recommended above be combined with water quality sampling to ensure that these inconsistencies are resolved.

Since the results from the detailed and town-wide data reviews consistently show impairments in almost all of Eastham' ponds and restoration activities will require significant coordination and guidance, it is recommended that the Town of Eastham consider development of an integrated pond remediation and monitoring program. This program would be tasked with addressing the existing impairments and prevent future impairments of each pond, develop ways to ensure the long term health of these ecosystems, and integrate on-going monitoring to assess long term water quality trends and efficacy of remedial projects. The suggested details of such a program are described in a series of recommendations and it is suggested that such a program could be jointly managed by SMAST and the Town of Eastham.

SMAST staff are available to assist the Town of Eastham in discussion of any of the recommended activities, as well as the pond analysis results contained in this report.

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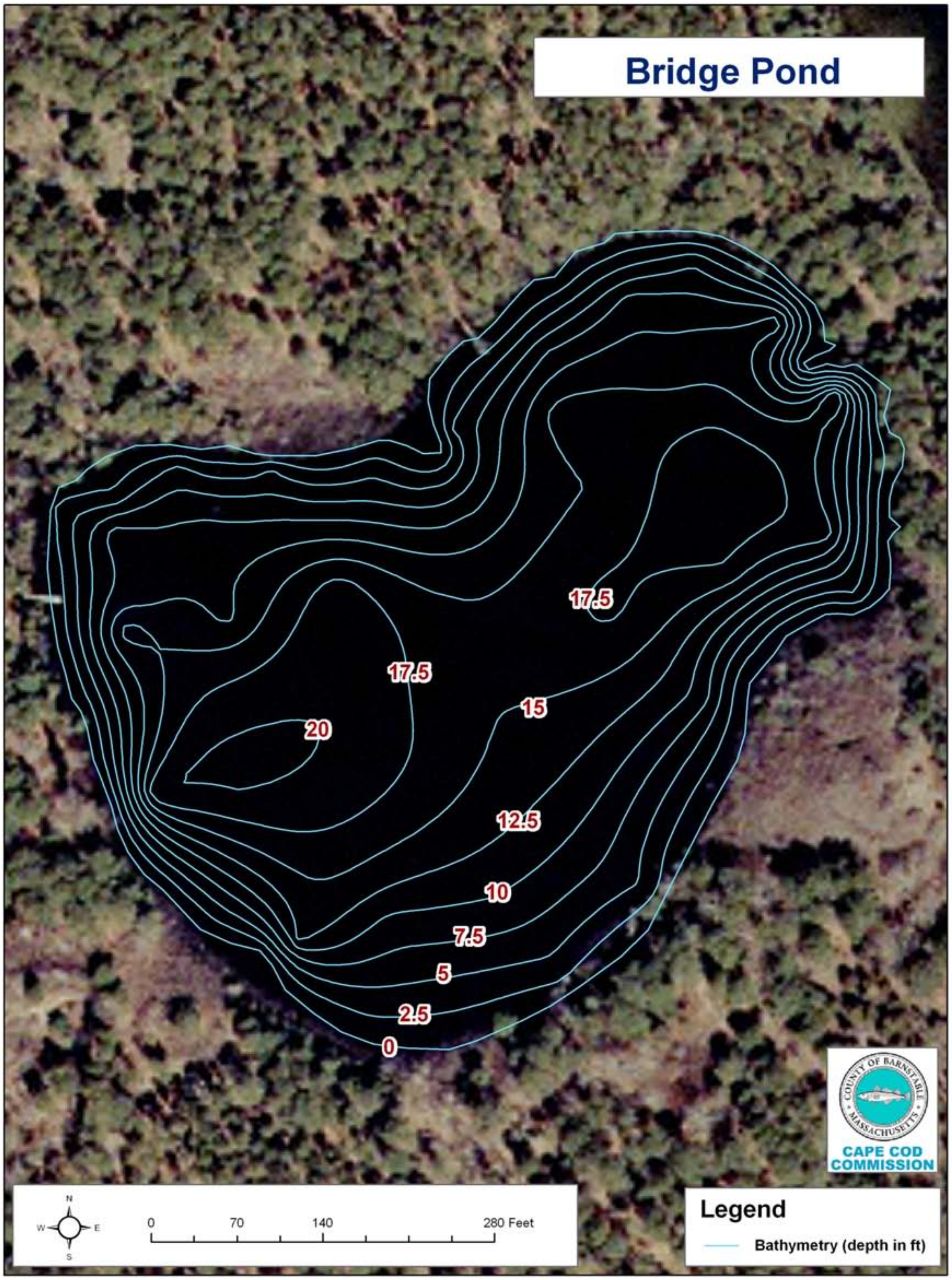
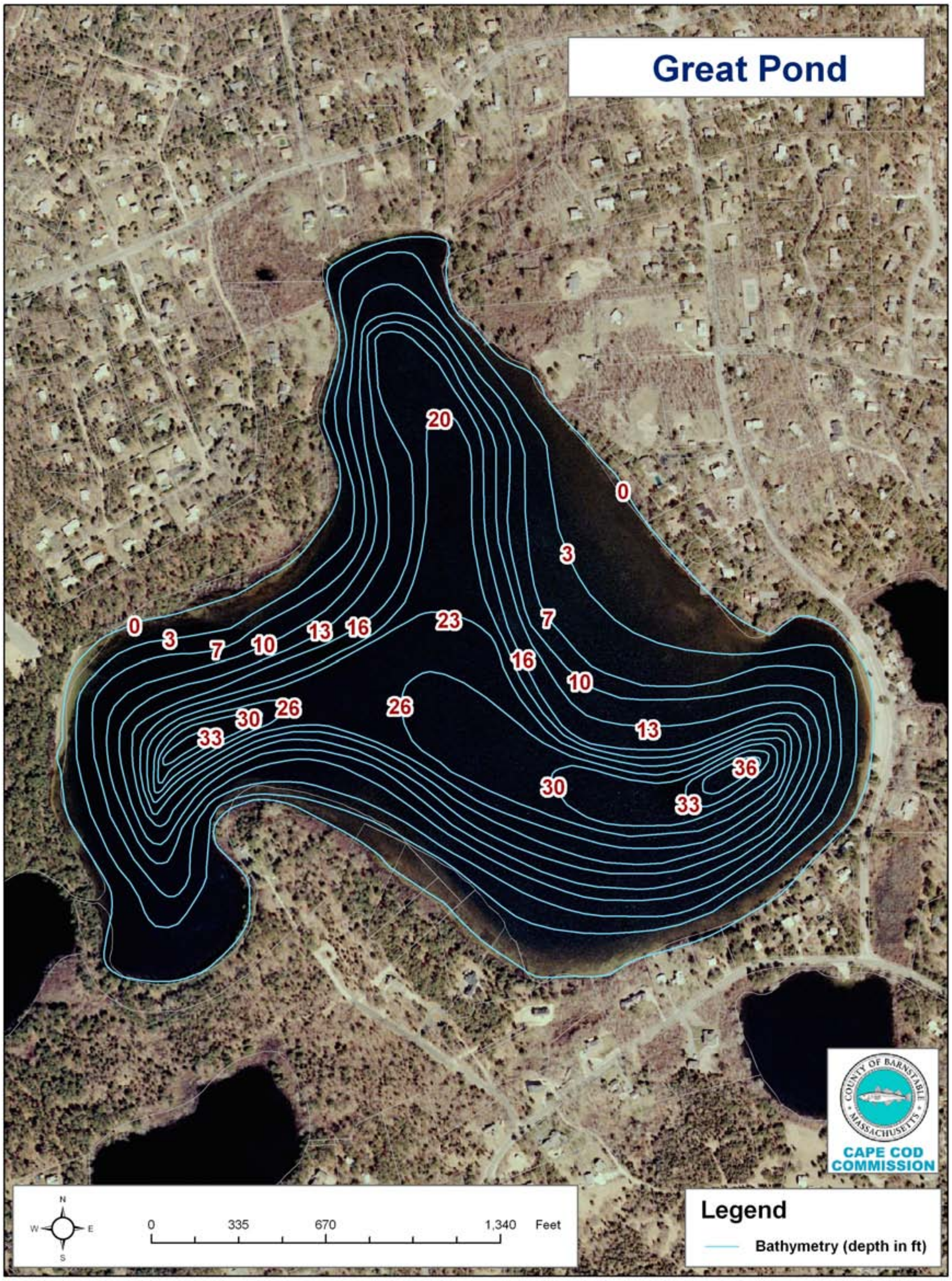
APPENDIX A

Pond Bathymetric Maps
Town of Eastham

contours developed by
Scott Michaud and Xiaotong Wu
Cape Cod Commission

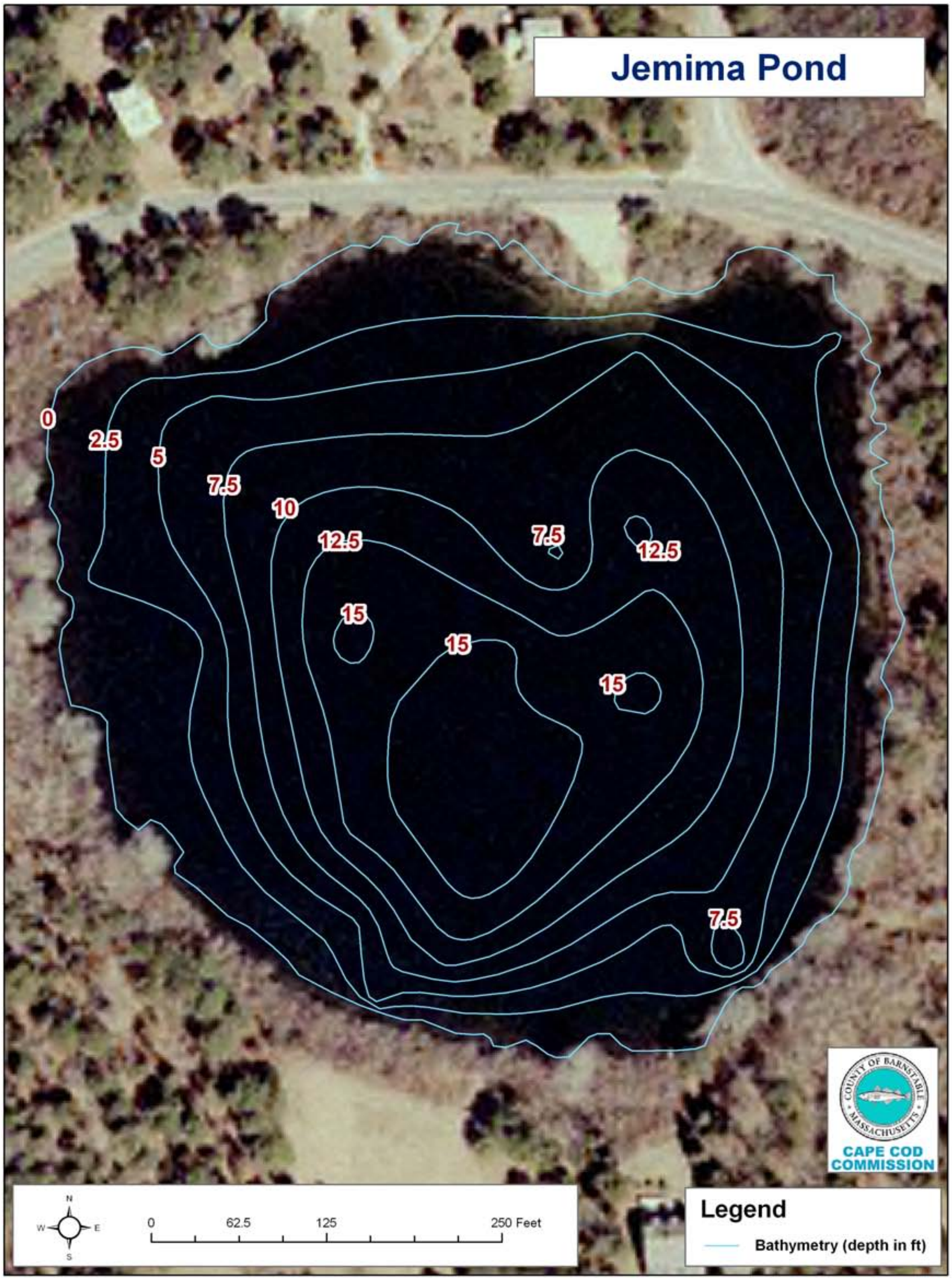
original data collection by
Caroline Kennedy


Bridge Pond
17.5
17.5
20
15
12.5
10
7.5
5
2.5
0
N
W
E
S
0
70
140
280 Feet
Legend
Bathymetry (depth in ft)
COUNTY OF BARNSTABLE
MASSACHUSETTS
CAPE COD COMMISSION



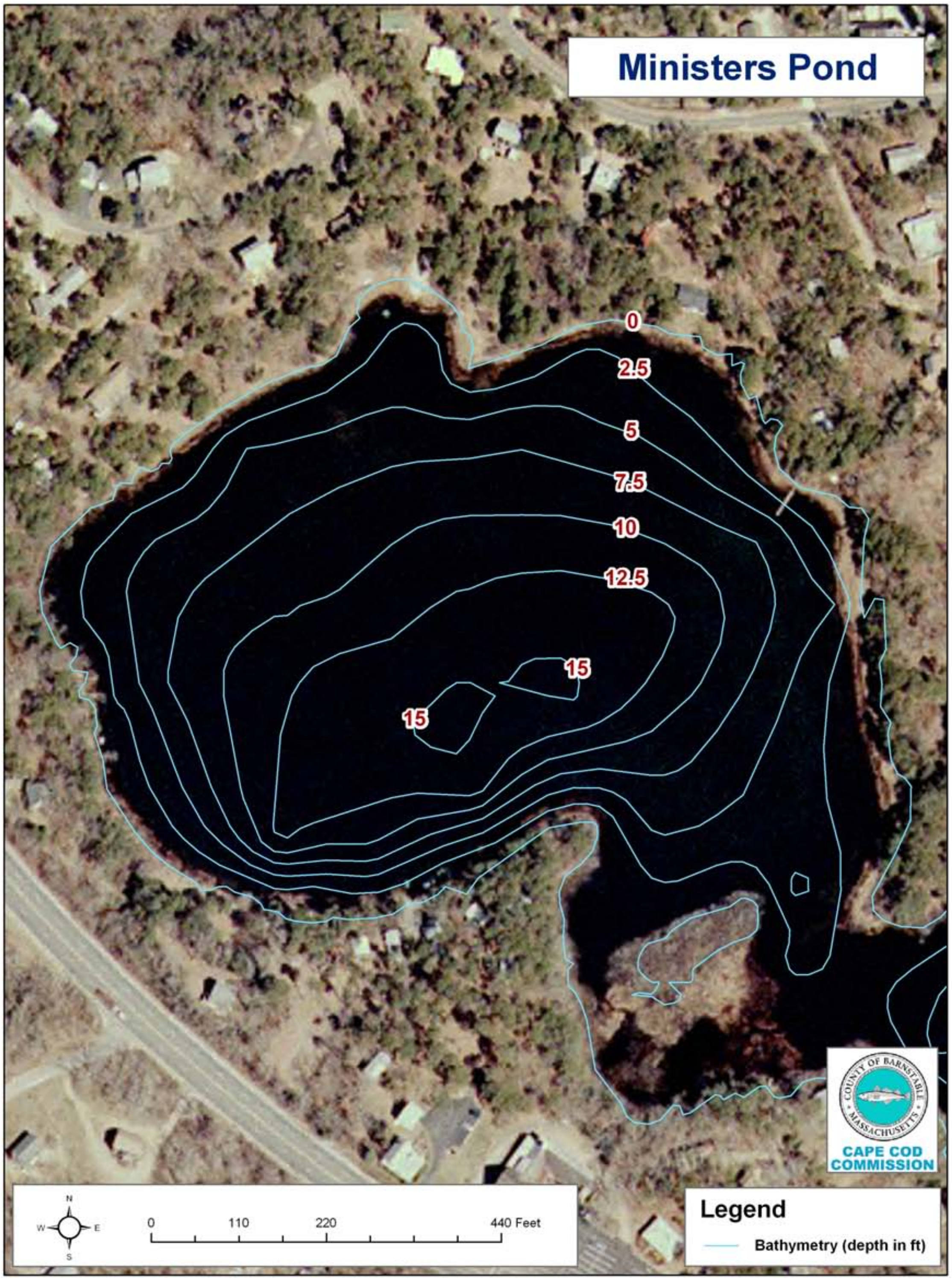
Great Pond
20
0
3
0
3
7
10
13
16
23
7
16
10
26
26
30
33
13
36
30
33
CAPE COD COMMISSION
COUNTY OF BARNSTABLE
MASSACHUSETTS
N
W
E
S
0
335
670
1,340
Feet
Legend
Bathymetry (depth in ft)

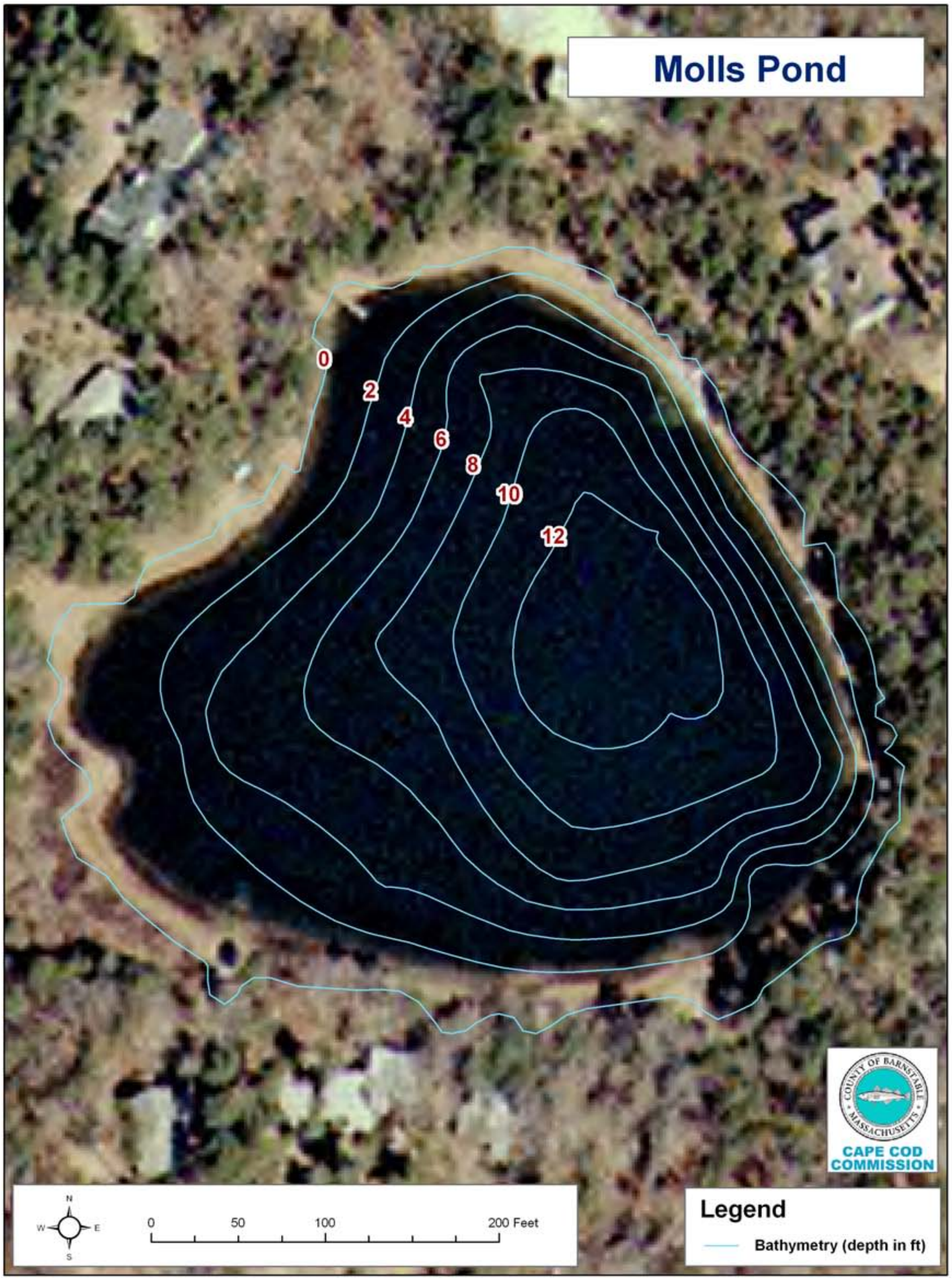
Herring Pond
35
30
20
10
0
20
10
0
20
30
N
W
E
S
0
212.5
425
850
Feet
Legend
Bathymetry (depth in ft)
COUNTY OF BARNSTABLE
MASSACHUSETTS
CAPE COD
COMMISSION



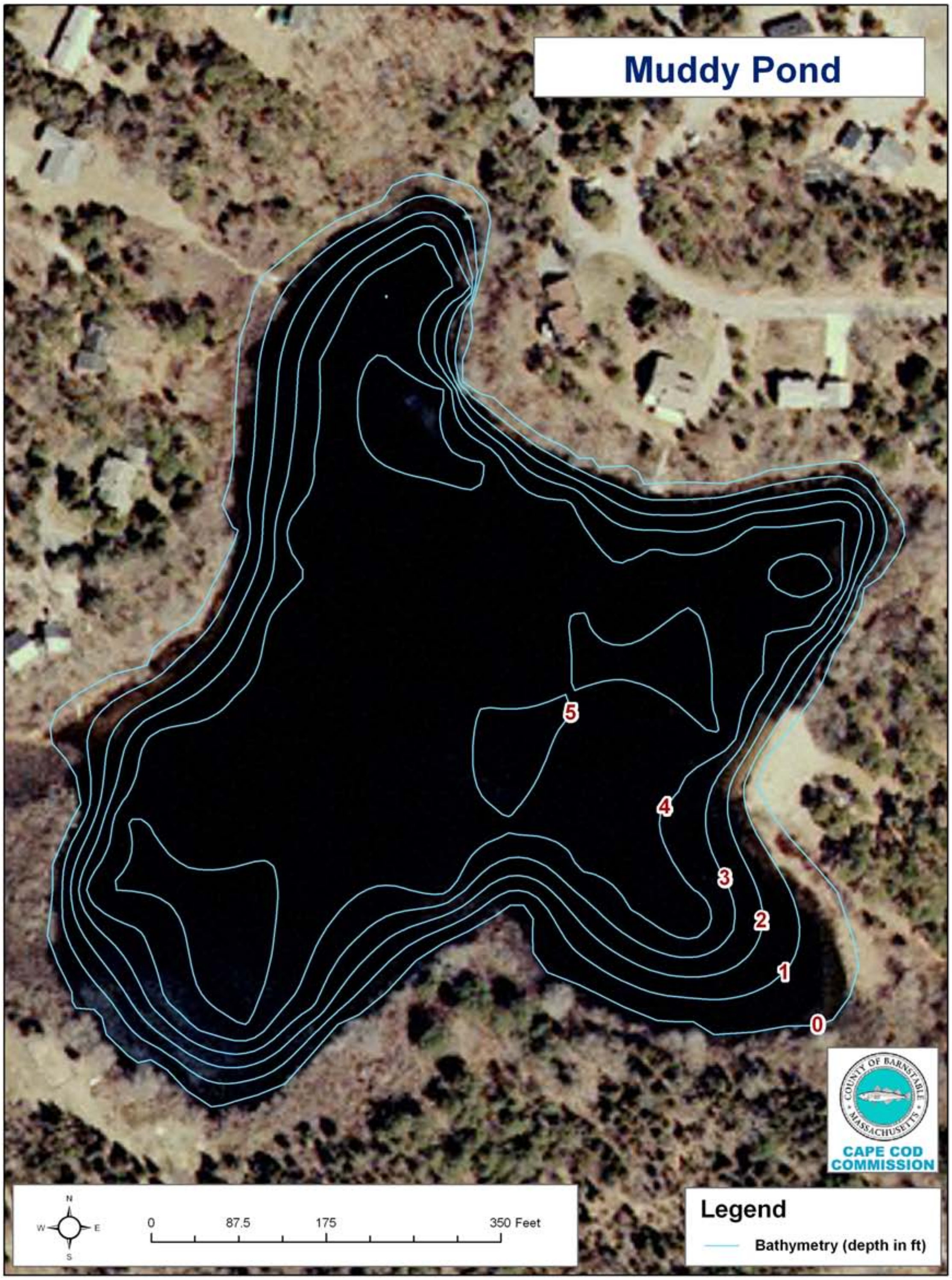
Jemima Pond
0
2.5
5
7.5
10
12.5
7.5
12.5
15
15
15
7.5
N
W
E
S
0
62.5
125
250 Feet
Legend
Bathymetry (depth in ft)
COUNTY OF BARNSTABLE
MASSACHUSETTS
CAPE COD COMMISSION

Long Pond
0
5
10
15
20
25
30
35
N
W
E
S
0
185
370
740
Feet
Legend
Bathymetry (depth in ft)
COUNTY OF BARNSTABLE
MASSACHUSETTS
CAPE COD COMMISSION

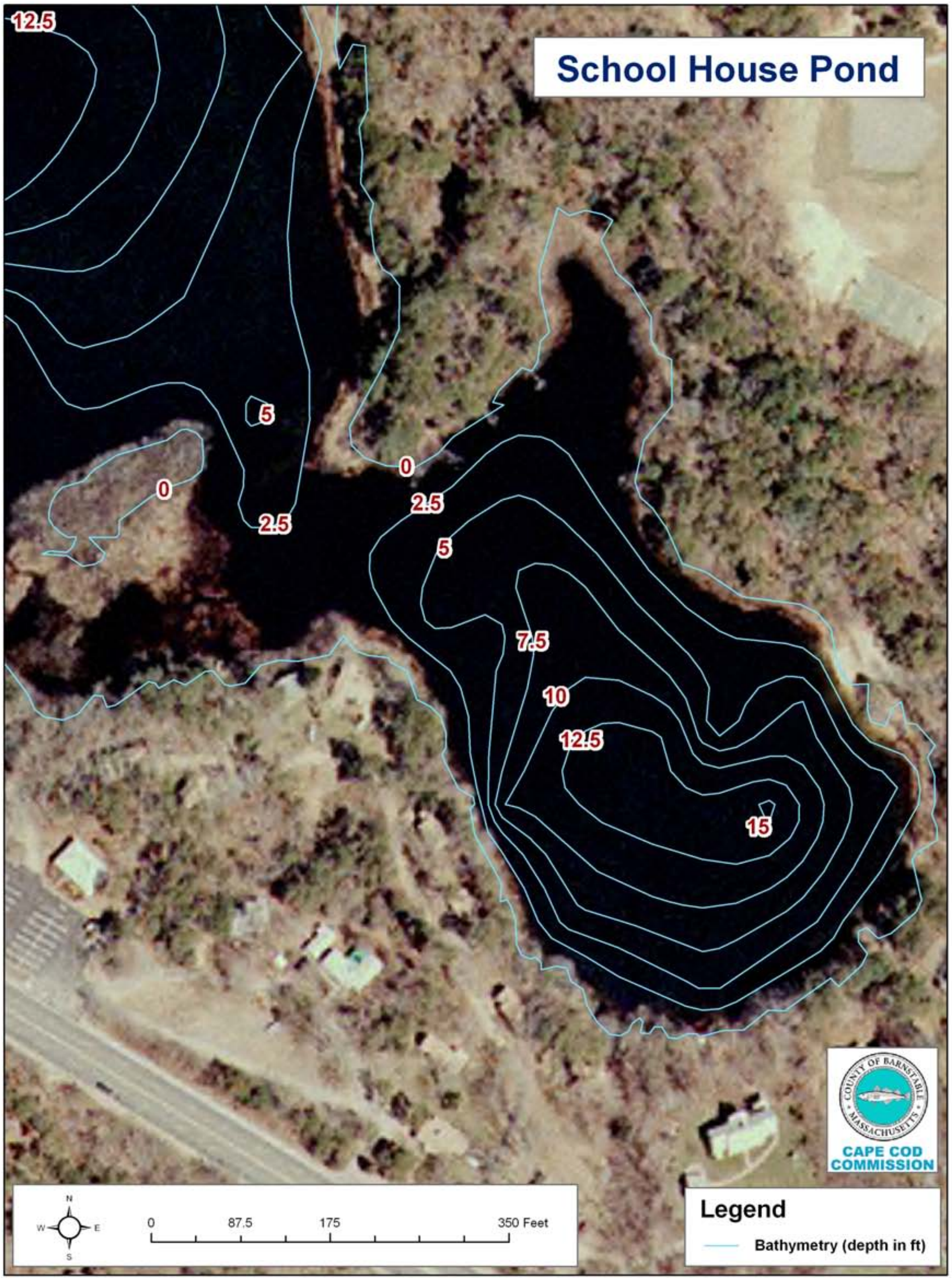

Ministers Pond
0
2.5
5
7.5
10
12.5
15
15
N
W
E
S
0
110
220
440 Feet
Legend
Bathymetry (depth in ft)
COUNTY OF BARNSTABLE
MASSACHUSETTS
CAPE COD COMMISSION

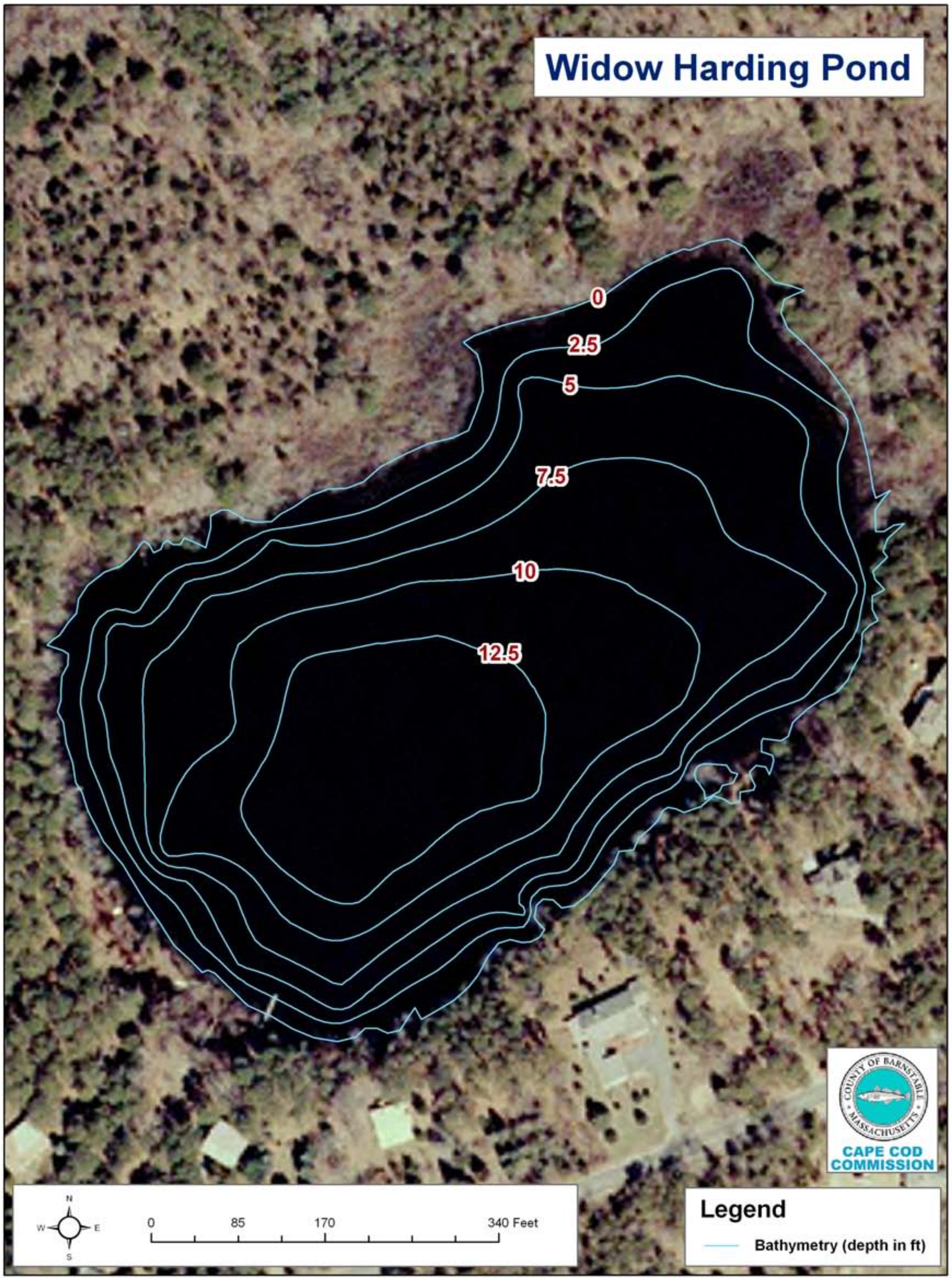


Molls Pond
0
2
4
6
8
10
12
N
W
E
S
0
50
100
200 Feet
Legend
Bathymetry (depth in ft)
COUNTY OF BARNSTABLE
MASSACHUSETTS
CAPE COD COMMISSION



Muddy Pond
5
4
3
2
1
0
COUNTY OF BARNSTABLE
MASSACHUSETTS
CAPE COD COMMISSION
N
W
E
S
0
87.5
175
350 Feet
Legend
Bathymetry (depth in ft)


School House Pond
12.5
5
0
0
2.5
2.5
5
7.5
10
12.5
15
N
W
E
S
0
87.5
175
350 Feet
Legend
Bathymetry (depth in ft)
COUNTY OF BARNSTABLE
MASSACHUSETTS
CAPE COD COMMISSION



Widow Harding Pond
0
2.5
5
7.5
10
12.5
N
W
E
S
0
85
170
340 Feet
Legend
Bathymetry (depth in ft)
COUNTY OF BARNSTABLE
MASSACHUSETTS
CAPE COD COMMISSION

APPENDIX B

Memo
to the
Town of Eastham

with

Recommendations
for
Year 2007 Pond Monitoring

CAPE COD COMMISSION

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(508) 362-3828
FAX (508) 362-3136
E-mail: frontdesk@capecodcommission.org
WATER EMAIL: water@capecodcommission.org

MEMORANDUM

TO: Dr. Karl Weiss, Chair, Eastham Water Resources Advisory Board
Sandy Bayne, Eastham PALS coordinator
Bruce Whitmore, Chair, Eastham Waste Water Management Planning Committee

CC: Jane Crowley, Health Agent, Town of Eastham
Henry Lind, Natural Resources Officer, Town of Eastham
Joyce Brookshire, Eastham Representative, Cape Cod Commission
Tom Cambareri, Water Resources Program Manager, Cape Cod Commission

FROM: Ed Eichner, Water Scientist, Cape Cod Commission

DATE: April 3, 2007

RE: Pond Monitoring Recommendations for 2007

As you requested, this memorandum is being prepared to assist the Town of Eastham in the development of a pond water quality-monitoring program for the spring/summer of 2007. More detailed, long-term monitoring recommendations will be included in the assessment and interpretation report planned for August.

Eastham volunteers under the guidance of the Water Resources Advisory Board (WRAB) have regularly collected data from 10 ponds, which are shown in Figure 1. Data consists of laboratory analysis results for water collected from the ponds and measurements collected at the pond at the same time as the water is collected (*i.e.*, field data). Water quality analyses of collected samples have been provided by labs at UMASS, Dartmouth, School of Marine Science and Technology (for the Pond and Lake Stewards [PALS] yearly snapshot) and Cape Cod National Seashore.

The majority of laboratory water quality datasets for most ponds generally consist of monthly to biweekly water quality samples collected during three summers (June-October 2002, 2003, and 2005; 2006 data is not yet available). This data is supplemented with additional once-a-year PALS snapshot data from 2001-2005 (2006 data is not yet available). Secchi transparency readings have generally been collected in the field on a monthly to biweekly basis between May and October from 2002 through 2006. Dissolved oxygen and temperature profiles throughout the water column have also generally been collected in the field twice a month between May and October for 2002 and 2006.

Given the slow travel time of phosphorus in groundwater, water quality conditions in most of these ponds should be fairly consistent with most of the variability occurring due to natural temperature-driven, seasonal changes. However, the available data from most of the ponds reveals significant variability especially in key parameters, such as nutrients.

Natural ecosystems tend to have a certain amount of variability; healthy ecosystems tend to fluctuate within a smaller range than impaired systems. Previous studies of nutrient fluctuations in natural systems have shown that even the most refined studies will have coefficient of variation (e.g., standard deviation divided by mean) of 30-40%, while measures such as Secchi or pH will tend to have lower percentages.[1] Review of Eastham's pond data shows that most ponds have total phosphorus readings with coefficients of variation (COVs) above 40% (average is 59%), while surface dissolved oxygen and Secchi readings are generally below 30%. While these findings suggest that additional laboratory water quality data collection would be useful, further review of the data suggests that this variability may be a reflection of the impairment and lack of stability in these ecosystems.

In general, most of the ponds have between 14-16 total phosphorus (TP) readings without including the most recent summer and slightly more dissolved oxygen and Secchi readings. Bridge Pond is an exception, having about half as many readings as the rest. Since Secchi and DO readings can be collected in the field and do not require laboratory analysis costs, their collection is relatively inexpensive and generally depends on the access to field equipment and volunteer time. Since the upper portions of the water columns in most of the ponds are well mixed by normal Cape Cod winds, the upper DO readings tend to be stable and, thus, have low COVs. Deeper in these ponds, closer to the sediments where DO can be impacted by excessive oxygen consumption in the sediments, COVs soar if the system is impaired. Other parameters that are impacted by low DO, such as nutrients, will also tend to have high COVs because concentrations will vary significantly throughout a summer.

In Eastham ponds, shallow DO readings have an average COV of 13%, while deep DO readings have an average COV of 104%. The average shallow COVs for total phosphorus and total nitrogen are also markedly less than deep COVs. This analysis suggests that among the parameters that have been monitored sufficient data has generally been gathered in order to begin development and evaluation of remedial and protection strategies for the following ponds: Depot, Great, Herring, Jemima, Minister, Molls, Muddy, Schoolhouse, and Widow Hardings.

More refined discussion of this will be included in the data review report, but this conclusion then leads to the question of whether additional monitoring will be beneficial or useful. Additional monitoring would be useful if the monitoring program is refocused into a tiered effort to address additional data needs for ponds in the Town. It is suggested that this effort focus on 1) sampling and assessment of ponds that have not been monitored, 2), collection of targeted data from the well-monitored ponds that will help to better define remedial and protection strategies, 3) long-term monitoring and review to assess whether negative water quality trends are impacting these ponds, and 4) provisions to monitor and review the benefits of any remedial or protection strategies that are implemented. Each of these recommendations is briefly discussed below.

Even though the current dataset is sufficient to begin to define remedial and protection strategies for the nine ponds that have been the primary focus of volunteer monitoring efforts, these systems should continue to be regularly monitored, but with reduced frequency, in order to assess whether the systems are changing significantly. It is recommended that the town consider changing the monitoring program for these ponds to a twice-annual sampling strategy. Water samples and field readings would be collected in April and August/September using the PALS sampling protocols and parameters. A brief review at the end of each sampling season should be conducted to identify training needs for the next season and identify any other potential concerns. Every five years, gathered data should be reviewed for trend analysis and long term monitoring concerns. In addition, at the time any remedial activities are initiated either in a watershed or within a pond, it is recommended that monitoring frequency would then be increased to at least once a month between April and November for at least one year or longer depending on projected groundwater flow times and/or pond residence times to assess whether projected benefits are realized. Details regarding the parameters to be measured could be worked out at the time the increased frequency is planned.

The reduced frequency of sampling on the ponds that have been monitored would allow volunteers to focus efforts on the approximately 13 other ponds in Eastham that have not been monitored, plus another year worth for Bridge Pond. It is recommended that the WRAB consider adding additional ponds to the sampling program. The Cape Cod Pond and Lake Atlas[2] lists Eastham as having 23 ponds, while approximately 10 are currently sampled. It would be useful to determine what is known about the ponds that are not sampled and assess whether monitoring and/or physical characterization (*e.g.*, bathymetry) is desired. This sampling should focus on ponds that are deep enough to maintain a reasonable depth year-round. Staff are available to assist in review/discussion of candidate ponds.

Targeted additional data from selected portions of these pond ecosystems will be necessary prior to the final development of remedial or protective strategies, but it is likely that this monitoring should be completed during the review of these strategies. Additional data to be collected would be evaluation of sediment nutrient (and potentially metals) concentrations, measurement of stormwater nutrient loads, and better measurement of stream inputs and outputs from selected ponds. These types of activities are traditionally conducted by lake management consultants developing management strategies, but with proper training and guidance, volunteers could collect the samples to reduce costs to obtain this information. Further discussion of this issue should be addressed on a pond-by-pond basis and will be discussed in further detail for the ponds selected for refined analysis in the review of monitoring data that the Commission is currently working on.

The above recommendations are dependent on adequate funding. Volunteers provide savings for labor costs and the town has made investments in equipment costs, but implementation of the above refocusing may require additional funding for laboratory analysis and, potentially, equipment costs. Staff are available to help the town evaluate potential costs for monitoring options.

In summary, data for the regular monitoring parameters is sufficient to begin the development of remedial/protective strategies for the following ponds: Depot, Great, Herring, Jemima, Minister, Molls, Muddy, Schoolhouse, and Widow Hardings. The Commission's data review report planned for April should help to prompt discussion of remedial/protective strategies for the six ponds selected for detailed review: Depot, Great, Herring, Minister, Muddy, and Schoolhouse. Plans should be considered to develop strategies for the other ponds. It is further recommended that existing volunteer monitoring be refocused into a reduced frequency, longer-term schedule for the nine ponds listed until management activities are implemented, Bridge Pond should continue to be monitored on a monthly basis, and consideration be given to extending monitoring to other ponds in Eastham that have not been monitored.

Please let me know if I can provide any additional information regarding the above recommendations.

REFERENCES

1. Håkanson, L. 2000. The role of characteristic coefficients of variation in uncertainty and sensitivity analyses, with examples related to the structuring of lake eutrophication models. *Ecological Modelling*. 131: 1-20.

2. Eichner, E.M., T.C. Cambareri, G. Belfit, D. McCaffery, S. Michaud, and B. Smith. 2003. Cape Cod Pond and Lake Atlas. Cape Cod Commission. Barnstable, MA.

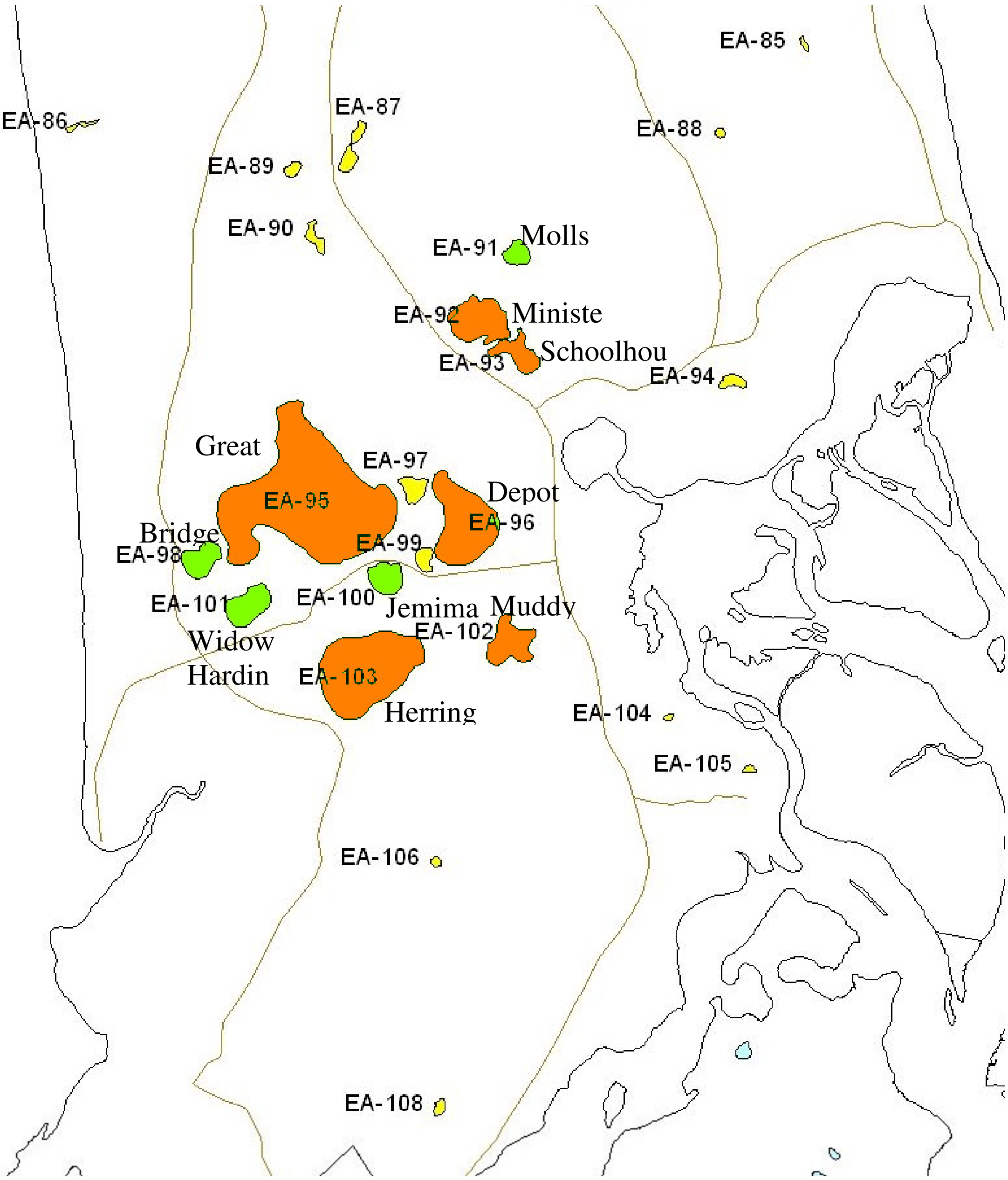

Figure 1. Eastham Ponds with regular WRAB sample data.

Named ponds are monitored on a regular basis by the Town of Eastham volunteers coordinated through the Water Resources Advisory Board. Ponds shaded orange/darker gray will be the subject of detailed evaluation in the Data Review and Interpretation report scheduled to be released in August.

APPENDIX C

Notes on Historic Land Uses near selected Eastham Ponds

by
Sandy Bayne

Historical Uses, Eastham

Town wide

I used these resources to determine the meager available information:

Written:
Joan Nugent's tricentennial pamphlet *Eastham, Working the Land*, 2001
Alice Lowe's *Nauset on Cape Cod: A History of Eastham*, 1968
Donald Trayser's *Eastham, Ma., 1651-1951,* 1951
Marilyn Schofield and Roberta Cornish's *Eastham*, 2003
Don Sparrow's transcription of his interview with John Ullman, 2001
Noel Beyle's *Go Eastham*, 2001
Henry Kittredge's *Cape Cod: Its People and Their History*, 1930
Town of Eastham's *Historical Property Survey Project for National Register of Historical Places*, very recent
WPA Federal Writer's Project's *Mass., A guide to Its Places and People*, 1937

Photographic:
Aerial photos flown 1937, 1948 for National Archives (CCNS)

Maps:
1851, 1866, and 1909 hand drawn survey maps

Oral/anecdotal:
Bob Mumford, Sarah Korjeff, Don Sparrow, Kate Alpert, Bobby Cornish, Marilyn Schofield, Barbara Sweetser.

HISTORICAL USES, EASTHAM

General

Population:
The 1851 survey map shows houses spread thinly along what was to become route 6. Although the survey map doesn't show it, there were population centers at Depot Pond/Samoset Rd., and in the Brackett Rd. area before the 1880's.

The 1880 census revealed 277 citizens, of whom 70 % fell into the categories of farmers (59), farm workers (37), and fishermen (100). The population never grew quickly until the mid 1900's. It is currently about 5500, which is thought to quadruple in the summer.

Land Use:
Eastham has always been a town whose main occupation was the production of foodstuffs marine and terrestrial.

Surprisingly, although Orleans, Chatham, Brewster, and Wellfleet were once part of Eastham, even as early as the 1880's a major shopping trip entailed a major trip to Orleans. A day's outing!

As elsewhere on the Cape, citizens kept a cow, horses, and chickens for their own use, and grew vegetables and fruit trees. Shellfish and finfish were abundant into this century. To support these activities ice, salt, and salt hay production was a necessity.

The Town was moderately prosperous in the 1830-1860 period, enough to sell its bounty. County historian Pratt noted that in 1844 Eastham sent 1000 bushels of corn to market, and that in earlier years it had sent 3000. This market declined precipitously by 1880.
Too, in the 1845-1865 period, Eastham and Orleans led the state in commercial egg production; the coming of the railroad in 1870 allowed eggs to be sent to Boston and, eventually, milk to Provincetown! (There were prosperous dairy farms on Fort Hill and Doane Rd. around the turn of the century.)

The town produced enough asparagus, turnips and cranberries to sell, the Eastham asparagus crop being marketed and recognized under brand names in Boston. (Of interest to pond studies is the fact that asparagus and even turnips need heavy manure to succeed in sandy soils.) Production peaked in 1920, and ended during the 40's.

A links style golf course existed from 1928 to 1950 at Salt Pond.

The railroad stations were on Samoset Rd. by Depot Pond, and at North Eastham west of Brackett Rd. At each of these locations there was a general store.

During the years 1866 to 1875 there was a tannery on Great Pond.

In 1885, there were two factories, both of which were gone by 1900. I cannot find any description of their location or products. However, industry never made a significant inroad, because of the lack of water power, lack of efficient transportation, and distance from coal supply. (There are no significant rivers and the trees were gone early on.) Even today industrial land is very limited.

In the mid 1800's, the area around Campground Rd. was the setting for the Millenium Grove, a busy religious campground, to which packet boats from Boston brought many thousands of fervent visitors. This navigable port area allowed packet boats to return to Boston laden with fish and tanned items. Both activities ended when the area silted in before 1900.

By late 1900's, wealthy Bostonians began to establish hunting camps.
Several of these were placed at the edges of ponds, where migrating birds would be flying and perhaps resting. The slow development of other forms of tourism began around the turn of the century. By 1929, there were one restaurant, three hotels, and two garages (but no gas sales).

The closure of the railroad in 1935 signaled the end to truck crop shipment, and the development of route 6 shifted town centers away from both the northern and southern depot areas toward the east. Today the route 6 corridor is home to restaurants, motels, gas stations and other commercial uses. Of these current uses, none fall within the 300 foot distance from the studied ponds.

Of the three cemeteries, two are on route 6 and not within 300 feet of ponds, and one is in the Herring Pond area.

Where I could find specific information on location, I have described those uses which fell near ponds in pond specific sections.

Depot Pond

The 1851 survey map shows little detail in this area. The 1909 survey map shows a scattering of homes south of the pond area. (The pond border is not sketched in!).

A 1928 aerial photo, commissioned by the hunting camp owners, shows some development to the south with some tree canopy, and in other directions, bare, perhaps farm land.

The Nov. 1938 aerials show thick scrub to the west, the south, and the north. The terrain is open to the east and northeast. There are a few houses on Samoset, mostly on the south side of the road.

Over time, most development was to the south of the pond.

The coal- heated depot, built in 1870, stood on the southeast corner of the intersection of Samoset Rd. and the railroad track. Across Samoset Rd. from it, on the southwest edge of Depot Pond, stood Clark's General Store, which housed the post office and the library as well. Moving east along Samoset Rd., along the southern edge of the pond, there was, and is, The Chapel in the Pines, a Unitarian church built in the 1890's, and the Town library, which was built in 1895. There was for some time a watering hole for horses on the pond just behind the library. The church currently seats 85 people, has a kitchen, and has an experimental peat SDS in addition to the T5 system.

There was an ice house to the east of the pond on Mill Rd. which was abandoned in the 1930's.

Great Pond

The 1851 survey map shows possible orchards (no key, but Adams believes these are orchards) on the NW and the NE, with a few houses scattered around the shores.
Clark's tannery was located from 1866 to 1875 just to the east of the promontory at the southern end of the pond now called Clark's Point. (Mumford locates tannery at approximate location of parcel 14-087.)

In the 1880's, Nickerson's Farm included Clark's Point and extended to the west through the land area now owned by the Town as conservation land, now called Wiley Park. Nickerson grew asparagus and turnips. There was a large asparagus farm north of the pond too.

By the 1890's, Clark's Point and Wiley Park were the site of hunting camps, as was the area at the north end of the pond off Kingsbury Rd.

Rental cottages were built on the southern end between Great Pond Rd. and Clark's Point in the early1900's. John Ullman recalls the one his family owned in 1910 in which chemical toilets were used. He states that there was a three story ice house nearby in which the two inch thick chunks of ice were insulated by eel grass. He further states that although pickerel were common, there were never any bass.

The 1928 aerial picture referred to in the Depot Pond discussion shows Clark's Point partially cleared but with a planted evergreen tree screen.

The 1938 aerials show cultivated land to the NW, NE, and E, with a few houses to the N, NE, S, and on Clark's Point. The land appears cleared, but not cultivated, to the SW of Clark's Point all the way to Bridge and Widow Harding Ponds to the west.

Most relevant to us perhaps is that there is a shore line woody buffer almost all the way around the pond!

The 1948 aerial shows the western edges in thick scrub growth, which extended almost all the way around Bridge Pond. The shoreline buffer around the pond continues to be visible.

Currently the Town operates two beaches on Great Pond, one at the western side in Wiley Park, and one at the east wedged between Great Pond Rd. and the pond. There's a bathroom at Wiley and a portable potty at Great Pond Rd. beach. The houses across Great Pond. Rd. from the beach are on tiny lots and are surrounded by wetlands and other ponds. Fish & Wildlife stocks the pond.

Muddy Pond

Muddy is shown on the 1866 survey (the second portion of the 1851 start). There appear to be cultivated fields all around, with an orchard to the NE.

The 1938 aerials (if viewing Muddy as an upright cross) show:

Farm fields to the NW, but not appearing to be within 300'.
Cleared, but not cultivated, land to the NE, SW, and east.
Wooded to the SE.

There is a road from Samoset Rd. to the North which runs almost to the pond.

I was able to obtain no anecdotal or personal info.

Today there is a cottage colony condo and route 6 to the east. On route 6 there are a gas station and the post office about 500' away.

Minister/Schoolhouse Pond

This pond has rather steep banks (for Eastham…)

The 1851 survey map shows no detail in this area.

The 1938 aerial shows fairly dense vegetation to the S and E, except for land of the new school to the east.

The W is vegetated along Schoolhouse and Minister as far N as just beyond the peninsula. Then the land is cleared to the NW, and somewhat thinly scrubby growth to the N all the way to the shore…no buffer here.

The church and rectory, built after 1920, are visible to the west on route 6.
Route 6 runs very close to the western edge, with a fairly steep terrain down to the pond.
In addition to the church, there are two cottage colony condo complexes close to the pond on the west. A Town cemetery lies across route 6 to the NW of Minister beyond the 300 foot delineation.

Don Sparrow says that in the mid 1930's there were "no houses" around Schoolhouse, but there was an ice business.

The old Schoolhouse, south of the pond on Nauset Rd. just beyond the 300' mark was closed in 1936; it now houses a schoolhouse museum. The "new" school on Schoolhouse Rd. just east of the pond was opened in 1936. It now serves as the elementary school housing a declining population of 200 kids. Iron bacteria have been an issue for the drinking water at the school.

Based on the groundwater contours we've seen, the landfill, NE of the pond, may have an effect on it as well.

Herring Pond

The 1851 survey map has no detail around this pond. It is known however, that the cemetery on Bridge Rd., upgradient to the east, and just beyond the railroad /bike trail, was in active use from 1754-1886.

The 1938 aerial shows the land cleared all around except for the area on the southern edge (now Crosby Village Rd.) which was fully treed. The only visible homes are the farmhouse at the corner of Herring Pond Rd. and Lawton Rd. to the west (current parcel 14-041) , and one to the NW. There are cultivated areas to the east, as well as the railroad track.

A road ran around the pond at the shore line.

There is shrubby growth visible to the N toward Jemima Pond and to the NW running west as far as the farmhouse mentioned above. Currently the Town operates a beach off Herring Brook Rd., serviced by a portable toilet, with a herring run abutting it (shows as unnumbered parcel on the plan you sent me). There is an off-site homeowners' association (upgradient to the east) which owns a private beach south of the pond. The Town owns a fairly large parcel of conservation land north of the pond as well (parcel 14-082A.). F & W stocks the pond.