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

FINAL REPORT

September 2009

for the

Town of Brewster

and

Barnstable County

Prepared by:

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Cover photo: Brewster shoreline of Long Pond (Ed Eichner, October 2007)

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Brewster PALS

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Executive Summary

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

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Cape Cod ponds are part of the regional aquifer system and, as such, are linked to drinking water and coastal estuaries, as well as any pollutants added to the aquifer. In Brewster, water quality in the ponds are generally a reflection of the amount of development around the ponds, including impacts from wastewater, fertilizers, and stormwater runoff, as well as the individual characteristics of each pond. Until the Cape Cod Pond and Lake Stewardship (PALS) program was created, water quality in most ponds was generally limited to anecdotal information from long time residents.

The Cape Cod PALS program provides a focus for local pond concerns and staff from Coastal Systems Program at the School of Marine Science and Technology (SMAST), University of Massachusetts Dartmouth and the Cape Cod Commission (CCC) provide training and guidance to local volunteers about collecting water samples, as well as discussing management of pond water quality and pond uses.

Volunteer water quality sampling activities have led to eight consecutive, annual PALS water quality snapshots, which have included free laboratory analysis through SMAST. Citizen enthusiasm for pond water quality has led to more grant-supported, citizen monitoring with laboratory services provided through the Cape Cod National Seashore. All these monitoring activities have created a large dataset of volunteer-collected pond water quality data in need of analysis and interpretation.

Through funding provided by Barnstable County, SMAST staff have been contracted by the CCC to review all available laboratory and field water quality data collected by Town of Brewster volunteers from 29 ponds between 2001 and 2007. In addition to the town-wide review, this review also includes more detailed review of six ponds selected by the Town of Brewster: Blueberry, Seymour, Canoe, Walkers, Upper Mill, and Lower Mill. These more detailed, pond-specific reviews include delineation of pond watersheds, development of water and phosphorus budgets, characterization of the ponds ecological status, and recommendations for next steps.

Regulations, Management Strategies and Nutrient Thresholds

Assessing the condition of a pond ecosystem is generally about both assessing the ecological conditions and comparing those conditions to regulatory thresholds. Regulatory standards are defined as an interpretation of a federal, state, or local law, while ecological gauges are generally based on comparisons to similar ponds in similar settings or to historic information about the pond under review. Since regulatory standards have the power of law, community action can be compelled by regulatory entities (usually the state), while meeting ecological gauges are usually based on the local value of the resource. Effective management strategies address both ecological and regulatory goals.

State Regulatory Standards, Clean Water Act and Pond TMDLs

All freshwater ponds in Massachusetts that are not drinking water supply sources are classified as "Class B" waters under Massachusetts Surface Water Quality Standards regulations (314 CMR 4). According to these regulations, Class B waters must have "consistently good aesthetic value" and have the following designated uses: "habitat for fish, other aquatic life, and wildlife, including for their reproduction, migration, growth and other critical functions, and for primary and secondary contact recreation" [314 CMR 4.05(3)(b)]. These regulations have been written to interpret the Massachusetts Clean Water Act (Massachusetts General Law c. 21, §§ 26 through 53) and the Massachusetts' role in implementing the federal Clean Water Act. The Massachusetts Department of Environmental Protection (DEP) is the regulatory agency responsible for implementation of both the state and federal Clean Water Acts.

Massachusetts Surface Water regulations have only three numeric standards: dissolved oxygen, temperature, and pH. Most of the other regulatory guidance is qualitative descriptions. Among the numeric standards, the most important from a general ecological perspective is dissolved oxygen. Survival of certain species, such as trout, is highly dependent on appropriate oxygen levels.

However, impairment of oxygen levels is more of a terminal condition for a pond ecosystem rather than a warning sign that conditions are worsening. Addition of excessive nutrients will usually be measured in raised nutrient concentrations and diminished clarity (caused by phytoplankton populations growing on the extra nutrients). Oxygen levels generally decline only after much of the results of the excessive growth have been deposited in the pond sediments and prompted excessive sediment oxygen demand.

According to the state surface water regulations, dissolved oxygen concentrations in ponds "shall not be less than 6.0 mg/l in cold water fisheries and not less than 5.0 mg/l in warm water fisheries" [314 CMR 4.05(3)(b)1.]. All the numeric regulatory standards have provisions to allow "natural" readings outside of the specified ranges; for example, pH readings in most Cape Cod ponds are lower than the state 6.5 limit, but a strong case is available that most ponds in the southeastern Massachusetts outwash plains of Cape Cod, Plymouth, and portions of Wareham have natural pH readings less than 6.5 (Eichner and others, 2003).

Any waters failing to meet the numeric standards in the state Surface Water regulations are defined as "impaired" for the purposes of federal Clean Water Act compliance. All impaired waters are required by the Act to have a Total Maximum Daily Load (TMDL) established for the contaminant that is creating the impairment. Under the Clean Water Act, states are required to create implementation plans to meet TMDLs; DEP guidance to date has focused on having community-based comprehensive wastewater plans include provisions to meet established TMDLs.

Other than the limited numeric standards, the other related state compliance threshold is whether a pond is supporting all designated uses. The pertinent portion of the regulations states that: "Unless naturally occurring, all surface waters shall be free from nutrients in concentrations that would cause or contribute to impairment of existing or designated uses…Human activities that result in the nonpoint source discharge of nutrients to any surface water may be required to be provided with cost effective and reasonable best management practices for nonpoint source control" [314 CMR 4.05(5)(b)3.]. Given that this is an interpretive threshold, it is often a pathway to begin to discuss pond ecological conditions.

Nutrient Limits for Brewster Ponds

In an effort to begin to address the high number of impaired waters around the United States, the federal Environmental Protection Agency (EPA) has proposed a procedure to develop "nutrient criteria" for various water resources, including lakes and ponds (EPA, 2000). This method relies on gathering data throughout an area or "ecoregion" with similar assemblages of natural communities and species. That data is then used to determine what are reasonable nutrient criteria or limits to protect the ponds in this area from impairments. At this point, EPA's method is used to produce numeric guidelines, not regulatory standards.

All of Cape Cod is within EPA's Atlantic Coastal Pine Barrens Ecoregion (Griffith and others, 1999). As a result of the initial Cape Cod PALS water quality snapshot in 2001, volunteers collected nutrient samples from 195 ponds. Using this data, CCC staff applied the EPA nutrient criteria procedures and determined nutrient criteria for total phosphorus, total nitrogen, and chlorophyll *a* (Eichner and others, 2003).

The EPA nutrient criteria guidance defines two approaches to determining nutrient criteria: one based on reviewing results from so-called "reference" or relatively pristine ponds and another based on all available pond data regardless of water quality conditions. The respective standards based on the surface water samples from the 2001 Cape Cod dataset are: chlorophyll *a*, 1.0 and 1.7 ppb; total nitrogen, 0.16 and 0.31 ppm; and total phosphorus, 7.5 and 10 ppb (Eichner and others, 2003).

Town-wide Pond Water Quality

Review of the volunteer data from 29 Brewster ponds monitored between 2001 and 2007 indicates that 24 of the ponds have average dissolved oxygen concentrations that fail to attain minimum state regulatory thresholds in at least one sampling station. The five ponds that meet the state minimum dissolved oxygen standards at all their stations are: Cahoon, Greenland, Smith, Walker, and Little Cliff.

Review of other ecological factors show that all of the ponds except for Higgins have at least one station where the average concentration exceeds the Cape Cod ponds 1.7 ppb chlorophyll *a* standard. All of the ponds except for Higgins, Little Cliff, Sheep, Slough, and Greenland have at least one station where the average total phosphorus exceeds the Cape Cod ponds 10 ppb standard. These same ponds also are the only ponds where average concentrations at all stations are less than the Cape Cod ponds 0.31 ppm total nitrogen standard. The fact that the nutrient lists and the dissolved oxygen lists are not the same reinforces the need to review and understand the individual characteristics of each pond.

Review of total nitrogen to total phosphorus ratios show that all ponds are phosphorus limited, which means that management of phosphorus will be the key for determining water quality in these ponds. It also means that reductions in phosphorus will have to be part of any remediation plans.

Detailed Pond Water Quality Assessments

Six ponds were selected by the Town for more detailed review by SMAST staff: Blueberry, Seymour, Canoe, Walkers, Upper Mill, and Lower Mill. These detailed reviews allow the review of water quality data completed in the town-wide overview to be enhanced and brought into a better context and understanding of how watershed and in-lake factors influence the water quality that is measured. These detailed reviews include: 1) the incorporation of watershed information, 2) development of water budgets to determine how water moves in an out of each pond, and 3) development of phosphorus budgets to help understand the likely sources of the nutrient for each individual pond. Development of the phosphorus budget includes review of surrounding land uses, which also allows project staff to develop estimates of both existing and future sources of phosphorus loads, better understand any phosphorus travel delays in the aquifer, and identify where additional information should be gathered before remediation plans are implemented.

Because phosphorus moves very slowly in Cape Cod aquifer conditions, it can take decades for some loads from even nearshore 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 as more of the phosphorus already in the aquifer reaches pond and the systems move closer to steady state.

The detailed review of the six individual ponds shows that Seymour, Canoe, and Blueberry are all impaired based on the state dissolved oxygen regulatory limits. Upper Mill is borderline impaired and Walkers and Lower Mill are not impaired under the state regulatory limits.

In contrast, all six of the detailed ponds are impaired based on the review of total phosphorus, chlorophyll *a*, and Secchi transparency. The individual circumstances of each pond show how the dissolved oxygen standards can be met while ecological conditions are impaired. For example, Walkers Pond meets the state dissolved oxygen limit. It meets the limit largely because of its location near the interior of the Cape, close to the highest point in the area and because of its shallow depth. Because of its elevation, it is exposed to close to the maximum wind energy available and because of its shallow depth, it has a relative small volume compared to its surface area. These factors mean that the water column in Walkers is very well mixed. This regular mixing allows any oxygen demand from the sediments to be addressed by the regular addition of atmospheric oxygen to the water column. And this allows Walkers to meet state dissolved oxygen standards even though it has average total phosphorus concentrations five times higher and average chlorophyll *a* concentrations 10 times higher than their respective Cape ponds standards.

Evaluation of the water and phosphorus budgets for the six detailed ponds generally revealed that additional information is going to be required before remediation options are evaluated for cost and effectiveness and remediation plans are adopted. A better understanding of sediment regeneration of phosphorus and the phosphorus contribution of bird populations are common needs for all of the detailed ponds. In addition, it is recommended that stormwater systems around the ponds be evaluated in order to develop measured, pond-specific phosphorus input of this source. Depending on how well the phosphorus budgets balance after developing this recommended information, it may also be necessary to complete rooted plant surveys in order to evaluate how much phosphorus may be bound in this portion of the plant community, as well as providing a baseline for future impacts. Completion of these activities will allow the town to more effectively review remediation options and clearly define which sources are most cost effective to address.

Conclusions and Next Steps

It is clear from the collected data that most of Brewster ponds have compromised water quality. Generally, these impairments do not affect their use for recreational purposes except perhaps for fishing, but the many of the ponds are ecologically impaired and some do not meet state regulatory standards. Those that do not meet state regulatory standards will be required to have TMDLs developed and plans will have to be prepared to meet the TMDLs. The town will also have to decide how it will choose to address those ponds that meet state standards, but are impaired based on all other known ecological measures.

Addressing the impairments will likely require a number of years given the likely costs. For this reason, it is recommended that the town complete more detailed reviews equivalent to those completed for the six selected ponds. Completion of these reviews will allow the town to begin to frame the full extent of the issues that need to be addressed.

Similarly, it is recommended that the town submit the results from the detailed review of the six ponds to the state Department of Environmental Protection for consideration and listing on the 2010 Integrated List. This list is revised by DEP every two years to satisfy federal requirements under Sections 303d and 305b of the Clean Water Act. Waters selected as impaired and added to this list are required to have TMDLs. The state's response to submittal of the six ponds will provide the town with guidance about how to approach remediation of these ponds, as well as guidance on how similar conditions will be regarded in Brewster's other ponds.

It is also recommended that the town consider beginning the process to develop the additional information identified as needed through the detailed review of the six selected ponds. This information will help the town refine the understanding of the ecosystems and ensure that future remediation plans will be directed at phosphorus sources that are cost effective and ecologically pertinent.

Finally, it is recommended that the town consider continuing the citizen monitoring program for the ponds. The available dataset for all the ponds means that they do not need to be monitored frequently, but it is recommended that they be sampled twice a year: once in April to establish pre-summer water quality conditions for that year and once in August/September to evaluate what are likely to be the worst water quality conditions of the year. It is further recommended that PALS Snapshot sampling protocols continue to be used for both sampling rounds. Continuation of this effort will allow the town to continue to track any changes, identify any significant problems before they become more serious, and lay the groundwork to minimize any future TMDL compliance monitoring.

This report contains ballpark cost estimates for all of the recommended activities, which are summarized below. SMAST staff are available to assist the town in the development of detailed tasks and associated costs to address these recommendations. Cost savings may be realized by utilizing volunteers and town staff wherever possible, as well as bundling tasks to minimize mobilization and reporting costs.

Table EX-1. Summary of Recommended Activities for Brewster Ponds

All recommended activities are discussed in greater detail in the report. Estimated costs are based on SMAST personnel costs for current fiscal year and stand alone projects. Lower total costs for each activity can be achieved by bundling activities together and development of more refined task activity lists. Selected tasks will require further discussion with the town to select among a variety of approaches; these are designated TBD (To Be Determined). SMAST staff are available to assist the town in developing such lists and refined costs.

Recommended Tasks		Section	Page #	Estimated Cost
1	All ponds: Characterize stormwater systems near ponds and, if the pond is impaired, sample stormwater to ascertain actual phosphorus contribution from runoff.	V.3.5.	45	TBD
2	Seymour Pond: Impaired under state regs, town should consider following steps to develop management plan and TMDL: a) road runoff and bird loads should be evaluated with targeted data collection b) collect and incubate sediment cores with accompanying water quality data c) update assessment in this report with Pond-specific information and develop a remedial plan d) consider rooted plant survey, including mapping, transects and species identification	VI.1.	50	$22,000 and $26,000 for data collection and updated assessment TMDL/mgmt plan: $10,000 to $12,000 plant survey: $8,000 to $10,000
3	Canoe Pond: Impaired under state regs, town should consider following steps to develop management plan and TMDL: a) road runoff and bird loads should be evaluated with targeted data collection b) collect and incubate sediment cores with accompanying water quality data c) update assessment in this report with Pond-specific information and develop a remedial plan d) consider rooted plant survey, including mapping, transects and species identification	VI.2.	59	$22,000 to $25,000 for data collection and updated assessment TMDL/mgmt plan: $10,000 to $12,000 plant survey: $7,000 to $9,000

Table EX-1. Summary of Recommended Activities for Brewster Ponds (cont'd)				
Recommended Tasks		Section	Page #	Estimated Cost
4	Blueberry Pond: Impaired under state regs, town should consider following steps to develop management plan and TMDL: a) road runoff and bird loads should be evaluated with targeted data collection b) collect and incubate sediment cores with accompanying water quality data c) update assessment in this report with Pond-specific information and develop a remedial plan d) consider rooted plant survey, including mapping, transects and species identification e) review potential future impact of Ocean Edge resort	VI.3.	67	$22,000 to $25,000 for data collection and updated assessment TMDL/mgmt plan: $10,000 to $12,000 plant survey: $7,000 to $9,000
5	Walkers Pond: Not impaired under state regs, but ecologically impaired, town should consider following steps if choosing to remediate: a) evaluations of road runoff and bird loads with targeted data collection b) collect and incubate sediment cores with accompanying water quality data c) update assessment in this report with Pond-specific information and develop a remedial plan d) consider rooted plant survey, including mapping, transects and species identification	VI.4.	75	No cost for MassDEP submittal $32,000 to $35,000 for data collection and updated assessment TMDL/mgmt plan: $10,000 to $12,000 plant survey: $8,000 to $10,000

Table EX-1. Summary of Recommended Activities for Brewster Ponds (cont'd)				
Recommended Tasks		Section	Page #	Estimated Cost
6	Upper Mill Pond: Borderline impaired under state regs, but definitively ecologically impaired, town submit report for review by MassDEP, town should consider following steps: a) town submit report for review by MassDEP to obtain feedback on compliance with state water quality regs If remedial plan/TMDL required or town decides to pursue remediation, the following steps are recommended: b) road runoff and bird loads should be evaluated with targeted data collection c) collect and incubate sediment cores with accompanying water quality data d) update assessment in this report with Pond-specific information and develop a remedial plan e) characterize the water and phosphorus flows from Canoe and Walkers Ponds and into Lower Mill Pond f) consider rooted plant survey, including mapping, transects and species identification	VI.5.	83	No cost for MassDEP submittal $42,000 to $45,000 for data collection and updated assessment TMDL/mgmt plan: $10,000 to $12,000 plant survey: $8,000 to $10,000
7	Lower Mill Pond: Borderline impaired under state regs, but definitively ecologically impaired, town submit report for review by MassDEP, town should consider following steps: a) town submit report for review by MassDEP to obtain feedback on compliance with state water quality regs If remedial plan/TMDL required or town decides to pursue remediation, the following steps are recommended: b) road runoff and bird loads should be evaluated with targeted data collection c) collect and incubate sediment cores with accompanying water quality data d) update assessment in this report with the Pond-specific information and develop a remedial plan e) characterize the water and phosphorus flows from Upper Mill Pond f) consider rooted plant survey, including mapping, transects and species identification	VI.6.	89	$41,000 to $44,000 for data collection and updated assessment TMDL/mgmt plan: $10,000 to $12,000 plant survey: $7,000 to $9,000

Table EX-1. Summary of Recommended Activities for Brewster Ponds (cont'd)				
Recommended Tasks		Section	Page #	Estimated Cost
8	Pond Monitoring/Town-wide: Continue monitoring all ponds that have available data; reduce frequency to twice a year: once in April to establish pre-summer water quality conditions for that year and once in August/September to evaluate what are likely to be the worst water quality conditions of the year. It is further recommended that PALS Snapshot sampling protocols continue to be used for both sampling rounds.	VIII.1	94	~$6,700 + volunteer time ($13,400 without PALS Snapshot)
9	Detailed review of Other Ponds with extensive data: Consider similar detailed reviews for the other 22 ponds that have citizen collected water quality data. Completing these reviews will allow the town to address town-wide water quality concerns in a more comprehensive fashion, especially if these reviews are completed prior to the completion of the Needs Assessment phase of the town-wide Comprehensive Wastewater Assessment.	VIII.2	94	TBD (depends on volunteer assistance, availability of CCC GIS assistance, and gathering of other data, such as stormwater loads; rough planning amount of $3,000 to $5,000 per pond)
10	Determine Regulatory Status for Six Detailed Ponds: Consider filing this report to obtain TMDL guidance and feedback from MassDEP during the 2010 round of the state's integrated list preparation (to satisfy federal requirements under Sections 303d and 305b of the Clean Water Act). The state's response will provide the town with guidance about how to approach remediation of these ponds, as well as guidance on how similar conditions will be regarded in Brewster's other ponds.	VIII.3	95	No cost

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Appendix

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

I. Introduction

The Town of Brewster has 76 ponds that collectively occupy 2,028 acres (Eichner and others, 2003). Of these ponds, 53 of them are greater than one acre and 28 of them are greater than ten acres. Over the course of the last ten years, local concerns about the water quality of Brewster's ponds have often become focused by algal blooms, fish kills, and concerns related to the impacts from population growth.

These concerns reflect similar pond concerns that are being raised Cape-wide. In 2000, a number of community partners, including the Cape Cod Commission (CCC), 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 to help 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 potential solutions could be shared and discussed 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.

Select towns, including Brewster, 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. Brewster'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 Brewster program uses the PALS sampling protocol as guidance and has included the collection of samples from 29 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 Brewster, requested CCC assistance to provide interpretation of volunteer-collected pond water quality data. The project scope developed by Brewster 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 to town volunteers on May 4, 2006. Subsequent consultation with town staff resulted in the following ponds being selected for detailed review: Upper Mill, Lower Mill, Walker, Blueberry, Seymour, and Canoe (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.

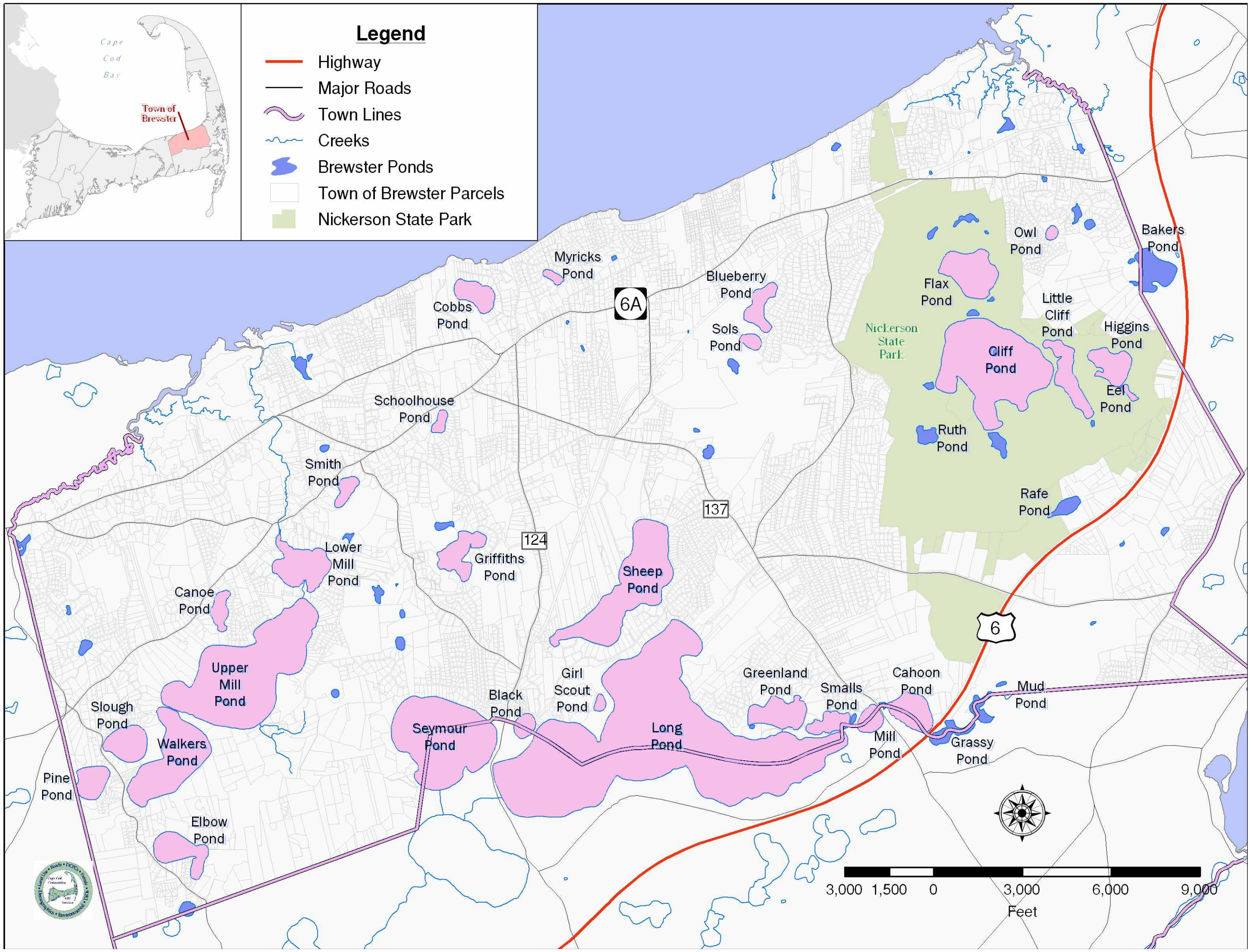


Figure I-1. Ponds regularly sampled by Brewster volunteers

Ponds colored pink have been regularly sampled by Brewster volunteers and their water quality information is reviewed in this report.

II. Pond Data Sources

During the initial 2001 PALS Snapshot, Brewster volunteers collected data from 26 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 have also been 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 2008 is included in the following analysis; 2008 data was not available during the analysis phase of this project. 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.

Table II-1 shows the frequency of field data collection in Brewster ponds between 2001 and 2007. The monthly counts in Table II-3 are based on the collection of temperature and dissolved oxygen profiles. Collection of water quality samples for later laboratory analysis occurred in approximately half of field data collection dates. This data collected 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.

Water quality samples were sent to either the SMAST or CCNS lab. The SMAST lab analysis and sample handling procedures are described in the SMAST Coastal Systems Analytical Facility Laboratory Quality Assurance Plan (2003), which is approved by the Massachusetts Department of Environmental Protection. These procedures, which are used for all PALS Snapshot samples, include the following parameters: total nitrogen, total phosphorus, chlorophyll-*a*, pH, and alkalinity. Detection limits for SMAST laboratory analytes and field data collection are listed in Table II-2.

In addition to the PALS Snapshots, the Brewster volunteers also benefited from laboratory services provided by CCNS lab. The CCNS lab results include analysis for the following parameters: total nitrogen, total phosphorus, chlorophyll-*a*, nitrate-nitrogen, ammonia-nitrogen, and ortho-phosphate. Laboratory services through the CCNS were grant funded and generally allowed monthly and bimonthly sampling during the summers of 2002 and 2003 and once or twice a year analyses for selected ponds during 2004 through 2007.

Table II-1. Field data collection frequency for Brewster Ponds (2001-2007)

	2001	2002							2003							
POND	Se	Jn	Jl	Au	Se	Oc	No	SUM	Ma	Jn	Jl	Au	Se	Oc	No	SUM
Black	1	2	2	3				7	1	2	2	2	2	1		10
Blueberry	1		2	2	2			6	1	1	2	2	2	1		9
Cahoon	1	1	2	3	1			7	1	2	2	2	2			9
Canoe	1	2	2	2	2			8	2	2	2	2	2	1		11
Cliff	1	2	2	2	1		1	8	1	2	2	2	1	2	1	11
Cobbs	1	1	2	2	2			7	1	2	2	2	2	2		11
Eel								0								0
Elbow	1			1				1				1				1
Flax	1	2	2	2	1	1	1	9	1	2	2	2	1	2	1	11
Girl Scout								0			3	2	1	2		8
Greenland	1	2	2	3	1			8	2	2	2	2	2	1		11
Griffiths	1			1				1	1	2	2	2	1			8
Higgins	1	2	2	2	1	1		8	2	2	1	2	1	1	1	10
Little Cliff	1	2	2	2	1			7	2	2	2	2	1			9
Long	1	2	2	2	1			7	2	2	2	1	1	1	1	10
Lower Mill	1	2	2	2	2			8	2	2	1	1	2			8
Mill	1		1	2	2			5	2	2	2	2	2	1		11
Myricks	1				1			1				1				1
Owl								0								0
Pine	1		1	3				4	1	2	2	2	2	1		10
Schoolhouse	1		2	2	3			7	1	1	2	2	2	2		10
Seymour	1	2	2	3	2			9			2	2	2	2		8
Sheep	1	2	2	2	1			7	2	2	2	2	1		1	10
Slough	1		2	2	3			7	1	1	2	2	2	2		10
Smalls	1		2	2	2			6	2	2	3	1	2	1		11
Smith	1							0					1			1
Sol's	1	2	1	2	1			6	1	2	2	2	2			9
Upper Mill	1			2				2		2	2	2	2	1		9
Walker	1	2	2	3	2			9	2	3	1	2	2	1		11
# of ponds SUM = # of readings	26	15	21	24	20	2	2	155	21	22	24	26	25	18	5	238

	2004									2005									2006								2007							Overall Sum
POND	Ap	Ma	Jn	Jl	Au	Se	Oc	No	SUM	Ap	Ma	Jn	Jl	Au	Se	Oc	No	SUM	Ma	Jn	Jl	Au	Se	Oc	No	SUM	Ma	Jn	Jl	Au	Se	Oc	SUM	2001-2007
Black		2	1	2	3	2			10		1		2	2	1			6								0		1	2	2	1		6	40
Blueberry		2	1	1	2	2			8	1	2	2	2	2	2	2		13	2	2	2	2	2	2		12	1			1			2	51
Cahoon					1				1		1	1	2	1				5								0				1			1	24
Canoe			1	2		2			5	1	1	2	2	2	1	1		10	1	2	1	2	2			8		2		1	1		4	47
Cliff		2	2	1	2	1	2	1	11		2	2	2	2	1			9	1	1	1	1	1			5	1				1		2	47
Cobbs			2	1	2	2	1		8		2	3	1	2	2			10		2	1	2	2			8	1			1			2	47
Eel						1			1						1			1				1				1					1		1	4
Elbow					1				1		1			1	2			4			2	2	1			5		1	1	1	1	1	5	18
Flax		2	2	1	3	1	2	1	12				2	2	1			5	1	1	1	1	1	1	1	7	1				1		2	47
Girl Scout		1				1			2									0	1							1							0	11
Greenland		2	2	2	2	2			10		1	2	2	2	1			8					1			1	1			1			2	41
Griffiths		2	1	1	2	2			8		1			2				3	2	2	1	1	1			7		1	1	1			3	31
Higgins		2	2	1	3	2	2		12		2	2	2	1	1	1		9	1	1	1	1	1	1	1	7	1				1		2	49
Little Cliff		2	2	1	3	1	2		11		2	2	2	2	1			9	1	1	1	1	1			5	1				1		2	44
Long		1	1	2	2	2	1		9		1		2	1				4			1	2	1			4					1		1	36
Lower Mill		1	1			1			3		2	2	1	2	1			8		1	1	1	1			4					1		1	33
Mill					1				1			1	2	1				4								0	1		1	1	1		4	26
Myricks					1				1				2	1		1	1	5	2		1		1			4	1	1	2		1	1	6	19
Owl		2	2	1	2	1			8		2	2	1	3	2			10			1	2	1			4			1	1	1	1	4	26
Pine		2	2	1	2	1			8			1	3	2	2	1		9		1	2	1	1	1		6	1	1	2	3	2	1	10	48
Schoolhouse			1	3	2	2			8		1	1	3	2	2			9		2	2	2	2			8	1			1			2	45
Seymour			2	2	2	2			8				2	1	2			5		2	2		2	1		7	1	1	1		1	1	5	43
Sheep		2	2	2	2	1	1	1	11		1	2	1	1	1	1		7	2	1	2	2	1			8	1				1		2	46
Slough			1	3	2	2			8		1		3	2	2			8		1	3	2	2			8							0	42
Smalls		2	2	2	2	2			10		1	2	3	2	1			9					1			1	1			1			2	40
Smith					1				1									0								0							0	3
Sol's			2	3	2	2			9			2	2	2	2	1		9								0							0	34
Upper Mill		1	1	2	1	1	1		7		1	2	1	3	2			9			3	2	2			7	1	1	1			1	4	39
Walker	1	2	2	2	1				8		2	3	2		2			9	1	2	2	3	2			10	2	2	2	3	2		11	59
# of ponds SUM = # of readings	1	17	22	21	25	23	8	3	200	2	20	18	24	25	22	7	1	197	11	15	20	19	22	5	2	138	16	9	10	14	17	6	86	1040

Note: All monitoring dates based on field collection of dissolved oxygen and temperature data. Number of ponds sampled each month is shown at the bottom of each column. The "SUM" for each year shows the number of sampling events for the listed pond during that year, while the rightmost column shows the total number of events between 2001 and 2007 by pond. About half of the sampling runs led to the collection of water samples for laboratory analyses. Laboratory analyses were completed by either the Coastal Systems Program Laboratory, School of Marine Science and Technology (SMAST), University of Massachusetts Dartmouth or the North Atlantic Coastal Laboratory at Cape Cod National Seashore (CCNS); PALS Snapshots would generally represent one or two sampling runs in August and/or September of each year.

Table II-2. Field and laboratory reporting units and detection limits for data collected for the Brewster 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)					

Regardless of the lab used, all data can be compared since sampling depths and field data collection procedures generally followed PALS protocols. Laboratory methods used at the CCNS lab are listed in Table II-3.

III. Town-wide Water Quality Data

In order to complete the town-wide data review, SMAST and Commission staff organized available monitoring data by pond and sampling depth. Since all sampling is based on the PALS sampling protocol, sampling runs, regardless of lab used, generally are sampled at the same depth. Thus, a pond like Slough Pond that is approximately 6 m deep would have two sampling stations/depths: a shallow sampling station at 0.5 m and a deep sampling station that is one meter off the bottom. The deepest stations depths vary due to slight changes in the sampling location and fluctuations in the pond's water level, but shallower stations are generally at depths specified by the PALS protocol.

The following analysis of the data 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 the summer season is the most ecological significant time period. It is also the period when most pond users would be likely to notice water quality while they spend recreational time in, on, or around the ponds.

Table II-3. 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

References

A. US EPA, Methods for Chemical Analysis of Water and Wastes, EPA-600/4-79-020, Revised March 1983, Method 350.1

B. Murphy, J. and J.P. Riley. 1962. A Modified Single Solution Method for the Determination of Phosphate in Natural Waters. Anal. Chim. Acta., 27: 31-36.

C. Zimmerman, C.F. et al., EPA Method 353.4, Determination of Nitrate+Nitrite in estuarine and Coastal Waters by Automated Colorimetric Analysis in An Interim Manual of Methods for the Determination of Nutrients in Estuarine and Coastal Waters., Revision 1.1, June 1991.

D. US EPA, Methods for Chemical Analysis of Water and Wastes, EPA-600/4-79-020, Revised March 1983, Method 365.1

E. Valderrama. 1981. The Simultaneous Analysis of Total Nitrogen and Total Phosphorus in Natural Waters. Marine Chemistry, 10:109-122.

F. Beach. 1986. Total Carbon and Nitrogen in Filtered Particulate Matter. Manual of Biological and Geochemical Techniques in Coastal Areas, MERL Series, Report No. 1, University of Rhode Island, Kingston, R.I.

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.

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, which are generally defined as 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.

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 Brewster's ponds, Long, Higgins, Cliff, Flax, and Sheep are deep enough to have these layers.

Once 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 five of the deepest Brewster ponds have low oxygen or anoxic conditions in their deepest layer.

State surface water regulations (314 CMR 4) have numeric standards for dissolved oxygen and temperature, as well as pH. 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 (or ppm) in cold water fisheries (*e.g.*, Long) and not less than 5.0 mg/l (or ppm) in warm water fisheries (*e.g.*, Canoe). These regulations also require that temperature not exceed 68^0F (20^0C) in cold-water fisheries or 83^0F (28.3^0C) in warm water fisheries.

Any waters failing to meet the numeric standards in the state surface water regulations are defined as "impaired" for the purposes of federal Clean Water Act compliance and all impaired waters are required by the Act to have a Total Maximum Daily Load (TMDL) established for the contaminant that is creating the impairment. TMDLs usually are expressed as a concentration limit or threshold. Under the Clean Water Act, states are required to create implementation plans to meet TMDLs; Massachusetts DEP guidance to date has focused on having community-based comprehensive wastewater management plans include provisions to ensure that waters meet TMDLs.

The occurrence of dissolved oxygen concentrations less than the Massachusetts surface water 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). Dissolved oxygen 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 Brewster 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 town-wide overview of all data collected, staff reviewed dissolved oxygen concentrations at depths specified by the PALS protocol. For the ponds selected for more refined review, dissolved oxygen concentrations are brought into greater context by considering their relations to other monitoring data (see Section V).

Among the 29 ponds in Brewster with volunteer data selected for the town-wide overview, there are 278 station depths. There are collectively over 7,000 dissolved oxygen concentration reading measured at these stations between 2001 and 2007. The number of readings per station depth varies between 3 and 47 (shallow stations at Smith and Walker, respectively). Based on an initial review, Cliff, Flax, Higgins, Long, and Sheep would be classified as definitive cold water fisheries, while Elbow, Little Cliff, Myricks, and Seymour have average summer temperatures that could meet the state regulatory definitions for cold water fisheries. The rest of the ponds would be considered warm water fisheries.

Among the 21 ponds less than nine meters (~30 ft) deep, referred to here as "shallow ponds", 17 have at least one station that has an average dissolved oxygen concentration less than the state warm water regulatory standard of 5 ppm. Cahoon, Greenland, Smith and Walker are the ponds that have average dissolved oxygen concentrations greater than 5 ppm at all depths.

Forty of the 133 depth stations (30%) in these ponds have average concentrations less that the state dissolved oxygen regulatory standard (Figure III-1).

Seven of the eight ponds greater than nine meters deep, referred to here as “deep ponds”, have at least one station that fails to meet the state regulatory standard for dissolved oxygen (Figure III-2). Little Cliff is the only pond of this group that meets the state dissolved oxygen standards. Of the 145 depth stations in these eight ponds, 60 (41%) have average dissolved oxygen concentrations less than the state regulatory standard of 6 ppm.

Project staff also identified stations where dissolved oxygen concentrations of 1 ppm or less had been measured. Concentrations of 1 ppm or less are generally lethal to fish. Among the 21 shallow ponds, 10 depth stations in seven ponds have average dissolved oxygen concentrations less than 1 ppm (see Figure III-1). Among the eight deep ponds, 15 depth stations in four ponds have average dissolved oxygen concentrations less than 1 ppm (see Figure III-2). The correspondence between average concentrations failing to meet state regulatory standards and the occurrence of anoxic conditions is fairly strong; of the 96 depth stations in Brewster ponds that have average dissolved oxygen concentrations less than the state regulatory standards, all but four also have dissolved oxygen minima of less than 1 ppm (see Figures III-1 and III-2).

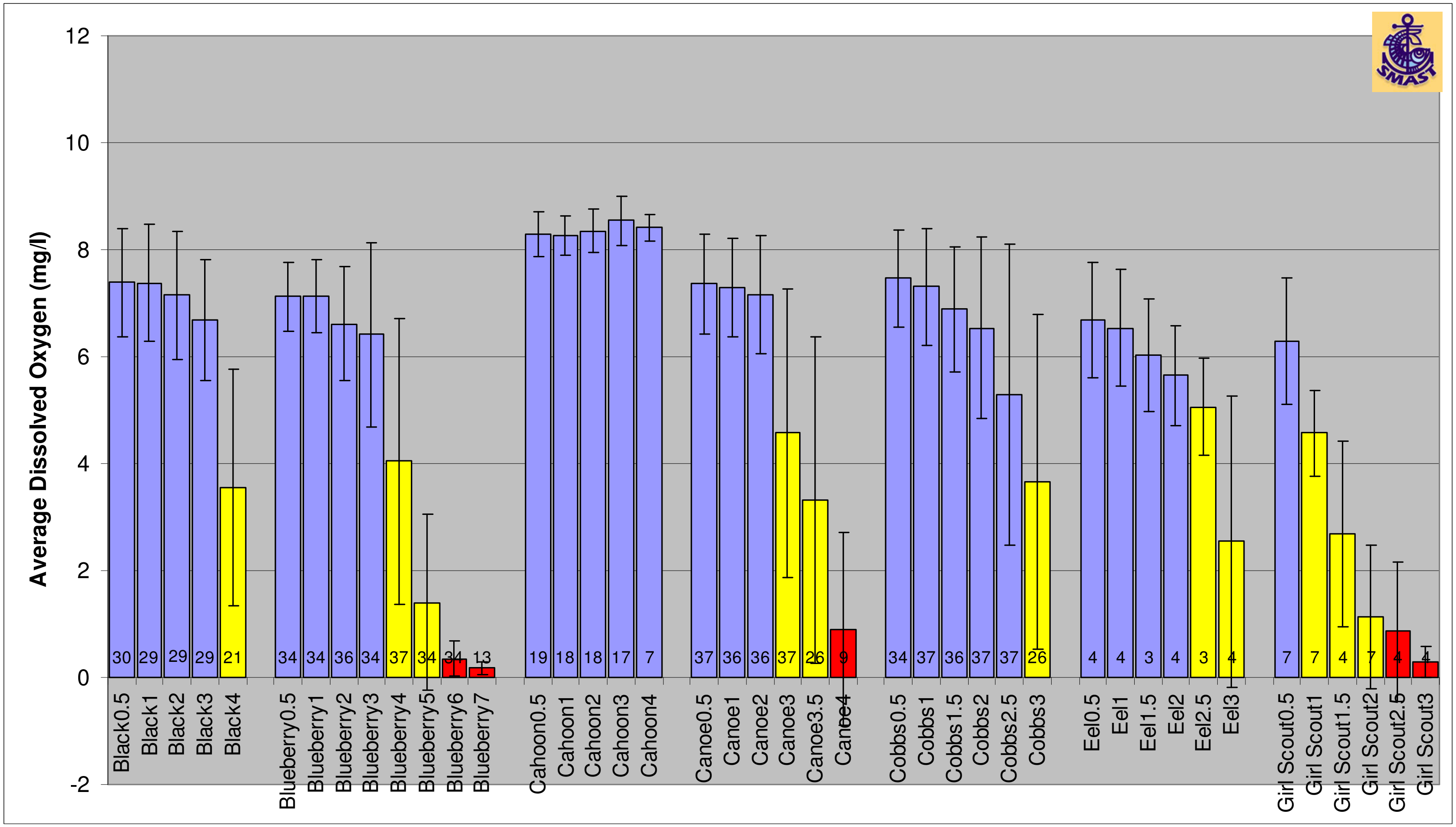


Figure III-1a. Average DO Concentrations in shallow Brewster Ponds 2001-2007 (Black to Girl Scout)

Source dissolved oxygen data is field measurements collected by Brewster volunteers. Pond names have the depths in meters at which readings were collected (*e.g.*, "Black0.5" is Black Pond readings collected at 0.5 m). Error bars show one standard deviation; all averages are corrected for outliers (± >two standard deviations). The State Dissolved Oxygen threshold for the warm-water ponds shown in this figure is 5 milligrams per liter of dissolved oxygen (314 CMR 4). Bars indicating average dissolved oxygen concentrations less than the state threshold are colored yellow, while stations with an average concentration less than 1 ppm, which is generally considered anoxic and lethal to fish, are colored red.

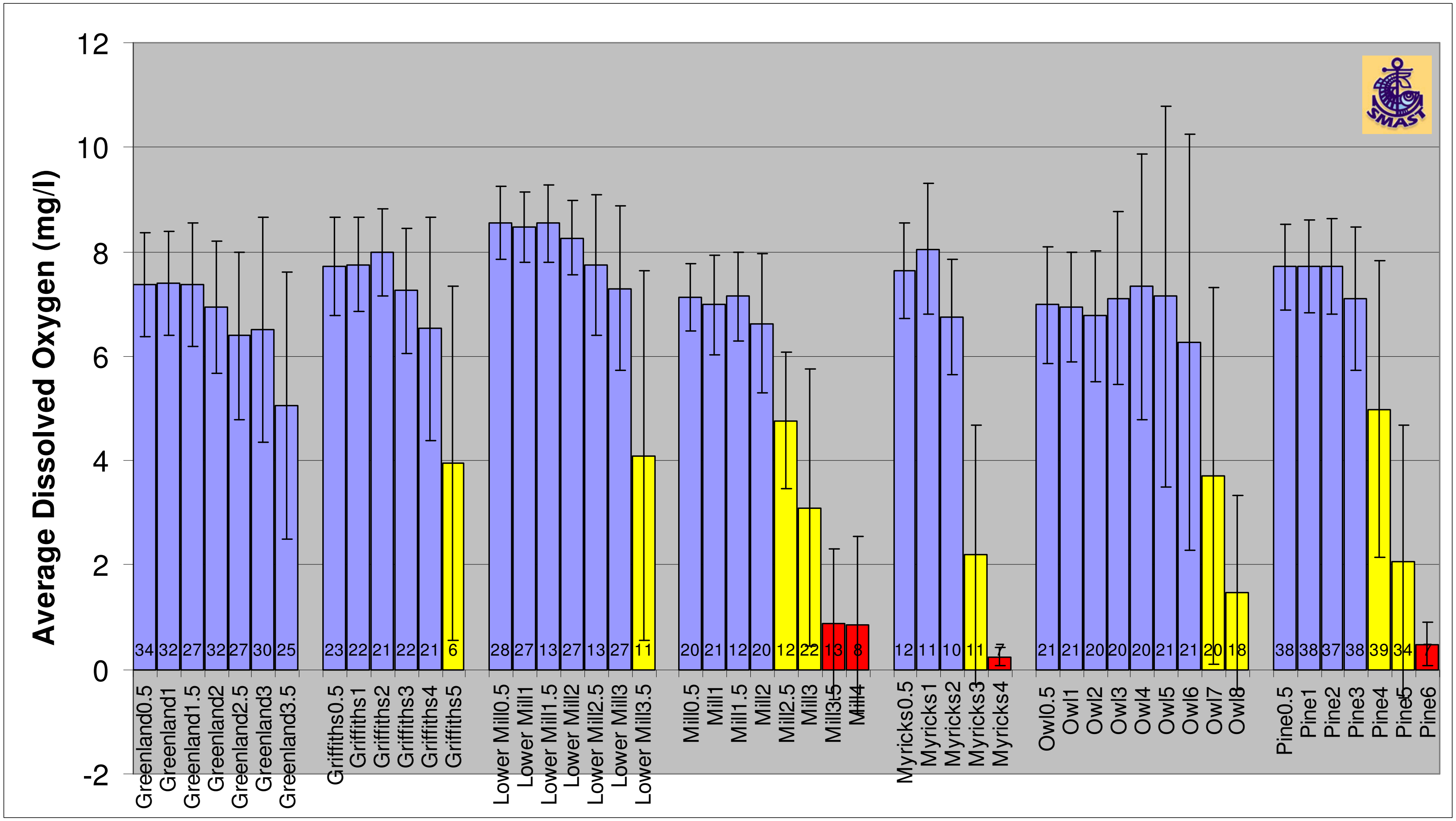


Figure III-1b. Average DO Concentrations in shallow Brewster Ponds 2001-2007 (Greenland to Pine)

Source dissolved oxygen data is field measurements collected by Brewster volunteers. Pond names have the depths in meters at which readings were collected (*e.g.*, "Pine0.5" is Pine Pond readings collected at 0.5 m). Error bars show one standard deviation; all averages are corrected for outliers (± >two standard deviations). The State Dissolved Oxygen threshold for shallow, warm-water ponds is 5 milligrams per liter of dissolved oxygen (314 CMR 4). Bars indicating average dissolved oxygen concentrations less than the state threshold are colored yellow, while stations with an average concentration less than 1 ppm, which is generally considered anoxic and lethal to fish, are colored red.

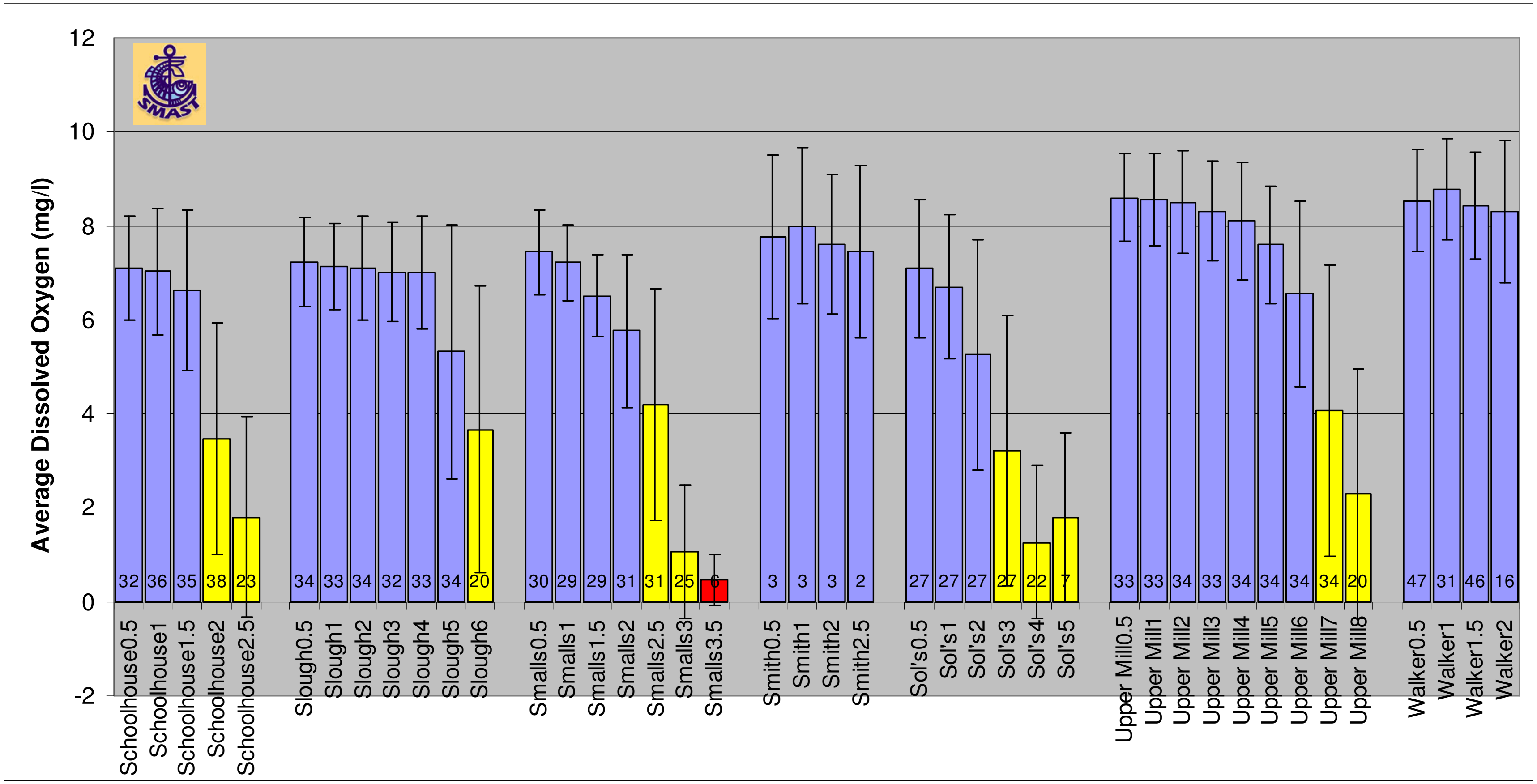


Figure III-1c. Average DO Concentrations in shallow Brewster Ponds 2001-2007 (Schoolhouse to Walker)

Source dissolved oxygen data is field measurements collected by Brewster volunteers. Pond names have the depths in meters at which readings were collected (*e.g.*, "Slough0.5" is Slough Pond readings collected at 0.5 m). Error bars show one standard deviation; all averages are corrected for outliers (± >two standard deviations). The State Dissolved Oxygen threshold for shallow, warm-water ponds is 5 milligrams per liter of dissolved oxygen (314 CMR 4). Bars indicating average dissolved oxygen concentrations less than the state threshold are colored yellow, while stations with an average concentration less than 1 ppm, which is generally considered anoxic and lethal to fish, are colored red.

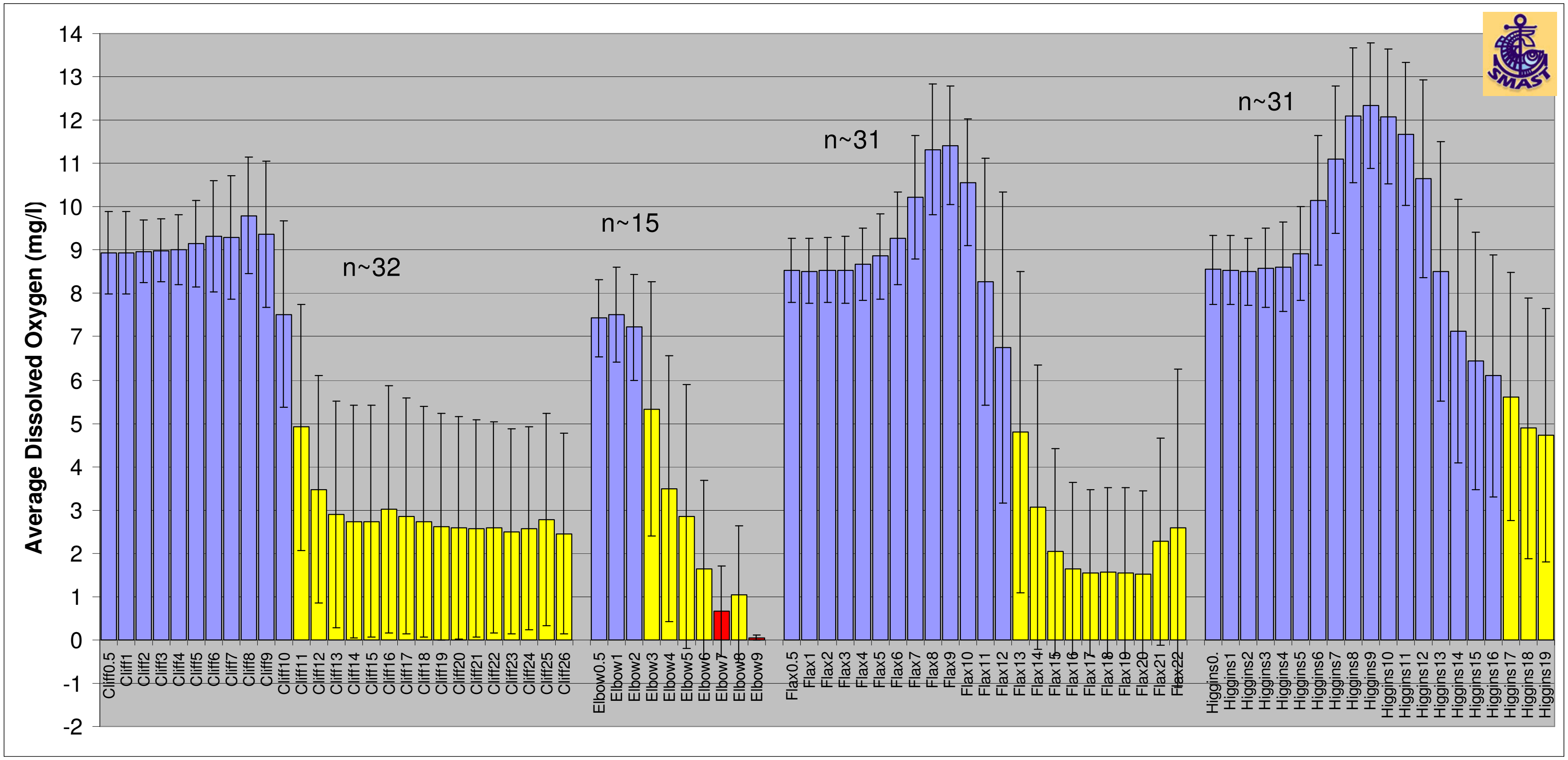


Figure III-2a. Average DO Concentrations in deep Brewster Ponds 2001-2007 (Cliff to Higgins)

Source dissolved oxygen data is field measurements collected by Brewster volunteers. Pond names have the depths in meters at which readings were collected (*e.g.*, "Flax0.5" is Flax Pond readings collected at 0.5 m). Error bars show one standard deviation; all averages are corrected for outliers (± >two standard deviations). The State Dissolved Oxygen threshold for deep, cold-water ponds is 6 milligrams per liter of dissolved oxygen (314 CMR 4). Bars indicating average DO concentrations less than the state threshold are colored yellow, while stations with an average concentration less than 1 ppm, which is generally considered anoxic and lethal to fish, are colored red. The general number of readings used to determine the averages in each pond are shown as approximate counts (e.g., "n~32"); the number of readings at each station is generally within 1 or 2 readings of this count.

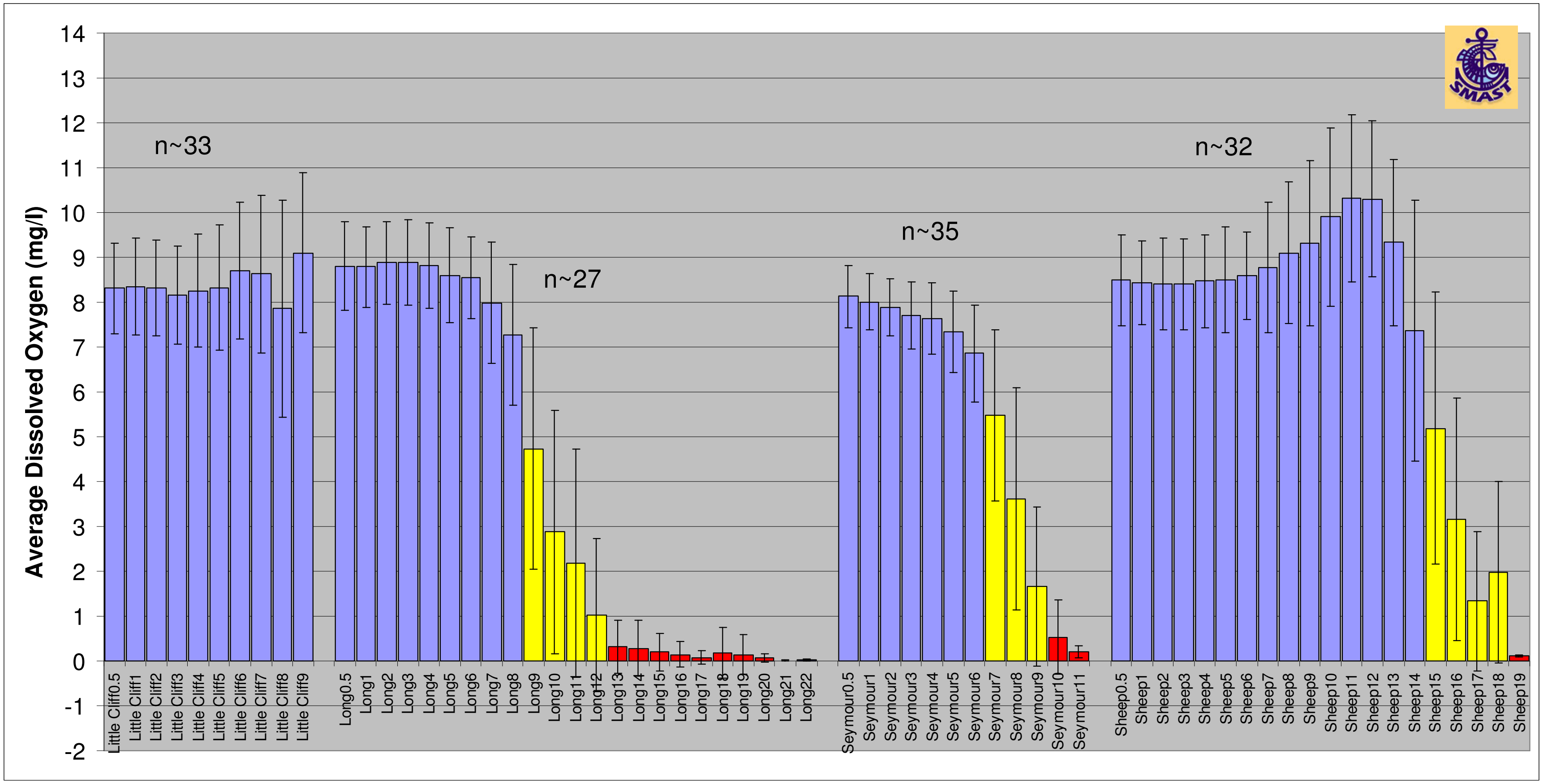


Figure III-2b. Average DO Concentrations in deep Brewster Ponds 2001-2007 (Little Cliff to Sheep)

Source dissolved oxygen data is field measurements collected by Brewster 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 one standard deviation; all averages are corrected for outliers (± >two standard deviations). The State Dissolved Oxygen threshold for deep, cold-water ponds is 6 milligrams per liter of dissolved oxygen (314 CMR 4). Bars indicating average DO concentrations less than the state threshold are colored yellow, while stations with an average concentration less than 1 ppm, which is generally considered anoxic and lethal to fish, are colored red. The general number of readings used to determine the averages in each pond are shown as approximate counts (e.g., "n~32"); the number of readings at each station is generally within 1 or 2 readings of this count.

III.1.2 Secchi Depth

A Secchi disc is an eight-inch disk with black and white quadrants that is slowly lowered into a pond to record how deep it can be seen; this depth is often referred to a "Secchi reading" and is sometimes referred to as water transparency or clarity. Because plankton or inorganic particle concentrations reduce clarity, Secchi readings are related to the amount of nutrients and are a good general measure of ecosystem condition. Secchi readings have been linked through a variety of analyses to trophic status or nutrient levels of lakes (*e.g*., Carlson, 1977). Although there is no state regulatory standard for Secchi depth, state regulations do have a clarity limit of 4 feet for safe swimming conditions (105 CMR 435).

Care should be taken when interpreting Secchi readings in shallow ponds, such as the majority of pond on the Cape, because the disk may be visible on the bottom in such ponds even if they have significant algal densities. This issue is addressed by determining relative Secchi readings. Relative Secchi readings compare the Secchi depth to total depth and allow clarity to be compared in ponds of different depths.

In Brewster, Secchi readings were generally collected by volunteers each time dissolved oxygen and temperature readings were collected. The number of Secchi readings in Brewster ponds ranged between 3 (Eel and Smith) and 47 (Walker) in the 2001 to 2007 dataset. As shown in Figure III-3, all the ponds except for Girl Scout and Walker have average Secchi readings that meet the state safe swimming clarity limit of 4 feet. Based on the available dataset, Girl Scout is 9.1 feet deep and Walker is 7.7 feet deep. Eight additional ponds have at least one reading (*i.e.*, minimum reading) less than 4 feet.

Average relative readings varied between 16% (Cliff) and 79% (Little Cliff). In Cliff, this means that although it is the deepest of the Brewster ponds at 26 m, on average its water is only clear enough to see a Secchi disc at 4.2 m. On the other extreme, 6.7 m of Little Cliff's 8.9 m depth is clear enough to see a Secchi disc.

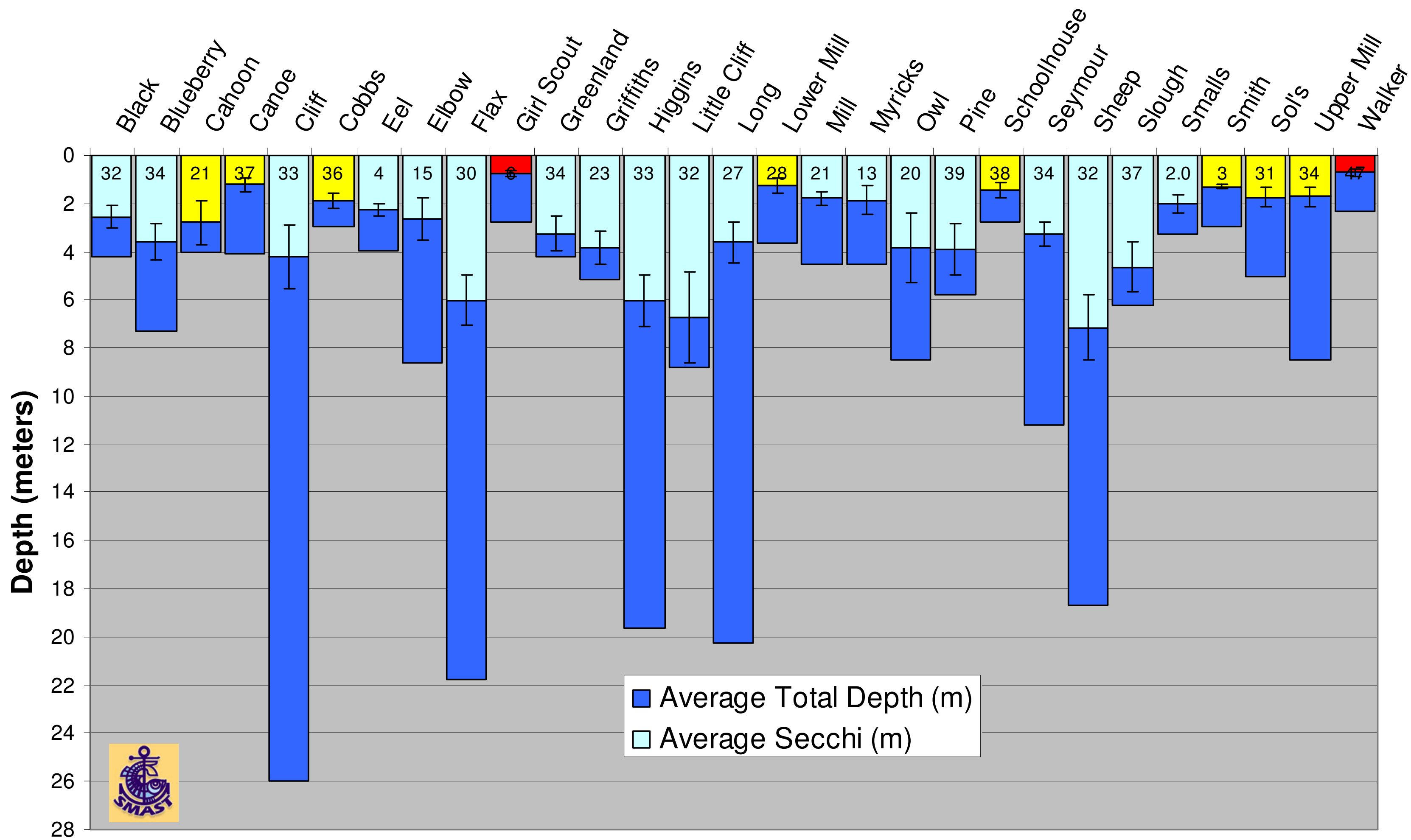


Figure III-3. Average Secchi Transparency Readings in Brewster Ponds 2001-2007

Source data is field measurements collected by Brewster volunteers using a standard Secchi disk. Error bars show one standard deviation; all values are corrected for outliers (± >two standard deviations). Numbers shown near the base of each bar indicate the number of Secchi readings used to calculate the averages. 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. Relative Secchi depth can be observed by comparing the average Secchi readings to the total depths.

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 2007 data; data from pre-2001 samples, which are discussed for the ponds selected for detailed review, used a variety of sampling protocols and 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 in freshwater systems, 90% or more of the phosphorus is bound in organic forms (plant and animal tissue or their wastes) and any available inorganic phosphorus [mostly orthophosphate (PO_4^{-3})] is quickly reused by the biota in a lake (Wetzel, 1983). Extensive research has been directed towards trying to determine the most important phosphorus pool for determining the overall productivity of lake ecosystems, but to date, most of the work has found that a measure of total phosphorus (TP) is the best predictor of productivity of lake ecosystems (*e.g.*, Vollenweider, 1968). The laboratory analysis techniques for TP provide a measure of all phosphorus in a water sample, including ortho-phosphorus and all phosphorus incorporated into organic matter, including algae. Of course, water samples do not account for phosphorus bound in rooted aquatic plants, but this tends to be a very small component of pond plant communities in Cape Cod lakes; Cape pond plant communities tend to be algal-dominated.

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. Since phosphorus moves very slowly in sandy aquifers (0.01-0.02 ft/d; Robertson, 2008), most of the sources of phosphorus entering Cape Cod ponds is from properties abutting the pond shoreline. Previous analysis of phosphorus loading to 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).

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). Use of this EPA method suggests that healthy freshwater pond ecosystems on Cape Cod should have average TP concentrations no higher than 7.5 to 10 ppb.

Average surface TP concentrations in 18 of the 29 Brewster ponds exceed the 10 ppb TP regional limit; only five of the surface stations have an average concentration less than 7.5 ppb (Figure III-4). Among the deepest ponds, all but Long and Seymour have surface concentrations below 10 ppb.

Overall, average TP concentrations among the 72 Brewster water quality sampling depths range between 4.1 ppb (3 m station in Higgins) and 196.9 ppb (deep station in Owl). Cliff, Elbow, Flax and Long have deep average concentrations 8 to 13 times higher than surface concentrations; this indicates sediment regeneration of phosphorus. On the other extreme, Higgins and Little Cliff have average deep concentrations that are approximately the same as average surface concentrations. Overall, among all 29 ponds, 49 of the 72 sampling stations (68%) have average TP concentrations exceeding 10 ppb.

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 pond phytoplankton forming organic nitrogen, and then is converted back to inorganic forms (nitrate- and ammonium-nitrogen) and released back into the pond in wastes from organisms higher up the food chain or by bacteria decomposing dead algae in the sediments. Total Kjeldahl nitrogen (TKN) is a combined 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, where phosphorus is readily abundant, 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). Nitrogen also tends to move rapidly through the aquifer system, traveling in its fully oxidized nitrate form with groundwater at average rate of a foot per day.

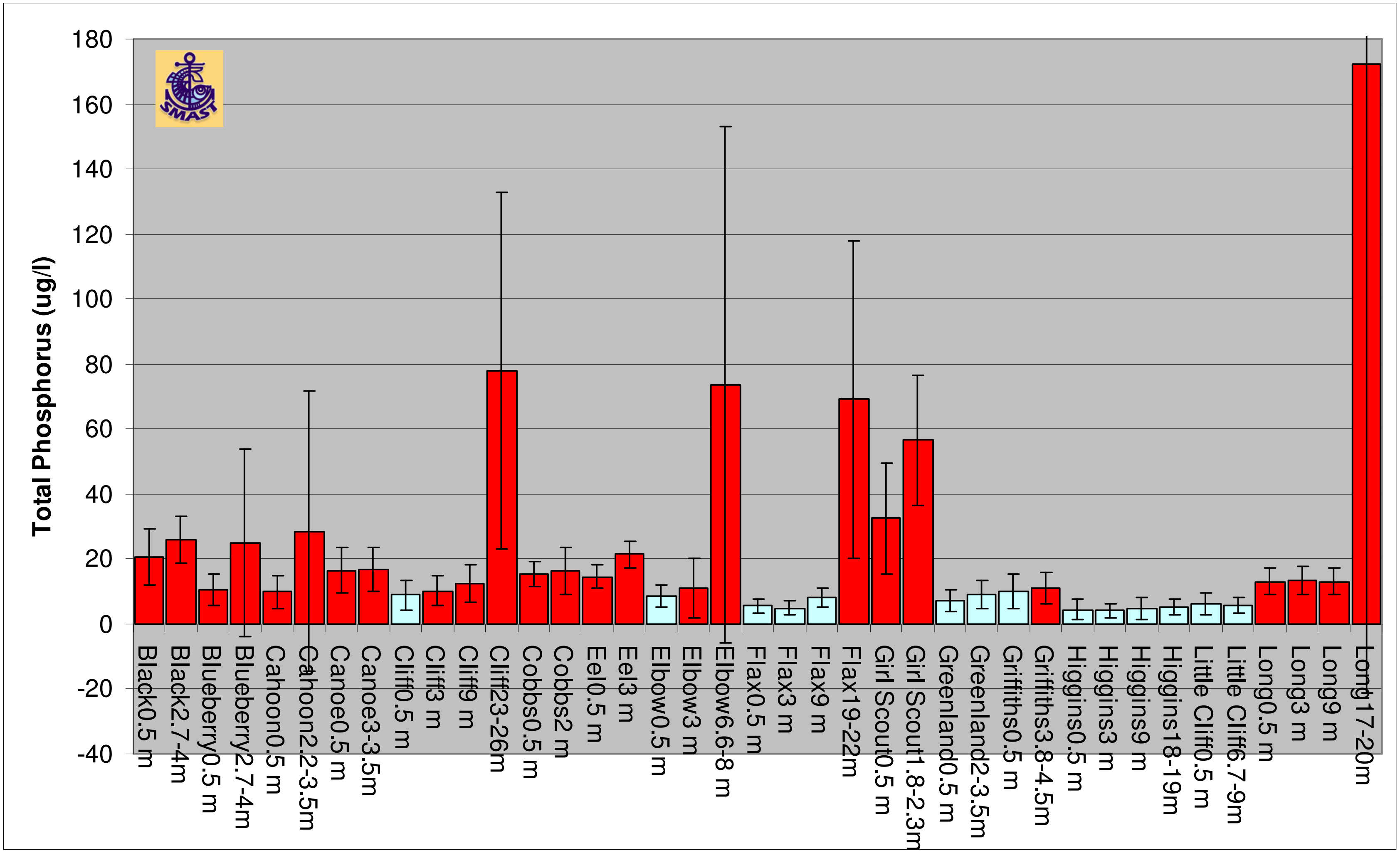


Figure III-4a. Average Total Phosphorus Concentrations in Brewster Ponds 2001-2007 (Black to Long)

Total phosphorus averages are based on pond data collected between June and September. Pond names have the station depths in meters (*e.g.*, "Black0.5" is Black Pond readings collected at 0.5 m). Error bars show one standard deviation; all averages are corrected for outliers (± >two standard deviations). Bars colored red have average concentrations greater than the Cape Cod TP threshold for healthy pond ecosystems (10 µg per liter of TP from Eichner and others, 2003).

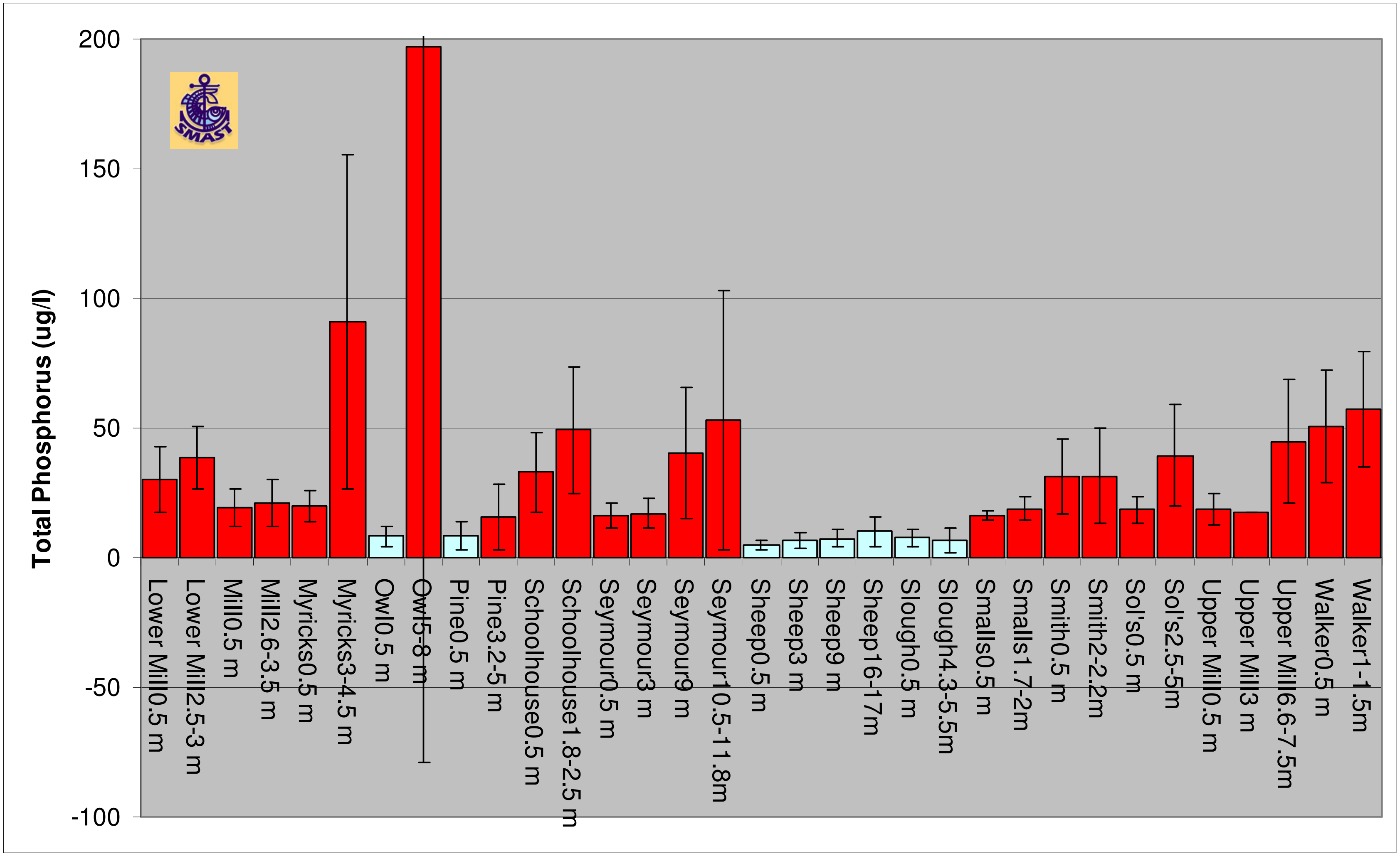


Figure III-4b. Average Total Phosphorus Concentrations in Brewster Ponds 2001-2007 (Lower Mill to Walker)
Total phosphorus averages are based on pond data collected between June and September. Pond names have the station depths in meters (*e.g.*, “Black0.5” is Black Pond readings collected at 0.5 m). Error bars show one standard deviation; all averages are corrected for outliers (± >two standard deviations). Bars colored red have average concentrations greater than the Cape Cod TP threshold for healthy pond ecosystems (10 micrograms (µg) per liter of TP from Eichner and others, 2003).

Because of these chemical and hydrologic characteristics, 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 Cape Cod ponds have concentration limit of 0.16 ppm, while the "healthy" threshold concentration is 0.31 ppm (Eichner and others, 2003).

Average surface concentrations in 20 of the 29 Brewster ponds exceed the 0.31 ppm threshold (Figure III-5). None of the station depths have an average concentration less than the 0.16-ppm TN "unimpacted" threshold. Average TN concentrations across all 72 depth stations range between 0.17 ppm (surface in Higgins) and 1.9 ppm (deep station in Long). The number of surface TN samples range between 2 (Eel) and 18 (Long). Among the deepest ponds, Elbow, Long and Seymour have average surface TN concentrations higher than 0.31 ppm. Flax and Long have deep average concentrations more than five times higher than surface concentrations, which indicate sediment regeneration of phosphorus. On the other extreme, Higgins, Little Cliff, and Sheep have average deep concentrations that are only slightly greater (1.3 to 1.5 times) than surface concentrations. Overall, average concentrations at 49 of the 72 station depths (68%) exceed the "healthy" 0.31-ppm TN limit.

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, so buffering of waters to reach more neutral pH generally occurs within ecosystems. One of the natural ways this occurs is through photosynthesis; when aquatic plants photosynthesize they take carbon dioxide and hydrogen ions out of the water causing pH to increase. This means that ponds with more photosynthesis, usually the ones that are more productive and higher nutrient loads, will tend to have higher pH measurements. Alkalinity is a measure of the compounds that shift pH toward more basic, higher values and is mostly determined by the concentrations of bicarbonate, carbonates, and hydroxides (Stumm and Morgan, 1981). Alkalinity is also a measure of the capacity of waters to buffer acidic inputs. Because pH and alkalinity are influenced by shared constituents, they are linked values.

Since the sandy soils that make up most of Cape Cod do not have extensive 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 ponds least impacted by development 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.

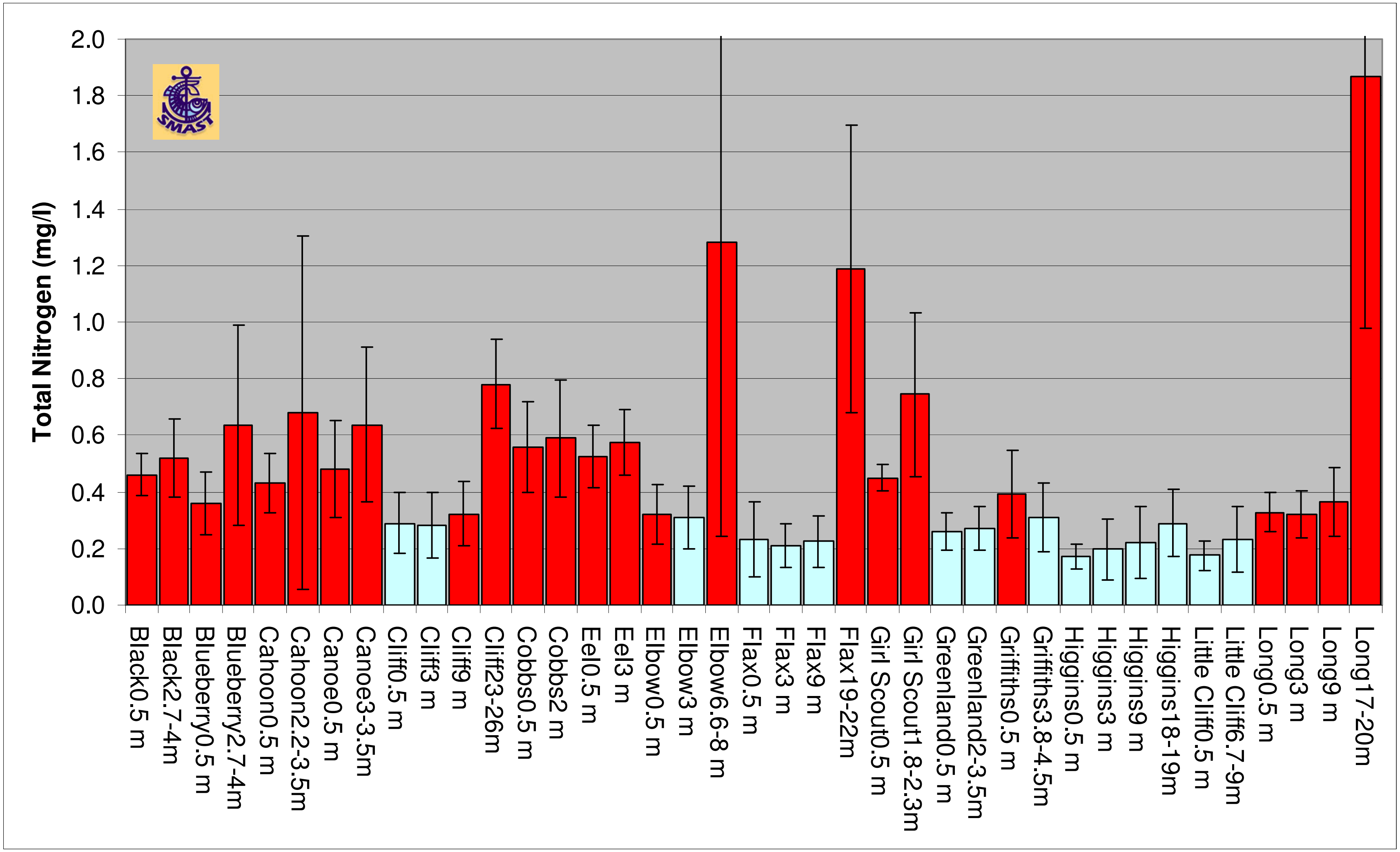


Figure III-5a. Average Total Nitrogen Concentrations in Brewster Ponds 2001-2007 (Black to Long)
Total nitrogen averages are based on pond data between June and September. Pond names have the depths in meters at which readings were collected (*e.g.*, "Black0.5" is Black Pond readings collected at 0.5 m). Error bars show one standard deviation; all averages are corrected for outliers (± >two standard deviations). Bars colored red have average concentrations greater than the Cape Cod TN threshold for healthy pond ecosystems (0.31 milligrams (mg) per liter of TN from Eichner and others, 2003).

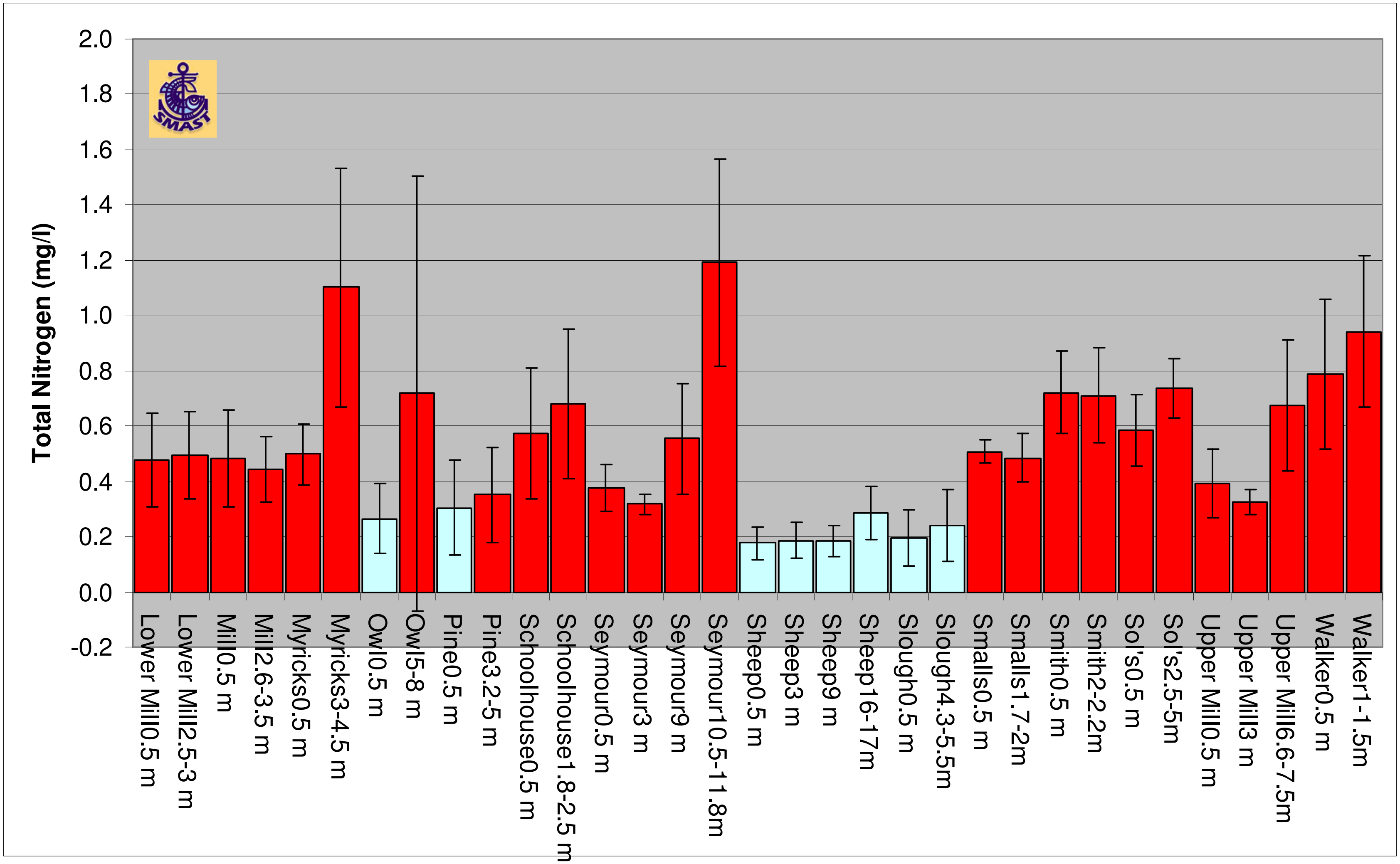


Figure III-5b. Average Total Nitrogen Concentrations in Brewster Ponds 2001-2007 (Lower Mill to Walker)
Total nitrogen averages are based on pond data between June and September. Pond names have the depths in meters at which readings were collected (*e.g.*, "Black0.5" is Black Pond readings collected at 0.5 m). Error bars show one standard deviation; all averages are corrected for outliers (± >two standard deviations). Bars colored red have average concentrations greater than the Cape Cod TN threshold for healthy pond ecosystems (0.31 milligrams (mg) per liter of TN from Eichner and others, 2003).

Average surface pH readings in 23 of the 29 Brewster ponds exceed 5.62. 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 (Girl Scout, both stations) to 7 (numerous stations). Average pH readings among all 71 Brewster pond depth stations range between 5.16 (shallow station in Pine) and 6.79 (the shallow station in Canoe) (Figure III-6). Overall 57 of the 71 stations (80%) have pH averages exceeding 5.62.

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

Chlorophyll is a family of the 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 many planktonic algae, or floating microscopic plants, are present in collected pond 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 growth by 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. Cape 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 were sampled and had surface CHL-a concentrations determined. The average concentration of these samples is 8.44 ppb with a range from 0.01 to 102.9 ppb. Using the US Environmental Protection Agency (2000) method for determining nutrient threshold criteria and the PALS 2001 sampling results, Eichner and others (2003) determined that unimpacted Cape Cod ponds have a CHL-a threshold concentration of 1.0 ppb and "healthy" Cape Cod ponds would have a threshold concentration of 1.7 ppb.

Average surface concentrations in all but three Brewster ponds (Flax, Higgins, and Sheep) exceed the "healthy" threshold concentration of 1.7 ppb. None of the surface stations are less than the 1.0 ppb unimpacted threshold. Among the 71 Brewster pond depth stations, with chlorophyll-a concentrations, including both surface and deep stations, average concentrations range between 0.6 ppb (deep station in Higgins) and 103.1 ppb (deep station in Myricks) (Figure III-7). The number of surface CHL-a samples among all the ponds range from one (Girl Scout) to 11 (Higgins). Overall 59 of 71 depth stations (83%) have average CHL-a concentrations greater than the Cape Cod-specific 1.7 µg/l "healthy" threshold concentration.

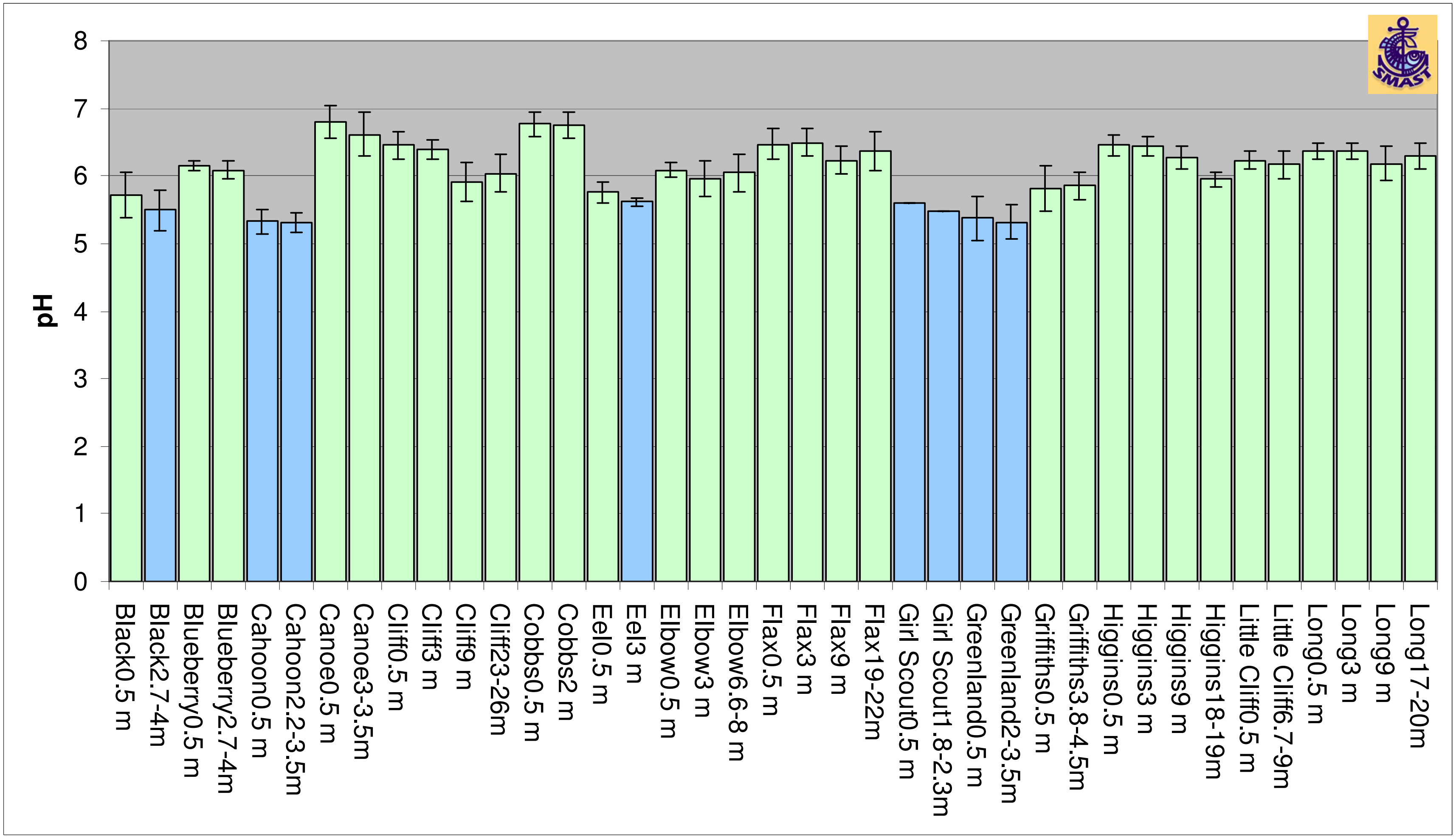


Figure III-6a. Average pH in Brewster Ponds 2001-2007 (Black to Long)

Average pH readings based on pond data between June and September. Pond names have the depths in meters at which readings were collected (e.g., "Black0.5" is Black Pond readings collected at 0.5 m). Error bars show one standard deviation; all averages are corrected for outliers (± >two standard deviations). Bars colored green have average readings above 5.62, which is the estimated "healthy" pH for Cape Cod ponds (Eichner and others, 2003) and approximates the natural pH of rainwater.

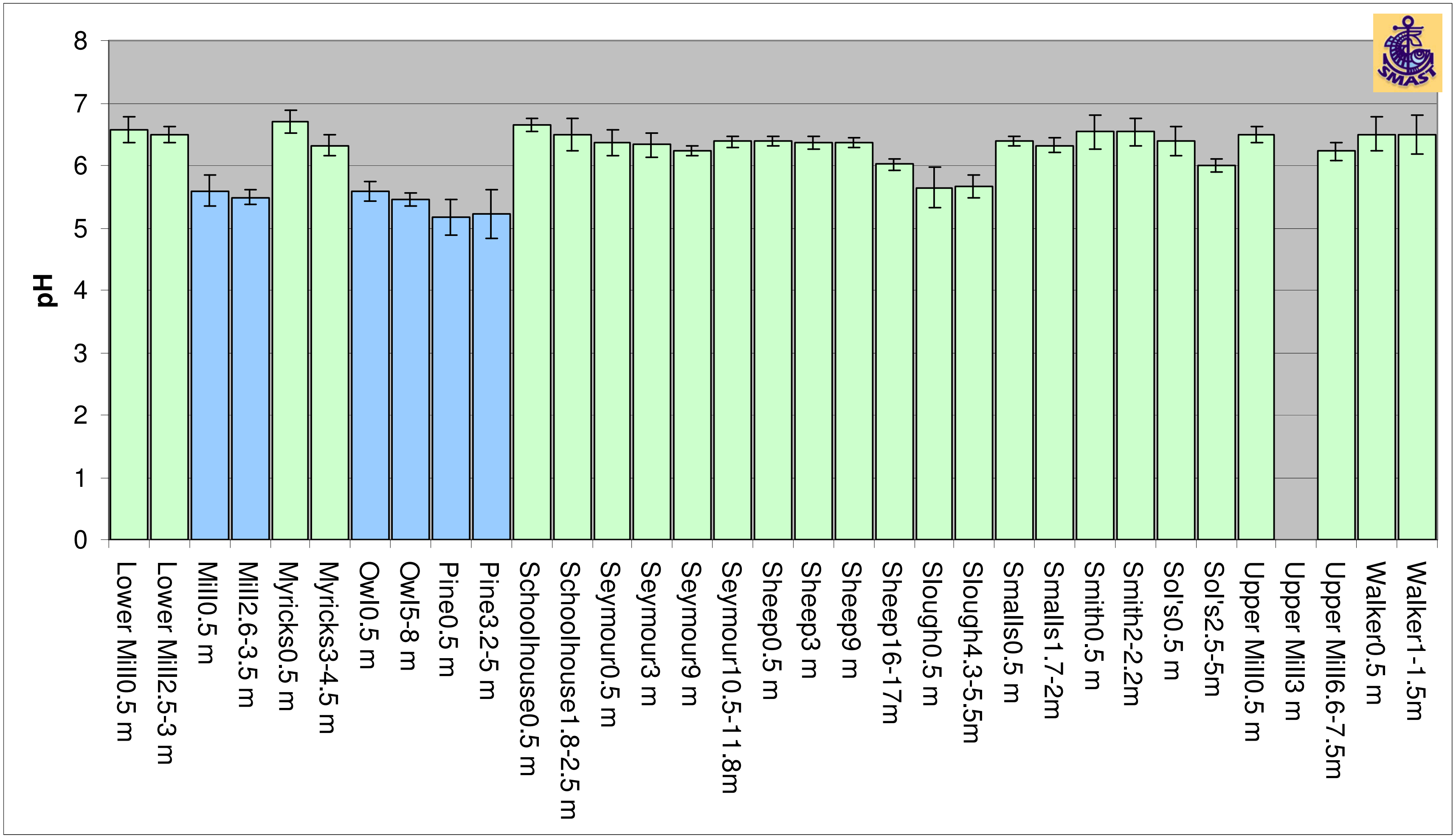


Figure III-6b. Average pH in Brewster Ponds 2001-2007 (Lower Mill to Walker)

Average pH readings based on pond data between June and September. Pond names have the depths in meters at which readings were collected (e.g., "Black0.5" is Black Pond readings collected at 0.5 m). Error bars show one standard deviation; all averages are corrected for outliers (± >two standard deviations). Bars colored green have average readings above 5.62, which is the estimated "healthy" pH for Cape Cod ponds (Eichner and others, 2003) and approximates the natural pH of rainwater.

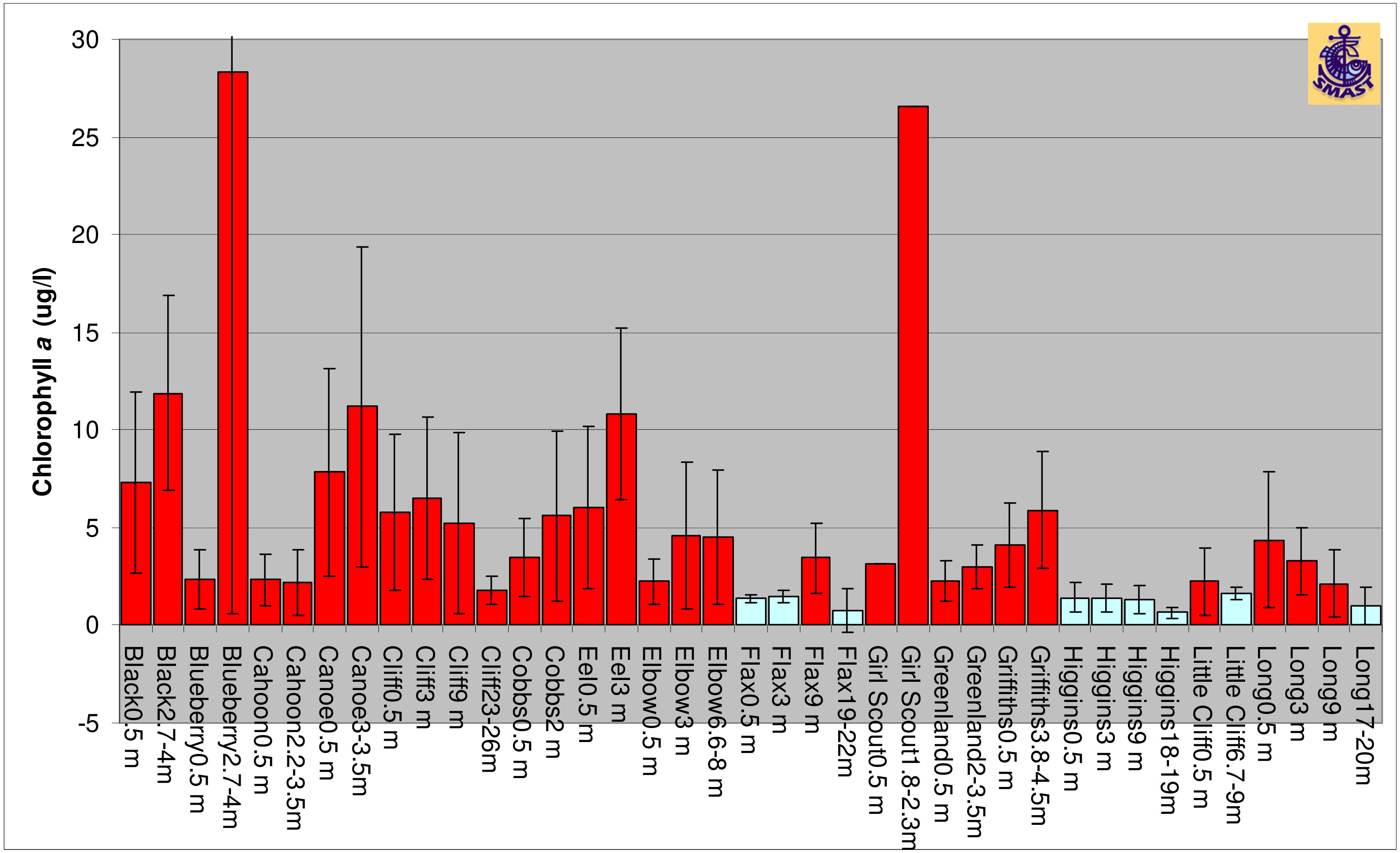


Figure III-7a. Average Chlorophyll-a Concentrations in Brewster Ponds 2001-2007 (Black to Long)

Chlorophyll *a* averages are based on pond data between June and September. Pond names have the depths in meters at which readings were collected (*e.g.*, “Black0.5” is Black 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). Error bars show one standard deviation; all averages are corrected for outliers (± >two standard deviations). Bars colored red have average concentrations greater than the Cape Cod chlorophyll-a threshold for healthy pond ecosystems (1.7 micrograms (µg) per liter of chlorophyll *a* from Eichner and others, 2003). Scale on the y-axis is adjusted to better show detail.

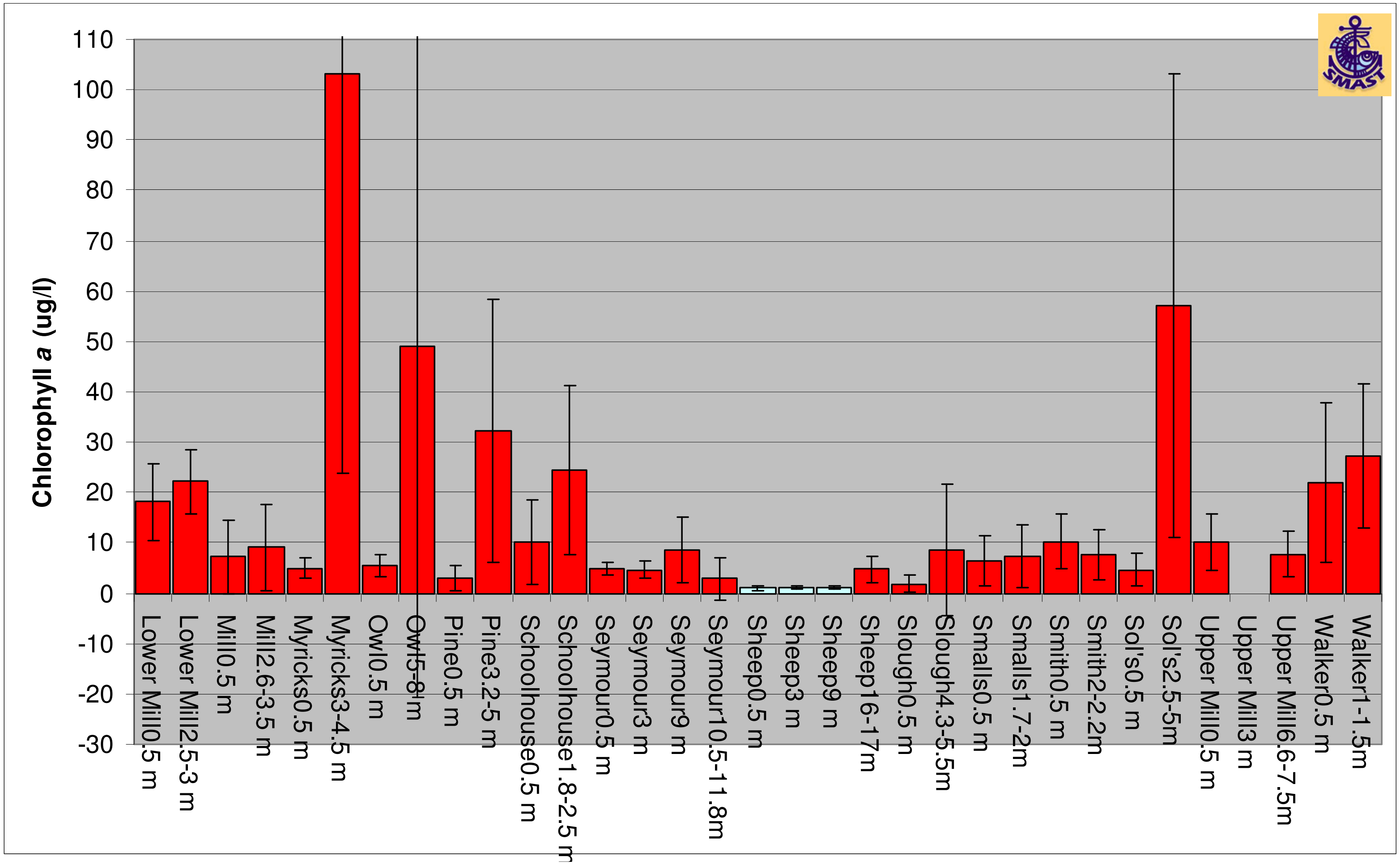


Figure III-7b. Average Chlorophyll-*a* Concentrations in Brewster Ponds 2001-2007 (Lower Mill to Walker)

Chlorophyll *a* averages are based on pond data between June and September. Pond names have the depths in meters at which readings were collected (*e.g.*, "Black0.5" is Black 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). Error bars show one standard deviation; all averages are corrected for outliers (± >two standard deviations). Bars colored red have average concentrations greater than the Cape Cod chlorophyll-a threshold for healthy pond ecosystems (1.7 micrograms (µg) per liter of chlorophyll *a* from Eichner and others, 2003). 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 and a trophic index is a way to organize and rank those biomass amounts. 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 was developed by Carlson (1977) based largely on data from Wisconsin and Minnesota lakes. 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 evaluations of Carlson's Index have 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. More in-depth pond by pond analysis of individualized measures (*e.g.*, total phosphorus, dissolved oxygen, macrophyte cover, etc.) and their various interactions 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. That said, available pond monitoring data on Cape Cod suggests that Cape pond ecosystems are naturally low in biomass and that higher trophic levels are generally associated with impacted or "unhealthy" pond ecosystems.

Figure IV-1 shows the trophic categories based on the average surface chlorophyll *a* concentrations in the Brewster ponds, as well as error bars showing one standard deviation (*i.e.*, 68% of all possible readings should be between the error bars). The length of the error bars show the variability in the data and how much conditions fluctuate within individual ponds. For example, Cliff Pond on average is classified under this index as a mesotrophic pond, but chlorophyll *a* concentrations fluctuate enough to place it on occasion in the oligotrophic or eutrophic categories.

Data from the 2001 PALS Snapshot indicated that a "healthy" freshwater pond on Cape Cod would have a threshold concentration of 1.7 ppb 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 based on a chlorophyll *a* concentration of 1 ppb (Eichner and others, 2003). The TSI for 1.7 ppb is shown on Figure IV-1. Both of these chlorophyll TSIs are classified as oligotrophic on the Carlson index (see Table IV-1 for generalized conditions). Based on the average TSIs from sampling between 2001 and 2007, 9 of the 29 Brewster ponds are oligotrophic. The majority 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, a preliminary overview of town-wide data was publicly presented to sampling volunteers and Brewster town staff. 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 state regulatory thresholds for the parameters discussed above and a weighting scheme based on whether the average concentrations exceed the nutrient criteria thresholds developed for Cape Cod ponds in

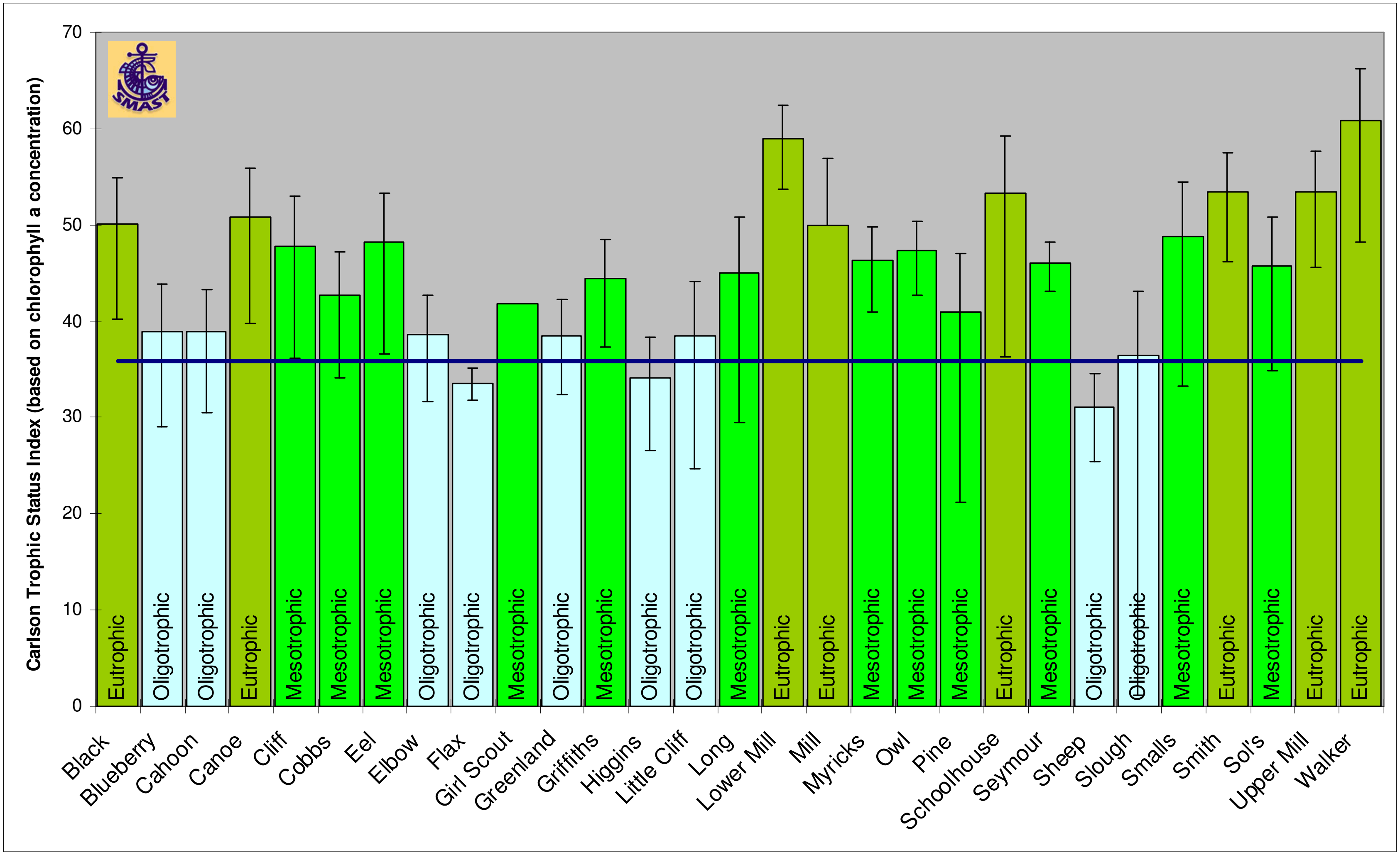


Figure IV-1. Trophic Status Index (TSI) in Brewster Ponds 2001-2007

TSI values are based on average surface chlorophyll *a* concentrations from data collected between June and September and corrected for outliers (± >2 std dev); error bars show TSI based on one standard deviation. Classification at base of each bar is based on TSI ranges in Carlson and Simpson (1996) for chlorophyll *a*; these classifications are described Table IV-1. Blue line shows the TSI value based on the "healthy" chlorophyll *a* threshold for Cape Cod ponds of 1.7 micrograms per liter (Eichner and others, 2003).

the Pond and Lake Atlas (Eichner and others, 2003). Exceedances of the "healthy" concentrations (*e.g.*, an average TP concentration greater than 10 ppb) were assigned a higher weight than exceedance of the "pristine" concentration (*e.g.*, average TP concentration greater than 7.5 ppb). The criteria were reviewed for each sampling station depth and resulting values were summed. Because deeper ponds have more depth stations, this ranking strategy assigns higher potential scores to deeper ponds than shallow ponds.

Because so many of the ponds exceed the "healthy" Cape Cod nutrient concentrations, this prioritization exercise resulted in most of the ponds being grouped in a relatively small range. The results of this analysis reinforced the conclusion that almost all of the ponds are impacted and that a prioritization strategy for the town to address pond water quality remediation will have to include other factors.

Following further discussions with town staff, five ponds were initially selected for more detailed evaluation: Blueberry, Upper Mill, Lower Mill, Seymour, and Walkers. Canoe Pond was later added to the evaluation list at the town's request. Detailed evaluations were limited to the following activities: watershed delineation and development of water and phosphorus budgets. Project staff also agreed to prepare recommendations for future monitoring and pond management activities.

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 Blueberry, Canoe, Upper Mill, Lower Mill, Seymour, and Walkers ponds

The six Brewster ponds selected for more detailed review are located in glacial outwash plain deposits referred to as the Harwich Plain Deposits (Oldale and Barlow, 1986). This 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 groundwater system on Cape Cod is composed of six independent groundwater flow cells. The Brewster ponds are located in the Monomoy Lens, which is the second largest of the flow cells and extends from the Bass River to Pleasant Bay. 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 aquifer system is bounded by the water table at its surface, the surrounding marine waters at it margins, and bedrock below (LeBlanc, *et. al.* 1986). The aquifer in the area of the six ponds selected for detailed review varies between 300 and 500 feet thick and the average groundwater flow rate is approximately one foot per day (Walter and Whealan, 2005).

Upper Mill Pond is the largest (257.4 acres) of the six ponds selected for detailed review (Table V-1). It is situated to the east of Setucket Road in a grouping of ponds that includes Canoe, Lower Mill, Walkers, Pine and Slough. Seymour is the deepest of the six ponds at 11 m, while Upper Mill is the next deepest at 8.5 m. Seymour is the second largest of the ponds (181.9 acres), followed by Walkers at 103.2 acres, Lower Mill at 50.4 acres, Blueberry at 21.3 acres, and Canoe at 13.6 acres. Since all of these ponds are greater than 10 acres, they are defined as waters of the Commonwealth and publicly-owned "Great Ponds."

Bathymetric data for the six Brewster ponds was generally collected from the Massachusetts Division of Fish and Wildlife on-line bathymetric maps (www.mass.gov/dfwele/dfw/habitat/maps/ponds/pond_maps_sd.htm), except for Canoe Pond. Canoe Pond bathymetry was determined by CCC GIS staff using depth data collected by Jon

Budreski in 2004. Pond volumes were determined from the bathymetric maps using GIS techniques and are shown in Table V-1. All available bathymetric maps included in Appendix A.

Table V-1. Physical Characteristics of Blueberry, Canoe, Upper Mill, Lower Mill, Seymour, and Walkers ponds

Pond	PALS ID	PALIS #	Area	Volume	Residence Time	Deepest Point
			Acres	Cubic meters	Years	Feet
Blueberry	BR-180	96022	21.3	893,884	1.84	27
Canoe	BR-269	96031	13.6	131,679	1.31	16
Lower Mill	BR-245	96188	50.4	1,249,705	0.21	13
Seymour	HA-306	96284	181.9	2,736,733	2.87	42
Upper Mill	BR-272	96324	257.4	16,505,696	3.16	30
Walkers	BR-313	96331	103.2	1,628,721	0.93	9

Notes:
1) Volume for all ponds developed by Cape Cod Commission staff based on a bathymetric maps prepared by the Massachusetts Division of Fish and Wildlife except for Canoe. DFW maps are available at: http://www.mass.gov/dfwele/dfw/habitat/maps/ponds/pond_maps_sd.htm). Canoe Pond bathymetry was determined by Jon Budreski in 2003.
2) PALS ID is a unique identification assigned to each pond by the Cape Cod Commission during the preparation of the Cape Cod Pond and Lake Atlas (Eichner and others, 2003), which is also the source of all area values.
3) PALIS #'s are state assigned pond identifiers (source: MAWRRC, 1985); this numbering system is not comprehensive for all ponds on the Cape.
4) Residence times are based on recharge within pond watersheds; original watershed delineations completed by the US Geological Survey using the 2005 version of their Monomoy Lens groundwater model (Walter and Whealan, 2005) and refined by SMAST staff to reflect actual pond geometry, streamflows, and surface water connections.

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). Blueberry and Seymour Ponds function in this way. In some cases, kettle ponds have small streams entering or leaving them; Lower Mill Pond is the headwater of Stony Brook and is lower pond in a series of connected ponds along with Walkers and Upper Mill.

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 and will fluctuate in response to extended periods of recharge/precipitation or drought (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 Brewster, the highest groundwater elevations are at the top of the Monomoy Lens near Long Pond, where the water table elevation is approximately 32 feet above mean sea level. Groundwater flows from the higher elevation toward Cape Cod Bay, passing through lower elevation ponds along the way. Approximate average elevations of the six ponds selected for detailed review, based on USGS quadrangles, are: Blueberry, 25 ft above mean sea level (msl); Canoe, 27 ft above msl; Upper Mill, 26 ft above msl; Lower Mill, 25 ft above msl;

Seymour, 29 ft above msl and Walkers, 26 ft above msl. It should be noted that there is little elevation change in the complex of ponds between Walkers and Lower Mill.

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 or watersheds to the ponds or estuaries (*e.g.*, Cambareri and Eichner, 1998). Assuming uniformly distributed recharge from precipitation across these watersheds, watershed areas are generally directly proportional to the flux of groundwater water entering and leaving 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 the Bass River to Orleans and encompasses the entire Monomoy Lens, where the Brewster ponds are located (Walter and Whealan, 2005). This model incorporates information characterizing groundwater levels, municipal drinking water supply pumping, available stream flow measurements, and hydrogeologic information developed over a number of decades. The model relies on the USGS three-dimensional, finite-difference groundwater model MODFLOW-2000 (Harbaugh, *et al*., 2000) and the USGS particle-tracking program MODPATH4 (Pollock, 1994). MODPATH4 uses output files from MODFLOW-2000 to track the simulated movement of water in the aquifer and was used to delineate the area at the water table that contributes water to wells, streams, ponds, and coastal water bodies. Average pumping rates (1995 to 2000) for the public water wells in the five towns over the Monomoy Lens are used as part of the dataset for the development of the model. The model simulates steady state, or long-term average, hydrologic conditions including a long-term average recharge rate of 27.25 inches/year and the pumping of public-supply wells at average annual withdrawal rates for the period 1995-2000 with a 15% consumptive loss. The recharge rate is based on the most recent USGS information and was modified for ponds, wetlands, and areas with land use development. The loss factor is applied geographically within the model and, in Brewster, is determined by using the distribution of residential buildings.

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. Since the model necessarily simplifies pond shorelines, model outputs were then refined by SMAST staff to produce pond watersheds that better reflect shoreline configuration and any available streamflow information (Figure V-1).

As indicated in Figure V-1, many of the selected ponds have hydrologic connections with each other, either through sharing watersheds or direct surface water connections. Given the density of ponds on Cape Cod, this type of connection is relatively common, but adds complexity to the review of individual ponds because information must then also be developed for the other, connected, ponds. Ponds closer to the edge of the aquifer (*e.g.*, Cape Cod Bay) are the most likely to receive flow from an upgradient pond. A portion of the outflow from an

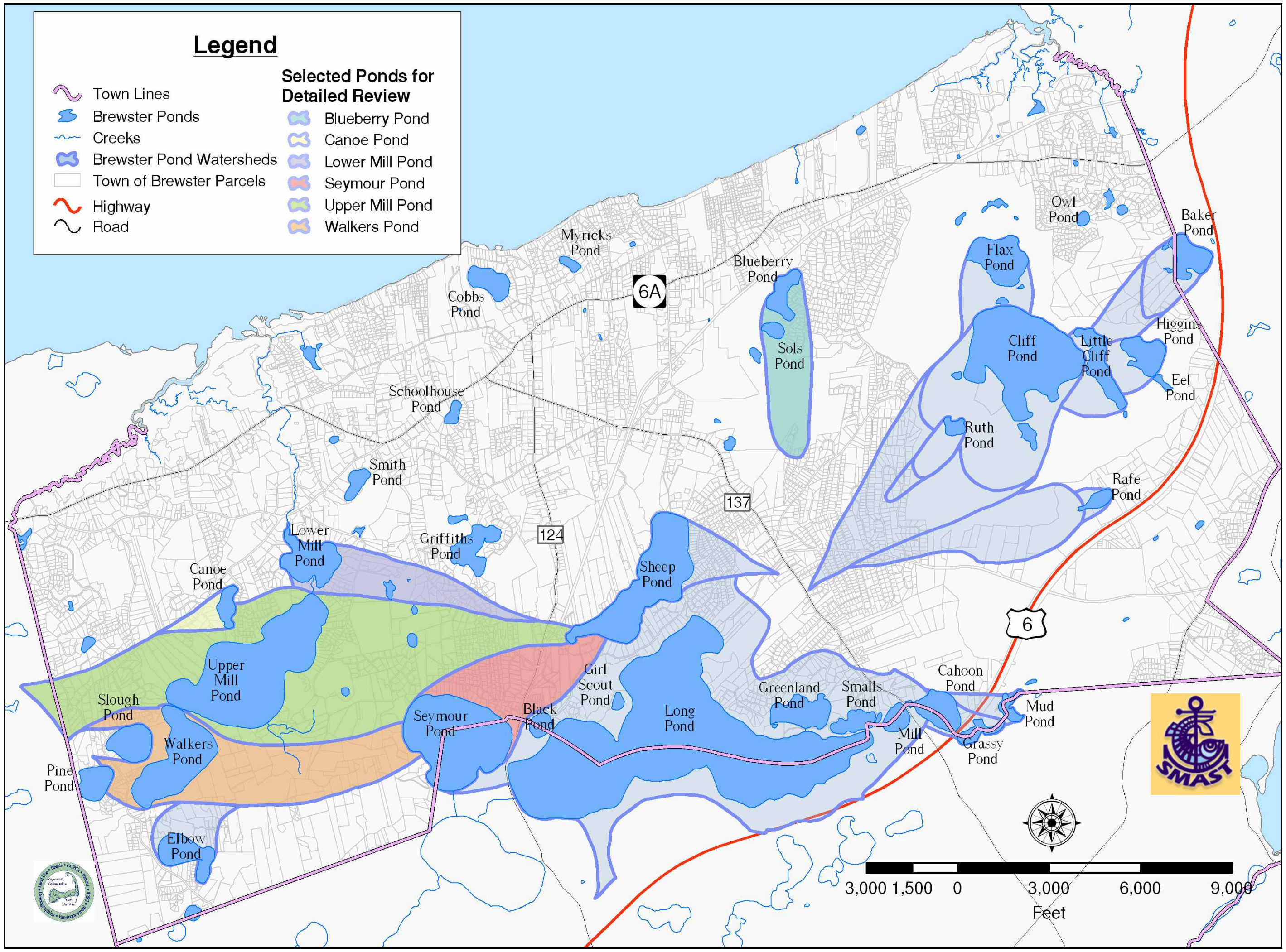


Figure V-1. Brewster Pond Watersheds

Watershed delineations were prepared by SMAST staff based on output from the US Geological Survey regional groundwater model (Walter and Whealan, 2005). Model outputs were corrected to reflect actual pond geometry and available streamflow information. Watersheds to the ponds selected for more detailed review are indicated. Watersheds in eastern Brewster are from the Pleasant Bay Massachusetts Estuaries Project Technical Report (Howes and others, 2006).

upgradient pond (*e.g.*, Seymour) can discharge into the watershed of a downgradient pond (*e.g.*, Upper Mill), 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.

Once the watershed delineations were completed, recharge from precipitation within these areas was compared to available streamflow information and the collected water quality data. With the volume of the pond and the volume of recharge from its watershed, one can determine the residence time of water in the pond. This information can then be compared to observed nutrient concentrations as a check on its reliability.

These 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 any of the ponds. This means that groundwater from the bottom of the lens, approximately 300 feet below the water table, would eventually rise and 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 these elevations, by addition of large-volume water supply well or wastewater discharge, for example, would have the potential to alter watershed delineations. These alterations could be evaluated using the groundwater model. Additional water table monitoring wells in an area of concern or better streamflow information would also add additional site-specific data that could be used to refine the watershed delineations presented in this report.

A pond water budget summarizes all the water inputs and outputs. In groundwater-fed ponds, such as those in Brewster, inflow from groundwater to the pond and outflow from the pond to groundwater tend to be the predominant factors in the budget. Although pond volumes may fluctuate on longer time scales (*e.g.*, years), the volume of ponds are relatively stable, so inputs and outputs should balance. Shorter term events, such as high volume rainstorms, can change the volume, but these changes are quickly assimilated by the aquifer and have little impact on an annual water budget (*e.g.*, Eichner and others, 1998). The water budget for Cape Cod ponds can generally be represented as:

$$\text{Groundwater}_{in} + \text{Precipitation} = \text{Groundwater}_{out} + \text{evaporation}$$

In the Brewster Ponds, each of the ponds presents slightly different budgets largely based on where they sit in the aquifer system and their relationship to surrounding ponds. For example, Walkers has two ponds (Slough and Pine) within its watershed, so the recharge within these pond watersheds must be accounted for when developing the budget to Walkers. Lower Mill, on the hand, is located at the terminal end of the pond complex that includes Walkers, Upper Mill, and Canoe, so flow from all the upgradient ponds must be accounted for when developing the water budget for Lower Mill.

Lower Mill also has a significant stream outflow that alters the general water budget equation presented above. Because streams can allow water to leave a pond with less resistance than discharging back to the surrounding groundwater, a stream can be a significant factor on the output side of a pond water budget (*e.g.*, Eichner, 2008). Of course, the individual characteristics of the pond and the stream will determine how much of an impact it will have on the budget.

Table V-2 presents the water budget for the six Brewster ponds selected for detailed reviews. The input portion of the water budget is composed of groundwater inflows, precipitation on the surface of the ponds, and road runoff from properties on the downgradient side of the pond. The runoff portion is included because previous analyses of Cape Cod stormwater collection systems have found that ponds, as the lowest elevation point, tend to be discharge areas for road runoff even from downgradient sources (*e.g*., Eichner, 2007). The groundwater inflows are based on the watershed areas shown in Figure V-1 and the groundwater recharge rate used by the Walter and Whealan (2005). Volumes for road runoff and net flows off the surface of the ponds are also based on values developed for the regional groundwater model. Outflow is based on streamflow out of the pond, evaporation off its surface, and groundwater outflow; groundwater outflow is based on the remaining difference after accounting for evaporation and stream outflow.

The stream outflow volumes in Table V-2 are largely unconfirmed. The USGS collected spot flow readings at the stream outflows of Upper Mill [1 cubic feet per second (cfs)] and Lower Mill (5 cfs) and these were generally used as calibration readings during the development of the Monomoy Lens groundwater model. Woods Hole Group determined an average flow of 4.12 cfs based on 13 readings collected at Stony Brook Mill for a one month period starting in December 2007 (WHG, 2008). There is also a potential stream connection between Canoe and Upper Mill, as well as between Walkers and Upper Mill.

Establishing long term flow records at the well established streams would be important for water quality management of the both the Mill Ponds, as well as Stony Brook. Stream gauges could be placed at the Stony Brook Mill, between Upper Mill and Lower Mill, and between Walkers and Upper Mill. Evaluation of flow should include monitoring of precipitation and groundwater levels in the area. Groundwater level information could be obtained from regular water level monitoring already conducted by the Cape Cod Commission. Establishing this information over at least one hydrologic year would help to establish how important these flows are for the transfer of nutrients between the ponds and, consequently, refine their nutrient management strategies.

Table V-2. Water budgets for Brewster 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 runoff. Road runoff of the "IN" budget is estimated based road areas within 300 ft of each pond on their downgradient side. Outflow is based on streamflow out of the pond, evaporation off its surface, and groundwater outflow; outflow is generally based on best professional judgment of groundwater interactions because streamflow data has not been collected. Precipitation and recharge rates are the same as used in Walter and Whealan (2005); groundwater outflow is based on the remaining difference after accounting for evaporation and stream outflow. Streamflow information is based on the watershed delineations and generally confirmed by limited data collection for Upper Mill (Walter and Whealan, 2005) and Lower Mill (Walter and Whealan, 2005; WHG, 2008). 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				Volume
			Groundwater	Pond Surface Precipitation	Downgradient Road Precipitation	TOTAL	Groundwater	Evaporation	Stream	TOTAL	
		ac	m3/y	m3/y	m3/y	m3/y	m3/y	m3/y	m3/y	m3/y	m3
Blueberry	BR-180	22	450,910	100,651	1,270	552,832	488,370	64,462		552,832	893,884
Canoe	BR-269	14	78,329	62,591	4,743	145,663	100,834	40,086		140,920	131,679
Seymour	HA-306	183	655,343	830,092	200	1,485,635	953,803	531,632		1,485,435	2,736,733
Walkers	BR-313	102	1,415,736	466,829	-	1,882,565	1,583,585	298,980		1,882,565	1,628,721
Upper Mill	BR-272	260	4,192,067	1,191,472	-	5,383,539	3,726,869	763,077	893,593	5,383,539	16,505,696
Lower Mill	BR-245	49	5,061,476	225,100	976	5,287,552	227,651	144,165	4,914,759	5,286,576	1,249,705

Pond	PALS #	Pond Area	IN			OUT		
			Groundwater	Pond Surface Precipitation	Downgradient Road Precipitation	GW	Evaporation	Stream
		m2	m3/y	m3/y	m3/y	m3/y	m3/y	m3/y
Blueberry	BR-180	89,048	82%	18%	0%	88%	12%	-
Canoe	BR-269	55,375	54%	43%	3%	72%	28%	-
Seymour	HA-306	734,400	44%	56%	0%	64%	36%	-
Walkers	BR-313	413,013	75%	25%	0%	84%	16%	-
Upper Mill	BR-272	1,054,120	78%	22%	0%	69%	14%	17%
Lower Mill	BR-245	199,151	96%	4%	0%	4%	3%	93%

V.3. Phosphorus Budgets

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 follows a relatively simple progression that begins with higher phosphorus concentrations and ends with low oxygen conditions: 1) more nutrients create more plants (usually phytoplankton in Cape Cod ponds), 2) which decrease clarity and create more decaying material falling to the pond bottom, 3) where bacteria consume oxygen while decomposing the dead plants. Low oxygen conditions produce chemical changes in the sediment materials that allow the phosphorus in the sediments that was previously bound in plant tissues to be release or 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 usually 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 ecosystem is limited by phosphorus is to review the balance between phosphorus and nitrogen in the pond water. 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 various portions/sources in the budget.

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, groundwater phosphorus from small sources, like septic systems, 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 and is not attenuated once it is in the groundwater system, flows with the groundwater, which generally moves 1 ft/d (or 111 m/yr). Because of the comparatively 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 Brewster ponds selected for more detailed review, project staff began the development of the watershed portion of the phosphorus budget by asking Brewster 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-2). 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 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 Brewster ponds selected for more detailed review.

Factor	Value	Units	Source
Wastewater P load	1	lb P/septic system	MEDEP, 1989 load
P retardation factor	25 - 37	Groundwater velocity/solute velocity	Robertson, 2008
Road surface P load	2.5 – 3.5	lb P/ac	EPA, 1983; Kellogg and others, 2006
Roof surface P load	3.5	lb P/ac	MEDEP, 1989
Natural Areas P conc.	0.05 – 0.35	kg/ha	Cadmus, 2007; Hendry and Brezonik, 1980
Recharge Rate	27.25	in/yr	Walter and Whealan, 2005
Precipitation Rate	44.8	in/yr	Walter and Whealan, 2005
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	0.02 to 0.3	lb P/ac	Literature review
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

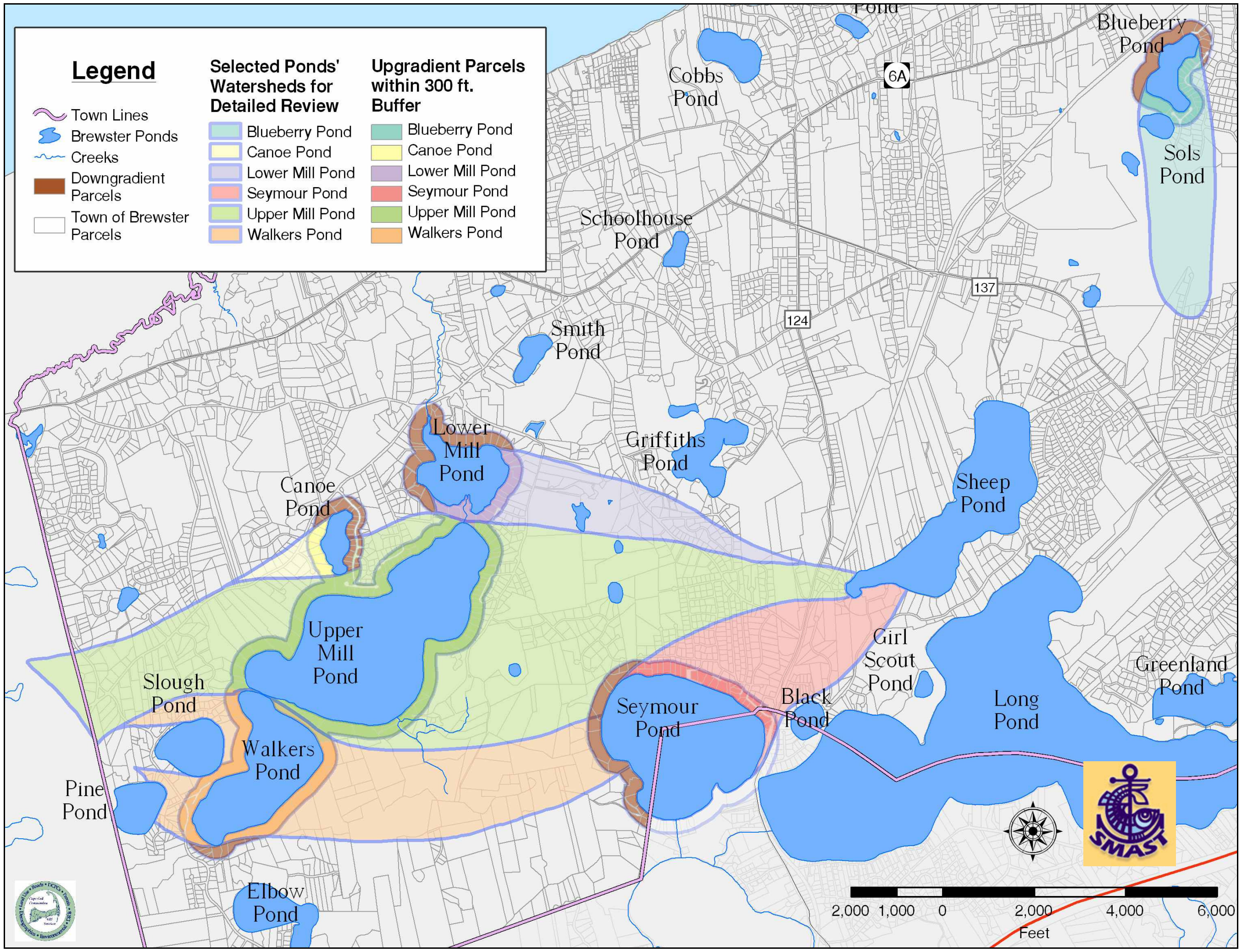


Figure V-2. Parcels reviewed in pond watershed phosphorus loading estimates.
Phosphorus loads are developed for parcels within 300 ft that are also within the pond watersheds; these parcels are colored darker within the watersheds. Watershed parcels outside of the 300 ft buffer are not assigned a phosphorus load except for road areas. Phosphorus loads are based on factors shown in Table V-3. Individual parcel data is based on Town Assessor information and review of Board of Health septic system records.

V.3.1 Wastewater Phosphorus Loading Factor

For wastewater phosphorus, previous Cape Cod pond phosphorus budgets (*e.g.*, Eichner, 2006) 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 (1 lb P/y) for each septic system bordering a pond or lake and located in sandy soils.

Because of phosphorus' chemical characteristics, field studies of phosphorus loads to ponds have typically had varied results that are very dependent on the individual characteristics of the site 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 for Lake Wequaquet. If one uses the average annual occupancy in the Town of Brewster during the 2000 Census (2.45 people per house), the per capita range results in an average septic system load range of 0.3 to 2.2 lbs.

Given that the MEDEP load falls into the range and is consistent with prior Cape Cod pond assessments, project staff proceeded with this factor as the initial wastewater phosphorus load assigned to septic systems. Staff then adjusted this load based on the individual circumstances of each pond by reviewing the distance between the septic system leachfields and the pond shoreline, as well as the age of the septic system and house. Consideration of these factors allows an assessment of whether the phosphorus from an individual house is likely to have reached the pond.

V.3.2. Lawn Fertilizer Phosphorus Loading Factor

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]. A multi-town survey also found that approximately half of Cape Codders do not use lawn fertilizers at all (White, 2003). MEDEP (1989) uses a fertilizer load from residences of 0.3 pounds per acre and this rate has been used in other Cape Cod pond phosphorus budgets (*e.g.*, Eichner, 2007).

Available research shows a wide range of phosphorus loads assigned to residential lawns. For example, Erickson and others (2005) tested phosphorus application rates on mixed turf and monoculture lawns for nearly four years. These studies found that leaching rates stabilized around 35% with average loading rates 33.7 and 20.3 lbs/ac, respectively. Conversely, Sharma and others (1996) evaluated phosphorus concentrations in recharge under urban lawn areas and found concentrations equivalent to loading rates between 0.02 and 0.2 lbs/ac. Rhode Island DEM has developed a phosphorus loading model based on various land uses (Kellogg and others, 2006). This model uses a range of 0 to 4.5 lbs/ac depending on the land use and the soil types and assigns a range of 0.6 to 0.7 lb/ac to the cumulative phosphorus load of low density residential development. Given that residential fertilization practices appear to favor low annual application rates, project staff completed the phosphorus budgets for the Brewster ponds using a range of rates: 0.02 to 0.3 lbs/ac.

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 is 0.9 kg/y per Cape Cod pond. In the development of phosphorus budgets for Brewster's ponds, project staff used both the areal load based on Scherer and others (1995) and the per pond load based on the Cape Cod Bird Club survey results.

V.3.4. Pond Surface Loading Factor

Previous pond phosphorus budgets on Cape Cod have used a 0.14 kilogram per hectare (kg/ha) phosphorus load on the pond surfaces (*e.g.*, Eichner, 2008). This rate is largely based on a 0.14 mg/l TP concentration assigned to precipitation in the diagnostic/feasibility study of Hamblin Pond in Barnstable (BEC, 1993). Subsequent reviews of phosphorus in precipitation have resulted in loads ranging from 0.05 kg/ha (Cadmus, 2007) to 0.35 kg/ha (Hendry and Brezonik, 1980). In Cape Cod ponds where surface precipitation would be expected to be the predominant source of phosphorus (i.e., ponds with little or no development around them), review of their TP concentrations suggest that the lower surface loading rates are more appropriate for Cape Cod ponds. Based on this, the phosphorus budgets for Brewster's ponds used a phosphorus load of between 0.05 and 0.14 kg/ha for phosphorus loading on pond surfaces.

V.3.5. Road Runoff Loading Factor

Previous phosphorus budgets on Cape Cod have used a range of 2.5 to 5.3 pound per acre (lb/ac) phosphorus load on the road surfaces (*e.g.*, Eichner, 2008). These rates are based on the results from the EPA National Runoff Survey (1983) and the MEDEP (1989), respectively. Subsequent assessments have generally lowered this range slightly. For example, Rhode Island Department of Environmental Management's nutrient loading manual (2006) suggests a range of 1 to 3.5 lb/ac for roads based on their literature review and low and high density residential development, respectively. Most other approaches, including TMDL assessments, group runoff loads into generalized land use categories (e.g., Cadmus, 2007). In order to try to constrain the impact of road runoff on the total loads, project staff decided to use a range of 2.5 to 3.5 lb/ac TP for road runoff. It is clear that this factor is largely dependent on site-specific characteristics of the amount of pavement, how the runoff is treated, and whether it discharges directly or indirectly into the pond. It is recommended that the individual stormwater systems surrounding all Brewster ponds be characterized and, if the pond is impaired, be sampled to ascertain the actual phosphorus contribution from road runoff.

VI. Individual Pond Reviews

VI.1. Seymour Pond

Seymour Pond is a 183-acre pond that is located to the west of Long Pond and is split by the town boundary between Brewster and Harwich (see Figure V-1). It is the deepest of the ponds selected from detailed review; its average deep point is 11 m (~36 ft).

Temperature data collected between 2001 and 2007 shows that the Seymour regularly stratifies during the summer; upper waters warm quicker than deeper waters eventually leading to separate temperature layers with cold waters below 7 m (Figure VI-1). This cold water volume is approximately 4% of the total volume of the pond. These deep waters meet state surface water regulations (314 CMR 4) temperature requirements for cold-water fisheries (20ºC or less), but do not meet the accompanying dissolved oxygen requirements (average concentrations all less than 6 ppm) (Figure VI-2).

It is project staff opinion that the lack of acceptable dissolved oxygen throughout the available cold water fishery means that Seymour Pond should be classified as an impaired water for the purposes of compliance with the state surface water regulations. Under the state and federal Clean Water Acts, impaired waters are required to have a total maximum daily load (TMDL) for the contaminant that is causing the impairment. Since the Massachusetts Department of Environmental Protection implements the state surface water regulations, this opinion would need to be submitted to MassDEP in order to get a definitive ruling.

Other water quality data generally confirm that Seymour is impaired. Average total phosphorus and chlorophyll *a* concentrations at all depth stations, throughout the water column, are above their respective Cape Cod pond water quality thresholds (Eichner and others, 2003). Average dissolved oxygen in the two deepest stations are anoxic (<1 ppm) and, therefore, lethal to fish. Average deep total phosphorus concentrations are more than three times greater than surface concentrations, which indicates that, on average during the summer, the sediments are regenerating phosphorus and creating the potential for additional phytoplankton growth in the water column.

Review of Secchi readings seem to indicate that these impaired conditions are worsening. Secchi clarity readings have increased slightly over the seven years, but so have the station depth readings (Figure VI-3). The increase in station depth mirrors increased groundwater levels over this same period (Cape Cod Commission water level records). Because the Secchi readings have a much smaller increase, it suggests that clarity is worsening in Seymour. Because clarity in Cape Cod ponds is generally determined by phytoplankton populations, which respond to phosphorus loads, these findings suggest that phosphorus loads are increasing. Average relative Secchi readings are very low (29%); the best in Brewster is Little Cliff Pond at 79% (see Figure III-2).

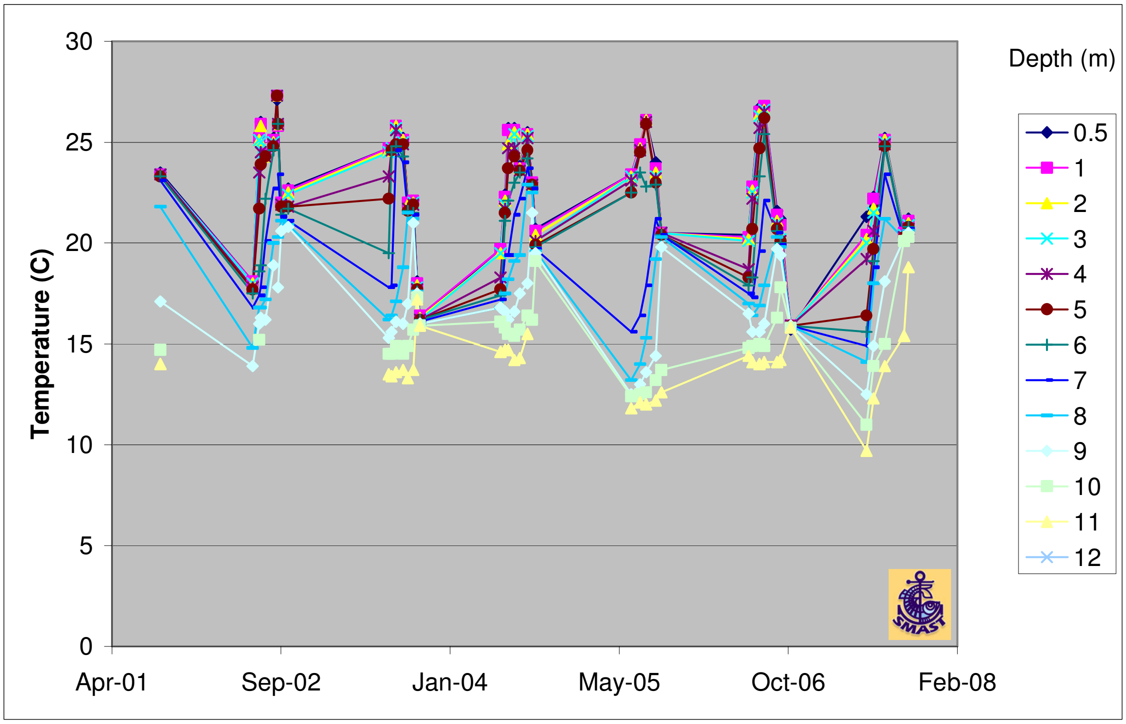
Comparison to a single August 1948 Secchi reading also tends to confirm worsening conditions over a longer time period. A 3.9 m deep Secchi reading was measured on August 17, 1948 by Massachusetts Division of Fisheries and Game staff (MADFG, 1948). This reading is half a meter deeper than any of the August Secchi readings measured between 2001 and 2007 and is 1.2 m deeper than the average August reading from this same data (n=8). This is consistent with comparison of current water quality conditions to monitoring data from other Cape ponds generally shows worsening conditions in ponds across Cape Cod (Eichner and others, 2003).

Review of nitrogen to phosphorus ratios in Seymour show that the pond is phosphorus limited, which means that control of phosphorus is the key nutrient for determining water quality in the pond and, therefore, is the nutrient/contaminant that should be targeted for a TMDL. Average surface N to P ratio during June through September is 48; generally water concentrations ratios above the Redfield ratio of 16 are phosphorus limited (Redfield and others, 1963). Nutrient regeneration from the Seymour's sediments makes these waters even more phosphorus limited; average N to P ratio in deep waters is 98.

Since phosphorus is the key for determining water quality in Seymour Pond, one of the next steps is to determine the sources and magnitude of phosphorus. Once this is completed, community discussions and cost estimates can help to determine what combination of phosphorus management strategies will be adopted to remediate Seymour Pond. Understanding the sources and magnitude of phosphorus is usually done through the development of a phosphorus budget.

As mentioned above, the phosphorus budget will account for all the various sources entering the pond water. Most of the sources will be from the watershed, but the pond sediments can also be an internal source. None of these sources have been measured directly, but information developed on ponds and lakes in similar settings can be used to develop a reasonable estimate. More detailed Seymour Pond-specific measurements would be necessary to refine the results presented here and are recommended for key factors such as road runoff, bird loading, and sediment regeneration.

In order to begin to develop a watershed phosphorus budget for Seymour 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.



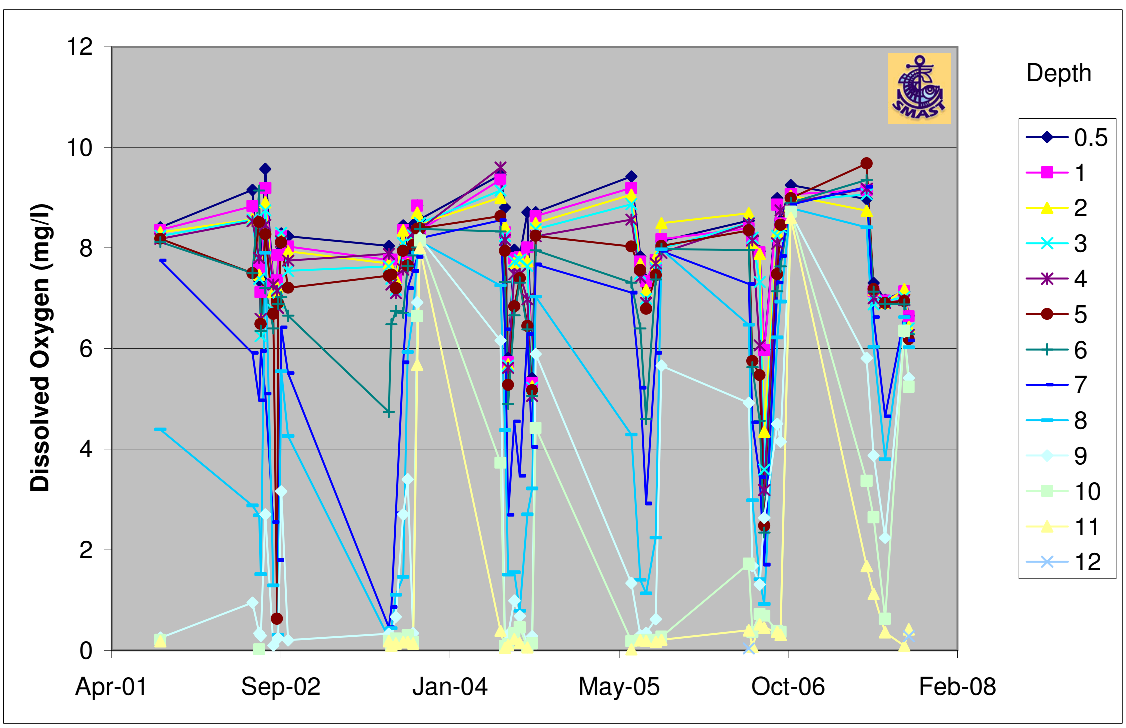


Figure VI-1. Seymour Pond Temperature and DO Readings 2001-2007
Summer temperature data shows warmer, shallower water overlying colder, deeper waters. During early spring and late fall, temperatures are relatively consistent throughout the water column. Dissolved oxygen concentrations show decreasing concentrations with increasing depth and regular anoxic (<1 ppm) concentrations during the summer. All data collected by Brewster volunteers using DO/Temp meters, including data from PALS Snapshots from 2001 to 2007.

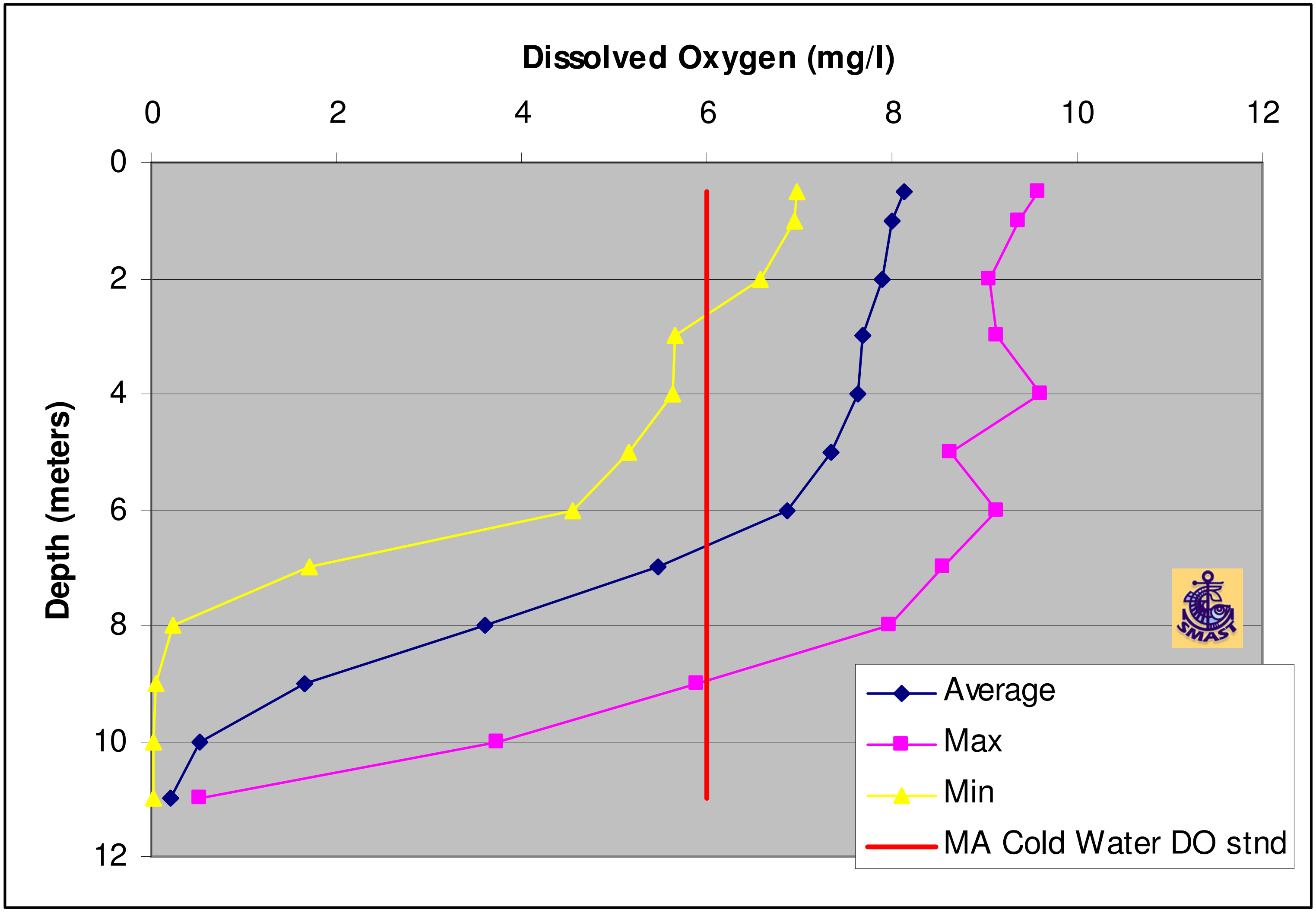


Figure VI-2. Seymour Pond: Average dissolved oxygen concentrations (June through September, 2001-2007)
Graph shows average DO profile based on data between 2001 and 2007 plus profiles based on maximum and minimum readings at each depth. Also shown is state surface water 6-ppm DO standard for cold water fisheries (314 CMR 4). Most depths have 35 readings.

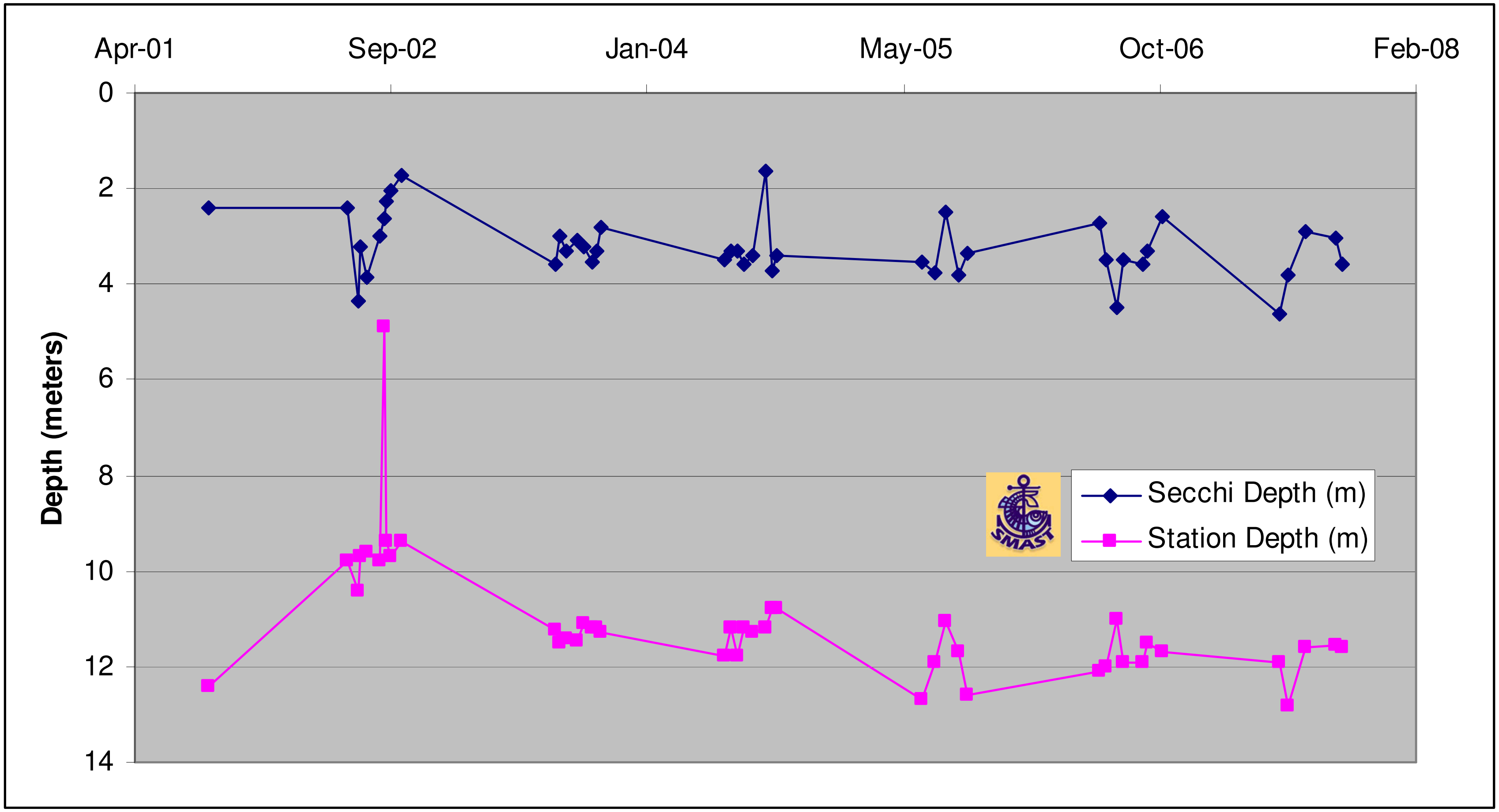


Figure VI-3. Seymour Pond: Secchi transparency readings 2001-2007
Blue data points are Secchi depth readings, while station depth measurements are shown in pink. All data collected by Brewster volunteers. Both station depth and Secchi depth have increasing trends over the sampling period; this is expected since groundwater levels also increased and pond elevations are related to groundwater elevations. However, Secchi readings are increasing at a rate only a third of the overall depth increase, which suggests that clarity is decreasing in Seymour. Secchi readings are 29% of the total depth on the pond on average.

Based on this land use review, there are 48 properties wholly or partially within the 300 ft buffer upgradient of Seymour Pond; 34 of them are single family residences with eight in Harwich and 26 in Brewster. There are also two two-family residences in Brewster and one developable residential property. None of the Brewster residences are connected to the municipal water supply and are assumed to get their water from private wells; six of the Harwich residences have water use. Twenty-six of the properties have septic system leachfields within 300 feet of the pond shore; the average distance for these systems is 213 feet. Average age of these residential septic systems is 22 years old with a total Title 5 design flow of 11,457 gallons per day. Using average water use in Brewster and the measured flows in Harwich, total estimated water use is 5,587 gpd or roughly half of the septic system design flow. Based on the age of the septic systems, distance to the pond, and the range of retention factors discussed above, septic systems are annually contributing between 2.7 and 8.2 kg of phosphorus to Seymour Pond with an estimated steady state load of 12 kg (Figure VI-4).

If phosphorus loading from runoff, lawns, birds, and precipitation are added to the wastewater load, the estimated annual phosphorus load to Seymour Pond, without including an estimate for internal sediment regeneration, has a range 10 to 38 kg. Within these loads, the sources that are the most uncertain are road runoff and birds; the wide range of these factors is evident in their changing percentages of the high and low loading estimates in Figure VI-4. Gathering of Seymour Pond-specific information is recommended to clarify these particular factors.

Based on the phosphorus loading analysis, the total annual load of phosphorus entering Seymour Pond is between 10 and 42 kg. Reviewing the water quality data can provide a reliability check on the average mass of phosphorus in Seymour Pond. After reviewing the 12 sampling runs completed between June and September, an average of 47 kg of phosphorus is in the water column of Seymour Pond. Since the residence time of water in the pond is 2.9 years (see Table V-1), this means that roughly 16.5 kg of phosphorus is being added to the water column each year. This calculation suggests that annual mass loading of phosphorus is closer to the lower estimates derived from the phosphorus budget, but it does not clarify the components of the load

Sediment regeneration is not included in the phosphorus budget estimates. Generally, the water quality data suggests that there is regeneration; most of the sampling runs show close to the same TP concentrations in the shallow and 3 m samples with an average doubling of concentration at the 9 m depth and then roughly another 50% increase at the deepest station. The consistency of this increasing gradient with depth shows sediment regeneration, but the general lack of samples in the spring does not allow a reasonable calculation of regeneration based on the water quality data alone. It is recommended that the town consider sampling of the sediments to develop a better idea of their contribution to the measured phosphorus in the pond.

Overall, it is recommended that the town consider pursuing some additional characterization of load components/sources before the Town pursues remedial activities. It is recommended that the Town target these efforts toward: 1) characterizing phosphorus flow into and out of the sediments, 2) measuring local phosphorus inputs from road runoff, and 3) getting a

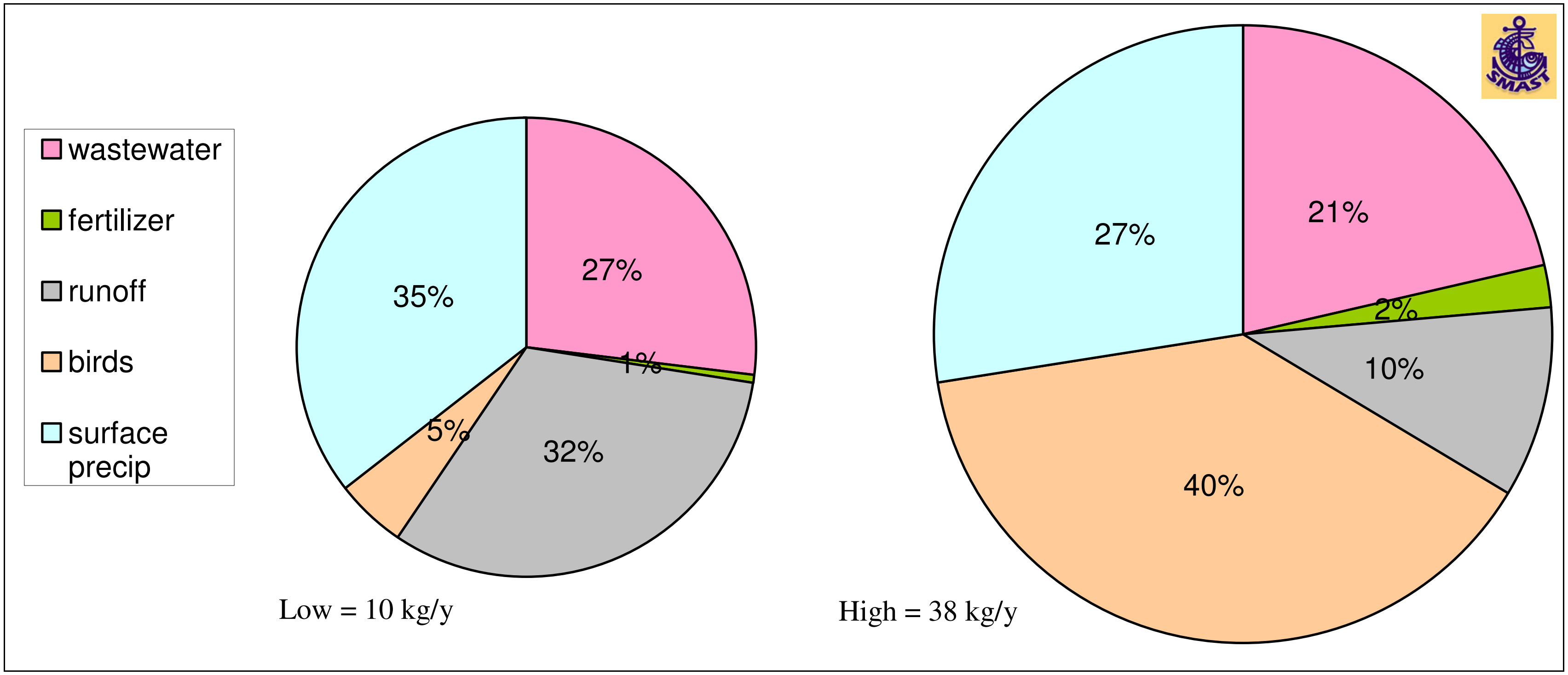


Figure VI-4. Seymour Pond: Estimated annual phosphorus budget
High and low estimates based on factors discussed in Section V.3 and presented in Table V-3. Average in-lake mass, corrected for residence time, results in an annual load of 16 kg based on measured water quality data (n=12 sampling runs). 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, including downgradient areas, within 300 ft buffer. Road runoff and bird loads are the most uncertain and it is recommended that the town evaluate these with targeted data collection. 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.

better understanding of the bird populations that use Seymour Pond. These activities could be combined with complimentary efforts that will provide all the information necessary to develop phosphorus TMDL for Seymour Pond and the necessary phosphorus reduction steps to meet the TMDL. These steps will allow the town to develop management strategies that can be confidently pursued.

In order to address these recommendations, SMAST staff recommend that these efforts include the following tasks, at a minimum: 1) collection and incubation of a minimum of three sediment sample cores to determine phosphorus content and regeneration potential related to dissolved oxygen thresholds, 2) a whole year of observation of bird populations on the pond, including identification of species, and 3) a survey of stormwater systems and measurement of runoff near Seymour Pond with regular testing of the phosphorus content of the runoff. It is also recommended that occasional water quality samples be collected from the pond using the standard PALS sampling depths to provide an integrated snapshot of the pond conditions and help to better understand sampling conditions during this period compared to average conditions.

Depending on how well the recommended information helps to settle the phosphorus budget, the town may also want to consider the completion of a comprehensive plant survey. In most Cape Cod ponds, the algal/phytoplankton portion of the plant community is very dominant and the relationship between phosphorus and pond ecosystems conditions is very strong. But in some impaired and/or heavily used ponds (*e.g.*, Long Pond in Barnstable), this relationship can be skewed by conditions that have created an extensive rooted aquatic plant community. In these ponds, most of the phosphorus is bound in the rooted plants and little is available for algae, so the clarity can be good, but much of the pond surface is covered with leaves from the rooted plants. Observations from PALS samplers between 2001 and 2007 have not noted extensive plant coverage in Seymour, but it may be useful during the development of remedial options to have a more definitive assessment. Although beyond the scope of this project, SMAST is available to assist the town in evaluating whether a comprehensive plant survey should be recommended for Seymour Pond.

SMAST staff have estimated that the cost of a stand alone project at Seymour Pond for these recommended activities for between $22,000 and $26,000 with another $10,000 to $12,000 for combining this information with past information and developing water quality management strategies and a recommended TMDL. A rooted plant survey, including mapping, transects and species identification, would have an estimated cost of between $8,000 and $10,000. Significant potential savings might be realized by completing these recommended analyses on a number of ponds and/or by incorporating citizen volunteer and town staff participation where appropriate. SMAST staff can discuss strategies with town staff and provide the town with a detailed scope of work if requested.

In addition, although the target watershed reductions are not clear at this point, application of relatively low cost, homeowner-initiated, best management practices around the pond shoreline would help to reduce external watershed loads. These practices would include: 1) maintaining, planting, or allowing regrowth of natural buffer areas between the pond and lawns/yards/houses and 2) installing treatment for or redirecting any direct stormwater runoff. The Town has already implemented a third activity that is usually recommended: 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 setback regulation in 2004. Review of the potential benefits and costs of the various nutrient management options could be evaluated as part of a slight expansion of the activities recommended above.

VI.2. Canoe Pond

Canoe Pond is a 14-acre pond that is the smallest of the Brewster ponds selected for detailed review, but is still considered a Great Pond under state regulations and, therefore, is a public pond. Canoe is approximately 4 m deep (~13 ft). Canoe is located just to the west of Upper and Lower Mill Ponds and is just south of Setucket Road (see Figure V-1).

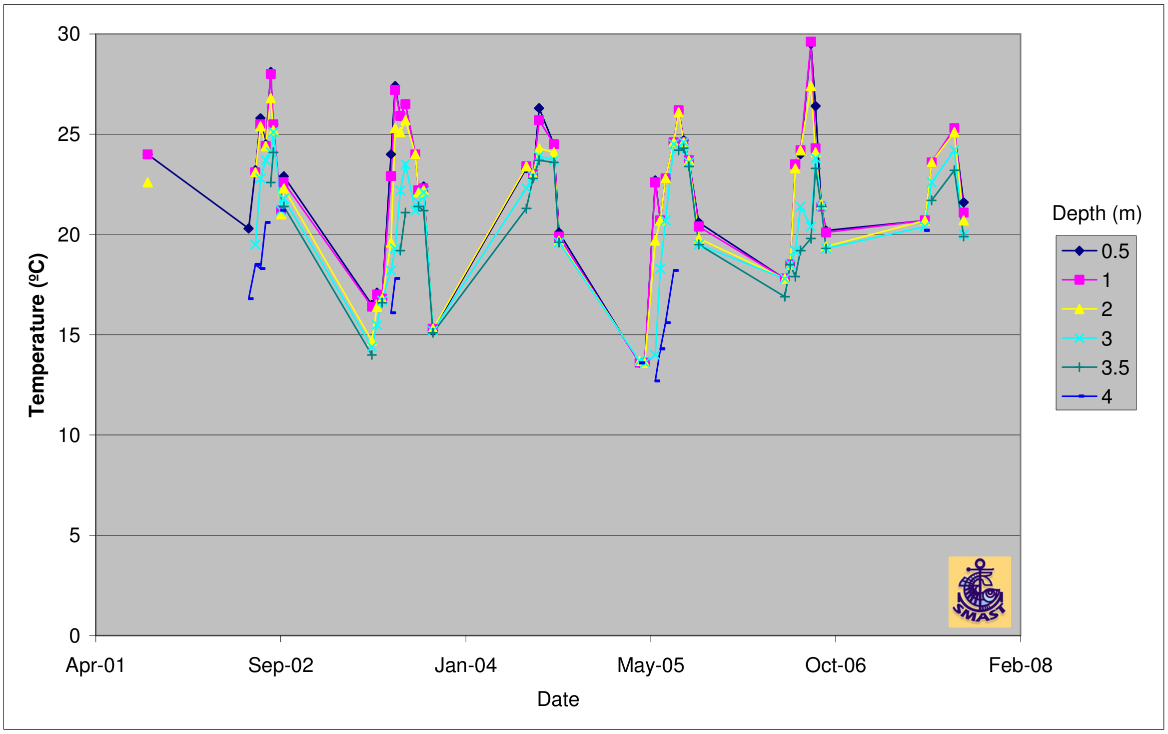
Temperature data collected between 2001 and 2007 shows that the water column in Canoe is generally well-mixed; temperatures at all depths are more or less the same throughout the summer (Figure VI-5). Based on the temperatures, Canoe would be classified as a warm water fishery under state surface water regulations (314 CMR 4). Under the regulations, warm waters are required to have dissolved oxygen concentrations of 5 ppm or greater. Waters at 3 m and deeper in Canoe fail to meet this concentration (Figure VI-6); these waters represent 9% of the total pond volume.

It is project staff opinion that the lack of acceptable dissolved oxygen in a significant volume of the pond means that Canoe Pond should be classified as an impaired water for the purposes of compliance with the state surface water regulations. It should also be noted that even though Canoe's water column is well-mixed, the sediment oxygen demand is sufficient to sustain this impairment even with regular replenishment from the atmosphere. Under the state and federal Clean Water Acts, impaired waters are required to have a total maximum daily load (TMDL) for the contaminant that is causing the impairment. Since the Massachusetts Department of Environmental Protection implements the state surface water regulations, this opinion would need to be submitted to MassDEP in order to get a definitive ruling.

Other water quality data generally confirm that Canoe is impaired. Average total phosphorus and chlorophyll *a* concentrations at all depth stations, throughout the water column, are above their respective Cape Cod pond water quality thresholds (Eichner and others, 2003). Average dissolved oxygen at the deepest station is anoxic (<1 ppm) and, therefore, lethal to fish. As would be expected based on the temperature readings, average deep total phosphorus concentrations are the same as surface concentrations, which suggests that any phosphorus regenerated from the sediments is easily mixed throughout the water column and can create the potential for additional phytoplankton growth in the water column.

Review of Secchi readings also seem to indicate that Canoe is impaired, but conditions appear to be relative stable. Both Secchi (n=37) and the deep point station depths do not have a distinct trend between 2001 and 2007 (Figure VI-7). Average relative Secchi reading is very low (30%); the best in Brewster is Little Cliff Pond at 79% (see Figure III-2).

Review of nitrogen to phosphorus ratios in Canoe show that the pond is phosphorus limited, which means that control of phosphorus is the key nutrient for determining water quality



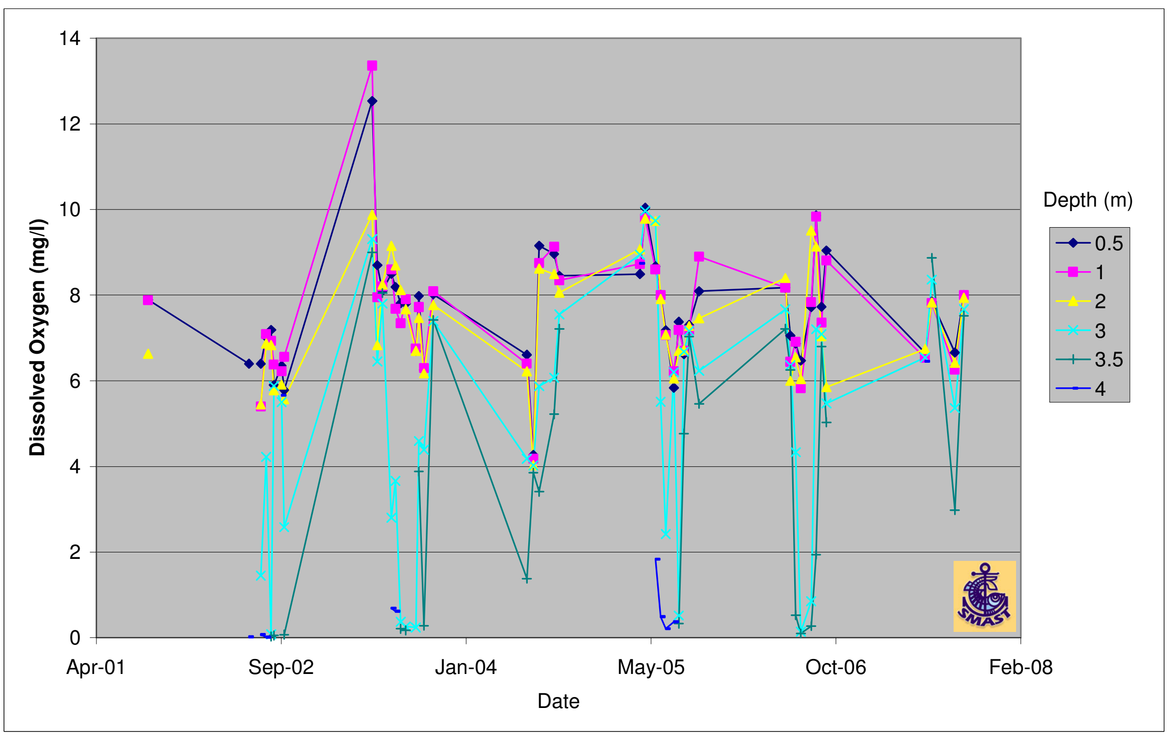


Figure VI-5. Canoe Pond Temperature and DO Readings 2001-2007

Temperature data shows well-mixed water column with generally consistent temperatures throughout the year. Dissolved oxygen concentrations show regular loss during summer that generally rises to 3 m below the surface. All data collected by Brewster volunteers using DO/Temp meters, including data from PALS Snapshots from 2001 to 2007.

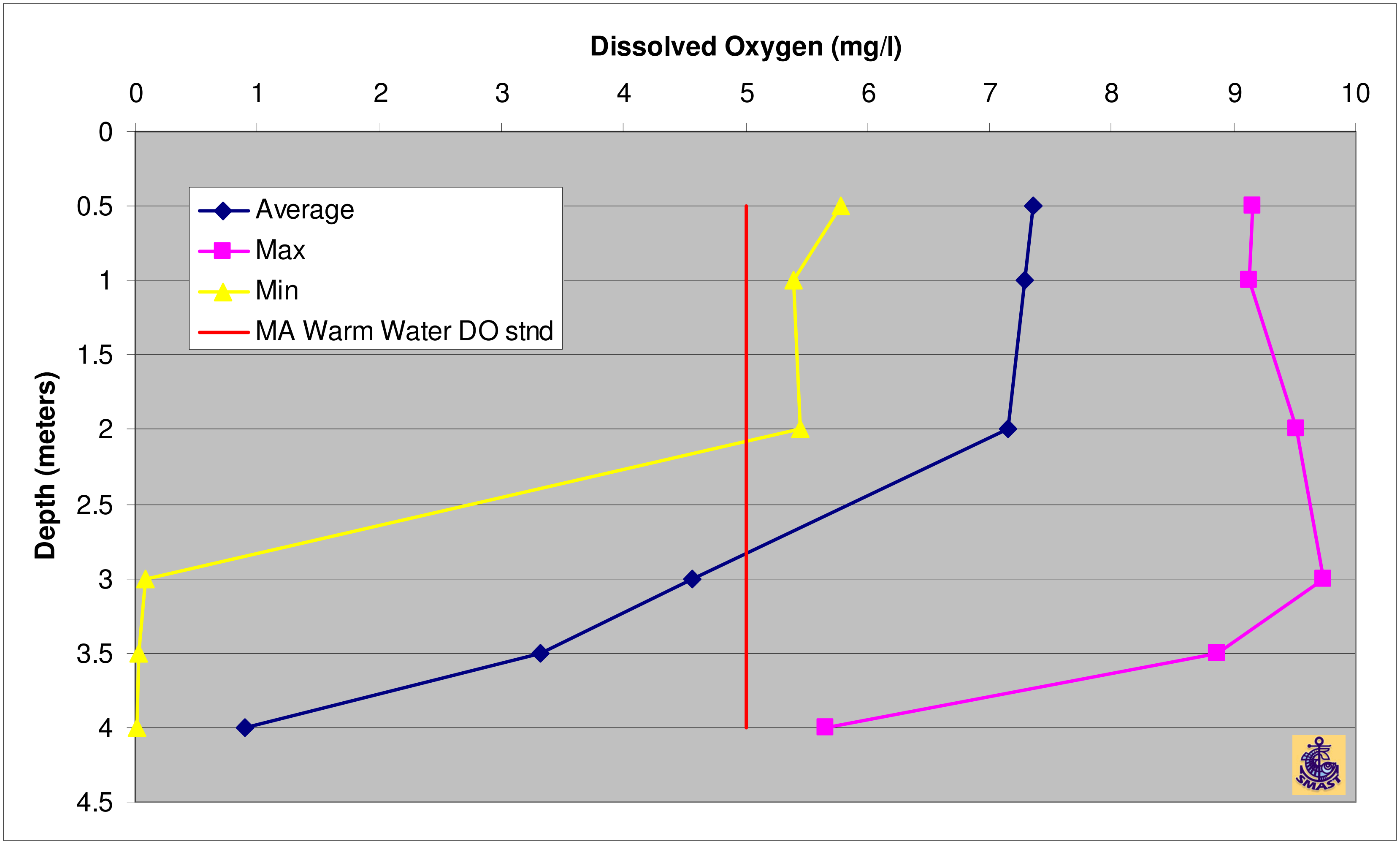


Figure VI-6. Canoe Pond: Average dissolved oxygen concentrations (June through September, 2001-2007)
Graph shows average DO profile based on data between 2001 and 2007 plus profiles based on maximum and minimum readings at each depth. Also shown is state surface water 5-ppm DO standard for warm water fisheries (314 CMR 4). Most depths have 37 readings. Waters 3 m and deeper on average do not attain the state regulatory threshold for dissolved oxygen.

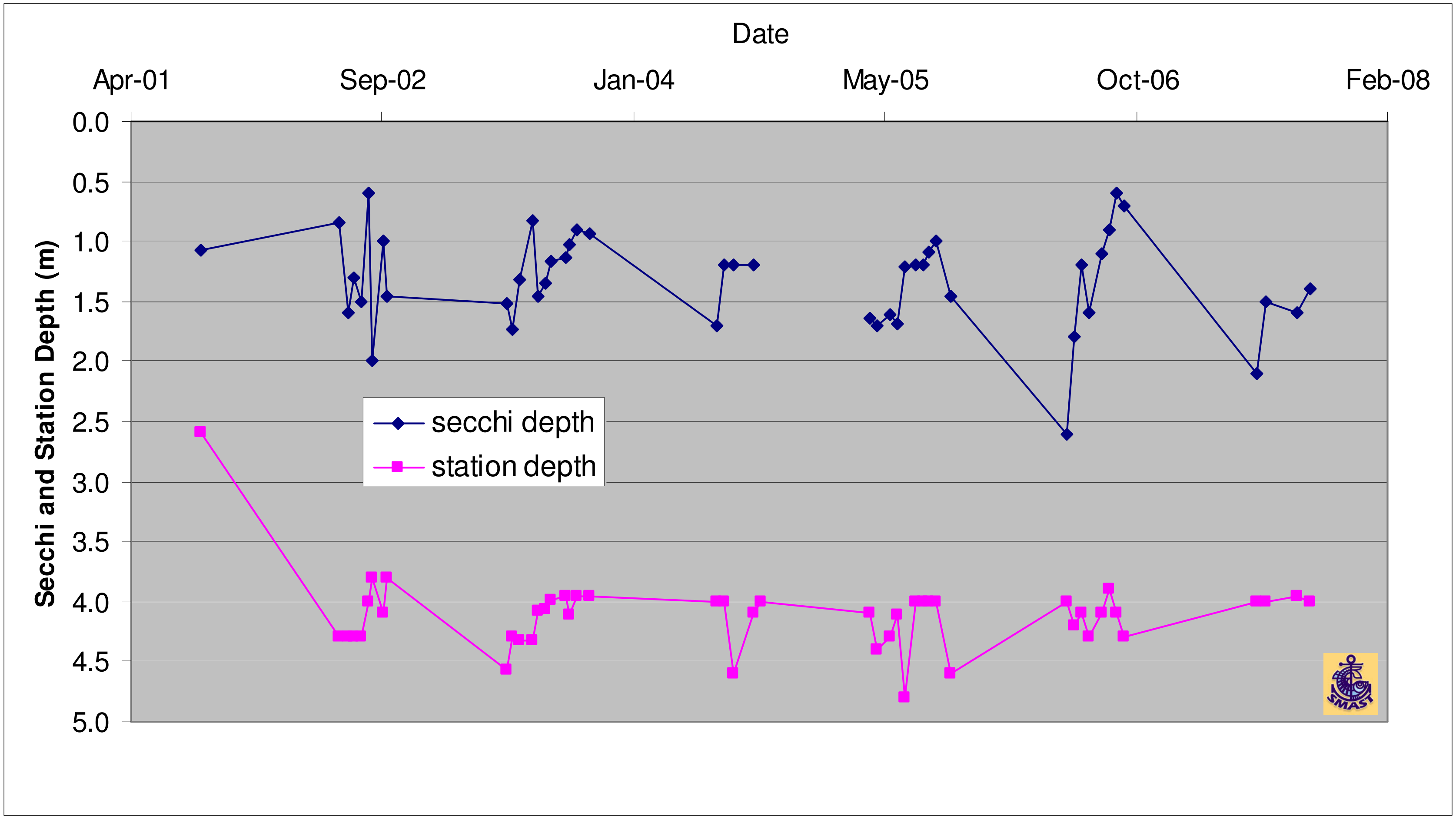


Figure VI-7. Canoe Pond: Secchi transparency readings 2001-2007
Blue data points are Secchi depth readings, while station depth measurements are shown in pink. All data collected by Brewster volunteers. Neither station depth nor Secchi depth have distinct trends over the sampling period; this suggests that conditions in the pond have been relatively stable during this sampling period. Secchi readings are 30% of the total depth on the pond on average.

in the pond and, therefore, is the nutrient/contaminant that should be targeted for a TMDL. Average surface N to P ratio during June through September is 68; generally water concentrations ratios above the Redfield ratio of 16 are phosphorus limited (Redfield and others, 1963). As would be expected for such a well-mixed pond, the average N to P ratio in deep waters is the same as the surface waters.

Since phosphorus is the key for determining water quality in Canoe Pond, one of the next steps is to determine the sources and magnitude of phosphorus. Once this is completed, community discussions and cost estimates can help to determine what combination of phosphorus management strategies will be adopted to remediate Canoe Pond. Understanding the sources and magnitude of phosphorus is usually done through the development of a phosphorus budget.

As mentioned above, the phosphorus budget will account for all the various sources entering the pond water. Most of the sources will be from the watershed, but the pond sediments can also be an internal source. None of these sources have been measured directly, but information developed on ponds and lakes in similar settings can be used to develop a reasonable estimate. More detailed Canoe Pond-specific measurements would be necessary to refine the results presented here and are recommended for key factors such as road runoff, bird loading, and sediment regeneration.

In order to begin to develop a watershed phosphorus budget for Canoe 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.

Based on this land use review, there are seven properties wholly or partially within the 300 ft buffer upgradient of Canoe Pond; three of them are single family residences, while the other four undeveloped, but developable, residential parcels. None of the Brewster residences are connected to the municipal water supply based on 2002 to 2004 water use and all are assumed to get their water from private wells. All three of the existing residences have septic system leachfields within 300 feet of the pond shore; the average distance for these systems is 206 feet. Average age of these residential septic systems is 11 years old with a total Title 5 design flow of 1,540 gallons per day. Using average single family residence water use in Brewster, total estimated water use is 526 gpd or roughly a third of the septic system design flow. Based on the age of the septic systems, distance to the pond, and the range of retention factors discussed above, none of the relatively young septic systems are contributing phosphorus to Canoe Pond (Figure VI-8). At steady state, these systems will contribute 1.4 kg/yr of wastewater phosphorus and at BO the load is projected to increase to 3.2 kg/yr.

The remaining sources of phosphorus loading (runoff, lawns, birds, and precipitation), without including an estimate for internal sediment regeneration, total between 2.3 to 4.1 kg.

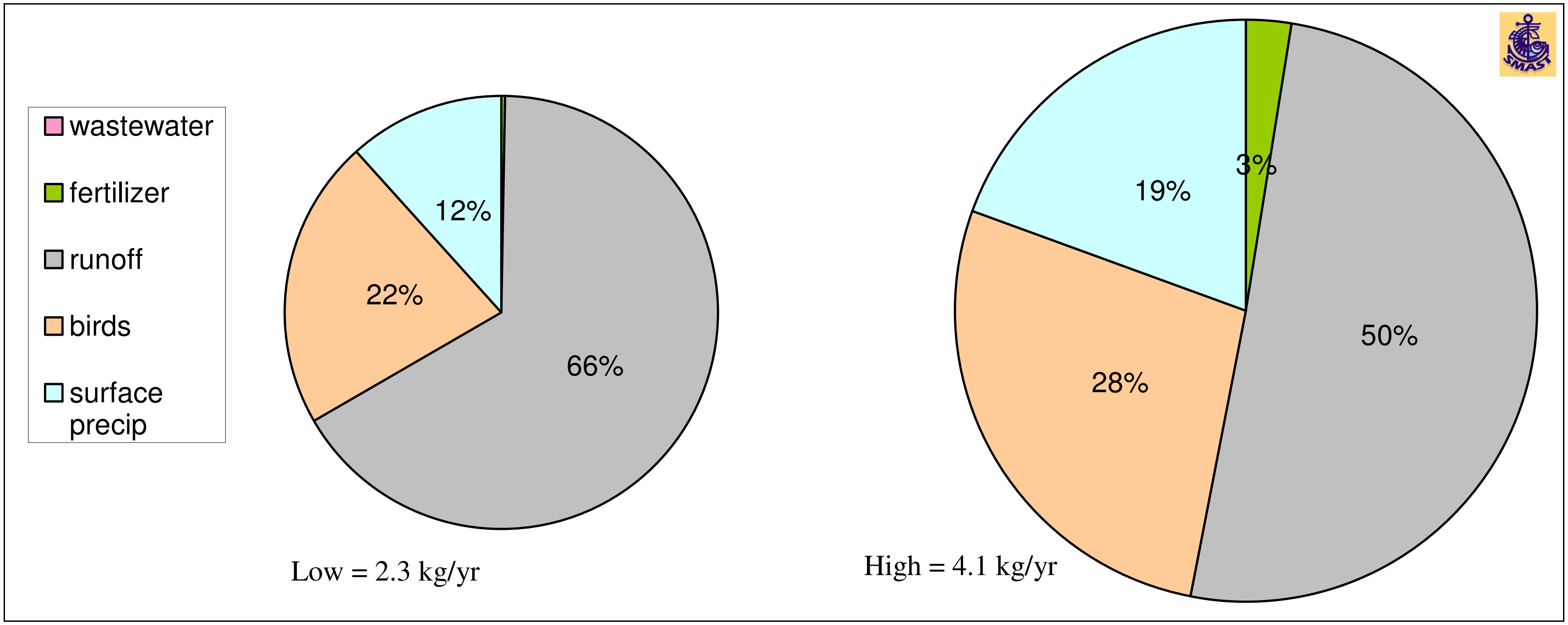


Figure VI-8. Canoe Pond: Estimated annual phosphorus budget
High and low estimates based on factors discussed in Section V.3 and presented in Table V-3. Average in-lake mass, corrected for residence time, results in an annual load of 1.8 kg based on measured water quality data (n=13 sampling runs). Based on the age of upgradient septic system leachfields and their distance to the shoreline, none are yet contributing phosphorus to the pond. Road loads are based exclusively on downgradient areas within a 300 ft buffer; there are no road areas within the upgradient 300 ft buffer. Road runoff and bird loads are the most uncertain and it is recommended that the town evaluate these with targeted data collection. 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.

Since there is no current projected wastewater load, this range is also the current total loading range. Within these loads, the sources that are the most uncertain are road runoff and birds; the wide range of these factors is evident in their changing percentages of the high and low loading estimates in Figure VI-8. It should also be noted that all of the road runoff is generated by downgradient roads based on the phosphorus loading assumption that roads within a 300 ft buffer on the downgradient side have drainage structures that discharge toward or into the pond. As noted in the water budget discussion, there is also a potential stream connecting Canoe to Upper Mill that is noted on aerial photographs. Clarifying its impact is also important for resolving the phosphorus budget. Gathering of Canoe Pond-specific information is recommended to clarify these factors.

Reviewing the water quality data can provide a reliability check on the average mass of phosphorus in Canoe Pond. After reviewing the 13 sampling runs completed between June and September, an average of 2.4 kg of phosphorus is in the water column of Canoe Pond. Since the residence time of water in the pond is 1.3 years (see Table V-1); this means that roughly 1.8 kg of phosphorus is being added to the water column each year. This calculation suggests that annual mass loading of phosphorus is closer to the lower estimates derived from the phosphorus budget, but it does not clarify the components of the load.

Sediment regeneration is not included in the phosphorus budget estimates, but the water quality data suggests that it is a component of the measured mass in the pond. Unfortunately, the available dataset has samples generally collected in August or September, so calculations cannot be made showing regeneration, which would generally be shown by an increase in TP concentrations as summer progresses. The only year that approaches this is 2002, which has July through September samples with consistently higher deep concentrations and concentrations that increase from July to August, but fall in September. Total nitrogen concentrations follow a similar pattern during these sampling runs. It is recommended that the town consider sampling of the sediments to develop a better idea of their contribution to the measured phosphorus in the pond, as well as collecting some deep water quality samples in the spring.

Overall, it is recommended that the town consider pursuing some additional characterization of load components/sources before the Town pursues remedial activities. It is recommended that the Town target these efforts toward: 1) characterizing phosphorus flow into and out of the sediments, 2) measuring local phosphorus inputs from road runoff, and 3) getting a better understanding of the bird populations that use Canoe Pond. These activities could be combined with complimentary efforts that will provide all the information necessary to develop a phosphorus TMDL for Canoe Pond and the necessary phosphorus reduction steps to meet the TMDL. These steps will allow the town to develop management strategies that can be confidently pursued.

In order to address these recommendations, SMAST staff recommend that these efforts include the following tasks, at a minimum: 1) collection and incubation of a minimum of three sediment sample cores to determine phosphorus content and regeneration potential related to dissolved oxygen thresholds, 2) a whole year of observation of bird populations on the pond, including identification of species, and 3) a survey of stormwater systems and measurement of runoff near Canoe Pond with regular testing of the phosphorus content of the runoff. It is also recommended that occasional water quality samples be collected from the pond using the standard PALS sampling depths to provide an integrated snapshot of the pond conditions and help to better understand sampling conditions during this period compared to average conditions.

Depending on how well the recommended information helps to settle the phosphorus budget, the town may also want to consider the completion of a comprehensive plant survey. In most Cape Cod ponds, the algal/phytoplankton portion of the plant community is very dominant and the relationship between phosphorus and pond ecosystems conditions is very strong. But in some impaired and/or heavily used ponds (*e.g.*, Long Pond in Barnstable), this relationship can be skewed by conditions that have created an extensive rooted aquatic plant community. In these ponds, most of the phosphorus is bound in the rooted plants and little is available for algae, so the clarity can be good, but much of the pond surface is covered with leaves from the rooted plants. Observations from PALS samplers between 2001 and 2007 have not noted extensive plant coverage in Canoe, but it may be useful during the development of remedial options to have a more definitive assessment. Although beyond the scope of this project, SMAST is available to assist the town in evaluating whether a comprehensive plant survey should be recommended for Canoe Pond.

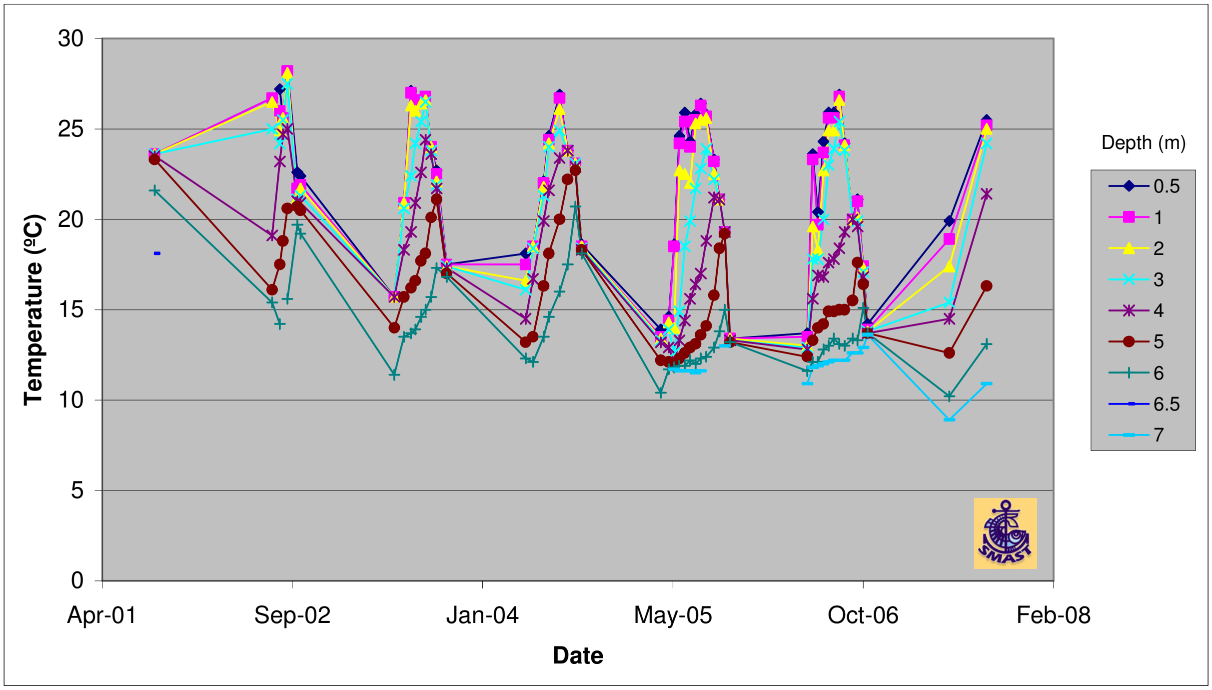
SMAST staff have estimated that the cost of a stand alone project at Canoe Pond for these recommended activities between $22,000 and $25,000 with another $10,000 to $12,000 for combining this information with past information and developing water quality management strategies and a recommended TMDL. A rooted plant survey, including mapping, transects and species identification, would have an estimated cost of between $7,000 and $9,000. Significant potential savings might be realized by completing these recommended analyses on a number of ponds and/or by incorporating citizen volunteer and town staff participation where appropriate. SMAST staff can discuss strategies with town staff and provide the town with a detailed scope of work if requested.

In addition, although the target watershed reductions are not clear at this point, maintenance of the natural buffers that generally and redirecting any direct stormwater runoff are relatively lost cost best management practices that can be pursued. These activities would help to minimize external watershed phosphorus loads. Review of the potential benefits and costs of the various nutrient management options could be evaluated as part of a slight expansion of the activities recommended above.

VI.3. Blueberry Pond

Blueberry Pond is a 22-acre, approximately 7 m deep (23 ft) pond. Blueberry is located in eastern Brewster, to the south of Route 6A, and west of Nickerson State Park (see Figure V-1). It is also adjacent to the Ocean Edge Resort.

Temperature data collected between 2001 and 2007 shows that the Blueberry develops regular stratification during the summer; upper waters warm quicker than deeper waters eventually leading to separate temperature layers with cold waters below 4 m (Figure VI-9). This cold water volume is approximately 16% of the total volume of the pond. These deep waters meet state surface water regulations (314 CMR 4) temperature requirements for cold-



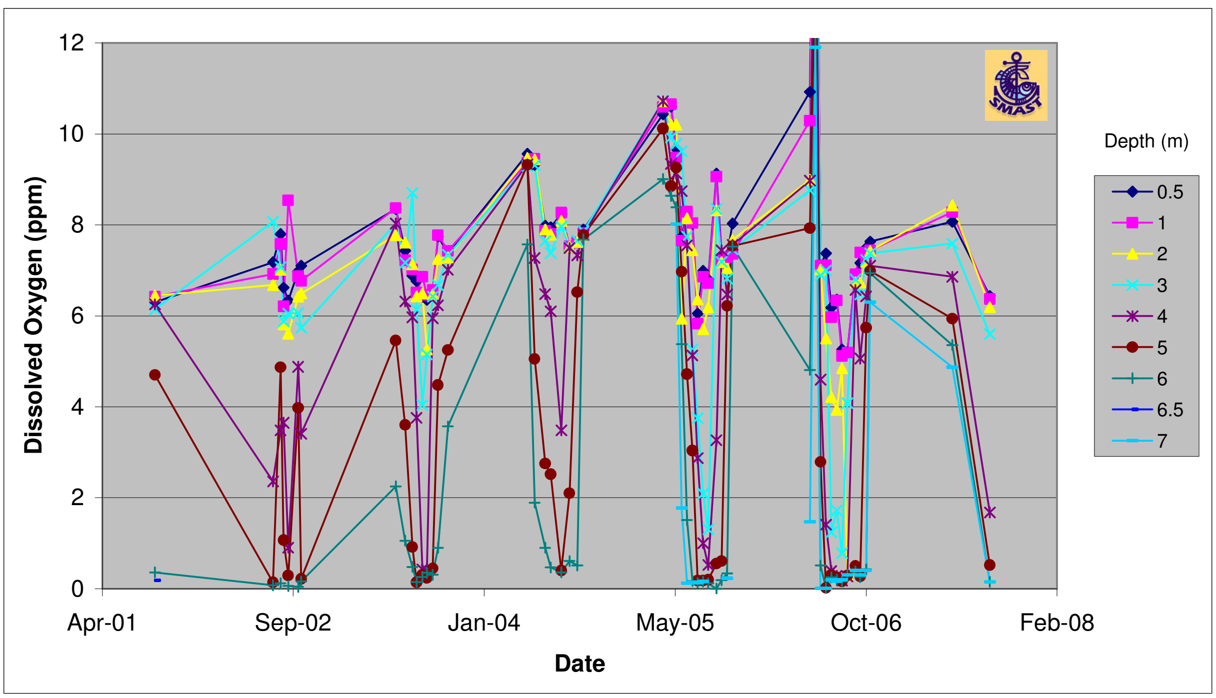


Figure VI-9. Blueberry Pond Temperature and DO Readings 2001-2007

Summer temperature data shows warmer, shallower water overlying colder, deeper waters. During early spring and late fall, temperatures are relatively consistent throughout the water column. Dissolved oxygen concentrations show decreasing concentrations with increasing depth and regular anoxic (<1 ppm) concentrations during the summer. All summer readings below 5 m fail to attain state DO standard of 5 ppm. All data collected by Brewster volunteers using DO/Temp meters, including data from PALS Snapshots from 2001 to 2007.

water fisheries (20ºC or less), but do not meet the accompanying dissolved oxygen requirements (average concentrations all less than 6 ppm) (Figure VI-10).

It is project staff opinion that the lack of acceptable dissolved oxygen throughout the available cold water fishery means that Blueberry Pond should be classified as an impaired water for the purposes of compliance with the state surface water regulations. Under the state and federal Clean Water Acts, impaired waters are required to have a total maximum daily load (TMDL) for the contaminant that is causing the impairment. Since the Massachusetts Department of Environmental Protection implements the state surface water regulations, this opinion would need to be submitted to MassDEP in order to get a definitive ruling.

Other water quality data generally confirm that Blueberry is impaired. Average total phosphorus and chlorophyll *a* concentrations at all depth stations, throughout the water column, are above their respective Cape Cod pond water quality thresholds (Eichner and others, 2003). Average dissolved oxygen in the two deepest stations are anoxic (<1 ppm) and, therefore, lethal to fish. Average deep total phosphorus concentrations are more than twice surface concentrations, which indicates that, on average during the summer, the sediments are regenerating phosphorus and creating the potential for additional phytoplankton growth in the water column.

Review of Secchi readings seem to indicate that these impaired conditions are worsening. Secchi clarity readings have been relatively constant over the seven years of data collection, but station depth readings have increased by approximately a meter (Figure VI-11). This increase in station depth mirrors increased groundwater levels over this same period (USGS water level records, well BMW44). Because the Secchi readings have not increased, but the total depth of the pond has generally increased, the data suggests that clarity is worsening in Blueberry. Because clarity in Cape Cod ponds is generally determined by phytoplankton populations, which respond to phosphorus loads, these findings suggest that phosphorus loads are increasing. Average relative Secchi readings are 47%, which, of course, have a decreasing trend. The best relative Secchi reading in Brewster is Little Cliff Pond at 79% (see Figure III-2).

Review of nitrogen to phosphorus ratios in Blueberry show that the pond is phosphorus limited, which means that control of phosphorus is the key nutrient for determining water quality in the pond and, therefore, is the nutrient/contaminant that should be targeted for a TMDL. Average surface N to P ratio during June through September is 80; generally water concentrations ratios above the Redfield ratio of 16 are phosphorus limited (Redfield and others, 1963). Nutrient regeneration from the Blueberry's sediments makes these waters even more phosphorus limited; average N to P ratio in deep waters is 239. The higher ratio in the sediments means that more nitrogen is being regenerated out of the sediments than phosphorus.

Since phosphorus is the key for determining water quality in Blueberry Pond, one of the next steps is to determine the sources and magnitude of phosphorus. Once this is completed, community discussions and cost estimates can help to determine what combination of phosphorus management strategies will be adopted to remediate Blueberry Pond. Understanding the sources and magnitude of phosphorus is usually done through the development of a phosphorus budget.

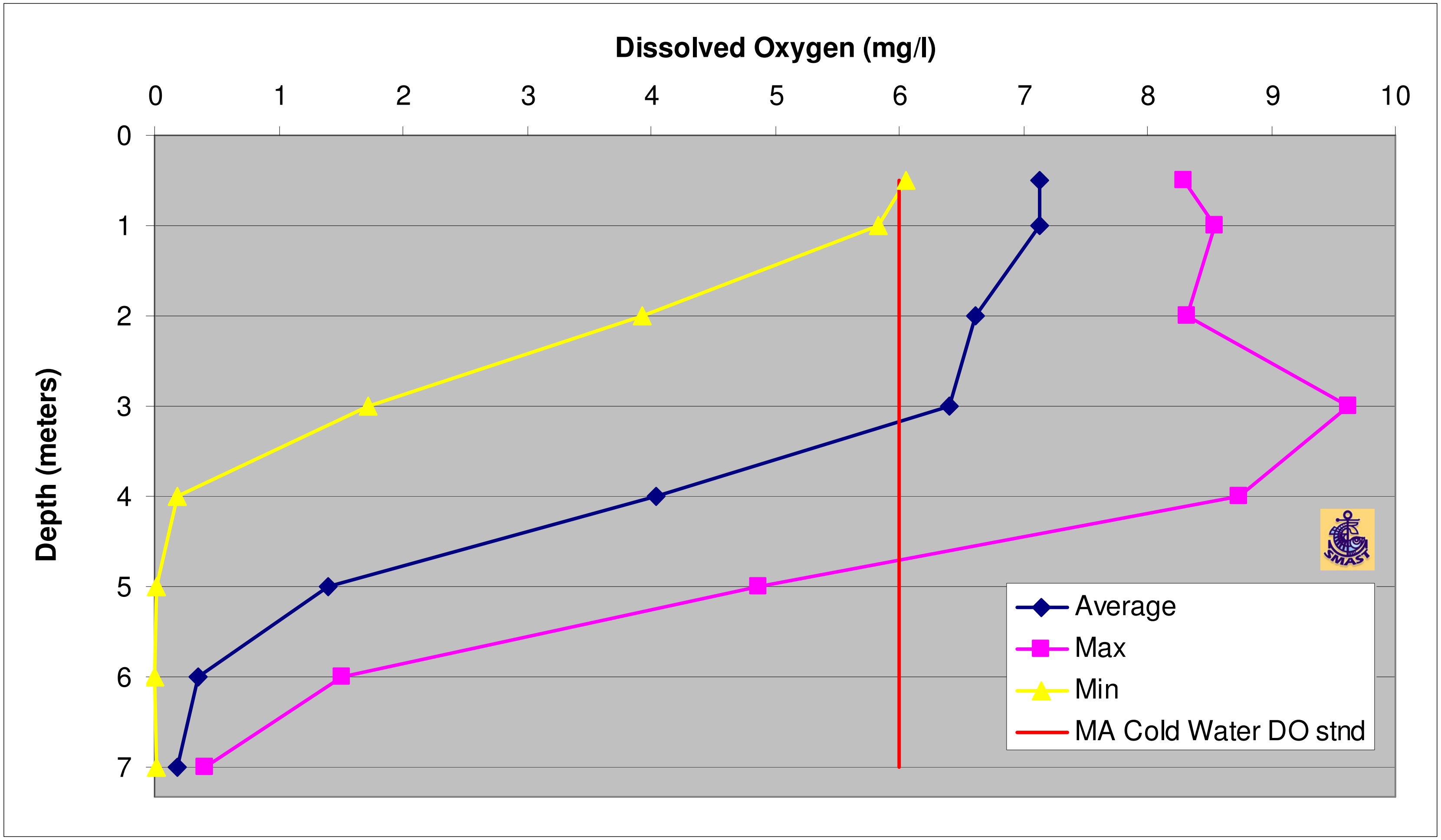


Figure VI-10. Blueberry Pond: Average dissolved oxygen concentrations (June through September, 2001-2007)
Graph shows average DO profile based on data between 2001 and 2007 plus profiles based on maximum and minimum readings at each depth. Also shown is state surface water 6-ppm DO standard for cold water fisheries (314 CMR 4). Most depths have 34 readings.

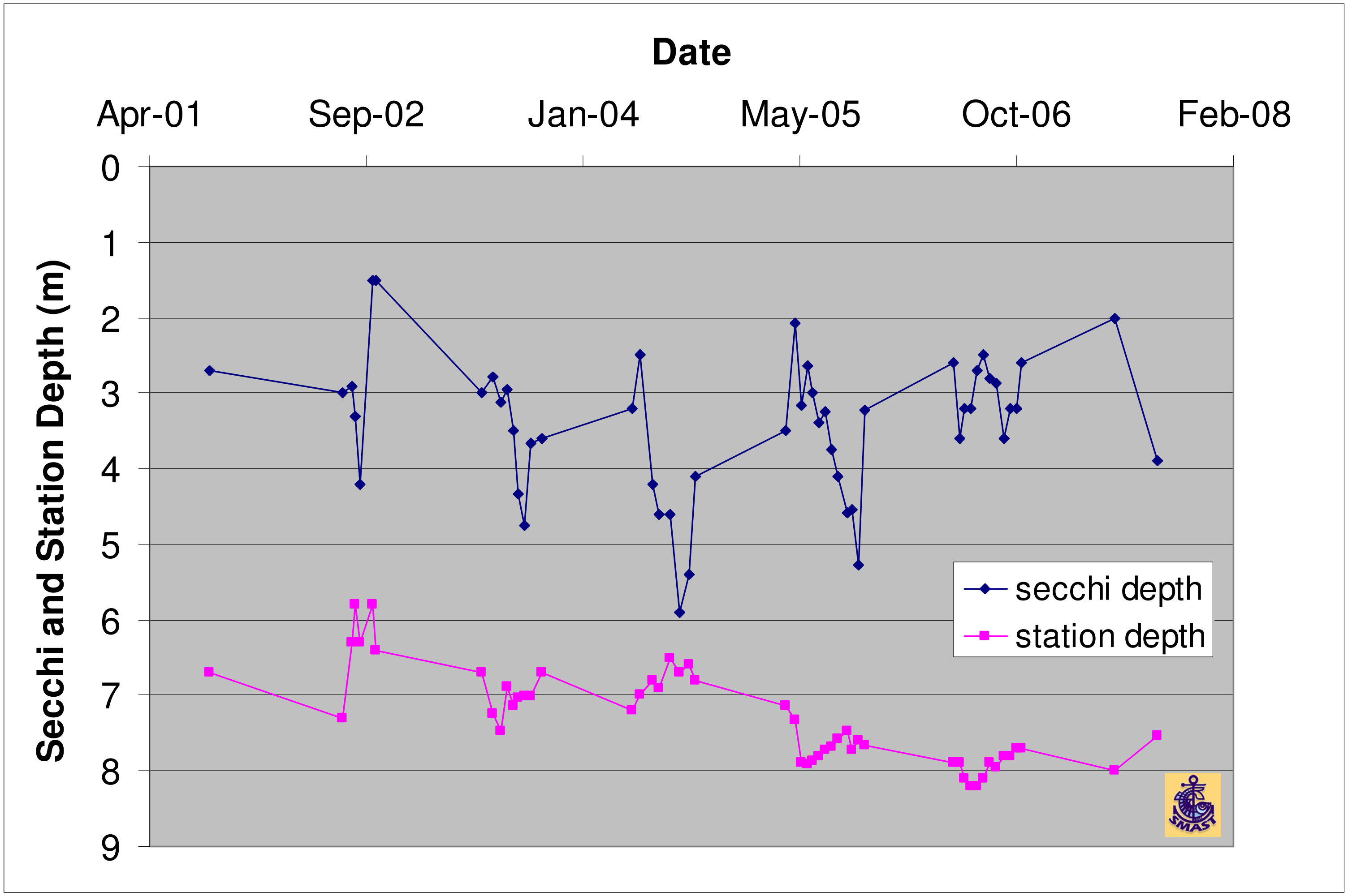


Figure VI-11. Blueberry Pond: Secchi transparency readings 2001-2007
Blue data points are Secchi depth readings, while station depth measurements are shown in pink. All data collected by Brewster volunteers. Station depth has an increasing trend over the sampling period; this is expected since groundwater levels also increased during the period and pond elevations are related to groundwater elevations. However, Secchi readings over the period do not have a trend, which seems to indicate worsening conditions. In addition, Secchi readings fluctuate over a very large range (40% of the total depth), which is also indicative of an impaired system. Secchi readings are 47% of the total depth on the pond on average.

As mentioned above, the phosphorus budget will account for all the various sources entering the pond water. Most of the sources will be from the watershed, but the pond sediments can also be an internal source. None of these sources have been measured directly, but information developed on ponds and lakes in similar settings can be used to develop a reasonable estimate. More detailed Blueberry Pond-specific measurements would be necessary to refine the results presented here and are recommended for key factors such as road runoff, bird loading, and sediment regeneration.

In order to begin to develop a watershed phosphorus budget for Blueberry 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.

Based on this land use review, there are 35 properties wholly or partially within the 300 ft buffer upgradient of Blueberry Pond; 26 of them are single family residences. There is also a portion of the Ocean Edge resort. Sol's Pond is located in the Blueberry's watershed just beyond the 300 ft buffer. None of the residences are connected to the municipal water supply based on 2002 to 2004 water use and are assumed to get their water from private wells. Eleven of the properties have septic system leachfields within 300 feet of the pond shore; the average distance for these systems is 165 feet. Average age of these residential septic systems is 19 years old with a total Title 5 design flow of 4,620 gallons per day. Using average residential water use in Brewster, total estimated water use is 1,929 gpd or roughly half of the septic system design flow. Volunteers reviewing BOH records also noted that Ocean Edge has a septic system leachfield with a 13,640 gpd design flow located 465 ft from the shoreline; this is a relatively large distance, but large discharges can speed phosphorus transport. It is unclear whether this discharge is having an impact, but further analysis is recommended. Based on the age of the septic systems within the 300 ft buffer, distance to the pond, and the range of retention factors discussed above, septic systems are annually contributing between 3.2 and 4.1 kg of phosphorus to Blueberry Pond with an estimated future steady state load of 12 kg (Figure VI-12).

The remaining sources of phosphorus loading (runoff, lawns, birds, and precipitation), without including an estimate for internal sediment regeneration, total between 3.3 to 6.7 kg. This includes an estimate of 40,000 square feet of fertilized golf course area associated with the portion of the Ocean Edge Resort course that is within 300 ft of the pond shoreline and inside the watershed. Within these loads, the sources that are the most uncertain are road runoff and birds; the wide range of these factors is evident in their changing percentages of the high and low loading estimates in Figure VI-12. Gathering of Blueberry Pond-specific information is recommended to clarify these particular factors.

Based on the phosphorus loading analysis, the annual load of phosphorus entering Blueberry Pond is between 6.5 and 10.7 kg. Reviewing the water quality data can provide a reliability check on the average mass of phosphorus in Blueberry Pond. After reviewing the 17

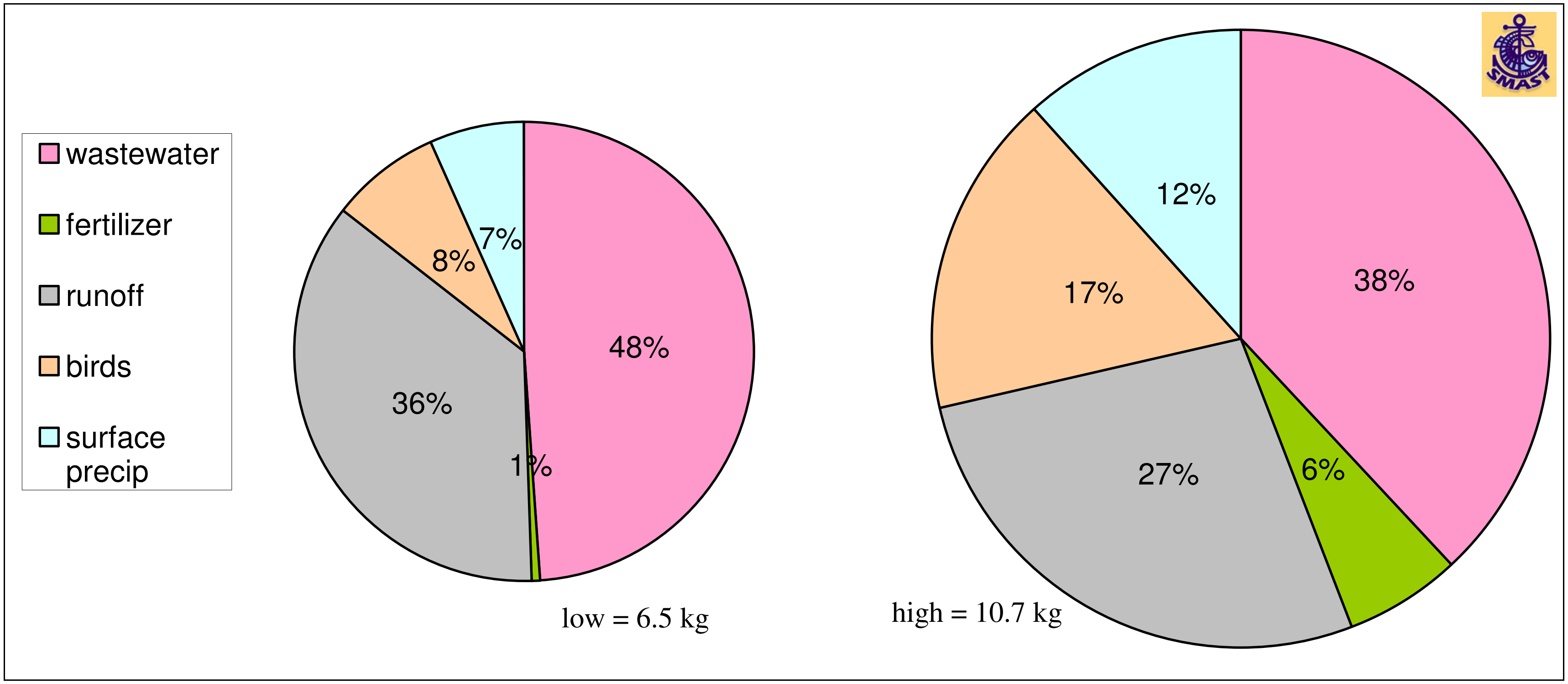


Figure VI-12. Blueberry Pond: Estimated annual phosphorus budget
High and low estimates based on factors discussed in Section V.3 and presented in Table V-3. Average in-lake mass, corrected for residence time, results in an annual load of 4 kg based on measured water quality data (n=17 sampling runs). Contribution of seasonal phosphorus regeneration from the sediments is not clear from available data, but has been estimated at 3 kg based on average mass in the pond; it is likely the source of the remainder of the phosphorus measured in the pond. It is recommended that this be measured directly through collection and testing of sediment cores. Based on the age of upgradient septic system leachfields and their distance to the shoreline, 11 of the 26 systems within a 300 ft buffer are contributing phosphorus to the pond. Road runoff and bird loads are the most uncertain and it is recommended that the town evaluate these with targeted data collection. Loads include an estimated fertilizer load from golf course areas within the 300 ft buffer and upgradient of the pond; further clarification of potential future wastewater loads from Ocean Edge is recommended.

sampling runs completed between June and September, an average of 12.8 kg of phosphorus is in the water column of Blueberry. Since the residence time of water in the pond is 1.8 years (see Table V-1), this means that roughly 7 kg of phosphorus is being added to the water column each year. This conclusions from this calculation must be somewhat tempered because the mass in the pond includes the contribution of sediment regeneration. If a correction is made based on the average load in the deep waters, approximately 4 kg per year is entering the pond. These calculations suggest that the overall mass calculated for the phosphorus budget is reasonable, but it does not clarify the components of the load

Sediment regeneration is not included in the phosphorus budget estimates. Review of TP concentrations measured in the shallow and deep samples generally show deep concentrations that are three times surface concentrations. Because data was not generally collected in early spring, reasonable estimates of sediment regeneration throughout the summer cannot be made, but review of available data generally show the highest concentrations in August or September. It is recommended that the town consider sampling of the sediments to develop a better idea of their contribution to the measured phosphorus in the pond.

Overall, it is recommended that the town consider pursuing some additional characterization of load components/sources before the Town pursues remedial activities. It is recommended that the Town target these efforts toward: 1) characterizing phosphorus flow into and out of the sediments, 2) measuring local phosphorus inputs from road runoff, and 3) getting a better understanding of the bird populations that use Blueberry Pond. In addition, it is also recommended that the potential future impact of Ocean Edge Resort be revisited. These activities could be combined with complimentary efforts that will provide all the information necessary to develop a phosphorus TMDL for Blueberry Pond and the necessary phosphorus reduction steps to meet the TMDL. These steps will allow the town to develop management strategies that can be confidently pursued

In order to address these recommendations, SMAST staff recommend that these efforts include the following tasks, at a minimum: 1) collection and incubation of a minimum of three sediment sample cores to determine phosphorus content and regeneration potential related to dissolved oxygen thresholds, 2) a whole year of observation of bird populations on the pond, including identification of species, and 3) a survey of stormwater systems and measurement of runoff near Blueberry Pond with regular testing of the phosphorus content of the runoff. It is also recommended that occasional water quality samples be collected from the pond using the standard PALS sampling depths to provide an integrated snapshot of the pond conditions and help to better understand sampling conditions during this period compared to average conditions.

Depending on how well the recommended information helps to settle the phosphorus budget, the town may also want to consider the completion of a comprehensive plant survey. In most Cape Cod ponds, the algal/phytoplankton portion of the plant community is very dominant and the relationship between phosphorus and pond ecosystems conditions is very strong. But in some impaired and/or heavily used ponds (*e.g.*, Long Pond in Barnstable), this relationship can be skewed by conditions that have created an extensive rooted aquatic plant community. In these ponds, most of the phosphorus is bound in the rooted plants and little is available for algae, so the clarity can be good, but much of the pond surface is covered with leaves from the rooted plants. Observations from PALS samplers between 2001 and 2007 have not noted extensive plant coverage in Blueberry, but it may be useful during the development of remedial options to have a more definitive assessment. Although beyond the scope of this project, SMAST is available to assist the town in evaluating whether a comprehensive plant survey should be recommended for Blueberry Pond.

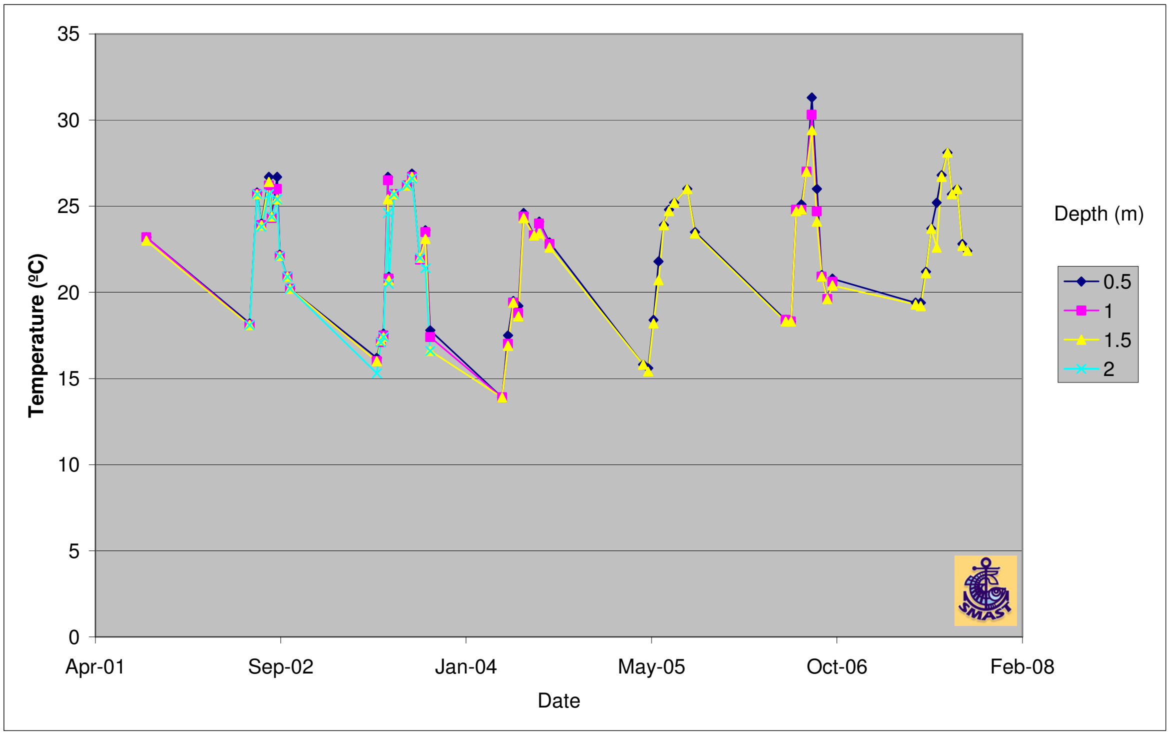
SMAST staff have estimated that the cost of a stand alone project at Blueberry Pond for these recommended activities between $22,000 and $25,000 with another $10,000 to $12,000 for combining this information with past information and developing water quality management strategies and a recommended TMDL. A rooted plant survey, including mapping, transects and species identification, would have an estimated cost of between $7,000 and $9,000. Significant potential savings might be realized by completing these recommended analyses on a number of ponds and/or by incorporating citizen volunteer and town staff participation where appropriate. SMAST staff can discuss strategies with town staff and provide the town with a detailed scope of work if requested.

In addition, although the target watershed reductions are not clear at this point, application of relatively low cost, homeowner-initiated, best management practices around the pond shoreline would help to reduce external watershed loads. These practices would include: 1) maintaining, planting, or allowing regrowth of natural buffer areas between the pond and lawns/yards/houses and 2) installing treatment for or redirecting any direct stormwater runoff. Review of the potential benefits and costs of the various nutrient management options could be evaluated as part of a slight expansion of the activities recommended above.

VI.4. Walkers Pond

Walkers Pond is a 102 acre pond located just to the east of Slough and Pine Ponds, which are also within Walkers watershed, just to the north of Elbow Pond, and to the west of Seymour Pond, which is also in Walkers watershed (see Figure V-4). Walkers has the third largest area of the Brewster ponds selected for detailed review, but is the shallowest of those selected. Walkers is approximately 2.4 m deep (~8 ft). Walkers is also the uppermost pond of the series of ponds leading to Stony Brook; Upper Mill and Lower Mill are the other two ponds leading to the brook.

Temperature data collected between 2001 and 2007 shows that the water column in Walkers is well-mixed; temperatures at all depths are more or less the same throughout the summer (Figure VI-13). It should be noted that temperatures since 2004 have an increasing trend of approximately 1°C per year. Based on the temperatures, Walker would be classified as a warm water fishery under state surface water regulations (314 CMR 4). Under the regulations, warm waters are required to have dissolved oxygen concentrations of 5 ppm or greater. Although there are infrequent dissolved oxygen concentrations lower than 5 ppm, average summer concentrations are above this regulatory limit (Figure VI-14).



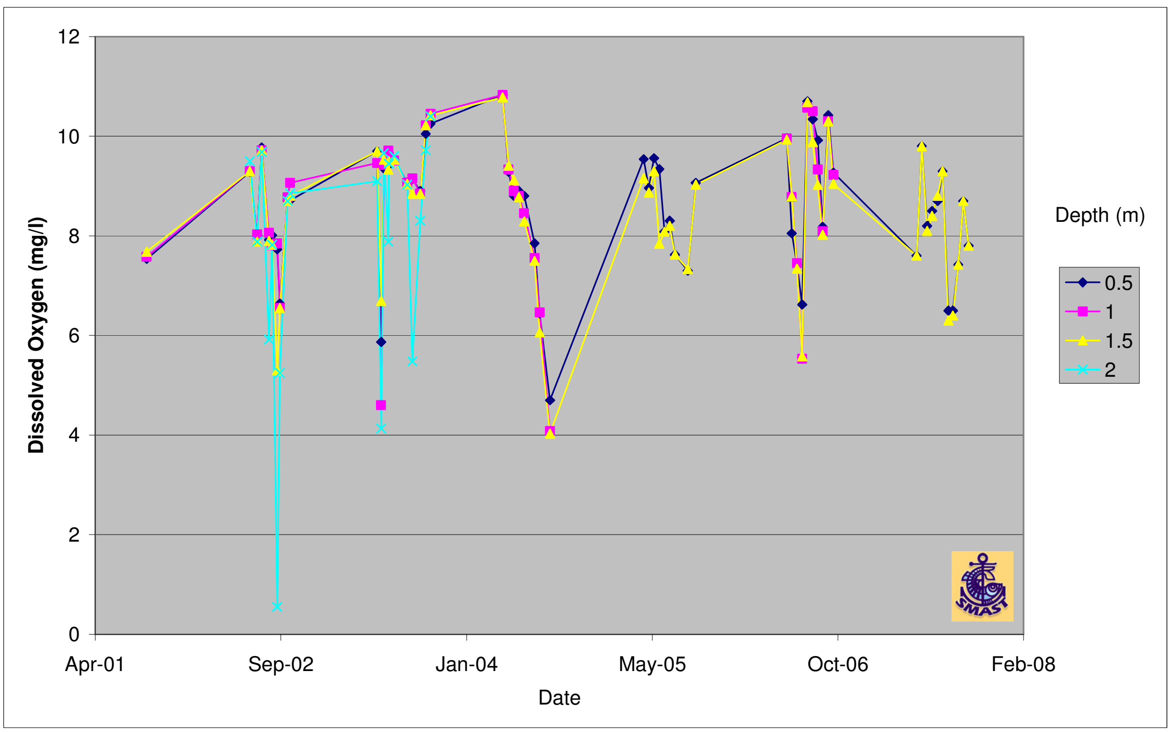


Figure VI-13. Walkers Pond Temperature and DO Readings 2001-2007
Temperature data shows well-mixed water column with generally consistent water column temperatures throughout the year. Dissolved oxygen concentrations show relatively large fluctuations during the summer, but most concentrations are above state regulatory minimums. All data collected by Brewster volunteers using DO/Temp meters, including data from PALS Snapshots from 2001 to 2007.

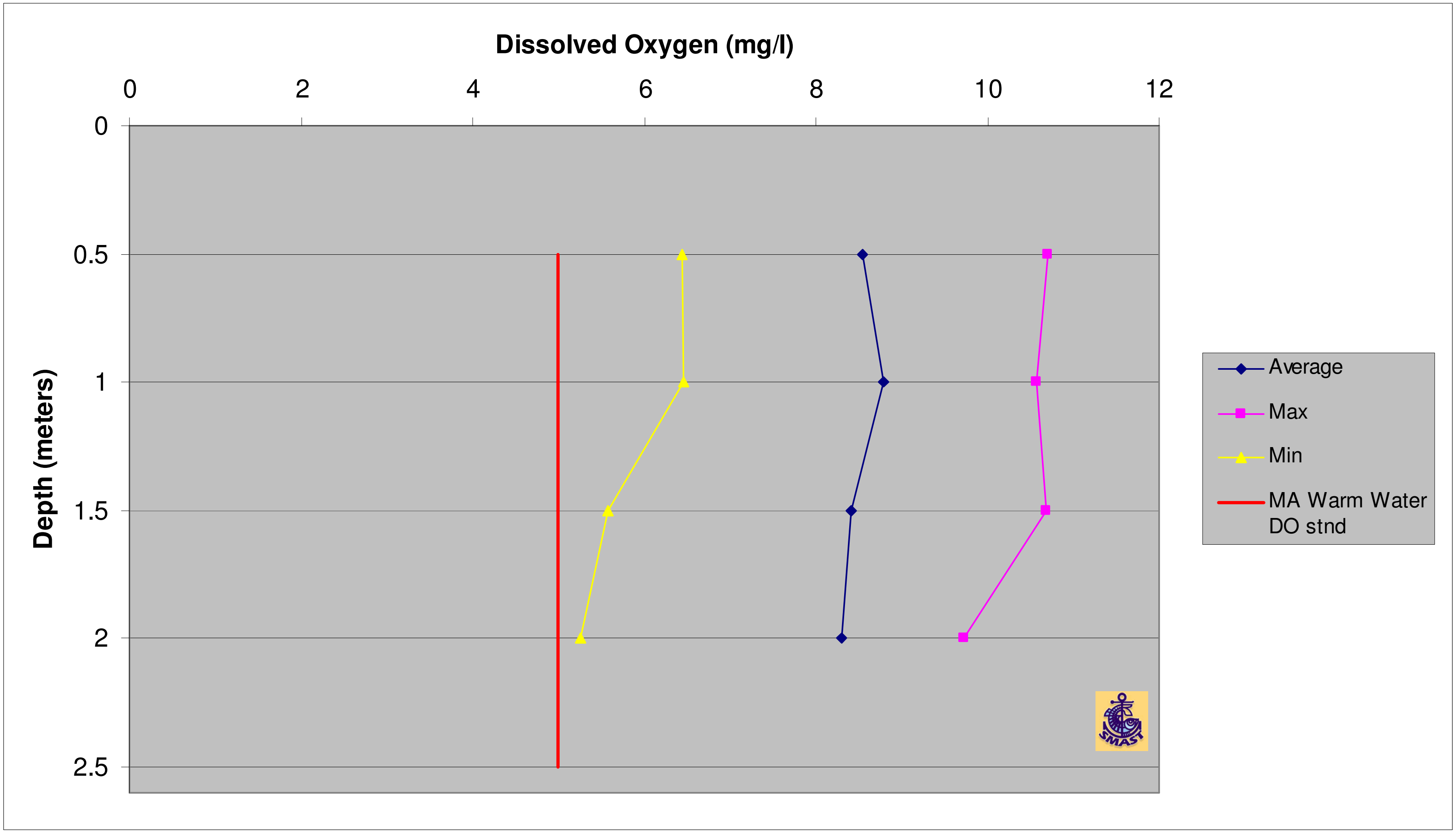


Figure VI-14. Walkers Pond: Average dissolved oxygen concentrations (June through September, 2001-2007)
Graph shows average DO profile based on data between 2001 and 2007 plus profiles based on maximum and minimum readings at each depth. Also shown is state surface water 5-ppm DO standard for warm water fisheries (314 CMR 4). Station depths have between 16 and 46 readings. All station concentrations exceed the state regulatory standard for dissolved oxygen.

It should also be noted, however, that the summer fluctuations in dissolved oxygen concentrations are relatively large and include regular instances of supersaturation. These kinds of fluctuations and supersaturation events are generally seen in impaired systems with large phytoplankton populations and sediment oxygen demand (*e.g.*, Eichner, 2004).

However, because dissolved oxygen, temperature, and pH readings are the only current, formal regulatory limits for pond water quality, it is project staff opinion that Walkers Pond would not be classified by the state Department of Environmental Protection as an impaired water under 314 CMR 4. It should be noted, however, that all the other water quality measures suggest that Walkers is impaired by excessive nutrients. DEP does not have numeric standards for nutrients.

Average total phosphorus and chlorophyll *a* concentrations are more than five and 10 times their respective Cape Cod-specific thresholds (10 ppb and 1.7 ppb, respectively)(Eichner and others, 2003). The average relative Secchi reading is only 32%, which is surprising in such a shallow pond. Overall Secchi readings are relatively stable, which indicates that conditions are not worsening (Figure VI-15). The best relative Secchi reading in Brewster is Little Cliff Pond at 79% (see Figure III-2).

Review of nitrogen to phosphorus ratios in Walkers show that the pond is phosphorus limited, which means that control of phosphorus is the key nutrient for determining water quality in the pond. Average surface N to P ratio during June through September is 34; generally water concentrations ratios above the Redfield ratio of 16 are phosphorus limited (Redfield and others, 1963). As would be expected for such a well-mixed pond, the average N to P ratio in deep waters is approximately the same (31) as the surface waters.

Since phosphorus is the key for determining water quality in Walkers Pond, one of the next steps is to determine the sources and magnitude of phosphorus. Understanding the sources and magnitude of phosphorus is usually done through the development of a phosphorus budget. Most of the sources in the budget will be from the watershed, but the pond sediments can also be an internal source. None of these sources have been measured directly, but information developed on ponds and lakes in similar settings can be used to develop a reasonable estimate. More detailed Walkers Pond-specific measurements would be necessary to refine the results presented here and are recommended for key factors such as road runoff, bird loading, and sediment regeneration.

In order to begin to develop a watershed phosphorus budget for Walkers 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.

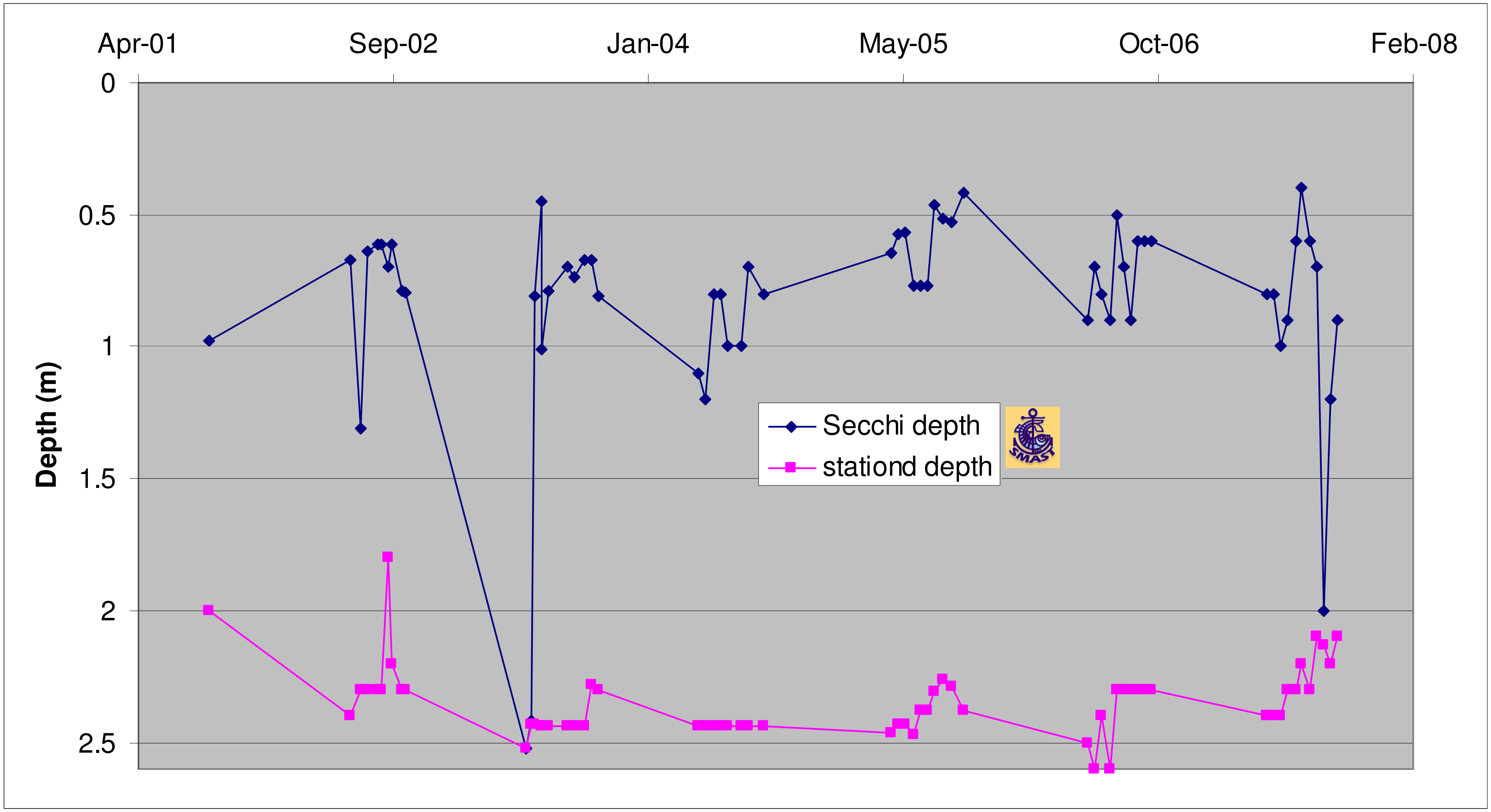


Figure VI-15. Walkers Pond: Secchi transparency readings 2001-2007
Blue data points are Secchi depth readings, while station depth measurements are shown in pink. All data collected by Brewster volunteers. Neither station nor Secchi depths have a discernable trend over the sampling period. Secchi readings are 32% of the total depth on the pond on average, which is third worst among ponds shallower than 5 m.

Based on this land use review, there are 40 properties wholly or partially within the 300 ft buffer upgradient of Walkers Pond; 21 of them are single family residences and 13 are government owned properties. The other properties are 6 undeveloped parcels, two of which are classified as developable, and one multi-family residence. None of the Brewster residences are connected to the municipal water supply based on 2002 to 2004 water use and are assumed to get their water from private wells. Thirteen of the existing single family residences and one government property (Camp Mitton) have septic system leachfields within 300 feet of the pond shore; the average distance for these leachfields is 184 feet. Average age of these residential septic systems is 22 years old with a total Title 5 design flow of 4,510 gallons per day. Camp Mitton has a septic system with a design flow of 1,960 gpd. Using average single family residence water use in Brewster, total estimated residential water use is 2,279 gpd or roughly half of the septic system design flow. Based on the age of the septic systems, distance to the pond, and the range of retention factors discussed above, 4 to 10 of the residential septic systems are contributing phosphorus to Walkers Pond (Figure VI-16). The wastewater load from Camp Mitton is projected to reach the pond between 7 to 16 years. The residential systems are contributing 1.8 to 4.5 kg/yr of wastewater phosphorus and will contribute 5.9 kg/y at steady state.

The remaining sources of phosphorus loading (runoff, lawns, birds, and precipitation), total between 4 to 16 kg without including an estimate for internal sediment regeneration. Within these loads, the sources that are the most uncertain are road runoff and birds; the wide range of these factors is evident in their changing percentages of the high and low loading estimates in Figure VI-16. It should be noted that the only downgradient area around Walkers Pond is the small portion of the isthmus between Walkers and Upper Mill, so watershed phosphorus sources come from both the east and west sides of the pond (see Figure V-4). Gathering of Walker Pond-specific information is recommended to clarify both road runoff and bird phosphorus loading.

Based on the phosphorus loading analysis, the annual load of phosphorus entering Walkers Pond is between 6 and 21 kg. Reviewing the water quality data can provide a reliability check on the loading analysis. After reviewing the nine sampling runs completed between June and September, an average of 89 kg of phosphorus is in the water column of Walkers. Since the residence time of water in the pond is 1.0 years (see Table V-1), this means that 89 kg of phosphorus is being added to the water column each year. This calculation suggests that there is a large phosphorus source that is unaccounted for in the loading analysis and that this source is likely related to past historic uses around the pond.

The likely source of this unaccounted load is the sediments regenerating phosphorus. Although the dissolved oxygen analysis does not show average concentrations lower than state standards, there are occasional drops in concentration that suggest that there is regular sediment oxygen demand. Given Walkers relatively high elevation, it is likely that the oxygen demand is usually met by winds blowing across its surface and mixing atmospheric oxygen into the water column. This mixing likely masks the demand and the sediment regeneration of phosphorus because any regenerated phosphorus would be rapidly mixed into the water column. More refined sampling of the sediments and continuous monitoring of dissolved oxygen concentrations would be necessary to further evaluate the sediment-water column interactions.

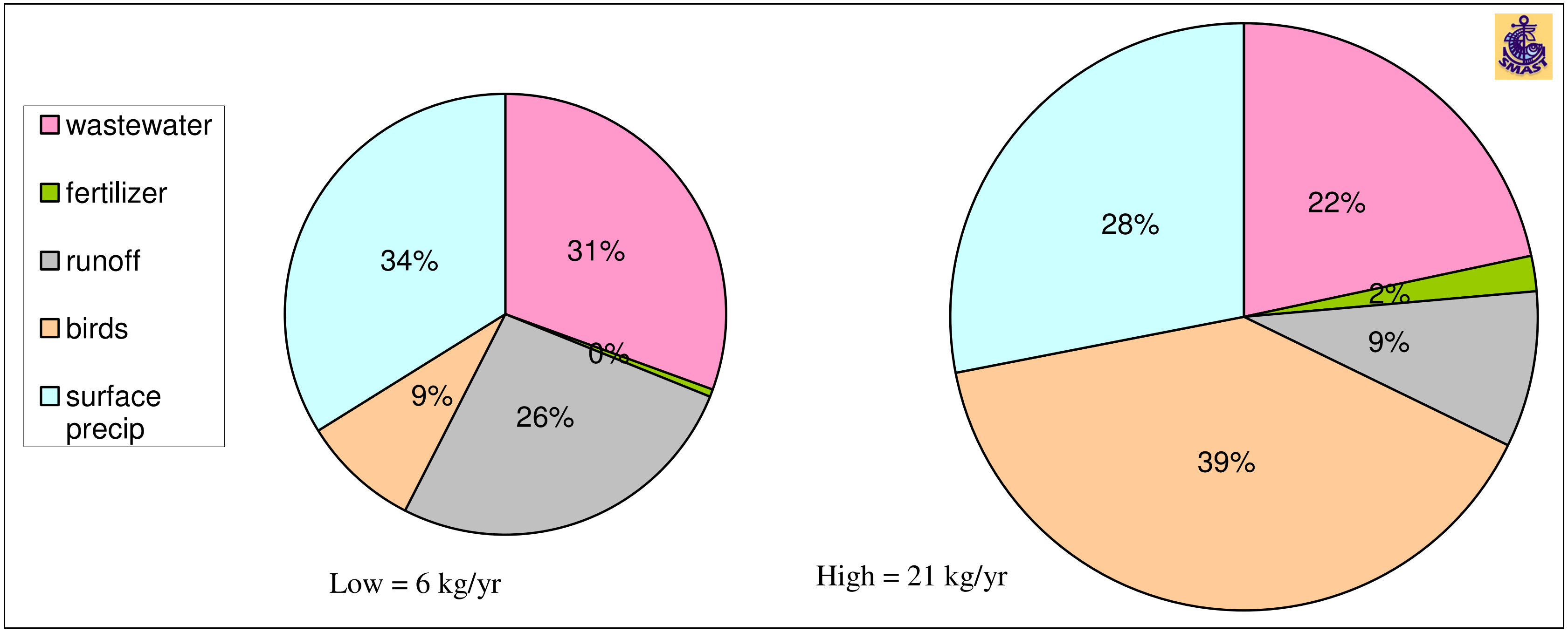


Figure VI-16. Walkers Pond: Estimated annual phosphorus budget
High and low estimates based on factors discussed in Section V.3 and presented in Table V-3. Average in-lake mass, corrected for residence time, results in an annual load of 89 kg based on measured water quality data (n=9 sampling runs). Contribution of seasonal phosphorus regeneration from the sediments is not clear from available data; it is likely the source of the remainder of the phosphorus measured in the pond. It is recommended that this be measured directly through collection and testing of sediment cores. Based on the age of upgradient septic system leachfields and their distance to the shoreline, 4 to 10 of the 13 systems within a 300 ft buffer are contributing phosphorus to the pond. Road runoff and bird loads are the most uncertain and it is recommended that the town evaluate these with targeted data collection.

Under the usual interpretation of state surface water regulations, Walkers Pond is not impaired and does not require a TMDL. However, based on ecological standards developed for Cape Cod ponds, it is impaired and will likely eventually meet the dissolved oxygen criteria that the state DEP uses for establishing whether a TMDL is required. So at this point, it is up to the Town of Brewster about how to respond to the water quality conditions in Walkers Pond.

If the town wishes to address the ecosystem impairment in Walkers, it is recommended that the town consider pursuing some additional characterization of load components/sources before the Town pursues remedial activities. It is recommended that the Town target these efforts toward: 1) characterizing phosphorus flow into and out of the sediments, 2) measuring local phosphorus inputs from road runoff, and 3) getting a better understanding of the bird populations that use Walkers. These activities could be combined with complimentary efforts that will provide all the information necessary to develop a phosphorus TMDL for Walkers Pond and the necessary phosphorus reduction steps to meet the TMDL. These steps will allow the town to develop management strategies that can be confidently pursued.

In order to address these recommendations, SMAST staff recommend that these efforts include the following tasks, at a minimum: 1) collection and incubation of a minimum of three sediment sample cores to determine phosphorus content and regeneration potential related to dissolved oxygen thresholds, 2) a whole year of observation of bird populations on the pond, including identification of species, and 3) a survey of stormwater systems and measurement of runoff near Walkers with regular testing of the phosphorus content of the runoff. SMAST may also be able to provide access to continuous dissolved oxygen meters that would allow a better quantification of sediment oxygen demand. It is also recommended that occasional water quality samples be collected from the pond using the standard PALS sampling depths to provide an integrated snapshot of the pond conditions and help to better understand sampling conditions during this period compared to average conditions.

Depending on how well the recommended information helps to settle the phosphorus budget, the town may also want to consider the completion of a comprehensive plant survey. In most Cape Cod ponds, the algal/phytoplankton portion of the plant community is very dominant and the relationship between phosphorus and pond ecosystems conditions is very strong. But in some impaired and/or heavily used ponds (*e.g.*, Long Pond in Barnstable), this relationship can be skewed by conditions that have created an extensive rooted aquatic plant community. In these ponds, most of the phosphorus is bound in the rooted plants and little is available for algae, so the clarity can be good, but much of the pond surface is covered with leaves from the rooted plants. Observations from PALS samplers between 2001 and 2007 have not noted extensive plant coverage in Walkers, but it may be useful during the development of remedial options to have a more definitive assessment. Although beyond the scope of this project, SMAST is available to assist the town in evaluating whether a comprehensive plant survey should be recommended for Walkers Pond.

SMAST staff have estimated that the cost of a stand alone project at Walkers Pond for these recommended activities between $32,000 and $35,000 with another $10,000 to $12,000 for combining this information with past information and developing water quality management strategies and a recommended TMDL. A rooted plant survey, including mapping, transects and species identification, would have an estimated cost of between $8,000 and $10,000. Significant potential savings might be realized by completing these recommended analyses on a number of ponds and/or by incorporating citizen volunteer and town staff participation where appropriate. SMAST staff can discuss strategies with town staff and provide the town with a detailed scope of work if requested.

If the town chooses to wait on addressing the ecosystem impairments in Walkers Pond, it is recommended that the town continue to collect water quality samples at least twice a year (once in April and another in August or September) and that this sampling include regular dissolved oxygen readings to gauge whether water quality conditions fail to attain state regulatory standards.

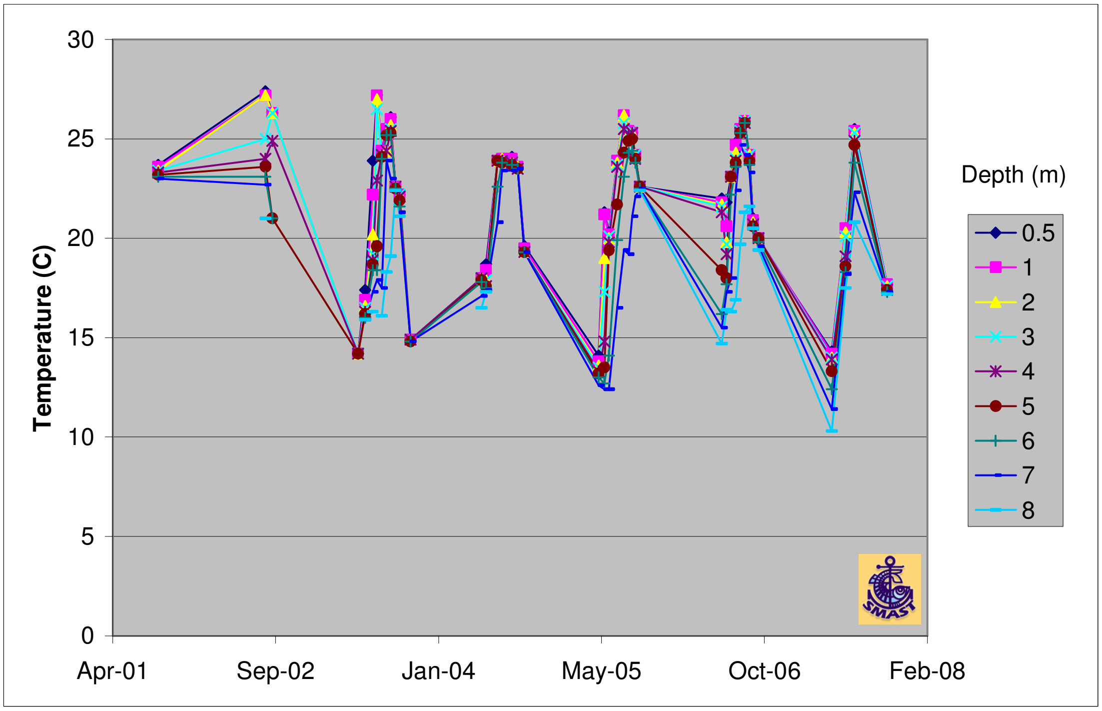
Regardless of the action chosen by the town, there are a number of best management practices that can be pursued to ensure that watershed loads are minimized. These include maintenance of the natural shoreline buffers and redirecting any direct stormwater runoff. These practices are relatively lost cost best management practices. More refined review of the potential benefits and costs of the various nutrient management options could be evaluated as part of a slight expansion of the activities recommended above.

VI.5. Upper Mill Pond

Upper Mill Pond is a 260-acre pond that is located to the north of Walkers Pond and east of Canoe (see Figure V-1). It is the largest of the ponds selected for detailed review and is 8.5 m (~28 ft) deep.

Temperature data collected between 2001 and 2007 shows that Upper Mill's water column is generally well mixed with slightly colder temperatures with increasing depth (Figure VI-17). On average, only the deepest waters (<1% of the volume) meet the state regulatory limit for cold-water fisheries (20ºC or less), so Upper Mill should be classified as a warm water fishery. As such, state surface water regulations (314 CMR 4) require the pond to have dissolved oxygen concentrations of 5 ppm or above. On average, waters 7 m and deeper fail to attain 5 ppm dissolved oxygen, the deep waters are approximately 6% of the total pond volume (Figure VI-18).

Based on dissolved oxygen concentrations only, Upper Mill is borderline impaired. When other water quality information is considered, it is clear that Upper Mill is clearly impaired. Average total phosphorus and chlorophyll *a* concentrations at all depth stations, throughout the water column, are above their respective Cape Cod pond water quality thresholds (Eichner and others, 2003). The deep waters have occasional anoxia (DO concentrations < 1 ppm). Average total phosphorus concentration at the deepest station (~ 7 m) is more than twice the surface concentration, which indicates significant regeneration of phosphorus from the sediments. Average Secchi transparency readings are 21% of the total pond volume, which is the second lowest percentage among all the Brewster Ponds (Cliff is the worst: 16%) (Figure VI-19). When all these measures are considered together, it is clear that Upper Mill should be considered impaired under state surface water regulations. Under the state and federal Clean Water Acts, impaired waters are required to have a total maximum daily load (TMDL) for the contaminant that is causing the impairment. Since the Massachusetts Department of



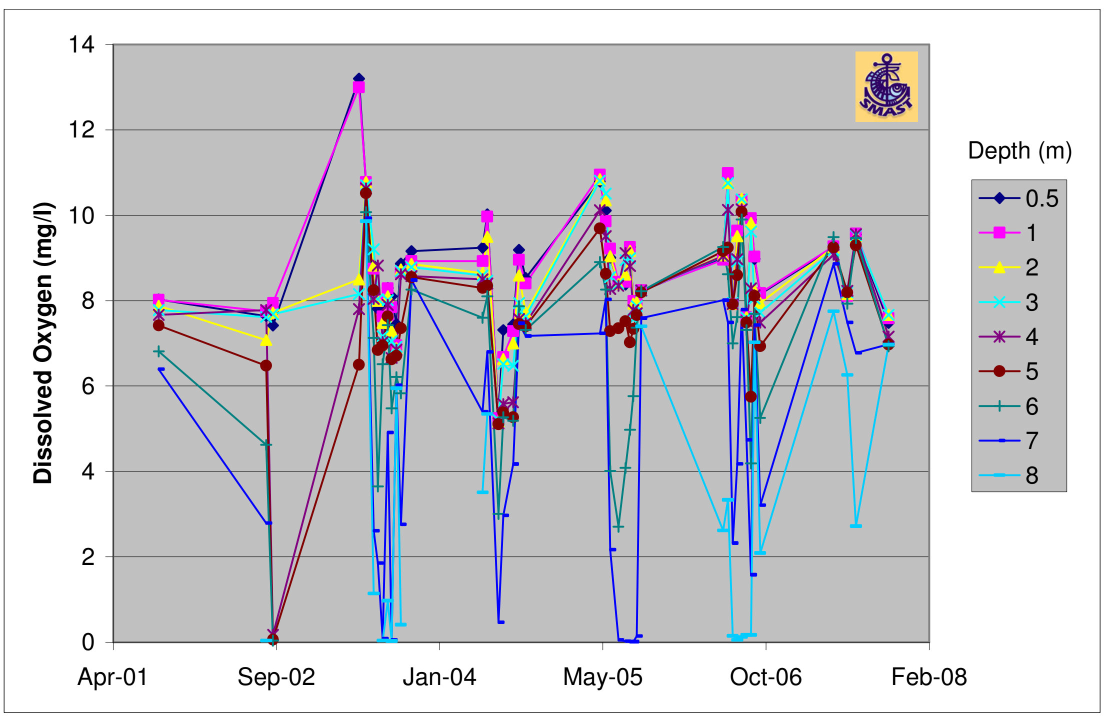


Figure VI-17. Upper Mill Pond Temperature and DO Readings 2001-2007
Temperature data shows well-mixed water column with generally consistent water column temperatures throughout the year. Dissolved oxygen concentrations show relatively large fluctuations during the summer with concentrations 7 m and deeper regularly below state surface water regulatory limits. All data collected by Brewster volunteers using DO/Temp meters, including data from PALS Snapshots from 2001 to 2007.

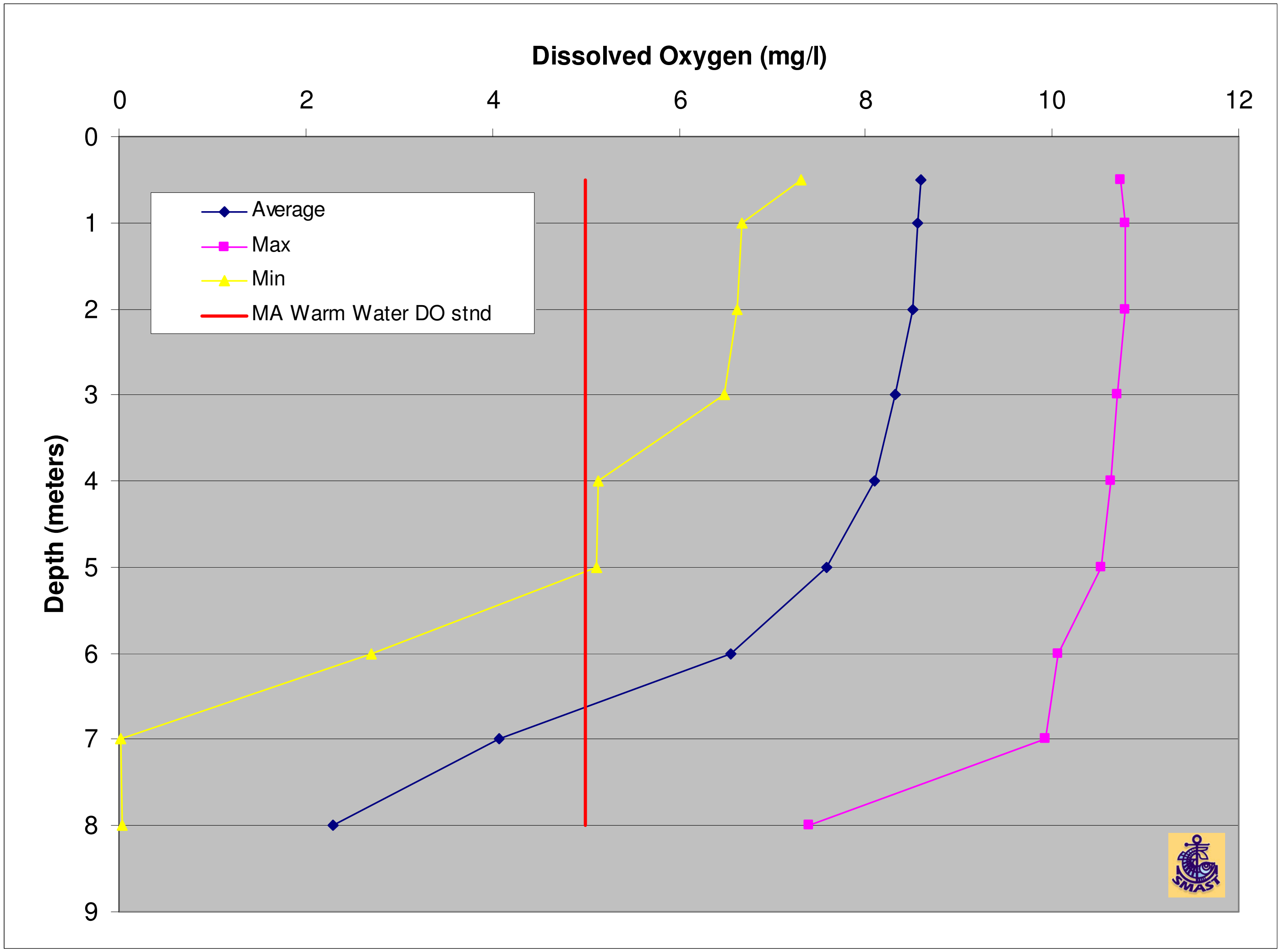


Figure VI-18. Upper Mill Pond: Average dissolved oxygen concentrations (June through September, 2001-2007)
Graph shows average DO profile based on data between 2001 and 2007 plus profiles based on maximum and minimum readings at each depth. Also shown is state surface water 5-ppm DO standard for warm water fisheries (314 CMR 4). Most station depths have between 33 and 34 readings. The two deepest stations have average concentrations below the state regulatory standard for dissolved oxygen and anoxic concentrations (< 1 ppm) have also been recorded at these stations.

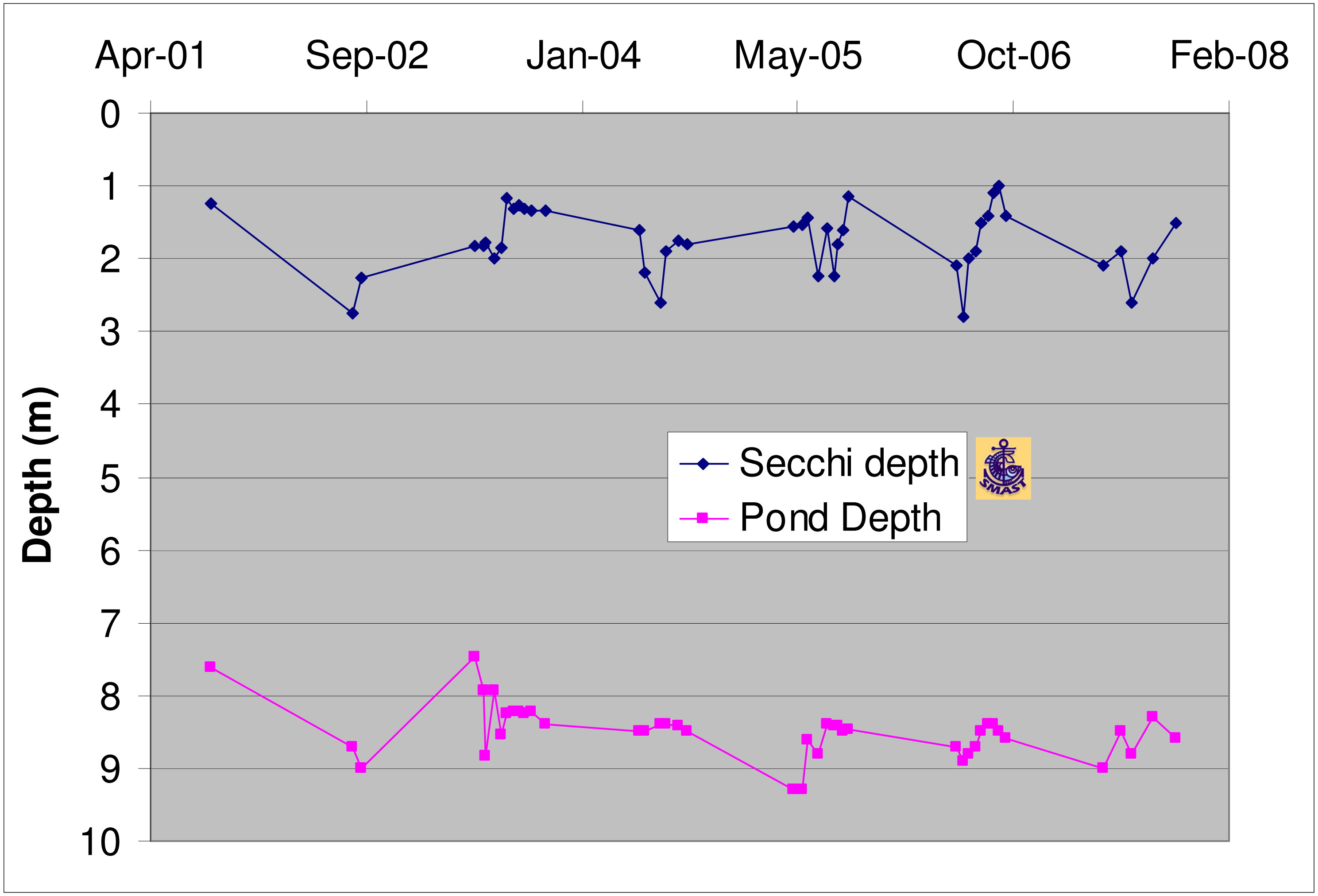


Figure VI-19. Upper Mill Pond: Secchi transparency readings 2001-2007
Blue data points are Secchi depth readings, while station depth measurements are shown in pink. All data collected by Brewster volunteers. Neither station nor Secchi depths have a discernable trend over the sampling period. Secchi readings are 21% of the total depth on the pond on average, which is second worst among all Brewster ponds.

Environmental Protection implements the state surface water regulations, this opinion would need to be submitted to MassDEP in order to get a definitive ruling.

Review of nitrogen to phosphorus ratios in Upper Mill show that the pond is phosphorus limited, which means that control of phosphorus is the key nutrient for determining water quality in the pond and, therefore, is the nutrient/contaminant that should be targeted for a TMDL. Average surface N to P ratio during June through September is 43; generally water concentrations ratios above the Redfield ratio of 16 are phosphorus limited (Redfield and others, 1963). At the deep station, which is influenced by regeneration of nutrients from the sediments, the average N to P ratio is 38, which indicates that more phosphorus than nitrogen is being regenerated.

Since phosphorus is the key for determining water quality in Upper Mill, one of the next steps is to determine the sources and magnitude of phosphorus. Once this is completed, community discussions and cost estimates can help to determine what combination of phosphorus management strategies will be adopted to remediate Upper Mill Pond. Understanding the sources and magnitude of phosphorus is usually done through the development of a phosphorus budget.

As mentioned above, the phosphorus budget will account for all the various sources entering the pond water. Most of the sources will be from the watershed, but the pond sediments can also be an internal source. None of these sources have been measured directly, but information developed on ponds and lakes in similar settings can be used to develop a reasonable estimate. More detailed Upper Mill Pond-specific measurements would be necessary to refine the results presented here and are recommended for key factors such as road runoff, bird loading, and sediment regeneration.

In order to begin to develop a watershed phosphorus budget for Upper Mill 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.

Based on this land use review, there are 96 properties wholly or partially within the 300 ft buffer upgradient of Upper Mill Pond; 67 of which are single family residences and 9 are developable residential parcels. None of the residences are connected to the municipal water supply based on 2002 to 2004 water use and are assumed to get their water from private wells. Thirty-eight of the existing residences have septic system leachfields within 300 feet of the pond shore; the average distance for these systems is 194 feet. Average age of these residential septic systems is 19 years old connected to a house that is, on average, 10 years old. These septic systems have a total Title 5 design flow of 18,590 gallons per day. Using average single family residence water use in Brewster, total estimated water use is 6,662 gpd or roughly a third of the septic system design flow. Based on the age of the septic systems, distance to the pond, and the range of retention factors discussed above, 13 to 24 of the septic systems are currently contributing between 6 and 11 kg of wastewater phosphorus annually to Upper Mill Pond (Figure VI-20). At steady state, these systems will contribute 17 kg/yr of wastewater phosphorus and at BO the load is projected to increase to 21 kg/yr.

The remaining sources of phosphorus loading (runoff, lawns, birds, and precipitation), total between 10 to 43 kg/yr without including an estimate for internal sediment regeneration. Within these loads, the sources that are the most uncertain are road runoff and birds; the wide range of these factors is evident in their changing percentages of the high and low loading estimates in Figure VI-20. Gathering of Upper Mill Pond-specific information is recommended to clarify both of these factors.

Based on the phosphorus loading analysis, the total annual load of phosphorus entering Upper Mill Pond is between 16 and 54 kg. Reviewing the water quality data can provide a reliability check on the loading analysis by calculating the average mass of phosphorus in Upper Mill Pond. After reviewing the 11 sampling runs completed between June and September, an average of 345 kg of phosphorus is in the water column of Upper Mill with an average of 15% in the waters 7 m and deeper. Since the residence time of water in the pond is 3.6 years (see Table V-1), this means that roughly 96 kg of phosphorus is being added to the water column each year.

The phosphorus budget to Upper Mill is further complicated by trying to understand the connections between Upper Mill and both Canoe and Walkers Pond. Canoe is in the watershed to Upper Mill, but the only significant way it can contribute to Upper Mill's phosphorus budget is if there is a direct connection to Upper Mill. Previous discussions with local observers of Canoe indicated that there is occasional connection to Upper Mill. It is beyond the scope of the current project to complete an evaluation of this impact, but it is recommended that additional field visits include a more refined review of this potential connection.

More significantly, Walkers Pond is directly upgradient of Upper Mill and the only direction that its water can move out of the pond is toward Upper Mill. If all the water exchanged out of Walkers entered Upper Mill without attenuation of phosphorus, an additional 89 kg/y would enter Upper Mill and provide a better balance for the phosphorus budget. The actual amount that reaches Upper Mill would likely be significantly reduced because there appears to be only a small direct surface water connection between the two ponds. The size of this connection suggests that the majority of the discharge into Upper Mill is via groundwater, which would also mean that a large portion of the accompanying phosphorus would be attenuated and the load from Walker would be reduced. It is recommended that further evaluation of Upper Mill in anticipation of preparation of a TMDL include characterization of the surface water connection between Walkers and Upper Mill and quantification of the load transferred to Upper Mill from Walkers.

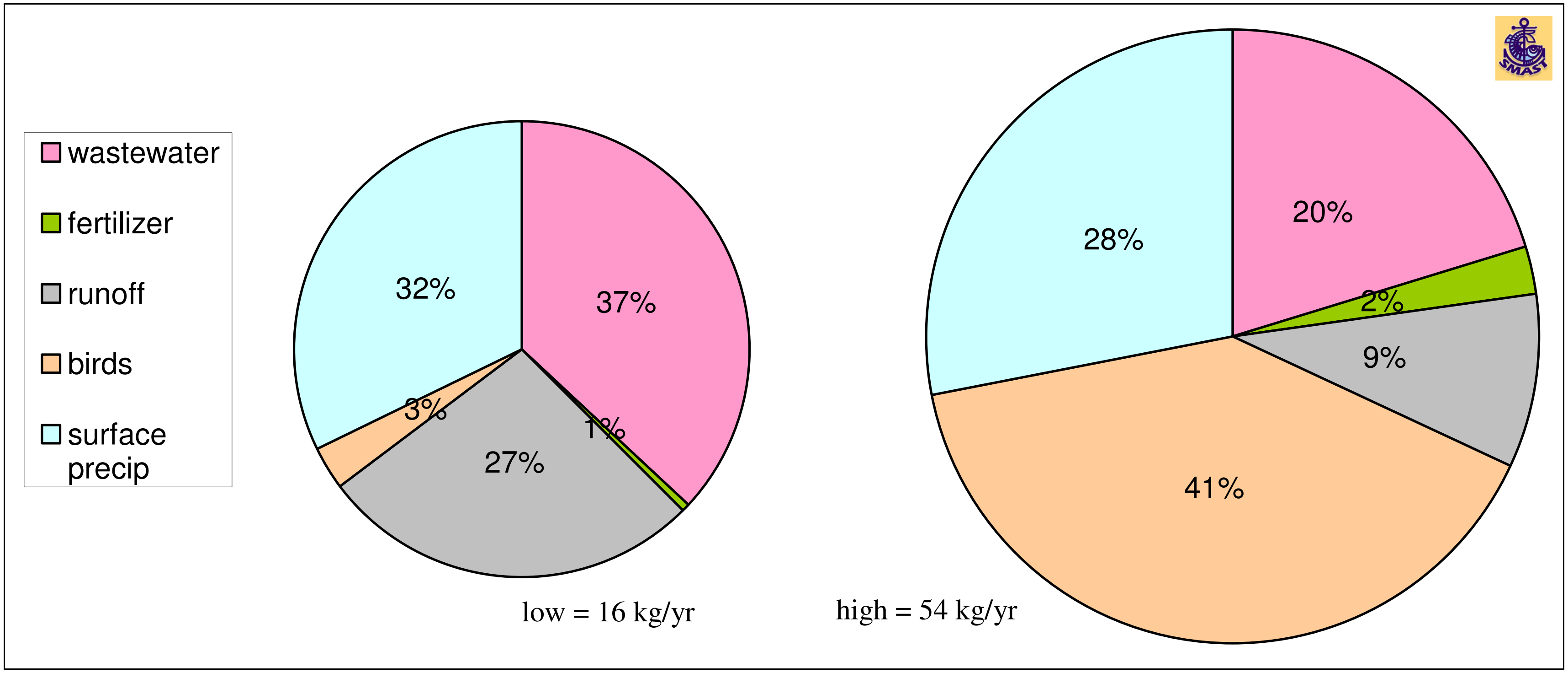


Figure VI-20. Upper Mill Pond: Estimated annual phosphorus budget
High and low estimates based on factors discussed in Section V.3 and presented in Table V-3. Average in-lake mass, corrected for residence time, results in an annual load of 96 kg based on measured water quality data (n=11 sampling runs). The remainder of the annual load is likely a combination of contribution of seasonal phosphorus regeneration from the sediments and from Walkers (and possibly Canoe); further information would necessary to quantify the percent contribution of each of these sources. It is recommended that the sediments be measured directly through collection and testing of sediment cores and measurement of the surface water connections can help to clarify Walker and Canoe contributions. Based on the age of upgradient septic system leachfields and their distance to the shoreline, 13 to 24 of the 67 residential septic systems within a 300 ft buffer are contributing phosphorus to the pond. Road runoff and bird loads are the most uncertain and it is also recommended that the town evaluate these with targeted data collection.

Sediment regeneration is not included in the phosphorus budget estimates, but the water quality data suggests that it is a component of the measured mass in the pond. There is a regular concentration gradient from the sediments to the water column in all summer sampling runs on Upper Mill. With the regular mixing indicated by the temperature profiles, any regenerated phosphorus would be rapidly mixed into the rest of the water column. Unfortunately, most of the available dataset has samples generally collected in mid-summer, so calculations cannot be made showing regeneration, which would generally be shown by an increase in TP concentrations as summer progresses. It is recommended that the town consider sediment characterization in order to better define this component of the phosphorus budget and be able to better define remedial activities to achieve a TMDL for Upper Mill Pond.

Overall, it is recommended that the town consider pursuing some additional characterization of load components/sources before the Town pursues remedial activities. It is recommended that the Town target these efforts toward: 1) characterizing phosphorus flow into and out of the sediments, 2) measuring local phosphorus inputs from road runoff, 3) getting a better understanding of the bird populations that use Upper Mill Pond, and 4) characterizing the water and phosphorus flows from Canoe and Walkers Ponds. The inflows of water and phosphorus should also be paired with outflow measurements to Lower Mill Pond. These activities could be combined with complimentary efforts that will provide all the information necessary to develop a phosphorus TMDL for Upper Mill Pond and the necessary phosphorus reduction steps to meet the TMDL. These steps will allow the town to develop management strategies that can be confidently pursued.

In order to address these recommendations, SMAST staff recommend that these efforts include the following tasks, at a minimum: 1) collection and incubation of a minimum of three sediment sample cores to determine phosphorus content and regeneration potential related to dissolved oxygen thresholds, 2) a whole year of observation of bird populations on the pond, including identification of species, 3) a survey of stormwater systems and measurement of runoff near Upper Mill Pond with regular testing of the phosphorus content of the runoff, and 4) monthly measurements for one year of flow and phosphorus loads from Canoe and Walkers into Upper Mill and matching measurements of outflow to Lower Mill Pond. It is also recommended that occasional water quality samples be collected from the pond during these efforts using the standard PALS sampling depths in order to provide an integrated snapshot of the pond conditions and help to better understand sampling conditions during this period compared to average conditions.

Depending on how well the recommended information helps to settle the phosphorus budget, the town may also want to consider the completion of a comprehensive plant survey. In most Cape Cod ponds, the algal/phytoplankton portion of the plant community is very dominant and the relationship between phosphorus and pond ecosystems conditions is very strong. But in some impaired and/or heavily used ponds (*e.g.*, Long Pond in Barnstable), this relationship can be skewed by conditions that have created an extensive rooted aquatic plant community. In these ponds, most of the phosphorus is bound in the rooted plants and little is available for algae, so the clarity can be good, but much of the pond surface is covered with leaves from the rooted plants. Observations from PALS samplers between 2001 and 2007 have not noted extensive plant coverage in Upper Mill, but it may be useful during the development of remedial options to have a more definitive assessment. Although beyond the scope of this project, SMAST is available to assist the town in evaluating whether a comprehensive plant survey should be recommended for Upper Mill Pond.

SMAST staff have estimated that the cost of a stand alone project at Upper Mill Pond for all these recommended activities for between $42,000 and $45,000 with another $10,000 to $12,000 for combining this information with past information and developing water quality management strategies and a recommended TMDL. A rooted plant survey, including mapping, transects and species identification, would have an estimated cost of between $8,000 and $10,000. Significant potential savings might be realized by completing these recommended analyses on a number of ponds and/or by incorporating citizen volunteer and town staff participation where appropriate. SMAST staff can discuss strategies with town staff and provide the town with a detailed scope of work if requested.

In addition, although the target watershed reductions are not clear at this point, maintenance of the natural buffers that generally and redirecting any direct stormwater runoff are relatively lost cost best management practices that can be pursued. These activities would help to minimize external watershed phosphorus loads. Review of the potential benefits and costs of the various nutrient management options could be evaluated as part of a slight expansion of the activities recommended above.

VI.6. Lower Mill Pond

Lower Mill Pond is a 49-acre pond that is located to the north of Upper Mill Pond and south of Stony Brook Road (see Figure V-1). Lower Mill is the terminus of a multi-pond watershed that includes Upper Mill, Walkers, Seymour, Slough, and Pine. It is also the headwaters of Stony Brook, which discharges into the Paines Creek estuary. Lower Mill is 3.7 m (~12 ft) deep.

Temperature data collected between 2001 and 2007 shows that Lower Mill's water column is generally well mixed with slightly colder temperatures with increasing depth; surface and deepest waters generally have only a 3 to 4ºC difference (Figure VI-21). All of depth stations have average temperature exceeding the state regulatory limit for cold-water fisheries (20ºC or less), so Lower Mill should be classified as a warm water fishery. As such, state surface water regulations (314 CMR 4) require the pond to have dissolved oxygen concentrations of 5 ppm or above. On average, waters 3.5 m and deeper fail to attain 5 ppm dissolved oxygen, these deep waters are less than 1% of the total pond volume (Figure VI-22). Based on dissolved oxygen concentrations only, Lower Mill is not impaired under the state surface water regulations.

However, when other water quality information is considered, it is clear that Lower Mill is impaired. The average surface total phosphorus concentration is three times the healthy Cape Cod pond water concentration of 10 ppb, while the surface chlorophyll *a* concentration is ten times the corresponding chlorophyll a concentration of 1.7 ppb (Eichner and others, 2003). The average Secchi transparency reading is 34% of the total pond depth (Figure IV-23). As a point of comparison, Eel Pond, which is approximately the same depth as Lower Mill has an average Secchi reading that is 57% of its total depth (see Figure III-2). When all these measures are

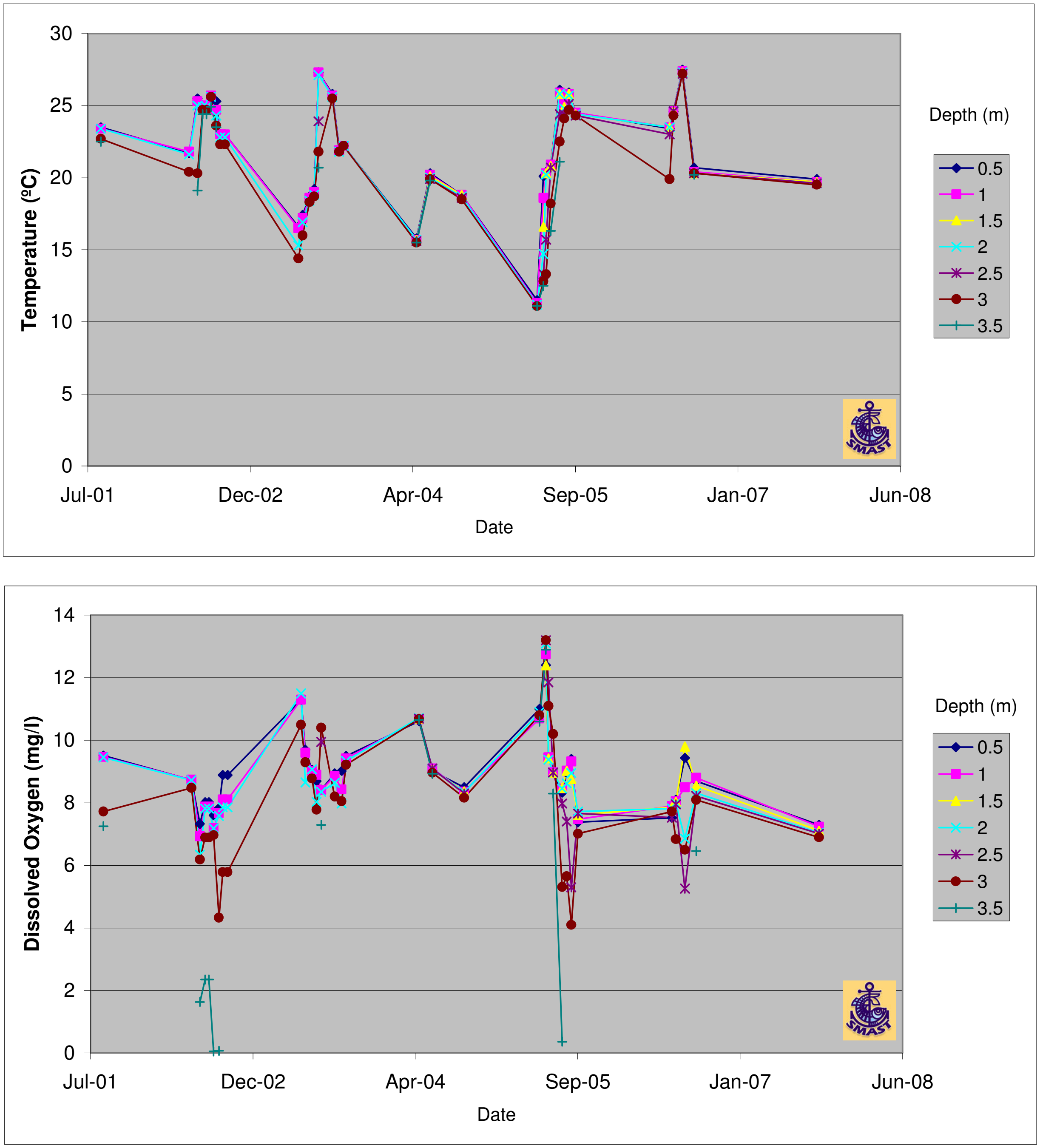


Figure VI-21. Lower Mill Pond Temperature and DO Readings 2001-2007
Temperature data shows well-mixed water column with generally consistent water column temperatures throughout the year. Dissolved oxygen concentrations show relatively large fluctuations during the summer but most readings are above state surface water regulatory limits. All data collected by Brewster volunteers using DO/Temp meters, including data from PALS Snapshots from 2001 to 2007.

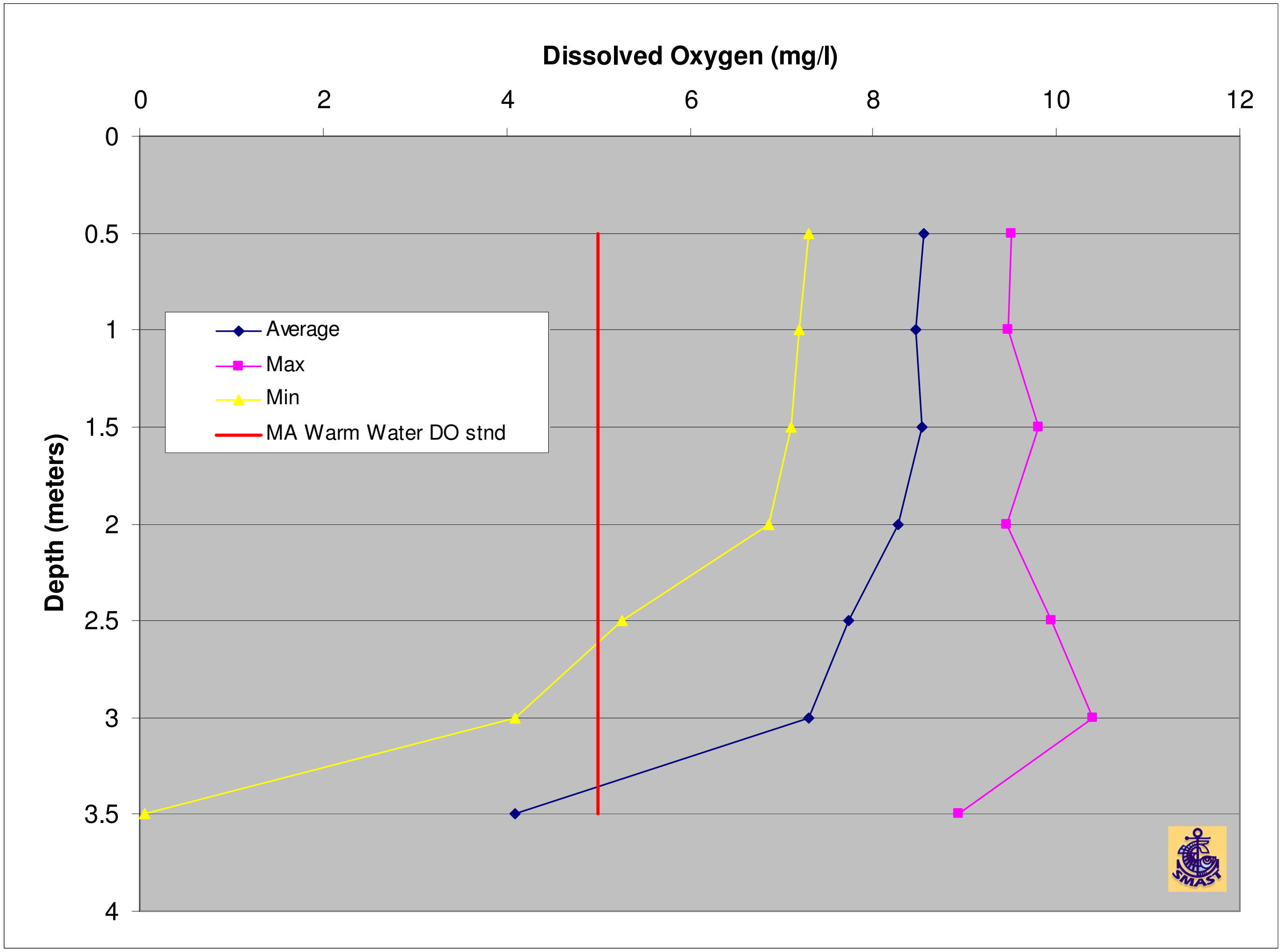


Figure VI-22. Lower Mill Pond: Average DO concentrations (June through September, 2001-2007)
Graph shows average dissolved oxygen profile based on data between 2001 and 2007 plus profiles based on maximum and minimum readings at each depth. Also shown is state surface water 5-ppm DO standard for warm water fisheries (314 CMR 4). Station depths have between 11 and 28 readings. Only the deepest station has an average concentration below the state regulatory standard for dissolved oxygen and recorded anoxic concentrations (< 1 ppm). This pond volume at this station is <1% of the total pond volume.

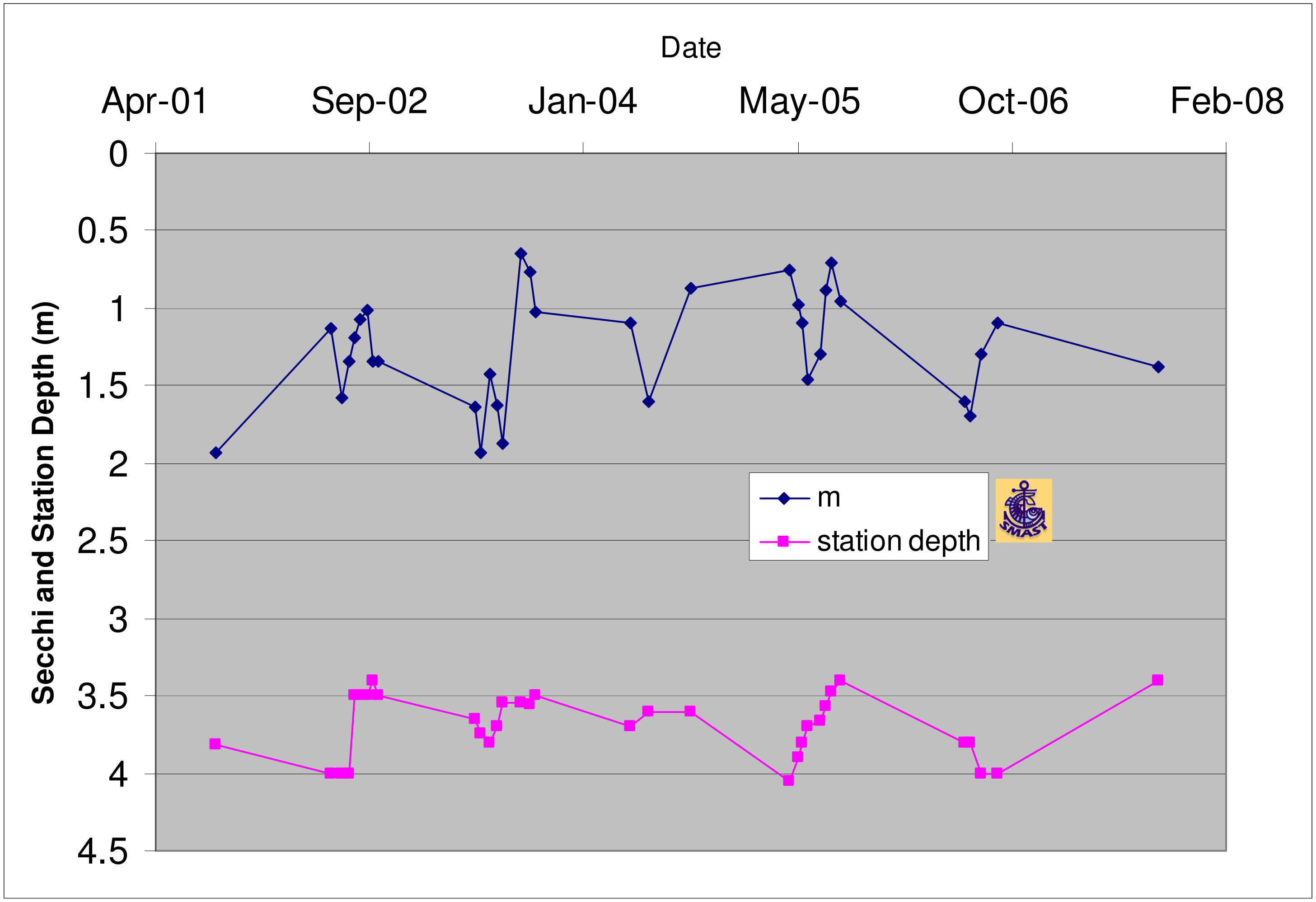


Figure VI-23. Lower Mill Pond: Secchi transparency readings 2001-2007
Blue data points are Secchi depth readings, while station depth measurements are shown in pink. All data collected by Brewster volunteers. Neither station nor Secchi depths have a discernable trend over the sampling period. Secchi readings are 34% of the total depth on the pond on average. This relative Secchi reading can be compared to Eel Pond, which is approximately the same depth, and has a relative Secchi reading of 57%.

considered together, it is clear that Lower Mill should be considered impaired under state surface water regulations. Under the state and federal Clean Water Acts, impaired waters are required to have a total maximum daily load (TMDL) for the contaminant that is causing the impairment.

Review of nitrogen to phosphorus ratios in Lower Mill show that the pond is phosphorus limited, which means that control of phosphorus is the key nutrient for determining water quality in the pond. Average surface N to P ratio during June through September is 34; generally water concentrations ratios above the Redfield ratio of 16 are phosphorus limited (Redfield and others, 1963). At the deep station, which is influenced by regeneration of nutrients from the sediments, the average N to P ratio is 26, which indicates that more nitrogen than phosphorus is being regenerated.

Since phosphorus is the key for determining water quality in Lower Mill, one of the next steps is to determine the sources and magnitude of phosphorus. Once this is completed, community discussions and cost estimates can help to determine what combination of phosphorus management strategies will be adopted to remediate Lower Mill Pond. Understanding the sources and magnitude of phosphorus is usually done through the development of a phosphorus budget.

As mentioned above, the phosphorus budget will account for all the various sources entering the pond water. Most of the sources will be from the watershed, but the pond sediments can also be an internal source. None of these sources have been measured directly, but information developed on ponds and lakes in similar settings can be used to develop a reasonable estimate. More detailed Lower Mill Pond-specific measurements would be necessary to refine the results presented here and are recommended for key factors such as road runoff, bird loading, and sediment regeneration.

In order to begin to develop a watershed phosphorus budget for Lower Mill 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.

Based on this land use review, there are 21 properties wholly or partially within the 300 ft buffer upgradient of Upper Mill Pond; 13 of which are single family residences and 6 are developable residential parcels. None of the residences are connected to the municipal water supply based on 2002 to 2004 water use and are assumed to get their water from private wells. Ten of the existing residences have septic system leachfields within 300 feet of the pond shore; two additional residences do not have adequate information in their BOH records to calculated distance to the shoreline. The average distance for the leachfields of the ten systems is 176 feet. Average age of these residential septic systems is 20 years old connected to a house that is, on average, 37 years old. These septic systems have a total Title 5 design flow of 4,180 gallons per day. Using average single family residence water use in Brewster, total estimated water use is

1,753 gpd or roughly half of the septic system design flow. Based on the age of the septic systems and the houses, distance to the pond, and the range of retention factors discussed above, nine of the septic systems are currently contributing 4.1 kg of wastewater phosphorus annually to Lower Mill Pond (Figure VI-24). At steady state, these systems will contribute 5.5 kg/yr of wastewater phosphorus and at BO the load is projected to increase to 8.6 kg/yr.

The remaining sources of phosphorus loading (runoff, lawns, birds, and precipitation), total between 2.9 to 8.9 kg/yr without including an estimate for internal sediment regeneration. Within these loads, the sources that are the most uncertain are road runoff and birds; the wide range of these factors is evident in their changing percentages of the high and low loading estimates in Figure VI-24. Gathering of Lower Mill Pond-specific information is recommended to clarify both of these factors.

Based on the phosphorus loading analysis, the total annual load of phosphorus entering Lower Mill Pond is between 7 and 13 kg. Reviewing the water quality data can provide a reliability check on the loading analysis by calculating the average mass of phosphorus in Lower Mill Pond. After reviewing the 14 sampling runs completed between June and September, an average of 43 kg of phosphorus is in the water column of Lower Mill. Since the residence time of water in the pond is 0.24 years (see Table V-1), this means that roughly 175 kg of phosphorus is being added to the water column each year.

The phosphorus budget to Lower Mill is further complicated by trying to understand the connections between Lower Mill and Upper Mill. Aerial photographs show that there is a surface water connection between the two ponds, but it is beyond the scope of this project to collect streamflow information. According to the annual water budget, 4.6 million cubic meters flows from Upper Mill to Lower Mill. Based on past experiences on the Cape, the stream connecting the two ponds does not appear to be large enough for this type of flow, but based on Upper Mill's average total phosphorus concentration and this flow, the maximum mass of phosphorus added to Lower Mill by Upper Mill would be 86 kg/yr. Some portion of this load would likely be retained during travel through the stream and it would be significantly diminished if a large portion of the flow from Upper Mill enters Lower Mill via groundwater. It is recommended that additional field visits include a more refined review of this potential connection.

This analysis indicates that in order to bring the phosphorus budget into balance, there needs to be another source of at least 75 kg/y. The only remaining significant unaccounted source is sediment regeneration. Changes in deep total phosphorus concentrations are inconclusive, largely because samples have not been collected early in the spring. Additional characterization of the sediments would be necessary to see how well it matches the calculated budget shortfall.

Overall, it is recommended that the town consider pursuing some additional characterization of load components/sources before the Town pursues remedial activities. It is recommended that the Town target these efforts toward: 1) characterizing phosphorus flow into and out of the sediments, 2) measuring local phosphorus inputs from road runoff, 3) getting a better understanding of the bird populations that use Lower Mill Pond, and 4) characterizing the

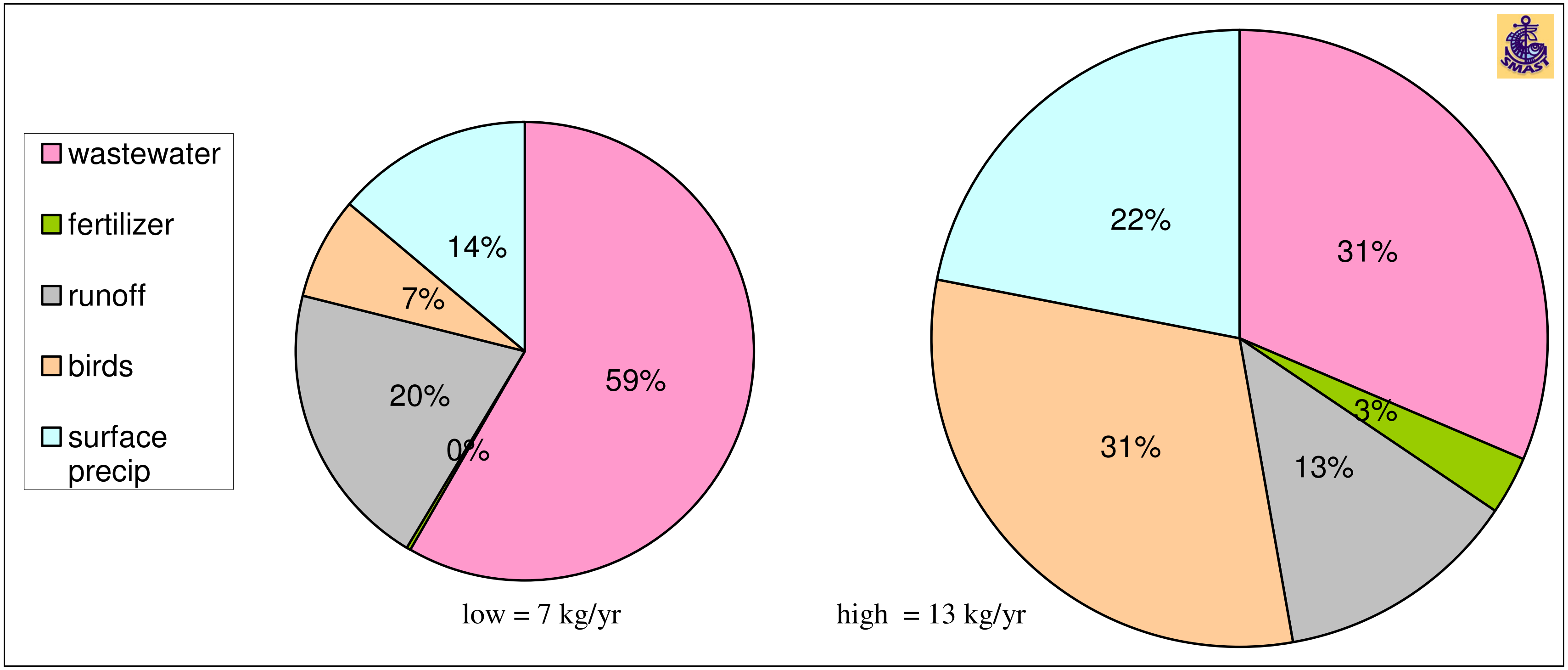


Figure VI-24. Lower Mill Pond: Estimated annual phosphorus budget

High and low estimates based on factors discussed in Section V.3 and presented in Table V-3. Average in-lake mass, corrected for residence time, results in an annual load of 175 kg based on measured water quality data (n=14 sampling runs). The remainder of the annual load is likely a combination of contribution of seasonal phosphorus regeneration from the sediments and from Upper Mill Pond; further information would necessary to quantify the percent contribution of each of these sources. It is recommended that the sediments be measured directly through collection and testing of sediment cores and measurement of the surface water connections can help to clarify Upper Mill contributions. Based on the age of upgradient septic system leachfields and their distance to the shoreline, 10 of the 13 residential septic systems within a 300 ft buffer are contributing phosphorus to the pond. Road runoff and bird loads are the most uncertain and it is also recommended that the town evaluate these with targeted data collection.

water and phosphorus flows from Upper Mill Pond. The inflows of water and phosphorus should also be paired with outflow measurements from Upper Mill Pond. These activities could be combined with complimentary efforts that will provide all the information necessary to develop a phosphorus TMDL for Lower Mill Pond and the necessary phosphorus reduction steps to meet the TMDL. These steps will allow the town to develop management strategies that can be confidently pursued.

In order to address these recommendations, SMAST staff recommend that these efforts include the following tasks, at a minimum: 1) collection and incubation of a minimum of three sediment sample cores to determine phosphorus content and regeneration potential related to dissolved oxygen thresholds, 2) a whole year of observation of bird populations on the pond, including identification of species, 3) a survey of stormwater systems and measurement of runoff near Lower Mill Pond with regular testing of the phosphorus content of the runoff, and 4) monthly measurements for one year of flow and phosphorus loads from Upper Mill into Lower Mill and matching measurements of outflow from Lower Mill to Stony Brook. It is also recommended that occasional water quality samples be collected from the pond during these efforts using the standard PALS sampling depths in order to provide an integrated snapshot of the pond conditions and help to better understand sampling conditions during this period compared to average conditions.

Depending on how well the recommended information helps to settle the phosphorus budget, the town may also want to consider the completion of a comprehensive plant survey. In most Cape Cod ponds, the algal/phytoplankton portion of the plant community is very dominant and the relationship between phosphorus and pond ecosystems conditions is very strong. But in some impaired and/or heavily used ponds (*e.g.*, Long Pond in Barnstable), this relationship can be skewed by conditions that have created an extensive rooted aquatic plant community. In these ponds, most of the phosphorus is bound in the rooted plants and little is available for algae, so the clarity can be good, but much of the pond surface is covered with leaves from the rooted plants. Observations from PALS samplers between 2001 and 2007 have not noted extensive plant coverage in Lower Mill, but it may be useful during the development of remedial options to have a more definitive assessment. Although beyond the scope of this project, SMAST is available to assist the town in evaluating whether a comprehensive plant survey should be recommended for Lower Mill Pond.

SMAST staff have estimated that the cost of a stand alone project at Lower Mill Pond for all these recommended activities between $41,000 and $44,000 with another $10,000 to $12,000 for combining this information with past information and developing water quality management strategies and a recommended TMDL. A rooted plant survey, including mapping, transects and species identification, would have an estimated cost of between $7,000 and $9,000. Significant potential savings might be realized by completing these recommended analyses on a number of ponds, perhaps the whole watershed feeding Lower Mill Pond, and/or by incorporating citizen volunteer and town staff participation where appropriate. SMAST staff can discuss strategies with town staff and provide the town with a detailed scope of work if requested.

In addition, although the target watershed reductions are not clear at this point, maintenance of the natural buffers that generally and redirecting any direct stormwater runoff are relatively lost cost best management practices that can be pursued. These activities would help to minimize external watershed phosphorus loads. Review of the potential benefits and costs of the various nutrient management options could be evaluated as part of a slight expansion of the activities recommended above.

VII. Summary of Findings for Individual Pond Reviews

VII.1. Seymour Pond

- 183 acres (Great Pond under state law)
- split between Brewster and Harwich
- 11 m (~36 ft) deep
- Cold water fishery under state surface water regulations (314 CMR 4)
- Impaired water based on state regulations, requires TMDL
- Also impaired based on phosphorus and chlorophyll *a* concentrations and Secchi
- Phosphorus limited
- TMDL should target phosphorus
- 48 properties wholly or partially within the 300 ft buffer and upgradient; 34 of them are single family residences with eight in Harwich and 26 in Brewster
- More refined information on internal sediment nutrient regeneration, bird populations, and road runoff are recommended to better target remedial strategies to reduce phosphorus loads. Town may also want to consider a rooted plant survey.

VII.2. Canoe Pond

- 14 acres (Great Pond under state law)
- 4 m (~13 ft) deep
- Warm water fishery under state surface water regulations (314 CMR 4)
- Impaired water based on state regulations, requires TMDL
- Also impaired based on phosphorus and chlorophyll *a* concentrations and Secchi
- Phosphorus limited
- TMDL should target phosphorus
- 7 properties wholly or partially within the 300 ft buffer and upgradient; three of them are single family residences and other four are developable, residential parcels
- More refined information on potential connection to Canoe Pond, internal sediment nutrient regeneration, bird populations, and road runoff are recommended to better target remedial strategies to reduce phosphorus loads. Town may also want to consider a rooted plant survey.

VII.3. Blueberry Pond

- 22 acres (Great Pond under state law)
- Sol's Pond within watershed
- 7 m (~23 ft) deep
- Cold water fishery under state surface water regulations (314 CMR 4)
- Impaired water based on state regulations, requires TMDL

- Also impaired based on phosphorus and chlorophyll *a* concentrations and Secchi
- Phosphorus limited
- TMDL should target phosphorus
- 35 properties wholly or partially within the 300 ft buffer and upgradient; 26 of them are single family residences along with a portion of the Ocean Edge resort
- More refined information on internal sediment nutrient regeneration, bird populations, root plant population, and road runoff are recommended to better target remedial strategies to reduce phosphorus loads. Town may also want to consider a rooted plant survey.

VII.4. Walkers Pond

- 102 acres (Great Pond under state law)
- Slough, Pine, and Seymour Ponds within watershed
- Uppermost pond of watershed to Lower Mill Pond, surface connect to Upper Mill Pond
- 2.4 m (~8 ft) deep
- Warm water fishery under state surface water regulations (314 CMR 4)
- Not impaired water based on dissolved oxygen standards in state regulations
- Phosphorus and chlorophyll *a* concentrations and Secchi show pond is impaired
- Phosphorus limited
- TMDL should target phosphorus
- 40 properties wholly or partially within the 300 ft buffer and upgradient; 21 of them are single family residences and 13 are government owned properties
- More refined information on potential connection to Upper Mill Pond, internal sediment nutrient regeneration, bird populations, and road runoff are recommended to better target remedial strategies to reduce phosphorus loads. Town may also want to consider a rooted plant survey.

VII.5. Upper Mill Pond

- 260 acre pond (Great Pond under state law)
- Middle pond of watershed to Lower Mill Pond, inflow from Walkers, outflow to Lower Mill
- potential inflow from Canoe
- 8.5 m (~28 ft) deep
- Warm water fishery under state surface water regulations (314 CMR 4)
- Borderline impaired water based on dissolved oxygen standards in state regulations
- Phosphorus and chlorophyll *a* concentrations and Secchi show pond is impaired
- Phosphorus limited
- TMDL should target phosphorus
- 96 properties wholly or partially within the 300 ft buffer and upgradient; 67 of them are single family residences and 9 are developable residential parcels
- More refined information on connections to Walker and Lower Mill Ponds, potential connection to Canoe, sediment nutrient regeneration, bird

populations, and road runoff are recommended to better target remedial strategies to reduce phosphorus loads. Town may also want to consider a rooted plant survey.

VII.6. Lower Mill Pond

- 49-acre pond (Great Pond under state law)
- terminal pond in watershed that includes Walkers, Seymour, Slough, and Pine Ponds
- 3.7 m (~12 ft) deep
- Warm water fishery under state surface water regulations (314 CMR 4)
- Not impaired water based on dissolved oxygen standards in state regulations
- Phosphorus and chlorophyll *a* concentrations and Secchi show pond is impaired
- Phosphorus limited
- TMDL should target phosphorus
- 21 properties wholly or partially within the 300 ft buffer and upgradient; 13 of them are single family residences and 6 are developable residential parcels
- More refined information on connections to Upper Mill Pond, sediment nutrient regeneration, bird populations, and road runoff are recommended to better target remedial strategies to reduce phosphorus loads. Town may also want to consider a rooted plant survey.

VIII. Next Steps

VIII.1. Future Citizen Monitoring

The available dataset for all the ponds considered under this project is primarily due to Brewster citizens volunteering to collect water quality data. Review of the available data has been used to create an initial assessment of the water quality in all of the sampled ponds and detailed review of selected ponds. It is recommended that monitoring of all ponds continue, but that the monitoring frequency be reduced to twice a year: once in April to establish pre-summer water quality conditions for that year and once in August/September to evaluate what are likely to be the worst water quality conditions of the year. It is further recommended that PALS Snapshot sampling protocols continue to be used for both sampling rounds.

VIII.2. Detailed Review of Other Ponds

The detailed reviews of the six selected ponds that are presented above provide assessments that can be used to judge whether the ponds meet state regulatory standards, as well as ecological status. However, in each case, these assessments identified other information needs that will need to be addressed prior to evaluation and costing of remedial options. It is recommended that the Town consider similar detailed reviews for the other 22 ponds that have citizen collected water quality data. Since these ponds include most of the large ponds in town, this step will allow the town to develop a better sense of how many of the ponds will require remedial activities, as well what additional information will be required in order to assess remedial options.

VIII.3. Regulatory Status for Six Detailed Ponds

The six ponds with detailed reviews that included watershed delineations, water and phosphorus budgets, and limiting nutrients all are impaired based on ecological measures, while only select ones are impaired according to state regulations. Those that are defined as impaired under state regulations will eventually be required to have a TMDL defined and, based on current DEP guidance, will need to have that TMDL addressed through a comprehensive wastewater management plan. It is recommended that the Town consider filing all the ponds as impaired during the 2010 round of the state's integrated list preparation (to satisfy federal requirements under Sections 303d and 305b of the Clean Water Act). The state's response will provide the town with guidance about how to approach remediation of these ponds, as well as guidance on how similar conditions will be regarded in Brewster's other ponds.

VIII.4. Development of Recommended Information for the Six Detailed Ponds

The six ponds with detailed reviews have a number of additional data needs that will help to understand how their ecosystems work and, thus, will help to better define what needs to be done to remediate them. Some of this additional data collection can be done by volunteers, some by town staff, and some will require higher level technical staff. SMAST staff can provide guidance to the town in how to approach this data collection in ways that will save money while addressing the technical requirements of the data collection. SMAST staff are willing to review the recommended data collection, options for collection, and potential costs with the Town.

IX. Conclusions

Cape Cod ponds are part of the regional aquifer system and, as such, are linked to drinking water and coastal estuaries, as well as any pollutants added to the aquifer. Until the Cape Cod Pond and Lake Stewardship (PALS) program was created, water quality in most Cape ponds was limited to anecdotal information from long time residents.

The Cape Cod PALS program provides a focus for local pond concerns and staff from Coastal Systems Program at the School of Marine Science and Technology (SMAST), University of Massachusetts Dartmouth and the Cape Cod Commission (CCC) provide training and guidance to local volunteers about collecting water quality samples, as well as discussing pond water quality and use management. Volunteer water quality sampling activities have led to eight consecutive, annual PALS water quality snapshots, which have included free laboratory analysis through SMAST for any collected pond water quality samples, and citizen enthusiasm has led to more grant-supported, citizen monitoring with laboratory services provided through the Cape Cod National Seashore. All these monitoring activities have created a large dataset of volunteer-collected pond water quality data in need of analysis and interpretation.

Through funding provided by Barnstable County, SMAST staff have been contracted by the CCC to review the available laboratory and field water quality data (over 10,000 data points) collected by Town of Brewster volunteers from 29 ponds between 2001 and 2007. This review also includes a detailed review of six ponds selected by the Town: Blueberry, Canoe, Seymour, Walkers, Upper Mill and Lower Mill. These detailed, pond-specific reviews include delineation of pond watersheds, development of water and phosphorus budgets, characterization of the ponds ecological status, and recommendations for next steps.

Review of the volunteer data from 29 Brewster ponds monitored between 2001 and 2007 indicates that 24 of the ponds have average dissolved oxygen concentrations that fail to attain minimum state regulatory thresholds in at least one sampling station. The five ponds that meet the state minimum dissolved oxygen standards at all stations are: Cahoon, Greenland, Smith, Walker, and Little Cliff.

Review of other ecological factors show that all of the ponds except for Higgins have at least one station where the average concentration exceeds the Cape Cod ponds 1.7 ppb chlorophyll *a* standard. By this criterion, 28 of the 29 ponds are impaired. All of the ponds except for Higgins, Little Cliff, Sheep, Slough, and Greenland have at least one station where the average total phosphorus exceeds the Cape Cod ponds 10 ppb standard. These same ponds also are the only ponds where average concentrations at all stations are less than the Cape Cod ponds 0.31 ppm total nitrogen standard. The fact that the nutrient lists and the dissolved oxygen lists are not the same reinforces the need to review the individual characteristics of each pond.

Review of total nitrogen to total phosphorus ratios show that all ponds are phosphorus limited, which means that management of phosphorus will be the key for determining water quality in these ponds. It also means that reductions in phosphorus will have to be part of any remediation plans.

Six ponds were selected by the Town for more detailed review by SMAST staff: Blueberry, Seymour, Canoe, Walkers, Upper Mill, and Lower Mill. These detailed reviews allow the review of water quality data completed in the town-wide overview to be enhanced and brought into a better context and understanding of how watershed and in-lake factors influence the water quality that has been measured. These detailed reviews incorporate watershed information, development of water budgets to determine how water moves in an out of each pond, and development of phosphorus budgets to help understand the likely sources of the phosphorus in each individual pond. The phosphorus budget development includes review of surrounding land uses, which also allows project staff to develop estimates of both existing and future sources of phosphorus loads, better understand the time of travel delays associated with phosphorus transport in the aquifer, and identify where additional information should be gathered before remediation plans are implemented.

Because phosphorus moves very slowly in Cape Cod aquifer conditions, it can take decades for some loads, even from nearshore 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 as more of the phosphorus already in the aquifer reaches pond and the systems move closer to steady state.

The detailed review of the six individual ponds shows that Seymour, Canoe, and Blueberry are all impaired based on dissolved oxygen limits in the state Surface Water Quality Regulations (314 CMR 4). Upper Mill is borderline impaired and Walkers and Lower Mill are not impaired under the state regulatory limits.

In contrast, all six of the detailed ponds are impaired based on the review of total phosphorus, chlorophyll *a*, and Secchi transparency. The individual circumstances of each pond show how the state dissolved oxygen standards can be met even when ecological conditions are severely impaired. Walkers Pond, for example, meets state dissolved oxygen standards even though it has average total phosphorus concentrations five times higher and average chlorophyll a concentrations 10 times higher than their respective Cape ponds standards. Dissolved oxygen standards in Walkers are met because of regular mixing of atmospheric oxygen.

Evaluation of the water and phosphorus budgets for the six detailed ponds generally revealed that additional information is going to be required before remediation plans are evaluated for cost and effectiveness. A better understanding of sediment phosphorus regeneration and the phosphorus contribution of bird populations are common needs for all of the detailed ponds. It is also recommended that stormwater systems around the ponds be evaluated in order to develop measured, pond-specific phosphorus input of this source. Depending on how well the phosphorus budgets balance after developing this recommended information, it may also be necessary to complete rooted plant surveys in order to evaluate how much phosphorus may be bound in this portion of the plant community, as well as providing a baseline for future impacts on this community. Completion of these activities will allow the town to more effectively review remediation options and clearly define which sources are most cost effective to address.

Ponds in the Town of Brewster require some additional attention to address their water quality impairments. SMAST staff are available to provide additional guidance, develop tasks and associated costs to address these impairments, help to ensure future regulatory compliance, and restore these systems.

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APPENDIX

Pond Bathymetric Maps
Town of Brewster

prepared by
Jay Detjens, GIS Analyst
Cape Cod Commission

Data sources:

all ponds except Canoe
Massachusetts Division of Fish and Wildlife
http://www.mass.gov/dfwele/dfw/habitat/maps/ponds/pond_maps_sd.htm

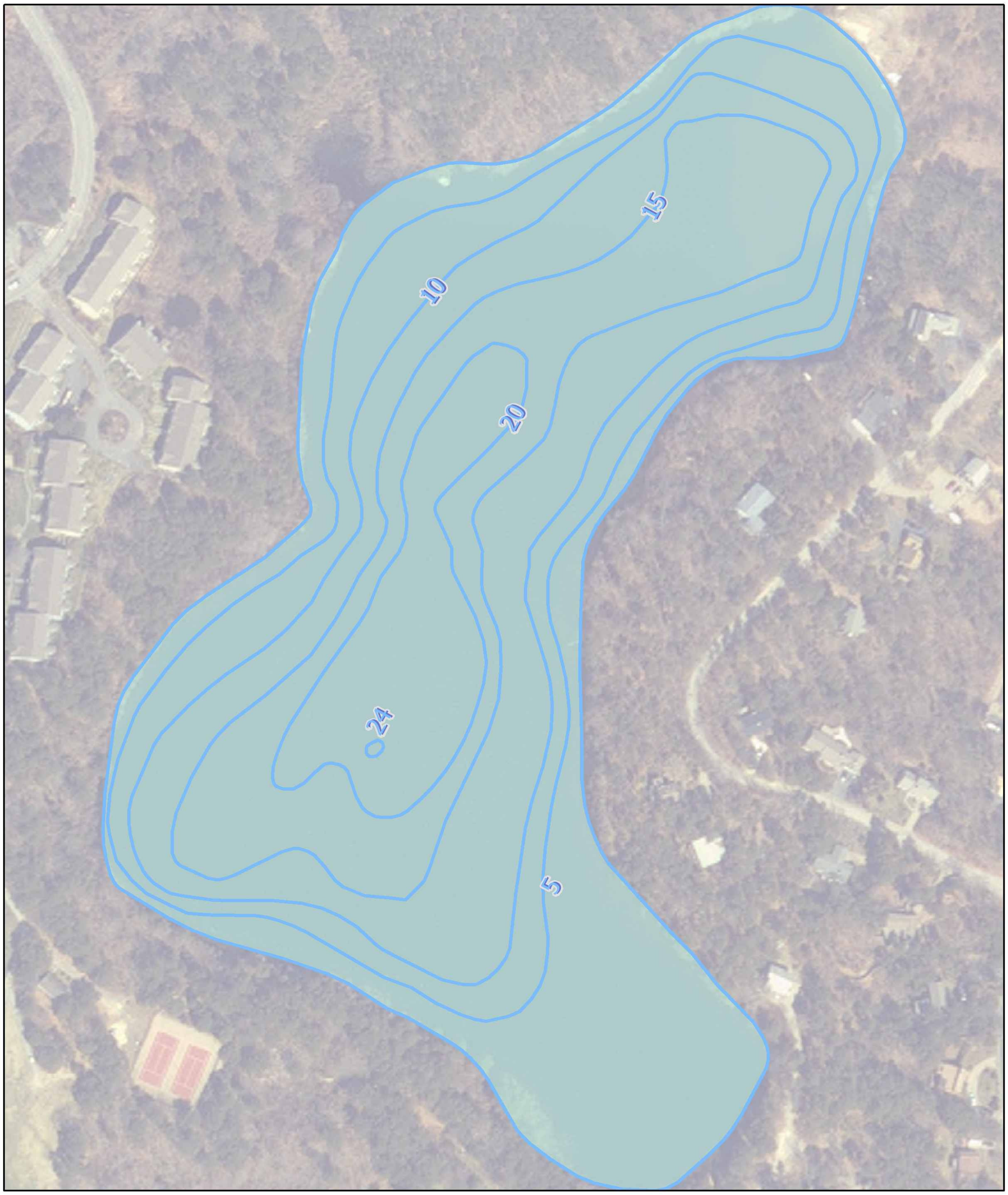
Canoe Pond
depth data collected by Jon Budreski in 2003

Blueberry Pond
Brewster, MA

Bathymetry
(depth in feet)

N
W E
S

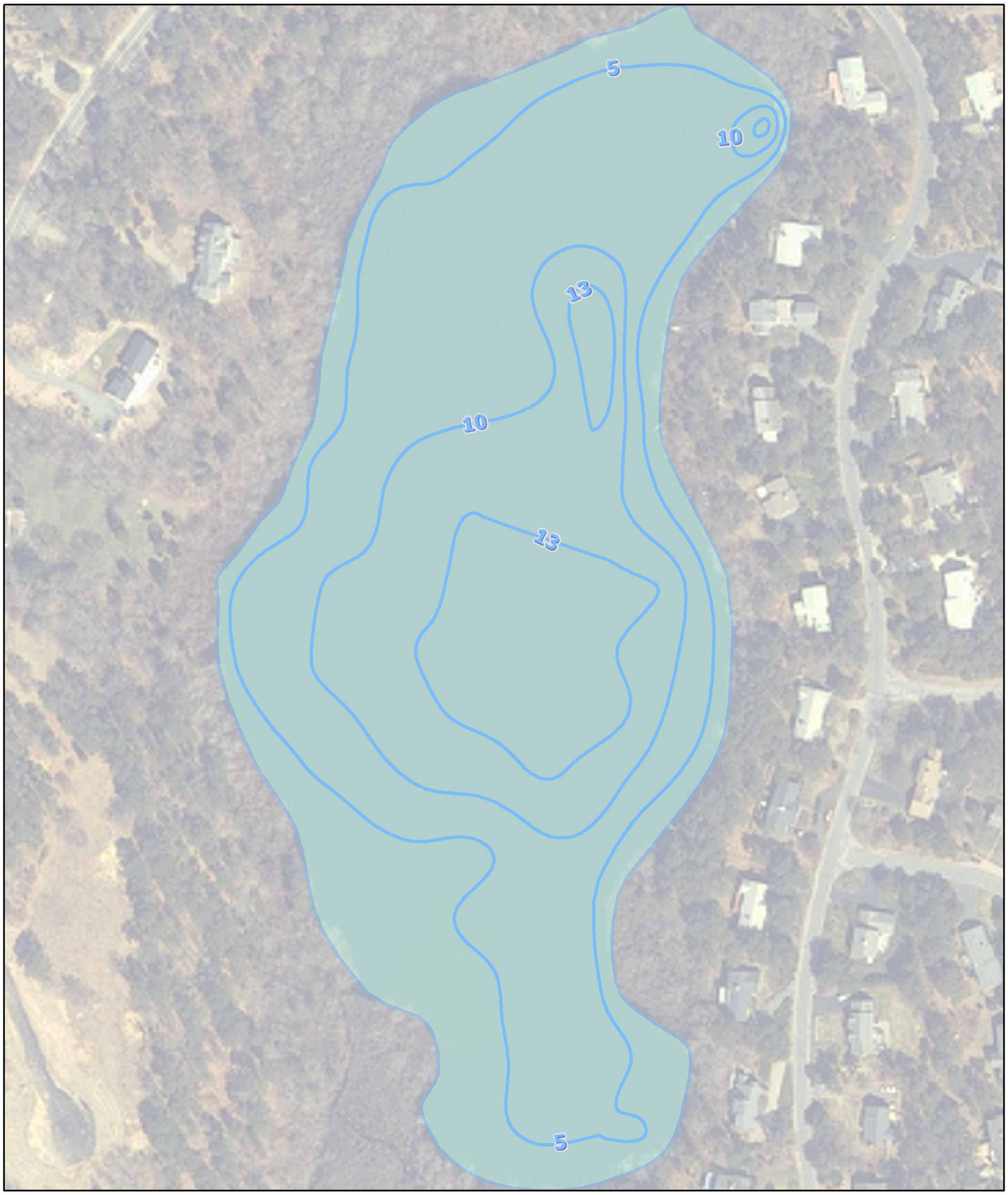
Feet
100 50 0 100 200 300



Canoe Pond
Brewster, MA

Bathymetry
(depth in feet)

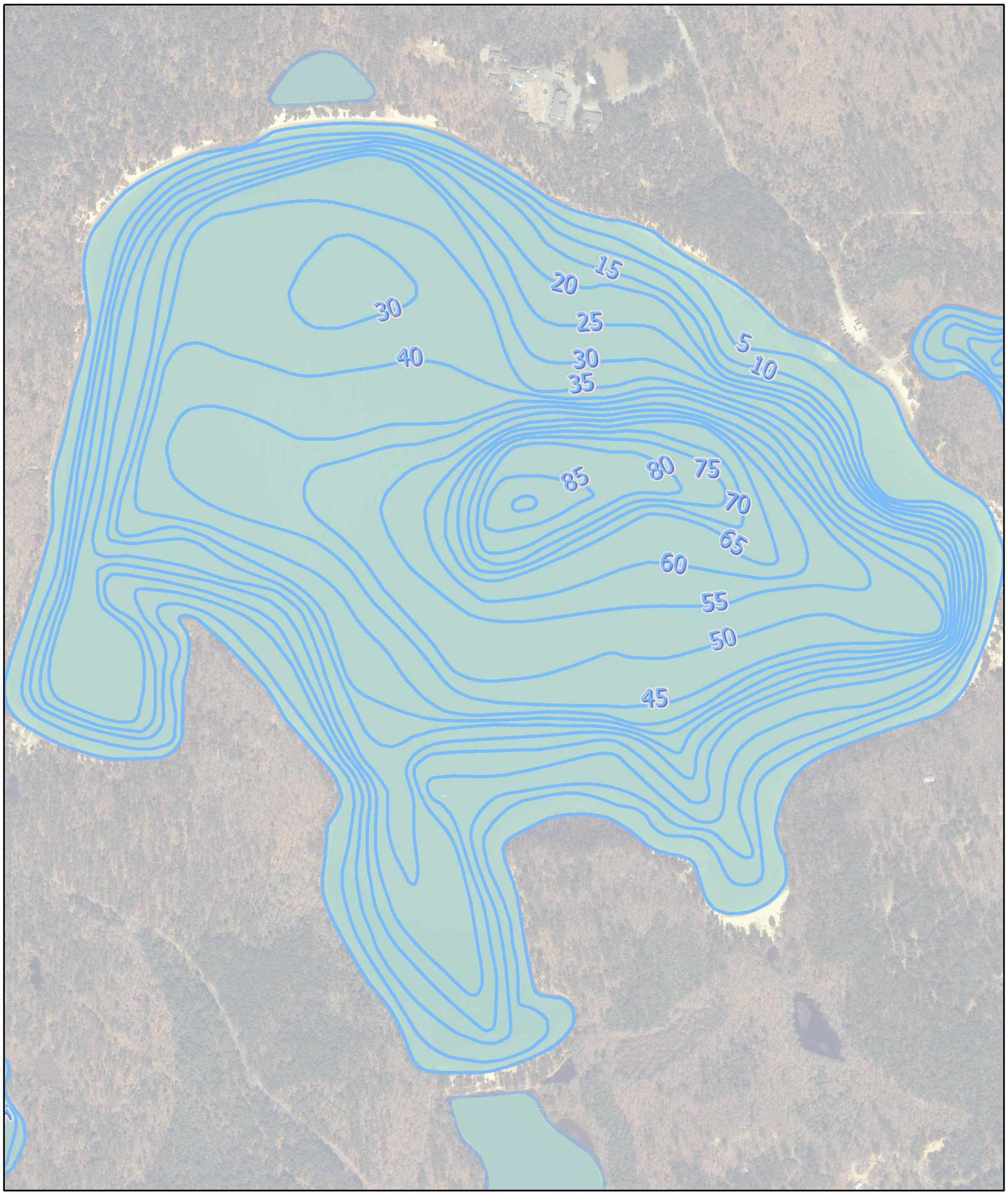
N
W E
S
Feet
80 40 0 80 160 240



Cliff Pond
Brewster, MA

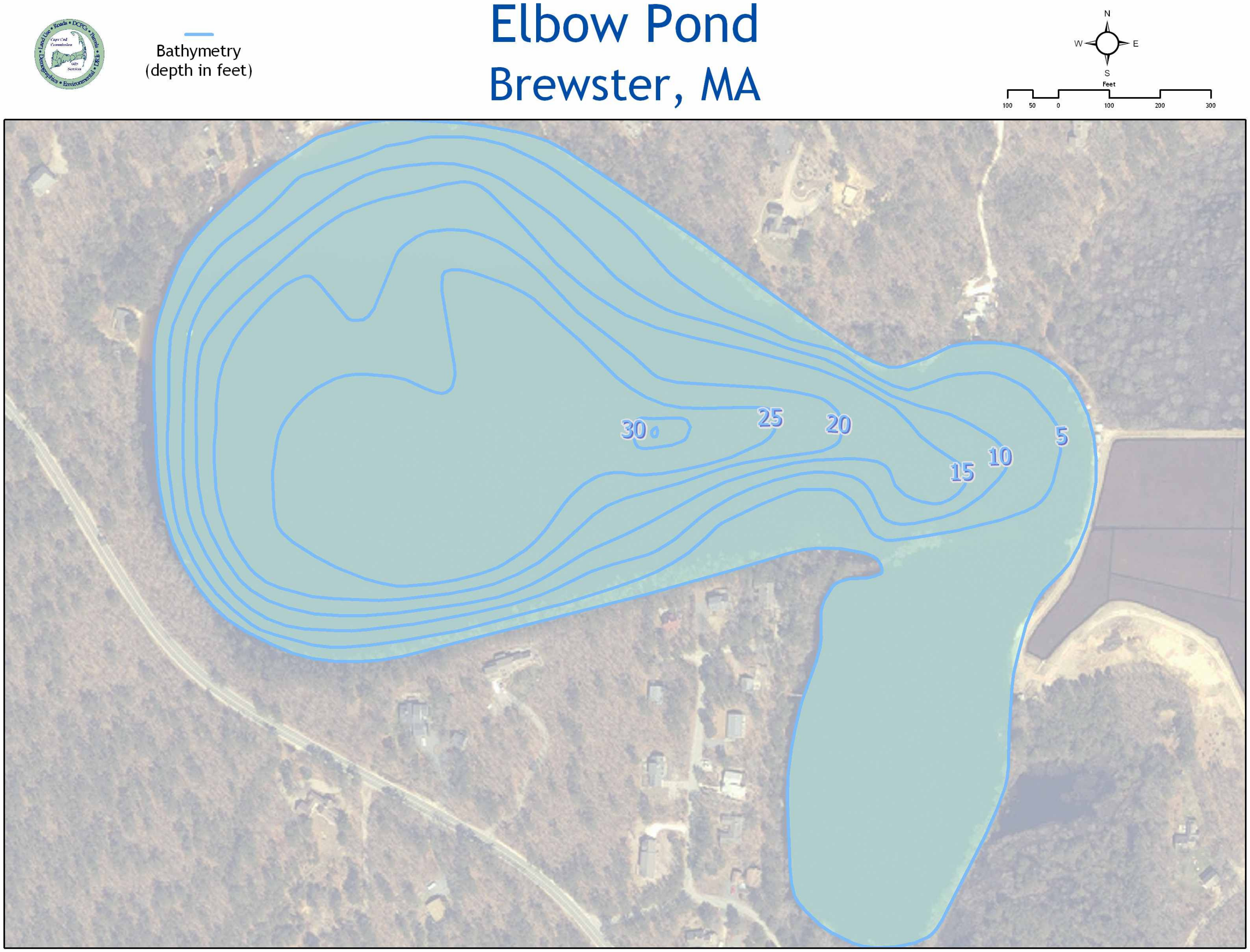
Bathymetry
(depth in feet)

N
W E
S
Feet
270 135 0 270 540 810



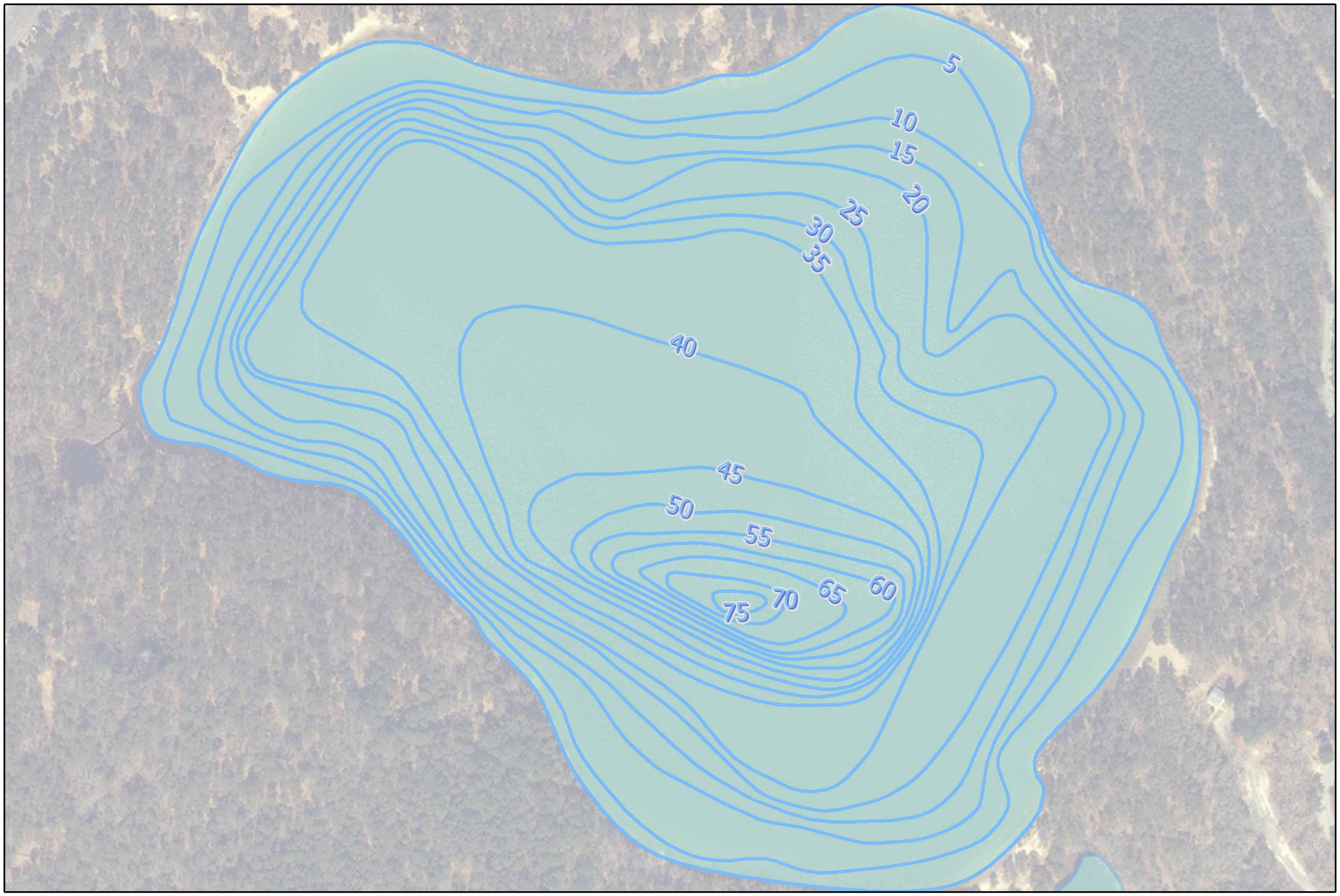
Elbow Pond
Brewster, MA

Bathymetry
(depth in feet)



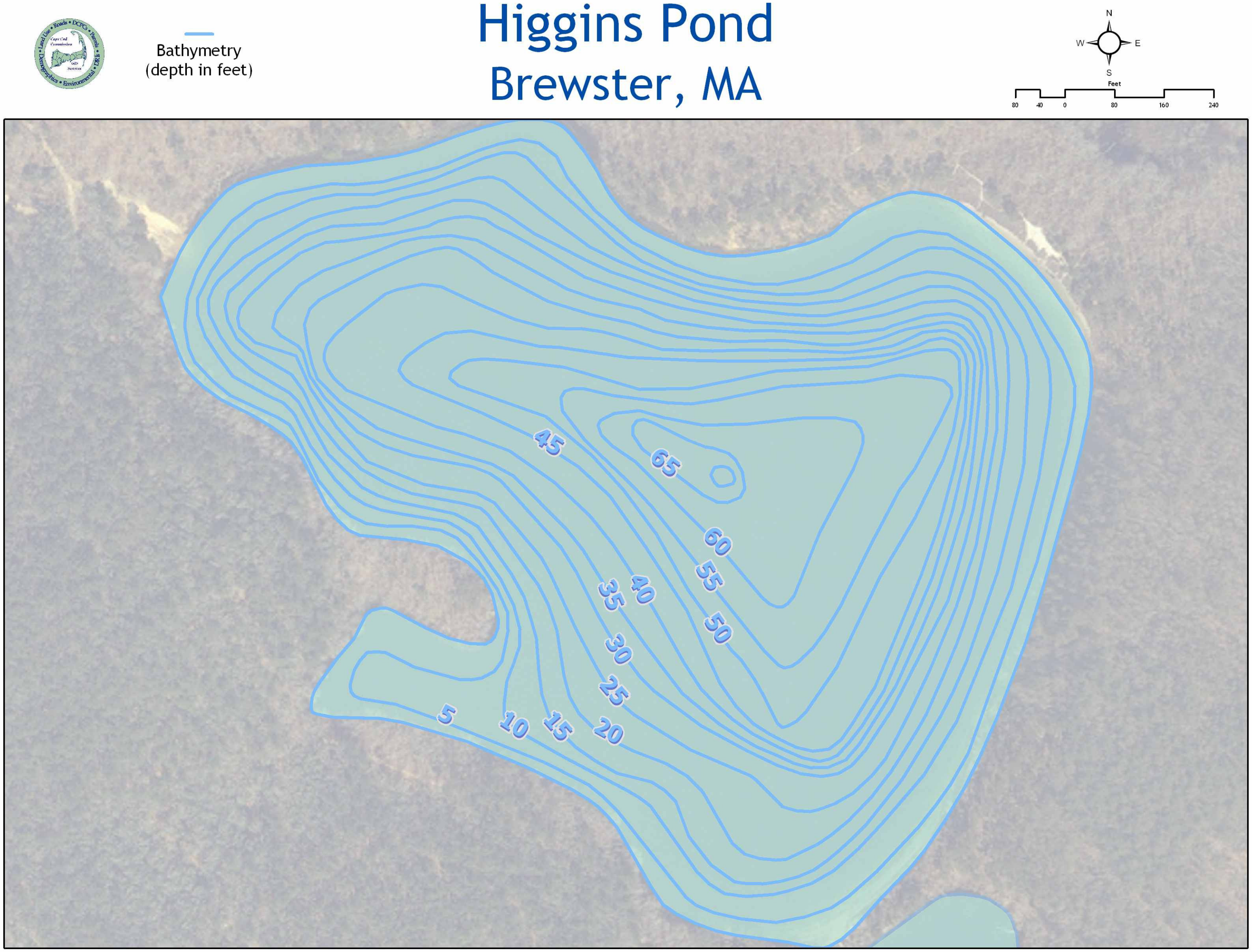
Flax Pond
Brewster, MA

Bathymetry
(depth in feet)



Higgins Pond
Brewster, MA

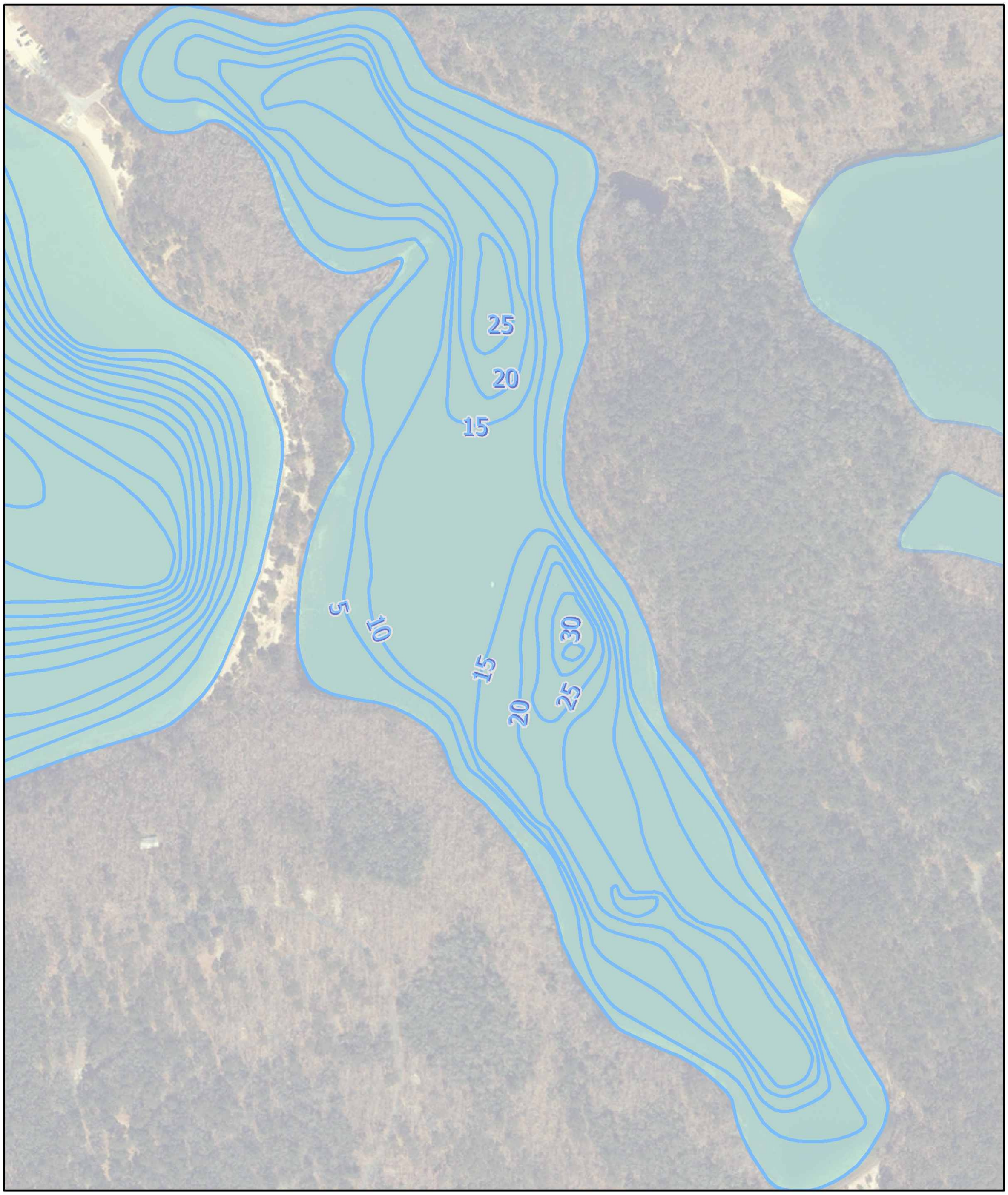
Bathymetry
(depth in feet)



Little Cliff Pond
Brewster, MA

Bathymetry
(depth in feet)

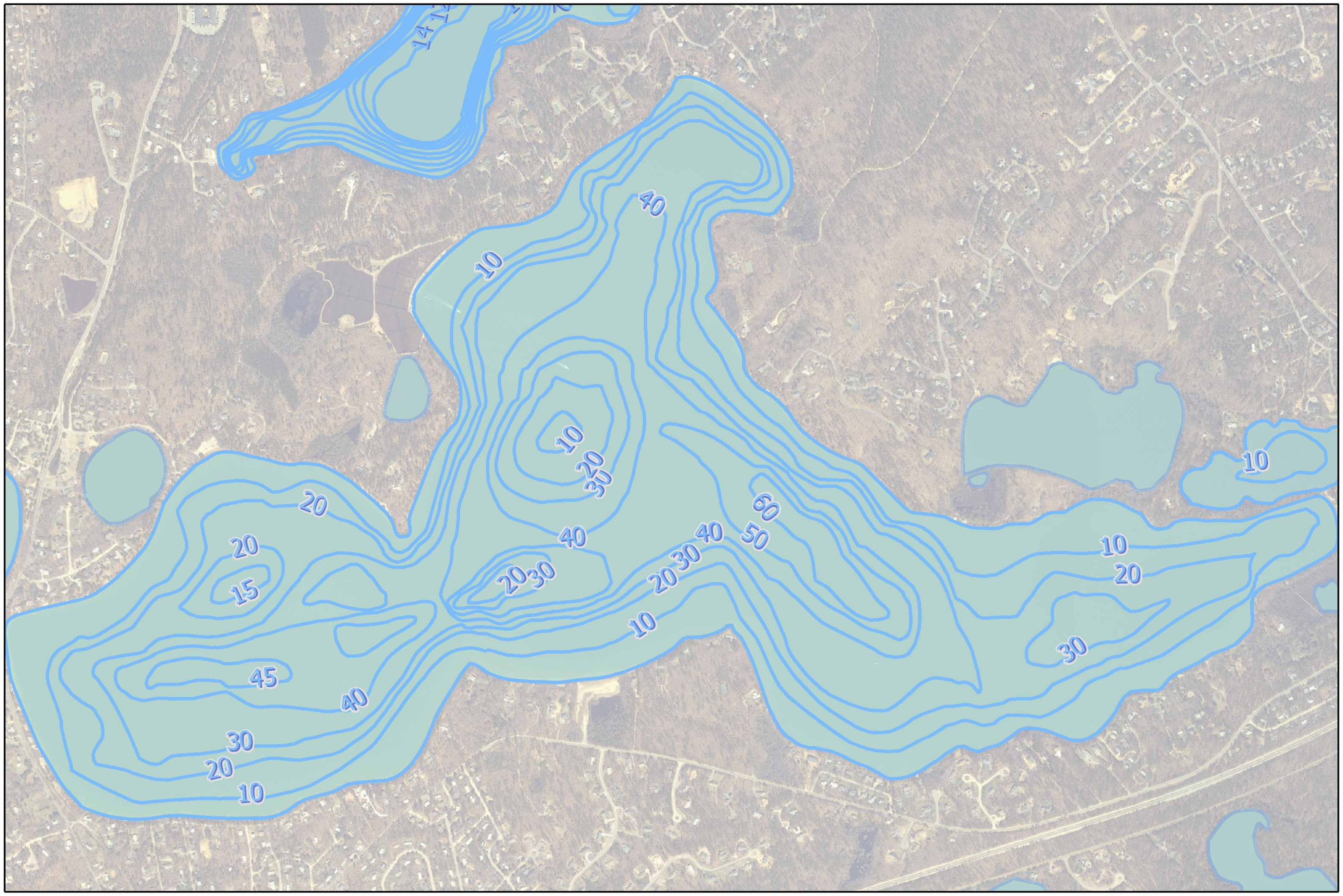
N
W E
S
Feet
150 75 0 150 300 450



Long Pond
Brewster, MA

Bathymetry
(depth in feet)

N
W E
S
Feet
475 237.5 0 475 950 1,425

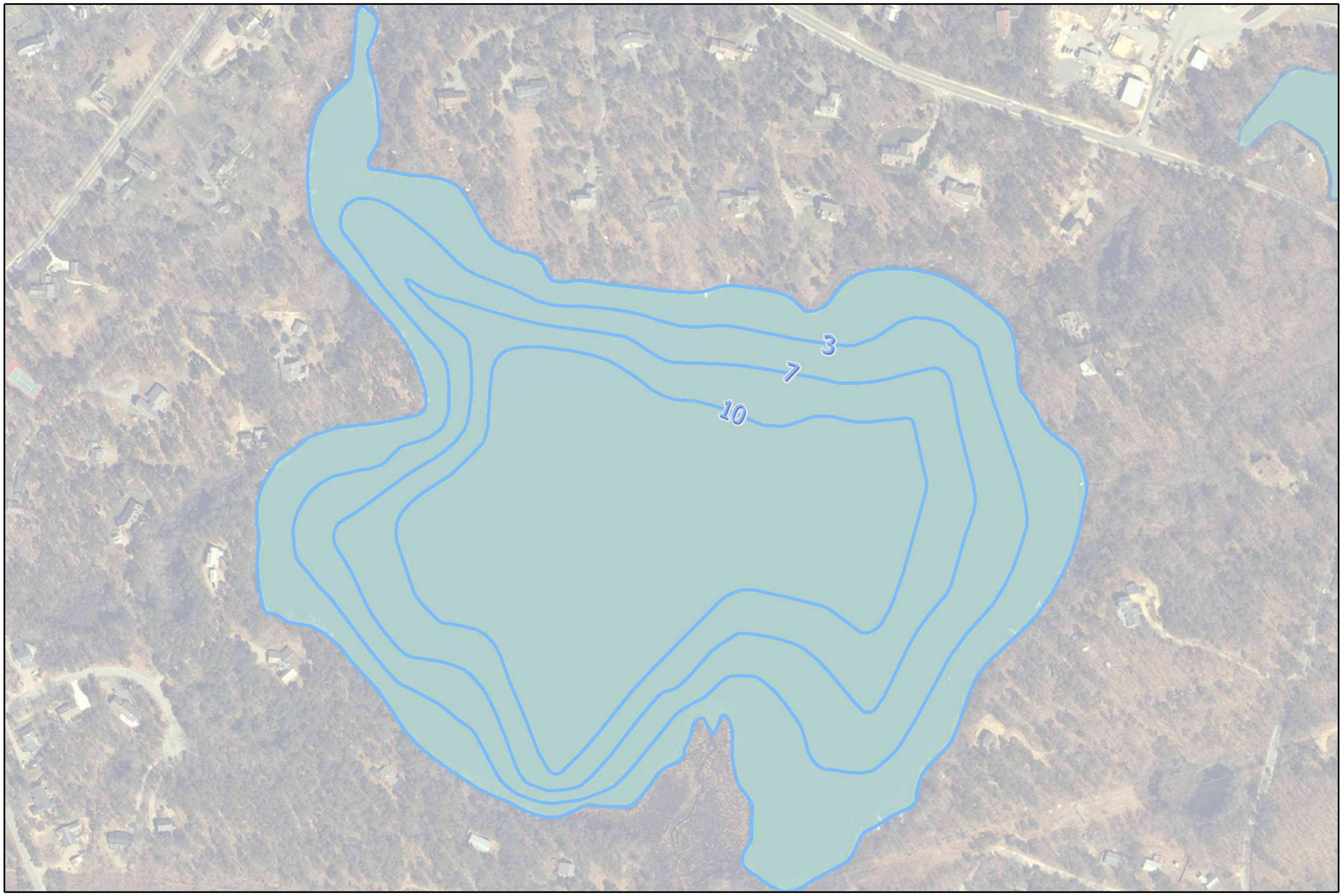


Lower Mill Pond
Brewster, MA

Bathymetry
(depth in feet)

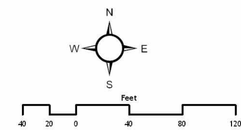
N
W E
S

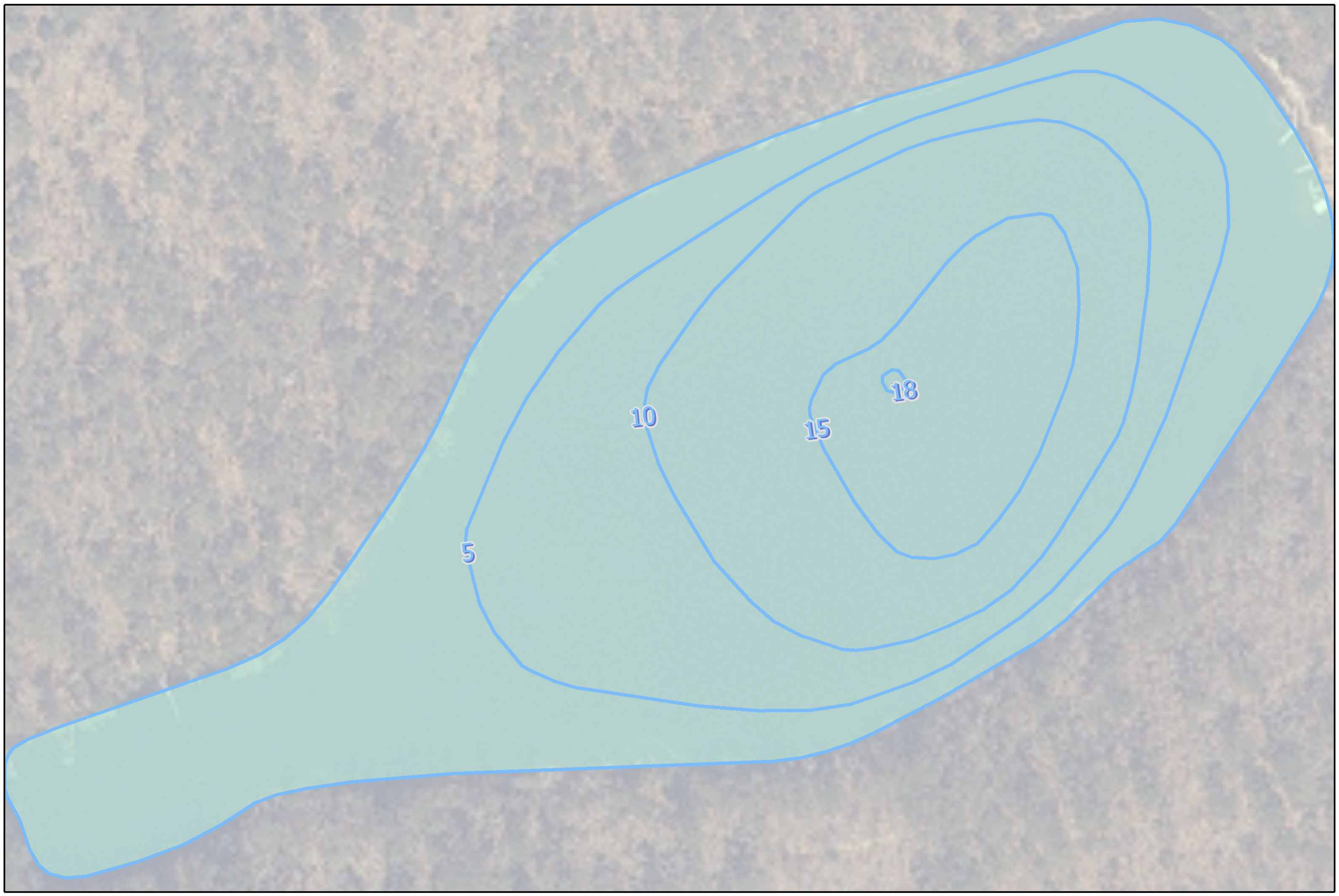
Feet
125 62.5 0 125 250 375



Rafe Pond
Brewster, MA

Bathymetry
(depth in feet)





Bathymetry
(depth in feet)

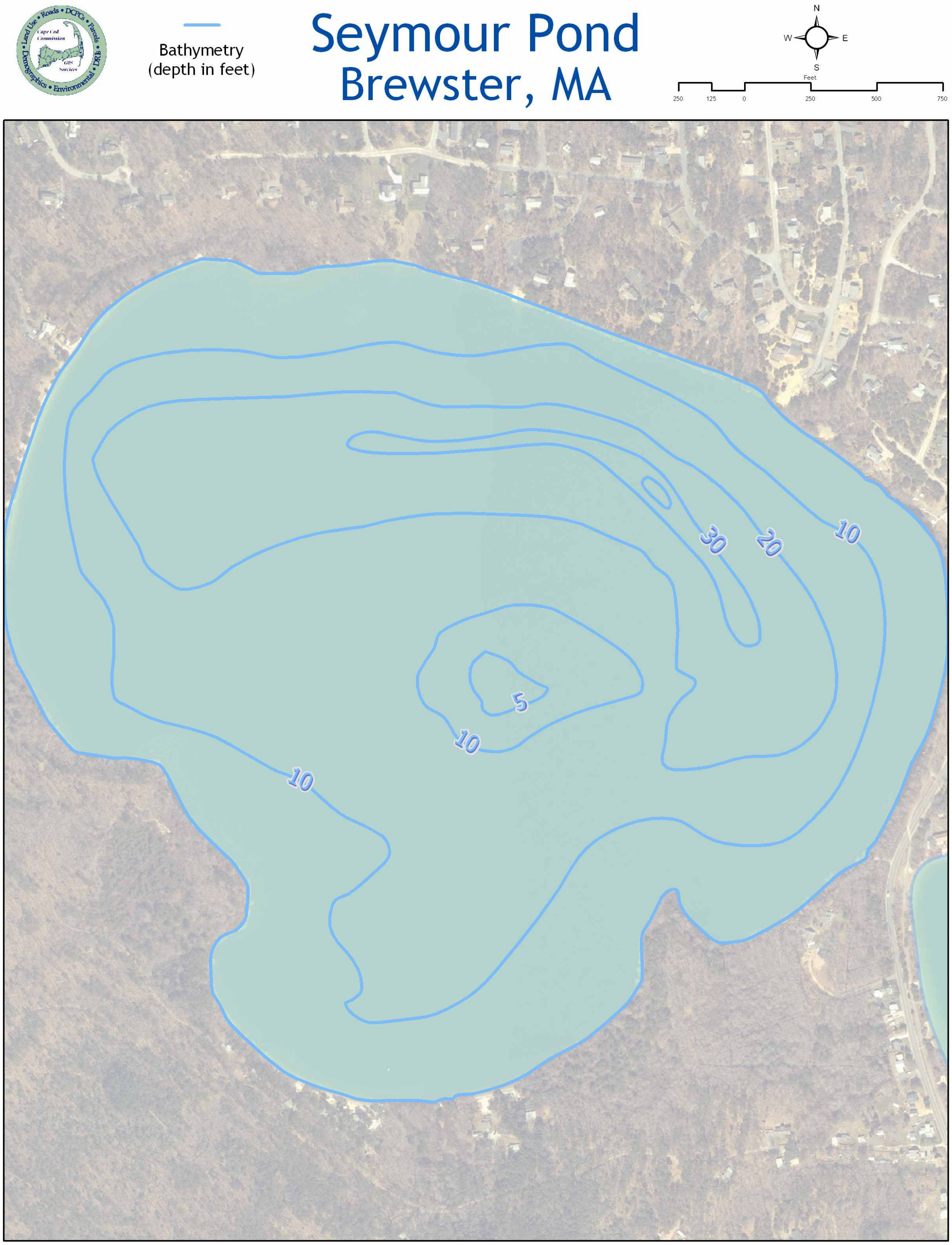
Ruth Pond
Brewster, MA

N
W E
S

Feet
50 25 0 50 100 150

Seymour Pond
Brewster, MA

Bathymetry
(depth in feet)

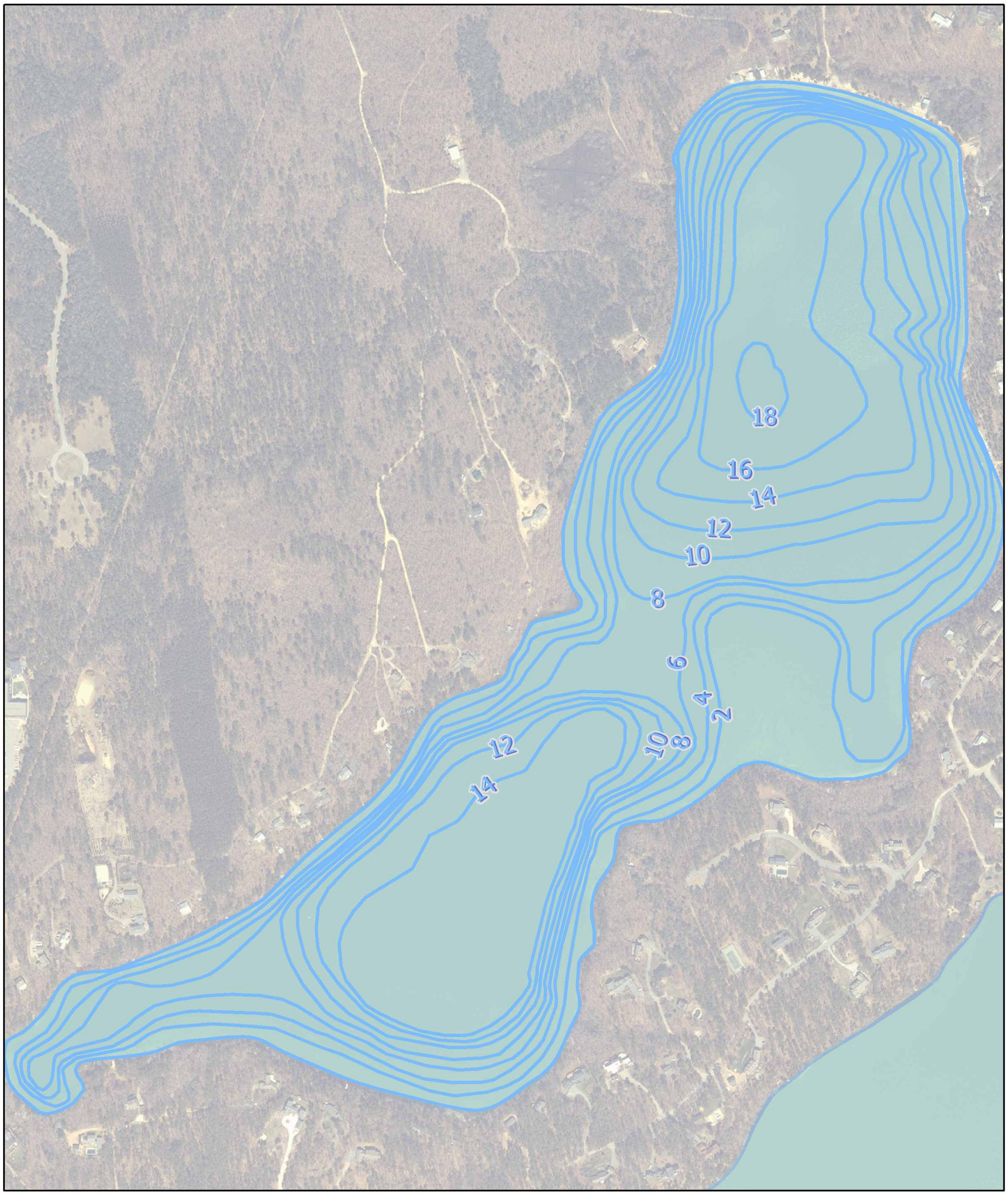


Sheep Pond
Brewster, MA

Bathymetry
(depth in feet)

N
W E
S

Feet
290 145 0 290 580 870

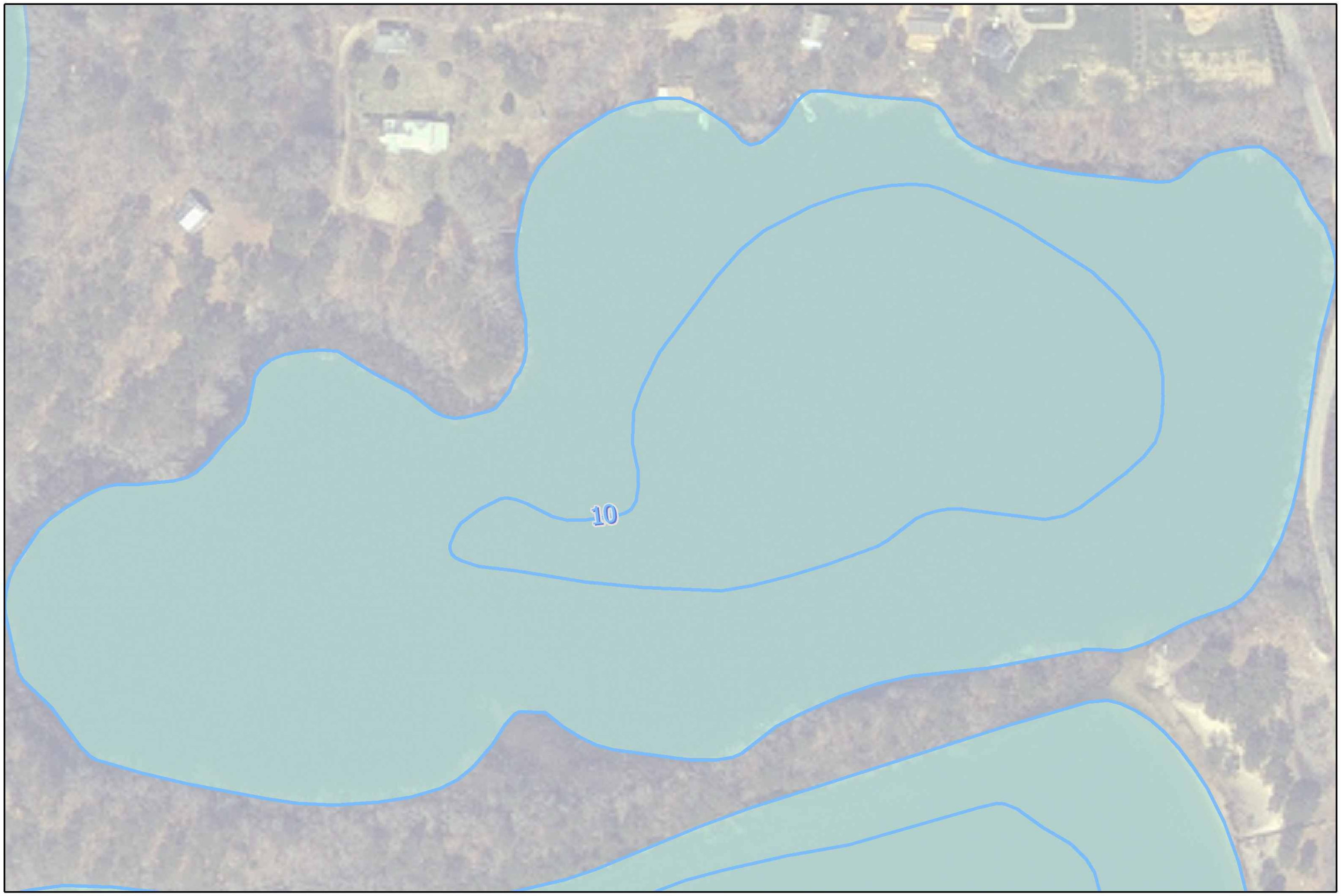


Smalls Pond
Brewster, MA

Bathymetry
(depth in feet)

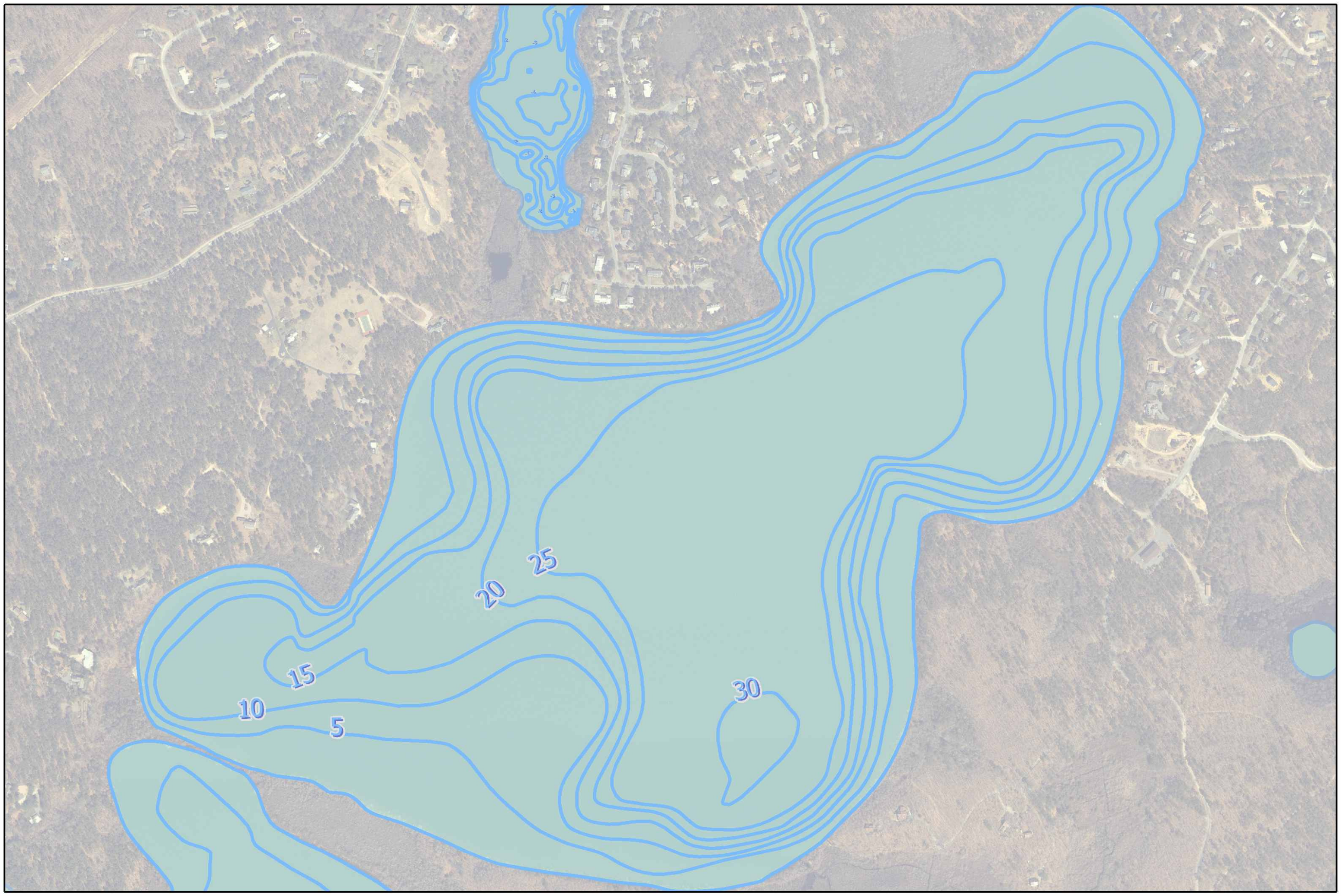
N
W E
S

Feet
50 25 0 50 100 150



Upper Mill Pond
Brewster, MA

Bathymetry
(depth in feet)



Walkers Pond
Brewster, MA

Bathymetry
(depth in feet)