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

FINAL REPORT

September 2009

for the

Town of Dennis

and

Barnstable County

Prepared by:

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Cover photo: Dennis pond samplers (Gerry Gallagher, 2004)

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Executive Summary

Dennis 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 Dennis, 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 access to University researchers, comprehensive links to other regional water quality management/assessment activities like the Massachusetts Estuaries Project and staff experienced with 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 also encouraged other data collection, including grant-supported, citizen monitoring with laboratory services provided through the Cape Cod National Seashore, and has led to extensive advocacy for pond water quality protection. The extensive 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 Dennis volunteers from 11 ponds between 2001 and 2008. In addition to the town-wide review, this review also includes more detailed review of six ponds selected by the Town of Dennis: Bakers, Cedar, Coles, Eagle, Flax and Scargo. 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 Code of Massachusetts Regulations 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 phytoplankton growth and excessive nutrients have occurred for a number of years, excessive plant growth has been deposited in the pond sediments, and its breakdown by sediment bacteria has prompted excessive 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). Dissolved oxygen, on the other hand, tends to be based on fish survival and has a single concentration threshold.

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 regulatory 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 and nutrient limits.

None of the Dennis ponds are currently listed as "impaired" on the comprehensive listing of state waters that DEP is required to prepare and update under the Clean Water Act. This list, officially known as the "Integrated List of Waters", places waters into five different categories with Category 5 being the impaired waters that require a TMDL. Only two of Dennis' ponds are listed on the current comprehensive list: Scargo and Flax (MassDEP, 2008). Both of these ponds are assigned to Category 3, which is for waters that are included in the list, but have not been assessed to determine whether they are impaired or not.

Nutrient Limits for Dennis 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 area ponds 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 freshwater pond 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 11 Dennis ponds monitored between 2001 and 2008 indicates that four of the ponds have average dissolved oxygen (DO) concentrations that fail to attain minimum state regulatory thresholds in at least one sampling station: Cedar, Hiram, Run, and Scargo. Because of the numeric standard for dissolved oxygen in the state regulations, these four ponds may require TMDLs provided other data, such as bathymetry and nutrient concentrations are consistent with the DO findings. The seven ponds that meet the state minimum dissolved oxygen standards at all their stations are: Bakers, Eagle, Flax, Fresh, North Simmons, and White.

Review of other ecological factors show that all of the ponds except for Bakers have average concentrations at all depth stations that exceed the Cape Cod ponds 1.7 ppb chlorophyll *a* standard. All of the ponds except for Bakers, Flax, Scargo, and White have all depth stations where the average total phosphorus exceeds the Cape Cod ponds 10 ppb standard. Eagle, Flax, Scargo, and White are the only ponds where average concentrations at least one station 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 and how land uses in the watershed influence observed concentrations. It also reinforces the need to understand nutrient concentrations and clarity readings since these will indicate the initial impacts of excessive nutrients prior to the terminal conditions associated with failing to meet the dissolved oxygen regulatory thresholds.

Review of average total nitrogen to total phosphorus ratios show that all ponds are phosphorus limited, which means that management of phosphorus will be a 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 of Dennis for more detailed review by SMAST staff: Bakers, Cedar, Coles, Eagle, Flax and Scargo. These reviews allow the limited assessment 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, including nearshore sources like 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 Scargo and Cedar are impaired based on the state regulatory limits for dissolved oxygen. Given that these regulatory limits are used to determine which waters are required to have TMDLs, this analysis suggests that Scargo and Cedar clearly meet the state regulatory definition of impaired and should have TMDLs developed in order to comply with the Clean Water Act. The other four ponds has average dissolved oxygen concentrations that exceed state regulatory minimums.

Review of the total phosphorus, chlorophyll *a*, and Secchi transparency results for the six selected ponds presents a somewhat more complex and nuanced assessment of their ecosystem health. Bakers is clearly not impaired and has exceptional clarity and total phosphorus and chlorophyll a concentrations that are less than the Cape Cod pond guidelines (Eichner and others, 2003). Coles meets the dissolved oxygen standards, but the average total phosphorus and chlorophyll a concentrations are two and eight times above their respective guidelines. Eagle and Flax has average dissolved oxygen concentrations above state standards, but the average TP and chlorophyll a concentrations are above guidelines and suggesting that continued monitoring is warranted. Flax also has occasional readings of anoxia in bottom waters, which suggests worsening conditions.

Evaluation of the water and phosphorus budgets for the six detailed ponds generally were consistent with the measured water quality conditions. Most of the ponds have very little development within their watersheds, except for Scargo and Cedar. Eagle's watershed phosphorus budget is almost all (85-88%) from stormwater, including a portion of a Route 6 rest area. Coles has one residence adding phosphorus to the pond, while Baker and Flax have four and two, respectively. All of the ponds except Coles will see increases in wastewater phosphorus loading with time; phosphorus from these residences is estimated to still be transit toward the pond.

A better understanding of sediment regeneration of phosphorus and pond-specific measurement of stormwater runoff phosphorus loads is a common need for all of the detailed ponds. Completion of these activities for the ponds that will need TMDLs will allow the town to more effectively review remediation options and clearly define which sources are most cost-effective to address.

Conclusions and Recommended Next Steps

It is clear from the collected data that Dennis ponds should be evaluated individually and that the characteristics of each pond, including the land use development in its watershed, have to be adequately understood before selecting appropriate management strategies. The monitoring results show a continuum of water quality/ecosystem conditions with probably one of the region's most pristine ponds (Bakers) and two ponds that fail to meet water quality minimums required in state regulations and will require TMDLs (Cedar and Scargo).

The ponds that fail to meet state water quality standards generally do not have conditions that will affect their use for recreational purposes except perhaps for fishing. In order to address the impairments, these ponds will require the development of TMDLs and remediation plans to meet the TMDLs. MassDEP current guidance is that TMDLs must be addressed through Comprehensive Wastewater Planning activities. Additional data collection for sediment and stormwater runoff contributions are recommended prior to finalizing TMDLs and development remediation plans and associated costs.

Addressing the water quality 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 comparable to those contained in this report for the five other ponds with extensive datasets. Completion of these reviews will allow the town to begin to frame the full extent of all water quality issues that need to be addressed.

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

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 included collection and characterization of sediment cores to detail existing and future potential phosphorus regeneration and measurement of stormwater flows and phosphorus loads for the two impaired ponds (Cedar and Scargo). It is also recommended that once this information is developed that the assessment in this report be updated and phosphorus reductions recommendations should be developed.

Finally, it is recommended that the town consider continuing the citizen monitoring program for the ponds. The relatively extensive dataset for the 11 ponds discussed in this report means that they do not need to be monitored frequently, but it is recommended that they be sampled at least 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 to enhance comparison to past data and that the town consider whether any of the 46 other ponds in town should also be monitored.

Continuation of this citizen monitoring effort will allow the town to track any changes and identify any significant problems before they become more serious in the four ponds without TMDL recommendations. It will also allow the town to prioritize water quality and wastewater management efforts from a position of knowledge. Continuation of monitoring will also allow the town to 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 Dennis Ponds

All recommended activities are discussed in greater detail in the report. Estimated costs are based on SMAST personnel costs for current fiscal year. 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	5 of 6 ponds selected for detailed review: Develop bathymetric information (only Scargo has bathymetry)	V.1.	26	TBD
2	All ponds: Develop bathymetric information for remaining town ponds (only two ponds have maps)	V.1.	26	TBD
3	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.	36	TBD
4	Baker Pond: collection of field data and water quality samples twice a year: April and Aug/Sept. Review data at 5 yr intervals unless significant change in the pond.	VI.1.	38	$200 + volunteer time ($400 without PALS Snapshot) Review cost: TBD
5	Cedar Pond: a) road runoff and bird loads should be evaluated with targeted data collection b) collect and incubate sediment cores c) measure stormwater flows and phosphorus loads; seven runoff locations noted d) update assessment in this report with the Pond-specific information and develop a remedial plan e) consider rooted plant survey, including mapping, transects and species identification	VI.2.	49	$15,000 to $16,000 TMDL/mgmt plan: $10,000 to $12,000 plant survey: $7,000 to $9,000
6	Coles Pond: collection of field data and water quality samples twice a year: April and Aug/Sept. Review data at 5 yr intervals unless significant change in the pond.	VI.3.	57	$200 + volunteer time ($400 without PALS Snapshot) Review cost: TBD
7	Eagle Pond: collection of field data and water quality samples twice a year: April and Aug/Sept. Review data at 5 yr intervals unless significant change in the pond.	VI.4.	65	$200 + volunteer time ($400 without PALS Snapshot) Review cost: TBD
8	Flax Pond: collection of field data and water quality samples twice a year: April and Aug/Sept. Review data at 5 yr intervals unless significant change in the pond.	VI.5.	73	$200 + volunteer time ($400 without PALS Snapshot) Review cost: TBD

Table EX-1. Summary of Recommended Activities for Dennis Ponds (cont'd)				
Recommended Tasks		Section	Page #	Estimated Cost
9	Scargo Lake: a) road runoff and bird loads should be evaluated with targeted data collection b) collect and incubate sediment cores c) measure stormwater flows and phosphorus loads; four runoff locations noted d) update assessment in this report with the Pond-specific information and develop a remedial plan	VI.6.	81	$25,000 to $27,000 TMDL/mgmt plan: $10,000 to $12,000
10	Pond Monitoring/Town-wide: Continue monitoring all ponds; 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	84	$2,400 + volunteer time ($4,800 without PALS Snapshot) (includes above costs for Baker, Coles, Eagle and Flax)
11	Detailed Review of Other Ponds: Consider similar detailed reviews for the other five ponds that have citizen collected water quality data: Fresh, Hiram, North Simmons, Run, and White. 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	85	TBD (depends on volunteer assistance, availability of CCC GIS assistance, and gathering of other data, such as bathymetry; rough planning amount of $3,000 to $5,000 per pond)
12	Determine Regulatory Status for Six Detailed Ponds: Consider filing Scargo and Cedar 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 Dennis' other ponds.	VIII.3	85	No cost

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

I. Introduction

The Town of Dennis has 57 ponds that collectively occupy 275 acres (Eichner and others, 2003). Of these ponds, 30 of them are greater than one acre and six of them are greater than ten acres. Over the course of the last ten years, local concerns about the water quality of Dennis'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 for 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 Dennis, 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. Dennis'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 Dennis program uses the PALS sampling protocol as guidance and has included the collection of samples from 11 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 Dennis, requested CCC assistance to provide interpretation of volunteer-collected pond water quality data. The project scope developed by Dennis 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 the town Water Quality Advisory Committee in May 2006. Following consultation with town staff, the Committee voted to select the following ponds for detailed review: Bakers, Cedar, Coles, Eagle, Flax, and Scargo (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.

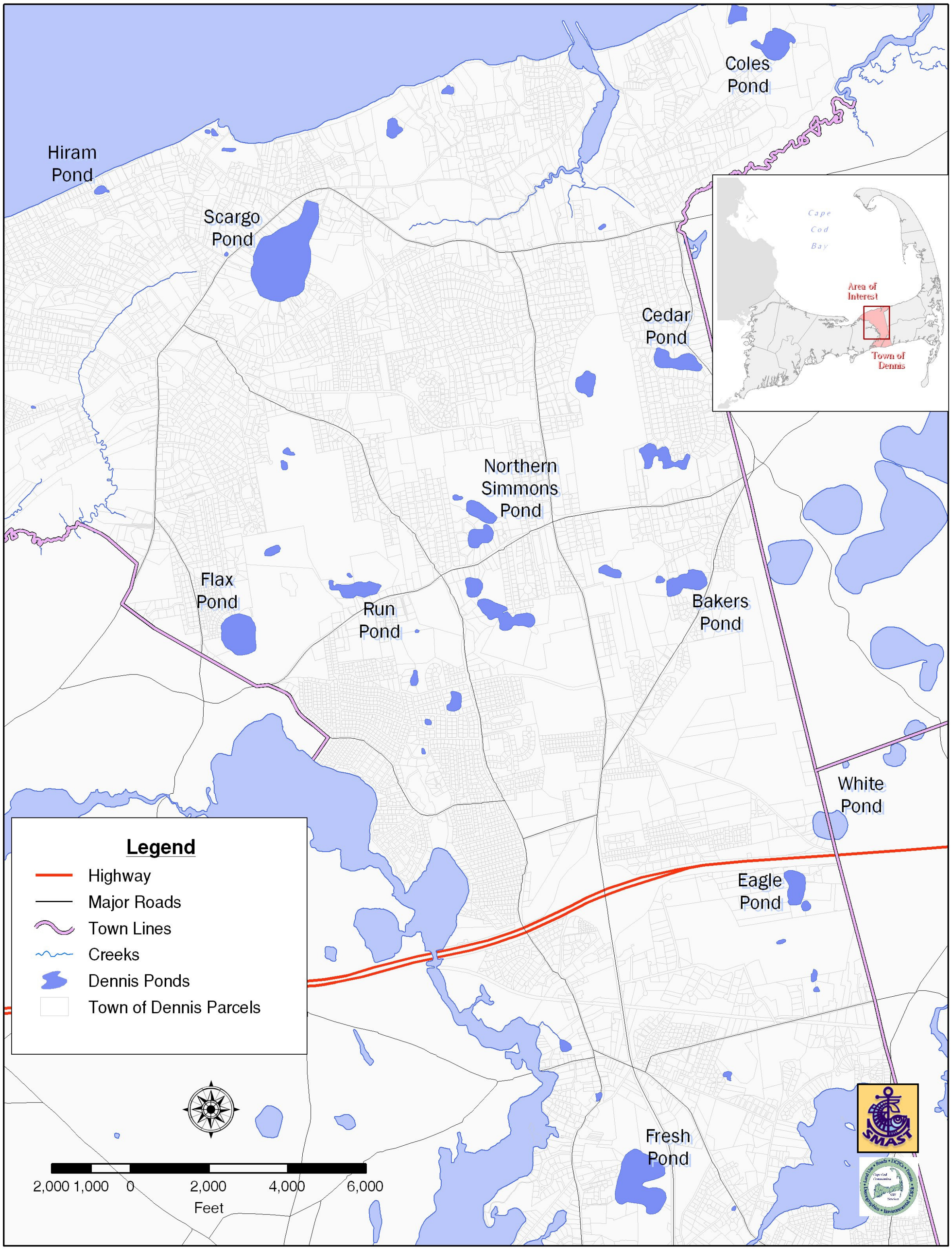


Figure I-1. Ponds regularly sampled by Dennis volunteers
The 11 ponds with name labels have been regularly sampled by Dennis volunteers and their water quality information is reviewed in this report. The Town of Dennis has a total of 57 ponds (Eichner and others, 2003).

II. Pond Data Sources

During the initial 2001 PALS Snapshot, Dennis volunteers collected data from 11 ponds. Field data was collected along with water quality samples that were analyzed by the Coastal Systems Program Laboratory, School for 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 in 2006 and prior years have been analyzed at the North Atlantic Coastal Laboratory at Cape Cod National Seashore (CCNS); samples collected in 2007 and 2008 were analyzed at the SMAST lab.

PALS Snapshots were completed every year between 2001 and 2008 and all data is included in the following analysis. 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 Dennis ponds between 2001 and 2008. 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. All data collected during this time was used for the initial overview of all the ponds that is discussed in Section III. Any historic 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 collected between 2001 and 2008 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. PALS Snapshot results from 2001 to 2008 and all sample results after 2003 were provided by the SMAST lab.

In addition to the PALS Snapshots, the Dennis 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. Two to three samples in 2002 and monthly sampling during 2003 were provided by the CCNS lab.

Table II-1. Field data collection frequency for Dennis Ponds (2001-2008)

	2001	2002						2003								2004							2005						
POND	Sep	Jul	Aug	Sep	Oct	Nov	SUM	May	Jun	Jul	Aug	Sep	Oct	Nov	SUM	May	Jun	Jul	Aug	Sep	Oct	SUM	May	Jun	Jul	Aug	Sep	Oct	SUM
Bakers	1	1		1		1	3	1	1	1	1	1	1	1	7	1	1	1	1	1	1	6	1	1	1	1	1	1	6
Cedar	1	1		1		1	3	1	1	1	1	1	1	1	7	1	1	1	1	1	1	6	1	1	1	1	1	1	6
Coles	1	1				1	2	1	1	1	1	1	1	1	7	1	1	1	1	1	1	6	1	1	1	1	1	1	6
Eagle	1		1	1	1	1	4	1	1	1	1		1	1	6	1	1	1	1	1	1	6	1	1	1	1	2	1	7
Flax	1						0	1	1	1	1	1	1	1	7	1	1	1	1	1	1	6	1	1	1	1	1	1	6
Fresh	1		1	1			2	1	1	1	1	1	1	1	7	1	1	1	1	1	1	6	1	1	1	1	1	1	6
Hiram	1	1		1		1	3	1	1	1	2	1	1	1	8	1	1	1	1	1	1	6	1	1	1	1	1	1	6
North Simmons	1		1	1	1	1	4	1	1	1	1	1	1	1	7	1	1	1	1	1	1	6	1	1	1	1	1	1	6
Run	1				1	1	2	1	1	1	1	1	1	1	7	1	1	1	1	1	1	6	1	1	1	1	1	1	6
Scargo	1					1	1	1	1	1	1	1	1	1	7	1	1	1	1	1	1	6	1	1	1	1	1	1	6
White	1		1	1			2	1	1	1	1	1	1	1	7	1	1	1	1	1	1	6	1	1	1	1	1	1	6
# of ponds SUM = # of sampling runs	11	4	4	7	3	8	26	11	11	11	11	10	11	11	77	11	11	11	11	11	11	66	11	11	11	11	11	11	67

	2006							2007								2008									Overall Sum
POND	Jun	Jul	Aug	Sep	Oct	Nov	SUM	Apr	May	Jun	Jul	Aug	Sep	Oct	SUM	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	SUM	2001-2008
Bakers	1	1	1	1	1		5	1	1	1	1	1	1	1	7	1	1	1	1	1	1	1		7	42
Cedar		1	1	1	1		4	1	1	1	1	1	1	1	7	1	1	1	1	1	1		1	7	41
Coles	1	1	1	1		1	5	1	1	1	1	1	1	1	7	1	1	1	1	1	1	1		7	41
Eagle	1	1		1	1		4		2	1	1	1	1	1	7	1	1	1	1	1	1	1		7	42
Flax	1	1	1	1	1		5	1	1	1	1	1	1	1	7		1	2	1		2	1		7	39
Fresh	1	1	1	1		1	5	1	1	1	1	1	1	1	7	1	1	1	1	1	1	1		7	41
Hiram		1	1	1	1		4	1	1	1	1	1	1	1	7	1	1	1	1	1	1		1	7	42
North Simmons	1	1	1	1	1		5	1	1	1	1	1	1	1	7		1	2	1		2	1		7	43
Run	1	1	1	1	1		5	1	1	1	1	1	1	1	7		1	2	1		2	1		7	41
Scargo	1	1		1	1		4	1	1	1	1	1	1	1	7		1	1	1	1	1	1		6	38
White	1	1	1	1		1	5	1	1	1	1	1	1	1	7	1	1	1	1	1	1	1		7	41
# of ponds SUM = # of sampling runs	9	11	9	11	8	3	51	10	11	11	11	11	11	11	77	7	11	11	11	8	11	9	2	76	451

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 "Overall Sum" shows the total number of sampling runs between 2001 and 2008 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 Dennis 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, sampling depths and field data collection procedures generally followed PALS protocols so all data could be compared. 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 CCC 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 White Pond that is approximately 7 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 station sampling 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 Dennis's ponds, only Scargo is 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. Scargo has low oxygen or anoxic conditions in its 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.*, Scargo) and not less than 5.0 mg/l (or ppm) in warm water fisheries (*e.g.*, White). 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 Dennis ponds. In the early years of the Dennis samplings, volunteers generally collected readings starting at 0.5 m and then each meter (0.5, 1.5, 2.5, etc.) Starting in 2006 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, staff reviewed the combined data of all dissolved oxygen concentrations. 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 11 ponds in Dennis with volunteer data selected for the town-wide overview, there are 119 station depths. There are collectively over 1,300 dissolved oxygen concentration reading measured at these stations between 2001 and 2008. The number of readings per station depth varies between 3 and 26. Based on an initial review, only Scargo would be classified as definitive cold water fisheries, while Flax and Hiram 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 eleven ponds, four have a depth station that has an average dissolved oxygen concentration less than the state regulatory standard: Cedar, Hiram, Run, and Scargo. All of these are the deepest stations in these ponds; on average 54% of the stations in each of these ponds fail to meet state minimum dissolved oxygen concentration. In addition to these, Flax, North Simmons, and White also have at least one station with a dissolved oxygen concentration reading less than 1 ppm. Overall, 26 of the 119 depth stations (22%) have average concentrations less that the state dissolved oxygen regulatory standard (Figure III-1).

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 Dennis, Secchi readings were generally collected by volunteers each time dissolved oxygen and temperature readings were collected. The number of Secchi readings in Dennis ponds ranged between 23 (Scargo) and 29 (North Simmons) in the 2001 to 2008 dataset. As shown in Figure III-2, all the ponds except for Fresh and Hiram have average Secchi readings that meet the state safe swimming clarity limit of 4 feet. Based on the available dataset, Fresh is 9.2 feet (2.8 m) deep and Hiram is 18.9 feet (5.7 m) deep. Three additional ponds (Cedar, Coles, and Run) have at least one reading less than 4 feet. These reading should be considered in use of these ponds for swimming activities.

Average relative readings varied between 8% (Hiram) and 97% (Bakers). In Hiram, this reading means that although it is 18.9 ft (5.7 m) deep, on average its water is only clear enough to see a Secchi disc at 1.4 ft (0.4 m) below the surface. On the other extreme, on average, 14.5 ft (4.4 m) of Bakers’ 15.4 ft (4.7 m) total depth is clear enough to see a Secchi disc from the surface.

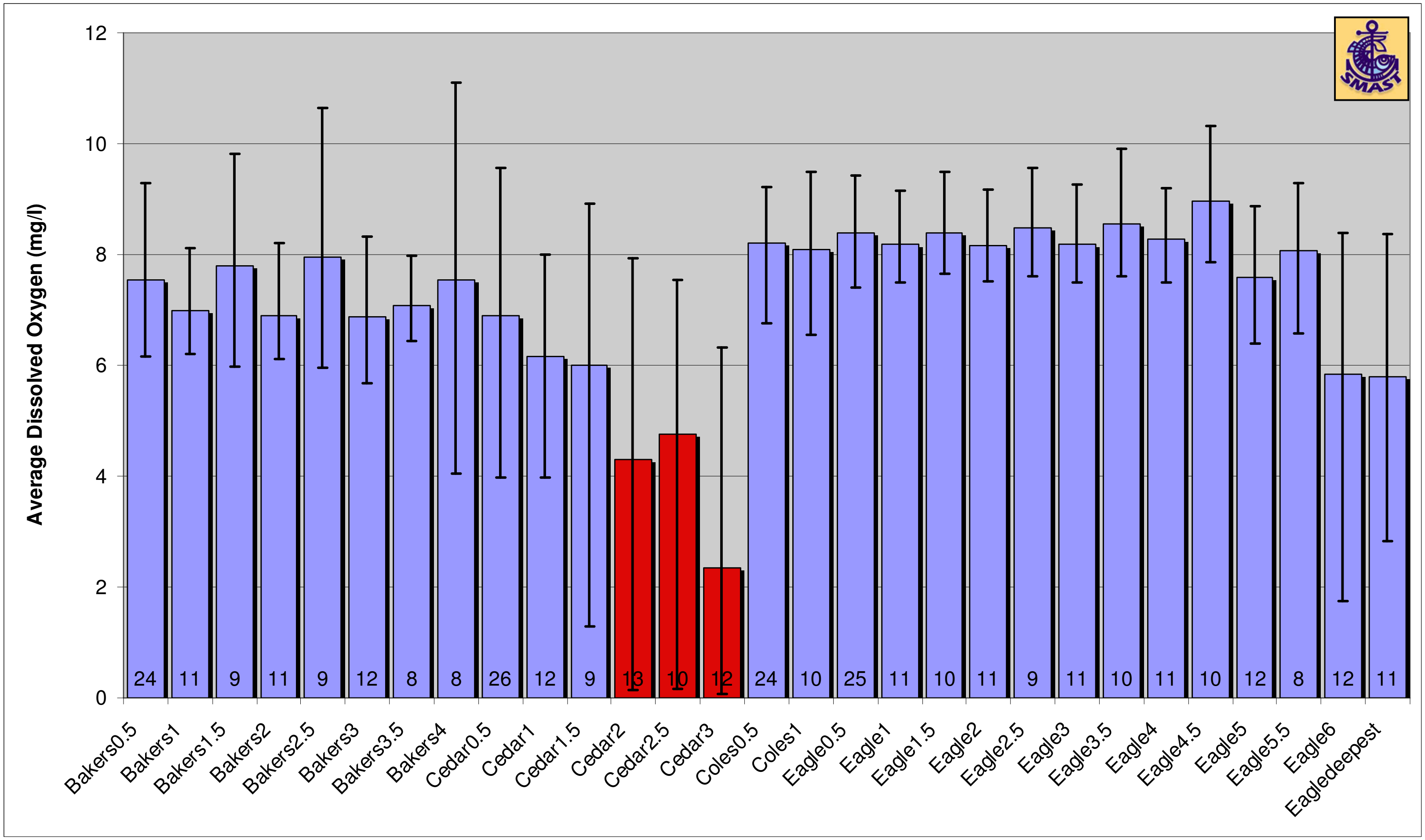


Figure III-1a. Average DO Concentrations in Dennis Ponds 2001-2007 (Bakers to Eagle)
Source dissolved oxygen data is field measurements collected by Dennis volunteers. Depth stations are indicated with the pond names and the depths in meters at which readings were collected (*e.g.*, "Cedar0.5" is Cedar Pond readings collected at 0.5 m). Error bars show one standard deviation; all averages are corrected for outliers (± >two standard deviations). The number at the base of each bar show the number of readings collected. The Massachusetts regulatory dissolved oxygen threshold for warm water fisheries is 5 milligrams per liter of dissolved oxygen (314 CMR 4); all ponds in this figure generally have temperatures that would classify them as warm water fisheries. Depth stations with average dissolved oxygen concentrations less than the state threshold are colored red.

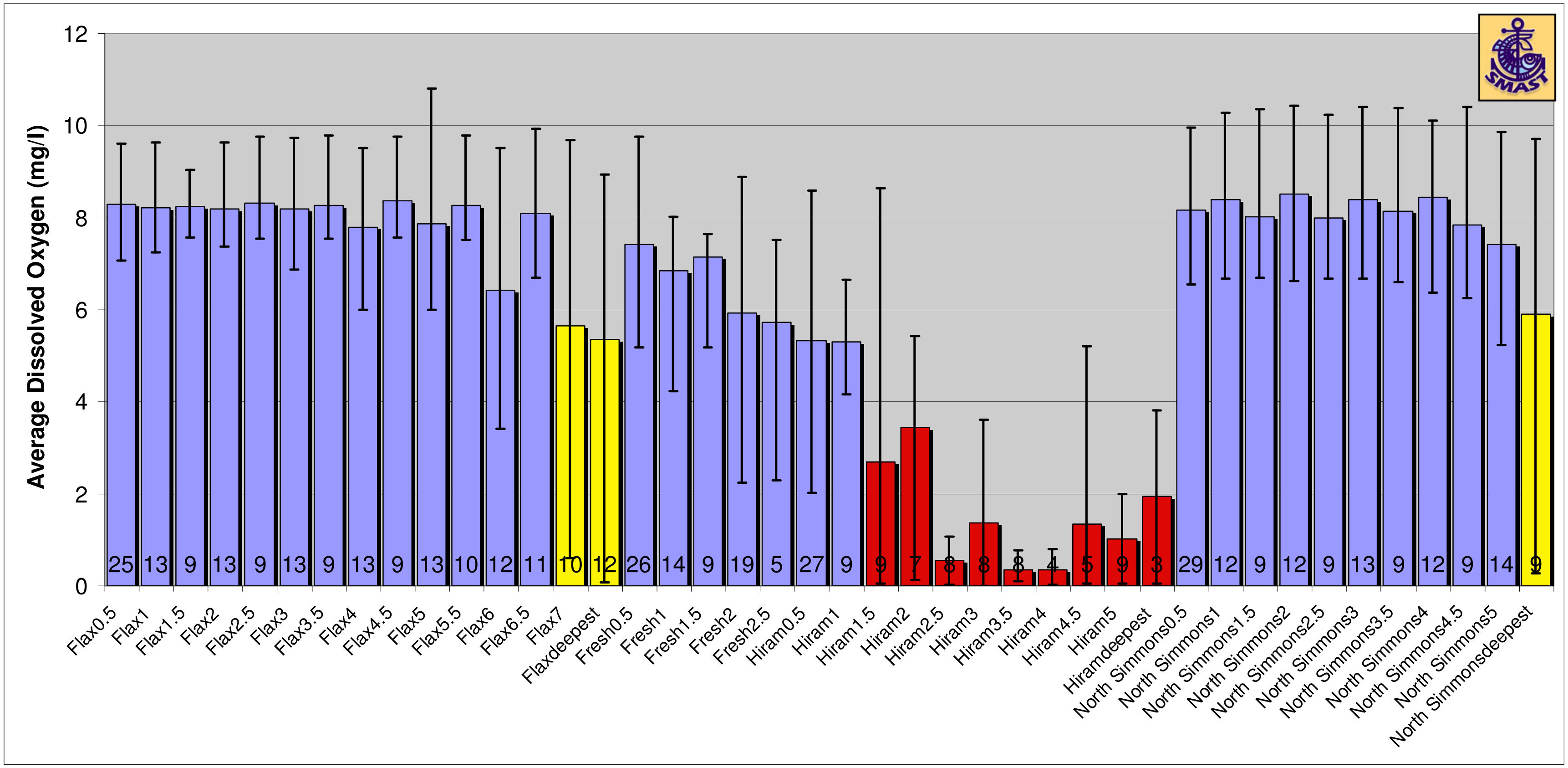


Figure III-1b. Average DO Concentrations in Dennis Ponds 2001-2007 (Flax to North Simmons)

Source dissolved oxygen data is field measurements collected by Dennis volunteers. Depth stations are indicated with the pond names and 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 number at the base of each bar show the number of readings collected. The Massachusetts regulatory dissolved oxygen threshold for warm water fisheries is 5 milligrams per liter of dissolved oxygen and 6 mg/l for cold water fisheries (314 CMR 4); Flax and Fresh have average deep temperatures that may classify them as cold water fisheries, but the depths of all ponds would generally classify them as warm water fisheries. Depth stations with average dissolved oxygen concentrations less than the state threshold are colored red, while stations with average concentration exceeding the threshold, but with at least one reading less than 1 ppm (*e.g.*, anoxic) are colored yellow.

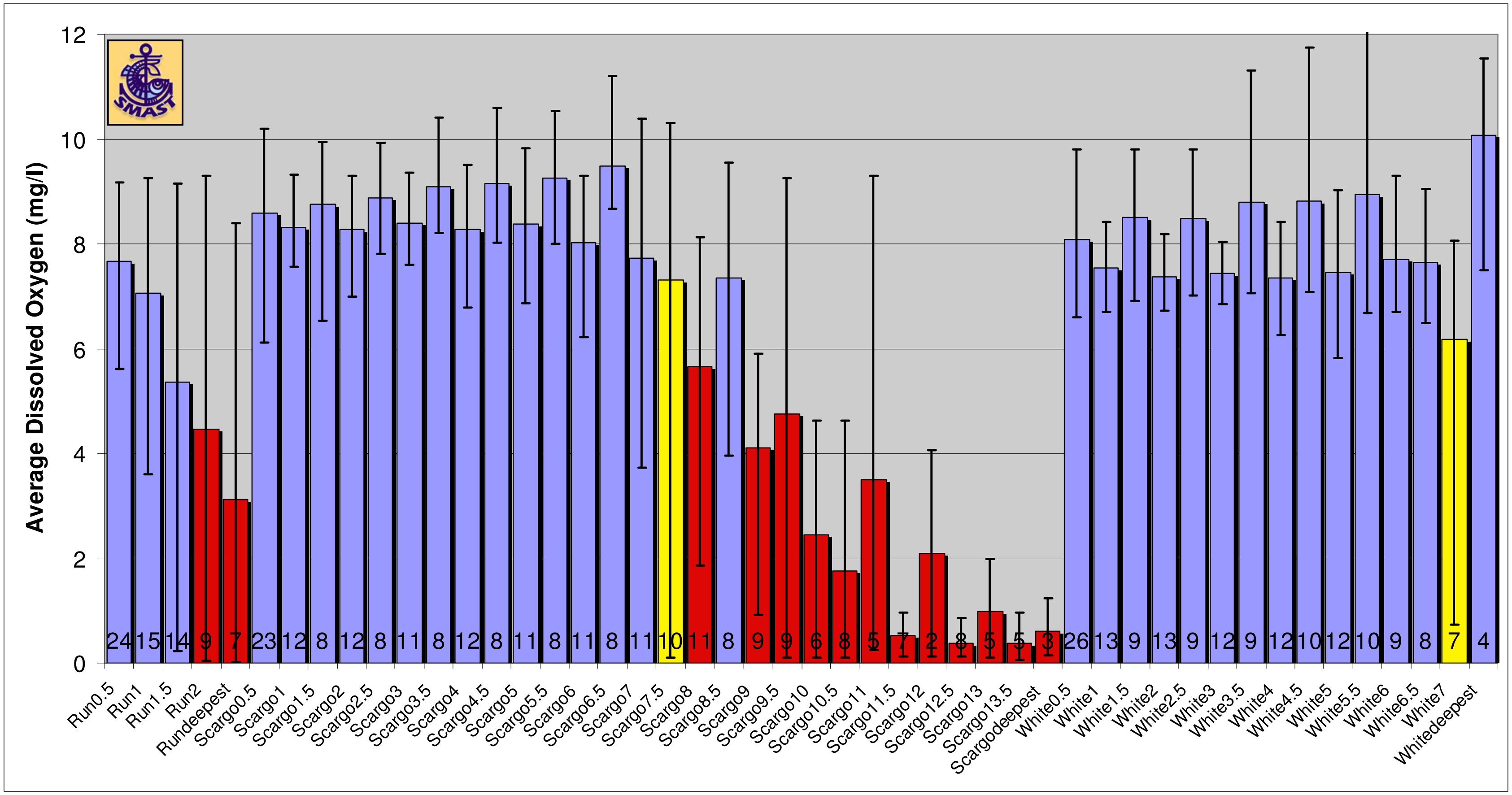


Figure III-1c. Average DO Concentrations in Dennis Ponds 2001-2007 (Run to White)

Source dissolved oxygen data is field measurements collected by Dennis volunteers. Depth stations are indicated with the pond names and the depths in meters at which readings were collected (*e.g.*, "Run0.5" is Run Pond readings collected at 0.5 m). Error bars show maximum and minimum readings; all averages are corrected for outliers (± >two standard deviations). The number at the base of each bar show the number of readings collected. The Massachusetts regulatory dissolved oxygen threshold for warm water fisheries is 5 milligrams per liter of dissolved oxygen and 6 mg/l for cold water fisheries (314 CMR 4); Scargo is a traditional cold water fishery pond, Run and Whites have maximum depths that would generally classify them as warm water fisheries. Depth stations with average dissolved oxygen concentrations less than the state threshold are colored red, while stations with average concentration exceeding the threshold, but with at least one reading less than 1 ppm (*e.g.*, anoxic) are colored yellow.

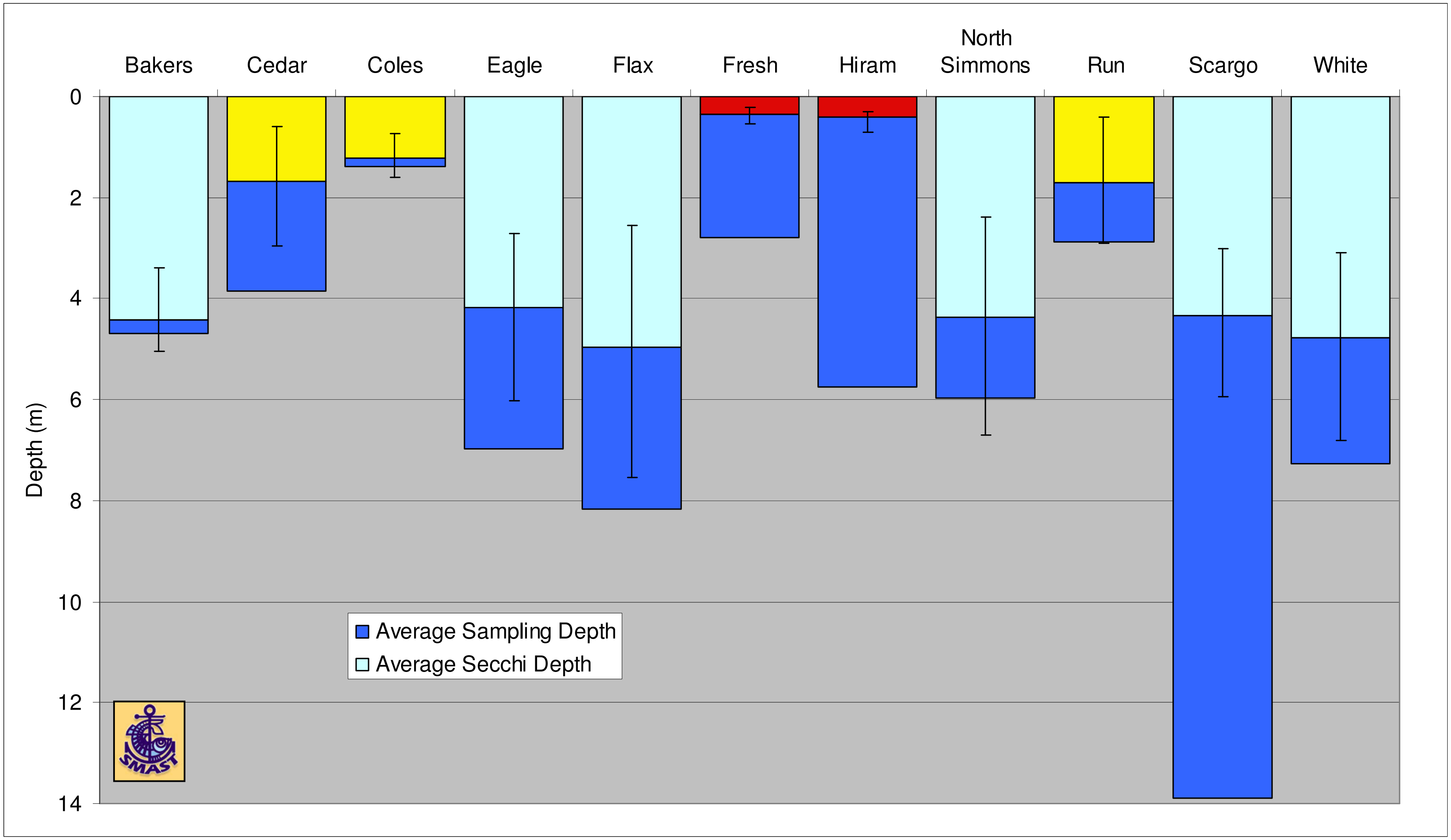


Figure III-2. Average Secchi Transparency Readings in Dennis Ponds 2001-2008
Source data is field measurements collected by Dennis volunteers using a standard Secchi disk. Error bars show maximum and minimum depths; all averages are corrected for outliers (± >two standard deviations). Number of readings range between 23 and 29. 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 a minimum recorded reading 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 2008 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 three of the 11 Dennis ponds are less than the 10 ppb TP regional limit; none of the surface stations have an average concentration less than 7.5 ppb (Figure III-4). Overall, 19 of the 24 Dennis ponds water quality sampling depths have average TP concentrations above 10 ppb. Concentrations range from 8.6 ppb (shallow station in Bakers) to 55.3 ppb (deep station in Hiram). Almost all the ponds have higher average concentrations at their deepest station, which is indicative of regeneration of phosphorus from bottom sediments. Hiram has the largest difference between surface and bottom concentrations with its average bottom concentration 76% higher than its average surface concentration. These concentration differences are much smaller than those observed in other town's ponds (*e.g.*, Eichner, 2009); the smaller difference is likely due to most of Dennis' ponds being shallow and, therefore, likely to have well-mixed water columns.

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.

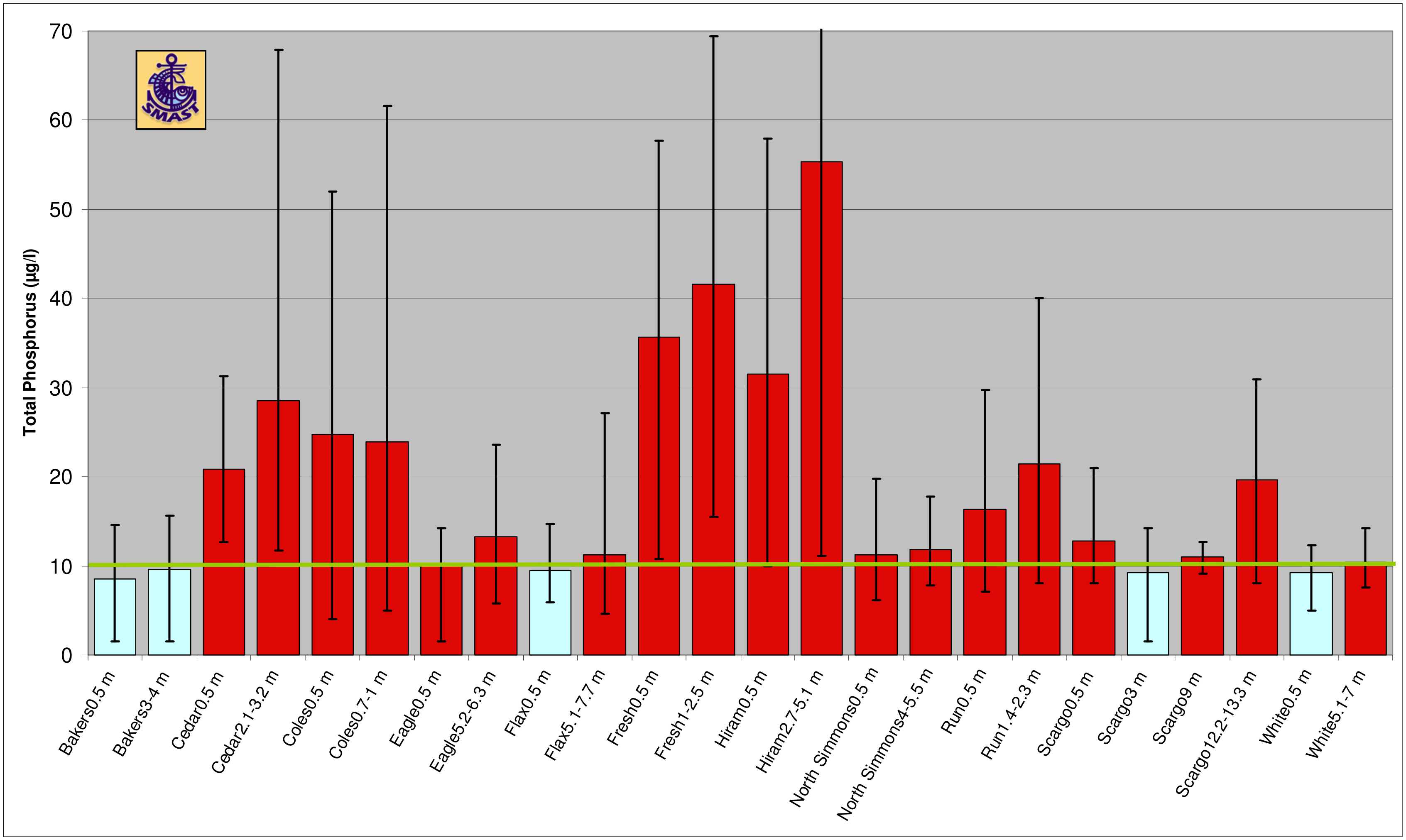


Figure III-3. Average Total Phosphorus Concentrations in Dennis Ponds 2001-2008

Averages are based on pond data collected between June and September. Pond names have the station depths in meters (*e.g.*, "Eagle0.5" is Eagle Pond readings collected at 0.5 m). Error bars show maximum and minimum concentrations; 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 TP per liter from Eichner and others, 2003). Threshold is also shown by green line. Hiram deep maximum is 149 µg/l; scale is reduced to show greater detail.

Because of these chemical and hydrologic characteristics, as well as the predominant use of septic systems for wastewater treatment, 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 TN concentrations in four of the 11 Dennis ponds are less than the 0.31 ppm TN regional limit; Flax is the only pond with an average concentration less than 0.16 ppm (Figure III-5). Overall, 17 of the 24 Dennis ponds water quality sampling depths have average TN concentrations above 0.31 ppm. Concentrations range from 0.12 ppm (deep station in Flax) to 1.29 ppm (deep station in Hiram). Four of the 11 ponds have higher surface than deep concentrations suggesting that these ponds are preferentially regenerating phosphorus from their sediments and that reduced dissolved oxygen in deeper waters has a threshold that has not been reached in these ponds to regenerate both phosphorus and nitrogen. Scargo has the largest difference between surface and bottom concentrations with its average bottom concentration 102% higher than its average surface concentration. These concentration differences are generally smaller than those observed in other town's ponds (*e.g.*, Eichner, 2009); the smaller difference is likely due to most of Dennis' ponds being shallow and, therefore, likely to have well-mixed water columns.

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

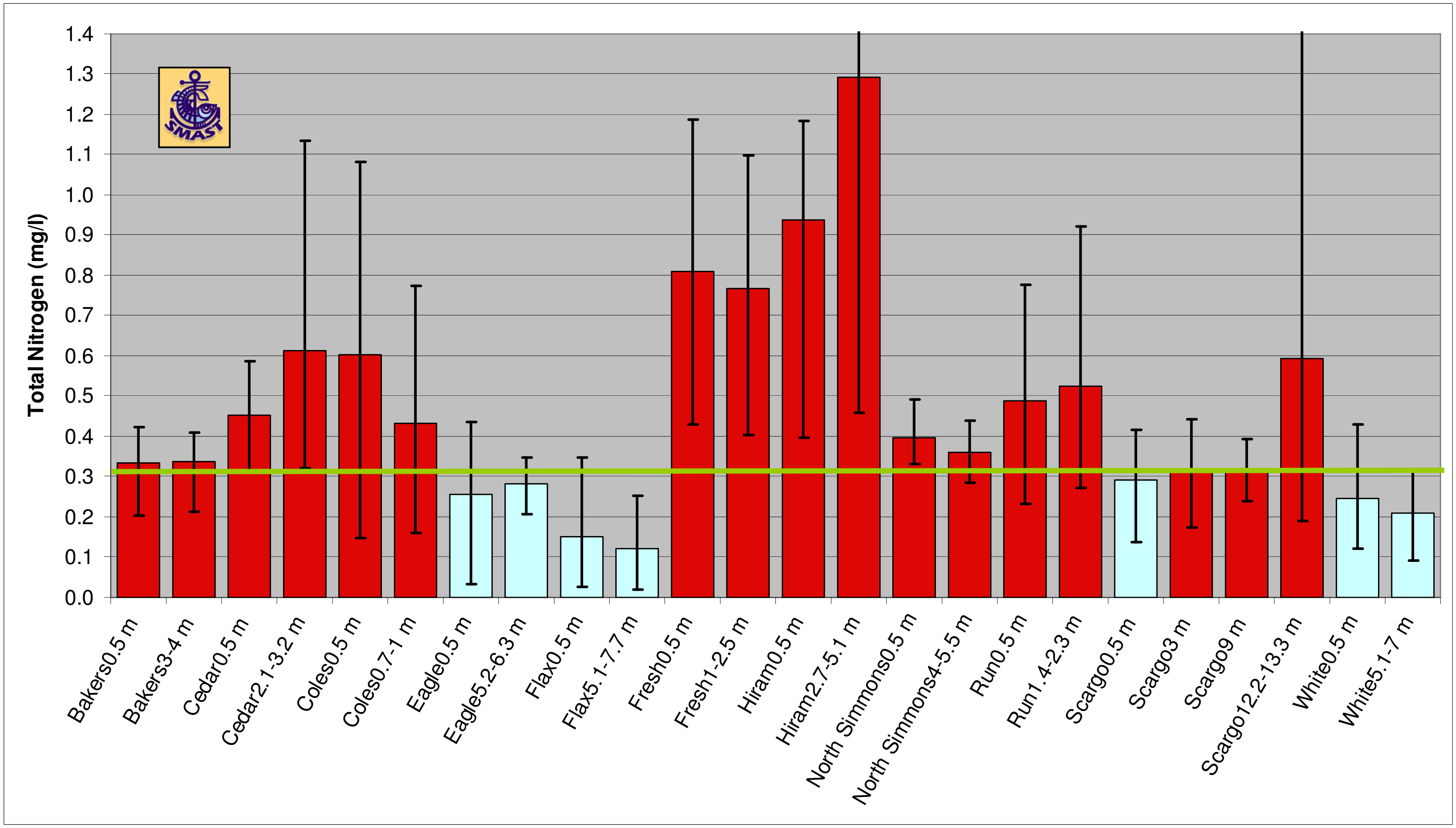


Figure III-4. Average Total Nitrogen Concentrations in Dennis Ponds 2001-2008

Averages are based on pond data collected between June and September. Pond names have the station depths in meters (*e.g.*, "Eagle0.5" is Eagle Pond readings collected at 0.5 m). Error bars show maximum and minimum concentrations; 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 (0.31 milligrams (mg) TN per liter from Eichner and others, 2003). Threshold is also shown by green line. Hiram and Scargo deep maximums are 2.1 and 1.6 mg/l, respectively; scale is reduced to show greater detail.

(Eichner and others, 2003). The lower 25th percentile among pH readings from the 2001 Snapshot, or the least impacted ponds, is 5.62.

Average surface pH reading in six of the 11 Dennis ponds are less 5.62 (**Figure III-6**). Overall, 13 of the 24 Dennis ponds water quality sampling depths have average pH readings above 5.62. Average readings range from 4.07 (deep station in Fresh) to 6.6 (3 m station in Scargo). Most of the shallow and deep averages are within a few percentage of each other, which should be excepted given that pH is calculated on a log scale. Five of the 11 ponds have higher surface than deep averages which should be expected given the relatively low nutrient concentrations in Dennis ponds and how photosynthesis increases pH. Run has the largest difference between surface and bottom concentrations with its average bottom reading 9% lower than its average surface concentration.

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 CHL-a concentrations in only one of the 11 Dennis ponds are less than the 1.7 ppb regional limit; Bakers is the only pond with an average surface concentration less than 1.7 ppb (Figure III-7). Overall, 22 of the 24 Dennis ponds water quality sampling depths have average CHL-a concentrations above 1.7 ppb. None of the average concentrations are less than 1 ppb. Concentrations range from 1.2 ppb (surface station in Bakers) to 45.6 ppb (deep station in Cedar). Four of the 11 ponds have significantly higher surface than deep

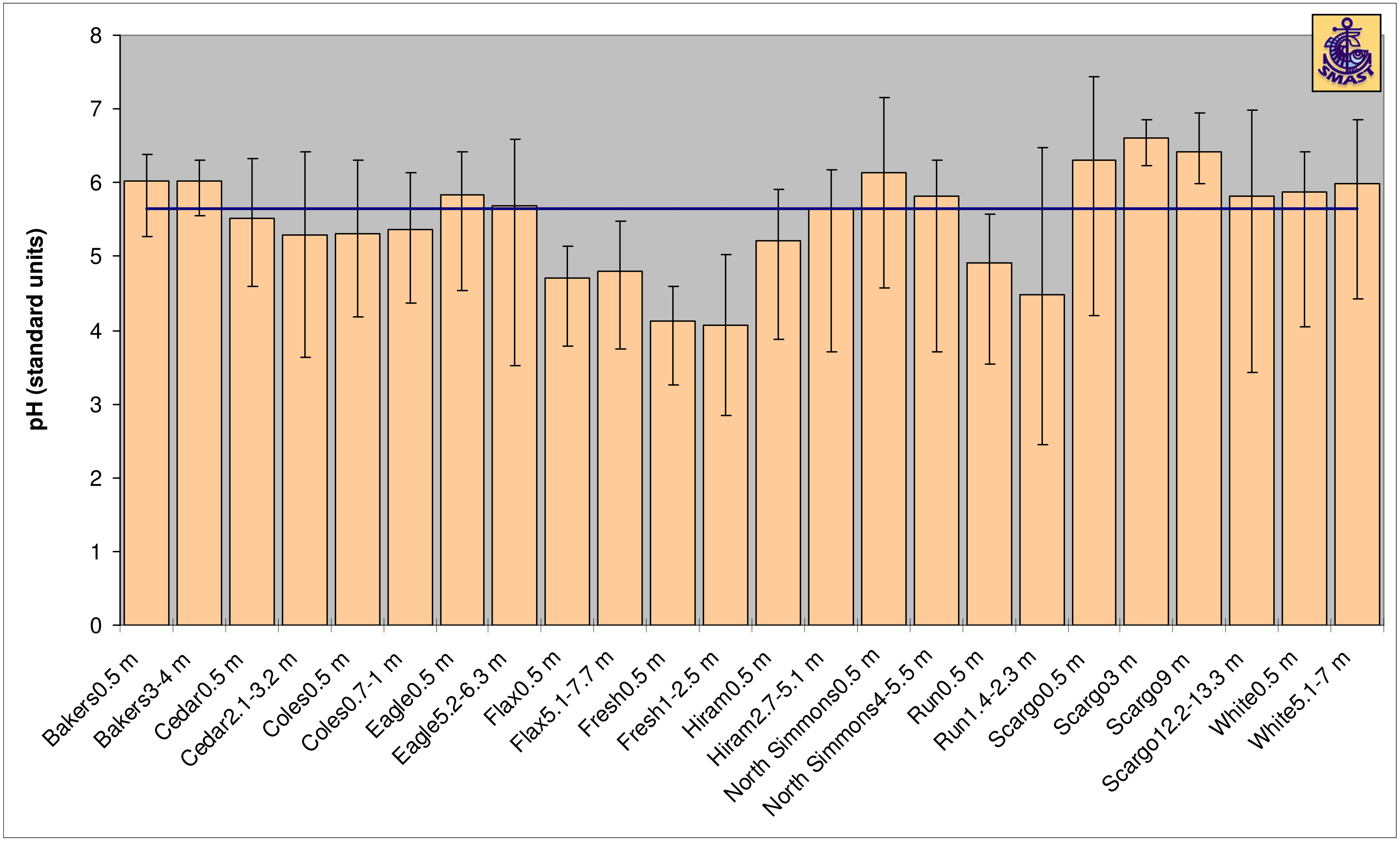


Figure III-5. Average pH in Dennis Ponds 2001-2008

Averages are based on pond data collected between June and September. Pond names have the station depths in meters (*e.g.*, “Eagle0.5” is Eagle Pond readings collected at 0.5 m). Error bars show maximum and minimum readings; all averages are corrected for outliers (± >two standard deviations). “Healthy” pH for Cape Cod ponds is 5.62, which was estimated by review of Cape-wide pond data from the 2001 PALS Snapshot (Eichner and others, 2003) and is indicated by the blue line. This pH also approximates the natural pH of rainwater.

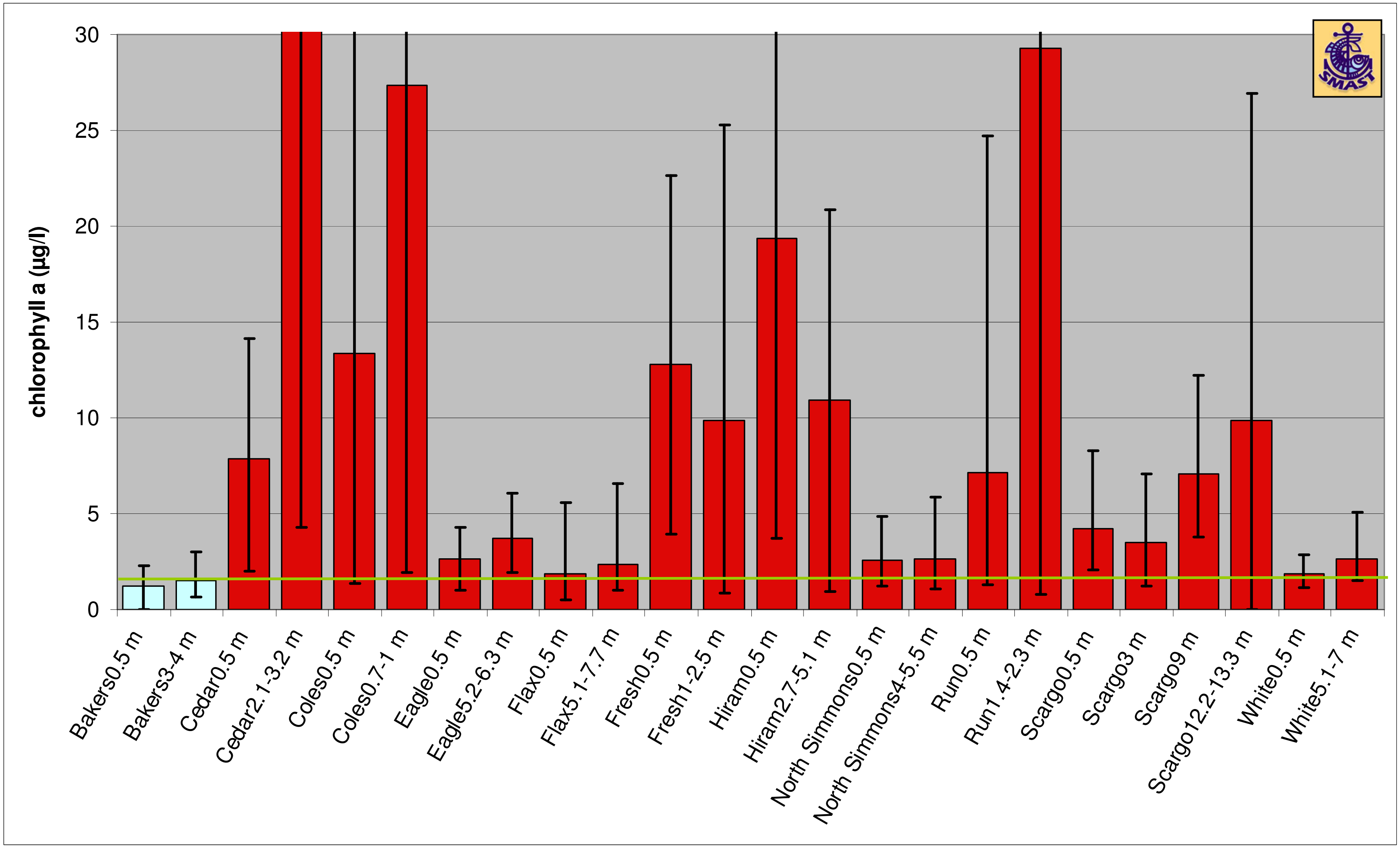


Figure III-6. Average Chlorophyll-a Concentrations in Dennis Ponds 2001-2008

Averages are based on pond data collected between June and September. Pond names have the station depths in meters (*e.g.*, "Eagle0.5" is Eagle Pond readings collected at 0.5 m). Error bars show maximum and minimum concentrations; all averages are corrected for outliers (± >two standard deviations). Bars colored red have average concentrations greater than the Cape Cod CHL-a threshold for healthy pond ecosystems (1.7 micrograms (µg) chlorophyll *a* per liter from Eichner and others, 2003). Threshold is also shown by green line. Cedar deep station average is 45.6 µg/l; scale on y-axis is reduced to show greater detail.

concentrations suggesting that these ponds are capturing the nutrients bound in phytoplankton and transferring them to the sediments. Further review and analysis of chlorophyll/phaeophytin ratios could help to confirm this; phaeophytin is a byproduct of chlorophyll a degradation and is regularly tested in the PALS Snapshot samples. Cedar has the largest difference between surface and bottom concentrations with its average bottom concentration 479% higher than its average surface concentration.

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.

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 Dennis 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, Flax Pond on average is classified under this index as an oligotrophic pond, but

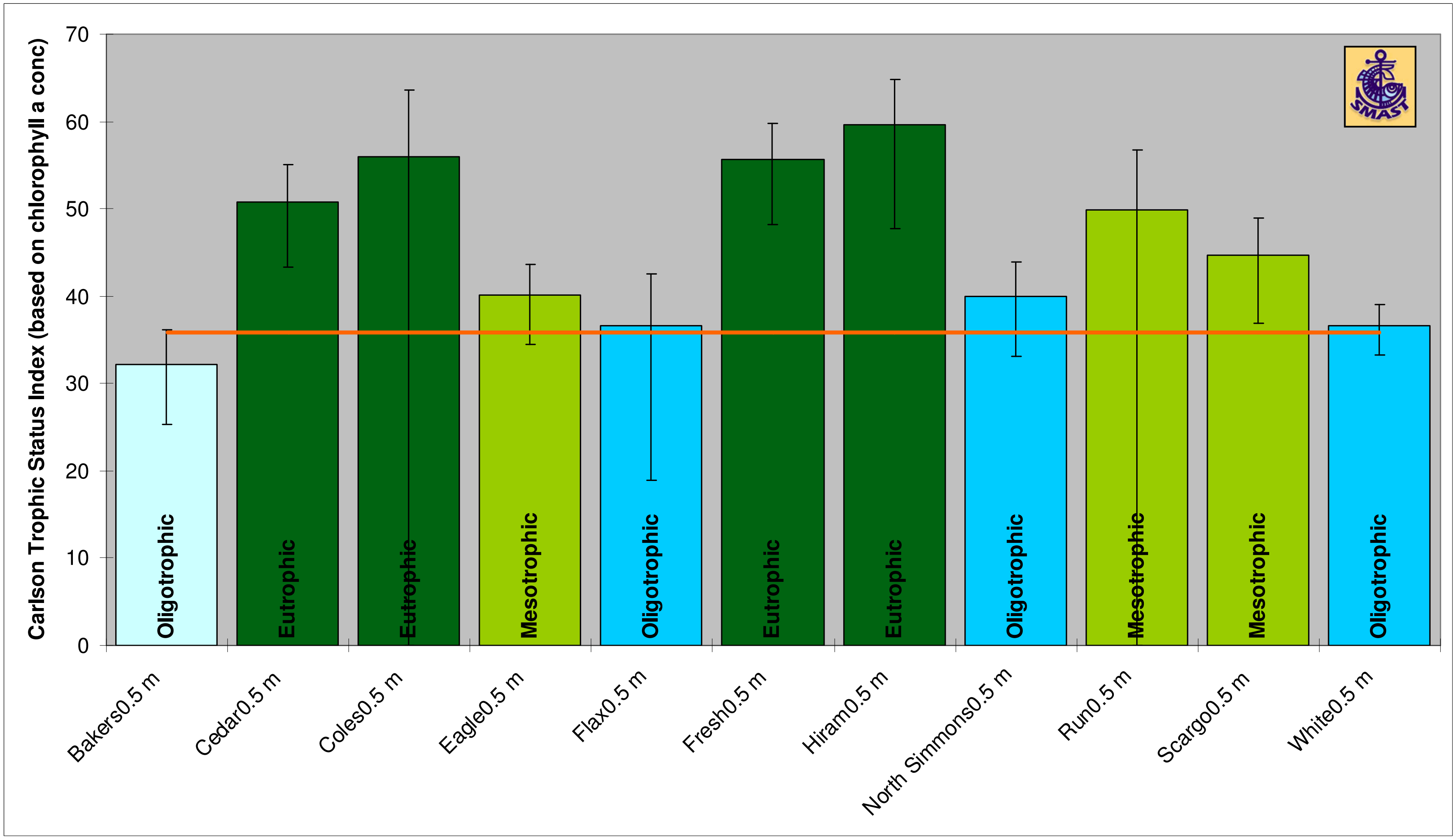


Figure IV-1. Trophic Status Index (TSI) in Dennis Ponds 2001-2007

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. Orange 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).

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					

chlorophyll *a* concentrations fluctuate enough to place it on occasion in the mesotrophic category.

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 (30.6 and 35.8) 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, none of the Dennis ponds are oligotrophic. All of the ponds are classified as either mesotrophic or eutrophic.

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

In June 2006, a preliminary overview of town-wide data was publicly presented to sampling volunteers and Dennis 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 the Pond and Lake Atlas (Eichner and others, 2003). Exceedances of the "healthy" concentrations (*e.g.*, an average TP concentration greater than 10 ppb) was 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, six ponds were initially selected for more detailed evaluation: Bakers, Cedar, Coles, Eagle, Flax, and Scargo. 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 Bakers, Cedar, Coles, Eagle, Flax, and Scargo ponds

The six Dennis 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 Dennis 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 200 and 350 feet thick and the average groundwater flow rate is approximately one foot per day (Walter and Whealan, 2005).

Scargo Pond is the largest (60 acres) of the six ponds selected for detailed review (Table V-1). It is situated just south of Route 6A and approximately 1,700 ft from Cape Cod Bay. Scargo is also the deepest of the six ponds at 13.9 m (45.6 ft), while Flax is the next deepest at 8.2 m (26.8 ft). Flax is the second largest of the ponds (16 acres), followed by Coles at 11 acres, Bakers at 10 acres, Cedar at 9 acres, and Eagle at 7 acres. Only ponds 10 acres or greater are considered public ponds, or waters of the Commonwealth and "Great Ponds."

As listed in Table V-1, bathymetric data is currently only available for Scargo. For the other ponds, SMAST staff reviewed selected Cape Cod ponds with bathymetric data and relationship between average and maximum depths. This ratio for the 20 ponds reviewed is 0.49. This is similar to the 0.467 value determined for hundreds of lakes in the Canadian shield (Wetzel, 1983). Project staff estimated volumes for Bakers, Cedar, Coles, Eagle, and Flax using the Cape Cod ratio, pond area, and the average station depth collected by samplers during Secchi readings. Application of this approach to the 20 ponds with bathymetry resulted in an average difference in mean depth of 18% with a range of 1 to 71% difference. It is strongly recommended that the town consider developing bathymetric information for the five ponds and then reevaluate the following analysis. Developing bathymetric information should also be considered for all the other ponds in town. Only two ponds in the Town of Dennis have available bathymetric maps; both maps are included in Appendix A**.**

Table V-1. Physical Characteristics of Bakers, Cedar, Coles, Eagle, Flax, and Scargo ponds

Pond	PALS ID	PALIS #	Area Acres	Volume Cubic meters	Residence Time Years	Deepest Point Feet
Bakers	DE-342		10	95,256	0.84	15.4
Cedar	DE-281		9	71,725	1.85	12.6
Coles	DE-201		11	30,925	0.31	4.6
Eagle	DE-447		7	97,087	3.88	22.9
Flax	DE-355	96090	16	263,032	1.01	26.8
Scargo	DE-236	96279	60	1,450,381	2.23	45.6

Notes:
1) Volume estimated for all ponds except Scargo; only Scargo has a completed bathymetric map. Volume estimates based on mean depth to surface area relationship from other ponds on the Cape with bathymetric measurements. Scargo bathymetry based on a bathymetric maps prepared by the Massachusetts Division of Fish and Wildlife: http://www.mass.gov/dfwele/dfw/habitat/maps/ponds/pond_maps_sd.htm).
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).
3) PALIS #'s are state assigned pond identifiers (source: MAWRRC, 1985); this numbering system is not comprehensive for all ponds on the Cape, so not all selected ponds have PALIS numbers.
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.
5) Deepest point readings are based on average station depth from monitoring data. DFW lists Scargo as having a 48 ft deepest point; maximum depth recorded at Scargo monitoring point by town samplers is 50.5 ft.

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). Review of aerial photos suggest that most of the selected Dennis ponds function in this way. In some cases, kettle ponds have small streams entering or leaving them. Scargo is only one of the ponds with an easily identified stream entering or leaving; Scargo has a small stream leaving it that connects it to the Sesuit Harbor estuary.

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 Dennis, the highest groundwater elevations are near Cedar Pond where the water table elevation is approximately 32 feet above mean sea level. Groundwater flows from these higher elevations toward Cape Cod Bay, Bass River or Vineyard/Nantucket Sound, passing through lower elevation ponds along the way. Approximate average elevations of the six ponds selected for detailed review, based on USGS quadrangles, are: Bakers, 29 ft above mean sea level (msl); Cedar, 32 ft above msl; Coles, 6 ft above msl; Eagle, 25 ft above msl; Flax, 30 ft above msl and Scargo, 12 ft above msl. These elevations first appeared on the 1943 version of the USGS quadrangles for this area and have not been altered in subsequent updates (see http://docs.unh.edu/nhtopos/Dennis7.5MA.htm for historic versions of the quadrangles).

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 Dennis 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 Dennis, 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).

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 system in some cases flows under the ponds. This means that only a small portion of the water upgradient of Cedar Pond, for example, flows through the pond; the majority of it flows under. These flow paths are different than most of the other modeled watersheds in the Monomoy Lens, which does not show underflow. In these cases, the model predicts that groundwater from the bottom of the lens, approximately 300 feet below the water table, eventually rises to 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 and accompanying flow paths, 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 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 Dennis, 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:

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

In the Dennis Ponds, each of the ponds is relatively isolated, so each of the watersheds is relatively unimpacted by nearby ponds or stream connections. 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.

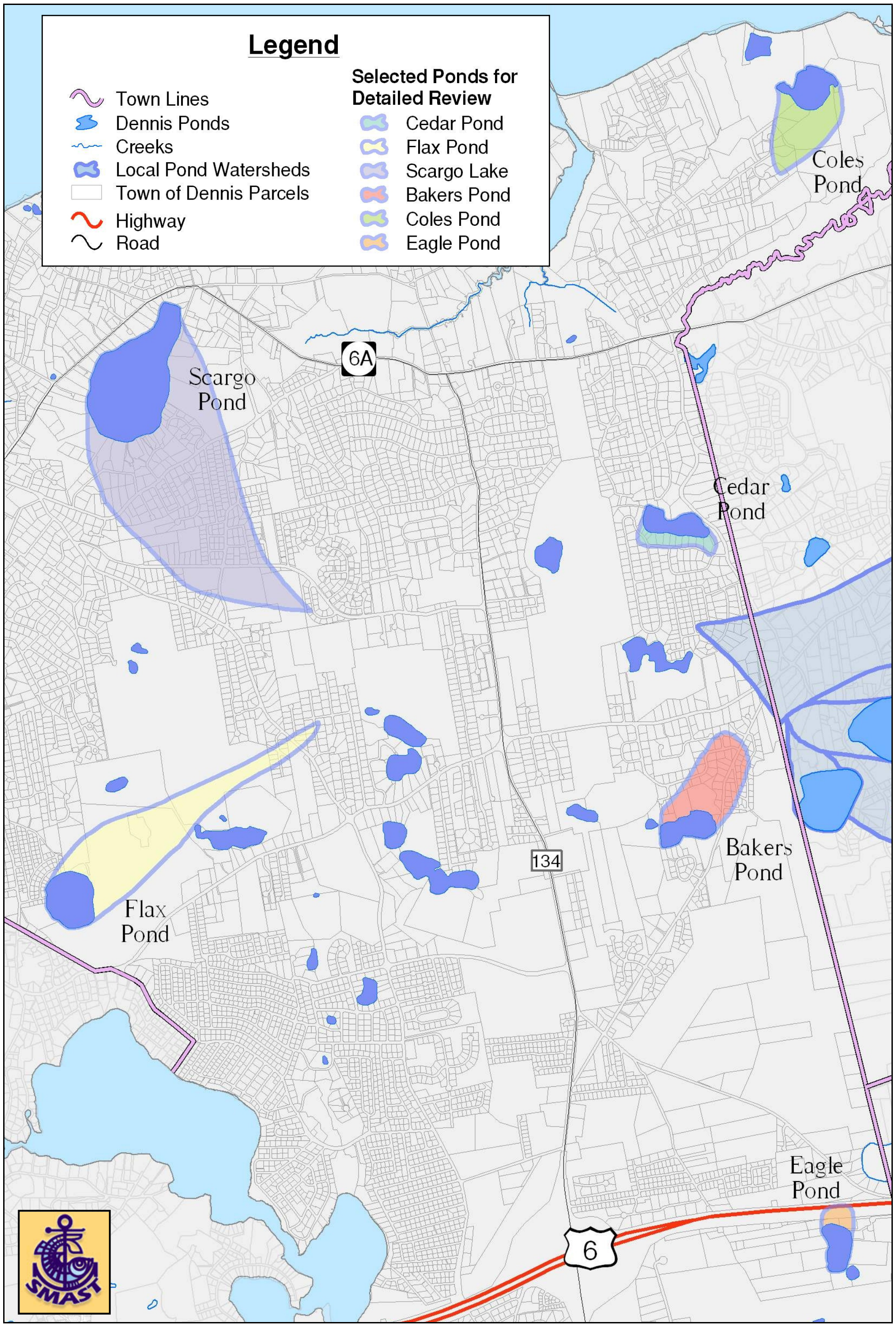


Figure V-1. Dennis Pond Watersheds
Watershed delineations were prepared by SMAST staff based on output from the US Geological Survey regional groundwater model (Walter and Whealan, 2005). Model outputs were corrected to reflect actual pond geometry and available streamflow information. Watersheds to the ponds selected for more detailed review are indicated. Watersheds in eastern Dennis are from a review of Brewster Ponds (Eichner, 2009).

Table V-2 presents the water budget for the six Dennis 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 runoff from roads within 300 feet 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 evaporation off its surface, and groundwater outflow; groundwater outflow is based on the remaining difference after accounting for evaporation. None of the ponds have measured streamoutflow.

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

Table V-2. Water budgets for Dennis 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 from each pond is based on evaporation off its surface, and groundwater outflow; none of the ponds have readily identified stream outlets and none have measured stream outflow. 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. The PALS# is a unique identifier developed for each pond by the Cape Cod Commission and listed in the Cape Cod Pond and Lake Atlas (Eichner and others, 2003).

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
Bakers	DE-342	10	97,264	46,755	3,418	147,437	117,493	29,944	-	147,437	95,256
Cedar	DE-281	9	23,218	43,081	12,105	78,405	38,708	27,591	-	66,300	71,725
Coles	DE-201	11	79,805	51,225	-	131,030	98,223	32,807	-	131,030	30,925
Eagle	DE-447	7	13,469	32,095	3,525	49,089	25,009	20,555	-	45,565	97,087
Flax	DE-355	16	233,354	74,174	4,202	311,730	260,024	47,505	-	307,528	263,032
Scargo	DE-236	60	552,644	272,227	8,286	833,157	650,524	174,348	-	824,871	1,450,381

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
Bakers	DE-342	41,365	66%	32%	2%	80%	20%	0%
Cedar	DE-281	38,115	30%	55%	15%	58%	42%	0%
Coles	DE-201	45,320	61%	39%	0%	75%	25%	0%
Eagle	DE-447	28,395	27%	65%	7%	55%	45%	0%
Flax	DE-355	65,623	75%	24%	1%	85%	15%	0%
Scargo	DE-236	240,845	66%	33%	1%	79%	21%	0%

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).

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 Dennis ponds selected for more detailed review, project staff began the development of the watershed portion of the phosphorus budget by asking Dennis 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. 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 Dennis 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

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 Dennis 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 Dennis 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 Dennis'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 with little or no development around them, where surface precipitation would be expected to be the predominant source of phosphorus, 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 Dennis'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 Dennis 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. Bakers Pond

Bakers Pond is a 10-acre pond that is located to the west of Airline Road (Figure VI-1). It has a small stream at its western end connecting it to an old cranberry bog. Based on volunteer collected data, it is has an average maximum depth of 4.7 m (15.4 ft), with a maximum recorded depth of 5.4 m (17.7 ft). It is the fourth largest of the ponds selected for detailed review.

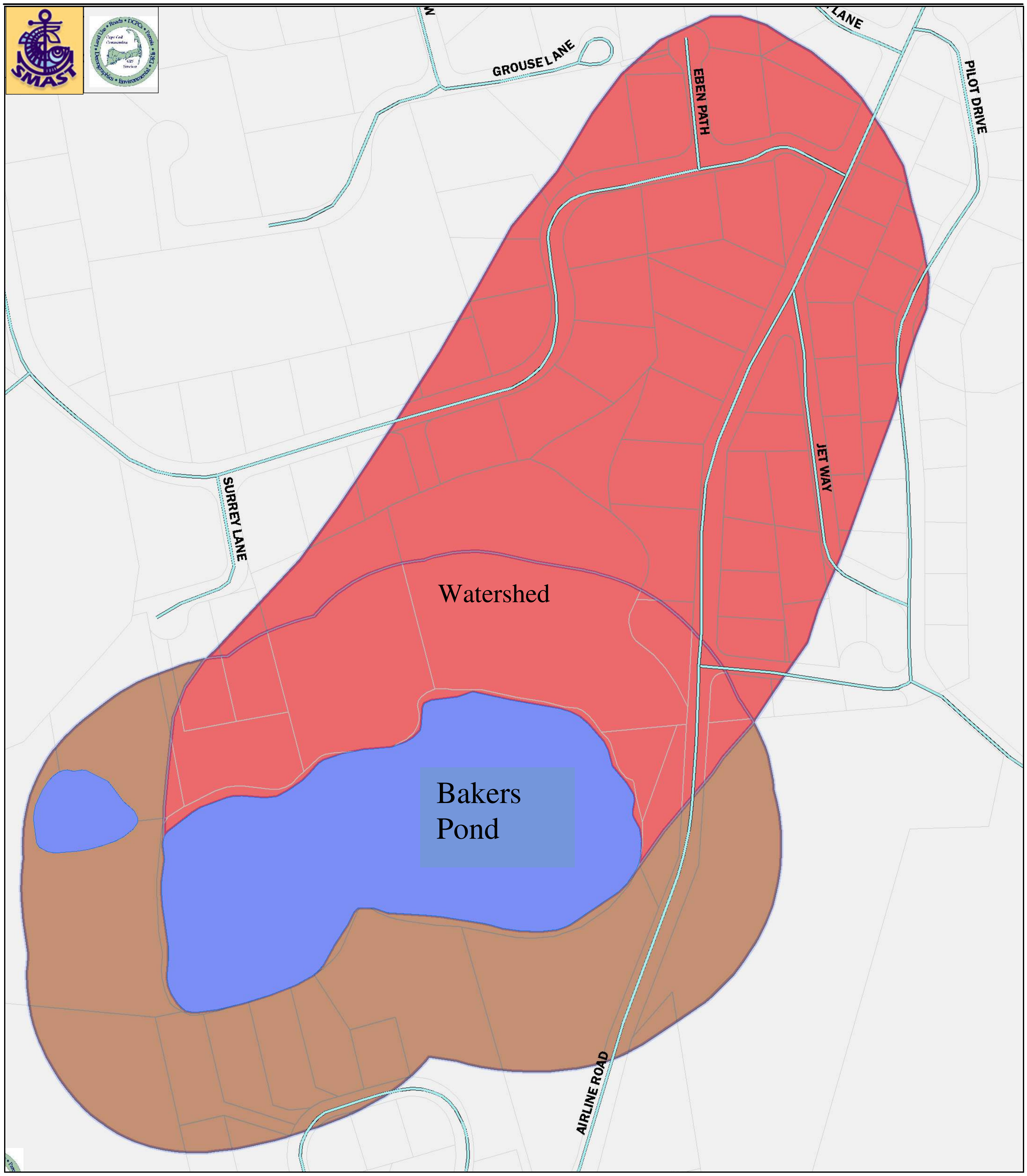


Figure VI-1. Bakers Pond watershed and phosphorus loading parcels
Phosphorus loads are developed for parcels within 300 ft that are also within the pond watershed. Watershed parcels inside the 300 ft buffer, but outside the watershed, are not assigned a phosphorus load except for road areas. Phosphorus 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 completed by town volunteers.

Temperature data collected between 2001 and 2008 shows that the Bakers water column is generally well mixed; there is little difference between average temperature between June and September at any of the depths (Figure VI-2). Only the deepest station (below 4 m) has an average temperature below 20ºC, which is the state surface water regulations (314 CMR 4) temperature threshold for cold-water fisheries. These temperature readings mean Bakers should be classified as a warm water fisheries pond.

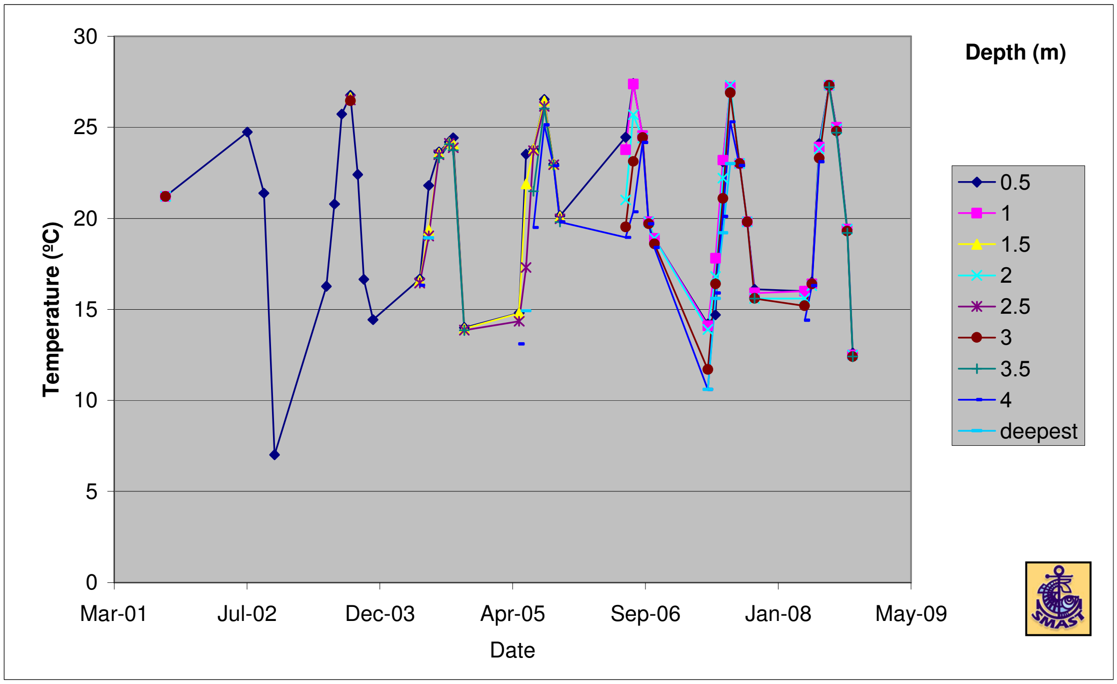
Because of this warm water classification, the state surface water dissolved oxygen standard for Bakers is 5 ppm (314 CMR 4). As shown in Figure VI-2, all station depths in Bakers regularly exceed 5 ppm. Of the 96 dissolved oxygen readings recorded during the summer in Bakers between 2001 and 2008, only one reading below 5 ppm was recorded. Based on this regulatory criterion, Bakers pond is not impaired.

Other water quality data generally confirm that Bakers Pond is not impaired. Average total phosphorus and chlorophyll *a* concentrations at all depth stations are less than their respective Cape Cod pond water quality thresholds (Eichner and others, 2003). Secchi transparency readings average 97% of the water column, which means light generally reaches within 0.2 m (11 inches) of the bottom at the pond's deepest point (Figure VI-3). This relative Secchi reading is the highest among all Dennis ponds and highest among all 56 ponds reviewed Dennis, Orleans, Eastham, and Brewster using Barnstable County funding (Eichner, 2008; Eichner, 2009a; Eichner, 2009b, respectively).

The deepest readings for total phosphorus and chlorophyll *a* show slightly elevated compared to surface readings. These concentration increases appear to indicate that the sediments are preferentially releasing some phosphorus, which, because of the clarity of the water, is being rapidly incorporated into phytoplankton. This preferential release is consistent with what would be more useful to sediment bacteria; iron reduction releases more energy than nitrate reduction for bacteria in low oxygen sediments (Stumm and Morgan, 1981). Since phosphorus is chemically bonded with iron in Cape Cod sands, the reduction of iron will break the iron-phosphorus bond and release the phosphorus back to the overlying water. This hypothesis is also supported by the total nitrogen concentrations, which show little difference between surface and deep stations in Bakers. It is recommended that the town consider regular Secchi monitoring and twice a year water sample collection to track this situation and ensure that phosphorus release from the sediments does not increase.

Review of nitrogen to phosphorus ratios in Bakers 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 that should be targeted to ensure that its water quality is maintained. Average surface N to P ratio during June through September is 88; generally water N to P ratios above 16, know as the Redfield ratio, are phosphorus limited (Redfield and others, 1963). Preferential phosphorus regeneration from the Bakers sediments makes the deeper waters slightly less phosphorus limited; average N to P ratio in deep waters is 77.

Since phosphorus is the key for determining water quality in Bakers Pond, one of the next steps for effective management is to determine the sources and magnitude of phosphorus. Once this is completed, community discussions can help to determine what combination of phosphorus



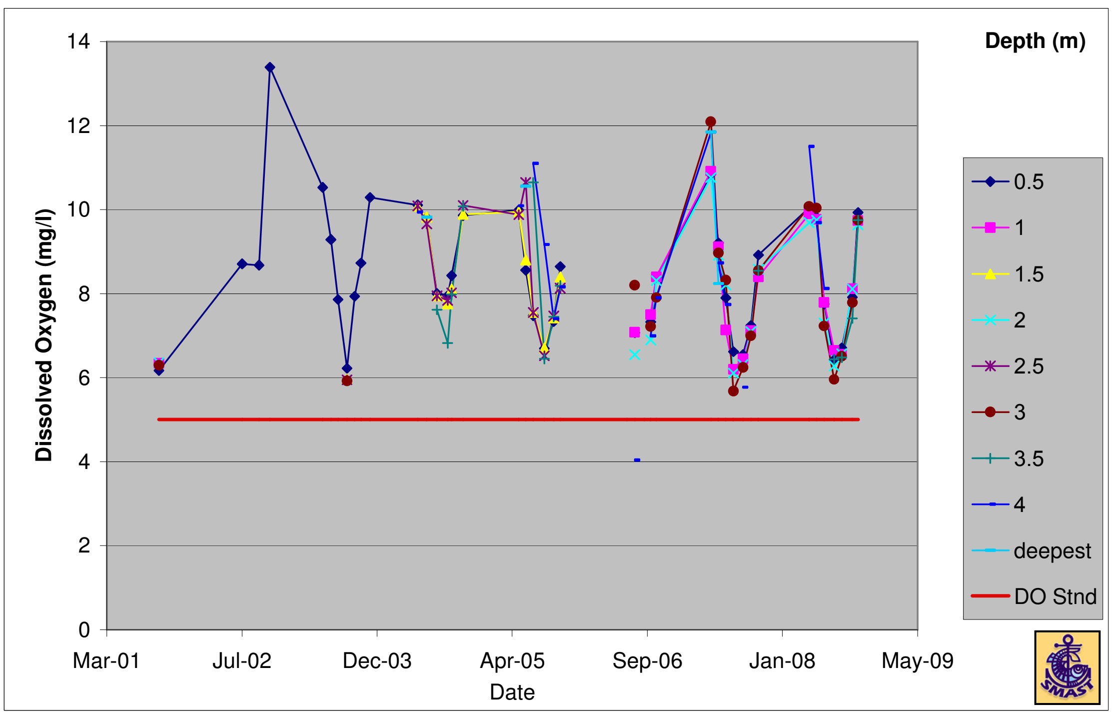


Figure VI-2. Bakers Pond Temperature and DO Readings 2001-2008
Temperature data shows relatively consistent temperatures throughout the water column regardless of season indicating well-mixed conditions. Summer temperatures generally average above 20°C, which classifies Bakers as a warm water fishery under state regulations (314 CMR 4). Dissolved oxygen concentrations show a similar well-mixed pattern with nearly all readings above the warm water fishery threshold of 5 ppm. All data collected by Dennis volunteers using DO/Temp meters, including data from PALS Snapshots from 2001 to 2008.

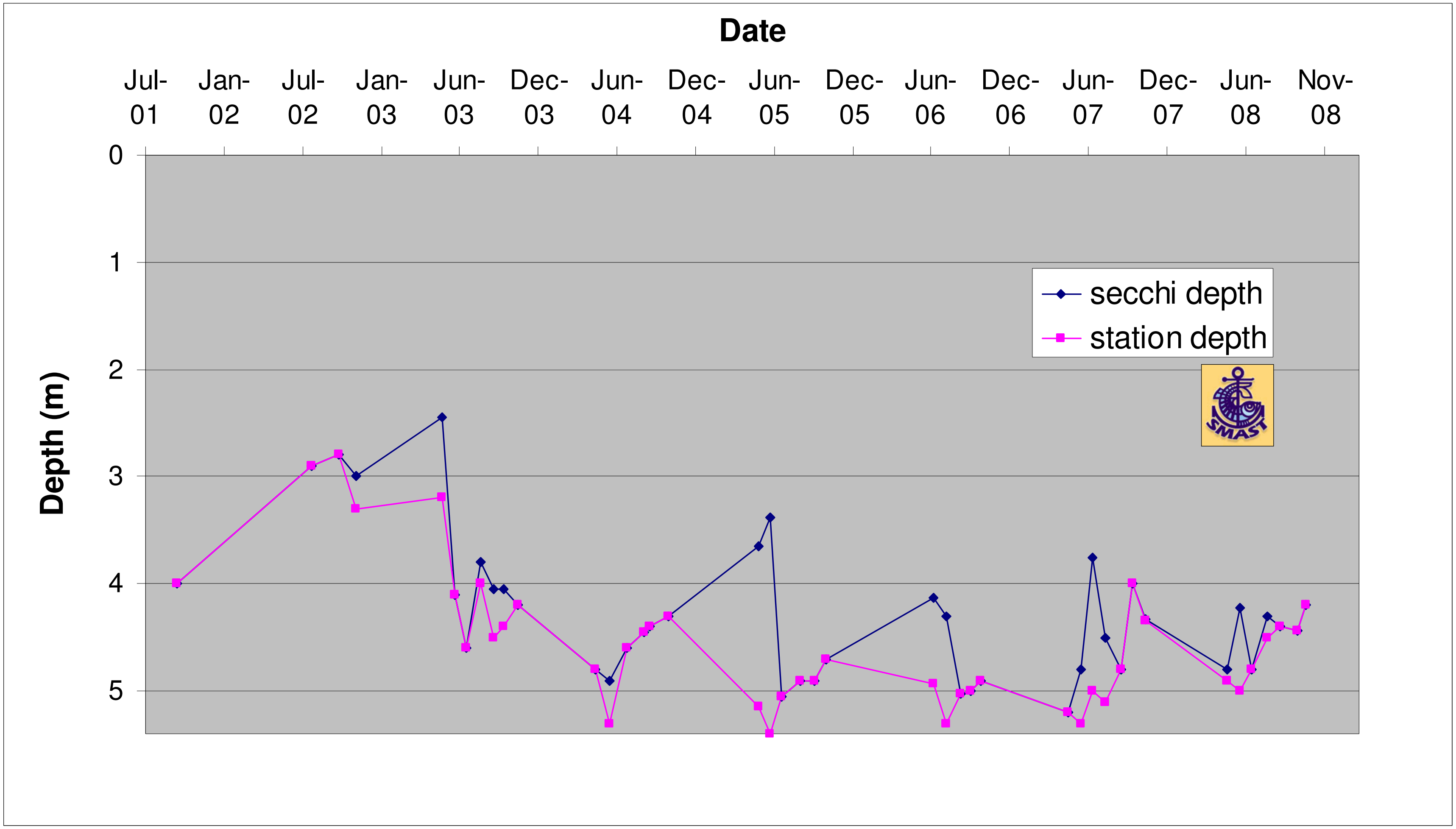


Figure VI-3. Bakers Pond: Secchi transparency readings 2001-2008
Blue data points are Secchi depth readings, while station depth measurements are shown in pink. All data collected by Dennis volunteers. Secchi readings are generally close to the bottom although they are consistently shallower in early summer (May/June). This is likely due to winter additions of organic matter being degraded and releasing nutrients when the pond begins to warm. Secchi readings are 97% of the total depth on the pond on average; this is the highest relative Secchi reading of all ponds in Dennis, as well as all ponds with significant Secchi datasets in Orleans (Eichner, 2008), Eastham (Eichner, 2009), and Brewster (Eichner, 2009).

management strategies will be adopted to preserve water quality in Bakers Pond. Accounting for all the sources and magnitude or loads of phosphorus is usually done through the development of a phosphorus budget. Phosphorus budgets usually consist of watershed sources, such as septic systems and road runoff, and internal pond sources, such as sediment regeneration and aquatic waterfowl.

Since directly measuring the components of a phosphorus budget was beyond the scope of this project, the phosphorus loads in this report are developed based on research that has evaluated these components. The research results are adjusted to address the particular details of the pond being evaluated. For example, available research on phosphorus transport from septic systems in sandy aquifers (*e.g.*, Robertson, 2008) is adjusted to reflect the number of septic systems around Bakers Pond instead of directly trying to measure the phosphorus transport from each system. This approach allows a reasonable estimate to be developed, but it can be refined with additional information. All phosphorus loading estimates are compared to measured data from Bakers Pond to evaluate the budget and this comparison is used to suggest components of the budget that would benefit from more refined data collection before pursuing management strategies. This approach ensures that whatever management strategies are selected effectively target the largest and most cost effective sources of phosphorus.

In order to begin to develop a watershed phosphorus budget for Bakers 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-1), 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 12 properties wholly or partially within the 300 ft buffer upgradient of Bakers Pond; five of them are single family residences and two additional properties that are classified by the town assessor as being developable for residential uses. Three additional properties are owned by the town and one additional is classified as undevelopable. All five of the residences are connected to the municipal water supply.

All five of the residences have septic system leachfields within 300 feet of the pond shore; the average distance for these systems is 232 feet. Average age of these residential septic systems is 17 years old, while the average age of the houses connected to the systems is 32 years old. Total Title 5 design flow of the septic systems is 1,540 gallons per day, while total water use in 2007 was 1,649 gpd. 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 1.4 and 2 kg of phosphorus to Bakers Pond with an estimated annual steady state load of 2.3 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 Bakers Pond, without including an

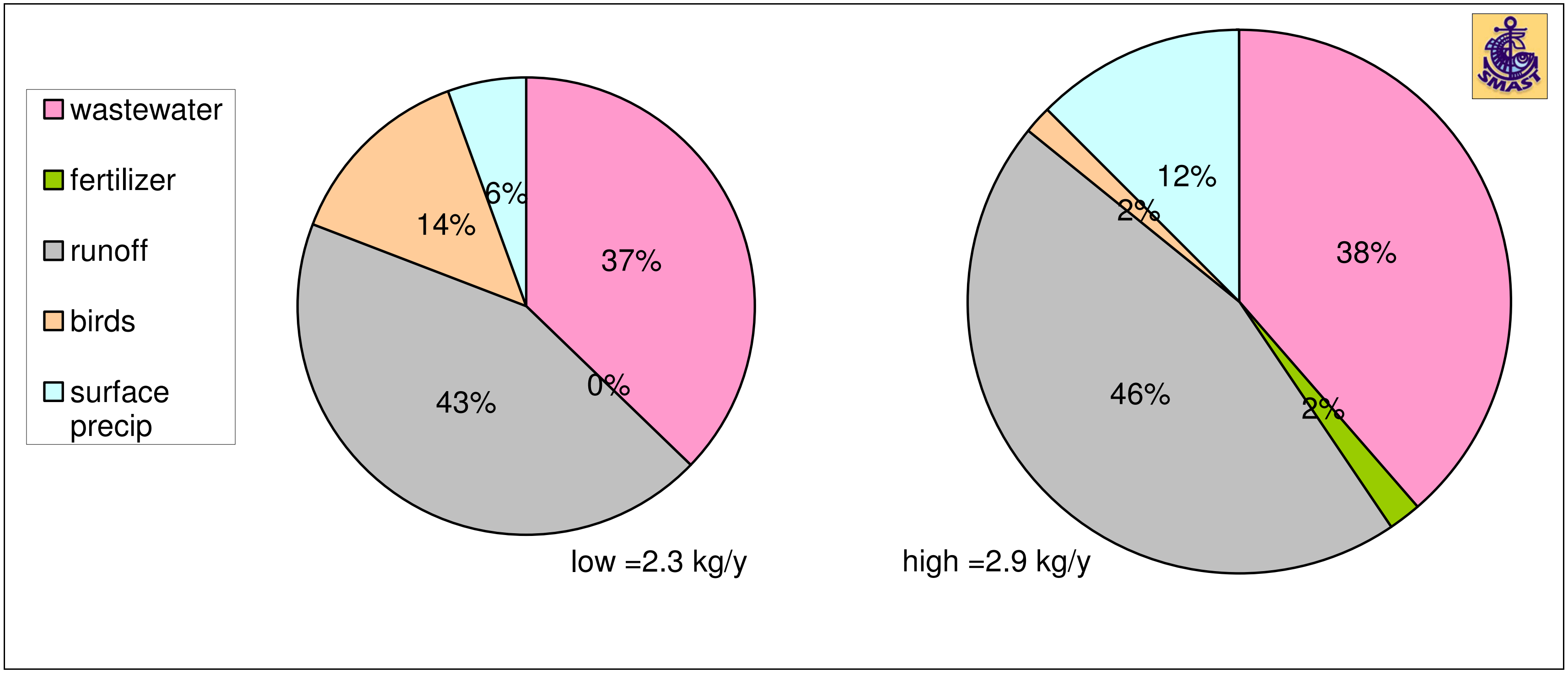


Figure VI-4. Bakers Pond: Estimated annual phosphorus budget
High and low estimates based on factors discussed in Section V.3 and presented in Table V-3. Average in-lake mass, corrected for residence time, results in an annual load of 1.1 kg based on measured water quality data (n=14 sampling runs). 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 if water quality conditions in the pond worsen. Contribution of seasonal phosphorus regeneration does not appear to be a significant source.

estimate for internal sediment regeneration, has a range 2.3 to 2.9 kg. Within these loads, the sources that are the most uncertain are road runoff and birds. Bird loading has a wide range, while road runoff is based on a number of assumptions that could be checked through a review of the stormwater structures around the pond. Gathering of Bakers Pond-specific information is recommended to clarify these particular factors if water quality conditions worsen in the pond.

Based on the phosphorus loading analysis, the total annual load of phosphorus entering Bakers Pond is between 2.3 to 2.9 kg. Reviewing the water quality data can provide a reliability check on the average mass of phosphorus in Bakers. After reviewing the 14 sampling runs completed between June and September, an average of 0.9 kg of phosphorus is in the water column of Bakers. Since the residence time of water in the pond is 0.84 years (see Table V-1), this means that roughly 1.1 kg of phosphorus is added to the water column each year. This result suggests that approximately 50% of the annual load is retained in the sediments. Independent confirmation by sediment testing would be necessary to further evaluate these calculations; phosphorus retention in sediments can be impacted by a large number of factors including residence time, iron availability, and sediment pH.

Sediment regeneration is not included in the phosphorus budget estimates. Generally, the water quality data does not suggest that there is significant regeneration. As mentioned, there is a slight rise in the average deep phosphorus concentration, but it is not significantly greater than the surface concentration. The dissolved oxygen data also does not show deep conditions that would favor phosphorus regeneration from the sediments. These conditions suggest sediment phosphorus regeneration should be monitored, but do not suggest a significant impact at this time.

Overall, water quality conditions in Bakers Pond are good. It has average dissolved oxygen concentrations above the minimum thresholds in the state regulations. Clarity is among the best for ponds that have been evaluated on the Cape. It is recommended that the town continue regular annual sampling of the pond to provide an early alert if conditions worsen.

VI.2. Cedar Pond

Cedar Pond is a 9-acre pond that is located to the west of Airline Road and north of Indian Field Drive (Figure VI-5). Aerial photography seems to show a fair amount of macrophytes (i.e., rooted plants) along its northern, downgradient shoreline. Based on volunteer collected data, it is has an average maximum depth of 3.8 m (12.6 ft), with a maximum recorded depth of 4.4 m (14.4 ft). It is the second smallest of the ponds selected for detailed review.

Temperature data collected between 2001 and 2008 shows that the Cedar water column is generally well mixed; there is little difference between average temperature between June and September at any of the depths (Figure VI-6). Only the deepest station (3 m) has an average temperature below 20ºC, which is the state surface water regulations (314 CMR 4) temperature threshold for cold-water fisheries. These temperature readings mean Cedar should be classified as a warm water fisheries pond.

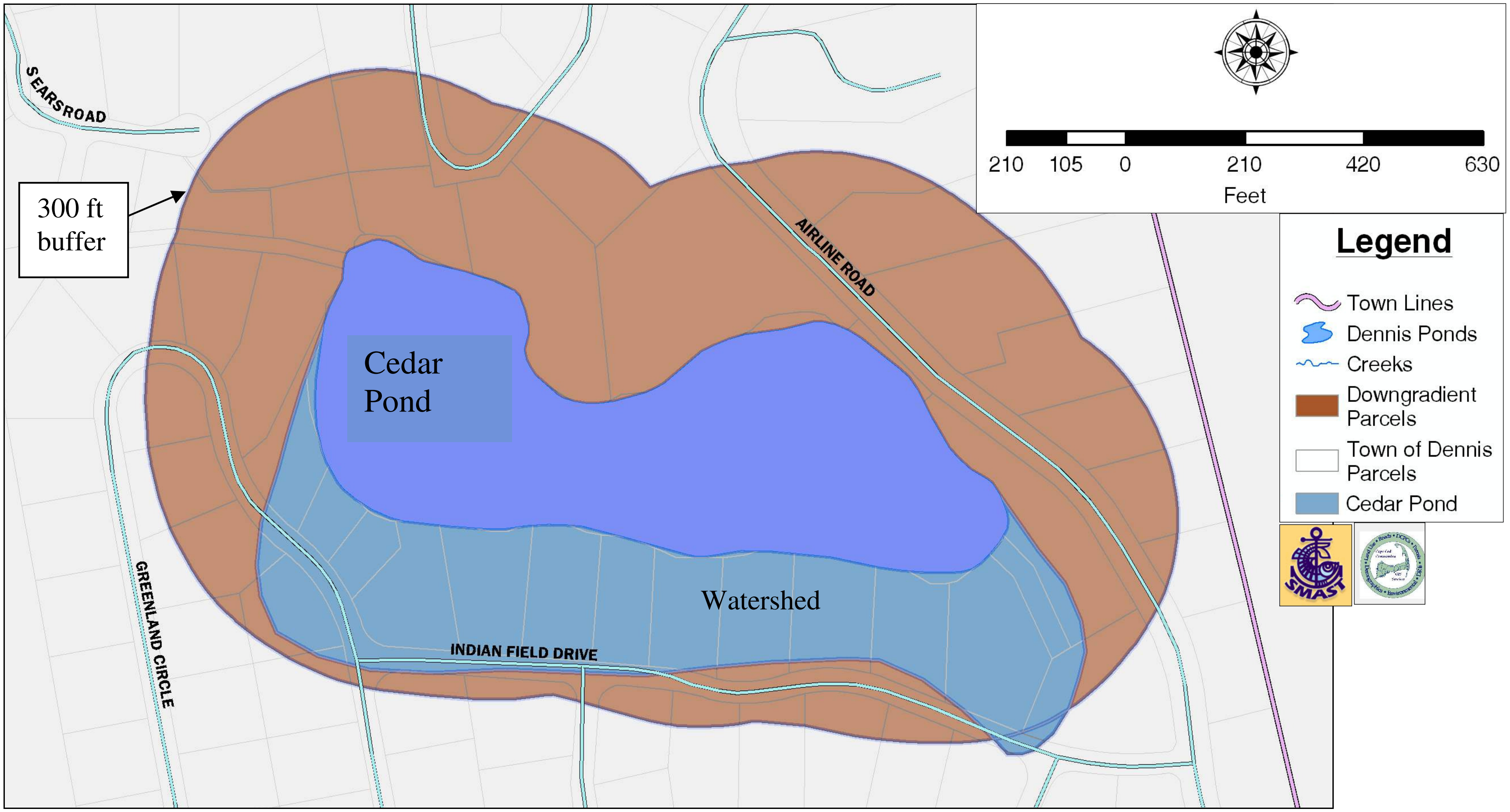


Figure VI-5. Cedar Pond watershed and phosphorus loading parcels
Phosphorus loads are developed for parcels within 300 ft that are also within the pond watershed. Watershed parcels inside the 300 ft buffer, but outside the watershed, are not assigned a phosphorus load except for road areas. Phosphorus 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 completed by town volunteers.

Because of this warm water classification, the state surface water dissolved oxygen standard for Cedar is 5 ppm (314 CMR 4). As shown in Figure VI-6, all station depths in Cedar have occasionally fallen below the 5 ppm threshold. In addition, average summer concentrations at the three stations 2 meters and deeper are less than 5 ppm. Based on this state regulatory criterion, Cedar Pond is impaired.

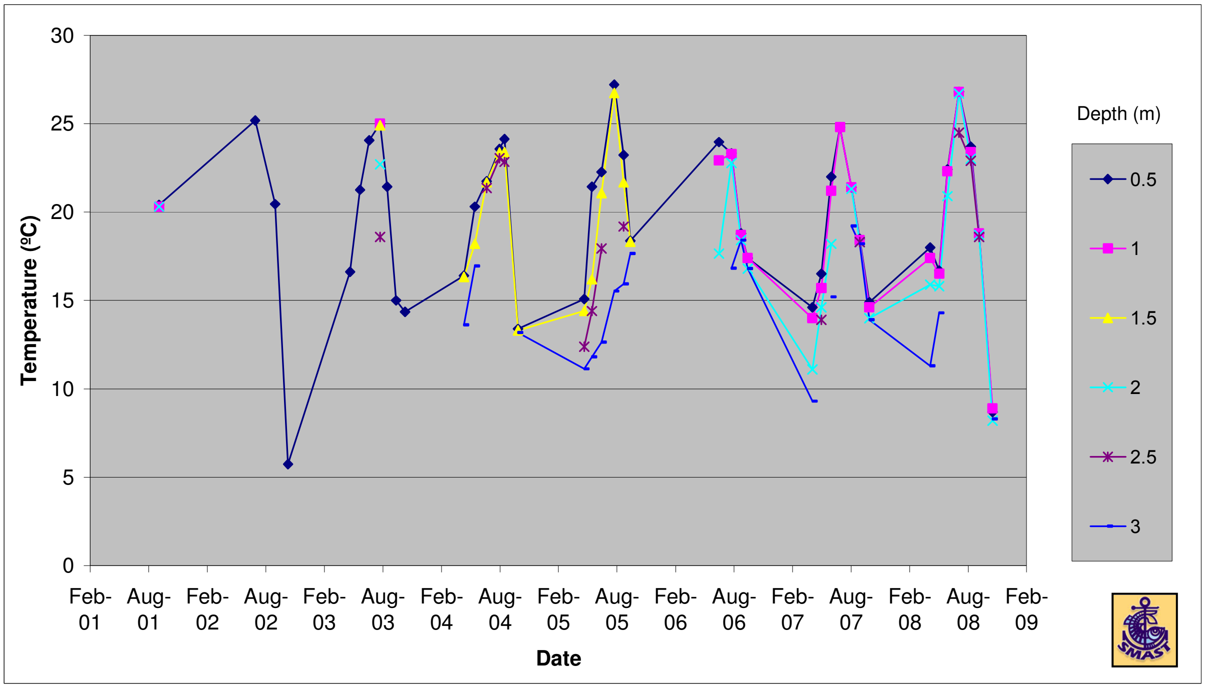
It is project staff opinion that the lack of acceptable dissolved oxygen in a significant volume of the pond means that Cedar Pond should be classified as an impaired water for the purposes of compliance with the state surface water regulations. It should also be noted that even though Cedar's water 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 Cedar Pond is impaired. Average total phosphorus at both depth stations is more than twice the 10 ppb Cape Cod regional guideline (Eichner and others, 2003). Correspondingly, average surface chlorophyll *a* concentration is more than four times the 1.7 ppb regional guideline. Secchi transparency readings average 45% of the water column, which is the fourth worst among the 10 Dennis ponds. These readings are also high variable (COV = 38%, second highest among the 10 Dennis ponds) (Figure VI-7). Highly variable Secchi readings are usually associated with unstable pond ecosystems. In addition, Cedar has had six Secchi readings (23% of all readings) less than the state minimum safe swimming criterion of 4 ft (1.22 m) .

The deepest readings for total phosphorus, total nitrogen, and chlorophyll *a* show elevated concentrations compared to surface readings. These readings are statistically significant at the $\rho<0.05$ level for TN and chlorophyll and just above this level for TP. These elevated concentrations are consistent with sediment nutrient regeneration. The chlorophyll and related phaeophytin concentrations suggest that the elevated deep chlorophyll concentrations are a mix of partial degraded phytoplankton and a vigorous phytoplankton population absorbing the maximum TP concentrations near the sediments before being mixed back into the upper water column.

Review of nitrogen to phosphorus ratios in Cedar 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 that should be targeted to remediate and restore water quality conditions. Average surface N to P ratio during June through September is 50; generally water N to P ratios above 16, know as the Redfield ratio, are phosphorus limited (Redfield and others, 1963). A similar ratio (49) in the deep waters show that nitrogen and phosphorus are being released from the sediments at essentially the same rate.

Since phosphorus is the key for determining water quality in Cedar Pond, one of the next steps for effective management is to determine the sources and magnitude of phosphorus. Once this is completed, community discussions can help to determine what combination of phosphorus



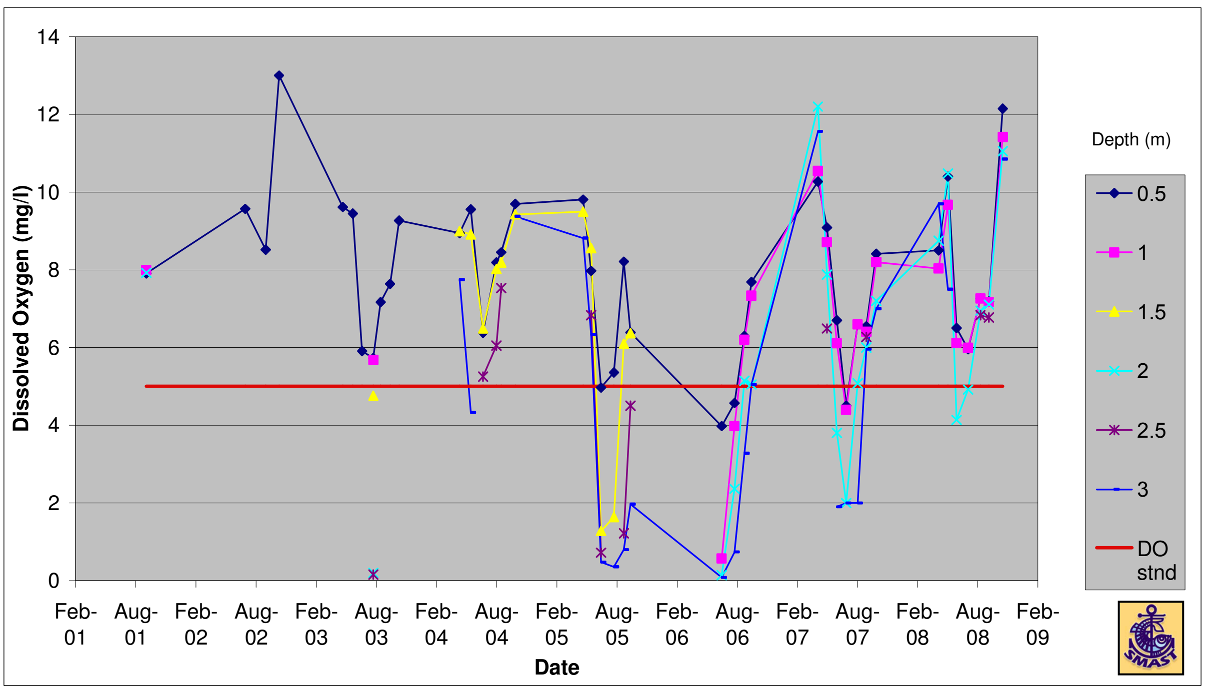


Figure VI-6. Cedar Pond Temperature and DO Readings 2001-2008
Temperature data shows relatively consistent water column temperatures regardless of season indicating well-mixed conditions. Summer temperatures generally average above 20°C, which classifies Cedar as a warm water fishery under state regulations (314 CMR 4). Dissolved oxygen concentrations show reductions with depth, indicating sediment oxygen demand. Conditions vary from year to year, but average concentrations at 2 m and deeper fail to attain the state warm water fishery threshold of 5 ppm. All data collected by Dennis volunteers using DO/Temp meters, including data from PALS Snapshots from 2001 to 2008.

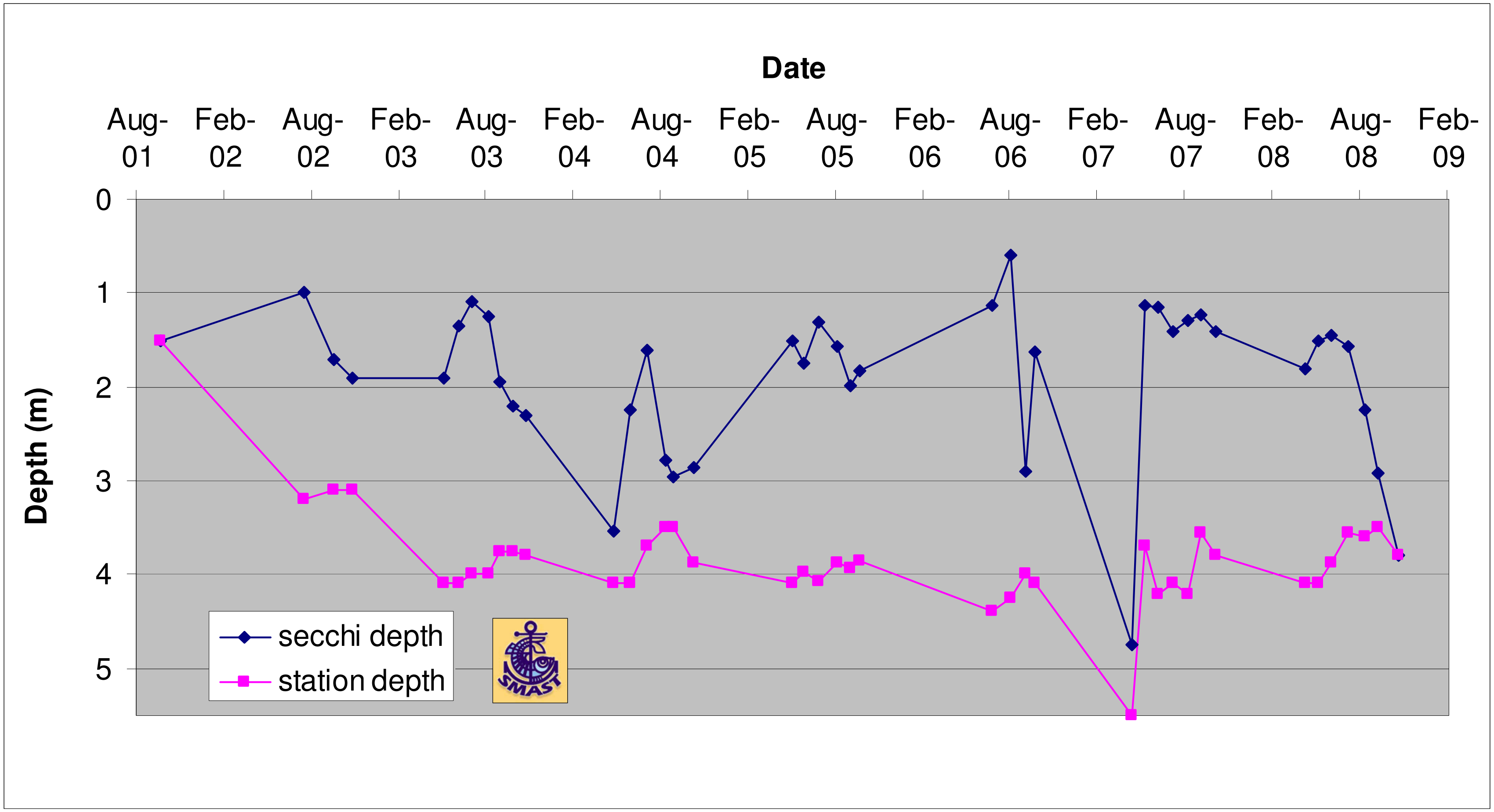


Figure VI-7. Cedar Pond: Secchi transparency readings 2001-2008
Blue data points are Secchi depth readings, while station depth measurements are shown in pink. All data collected by Dennis volunteers. Secchi readings are, on average, 45% of the total depth during June through September. Secchi readings in Cedar are extremely variable; the coefficient of variation is 38%, which is the second highest among the 10 ponds in Dennis with monitoring data.

management strategies will be adopted to remediate and restore water quality in Cedar Pond. Accounting for all the sources and magnitude or loads of phosphorus is usually done through the development of a phosphorus budget. Phosphorus budgets usually consist of watershed sources, such as septic systems and road runoff, and internal pond sources, such as sediment regeneration and aquatic waterfowl.

Since directly measuring the components of a phosphorus budget was beyond the scope of this project, the phosphorus loads in this report are developed based on research that has evaluated these components. The research results are adjusted to address the particular details of the pond being evaluated. For example, available research on phosphorus transport from septic systems in sandy aquifers (*e.g.*, Robertson, 2008) is adjusted to reflect the number of septic systems around Cedar Pond instead of directly trying to measure the phosphorus transport from each system. This approach allows a reasonable estimate to be developed, but it can be refined with additional information. All phosphorus loading estimates are compared to measured data from Cedar Pond to evaluate the budget and this comparison is used to suggest components of the budget that would benefit from more refined data collection before pursuing management strategies. This approach ensures that whatever management strategies are selected effectively target the largest and most cost effective sources of phosphorus.

In order to begin to develop a watershed phosphorus budget for Cedar 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-1), 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 18 properties wholly or partially within the 300 ft buffer upgradient of Cedar Pond; 15 of them are single family residences and two additional properties that are classified by the town assessor as being undevelopable for residential uses. One additional properties is owned by the town. All 15 of the residences are connected to the municipal water supply.

Twelve of the 15 residences have septic system leachfields within 300 feet of the pond shore; the average distance for these systems is 169 feet. Average age of both these residential septic systems and the houses connected to them is 29 years old. Total Title 5 design flow of the septic systems is 4,620 gallons per day, while total water use in 2007 was 2,721 gallons per day. 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 5.4 kg of phosphorus to Cedar Pond with an estimated annual steady state load from wastewater of 5.4 kg (Figure VI-8).

If phosphorus loading from runoff, lawns, birds, and precipitation are added to the wastewater load, the estimated annual phosphorus load to Cedar Pond, without including an

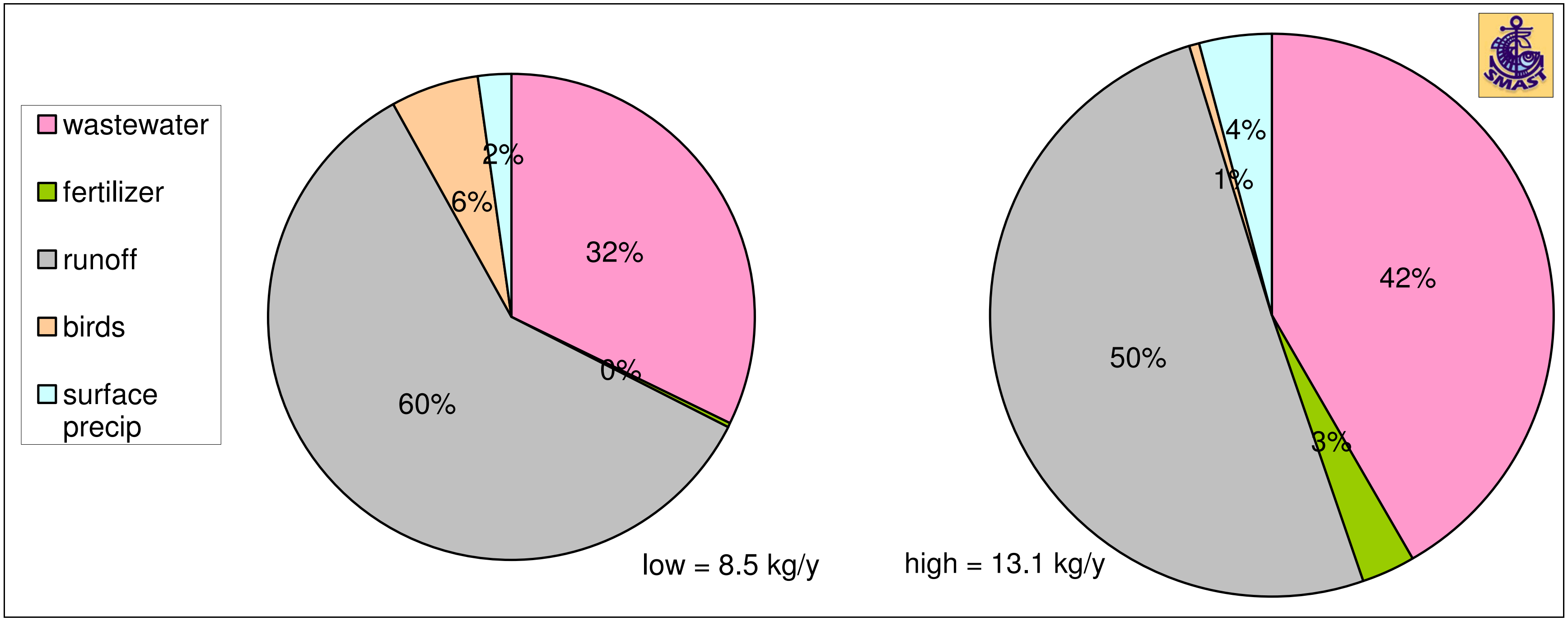


Figure VI-8. Cedar Pond: Estimated annual phosphorus budget
High and low estimates based on loading factors discussed in Section V.3 and presented in Table V-3. Average in-lake mass, corrected for residence time, results in an annual watershed load of 0.9 kg based on measured water quality data (n=14 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; given the importance of road runoff to the overall phosphorus budget, it is recommended that the town evaluate this load with targeted data collection prior to implementing remedial strategies. Average contribution of seasonal phosphorus regeneration is estimated from water quality data at approximately 0.2 kg/y, but water quality data shows that it is extremely variable ranging as high as an estimated 12.5 kg contribution.

estimate for internal sediment regeneration, has a range 8.5 to 13.1 kg. Within these loads, the sources that are the most uncertain are road runoff and birds. Bird loading is a relatively small portion of the load, but road runoff is the predominant source in both the high and low estimates. Road runoff is based on a number of assumptions that could be checked through a review of the stormwater structures around the pond. Gathering of Cedar Pond-specific information is recommended to clarify this particular factor and allow better targeting of remedial activities.

Based on the phosphorus loading analysis, the total annual load of phosphorus entering Cedar Pond is between 8.5 to 13.1 kg. Reviewing the water quality data can provide a reliability check on the average mass of phosphorus in Cedar. After reviewing the 14 sampling runs completed between June and September, an average of 1.9 kg of phosphorus is in the water column of Cedar. Since the residence time of water in the pond is 1.85 years (see Table V-1), this means that roughly 1.0 kg of phosphorus is added to the water column each year. This results suggests that approximately 90% of the annual load is retained in the sediments, which is generally inconsistent with testing from other ponds (*e.g.*, Dillon and Evans, 1992; Eichner, 2009). It is likely that this result means that a large portion of the watershed load is still in transit in the aquifer and has not reached the pond. Independent confirmation by sediment testing would be necessary to further evaluate the phosphorus in the sediments and the current and potential maximum regeneration; phosphorus retention in sediments can be impacted by a large number of factors including residence time, iron availability, and sediment pH.

Review of the water quality data suggests that the sediments contribute approximately 17% of the phosphorus mass in the pond on average. However, there is a significant variability to this contribution; a maximum of 85% of the mass estimated in the water column came from the sediments on the 8/22/06 sampling run. Since this date corresponds to the worst dissolved oxygen conditions, it suggests that there is a fairly large pool of sediment phosphorus that could be released if dissolved oxygen conditions/sediment oxygen demand worsens. Again, this could be evaluated by collecting and testing sediment cores to evaluate potential maximum regeneration.

Overall, water quality conditions in Cedar Pond are impaired. Available monitoring data consistently shows exceedances of various thresholds and that phosphorus control is the key for remediating the pond. It has average dissolved oxygen concentrations at 2 m and deeper that are below the minimum thresholds in the state surface water regulations. It has total phosphorus concentrations that are at least double the Cape Cod maximum guideline of 10 ppb (Eichner and others, 2003). It has surface chlorophyll concentrations that are more than four times higher than the Cape Cod maximum guideline of 1.7 ppb. Secchi/clarity readings indicate a highly unstable ecosystem, which is consistent with excessive nutrient loads. In addition, water quality data shows that there is the potential for significant release of additional phosphorus from the sediments and watershed loading analysis indicates that at additional phosphorus has been discharged within the aquifer, but has not yet reached the pond. Impaired waters are required to have TMDLs under the state and federal Clean Water Act; in this case, the TMDL would be a phosphorus concentration limit.

In order to begin to address the water quality impairments in Cedar Pond, it is recommended that the town consider the following recommendations:

1) complete a bathymetric map of the pond

Completing a bathymetric map will allow a calculation of pond volume and provide a better sense of the volume of impaired water and sediments. The data gathering portion of this activity could be completed by volunteers using a Secchi disk and a GPS. Collected data would then need to be interpreted and developed into bathymetric contours.

2) collect and incubate sediment cores

Based on the water quality data, it is apparent that nutrients are being regenerated from the sediments. What is unclear is the relationship between dissolved oxygen and the amount of phosphorus regenerated. Collecting sediment cores and incubating them at various dissolved oxygen concentrations will allow the town to have a quantitative relationship between DO phosphorus regeneration and provide a more definitive assessment of the sediment contribution to the phosphorus mass in the pond. Having this information will also provide a better assessment of the water quality benefits of reducing or eliminating the sediment regeneration source. Usually water quality samples and typical field data (DO/Temperature profiles, Secchi reading) are collected at the same time as the sediment samples to understand pond conditions at the time of core collection. These types of sediment cores traditionally are collected by professional staff using SCUBA and incubation requires collection of laboratory samples and monitoring of DO concentrations. A minimum of three cores are recommended. SMAST staff have extensive experience completing these activities through the Massachusetts Estuaries Project.

3) measure stormwater flows and phosphorus loads

Stormwater phosphorus loads are a large portion of the watershed load calculated in the phosphorus budget. This estimate is based on reasonable assumptions, but the town would benefit from developing Cedar Pond-specific measurements of stormwater load. Volunteers who reviewed land use for this report noted seven runoff locations from the roads surrounding Cedar. Having pond specific data would ensure that remediation plans are directed at the largest and most cost effective sources.

4) Update the above assessment with the Cedar Pond-specific information and develop a remedial plan

Collection of the recommended data will allow the assessment in this report to be updated and refined. This updated assessment could include a recommended TMDL that would then have to be approved by MassDEP and USEPA. The updated assessment result could then, in turn, be used to review remedial options and their costs to address the primary causes of the water quality impairments and, through a public process, select the preferred options and develop a remedial plan to restore Cedar Pond.

In addition to the above recommendations, the town may also want to consider getting a better understanding of the bird populations that use Cedar Pond and the rooted plants in the pond. Although bird loading is a small component of the estimated load, it is relatively uncertain. Volunteer bird watchers could be recruited to take regular observations including the identification of species. Optimally, these observations would be collected during the course of one year. Completion of a comprehensive plant survey would allow the assessment to have a better sense of how phosphorus is utilized by the plant community in the pond. 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 2008 have noted 10% lilly coverage on Cedar, which is relatively high for Cape Cod ponds.

SMAST staff have estimated that the cost of a stand alone project at Cedar Pond for these recommended activities between \$22,000 and \$25,000, including the rooted plant survey, with another \$10,000 to \$12,000 for 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. It is further recommended that the town continue regular annual sampling of the pond while further work is considered and after adoption of remedial strategies to monitor the levels of improvement. SMAST staff can discuss the range of strategies and estimated costs with town staff and can provide the town with a detailed scope of work if requested.

VI.3. Coles Pond

Coles Pond is a 11-acre pond that is located approximately 750 ft south of Cape Cod Bay and to the west of South Street (Figure VI-9). Based on volunteer collected data, it is has an average maximum depth of 1.4 m (4.6 ft), with a maximum recorded depth of 1.8 m (5.9 ft). It is the third largest of the ponds selected for detailed review.

Temperature data collected between 2001 and 2008 shows that the Coles water column is generally well mixed. As would be expected in such a shallow pond, there is little difference in average temperatures at either the 0.5 or 1 m depth stations between June and September (Figure VI-10). Since both stations have average temperatures above the 20ºC regulatory temperature, Coles would be classified as a warm water fishery under the state surface water regulations (314 CMR 4).

Under the state surface water regulations, warm water fisheries are required to have dissolved oxygen concentrations of 5 ppm or above. As shown in Figure VI-10, both station depths in Coles are consistently above the 5 ppm threshold. Dissolved oxygen concentrations at the 0.5 and 1 meter depths in Coles average 8.1 and 8.2 ppm, respectively. These near saturation concentrations should not be surprising given the shallow depth of Coles; because of their relatively small volume, normal winds blowing across the surface of shallow ponds keep their water columns well mixed and provide regular replenishment of oxygen consumed by the sediments. Based on the state regulatory dissolved oxygen criterion, Coles Pond is not impaired.

The Secchi readings generally support non-impaired conditions, but also show suggest that nutrient levels in the pond should be monitored. Average Secchi depth is 1.2 m and is 88%

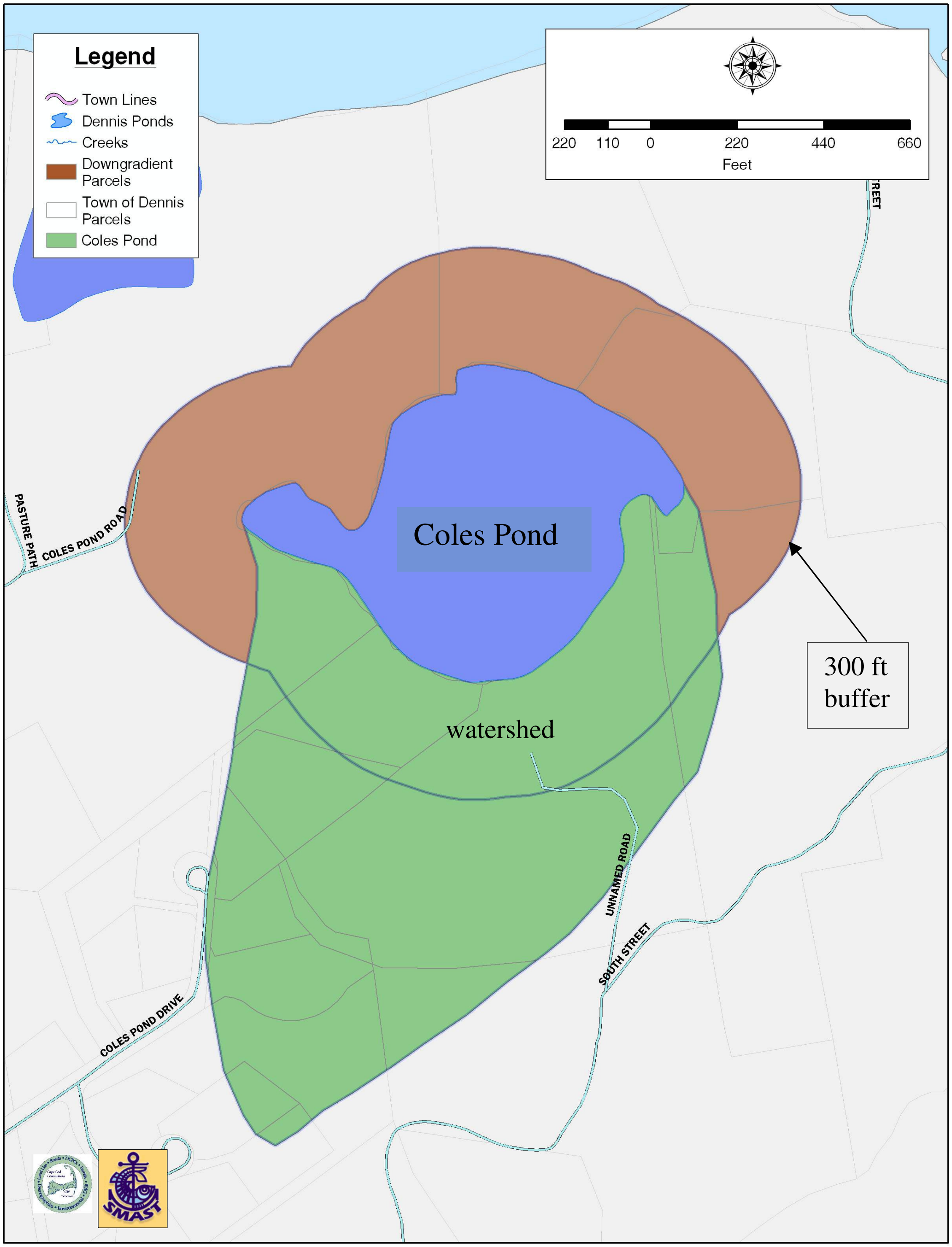
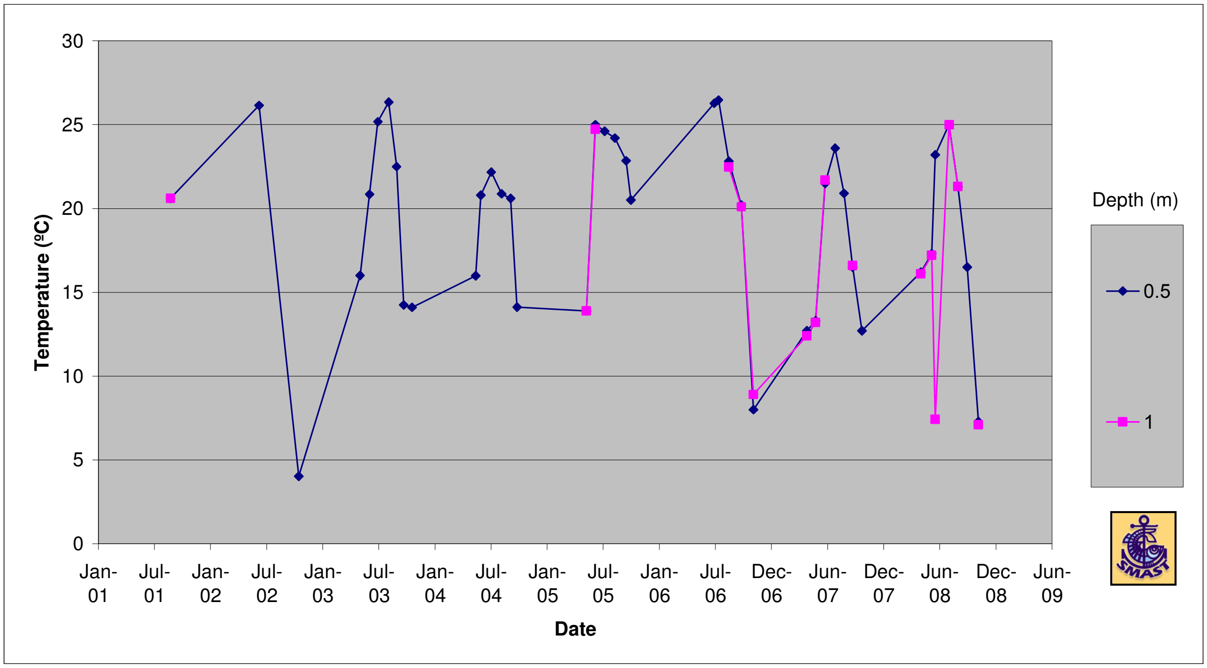


Figure VI-9. Coles Pond watershed and phosphorus loading parcels
Phosphorus loads are developed for parcels within 300 ft that are also within the pond watershed. Watershed parcels inside the 300 ft buffer, but outside the watershed, are not assigned a phosphorus load except for road areas. Phosphorus 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 completed by town volunteers.



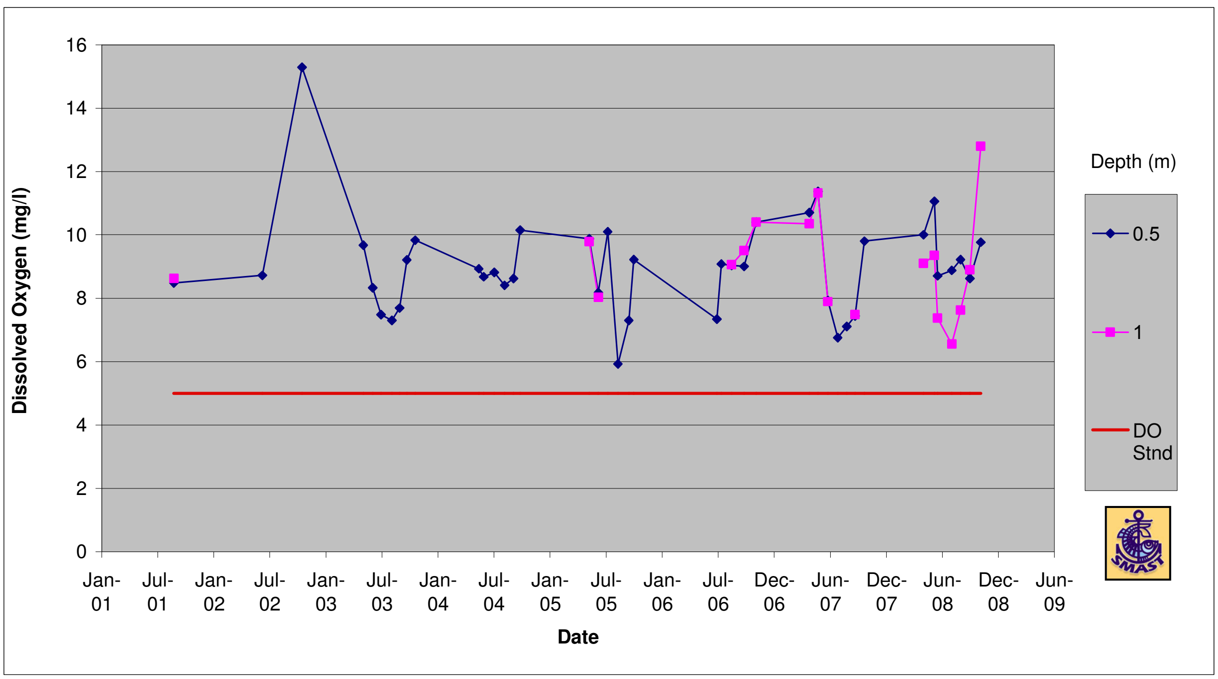


Figure VI-10. Coles Pond Temperature and DO Readings 2001-2008

Temperature data shows relatively consistent temperatures throughout the water column regardless of season indicating well-mixed conditions. Summer temperatures generally average above 20°C, which classifies Coles as a warm water fishery under state regulations (314 CMR 4). Dissolved oxygen concentrations show a similar well-mixed pattern with nearly all readings above the warm water fishery threshold of 5 ppm. All data collected by Dennis volunteers using DO/Temp meters, including data from PALS Snapshots from 2001 to 2008.

of the average maximum depth (Figure VI-11). While this is generally a desirable relative Secchi reading, the readings show that light regularly fails to reach the bottom during the summers of 2003 to 2007. At the chlorophyll concentration guideline for Cape Cod ponds, light should reach the bottom of a 1.8 m deep pond (Wetzel, 1983).

This concern is reinforced when the other water quality data for Coles is considered. Average total phosphorus at both depth stations is more than twice the 10 ppb Cape Cod regional guideline (Eichner and others, 2003). Correspondingly, average surface chlorophyll *a* concentration is more than seven times the 1.7 ppb regional guideline. Given that elevated phosphorus and chlorophyll concentrations generally lead to higher oxygen demand and dissolved oxygen reductions, it is suggested that Coles Pond should be regularly monitored to ensure that conditions do not worsen.

Review of nitrogen to phosphorus ratios in Coles 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 that should be targeted to remediate and restore water quality conditions. Average surface N to P ratio during June through September is 59; generally water N to P ratios above 16, know as the Redfield ratio, are phosphorus limited (Redfield and others, 1963).

Since phosphorus is the key for determining water quality in Coles Pond, understanding the sources of the phosphorus, their magnitude, and whether they will likely increase or not are key steps for effective water quality management. Since the pond is borderline impaired, developing understanding of phosphorus sources will assist the community discussions about management activities that the town may want to pursue. Accounting for all the sources and magnitude or loads of phosphorus is usually done through the development of a phosphorus budget. Phosphorus budgets usually consist of watershed sources, such as septic systems and road runoff, and internal pond sources, such as sediment regeneration and aquatic waterfowl.

Since directly measuring the components of a phosphorus budget was beyond the scope of this project, the phosphorus loads in this report are developed based on research that has evaluated these components. The research results are adjusted to address the particular details of the pond being evaluated. For example, available research on phosphorus transport from septic systems in sandy aquifers (*e.g.*, Robertson, 2008) is adjusted to reflect the number of septic systems around Coles Pond instead of directly trying to measure the phosphorus transport from each system. This approach allows a reasonable estimate to be developed, but it can be refined with additional information. All phosphorus loading estimates are compared to measured data from Coles Pond to evaluate the budget and this comparison is used to suggest components of the budget that would benefit from more refined data collection before pursuing management strategies. This approach ensures that whatever management strategies are selected effectively target the largest and most cost effective sources of phosphorus.

In order to begin to develop a watershed phosphorus budget for Coles 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-9), 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

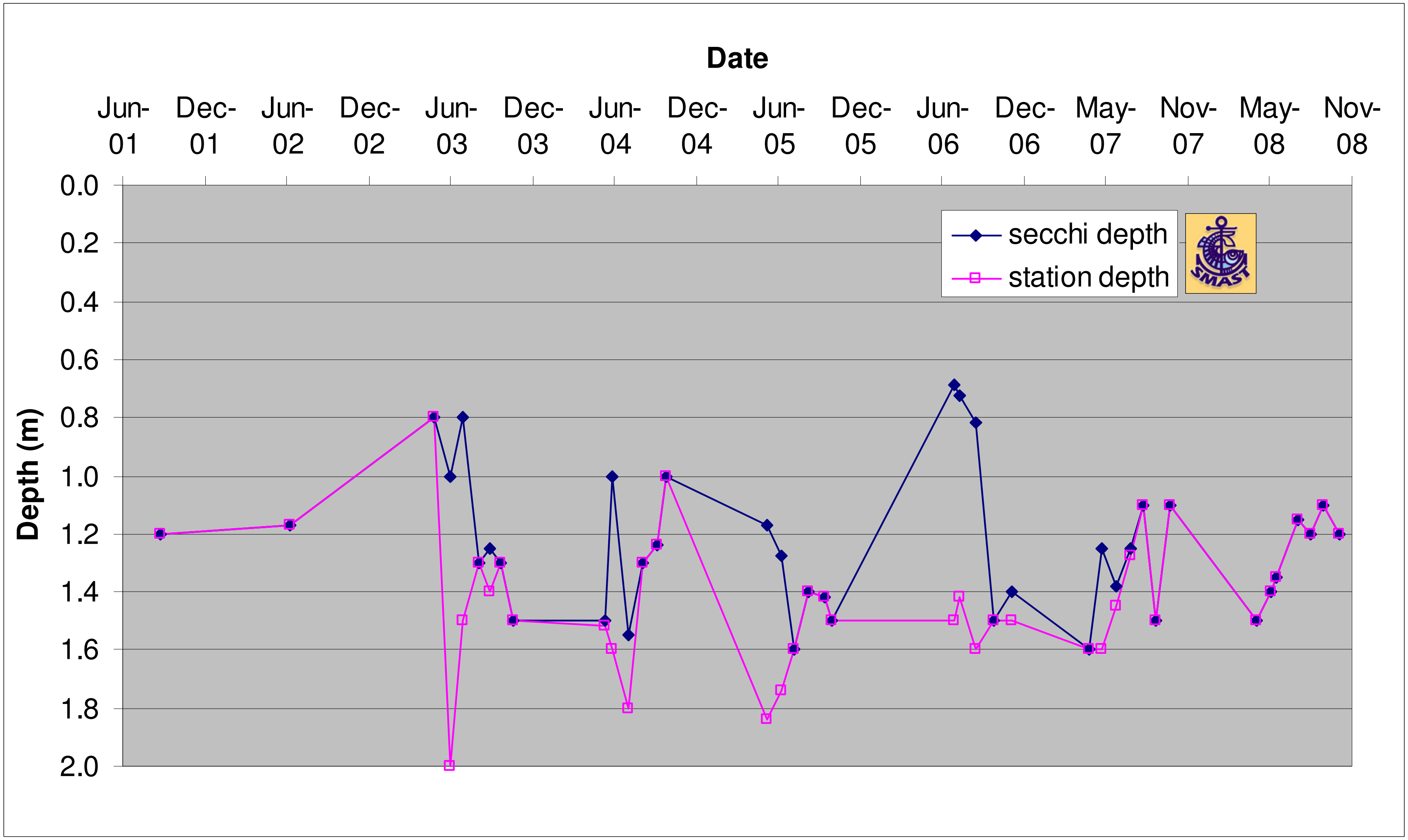


Figure VI-11. Coles Pond: Secchi transparency readings 2001-2008

Blue data points are Secchi depth readings, while station depth measurements are shown in pink. All data collected by Dennis volunteers. Secchi readings are, on average, 88% of the total depth during June through September. Less than 100% relative Secchi readings occurred during the summers of 2003 to 2007 and loss of clarity of 50% or more of the water column occurred during two summers during the same period.

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 three properties wholly or partially within the 300 ft buffer and upgradient of Coles Pond; two of them are owned by the Town of Dennis and one is classified by the town assessor as a single family residence. The residence is connected to the municipal water supply and uses an average of 247 gallons per day. The septic system has a Title 5 design flow of 550 gallons per day and its leachfield is located approximately 100 feet from the shore of the pond. Based on the age of the residence and its septic system, it is estimated that it is contributing 0.45 kg of phosphorus to the pond (Figure VI-12). Since there are no other developable lots upgradient and within the 300 ft buffer, any additional wastewater phosphorus load would have to come from intensification of development on this single family residential lot. .

If phosphorus loading from runoff, lawns, birds, and precipitation are added to the wastewater load, the estimated annual phosphorus load to Coles Pond, without including an estimate for internal sediment regeneration, has a range 1.25 to 1.30 kg. Within these loads, the source that is the most uncertain is loading from birds. Gathering of Coles Pond-specific information would be necessary to clarify this particular factor.

Based on the phosphorus loading analysis, the total annual load of phosphorus entering Coles Pond is 1.3 kg. Reviewing the water quality data can provide a reliability check on the average mass of phosphorus in Coles. After reviewing the 17 sampling runs completed between June and September, an average of 0.8 kg of phosphorus is in the water column of Coles. Since the residence time of water in the pond is 0.3 years (see Table V-1), this means that roughly 2.5 kg of phosphorus is added to the water column each year. This analysis suggests that there is an unaccounted source of phosphorus entering Coles.

Review of the water quality data appears to rule out the sediments as a significant source. As mentioned above, dissolved oxygen concentrations are relatively high at both depths (0.5 and 1 m). In additions, phosphorus concentrations at these two depths average 25 and 24 ppb, respectively. Further evaluation of the pond would be necessary to identify the unaccounted phosphorus source.

Overall, water quality conditions in Coles Pond are generally acceptable, but excessive phosphorus and chlorophyll concentrations and occasional significant loss of clarity (>50%) suggest that Coles should be monitored regularly to ensure that conditions do not worsen. It is recommended that the town consider monitoring Coles twice a year: once in April and again in August/September. Monitoring should include field measurements of dissolved oxygen, temperature, and Secchi clarity, as well as collection of water quality samples following PALS protocols. Data should be reviewed at five year intervals unless results suggest a significant change in the system. It is recommended that the town consider a contingency plan to increase monitoring frequency if significant changes occur. Since dissolved oxygen concentrations are above the state regulatory minimum, no TMDL or additional targeted monitoring are recommended at this time.

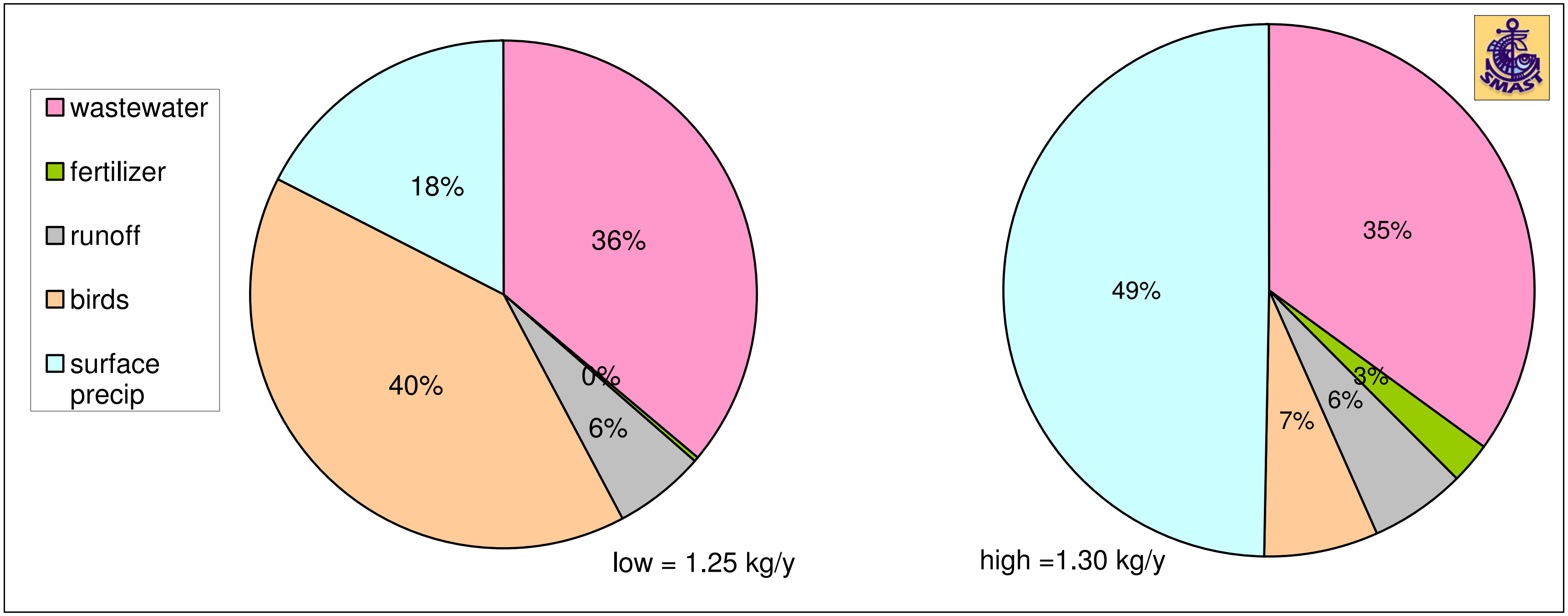


Figure VI-12. Coles Pond: Estimated annual phosphorus budget

High and low estimates based on loading factors discussed in Section V.3 and presented in Table V-3. Average in-lake mass, corrected for residence time, results in an annual watershed load of 2.5 kg based on measured water quality data (n=17 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. Bird loads are the most uncertain; gathering of Coles Pond-specific information would be necessary to clarify this particular factor. The water quality data does not suggest that there is any significant seasonal phosphorus regeneration from the sediments.

VI.4. Eagle Pond

Eagle Pond is a 7 acre pond located just to the south of the Mid-Cape Highway (Route 6) and approximately 0.25 miles northeast of the municipal landfill (Figure VI-13). While Eagle has the smallest area of the six ponds selected for detailed review, it is the third deepest with an average maximum depth of 7.0 m (23 ft), with a maximum recorded depth of 7.6 m (25 ft).

Temperature data collected between 2001 and 2008 shows that the Eagle water column is generally well mixed. On average, there is a slight decline in temperature with depth, but the average temperature at the surface between June and September is less than two degrees higher than the average temperature at the deepest station (Figure VI-14). Since all depth stations have average temperatures above the 20ºC state regulatory temperature, Eagle would be classified as a warm water fishery under the state surface water regulations (314 CMR 4).

Under the state surface water regulations, warm water fisheries are required to have dissolved oxygen concentrations of 5 ppm or above. As shown in Figure VI-14, summer dissolved oxygen concentrations at the deepest station regularly fall below the state regulatory threshold during the summer, but no readings below the threshold were recorded for any other depth stations. In fact, the average dissolved oxygen concentration at the deepest station between June and September is above the 5 ppm state regulatory threshold. Based on the state regulatory dissolved oxygen criterion, Eagle Pond is not impaired.

The Secchi readings generally support non-impaired conditions, but also suggest that nutrient levels in the pond should be monitored. Average Secchi depth is 4.2 m and average relative Secchi reading is 60% of the average maximum depth (Figure VI-15). Relative Secchi readings range between 40% and 82% between June and September. The minimum recorded reading is slightly more than twice the state regulatory limit (4 ft) for safe swimming clarity.

Other water quality data presents a slightly more mixed assessment. Average summer total phosphorus concentrations at both the surface and deep stations are slightly above the 10 ppb Cape Cod regional guideline (Eichner and others, 2003). The deep station average is slightly elevated above the surface concentration suggesting some limited sediment regeneration. Average summer chlorophyll concentrations show a similar pattern to phosphorus. The average surface chlorophyll concentration is 2.6 ppb, as compared to the 1.7 ppb regional guideline. These elevated concentrations are somewhat surprising given the general lack of development around Eagle Pond, but concentrations may be influenced by historic land uses including what appears to be an abandoned cranberry bog off the southeastern shore. More refined analysis of land use and the available water quality may provide additional insights.

Review of nitrogen to phosphorus ratios in Eagle 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 51; generally water N to P ratios above 16, know as the Redfield ratio, are phosphorus limited (Redfield and others, 1963). Bottom waters have a similar N to P ratio (48), which is consistent with the well mixed water column.

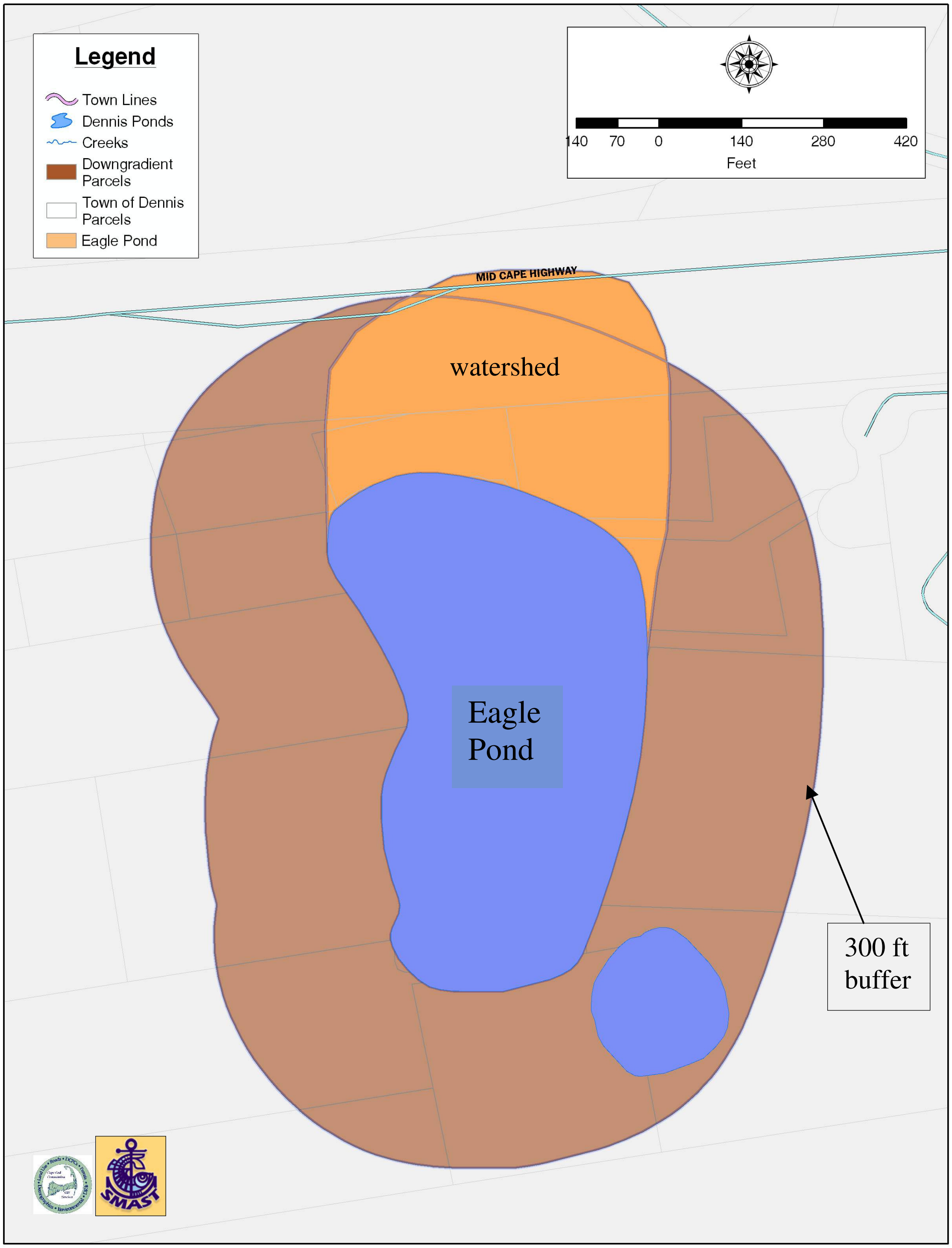
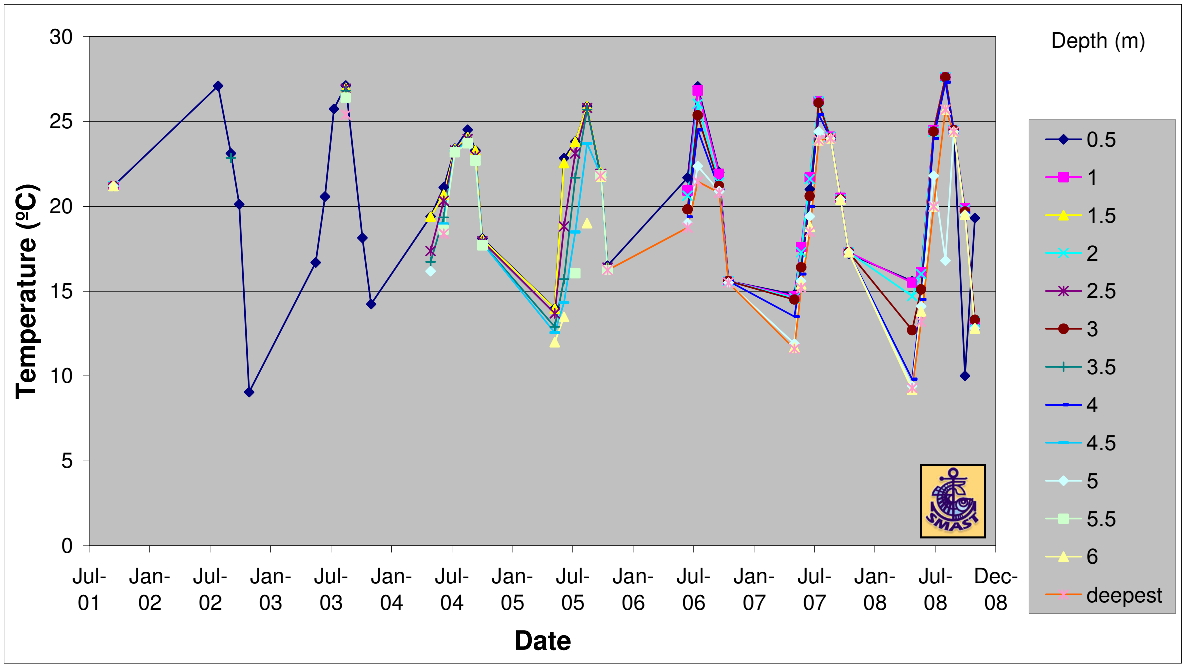


Figure VI-13. Eagle Pond watershed and phosphorus loading parcels
Phosphorus loads are developed for parcels within 300 ft that are also within the pond watershed. Watershed parcels inside the 300 ft buffer, but outside the watershed, are not assigned a phosphorus load except for road areas. Phosphorus 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 completed by town volunteers.



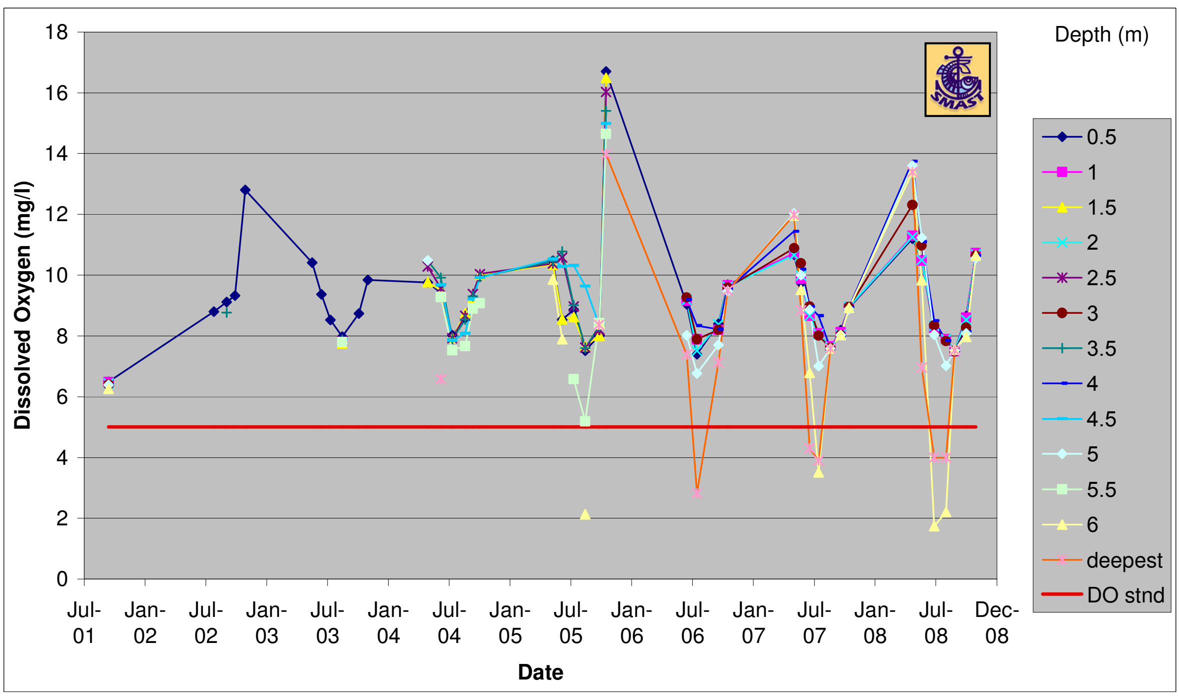


Figure VI-14. Eagle Pond Temperature and DO Readings 2001-2008
Temperature data shows relatively consistent temperatures throughout the water column regardless of season indicating generally well-mixed conditions. Summer temperatures average above 20°C, which classifies Eagle as a warm water fishery under state regulations (314 CMR 4). Dissolved oxygen concentrations generally show a similar well-mixed pattern with all but the deepest readings above the warm water fishery threshold of 5 ppm. All data collected by Dennis volunteers using DO/Temp meters, including data from PALS Snapshots from 2001 to 2008.

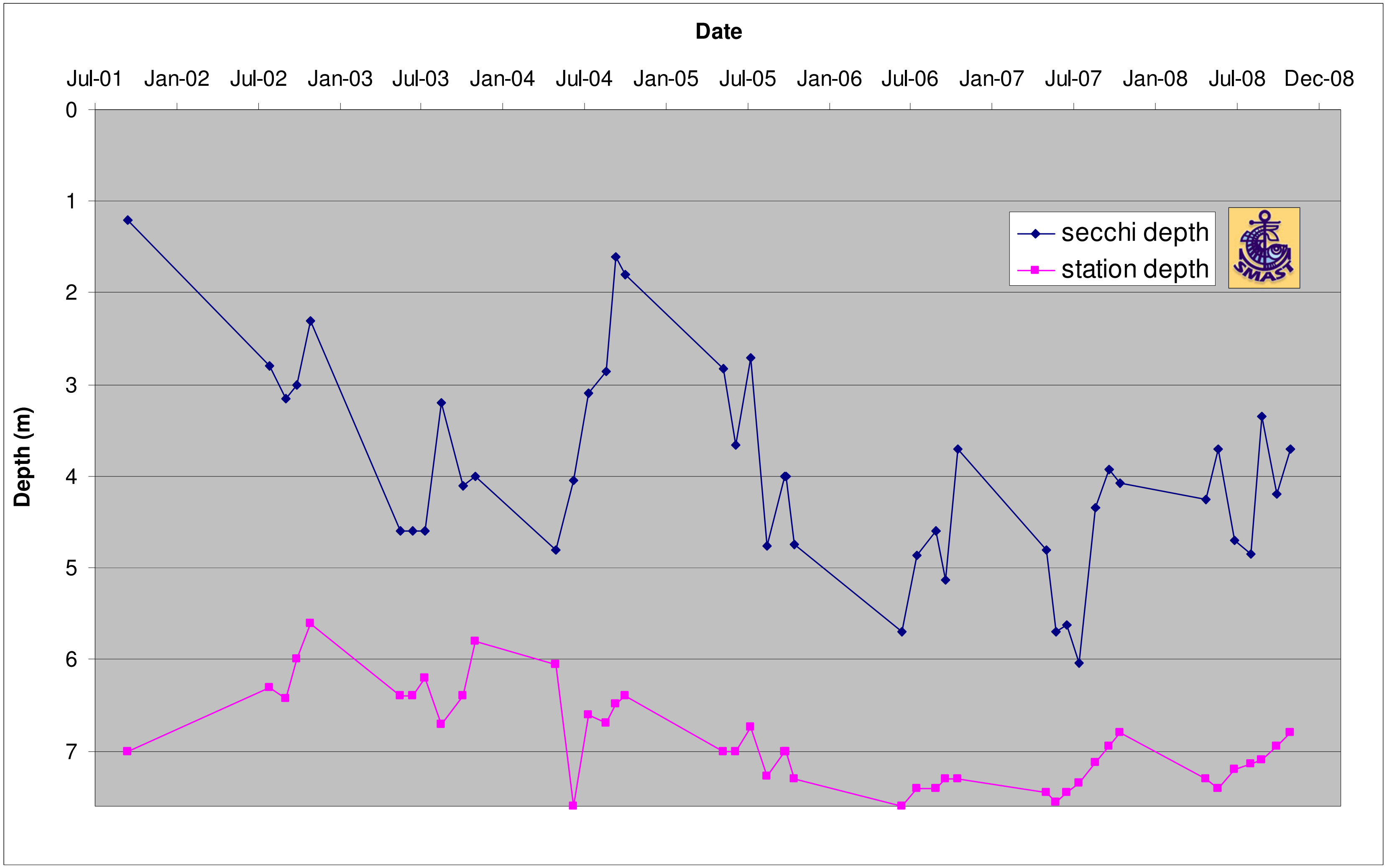


Figure VI-15. Eagle Pond: Secchi transparency readings 2001-2008
Blue data points are Secchi depth readings, while station depth measurements are shown in pink. All data collected by Dennis volunteers. Secchi readings are, on average, 60% of the total depth during June through September. Relative Secchi readings range between 40% and 82% of total depth.

Since phosphorus is the key for determining water quality in Eagle Pond, one of the next steps for effective management is to determine the sources and magnitude of phosphorus. Once this is completed, community discussions can help to determine what combination of phosphorus management strategies can be adopted to preserve water quality in Eagle Pond. Accounting for all the sources and magnitude or loads of phosphorus is usually done through the development of a phosphorus budget. Phosphorus budgets usually consist of watershed sources, such as septic systems and road runoff, and internal pond sources, such as sediment regeneration and aquatic waterfowl.

Since directly measuring the components of a phosphorus budget was beyond the scope of this project, the phosphorus loads in this report are developed based on research that has evaluated these components. The research results are adjusted to address the particular details of the pond being evaluated. For example, available research on phosphorus transport from septic systems in sandy aquifers (*e.g.*, Robertson, 2008) is adjusted to reflect the number of septic systems around Eagle Pond instead of directly trying to measure the phosphorus transport from each system. This approach allows a reasonable estimate to be developed, but it can be refined with additional information. All phosphorus loading estimates are compared to measured data from Eagle Pond to evaluate the budget and this comparison is used to suggest components of the budget that would benefit from more refined data collection before pursuing management strategies. This approach ensures that whatever management strategies are selected effectively target the largest and most cost effective sources of phosphorus.

In order to begin to develop a watershed phosphorus budget for Eagle 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 VI-13), 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 six properties both wholly or partially within the 300 ft buffer and upgradient of Eagle Pond; four of them are single family residences, one is classified by the town assessor as being undevelopable for residential uses, and one is classified by the town assessor as being developable for industrial uses. In addition, the right-of-way for Route 6, including the rest area east of Exit 9, is also within this area. All four of the residences are connected to the municipal water supply.

Of the four residences, only one has a septic system leachfield within 300 ft and within the watershed. Based on the review of town Board of Health records, this leachfield is 157 feet from the pond shore and is six years old. Total Title 5 design for the system is 330 gallons per day (gpd) and total water use in 2007 was 33 gpd. Based on the age of the septic system, distance to the pond, and the range of retention factors discussed above, the septic system is not yet contributing any phosphorus to Eagle Pond (Figure VI-16). At steady-state, this septic system is estimated to contribute 0.45 kg of phosphorus per year.

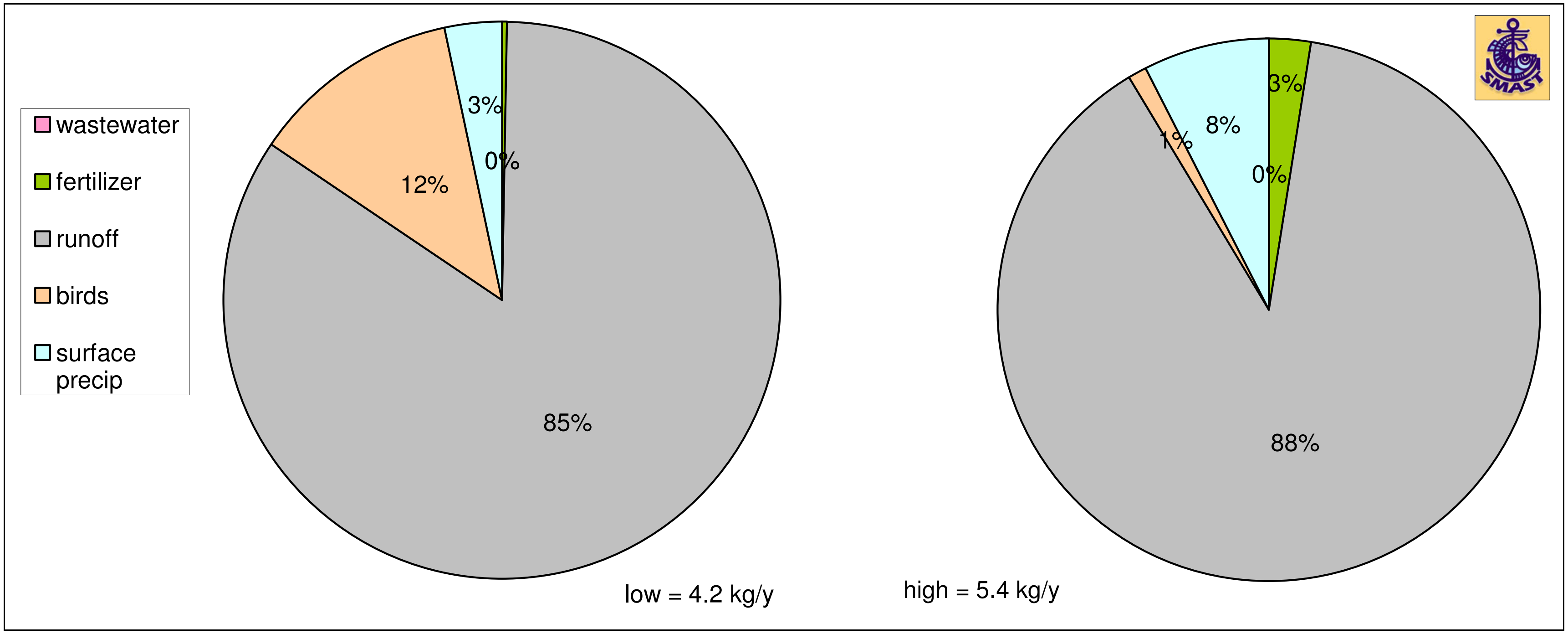


Figure VI-16. Eagle Pond: Estimated annual phosphorus budget

High and low estimates based on loading factors discussed in Section V.3 and presented in Table V-3. Average in-lake mass, corrected for residence time, results in an annual watershed load of 0.25 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. Bird loads are the most uncertain; gathering of Eagle Pond-specific information would be necessary to clarify this particular factor. The water quality data does not suggest that there is any significant seasonal phosphorus regeneration from the sediments. The lack of balance between annual loading estimates and observed mass in the pond suggest that stormwater runoff load is overestimated; additional refinement of this load would require Eagle Pond-specific measurements.

The predominant source of phosphorus reaching Eagle Pond is from road runoff. Based on the land use analysis, there is approximately 2 acres of road surfaces upgradient of Eagle Pond and approximately another acre downgradient of the pond. Field observations by town volunteers indicated that there are runoff erosion channels from the Route 6 rest area to Eagle Pond. Road runoff is projected to contribute between 85% to 88% of the phosphorus load currently reaching Eagle Pond.

If phosphorus loading from lawns, birds, and precipitation are added to the runoff load, the estimated annual phosphorus load to Eagle Pond, without including an estimate for internal sediment regeneration, has a range 4.2 to 5.4 kg. Gathering of Eagle Pond-specific information would be necessary to clarify all the factors, including possible contributions by the small pond/bog to the southeast and the apparent historic connections to cranberry bogs in Harwich. An additional factor that should be considered is the potential impacts, both on nutrient and groundwater flow paths, of the large septic system (>21,000 gpd Title 5 design flow) associated with the nursing home located just to the east of the pond.

Based on the phosphorus loading analysis, the total annual load of phosphorus entering Eagle Pond is 4.2 to 5.4 kg. Reviewing the water quality data can provide a reliability check on the average mass of phosphorus in Eagle. After reviewing the 12 sampling runs completed between June and September, an average of 1.0 kg of phosphorus is in the water column of Eagle. Since the residence time of water in the pond is 3.9 years (see Table V-1), this means that roughly 0.25 kg of phosphorus is added to the water column each year. This analysis suggests that the load from the predominant source, road runoff, is overestimated. Some portion of the annual load will be buried in the sediments and be removed from the water column; other phosphorus loading analyses have indicated phosphorus attenuation rates in Cape Cod ponds of 50% or more (e.g., Eichner, 2008). More refined sampling of runoff sources and/or the sediments in Eagle Pond would be necessary to refine the phosphorus loads.

Overall, water quality conditions in Eagle Pond are generally acceptable. Dissolved oxygen concentrations are generally above the state regulatory threshold of 5 ppm. Secchi readings indicate some impacts, but are also acceptable. Average phosphorus and chlorophyll concentrations are at or above their respective Cape Cod guidelines, which suggests that continued monitoring should occur. This monitoring can provide an early warning to the town if conditions in the pond change rapidly.

It is recommended that the town consider monitoring Eagle twice a year: once in April and again in August/September. Monitoring should include field measurements of dissolved oxygen, temperature, and Secchi clarity, as well as collection of water quality samples following PALS protocols. Data should be reviewed at five year intervals unless results suggest a significant change in the system. It is further recommended that the town consider a contingency plan to increase monitoring frequency if significant changes occur. Since dissolved oxygen concentrations are above the state regulatory minimum, no TMDL or additional targeted monitoring are recommended at this time.

It is also recommended that the town track potential changes to stormwater management on Route 6. If modifications to stormwater structures on the highway are proposed, this may be the opportunity to encourage Massachusetts Highway Department to adopt best management techniques to infiltrate runoff rather than allowing it create channels and directly reach the pond.

VI.5. Flax Pond

Flax Pond is a 16 acre pond located just to the north of Setucket Road and approximately a third of a mile north of the Follins Pond portion of the Upper Bass River estuary (Figure VI-17). Flax is the second largest of the six ponds selected for detailed review and is estimated to be the second deepest; it has an average maximum depth of 8.2 m (27 ft), with a maximum recorded depth of 8.9 m (29 ft).

Temperature data collected between 2001 and 2008 shows that the Flax water column has some temperature layering of warm water over cold early in most summers, but these conditions disappear by the end of summer (August/September). June conditions generally see 4-10ºC temperature difference between surface and deep waters, but by late August/September the surface warmth has mixed throughout the water column and this temperature difference has shrunk to 1-3ºC (Figure VI-18). These transitions mean that in early summer Flax Pond is similar to a cold water fishery under state regulatory definitions, but by late summer it has become more like a warm water fishery. Since Flax does not maintain cold water fishery conditions, project staff suggest that it should be classified as a warm water fishery under the state surface water regulations (314 CMR 4).

Under the state surface water regulations, warm water fisheries are required to have dissolved oxygen (DO) concentrations of 5 ppm or above, while cold water fisheries must have DO concentrations of 6 ppm or above. Both DO thresholds are compared to Flax's recorded concentrations in Figure VI-18. These DO readings show that the deepest water regularly fall below the state DO thresholds and are occasionally anoxic (DO concentration <1 ppm), but on average DO concentrations in Flax are above the state 5 ppm minimum throughout the water column. Based on the state regulatory dissolved oxygen criterion, Flax Pond is not impaired.

The Secchi readings suggest that water quality conditions are a bit more of a concern than suggested by the dissolved oxygen data. Average Secchi depth is 5 m (16.3 ft) and average relative Secchi reading is 57% of the average maximum depth (Figure VI-15). And the minimum Secchi reading (2.55 m, 8.4 ft) is more than twice the state regulatory limit (4 ft) for safe swimming clarity. But the Secchi readings fluctuate over a fairly large range: relative Secchi readings range between 31% and 91% between June and September. Pond ecosystems with variable conditions tend to be more unstable and have more fluctuations in nutrient loads.

Laboratory water quality data, on the other hand, seems to support relatively acceptable conditions. Average summer total phosphorus concentrations at both the surface and deep stations are slightly below and slightly above, respectively, the 10 ppb Cape Cod regional guideline (Eichner and others, 2003). The higher deep station average suggests some limited sediment regeneration. Average summer chlorophyll concentrations show a similar pattern to phosphorus. The average surface chlorophyll concentration is 1.8 ppb, as compared to the 1.7 ppb regional guideline, while the deeper concentration averages 2.3 ppb.

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

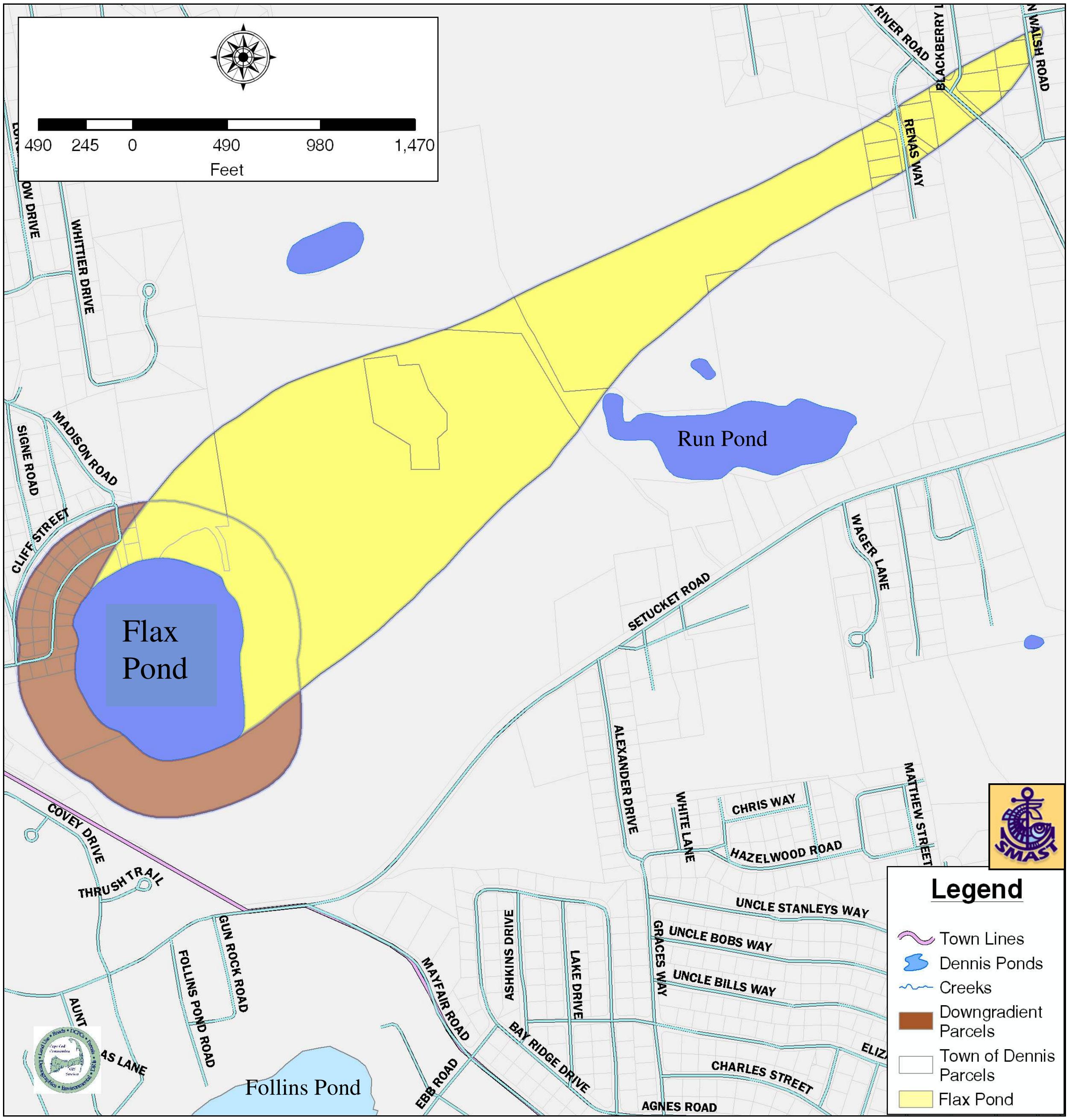
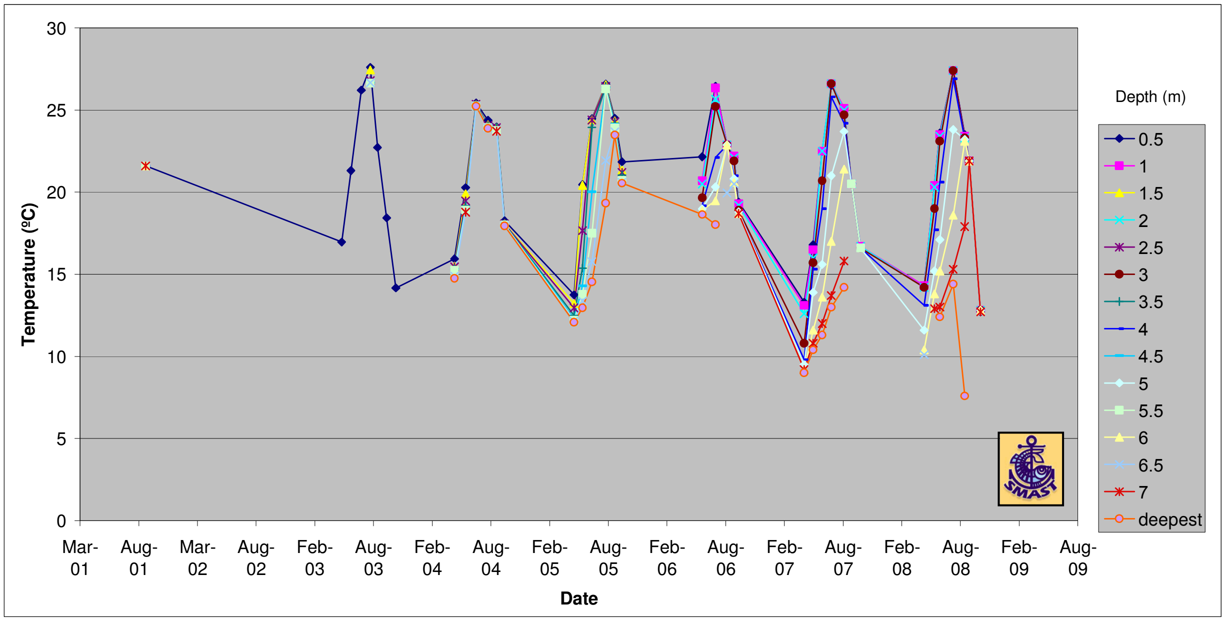


Figure VI-17. Flax Pond watershed and phosphorus loading parcels
Phosphorus loads are developed for parcels within 300 ft that are also within the pond watershed. Watershed parcels inside the 300 ft buffer, but outside the watershed, are not assigned a phosphorus load except for road areas. Phosphorus 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 completed by town volunteers.



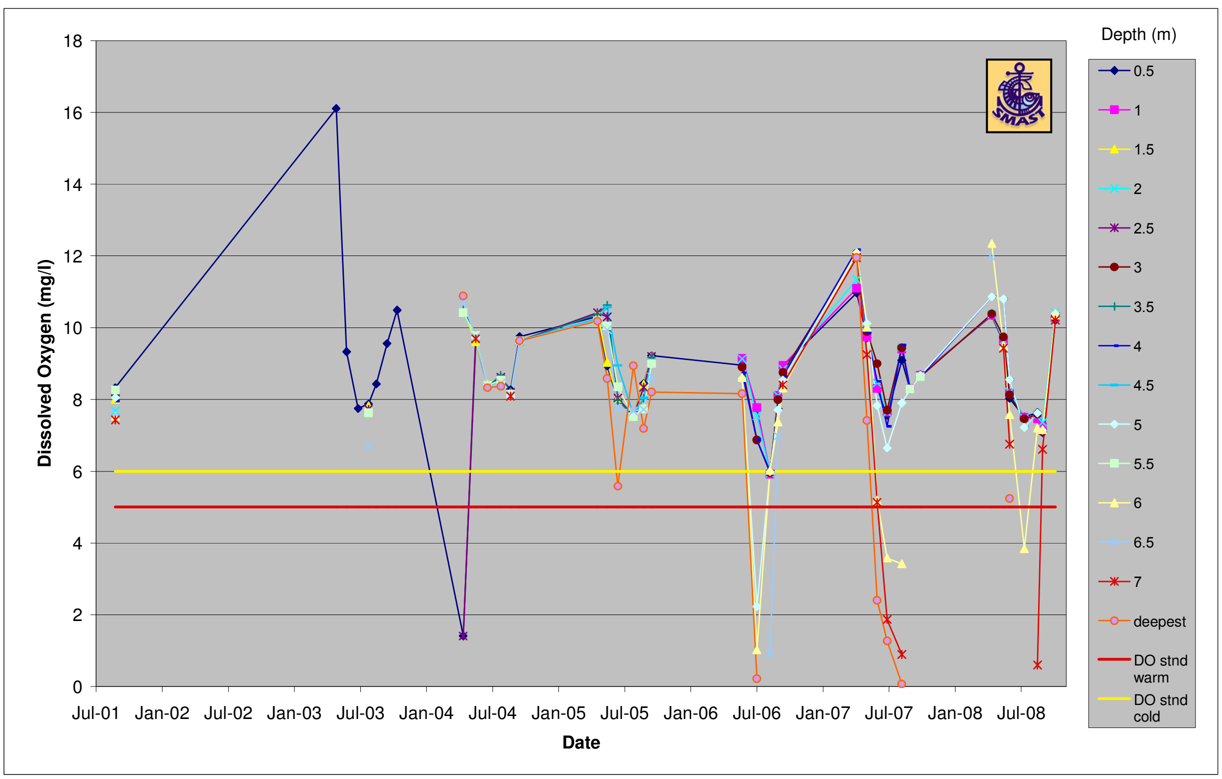


Figure VI-18. Flax Pond Temperature and DO Readings 2001-2008
Temperature data show early summer stratification followed by relatively consistent readings in late summer. Late summer temperatures average above 20°C, which classifies Flax as a warm water fishery under state regulations (314 CMR 4). Dissolved oxygen concentrations show regular anoxic concentrations in the deepest water, but average summer concentrations are above state warm water regulatory threshold of 5 ppm. All data collected by Dennis volunteers using DO/Temp meters, including data from PALS Snapshots from 2001 to 2008.

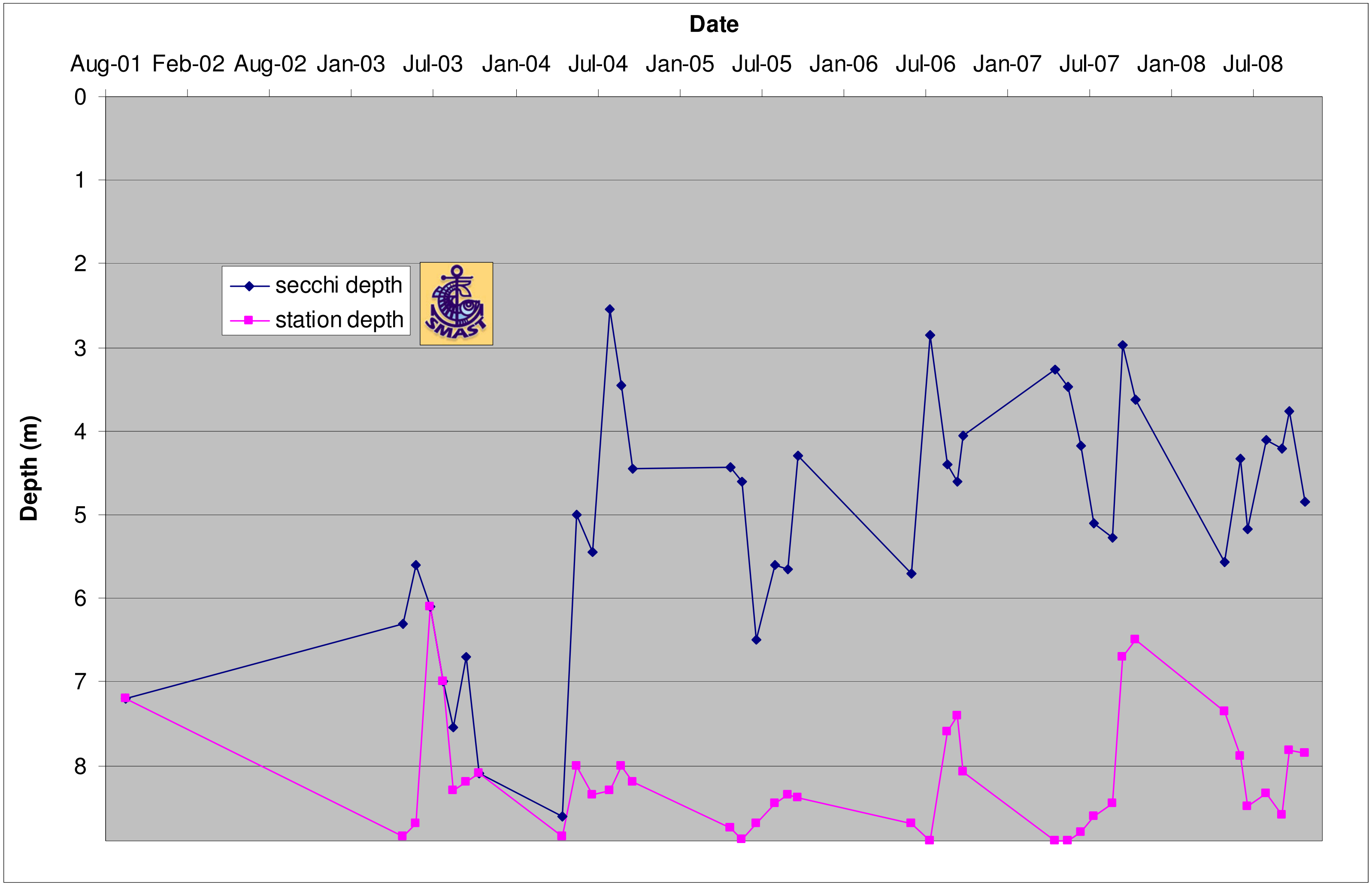


Figure VI-19. Flax Pond: Secchi transparency readings 2001-2008
Blue data points are Secchi depth readings, while station depth measurements are shown in pink. All data collected by Dennis volunteers. Secchi readings are, on average, 57% of the total depth during June through September. Relative Secchi readings range between 31% and 91% of total depth.

in the pond. However, the average surface N to P ratio is much smaller than found in other ponds suggesting that the Flax is receiving a much lower nitrogen load than other Dennis ponds; this suggestion would be consistent with the general lack of development in its watershed. The average surface N to P ratio for June through September is 32; generally water N to P ratios above 16, know as the Redfield ratio, are phosphorus limited (Redfield and others, 1963). Bottom waters have even a lower N to P ratio (24), which suggests that more phosphorus than nitrogen is regenerated from the sediments. Other observations in Cape ponds with limited development have suggested that nitrogen and phosphorus may play a more balanced role in determining water quality, but nitrogen from septic systems in their watersheds make them more phosphorus limited. Further research would be necessary to refine this issue.

At this point, phosphorus appears to be the key for determining water quality in Flax Pond and, as such, one of the next steps for effective management is to determine the sources and magnitude of phosphorus. Once this is completed, community discussions can help to determine what combination of phosphorus management strategies can be adopted to preserve water quality in Flax Pond. Accounting for all the sources and magnitude or loads of phosphorus is usually done through the development of a phosphorus budget. Phosphorus budgets usually consist of watershed sources, such as septic systems and road runoff, and internal pond sources, such as sediment regeneration and aquatic waterfowl.

Since directly measuring the components of a phosphorus budget was beyond the scope of this project, the phosphorus loads in this report are developed based on research that has evaluated these components. The research results are adjusted to address the particular details of the pond being evaluated. For example, available research on phosphorus transport from septic systems in sandy aquifers (*e.g.*, Robertson, 2008) is adjusted to reflect the number of septic systems around Flax Pond instead of directly trying to measure the phosphorus transport from each system. This approach allows a reasonable estimate to be developed, but it can be refined with additional information. All phosphorus loading estimates are compared to measured data from Flax Pond to evaluate the budget and this comparison is used to suggest components of the budget that would benefit from more refined data collection before pursuing management strategies. This approach ensures that whatever management strategies are selected effectively target the largest and most cost effective sources of phosphorus.

In order to begin to develop a watershed phosphorus budget for Flax 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 VI-13), 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 39 properties within the 300 ft buffer, but only six properties are also upgradient and in the watershed of Flax Pond. Of these six, three of them are single family residences, two are undeveloped, and one, which occupies the majority of this area is owned by the Town of Dennis Conservation Commission. Volunteers also noted runoff from Madison Road into the pond, as well as a number of ditches along the southeast shoreline. Review of aerial photographs appear to show abandoned cranberry bogs to the east that may also be connected to Run Pond. Two of the three single family residences have 2007 water use and are connected to the municipal water supply.

All three residences have septic system leachfields within 150 ft of the pond shoreline. Based on the review of town Board of Health records, the average distance for these three leachfields is 95 feet from the pond shore and is 15 years old. In contrast, the average age of the houses is 39 years old with one of the houses built in 1954 and another in 1964. Total Title 5 design for the three systems is 660 gallons per day (gpd) and total water use in 2007 for the two systems was 66 gpd. Based on the age of the septic system, distance to the pond, and the range of retention factors discussed above, the two older house are likely contributing phosphorus to the pond, but their septic systems may not be if their relatively younger leachfields are located in a different groundwater flow path than the older systems they replaced. At steady-state, the three septic systems are estimated to contribute 1.4 kg of phosphorus per year.

The predominant source of phosphorus reaching Flax Pond is from road runoff. Based on the land use analysis, there is approximately 1.1 acres of road surfaces within 300 ft of Flax Pond and of this 88% is downgradient of the pond. It is unclear whether more impervious surfaces outside of 300 ft near Madison Road might also be contributing to the pond. Overall, road runoff is projected to contribute between 47% to 49% of the estimated phosphorus load currently reaching Flax Pond.

Of the estimated sources of phosphorus, the most uncertain is loading from birds. The uncertainty of this factor could be reduced by counting and identification of bird populations on Flax Pond over a one year period. This activity could be completed by volunteers with skills to identify bird species.

If phosphorus loading from lawns, birds, and precipitation are added to the runoff load, the estimated annual phosphorus load to Flax Pond, without including an estimate for internal sediment regeneration, has a range 3.3 to 4.1 kg (Figure VI-20). Gathering of Flax Pond-specific information would be necessary to clarify all the factors.

Reviewing the water quality data can provide a reliability check on the average mass of phosphorus in Flax. After reviewing the 13 sampling runs completed between June and September, an average of 2.5 to 2.9 kg of phosphorus is in the water column of Flax depending on whether the shallow and deep readings are averaged or not. Since the residence time of water in the pond is 1.01 years (see Table V-1), this means that roughly 2.5 to 2.9 kg of phosphorus is added to the water column each year. Given that some portion of the annual load will likely be buried in the sediments and be removed from the water column, these annual estimates of loading are reasonable. Other phosphorus loading analyses have indicated phosphorus attenuation rates in Cape Cod ponds of 50% or more (e.g., Eichner, 2008); the attenuation rates in this case are between 25% and 40%, but this may be appropriate for Flax Pond given its lower N to P ratio. More refined sampling of runoff sources and/or the sediments in Flax Pond would be necessary to refine the phosphorus loads and the phosphorus burial rates.

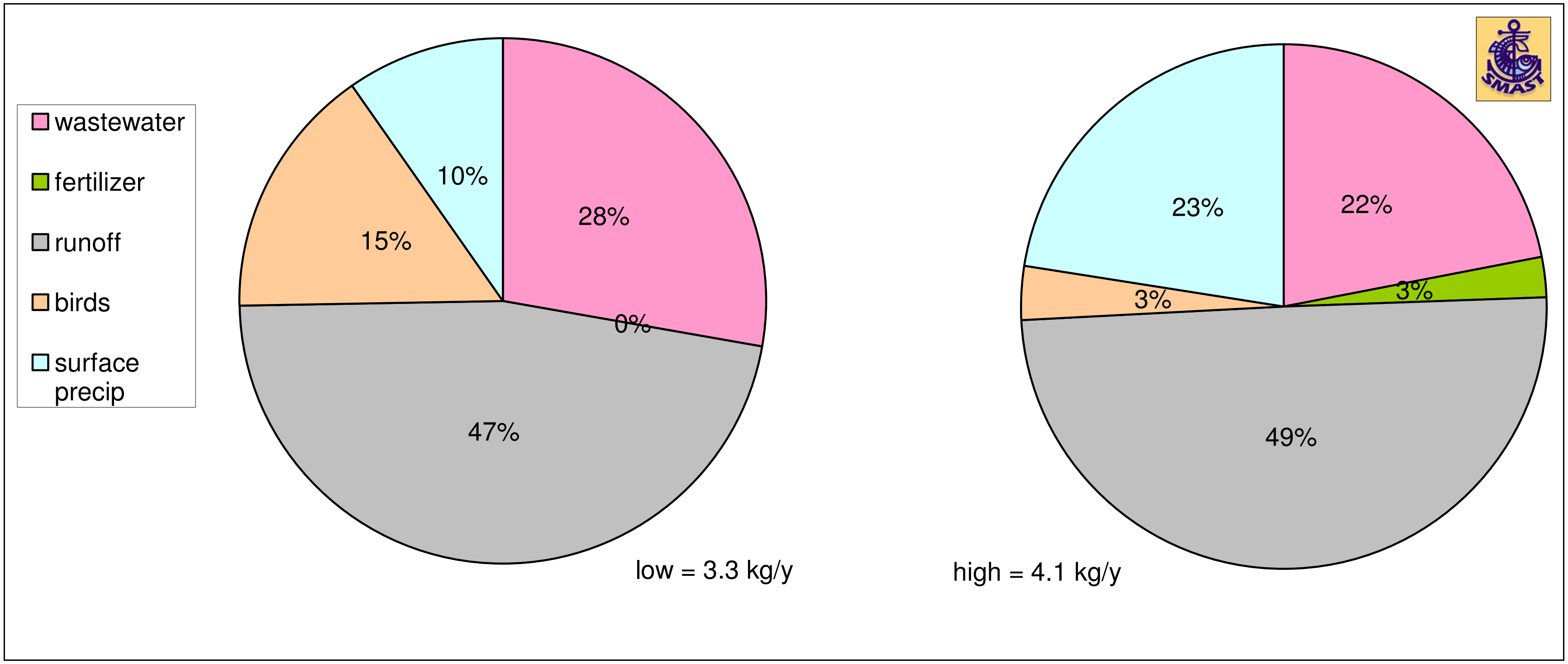


Figure VI-20. Flax Pond: Estimated annual phosphorus budget
High and low estimates based on loading factors discussed in Section V.3 and presented in Table V-3. Average in-lake mass, corrected for residence time, results in an annual watershed load of 0.25 kg based on measured water quality data (n=12 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. Bird loads are the most uncertain; gathering of Flax Pond-specific information would be necessary to clarify this particular factor. The water quality data does not suggest that there is any significant seasonal phosphorus regeneration from the sediments. These estimated loads appear to be reasonable when compared to the average measured phosphorus mass in the water column. Additional refinement of these loads would require Flax Pond-specific measurements.

Overall, water quality conditions in Flax Pond are generally acceptable. Dissolved oxygen concentrations are generally above the state regulatory threshold of 5 ppm. Secchi readings indicate some impacts and fairly high variability, but are acceptable provided they do not worsen. Average phosphorus and chlorophyll concentrations are at or slightly above their respective Cape Cod guidelines, which also suggests that continued monitoring should occur. This monitoring can provide an early warning to the town if conditions in the pond change rapidly.

It is recommended that the town consider monitoring Flax twice a year: once in April and again in August/September. Monitoring should include field measurements of dissolved oxygen, temperature, and Secchi clarity, as well as collection of water quality samples following PALS protocols. Data should be reviewed at five year intervals unless results suggest a significant change in the system. It is further recommended that the town consider a contingency plan to increase monitoring frequency if significant changes occur. Since dissolved oxygen concentrations are above the state regulatory minimum, no TMDL or additional targeted monitoring are recommended at this time.

VI.6. Scargo Lake

Scargo Lake is a 59.5 acre pond located just to the south of Route 6A and just to the north of Scargo Hill Road approximately a third of a mile north of the Follins Pond portion of the Upper Bass River estuary (Figure VI-21). Scargo is the largest of the six ponds selected for detailed review and the largest in Dennis. It is also one of two ponds in Dennis with a bathymetric map (included in the Appendix) and is also estimated to be the deepest; it has an average maximum depth of 13.9 m (45.6 ft), with a maximum recorded depth of 15.4 m (50.5 ft).

Temperature data collected between 2001 and 2008 shows that the Scargo water column during the summer generally fits the classical temperature stratified layering of kettle ponds. On average, warm, well-mixed surface waters above the state regulatory limit of 20ºC and with a 1-3ºC range are located above 7 m. At 7 m and deeper, average temperatures decrease with increasing depth, declining from 18ºC to 11ºC (Figure VI-22). These temperatures and the temperature layering or stratification, means that Scargo should be classified as a cold water fishery under the state surface water regulations (314 CMR 4).

Under these regulations, cold water fisheries are required to have dissolved oxygen (DO) concentrations of 6 ppm or above. As shown in Figure VI-22, DO concentrations in deeper waters in Scargo regularly fall below the state threshold. Average concentrations at 8 m depth and deeper are below 6 ppm, which means that only one meter of the available cold water fishery meets the state DO criterion. Waters at 11.5 m and deeper are, on average, anoxic or devoid of oxygen. Based on the state regulatory dissolved oxygen criterion, Scargo Pond is impaired and, consequently, is required to have a TMDL under the state and federal Clean Water Act.

Secchi readings suggest that these impaired conditions are relatively stable. Average Secchi depth is 4.3 m (14.2 ft) and average relative Secchi reading is 33% of the average maximum depth (Figure VI-23). While this relative Secchi reading is the worst among the ponds selected for detailed review, the variance in the readings is the second smallest after Bakers. These results mean that although there is an impairment in Scargo, the impairment is very stable over the eight years of readings and does not appear to be worsening rapidly.

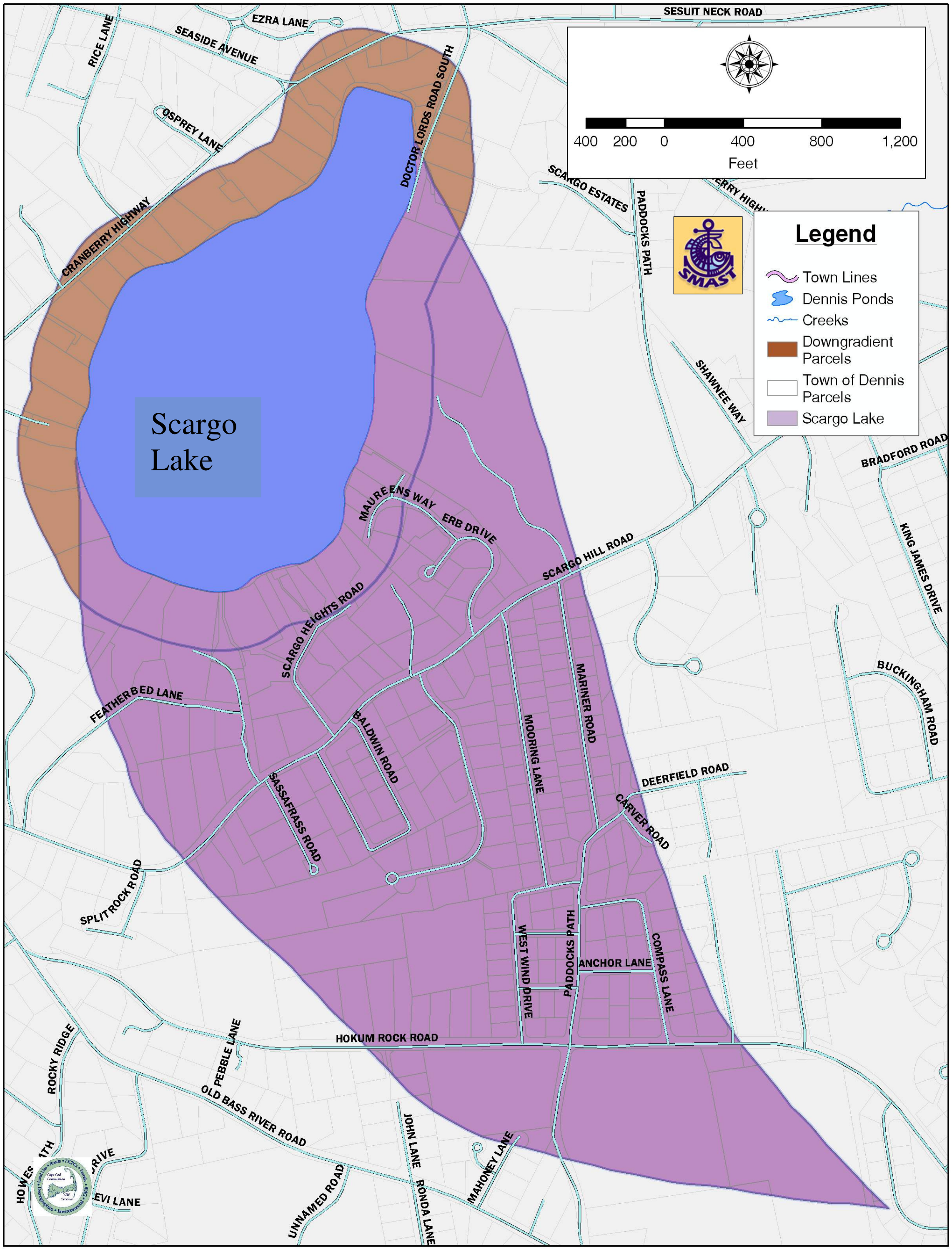
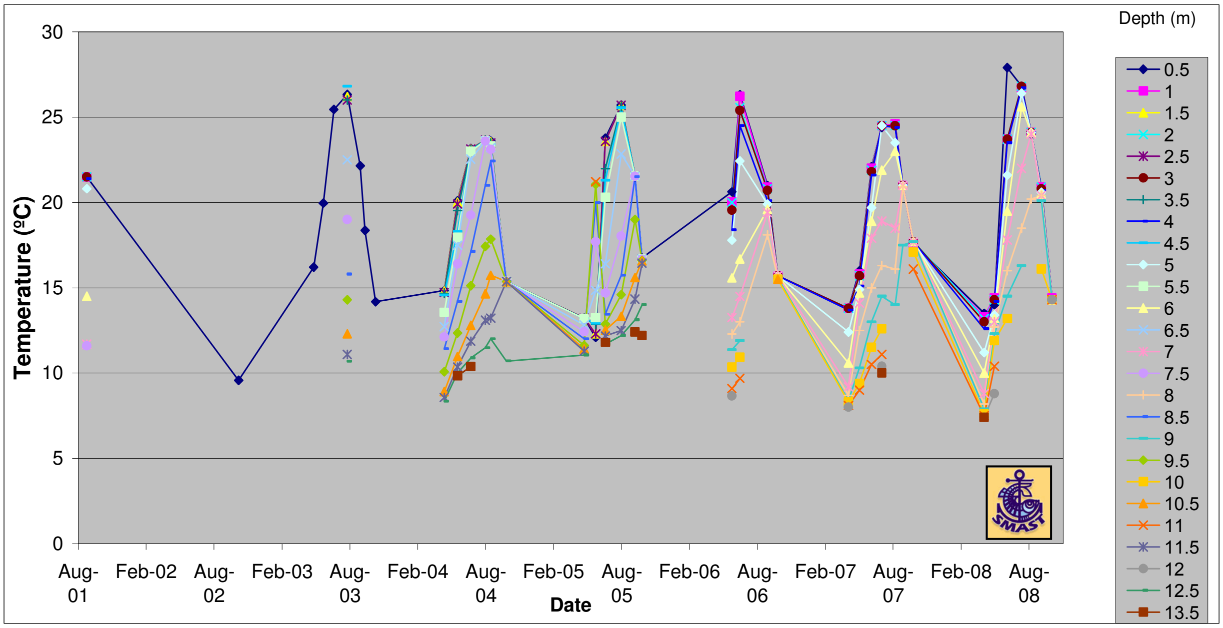


Figure VI-21. Scargo Lake watershed and phosphorus loading parcels
Phosphorus loads are developed for parcels within 300 ft that are also within the pond watershed. Watershed parcels inside the 300 ft buffer, but outside the watershed, are not assigned a phosphorus load except for road areas. Phosphorus 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 completed by town volunteers.



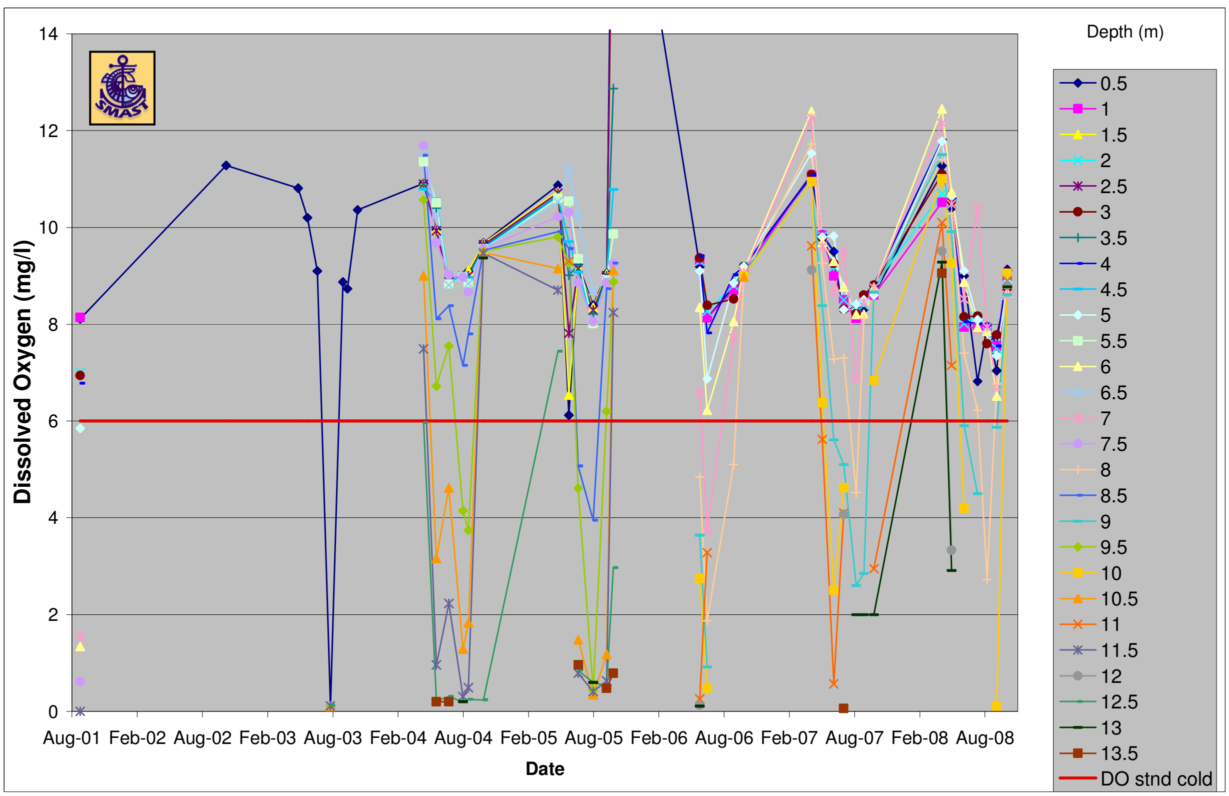


Figure VI-22. Scargo Lake Temperature and DO Readings 2001-2008

Temperature data show regular summer stratification followed relatively consistent water column temperatures generally in October. Deep temperature average below 20°C, which classifies Scargo as a cold water fishery under state regulations (314 CMR 4). Dissolved oxygen concentrations show regular summer anoxia in the deepest waters and average summer concentrations at 7 m and deeper below the state cold water regulatory threshold of 6 ppm. All data collected by Dennis volunteers using DO/Temp meters, including data from PALS Snapshots from 2001 to 2008.

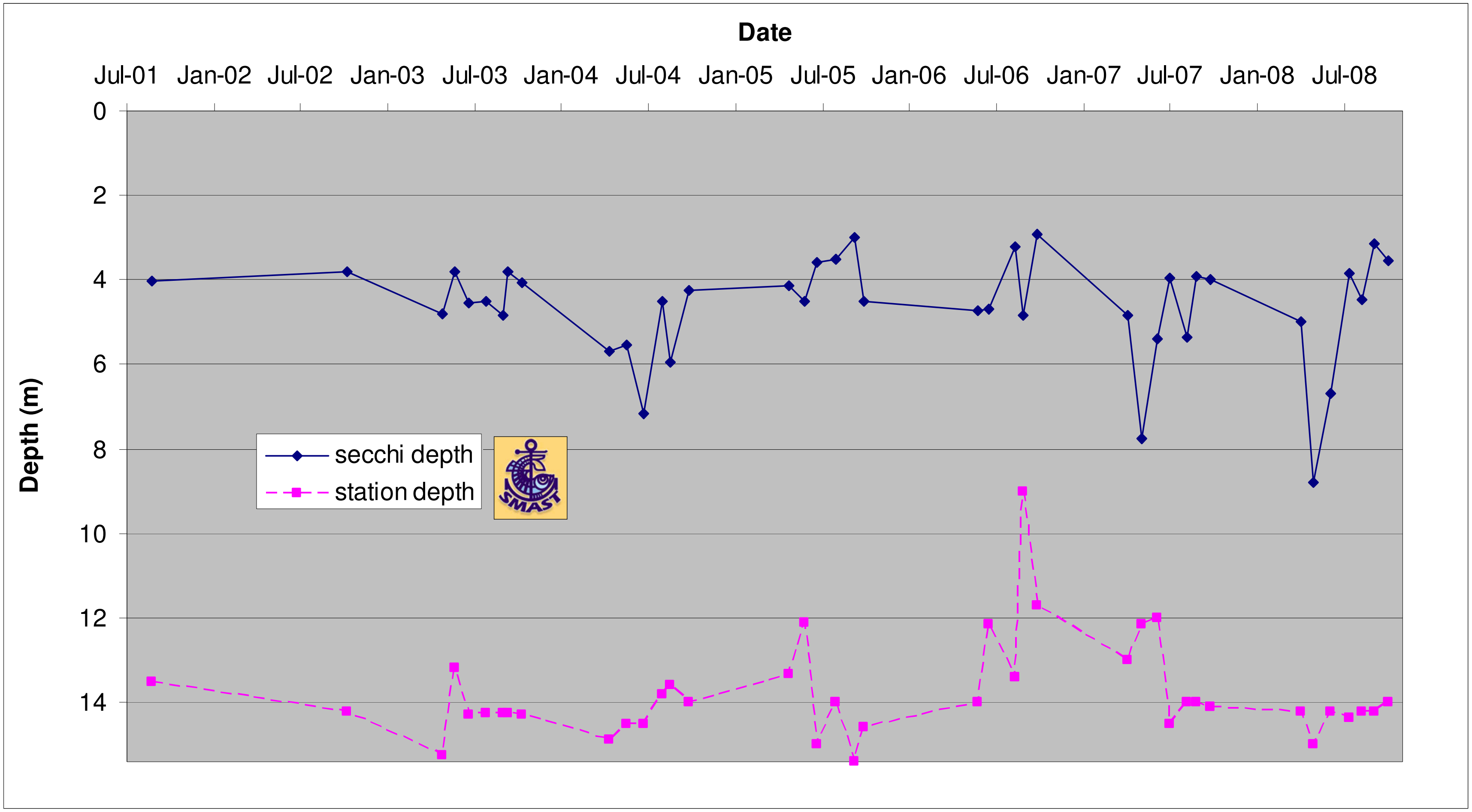


Figure VI-23. Scargo Lake: Secchi transparency readings 2001-2008

Blue data points are Secchi depth readings, while station depth measurements are shown in pink. All data collected by Dennis volunteers. Secchi readings are, on average, 33% of the total depth during June through September. Secchi reading show relatively small variance, indicating that while water quality conditions are impaired, they are relatively stable.

Laboratory water quality data reinforces that the impairment in Scargo is generally deeper in the pond. Average summer surface total phosphorus concentration is slightly higher (12.8 ppb) than the 10 ppb Cape Cod regional guideline (Eichner and others, 2003). In contrast, the deepest station, with an average depth of 12.8 m, has an average summer TP concentration of 19.7 ppb. The higher deep station average suggests some sediment regeneration, which would be consistent with the anoxic dissolved oxygen readings. Chlorophyll a concentrations are even worse than phosphorus readings; the average summer surface chlorophyll concentration is 4.2 ppb, as compared to the 1.7 ppb regional guideline.

Review of nitrogen to phosphorus ratios in Scargo show that the pond is phosphorus limited, which means that control of phosphorus is the key nutrient for determining water quality in the pond. The average surface N to P ratio for June through September is 54; generally water N to P ratios above 16, know as the Redfield ratio, are phosphorus limited (Redfield and others, 1963). Bottom waters have a similar N to P ratio (57), which suggests that although TP concentrations show sediments are regenerating phosphorus that has fallen to the sediments, this regeneration is a relatively small source compared to watershed sources. Evaluation of the mass of phosphorus in the pond based on water quality measurements reinforces this suggestion; on average, only 12% of the total mass of phosphorus in the pond is in the waters deeper than 9 m.

At this point, phosphorus appears to be the key for determining water quality in Scargo Lake and, as such, one of the next steps for effective management is to determine the sources and magnitude of phosphorus. Once this is completed, community discussions can help to determine what combination of phosphorus management strategies can be adopted to preserve water quality in Scargo Lake. Accounting for all the sources and magnitude or loads of phosphorus is usually done through the development of a phosphorus budget. Phosphorus budgets usually consist of watershed sources, such as septic systems and road runoff, and internal pond sources, such as sediment regeneration and aquatic waterfowl.

Since directly measuring the components of a phosphorus budget was beyond the scope of this project, the phosphorus loads in this report are developed based on research that has evaluated these components. The research results are adjusted to address the particular details of the pond being evaluated. For example, available research on phosphorus transport from septic systems in sandy aquifers (*e.g.*, Robertson, 2008) is adjusted to reflect the number of septic systems around Scargo Lake instead of directly trying to measure the phosphorus transport from each system. This approach allows a reasonable estimate to be developed, but it can be refined with additional lake-specific measurements. All phosphorus loading estimates are compared to measured data from Scargo Lake to evaluate the budget and this comparison is used to suggest components of the budget that would benefit from more refined data collection before pursuing management strategies. This approach ensures that whatever management strategies are selected effectively target the largest and most cost effective sources of phosphorus.

In order to begin to develop a watershed phosphorus budget for Scargo Lake, 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 VI-21), 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 62 properties within the 300 ft buffer and 28 of these are also upgradient and in the watershed of Scargo Lake. Of these 28, 12 of them are single family residences, one is a multi-family residence, three are undeveloped, and four are owned by the Town of Dennis. Three of the town owned properties are owned by the Conservation Commission and two of them have beaches as noted by the volunteer land use review. Volunteers also noted four road runoff locations reaching the pond. Nine of the single family residences have 2007 water use and are connected to the municipal water supply.

Five of the single family residences have septic system leachfields within 300 ft of the pond shoreline, while six do not have enough detail in their Board of Health records to determine the distance. Of the systems with estimated distances, the average distance for these leachfields is 222 feet from the pond shore and is 25 years old. In contrast, the average age of the houses is 54 years old. Average Title 5 design for the all 12 single family residential systems is 440 gallons per day (gpd) (or four bedrooms), which equates to a total design flow of 5280 gpd. In contrast, the total 2007 water use for the nine single family residences with water use is 1,868 gpd. Based on the age of the septic systems, distance to the pond, and the range of retention factors discussed above, six to ten of the single family residences are likely contributing phosphorus to the pond, but based on the age of the houses ten of the 12 would be contributing. An additional consideration in this assessment is whether the newer septic systems are in different groundwater flowpaths than the ones they replaced; if they are the age of the septic systems is more important than the age of the houses in determine the wastewater component of the phosphorus load. Wastewater loading from all properties is estimated at between 3.6 and 5.4 kg/y. At steady-state, septic systems are estimated to contribute 5.9 kg of phosphorus per year.

Stormwater runoff contributes phosphorus to Scargo that nearly matches the wastewater load. Based on the land use analysis, there is approximately 2.7 acres of road surfaces within 300 ft of Scargo Lake and of this 75% is downgradient of the pond. It is unclear whether more impervious surfaces outside of 300 ft, from longer portions of Route 6A for example, may be discharged into the pond. Scargo-specific measurement of stormwater runoff and evaluation of nearby stormwater structures would help to clarify the actual contribution of stormwater to the pond's phosphorus load. Overall, road runoff is projected to contribute between 33% to 40% of the estimated phosphorus load currently reaching Scargo Lake.

Of the estimated sources of phosphorus, the most uncertain is loading from birds. The uncertainty of this factor could be reduced by counting and identification of bird populations on Scargo over a one year period. This activity could be completed by volunteers with skills to identify bird species. However, bird loading is clearly a relatively minor source in the overall watershed budget of Scargo Lake.

If phosphorus loading from lawns, birds, and precipitation are added to the runoff load, the estimated annual phosphorus load to Scargo Lake, without including an estimate for internal sediment regeneration, has a range 8.8 to 14.3 kg (Figure VI-24). Gathering of Scargo Lake-specific information would be necessary to clarify all the factors.

Reviewing the water quality data can provide a reliability check on the average mass of phosphorus in Scargo. After reviewing the 13 sampling runs completed between June and September, an average of 19.7 kg of phosphorus is in the water column. Of this load, it is estimated that 1.9 kg is from sediment regeneration. After correcting for the sediment regeneration and accounting for the residence time of water in the portion of the water column not significantly impacted by regeneration (2.1 years), the annual load based on the measured phosphorus concentrations is 8.4 kg. Given that some portion of the annual load will likely be buried in the sediments and be removed from the water column, this analysis suggests that the watershed load is likely toward the higher end of the annual loading estimates. Other phosphorus loading analyses have indicated phosphorus attenuation rates in Cape Cod ponds of 50% or more (e.g., Eichner, 2008); if the 14.3 kg/y loading estimate is used, the phosphorus attenuation rate for Scargo would be 41%. More refined sampling of runoff sources and the sediments in Scargo Lake would be necessary to refine the phosphorus loads and the phosphorus sediment burial rates.

Overall, water quality conditions in Scargo Lake are generally impaired. Based on its average summer temperature readings, it is a cold water fishery. Average summer dissolved oxygen concentrations are less than the state surface water regulations minimum of 6 ppm. Secchi readings are consistent with the impaired conditions seen in the dissolved oxygen, but are relatively consistent, indicating that conditions have not worsened over the seven years of monitoring. Average phosphorus and chlorophyll concentrations are slightly above or significantly above their respective Cape Cod guidelines, which also generally confirm the impaired conditions. Review of nitrogen to phosphorus ratios show that phosphorus control is the key to improving Scargo Lake. Impaired waters are required under state regulations to develop a TMDL to address the source of the impairment, which for Scargo is excessive phosphorus.

In order to begin to address the water quality impairments in Scargo Lake, it is recommended that the town consider the following recommendations:

1) measure stormwater flows and phosphorus loads

Stormwater phosphorus loads are a large portion of the watershed load calculated in the phosphorus budget presented above. This estimate is based on reasonable assumptions, but the town would benefit from developing Scargo Lake-specific measurements of stormwater load. Volunteers who reviewed land use for this report noted four runoff locations from the roads surrounding Scargo. Detailing the contributing areas to these runoff sources and their annual loads would ensure that remediation plans are directed at the largest and most cost effective sources.

2) collect and incubate sediment cores

Based on the water quality data, it appears that the sediments regenerate phosphorus and contribute approximately 12% of the mass in the waters of Scargo Lake. Although phosphorus sediment regeneration is related to anoxic conditions, it is unclear whether the amount

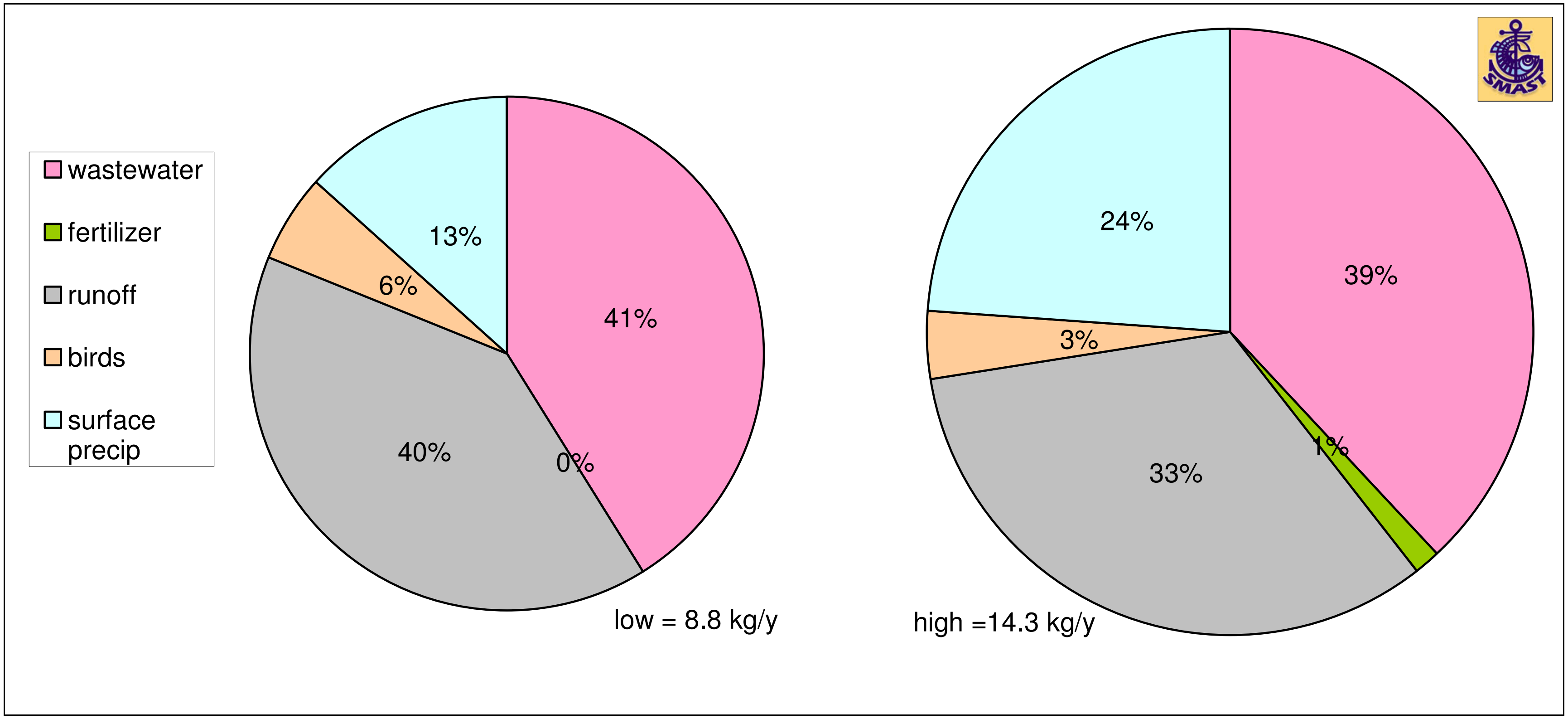


Figure VI-24. Scargo Lake: Estimated annual phosphorus budget
High and low estimates based on loading factors discussed in Section V.3 and presented in Table V-3. Average in-lake mass, corrected for residence time and sediment regeneration, results in an annual watershed load of 8.4 kg based on measured water quality data (n=13 sampling runs) and without accounting for sediment burial. 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. Bird loads are the most uncertain; gathering of Scargo Lake-specific information would be necessary to clarify this particular factor, but it is a relatively minor portion of the budget. These estimated loads appear to be reasonable when compared to the average measured phosphorus mass in the water column. Additional refinement of these loads would require Scargo Lake-specific measurements and could include direct measurement of stormwater loads and sediment regeneration.

regenerated could be increased and what conditions might cause an increase in regeneration. The current working hypothesis for remedial solutions is that controls of watershed phosphorus are the key to remediating Scargo Lake, but collection and incubation of sediment cores would allow an independent confirmation of the availability of the phosphorus in the sediments and what conditions would encourage its regeneration. These types of sediment cores traditionally are collected by professional staff using SCUBA and incubation requires collection of laboratory samples and monitoring of DO concentrations. A minimum of three cores are recommended. SMAST staff have extensive experience completing these activities through the Massachusetts Estuaries Project.

3) Update the above assessment with the Scargo Lake-specific information and develop a remedial plan

Collection of the recommended data will allow the assessment in this report to be updated and refined and allow the development of linked watershed/pond water quality model. This model could then be used to test and establish potential costs associated with various remedial options. This updated assessment could also include a recommended TMDL that would then have to be submitted and approved by MassDEP and USEPA.

In addition to the above recommendations, the town may also want to consider getting a better understanding of the bird populations that use Scargo Lake. Although bird loading is a small component of the estimated load, it is relatively uncertain. Volunteer bird watchers could be recruited to take regular observations including the identification of species. Optimally, these observations would be collected during the course of one year.

SMAST staff have estimated that the cost of a stand alone project at Scargo Lake for these recommended activities between \$25,000 and \$27,000 with another \$10,000 to \$12,000 for developing water quality management strategies and a recommended TMDL. 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. It is further recommended that the town continue regular annual sampling of the pond while further work is considered and after adoption of remedial strategies to monitor the levels of improvement. SMAST staff can discuss the range of strategies and estimated costs with town staff and can provide the town with a detailed scope of work if requested.

VII. Summary of Findings for Individual Pond Reviews

VII.1. Bakers Pond

- 10 acres (Great Pond under state law)
- No bathymetric map; average measured maximum depth 4.7 m (15.4 ft)
- Warm water fishery under state surface water regulations (314 CMR 4)
- Average summer dissolved oxygen concentrations above state minimum standards throughout water column
- Exceptional average water clarity
- Average phosphorus and chlorophyll concentrations below Cape Cod-specific pond guidelines

- Acceptable water based on state regulations, does not require TMDL
- Phosphorus limited
- 12 properties wholly or partially within the 300 ft buffer and in Bakers watershed; five of them are single family residences
- Continued limited annual water quality monitoring recommended to provide early warning of worsening conditions.

VII.2. Cedar Pond

- 9 acres (not a Great Pond under state law)
- No bathymetric map; average measured maximum depth 3.8 m (12.6 ft)
- Warm water fishery under state surface water regulations (314 CMR 4)
- Average summer dissolved oxygen concentrations fall below state minimum standards 2 m and deeper and occasionally throughout water column
- Impaired water based on state regulations, requires TMDL
- Average phosphorus and chlorophyll *a* concentrations and Secchi readings consistent with impaired conditions
- Occasionally fails to have sufficient clarity for safe swimming
- Sediment regeneration of phosphorus
- Phosphorus limited
- TMDL should target phosphorus
- 18 properties wholly or partially within the 300 ft buffer and in Cedar watershed; 15 of them are single family residences
- Stormwater and wastewater are predominant sources in pond phosphorus budget
- Collection of Cedar Pond-specific information recommended: 1) bathymetric map, 2) collection and incubation of sediments cores to test phosphorus regeneration potential and remediation options, and 3) measure stormwater runoff phosphorus contributions.
- Once pond-specific information collected, it is recommended that the Town consider updating this current water quality assessment to review remedial options and costs and develop preferred approach for remediation
- Estimated cost for stand alone Cedar Pond project to collected recommended information is $22,000 to $25,000 with another $10,000 to $12,000 for developing water quality management strategies and a recommended TMDL

VII.3. Coles Pond

- 11 acres (Great Pond under state law)
- No bathymetric map; average measured maximum depth 1.8 m (5.9 ft)
- Warm water fishery under state surface water regulations (314 CMR 4)
- Average summer dissolved oxygen concentrations above state minimum standards throughout water column
- Average phosphorus and chlorophyll *a* concentrations and Secchi readings consistent with impaired conditions
- Phosphorus limited
- Three properties wholly or partially within the 300 ft buffer and in Coles watershed; one of them is a single family residence

- Phosphorus budget suggests that there is an unaccounted source of phosphorus entering pond
- No TMDL or additional assessment recommended at this point given the limited development in the watershed, but regular annual monitoring is recommended to provide early warning of worsening conditions.

VII.4. Eagle Pond

- 7 acres (not a Great Pond under state law)
- No bathymetric map; average measured maximum depth 7.0 m (23 ft)
- Warm water fishery under state surface water regulations (314 CMR 4)
- Average summer dissolved oxygen concentrations above state minimum standards throughout water column
- Average Secchi readings consistent with non-impaired water quality
- Average phosphorus and chlorophyll *a* concentrations above Cape Cod-specific pond guidelines; may be due to historic, rather than current, land uses
- Acceptable water based on state regulations, does not require TMDL
- Phosphorus limited
- Six properties wholly or partially within the 300 ft buffer and in Eagle watershed; four of them are single family residences; also includes a portion rest area on Route 6;
- Stormwater is predominant source in pond phosphorus budget, but appears to be overestimated given measured water quality data
- Continued limited annual water quality monitoring recommended to provide early warning of worsening conditions
- Also recommended that town track potential changes to Route 6 for opportunities to encourage better stormwater management

VII.5. Flax Pond

- 16 acre pond (Great Pond under state law)
- No bathymetric map; average measured maximum depth 8.2 m (27 ft)
- Warm water fishery under state surface water regulations (314 CMR 4), but has cold water fishery characteristics early in summer
- Average summer dissolved oxygen concentrations above state minimum standards throughout water column, but has occasional anoxia near sediments
- Average Secchi readings consistent with non-impaired water quality, but large fluctuations suggest unstable/impaired conditions
- Average phosphorus and chlorophyll *a* concentrations slightly above Cape Cod-specific pond guidelines; do not suggest impaired conditions
- Acceptable water based on state regulations, does not require TMDL
- Phosphorus limited
- Six properties wholly or partially within the 300 ft buffer and in Flax watershed; three of them are single family residences; majority of area occupied by Town-owned conservation land
- Potential historic connection to nearby cranberry bogs and Run Pond
- Stormwater is predominant source in pond phosphorus budget

- Continued limited annual water quality monitoring recommended to provide early warning of worsening conditions

VII.6. Scargo Lake

- 59.5-acre pond (Great Pond under state law)
- Has state-posted bathymetric map; average measured maximum depth of 13.9 m (45.6 ft)
- Cold water fishery under state surface water regulations (314 CMR 4)
- Average summer dissolved oxygen concentrations 8 m and deeper fail to attain state minimum standards; waters 11.5 and deeper are anoxic
- Impaired water based on state regulations, requires TMDL
- Secchi readings are consistent with impaired conditions, but indicate that impaired conditions are relatively stable and have not worsened between 2001 and 2008
- Average chlorophyll *a* concentrations are consistent with impaired conditions
- Average surface total phosphorus concentrations are just above Cape Cod-specific guideline, but deep concentrations show impact of sediment regeneration
- Phosphorus limited
- TMDL should target phosphorus
- 28 properties wholly or partially within the 300 ft buffer and in Scargo watershed; 12 of them are single family residences and one multi-family residence; volunteers noted four road runoff input locations
- Wastewater and stormwater are predominant sources in pond phosphorus budget; sediments estimated to contribute 12%
- Collection of Scargo Lake-specific information recommended: 1) measure stormwater runoff phosphorus contributions and 2) collection and incubation of sediments cores to test phosphorus regeneration potential and remediation options.
- Once pond-specific information collected, it is recommended that the Town consider updating this current water quality assessment to review remedial options and costs and develop preferred approach for remediation
- Estimated cost for stand alone Cedar Pond project to collected recommended information is $25,000 to $27,000 with another $10,000 to $12,000 for developing water quality management strategies and a recommended TMDL

VIII. Recommended Next Steps

VIII.1. Future Citizen Monitoring

The available dataset for all the ponds considered under this project is primarily due to Dennis 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. Continuing this sampling will:

1) provide early warning of significant changes in water quality,

2) provide a longer-term, more comprehensive understanding of pond conditions, and
3) provide an on-going baseline for water quality management by the Town with regards to TMDLs, impacts of current and future proposed land use activities, and comprehensive wastewater management.

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 an initial assessment of their ecological status. However, in each case, these assessments identified other information needs that are needed for more definitive assessment and/or information that will need to be developed prior to evaluation and costing of remedial options. It is recommended that the Town consider similar detailed reviews for the other five ponds that have citizen collected water quality data: Fresh, Hiram, North Simmons, Run, and White. 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.3. Regulatory Status for Six Detailed Ponds

The two of the six ponds with detailed reviews that included watershed delineations, water and phosphorus budgets, and limiting nutrients 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 these two ponds (Scargo and Cedar) 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 Dennis's other ponds. The current (2008) integrated DEP list has Scargo and Flax listed as Category 3 "No Uses Assessed" waters; waters in this category are included in the list but have no completed assessment and no determination of their water quality.

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

The two ponds characterized as impaired in this report have recommended additional data collection prior to development of remedial options; this data collection will provide a better understanding of the ecosystems and provide a better basis for determine which remedial options can address the underlying causes of the impairment, as well as providing a better basis for determining the costs associated with the options. 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.

In addition to remediation, one of the major deficiencies in all the detailed assessments completed for the six ponds was the lack of bathymetry. Bathymetry helps to define the volume of the ponds, which is important for understanding the measured concentrations from the water quality samples. Project staff have estimated volumes based on relationships between depths and areas of other ponds on the Cape, but it is recommended that bathymetry be developed for the five ponds with detailed assessments (Scargo already has a bathymetric map), as well as the other ponds in town. The bathymetric information can be collected by volunteers with the proper equipment. SMAST staff can provide guidance to the town on the development of this information, as well as providing the post-collection creation of the bathymetric maps.

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 4,200 data points) collected by Town of Dennis volunteers from 11 ponds between 2001 and 2008. This review also includes a detailed review of six ponds selected by the Town: Bakers, Cedar, Coles, Eagle, Flax and Scargo. 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 11 Dennis ponds monitored between 2001 and 2008 indicates that four ponds have at least one depth station that has an average dissolved oxygen concentration less than the state regulatory minimum: Cedar, Hiram, Run, and Scargo. Given the regulatory standards, these ponds are candidates for being classified as "impaired waters" and, thus, requiring a TMDL. Three other ponds (Flax, North Simmons, and White) have individual measurements where waters had oxygen insufficient to sustain fish (<1 ppm).

Review of other ecological factors show that all of the ponds except for Bakers have average chlorophyll concentrations that exceed the Cape Cod ponds 1.7 ppb guideline. This suggests that most of these ponds are receiving more nutrients than they should. This is reinforced by the review of average phosphorus concentrations, which shows that 10 of the 11 ponds (Bakers is the exception) have at least one station with an average concentration greater than the Cape Cod ponds 10 ppb guideline. The details of the depths where the exceedances occur and the magnitude of the exceedance reinforce the need to review the individual characteristics of each pond.

Review of total nitrogen to total phosphorus ratios in the six ponds selected for detailed review 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.

The detailed reviews completed for the six ponds selected by the town build on the town-wide water quality overview and enhance and provide a better context by understanding of how watershed and in-lake factors influence the measured water quality. 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 Scargo and Cedar are impaired based on dissolved oxygen limits in the state Surface Water Quality Regulations (314 CMR 4) and will likely require TMDLs. In contrast, all but Baker of the six selected ponds have average concentrations exceeding the Cape Cod-specific pond guidelines for total phosphorus and chlorophyll *a*. The individual circumstances of each pond show how the state dissolved oxygen standards can be met even when ecological conditions are severely impaired. Coles Pond, for example, meets state dissolved oxygen standards even though it has average total phosphorus concentrations two times higher and average chlorophyll a concentrations 8 times higher than their respective Cape ponds standards. Dissolved oxygen standards in Coles are met because of its shallow depth and regular mixing of atmospheric oxygen. Project staff recommended that these conditions in Coles continue to be monitored given that the watershed analysis showed that only one house contributes phosphorus to the pond and additional data would be necessary to better understand the causes of the high phosphorus concentrations.

The better understanding of this pond ecosystem points out the need for additional information before the town develops remedial options and their associated costs. Key among these are better understanding of sediment phosphorus regeneration, stormwater phosphorus contributions, and pond bathymetry. Collecting sediment samples will clarify how much the sediments contribute to the observed phosphorus concentrations, how much they could contribute in worsened conditions, and whether this source needs to be addressed in remedial solutions. Stormwater contributions of phosphorus were identified as a major source in all of the watershed analyses, but site-specific information would ensure that any town remediation activities are appropriately targeted. Bathymetry or comprehensive depth information is only available for Scargo and Fresh; developing this information will provide more definitive understanding of measured nutrient concentrations and, consequently, any remedial solutions designed to reduce these concentrations. 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.

Addressing the pond water quality concerns in Dennis will require addition information, coordinated effort with state regulations, and incorporation of goals into the town Comprehensive Wastewater Planning efforts. 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 A

Available
Pond Bathymetric Maps
Town of Dennis

prepared by
Jay Detjens, GIS Analyst
Cape Cod Commission

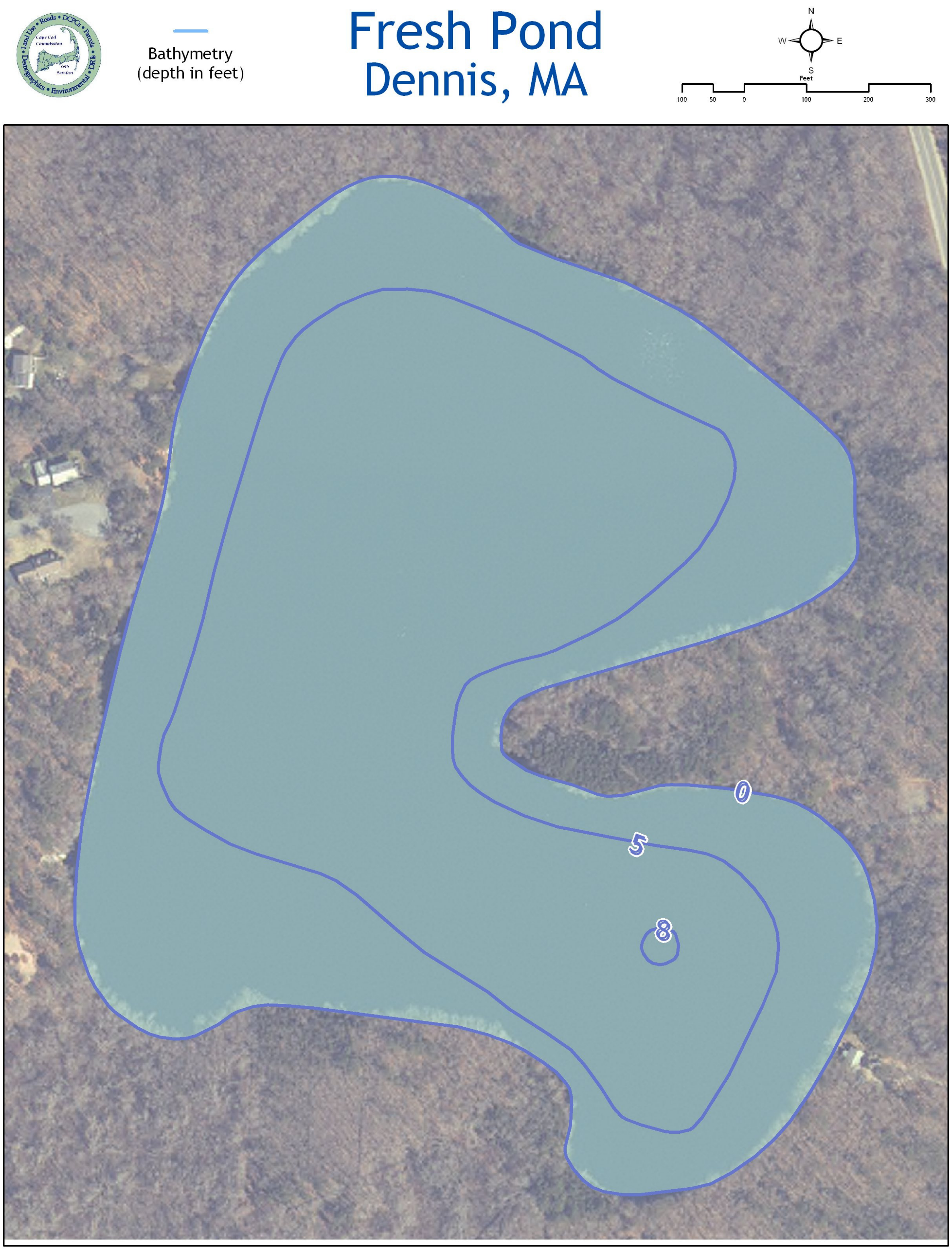
Data sources:

Fresh Pond bathymetry from
Cape Cod Pond and Lake Atlas (Eichner and others, 2003)

Scargo Lake bathymetry from
Massachusetts Division of Fish and Wildlife
http://www.mass.gov/dfwele/dfw/habitat/maps/ponds/pond_maps_sd.htm

Fresh Pond
Dennis, MA

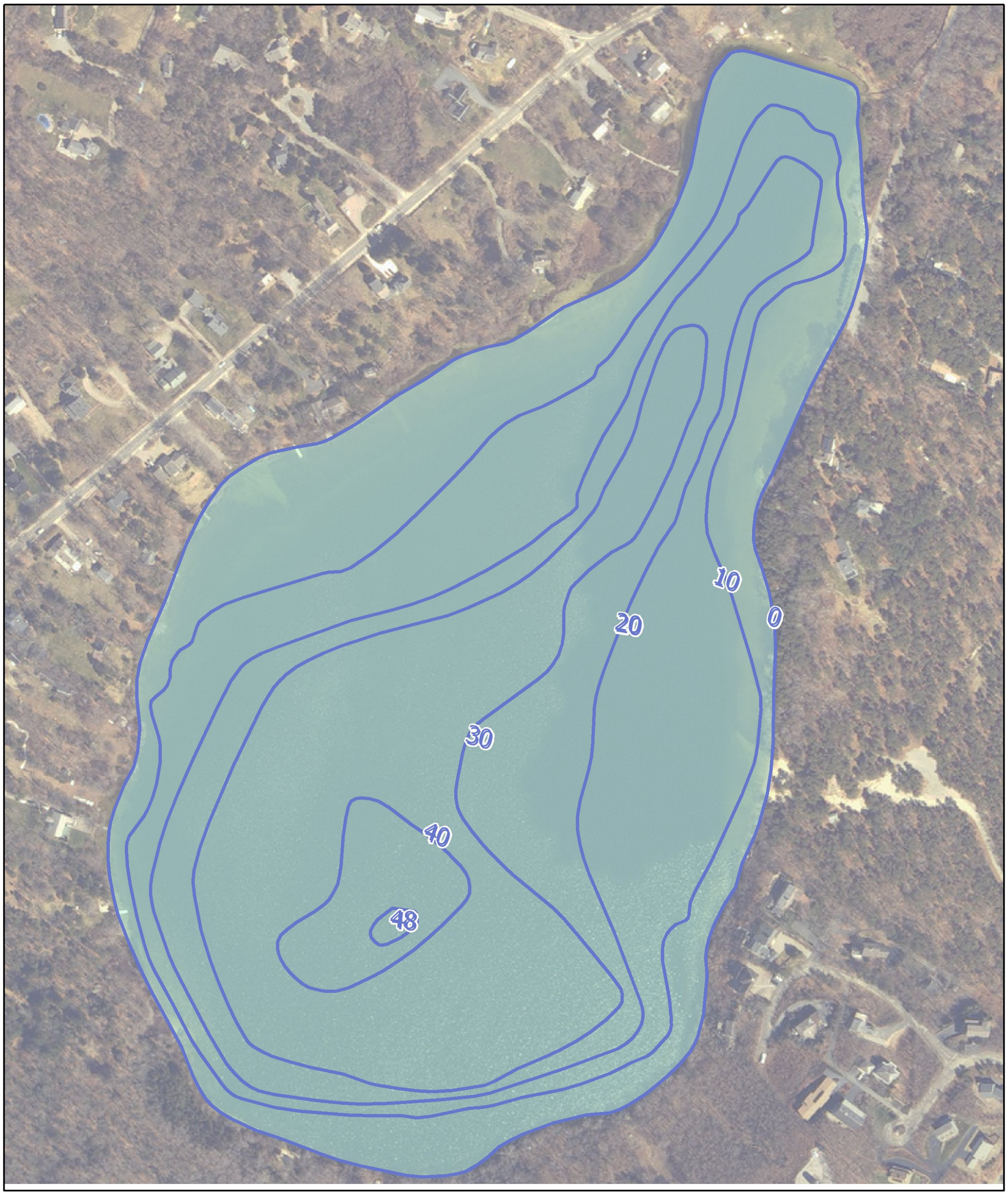
Bathymetry
(depth in feet)



Scargo Lake
Dennis, MA

Bathymetry
(depth in feet)

N
W E
S
Feet
150 75 0 150 300 450



APPENDIX B

Dennis Ponds Sampling Sheet

Baker Pond example

DENNIS-WQAC LAKE AND POND SAMPLING DATA SHEET
Cape Cod 2009 Pond Sampling/Stewardship program

LAKE/POND NAME: **BAKERS**
TOWN: **Dennis** Sample Collector(s):____
Date: / /2009 Time Started :____:____:____am pm

Observations (write in or circle as appropriate):
Water Color:_______________ 1. blue; 2. brown; 3. green; 4. blue/green; 5. red/orange; 6. white; 7. Other
Weather (circle): 1. Cloudless 2. Ptly cloudy 3. Overcast; 4. Rain 5. Fog/haze 6. Drizzle 7. Intermit. Rain
Wind (circle): 1. Calm 2. Light Breeze 3. Steady wind 4. Strong wind

Plants on Pond (check conditions):		over 50%	25% to 50%	10% to 25%	up to 10%	less than 1%
Water lilies:						
Floating algae:						
Emergent grasses / sedges:						
Other plant #1						
Other plant #2						
Birds						
Animals						
Notes:						

Buoy (deepest point): Coordinates: 41 43.189 N ; 70 08.678 W Moved: Yes / No

TOTAL SECCHI DEPTH: __________________**meter** **TARGET DEPTH:** __**4.5 M (5.2M 4/07)**__

SECCHI READING: Disappearing __________meter Reappearing __________meter

DISSOLVED OXYGEN/TEMPERATURE PROFILE

Meter Manufacturer: YSI 550A CIRCLE: **Short Cord** **Long Cord**
Record DO/Temp profile in one-meter increments ***except*** *for the first surface reading which is taken at 0.5 m (for example: 0.5 m, 1 m, 2 m, 3 m etc.) If the pond is shallow (3 meters or less), record readings at 0.5 m increments, for example: 0.5 m, 1 m, 1.5m, etc.).* ***Initial Reading*** *is with probe still in chamber.*

Depth (m)	Temp (◦C)	Dissoved Oxygen (mg/l)	Depth (m)	Temp (◦C)	Dissoved Oxygen (mg/l)	Depth (m)	Temp (◦C)	Dissoved Oxygen (mg/l)
Initial Reading						**1M from Bottom**		
0.5								
1.0								
2.0								
3.0								
4.0								
5.0								
6.0								
7.0								
8.0								

COMPLETE BOTH SIDES OF DATA SHEET

LAKE/POND NAME: **BAKERS**

TOWN: **Dennis (DE-WQAC)** Sample Collector(s):____

WATER QUALITY SAMPLING

LIST POND NAME, SAMPLE DEPTH, AND DATE ON BOTTLE LABEL

⇒POND GREATER THAN 9 METERS DEEP⇐ SCARGO	
Sampling Depth a. Just below the surface b. 3 m down c. 9 m down d. 12 m down e. 1 m above the bottom	Bottle lable (Pond Name, Sample Depth, & Date)

⇒POND LESS THAN 9 METERS DEEP MOST PONDS EXCEPT SCARGO⇐	
Sampling Depth a. Just below the surface d. 1 m above the bottom	Bottle lable (Pond Name, Sample Depth, & Date)

⇒In ponds ~1 m deep, please collect two samples just below the surface

TIME SAMPLING COMPLETED: __:__:__ (AM or PM)

All water samples must be kept cold, in a cooler with ice packs, and delivered to designated site the same day as samples taken(before 3:00 PM)!

Coastal Systems Program,SMAST, UMASS,Dartmouth, 706 South Rodney French Blvd.,New Bedford
Delivery point Bourne Bridge Circle, MA State Police Barracks
Cape Cod Commission offices are at 3225 Main Street/Route 6A in Barnstable Village
(across from the Post Office)

SAMPLE SIGNOFFS

	Signature	Received Date/Time	Delivered Date/Time
Pond Testors			
Sampling Coordinator			
Cape Cod Commission			
SMAST			

COMPLETE BOTH SIDES OF DATA SHEET