Scargo Lake
Water Quality Management Report

Draft FINAL REPORT
October 2012

for the

Town of Dennis

Prepared by:

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Department of Natural Resources

Prepared By

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Cover photo: 2012 Scargo Lake Regatta courtesy of Wixon Middle Level Academy, N.H. Wixon Middle School

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The authors acknowledge the contributions of the many individuals and boards who have worked tirelessly for the restoration and protection of the pond and lakes in the Town of Dennis. Without these pond stewards and their efforts, this project would not have been possible.

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Executive Summary

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Scargo Lake is the largest (60 acres) and deepest (50 ft) freshwater pond in the Town of Dennis. It is located to the north of Scargo Hill and south of Route 6A. The lake has two public beaches (Scargo Beach and Princess Beach) and a public boat ramp located off Route 6A. A stream outlet in the northeast section connects the lake to Sesuit Harbor.

Over the past 10 years or so, citizen volunteers have worked through advocacy and sampling time to develop key information about the water quality of Scargo Lake. In 2009, with the guidance of the town Water Quality Advisory Committee and the town Natural Resource Department, staff from the Coastal Systems Program, School for Marine Science and Technology (SMAST), University of Massachusetts Dartmouth completed a review of available water quality data and assessed where key targeted information was necessary to develop a water quality management plan (Eichner, 2009). The targeted data collection included collecting of Scargo Lake-specific measures of stormwater runoff, sediment nutrient regeneration, bird populations, and an updated bathymetric map (Eichner and Howes, 2012). This report utilizes this information to provide an assessment of steps needed to restore Scargo Lake.

Review of surface water conditions in Scargo Lake show conditions that are acceptable for swimming and other contact recreation. There has been no evidence of extensive algal blooms, blue-green algal blooms or fish kills; conditions that have impacted other Cape Cod ponds such as Hinckleys Pond in Harwich, Mystic Lake in Barnstable, and Long Pond in Brewster/Harwich. Total phosphorus and chlorophyll concentrations in this upper, warm layer, which extends down to 7-9 m, are elevated, but not exceptionally high.

However, deeper in Scargo Lake, in the colder waters deeper than 9 m, are conditions that impair this portion of the lake habitat and raise concerns the future surface water quality of the whole lake. During a given year, the earliest water quality data available is from April and this data shows that oxygen demand from the pond sediments has already begun to consume oxygen from overlying waters. These conditions persist and worsen throughout the summer, eventually reaching up to the bottom of the warm surface water layer and, on occasion, into the surface water layer. Review of collected water quality data shows that these low oxygen conditions release phosphorus, but overall phosphorus concentrations appear to be low enough and residual oxygen is high enough in the upper portions of the cold layer that extensive algal blooms are not initiated.

These diminishing oxygen concentrations are due to sediment oxygen demand, but there is no indication that the phosphorus released from these sediments is seeping into the upper waters in a significant mass. The sediment testing indicates that aerobic sediments in the 4-8 m depth range are the primary sediment phosphorus source during the summer. The collection of

phosphorus in these sediments may be facilitated by an extensive freshwater mussel population. Chlorophyll-a readings show that phytoplankton are growing more extensively at the low oxygen boundary (9 m), but these do not seem to be extensively impacting concentrations in the waters above them. Overall review of sediment data shows that the pond is collecting more phosphorus each year and it is likely that this will gradually worsen dissolved oxygen conditions over time without intervention. There is, however, no discernible trend of worsening dissolved oxygen conditions or Secchi clarity over the past 10 years.

Review of potential next steps for the management of Scargo Lake largely depends on the criteria that are used to judge its water quality conditions. Massachusetts Department of Environmental Protection (MassDEP) regulatory standards for surface waters require dissolved oxygen concentrations in lakes with cold water fisheries to have dissolved oxygen (DO) concentrations of 6 ppm or above (314 CMR 4.05(3)(b)1). As shown in the DO profiles, the cold water fishery in Scargo Lake regularly disappears during the summer as sediment oxygen demand drops DO concentrations below 6 ppm throughout the whole cold water layer and with anoxic conditions (<1 ppm) in the deepest waters. Water quality conditions in Scargo Lake meet all of the other provisions of the surface water regulations, including: temperature, pH, bacteria, solids, color and turbidity, oil and grease, and taste and color. Based on the DO criterion, it is likely that MassDEP would require a TMDL for Scargo Lake under the Clean Water Act and, eventually, some sort of management actions to attain the TMDL. What the TMDL would be, however, would likely require some negotiations with MassDEP, since no phosphorus TMDLs have been developed by MassDEP for deep water lakes within the Scargo Lake Ecoregion (*i.e.*, southern Plymouth, Cape Cod, Martha's Vineyard and Nantucket).

The review of the 2001 PALS Snapshot data suggested that a target TP concentration range for Cape Cod ponds should be between 7.5 and 10 ppb (Eichner and others, 2003). Average late summer surface TP concentrations in Scargo Lake in the waters less than 9 m are 10.3 ppb, while the deepest waters average 22.9 ppb. The shallow concentration and the deep DO impairments suggest that the TP should be lower than 10 ppb. In order to achieve 7.5 ppb TP, the average mass of TP in the upper waters of Scargo Lake would need to be reduced from 16 kg to 9.8 kg. In order to meet this lower mass, the annual watershed load would need to be reduced by 3 kg from the current annual load of 5.5 to 9.8 kg.

The largest controllable load entering Scargo Lake from its watershed is wastewater. If wastewater alone was targeted for the potential phosphorus reduction, wastewater phosphorus loads would need to be reduced 55 to 83%. No other single controllable source could attain the 3 kg reduction. However, since wastewater phosphorus takes decades to reach Scargo Lake, immediate reductions in wastewater phosphorus would address the long term maintenance of appropriate TP loads, but would not address the MassDEP dissolved oxygen criterion.

The goal in addressing the MassDEP DO criterion can likely be met by establishing some stable trout habitat; not the whole the cold water layer, but some portion. If a layer of high DO (>6 ppm), cold water can be sustained, it will provide some trout habitat, as well as protecting the warm, upper waters of the lake from regenerated deep water phosphorus. Project staff reviewed available options and recommend that the town consider implementing a hypolimnetic aeration project.

Hypolimnetic aeration is a process of controlled injection of air into the deep water in such a way that the cold water layer is maintained and oxygen levels are increased. It is

recommended that this process be confined to the deep basin of Scargo Lake in depths below 9 m. Since the layers do not begin to form until April, the system could be turned on in May and run through September. Deep dissolved oxygen concentrations naturally begin to recover in October, as rapid cooling of the lake begins to breakdown the layers, so the system could be turned off at that point.

The area of the deep basin below 9 m is 16 acres and the average depth of this layer is 2 m. This volume and area is relatively small for the application of hypolimnetic aeration and great care would be necessary in the design to have an air flow that sustains the thermal layering. Based on ranges of cost presented in the MassGEIR (MassDEP/MassDCR, 2004) and updated to 2011 dollars, the likely cost range would be $10,000 to $60,000. Preliminary calculations of necessary air flow are small, so capital costs should be relatively small, but costs such as design, energy, and regulatory approval would likely push the costs toward the higher estimate. Long term maintenance would also have to be factored into the cost estimates. There are a number of design options.

Use of hypolimnetic aeration would be a long term solution that would need to be initiated and maintained each summer. Proper air/oxygen flows, mixing, and adequate characterization of the treated ponds are key factors in the most successful installations. Successful installations have no negative impacts on fish, shellfish, or plants. Unsuccessful installations present the opportunity to increase the transfer of phosphorus from deep waters to the more productive shallow waters and/or to destabilize the thermal layering and compromise the cold water fishery. If this is combined with reductions in watershed phosphorus inputs, the lake will gradually (over decades) reduce the mass of phosphorus in the sediments and the sources from the watershed will not replenish this mass.

Part of the long term success of the proposed in-lake treatment is going to be successful complementary reductions in watershed phosphorus inputs. As mentioned above, wastewater reductions would have the greatest impact. Wastewater is currently estimated to annually contribute 3.6 to 5.4 kg to Scargo Lake, which is greater than half of the watershed input. Removal of this whole load would reduce the mass in the lake to 34 to 44% of current levels and result in TP concentrations of 3.1 to 7.4 ppb without factoring in the sediment contributions.

Accomplishing this type of reduction, however, would present a number of challenges. The houses on the western edge of the lake are located in areas of significant elevation changes and wastewater collection to either neighborhood treatment facilities or a larger facility would have to address these changes with pumps that would add operation and design costs. In addition to these costs, wastewater facilities siting issues and costs would also be an issue. It might be possible to address these comprehensively during town-wide discussions of wastewater infrastructure to meet estuary TMDLs.

Table of Contents

Scargo Lake Water Quality Management Report

draft Final Report

October 2012

List of Figures
Scargo Lake Water Quality Management Report
draft Final Report
October 2012

List of Tables

Scargo Lake Water Quality Management Report

draft Final Report

October 2012

I. Introduction

The Town of Dennis has 57 ponds that collectively occupy 275 acres; the largest and the deepest of these ponds is Scargo Lake (**Figure I-1**). Scargo Lake is 60 acres and 15 m deep. In order to address community concerns about their water quality, pond sampling strategies were developed, volunteer samplers were trained, and initial data reviews were completed working with University of Massachusetts Dartmouth School for Marine Science and Technology (SMAST) staff and other regional partners. Sampling of Dennis ponds by town volunteers began in 2001 and have been sustained through the Cape Cod Pond and Lake Stewards (PALS) program with sampling continuing and expanding through 2011 (Eichner and others, 2003).

In 2009, SMAST staff completed a review and synthesis of the available pond sampling data at the town's request (Eichner, 2009). This review identified water quality problems in a number of the ponds. It also included a series of recommendations for a) targeted data collection to help better define water quality management options, as well as recommendations to b) develop pond-specific management plans to facilitate discussion and ultimately achieve sustainable water quality conditions in the town's ponds. The town, through the Water Quality Advisory Committee, prioritized these recommendations and began addressing the first recommendations in 2010.

The Water Quality Advisory Committee decided to first address the targeted data collection recommended for Scargo Lake. Eichner (2009) identified three significant data needs for understanding the sources of phosphorus in the lake and providing the solid basis for a water quality management plan: 1) a characterization of the sediments and their contribution to lake nutrient balance (and impairment), 2) a characterization of nutrient inputs from stormwater, and 3) an understanding of potential nutrient contributions by birds. These efforts were completed in 2010 and 2011 and are documented in a SMAST Technical Memorandum (Eichner and Howes, 2012).

The second phase of recommended work for Scargo Lake was started this year: the development of Scargo Lake Water Quality Management Report. This report uses the targeted data collected during the first phase and available water quality data collected since 2001 to develop a conceptual model of Scargo Lake and use this model and the collected data to review water quality management options. This report details the development of the model and review of selection options. Recommendations for targeted data collection are proceeding for other ponds in the Town of Dennis (Eagle Pond and Cedar Pond) and will be summarized in a separate SMAST Technical Memorandum.

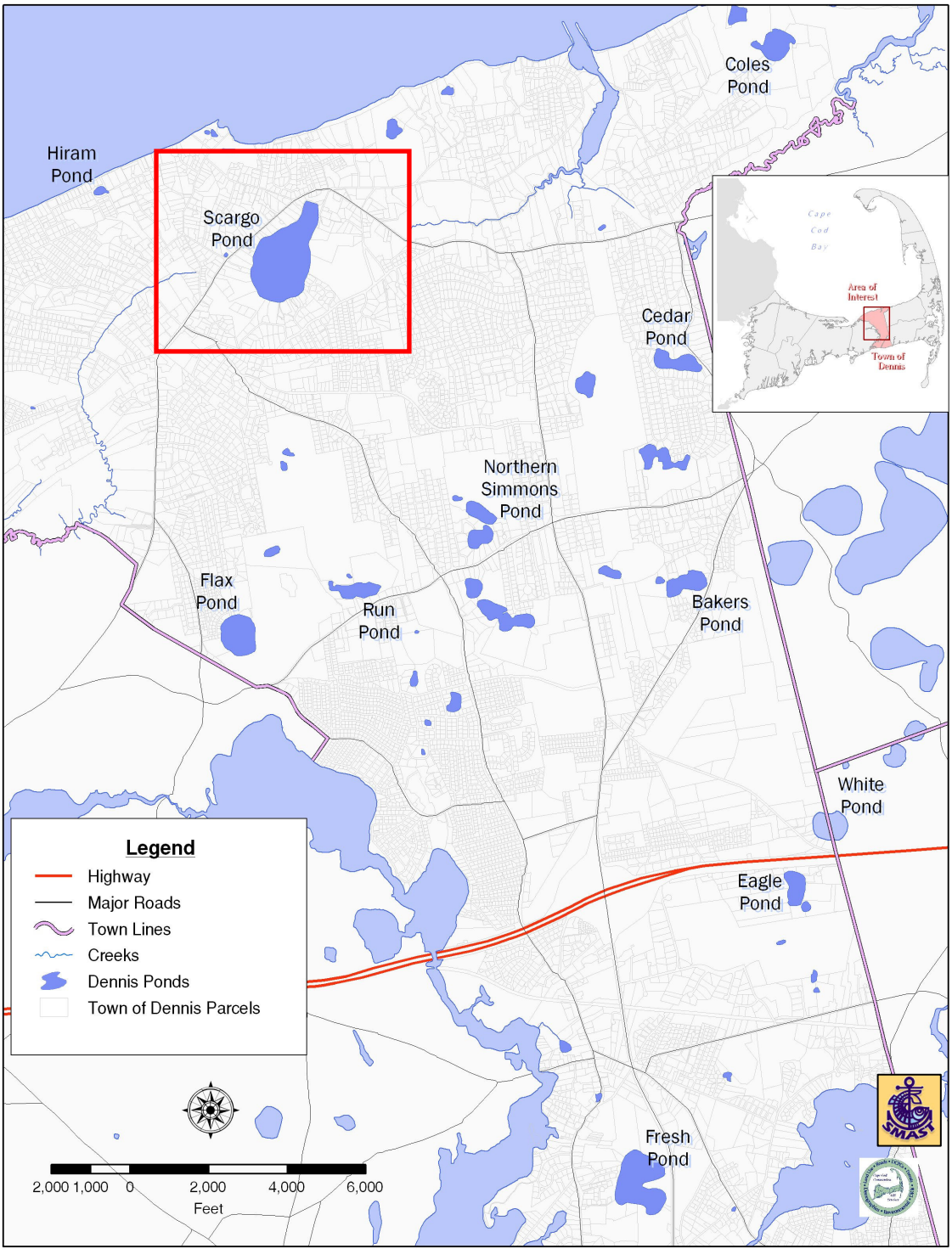

Figure I-1. Location of Scargo Lake in the Town of Dennis, MA

The Town of Dennis has a total of 57 ponds, of which Scargo Lake (red box) is the largest and the deepest (Eichner and others, 2003). This figure is adapted from Eichner (2009) and the named ponds are those that are regularly sampled by town volunteers and the Dennis Water Quality Advisory Committee.

II. Scargo Lake Bathymetry and Water Budget

A lake water budget accounts for the water entering and leaving the lake. Knowing the volume of the lake, the watershed area, and streamflows of water entering or leaving the lake, the flux of water can be used to calculate a residence time or the time that an average volume of water remains in the lake. The water budget is also used to provide some insight into how long nutrients or pollutants remain in the lake.

In order to refine the volume of Scargo Lake, CSP/SMAST staff completed the bathymetric survey on June 28, 2011 (Eichner and Howes, 2012). Depth readings were sufficient to produce bathymetric contours of 5-ft intervals (**Figure II-1**). This contour density is an improvement over the 10-ft contour intervals previously available on the historic MADFW bathymetric map. The survey was completed using a differential GPS for positioning mounted on a boat with a survey-grade fathometer.

Total volume for Scargo Lake based on the new contours is 1,563,037 m3, which is 8% larger than the volume based upon the historic MADFW bathymetric map. This result should not be surprising given that the CSP/SMAST bathymetric survey identified deeper holes north of the main basin that were not identified in the MADFW bathymetric map. The larger volume increased the average depth of Scargo Lake from 6.0 m (19.7 ft) to 6.5 m (21.2 ft).

In order to understand the watershed to Scargo Lake, it is important to understand its hydrogeologic setting. Scargo Lake is located in an area of Lake Deposits and Dennis Ice-Contact Deposits (**Figure II-2**). Most of the southern shore of Scargo Lake abuts the Ice-Contact Deposits, which accumulated at the face of the continental ice sheet during the Laurentide glacial stage (Oldale, 1992). These materials tend to be coarse sand and gravel with mixes of silt, clay, and till. The Lake itself is situated in Lake Deposits, which are the younger, and accumulated when the continental ice sheet was located in a relative stable location in Cape Cod Bay and a lake formed south of the ice sheet. The lake trapped sediments flowing off the face of the ice sheet. These materials tend to be fine sediments and clays.

The watershed to Scargo Lake includes both geologic deposits plus portions of the Harwich Outwash Plain Deposits. This watershed was recently delineated by the US Geological Survey (USGS) using their regional groundwater model of the Monomoy Lens (Walter and Whealan, 2005). The delineation was completed as part of the Massachusetts Estuaries Project (MEP) and will be included in the Sesuit Harbor MEP report (Howes, *et al.*, in preparation).

Watershed water entering Cape Cod kettle ponds enters the pond along the upgradient shoreline and generally discharges back to the groundwater system along the downgradient shoreline (Walter and others, 2002). If there is a stream entering or leaving the pond, it can act as a path of least resistance and will focus groundwater into the pond or pond water discharging out of the pond into the stream. There are no streams entering Scargo Lake, but there is a stream discharging from the lake along the northeastern edge that ultimately flows to Sesuit Harbor. The Sesuit Harbor MEP report includes monitoring of this stream and shows that the stream drains off ~40% of the watershed flow that enters the lake, which means that the remainder of the watershed flow re-enters the groundwater along the downgradient (northern) shoreline of the lake.

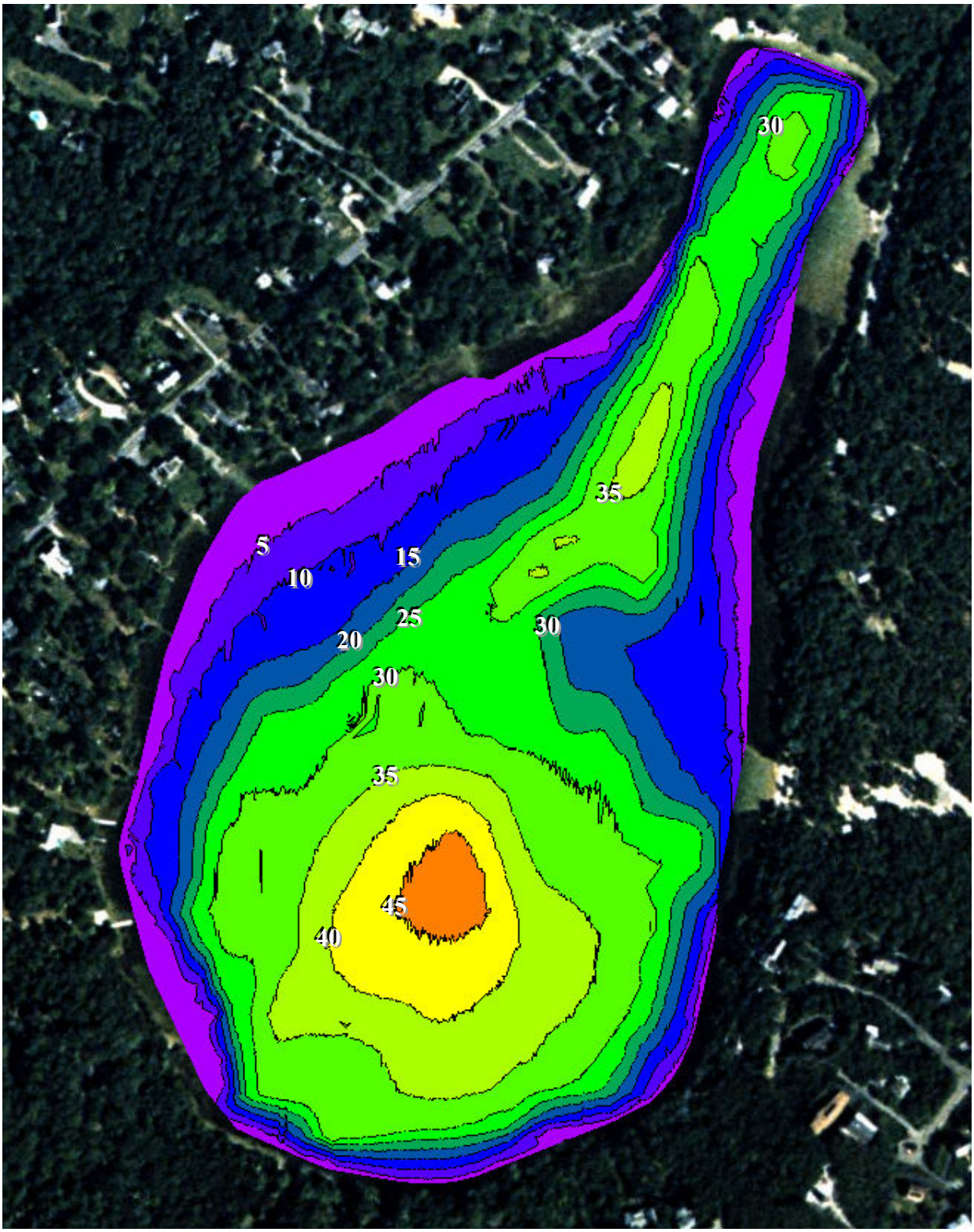

Figure II-1. Scargo Lake Bathymetry

Bathymetry developed by SMAST/CSP personnel on June 28, 2011 using a differential GPS for positioning mounted on a boat with a survey-grade fathometer. Total volume is 1,563,037 m3, which is 8% larger than the volume based upon the historic MADFW bathymetric map.

Collectively, the watershed and flow information provides the basis for a water budget for Scargo Lake. A pond water budget summarizes all the water inputs and outputs. 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 temporarily 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). **Table II-1** shows the Scargo Lake water budget, which can be represented as:

$$Groundwater_{in} + Precipitation = Groundwater_{out} + streamflow_{out} + evaporation$$

Table II-1. Scargo Lake Water Budget					
	Groundwater	Water Surface Precipitation	Water Surface Evaporation	Streamflow	TOTAL
	m3/yr	m3/yr	m3/yr	m3/yr	m3/yr
Water In	553,306	272,226			825,532
Water Out	320,495		174,347	330,690	825,532
Balance	+ 232,811	+272,226	-174,347	-330,690	0

This water budget is an update on the budget included in Eichner (2009) due to information developed during this project. The 2009 budget included water inputs from projected runoff from roads within a 300 ft buffer along the downgradient side of the lake and did not include the stream outflow information. The stormwater evaluation completed under this project showed that the only significant stormwater input along the downgradient side of the lake is the Scargo Lake boat ramp off Route 6A (**see Section XXX**). Further, staff observations during a significant storm event showed that there was little or no flow from Route 6A on to the boat ramp; the runoff was generated within the boat ramp. For this reason, the road runoff on the downgradient side of Scargo Lake is excluded from the revised water budget completed for this project. The MEP streamflow information was developed following the release of the 2009 budget, but is also included here.

Once the water budget is completed, this information can be combined with the volume information to develop a water residence time. A residence time is the average length of time a given volume of water remains in the lake and is important for understanding the water quality data. Eichner (2009) reported a residence time of 2.2 years. With the revision in this report to the pond volume and the clarification in the streamflow, the residence time of water in Scargo Lake is 2.4 years.

III. Scargo Lake Water Quality Data and Review

In 2001, Dennis volunteers were trained using the Cape Cod Pond and Lake Stewards (PALS) sampling protocol and sampled 11 Dennis ponds. This same sampling protocol, including both field data collection and water quality samples, has been used by sampling volunteers for each subsequent PALS Snapshot through 2011 with data collection in Scargo Lake generally in August. Non-Snapshot sampling has sometimes followed the PALS protocol, but on occasion has been limited to only field data collection or collection of water samples as more limited number of depths. Very refined sampling of Scargo Lake was completed by SMAST staff for this project during 2010 with water samples generally collected at each meter of depth. All Scargo Lake PALS Snapshot water quality samples and non-Snapshot samples in 2007, 2008, 2010, and 2011 have been analyzed by the Coastal Systems Program Laboratory, School for Marine Science and Technology (SMAST), University of Massachusetts Dartmouth. **Table III-1** shows the frequency of field data collection in Scargo Lake between 2001 and 2011. Most of the water quality samples collected from Scargo Lake have been collected in August and September with most of these related to PALS sampling.

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 and Dennis samples analyzed at the SMAST lab, 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 III-2**. Two sampling runs in 2002 and six during the summer of 2003 were analyzed at the North Atlantic Coastal Laboratory at Cape Cod National Seashore (CCNS); CCNS lab procedures are listed in **Table III-3**. The September, October, and November 2010 water quality sampling runs completed by SMAST staff included water quality samples collected at 1 m increments.

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 (every meter) of dissolved oxygen and temperature, Secchi disk transparency, and a measure of station depth. The PALS Snapshots have been supported by free laboratory analyses from the SMAST Coastal Systems Analytical Facility Laboratory for 11 years and are coordinated in conjunction with the Cape Cod Commission.

Table III-1. Data collection frequency for Scargo Lake (2001-2011)												
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2001									X			
2002							X				X	
2003					X	X	X	X	X	X	X	
2004					X	X	X	X	X	X		
2005					X	X	X	X	X	X		
2006						X	X		X	X		
2007				X	X	X	X	X	X	X		
2008				X	X	X	X	X	X	X		
2009								X				
2010				X				X	X	X	X	
2011				X				X				
KEY	X	Complete PALS protocol followed, including water quality samples collected at surface (0.5 m, 3 m, 9 m, and 1 m off the bottom), field data collection of dissolved oxygen and temperature profiles (1 m increments) and Secchi transparency, and samples analyzed for total nitrogen, total phosphorus, chlorophyll-*a*, pH, and alkalinity and											
	X	Lab samples & field data collected (only surface and deep samples collected)										
	X	Some field data collected										

Note: Laboratory analyses were completed by 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).

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

Table III-3. Laboratory methods and detection limits for pond water samples analyzed by the Cape Cod National Seashore lab.

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

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

III.A. 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, like Scargo Lake, 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.

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, with descriptive standards for general water quality

conditions. Under the numeric standards in these regulations, deep ponds, like Scargo Lake that are not drinking water supplies are required to have a dissolved oxygen concentration of not less than 6.0 mg/l (or 6 ppm). These regulations also require that deep lakes have temperatures that do not exceed 68^0F (20^0C). 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).

Scargo Lake has had 44 temperature and dissolved oxygen profiles collected since 2001. All of these profiles occurred between April and November with between 3 (November) and 8 (August) monthly profiles. Average temperature readings show a typical seasonal pattern of deep lakes with fairly consistent water column temperatures in April, increasingly warm surface temperatures as the summer progresses and a gradual return to fairly consistent water column temperatures in November (**Figure III-1**). July and August temperatures have the greatest differences between surface and bottom temperatures consistent with summer stratification or layering with warm surface waters covering cold bottom waters. Maximum summer surface temperature in the available data was 27.9°C (6/23/08), while the lowest summer bottom temperature was 8.6°C (6/16/06 @ 13 m). As would be expected, surface temperatures have the widest range (27.9 to 9.6°C @ 0.5 m), while the range of deep temperatures is more limited (12.4 to 7.4 °C @ 13.5 m).

Average dissolved oxygen concentrations show an impact of sediment oxygen demand throughout the April to November timeframe with the greatest demand in August and September (**Figure III-2**). As the summer progresses, surface dissolved oxygen concentrations decrease as temperatures increases; average April surface dissolved oxygen concentration is 11 mg/L, while average August concentration is 7.2 mg/L. Average dissolved oxygen concentrations less than the state 6 mg/L regulatory limit are the shallowest in August (7 m depth); this depth means the entire hypolimnion (or the cold water fishery) is below the state 6 mg/L standard. At this depth, it also means that low oxygen conditions and higher phosphorus concentrations that typically accompany them are regularly bleeding through into the warmer upper layers. From May to September for the 11 year period between 2001 and 2011, 100% of the dissolved oxygen concentrations at 10 meters and deeper are less than the 6 mg/L state standard with 100% of the concentrations at 8 meters, or to the top of hypolimnion, less than the standard in August.

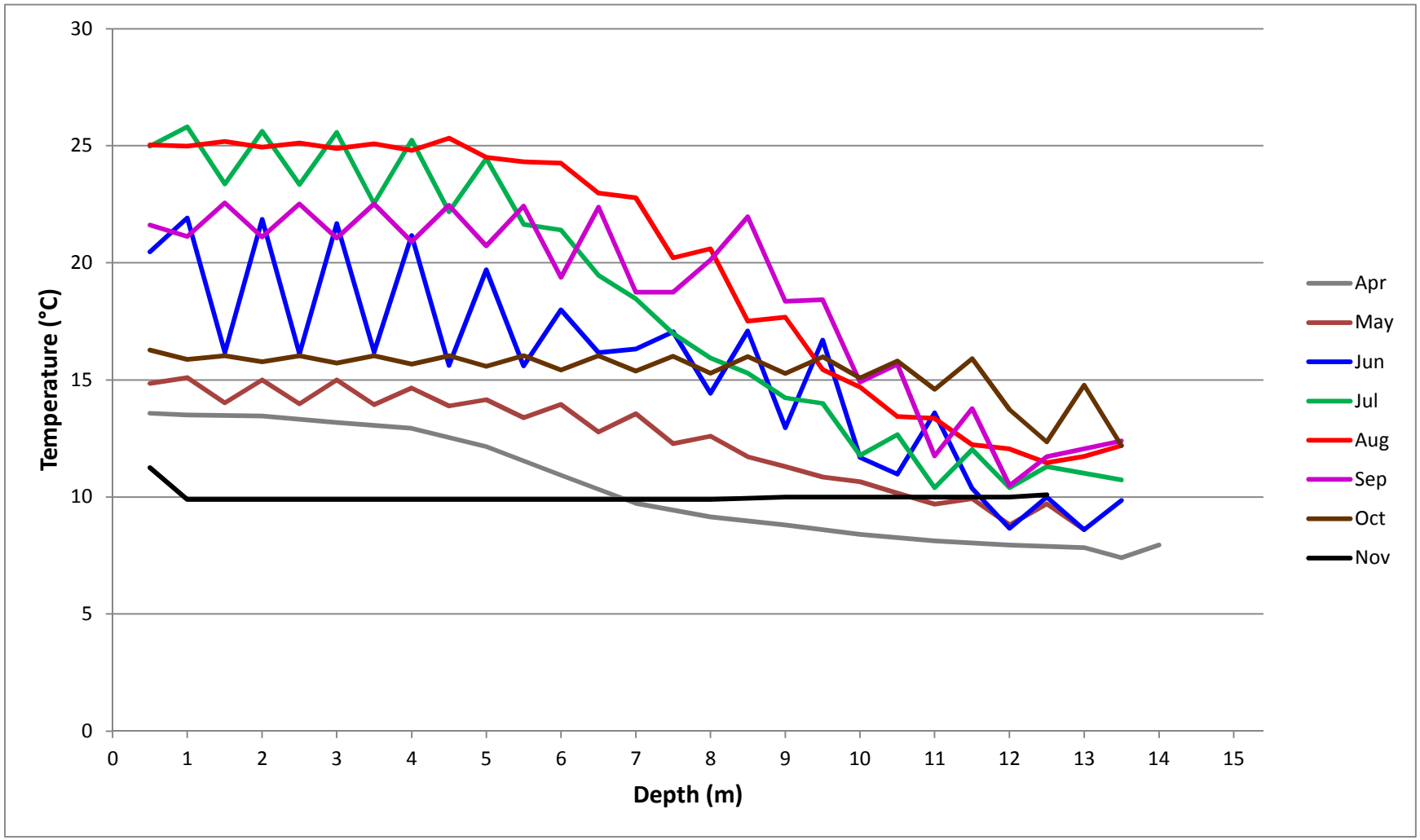


Figure III-1. Scargo Lake Average Monthly Temperature Profiles

Profiles are based on readings collected between 2001 and 2011. Average April readings show initial warming of upper waters followed by more warming in each subsequent month until September when temperatures cool from August eventually returning to the same temperature throughout the water column in November. Surface temperatures vary from 11 to 25°C, while bottom temperatures vary from 7.7 to 12.2°C.

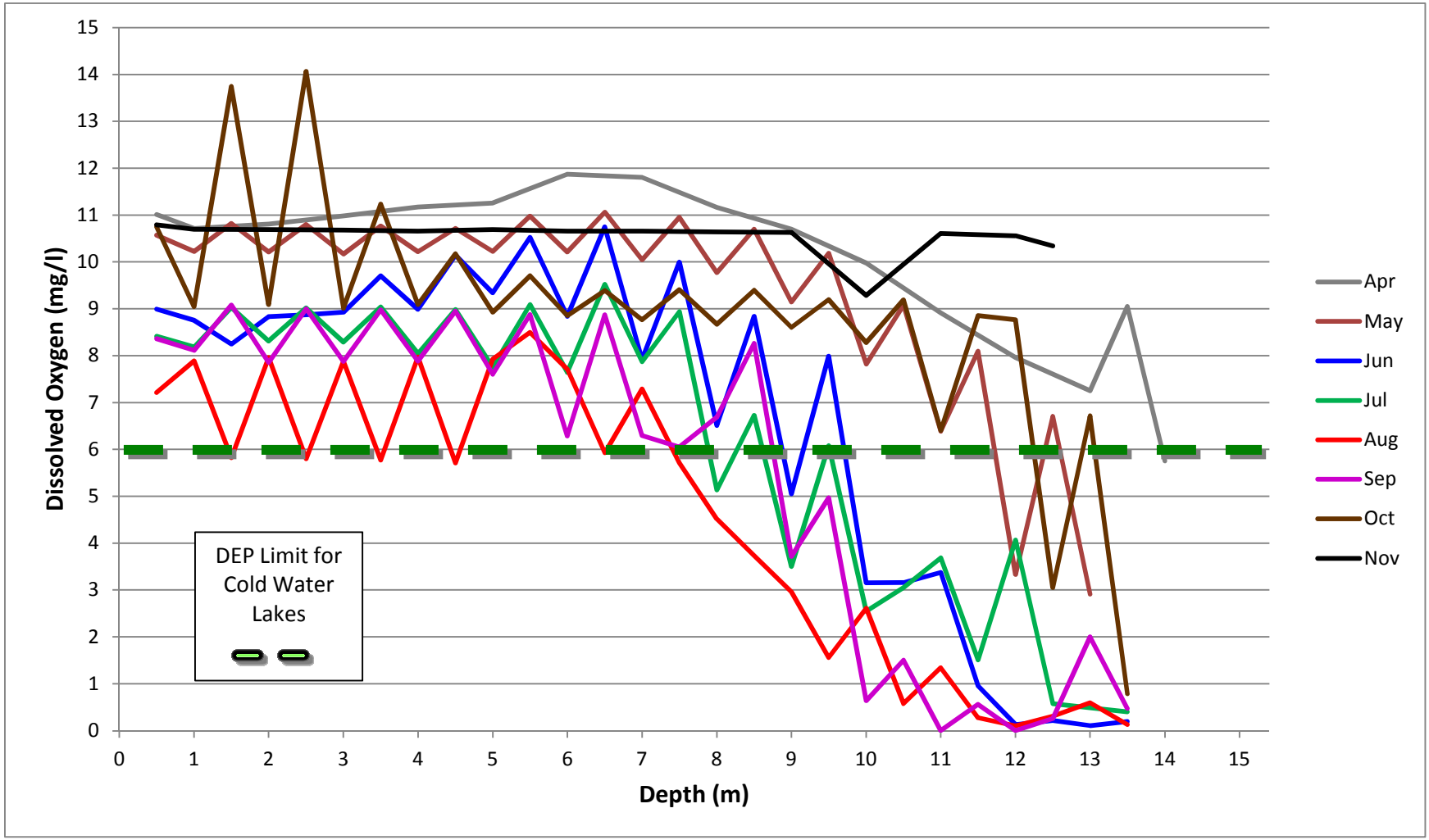


Figure III-2. Scargo Lake Average Monthly Dissolved Oxygen Profiles

Profiles are based on readings collected between 2001 and 2011. Average April readings show initial sediment oxygen demand reducing oxygen concentrations in the near-sediment waters. These conditions worsen and rise higher in the water column in each subsequent month, leading to anoxia in bottom waters beginning in June and persisting through September. The breakdown of stratification in October gradually resupplies oxygen to the deeper waters and leads to well-mixed conditions in November.

The majority of phosphorus release from sediments occurs when anoxic conditions are establish (DO<1 ppm) and the iron materials binding phosphorus are solubilized freeing inorganic phosphorus. Based on the available data, anoxic conditions do not occur in April, occur rarely in May, are relatively consistent below 11 m in June and July, are consistent below 10 m in August with occasional rises to 9 m, somewhat similar in September but with more fluctuations, back down to 12 m in October, and no occurrences in November. This pattern means that there is usually water with residual oxygen between the bottom of the epilimnion at 9 m and the anoxic, high phosphorus water below. On occasion, though, the anoxia reaches the epilimnion and would allow the transfer of phosphorus to the more productive upper waters.

III.B. Secchi Depth/Transparency

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" or 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).

Scargo Lake always meets the safe swimming clarity standard throughout the 2001 to 2011 monitoring period; the minimum clarity recorded over 29 readings is 3 meters or 9.8 ft. Average monthly readings peak in May and decline through the summer and into October (**Figure III-3**). May and September have the greatest variability in readings, which is consistent with the temperature transitions into and out of summer months, respectively, that are seen during these months. The decreasing clarity matches the increase in phosphorus concentrations measured between April and August/September.

III.C. Phosphorus

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). 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.

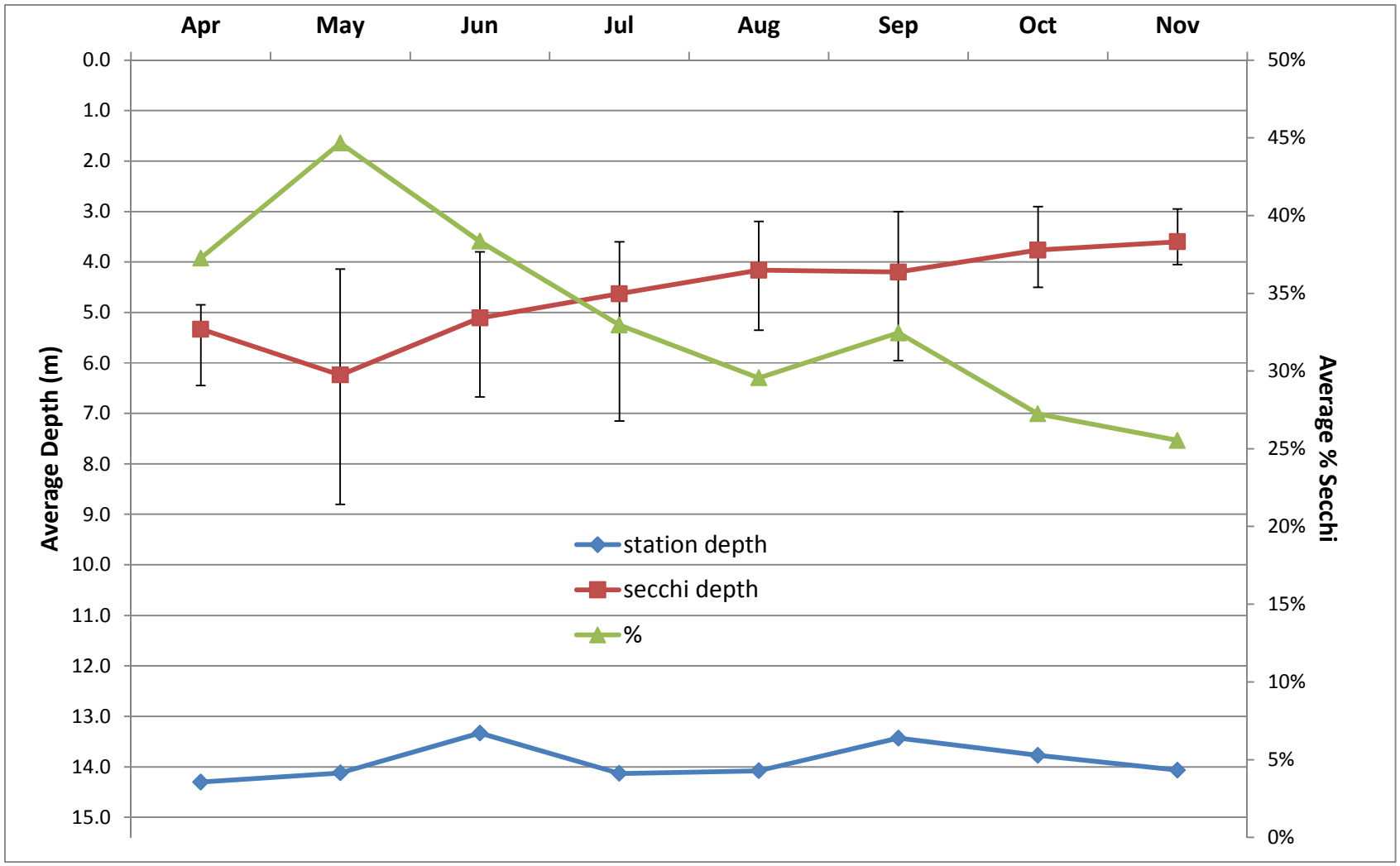


Figure III-3. Scargo Lake Average Monthly Secchi Clarity

48 Secchi readings were collected between 2001 and 2011. The red line shows the average monthly Secchi depth reading, while the blue line shows the average station depth. The green line shows the average % of the water column that is clear; this reading and the average Secchi depth peaks in May then declines throughout the rest of the dataset until November. Review of all Secchi readings show no trend over the dataset.

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 current 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 was 16 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 µg/l, while "unimpacted" ponds should have a surface TP concentration no higher than 7.5 µg/l (Eichner and others, 2003). Use of this EPA method suggests that healthy freshwater pond ecosystems on Cape Cod should have average TP concentrations between 7.5 to 10 µg/l.

Average late summer surface TP concentrations in Scargo Lake are 11.3 µg/l (August and September), while the deepest sampling station averages 22.9 µg/l. This difference is consistent with low dissolved oxygen creating conditions favoring phosphorus regeneration from the sediments. Average concentrations at 3 and 9 m depths are similar to the surface water averages (9.3 and 10.3 µg/l, respectively), which means that, on average, summer conditions do not allow regenerated TP from the deepest sediments to significantly impact the upper waters although low oxygen waters do occasionally reach the 9 m depth. These concentrations are consistent with the oxygen profile readings, which generally show at least residual oxygen in water between the anoxic bottom waters and the warmer epilimnion. April average concentrations are not statistically different from those in summer except for the deepest samples, which are significantly higher in late summer ($\rho<0.06$). **Figure III-4** shows the average TP concentrations at the standard PALS sampling depths in April, August, September, and October; all other months have two samples or less.

III. D. Nitrogen

Nitrogen is one of the primary nutrients that prompt plant growth in surface water systems (phosphorus and potassium being the other two), but is usually not the limiting nutrient or nutrient controller of biomass production in freshwater lakes. 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.

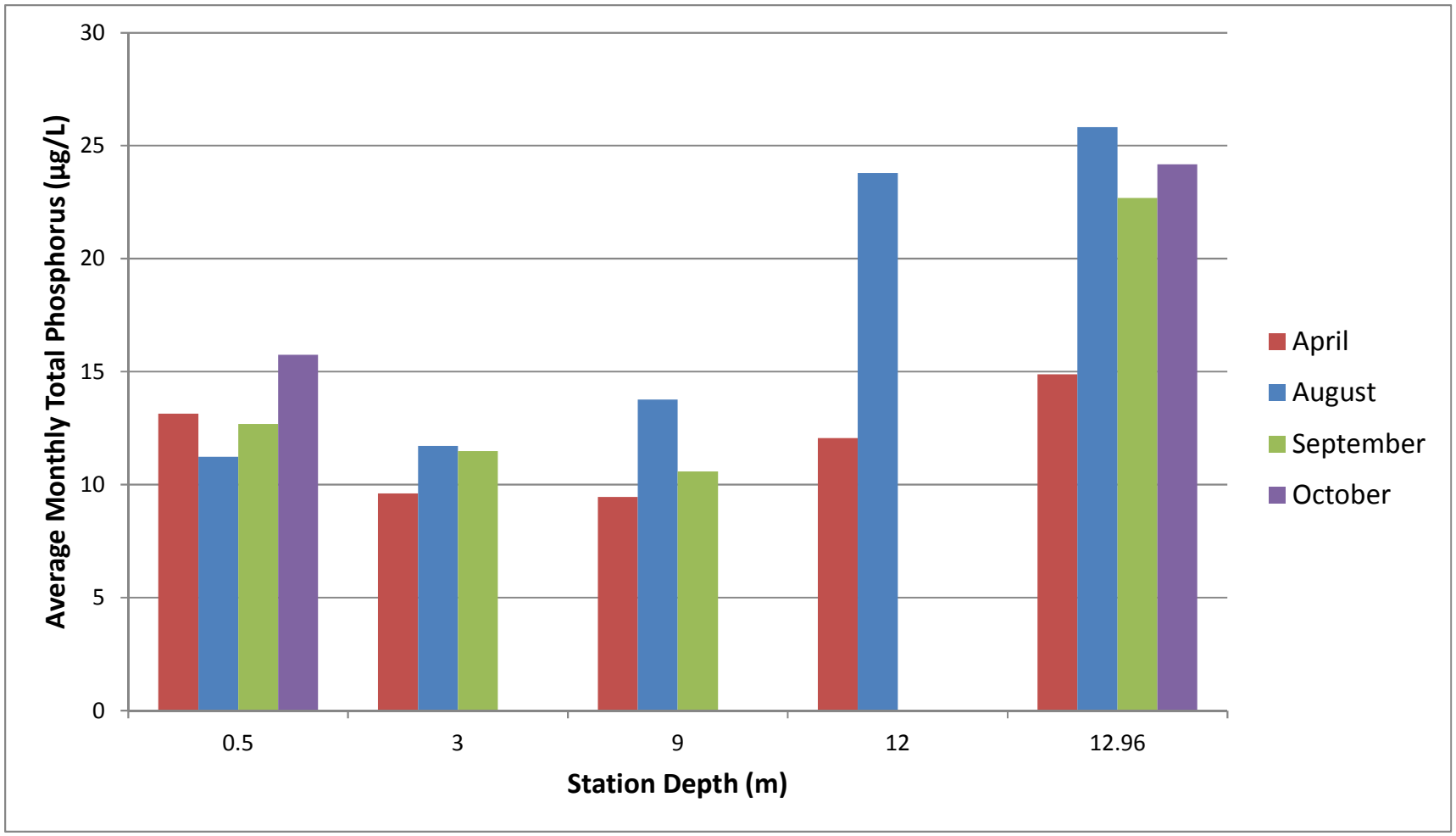


Figure III-4. Scargo Lake Average Monthly Total Phosphorus

Readings are shown for April, August, September and October. Average concentrations at 0.5, 3, and 9 m depths are relatively consistent in all months. Deeper readings increase during August and are generally sustained through October. All summer averages are greater than the 7.5 to 10 µg/L limit recommended for Cape Cod ponds (Eichner and others, 2003). Station depths are based on standard PALS protocols; the deepest reading is based on the overall average depth of one meter off the bottom. All averages are based on a minimum of two readings. April averages are based on 2-3 readings, while August and September averages are based on 3-7 readings. October readings at the 0.5 m and 12.96 m depths are based on 3 readings.

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 one foot per day.

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).

August and September averages show that average summer surface TN concentrations in Scargo Lake are 0.33 mg/l, while the deepest sampling station averages 0.96 mg/l. Average concentrations at 3 and 9 m depths are similar to the surface water averages (0.36 and 0.37 mg/l, respectively). These concentration differences are consistent with low dissolved oxygen creating conditions favoring nitrogen regeneration from the sediments and are consistent with the pattern seen in the TP readings that show that the high concentrations in the deep water do not seem to be impacting the upper, shallow waters. Samples in April at not statistically different from those in August/September except for the deepest samples, which are significantly higher in August/September ($\rho<0.07$). **Figure III-5** shows the average TN concentrations at the standard PALS sampling depths in April, August, September, and October; all other months have two samples or less.

III.E. 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, either through natural groundwater or river inputs from carbonate rich watershed or through photosynthetic activity. Photosynthesis is one of the primary ways pH increases in surface waters; 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 have 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

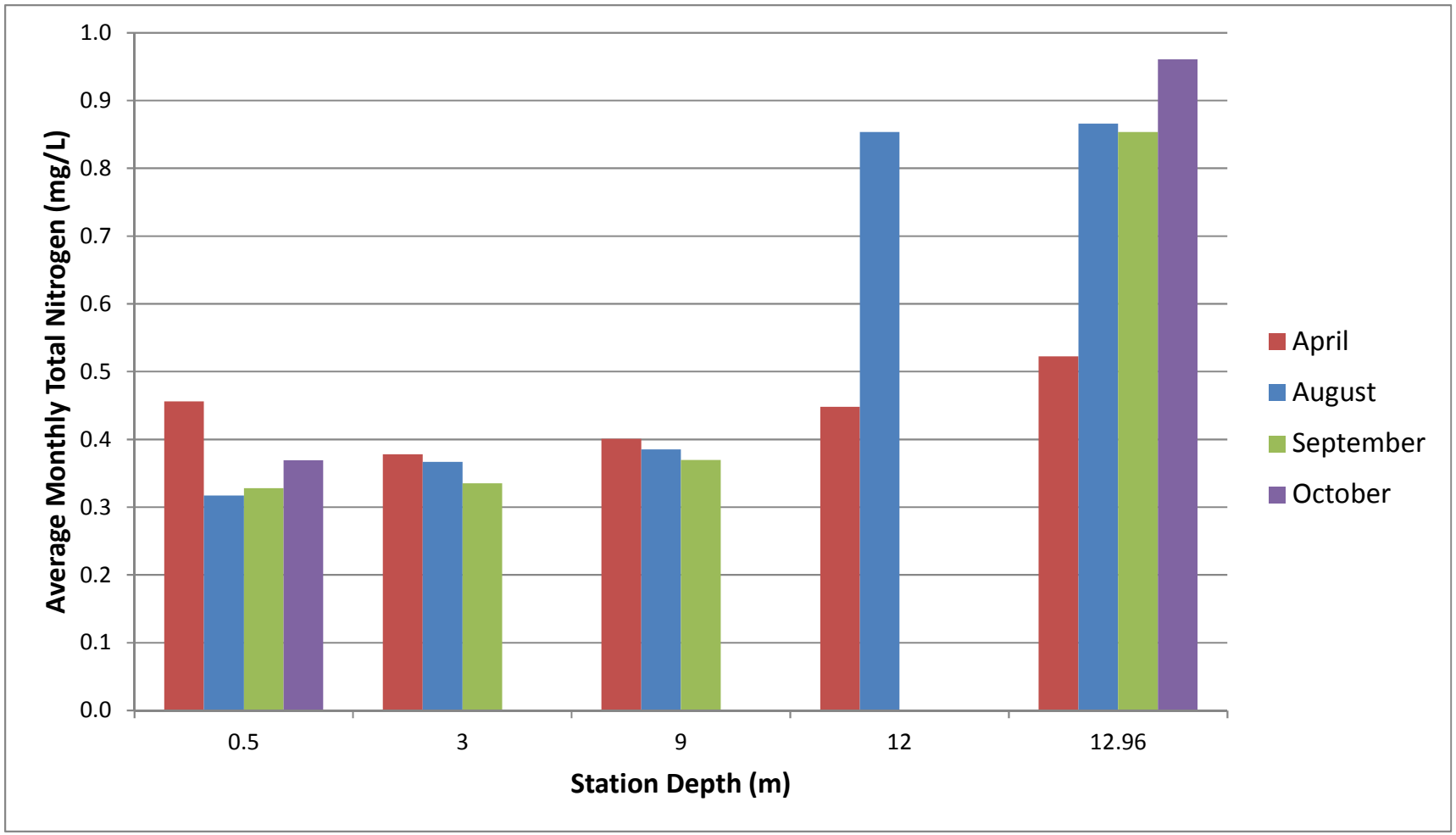


Figure III-5. Scargo Lake Average Monthly Total Nitrogen

Readings are shown for April, August, September and October. Average concentrations at 0.5, 3, and 9 m depths are relatively consistent in all months. Deeper readings increase during August and are generally sustained through October. All summer averages are greater than the 0.16 to 0.31 mg/L limit recommended for Cape Cod ponds (Eichner and others, 2003). Station depths are based on standard PALS protocols; the deepest reading is based on the overall average depth of one meter off the bottom. All averages are based on a minimum of two readings. April averages are based on 2-3 readings, while August and September averages are based on 3-7 readings. October readings at the 0.5 m and 12.96 m depths are based on 3 readings.

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 with ponds least impacted by development having pH's closest to the low rain pH. 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 mg/L (Eichner and others, 2003). The lower 25th percentile among pH readings from the 2001 Snapshot, or the least impacted ponds, is 5.62.

Scargo Lake has average summer pH readings generally around 6 with lower pH readings in April and the highest generally in August, when the phytoplankton population would be most active. During a given month, pH readings are generally higher in shallower waters than in the deeper ones, again consistent with where most of the phytoplankton populations would be concentrated. Scargo had the highest average surface pH concentrations among the 11 pond regularly sampled by the Town of Dennis (Eichner, 2009). The pH readings are generally below the state water quality standard limit of 6.5 (310CMR4.05(3)(b.)3), but these are mostly natural conditions except for the summer increases due to phosphorus additions. Alkalinity concentrations were only generally done with PALS Snapshot samples, so most of the readings occurred in August or September. Average August/September surface alkalinity in Scargo Lake was 10.4 mg/L $CaCO_3$ with an increase to 20.5 mg/L in the deepest station. These alkalinity readings are also consistent with the low oxygen conditions and sediment regeneration of chemical constituents.

III.F. Chlorophyll-*a* and Phaeophytin

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* is a specific pigment in the chlorophyll family and plays a primary role in photosynthesis (USEPA, 2000). Phaeophytin is a breakdown product of the chlorophyll molecule, which is usually indicative of phytoplankton degradation.

Because phosphorus, the limiting nutrient in most Cape Cod ponds, is needed for growth by both microscopic 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 macrophytes are the dominant plant community. 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 Pond 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 chlorophyll-*a* concentrations determined (Eichner, *et al.*, 2003). The average concentration of these samples was 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 chlorophyll-*a* threshold concentration of 1.0 ppb and "healthy" Cape Cod ponds would have a threshold concentration of 1.7 ppb. Review of the 11 Dennis ponds monitoring data found that only one pond (Bakers) had average surface chlorophyll-*a* concentrations less than the 1.7 ppb regional limit (Eichner, 2009).

Scargo Lake has an average summer surface chlorophyll-*a* concentration of 3.6 ppb (**Figure III-6**). Chlorophyll-*a* concentrations were only generally done with PALS Snapshot samples, so most of the readings occurred during the most biologically active period in August or September. However, the Town has collected April samplings since 2008 and these show statistically significant increase in surface summer chlorophyll-*a* concentrations; average concentrations at 0.5 m, 3 m, and 9 m are all significantly higher in August/September compared to April. The deep station, however, as expected by the light limitations at that depth, do not show a significant increase. These concentrations are consistent with an addition of phosphorus during the summer, but the depth profile and the TP, TN, and DO readings suggest that the addition is not from the hypolimnion. All summer averages are greater than the 1.0 to 1.7 µg/L limit recommended for Cape Cod ponds (Eichner and others, 2003).

The average summer chlorophyll concentrations also show a maximum average concentration at 9 m (7.4 ppb). This concentration is more than twice the average concentrations at 0.5 and 3 m and is consistent with phytoplankton utilizing higher phosphorus concentrations in the deeper, hypoxic waters.

Phaeophytin concentrations are generally low in upper waters; they average 23%, 29%, and 33% of August/September chlorophyll concentrations at 0.5 m, 3 m, and 9 m, respectively. But at the deepest station, nearest the sediments, the relationship reverses and the average summer phaeophytin is nearly 8X the chlorophyll concentration (see **Figure III-6**). These readings would be consistent with degrading phytoplankton settling to the bottom sediments; it is also an expression of how lakes capture and retain nutrients and carbon.

Comparison of the two pigment concentrations is also notable for differences in seasonal ratios. In April, average chlorophyll concentrations are 25X phaeophytin concentrations in the surface waters (0.5 m and 3 m), 5X concentrations at 9 m, and approximately the same at the deepest station (1.2X). In August/September, the average chlorophyll-*a* concentration at 9 m is 34X the phaeophytin concentration and the deepest station has decreased to 0.1X. These readings reinforce the seasonal stratification structure of the lake water column and how the deepest waters are capturing the nutrients and carbon in dying phytoplankton.

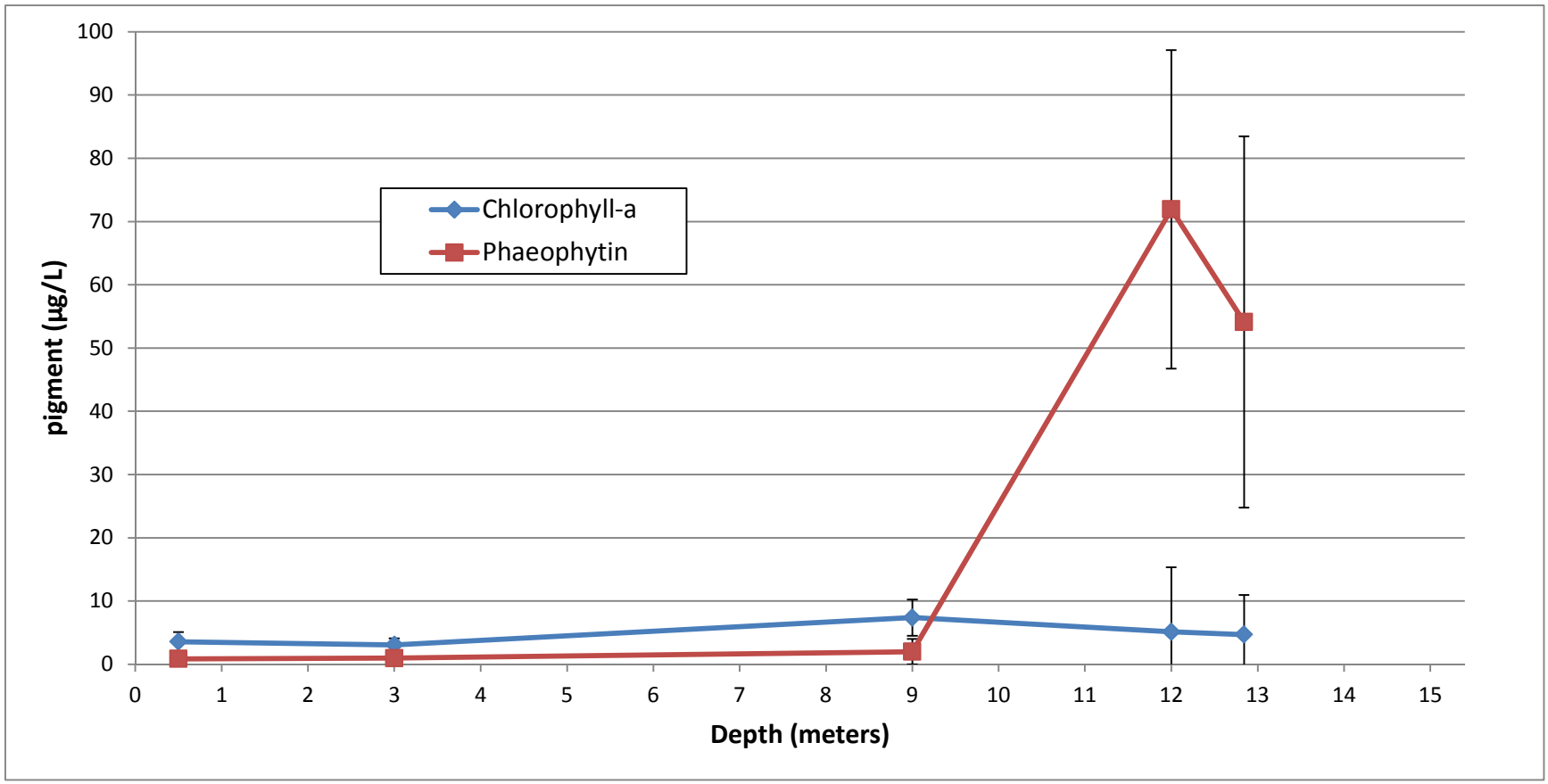


Figure III-6. Scargo Lake Average August/September Pigment Concentrations

Average chlorophyll-a and phaeophytin concentrations are shown at each of the depths based on standard PALS protocols; the deepest reading is based on the overall average depth of one meter off the bottom. Chlorophyll-a concentrations average 3.6 µg/L, 3.1 µg/L, 7.4 µg/L, 5.1 µg/L, and 4.7 µg/L at the respective depths. The doubling of the average at 9 m is thought to be due to phytoplankton utilizing higher phosphorus concentrations near the top of the hypolimnion; however, no accompanying indication of higher TP concentrations is seen in the phosphorus data. The increase with phaeophytin is likely due to settling of degrading phytoplankton. All summer chlorophyll-a averages are greater than the 1.0 to 1.7 µg/L limit recommended for Cape Cod ponds (Eichner and others, 2003).

IV. Other Key Ecosystem Functions/Measures

IV.A. Scargo Lake Bird Population Survey

As part of the overall project to clarify and prioritize future water quality management strategies for Scargo Lake, CSP/SMAST staff developed a Scargo Lake Bird Population Survey. This effort included developing a survey strategy, conducting the survey for approximately one year, and using the survey results to develop a Scargo Lake-specific phosphorus load for birds (Eichner and Howes, 2012). The survey was completed using volunteer bird counters and was undertaken based on the recommendation in Eichner (2009) that direct measurement of Scargo Lake-specific factors would help to target strategies in ways that would actually benefit Scargo Lake.

In order to complete the Scargo Lake Bird Population Survey, project staff divided the lake into quadrants. Volunteers were asked identify the bird species (by common name) within each quadrant, count the number of birds for each species, and note whether they were greater than or less than 20 feet from the shore. Counts were to occur at least every two weeks. The volunteer team of John Harper and Cliff Adams began counting on October 10, 2010 and conducted 54 counts before completing the counting on September 30, 2011.

The average number of birds on the lake was 34 with a range of 0 to 167 birds. October and January averaged the highest number of birds (~70), while February to June generally averaged between 5 and 26 (**Figure IV-1**). Overall, Mallards (*Anas platyrhynchos*) are the most frequent birds (55%) on the lake with Herring Gulls (*Larus smithsonianus*) as the next most frequent (33%). Mallards and Herring Gulls collectively average 85% of the counted birds on a monthly basis. Review of the spatial distribution shows that most of the birds (65%) are in Quadrants 3 and 4, which is the shallower end of the lake. Birds also preferred staying away from the shoreline, with 58% being more than 20 feet from the lake shore. Generally, Mallards were within 20 feet of the shore, while Herring Gulls were more than 20 ft from the shore, but there are a couple of occasions where large Mallard counts were recorded in deeper waters.

Scherer and others (1995) conducted a highly detailed bird count and phosphorus loading estimate for a large lake in the state of Washington. This study also provides a review of net phosphorus contributions by a number species including Mallards and Gulls. In the study, the authors detail the weight of species-specific bird droppings, their total phosphorus content, the likely probability that droppings will enter the lake, and the percentage of phosphorus that is new phosphorus rather than recycled phosphorus already in the lake for 11 species or functional groups of species. Using these factors, SMAST staff determined the bird phosphorus load on each day birds were counted. These loads were then averaged and a net annual Scargo Lake-specific phosphorus load of 0.57 kg from birds was determined.

IV.B. Scargo Lake Stormwater Survey

As part of the overall project to clarify and prioritize future water quality management strategies, CSP/SMAST staff completed a Scargo Lake Stormwater Survey. This effort identified the primary direct stormwater discharge locations around the lake and sampled the four locations during three storm events (Eichner and Howes, 2012). This effort was undertaken based on the recommendation in Eichner (2009) that direct stormwater runoff to the lake was largely unquantified and detailing Scargo Lake-specific measurements would help to target

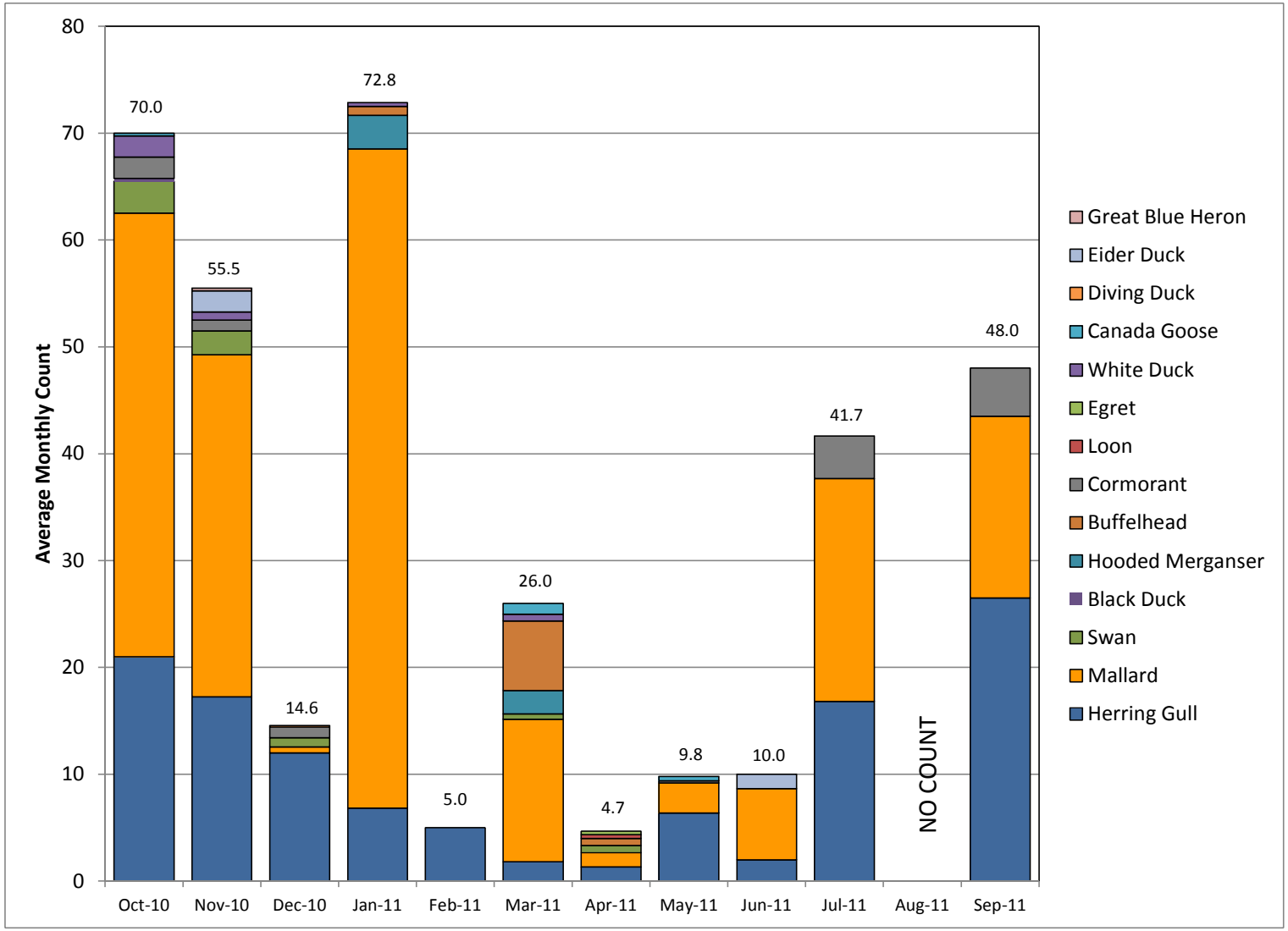


Figure IV-1. Average Monthly Bird Counts on Scargo Lake (October 10, 2010 and September 30, 2011).
Surveys per month ranged between 3 and 7. No readings were collected in August 2011. Overall average is 34 birds per month with a total count of 1,848 birds. Mallards and herring gulls are the most common birds observed.

strategies in ways that would actually benefit Scargo Lake. Unlike groundwater inflows, stormwater discharges can contain high concentrations of phosphorus and can have a disproportionate effect on the lake phosphorus balance.

In order to complete the Scargo Lake Stormwater Survey, project staff completed an area reconnaissance survey, traveling to locations around the lake during two storms to assess where runoff discharged into the lake. This survey found stormwater runoff into the lake from the parking lot at Scargo Beach (**Figure IV-2**) and at the boat ramp on the north side of the lake (**Figure IV-3**). This survey also identified historic runoff channels from Gretchen's Way/Erb Drive to Princess Beach; catch basins at the eastern end of Gretchen's Way have relatively new berms approximately two feet tall on their downstream side that appear to have only recently prevented runoff to the lake (**Figure IV-4**). Runoff channels through the woods to Princess Beach have debris from some of the materials currently around the catch basin indicating past flows from the road to the beach. The runoff channels also show evidence of past flows to the beach to within a few feet of the shoreline, but no evidence of direct discharge to the lake. It is possible that direct discharge channels have been obscured by regular water level fluctuations in the lake. Collectively for the survey, two runoff sampling locations were established at Scargo Beach, one at the boat ramp, and one just upstream of the catch basin on Gretchen's Way.

Project staff collected stormwater samples on the following dates during 2011: April 13, June 22, and August 15. Rain events of less than 0.25 inches in 24 hours do not typically generate sufficient stormwater flows for runoff, so staff attempted to sample only during large forecasted storms. The runoff generated by the April 13 storm was significantly larger than either of the other two storm events (**Figure IV-5**); recorded precipitation at Hyannis Airport on April 13 was 2.66 inches, while June 22 was 0.74 inches and August 15 was 1.4 inches. Due to the lack of specific discharge pipes, sample collection and volume measurements were made by channeling the runoff using sand bags to create a central point to collect water samples. Flow rates were also measured at these points Flow readings and water quality samples were collected a minimum of three times during each storm event in order to gauge intensity and provide a reliable basis for event-mean concentrations (EMC). Timing of sampling strived to capture the initial "first flush" and peak of each stormwater event, as well as a reasonable sampling of the whole event. Water samples for chemical analysis were collected into one liter polypropylene bottles using a Geo Pump, with analysis by the Coastal Systems Analytical Facility at the School of Marine Science and Technology (SMAST), University of Massachusetts Dartmouth in New Bedford. Samples were analyzed for the following constituents: total phosphorus (TP), ortho-phosphorus, total nitrogen (TN), nitrogen component species (NH4, NO3+NO2, TDN, and PON), POC, and alkalinity. Flow and EMC data were used to determine loads of TP and TN during each storm (**Figure IV-6**). The load information showed that although the April 13 storm was much larger than the other two measured storms and the loads typically followed this same pattern, there were sampling locations where greater loads were measured during the other two storms.

Figure IV-2. Scargo Beach: Scargo Lake Stormwater Sampling.
The parking lot at Scargo Beach and the driveway to the south generate stormwater that discharges directly into Scargo Lake through runoff channels eroded through the buffer strip (right-hand picture). CSP/SMAST staff temporarily focused these channels into two discharge points for sampling.

Figure IV-3. Scargo Boat Ramp: Scargo Lake Stormwater Sampling.
The boat ramp on the north side of Scargo Lake receives runoff from the upgradient roadway as well as generating stormwater from its semi-pervious surface. The combined stormwater flow creates diffuse runoff channels that discharge directly into Scargo Lake. The aerial photo from Google Earth on the left-side shows a sediment deposition delta in the lake that is likely predominantly due to boats being removed from the lake, but is also likely partially due to fine sediments deposited by stormwater runoff. CSP/SMAST staff temporarily focused the runoff channels into one discharge point for sampling.

Figure IV-4. Gretchen Way/Erb Drive/Princess Beach: Scargo Lake Stormwater Sampling.
Gretchen Way/Erb Drive slopes steeply toward Scargo Lake and the catchbasin shown in A (and by the yellow dot) collects a large portion of the road's stormwater runoff. The berms around the catchbasin appear to be relatively new (right photo with flat black stones) and adjacent woods show evidence of erosion channels that extend onto Princess Beach (blue dot and lower right photo). These runoff channels indicate that stormwater runoff historically has discharged to within feet of the Scargo Lake shoreline and likely discharged directly to lake waters. Note, shoreline channels are not visible, most likely due to reworking by waves and lake water level fluctuates, CSP/SMAST staff collected stormwater samples prior to the catch basin to assess potential past discharges to Scargo Lake from this area.

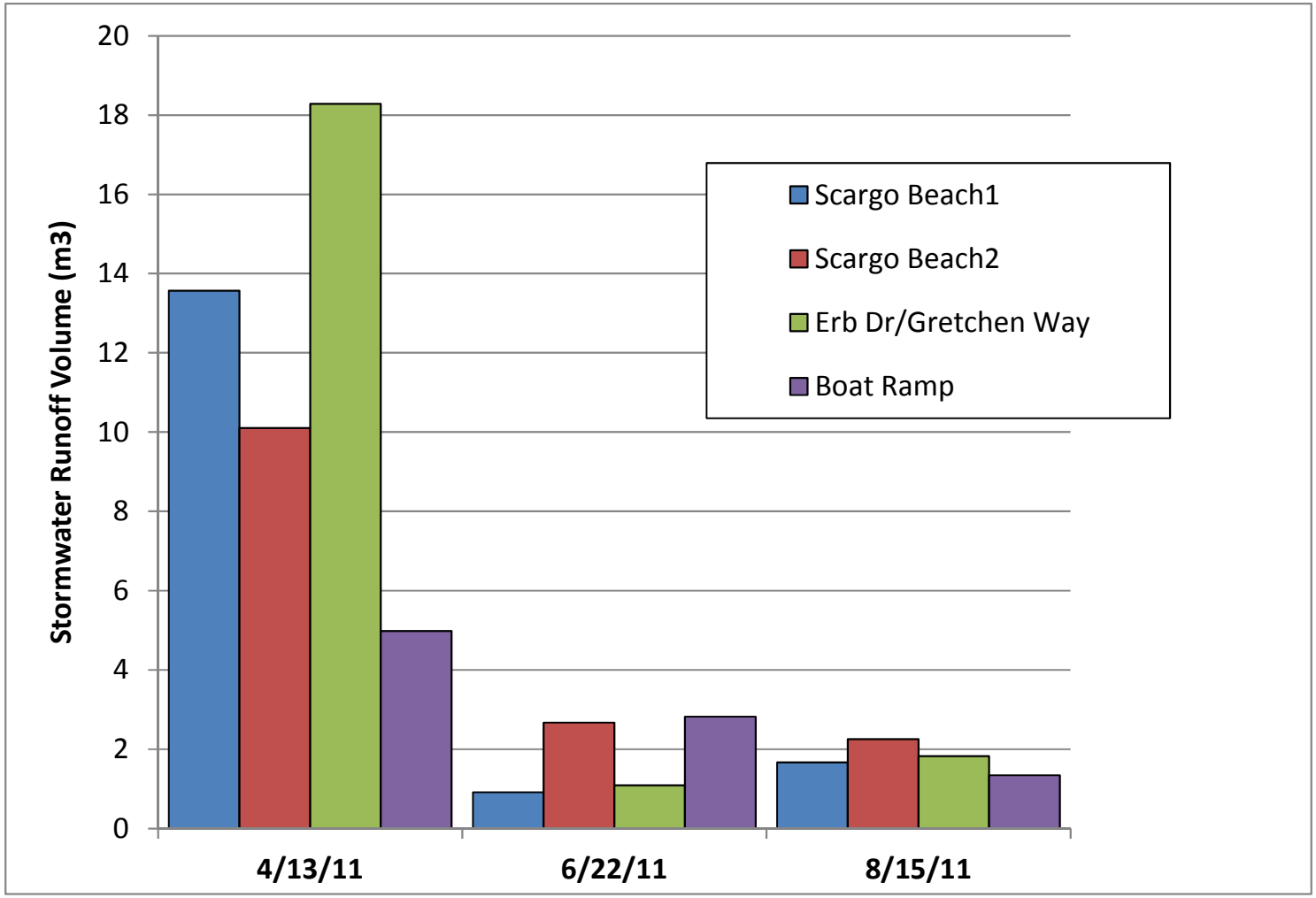


Figure IV-5. Measured 2011 Stormwater Runoff Volumes: Scargo Lake.

Runoff volumes are sum totals of each storm event. The April 13, 2011 storm generated much larger stormwater runoff volumes than either the 6/22 or 8/15 storms. According to precipitation recordings at Hyannis Airport (the closest gauge), precipitation on each of the dates was 2.66, 0.74, and 1.4 inches, respectively. Runoff volumes are based on a minimum of three readings during the course of the storm. Differences in generated volumes can be based on the catchment areas and surface materials (*e.g.*, blacktop vs. stone), as well as timing of measurements. Erb Drive flows do not reach Scargo Lake, but may have in the past.

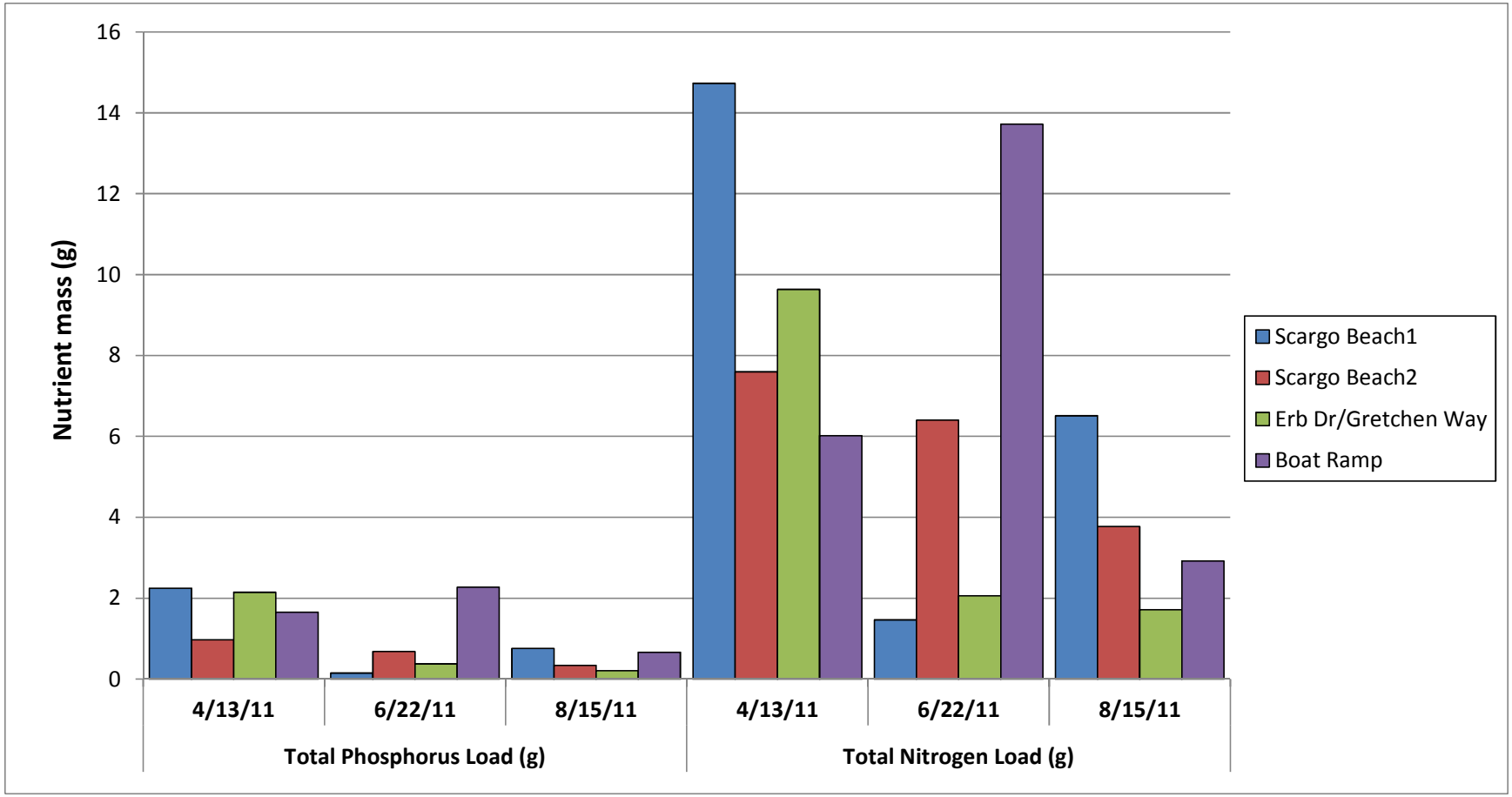


Figure IV-6. Measured Stormwater Nutrient Loads (Total Phosphorus and Total Nitrogen): 2011 Scargo Lake. Nutrient loads are sum totals of each storm event. The April 13, 2011 storm cumulatively generated more nutrient inputs to Scargo Lake than either of the other two storms, but at selected locations higher nutrient loads were measured during the other two storms. For example, a total phosphorus load of 2.3 g was measured at the Scargo Boat Ramp during the 6/22 storm, while a load of 1.6 g was recorded during the 4/13 storm. More extensive review of the stormwater data and its relationship to water quality management strategies will occur during the subsequent Scargo Lake Water Quality Management Report. Erb Drive loads do not reach Scargo Lake, but may have in the past.

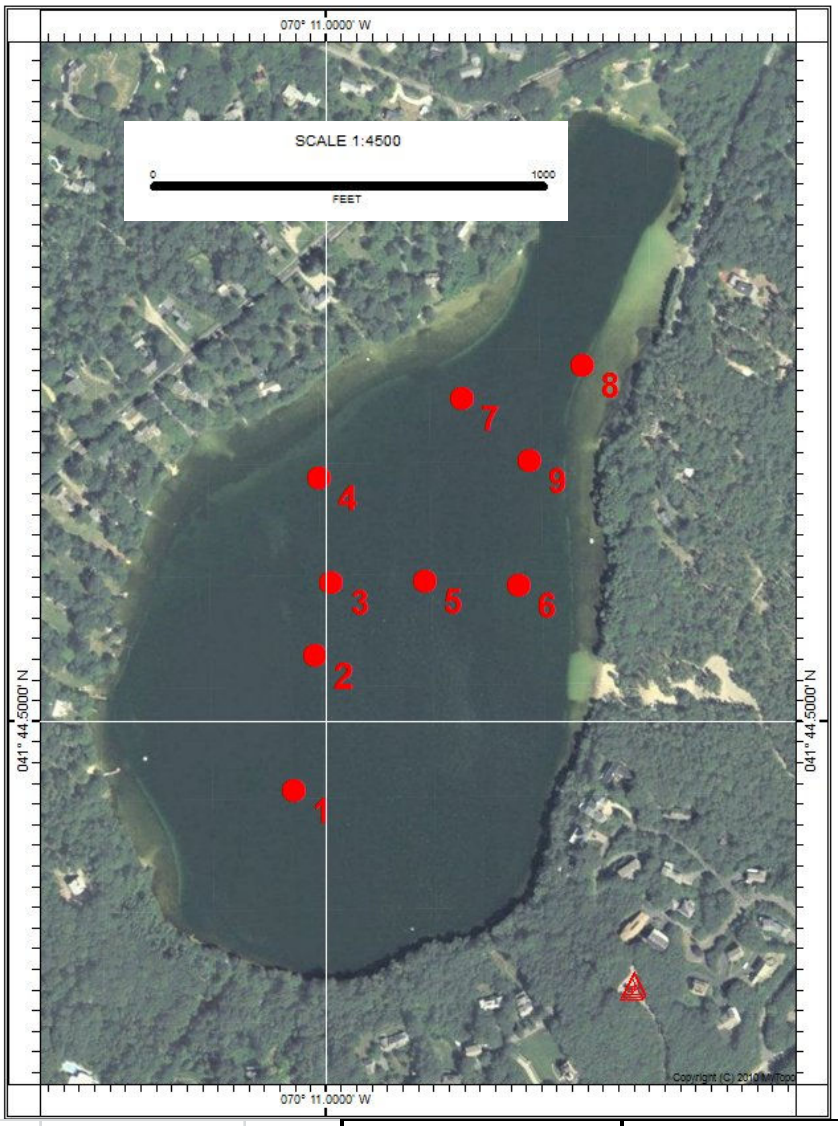
In order to develop a Scargo Lake-specific annual stormwater phosphorus load, project staff used the measured data from the three storms and extrapolated their sums up to the average runoff of 40 inches per year, which is the conventional runoff used on Cape Cod (Eichner and Cambareri, 1992). Although the three storms are in April, June, and August, the April storm was exceptionally large; between 1993 and 2006, 40% of the monthly precipitation totals at Hyannis were less than the precipitation measured during this one storm. Given the statistical balance offered by this storm, extrapolation is reasonable and may be slightly conservative. Using this approach the annual total phosphorus load from stormwater runoff from the existing roads around Scargo Lake is 0.0135 kg. Based on the readings at Erb Drive, the past potential annual stormwater load from all sites is 0.0141 kg.

IV.C. Scargo Lake Sediment Survey

Prior evaluation of Scargo Lake water quality data suggested that the sediments occasionally impact phosphorus concentrations in Scargo Lake (Eichner, 2009). In order to assess this impact and potential future impacts, CSP/SMAST staff collected and incubated sediment cores at various depths around the lake to evaluate nutrient regeneration from the sediments under oxidizing and reducing conditions.

Eight sediment cores were collected on August 20, 2010 and another eight cores were collected on January 10, 2012 (**Figure IV-7**). The initial cores were analyzed for aerobic phosphorus regeneration, while the second set of cores was analyzed for both aerobic and anoxic regeneration. During both summer and winter coring events standard handling, incubation, and sampling procedures were followed based on the methods of Jorgensen (1977), Klump and Martens (1983), and Howes (1998). During the incubations, water samples were withdrawn periodically and chemical constituents were determined. Rates of sediment nutrient release were determined from linear regression of analyte concentrations through time. All analyses were completed at the Coastal Systems Program Laboratory, School for Marine Science and Technology (SMAST), University of Massachusetts Dartmouth using standard methods for analysis and sediment geochemistry.

There are a number of factors that control the release of phosphorus from lake sediments aside from redox and temperature relationships (*e.g.*, aluminum and/or iron content), but transition from aerobic to anaerobic conditions generally liberates significant phosphorus. Release of phosphorus during this transition generally follows a sigmoidal curve with three phases: 1) initial hypoxic and anaerobic decomposition attenuated by sediment iron; 2) chemical release of bound phosphate and anaerobic decomposition; and 3) anaerobic decomposition in the absence of significant sediment iron. The second phase typically involves the rapid reduction and solubilizing of iron, which breaks iron/phosphorus bonds and liberates phosphorus. This phase is typically very rapid with a pulse-like release of phosphorus and is followed by a relative constant release in the third phase that ends when the anaerobic conditions cease. The key phase 2 and 3 anaerobic releases in Scargo Lake would be the deepest cores (1, 2, 3) since these would be the depths where anaerobic conditions would occur.



			8/10/2010				1/10/2012			
Town	Location	Site ID	Latitude		Longitude		Latitude		Longitude	
DENNIS	SCARGO LAKE	SGO1	41	44.465	70	11.022	41	44.466	70	11.019
DENNIS	SCARGO LAKE	SGO2	41	44.535	70	11.064	41	44.531	70	11.052
DENNIS	SCARGO LAKE	SGO3	41	44.566	70	10.998	41	44.565	70	10.991
DENNIS	SCARGO LAKE	SGO4	41	44.618	70	11.006	41	44.618	70	11.002
DENNIS	SCARGO LAKE	SGO5	41	44.567	70	10.936	41	44.568	70	10.919
DENNIS	SCARGO LAKE	SGO6	41	44.565	70	10.875	41	44.566	70	10.865
DENNIS	SCARGO LAKE	SGO7	41	44.656	70	10.912	41	44.659	70	10.911
DENNIS	SCARGO LAKE	SGO8	41	44.472	70	10.834				
DENNIS	SCARGO LAKE	SGO9					41	44.626	70	10.868

Figure IV-7. Scargo Lake Sediment Core Locations.

Sediment cores were collected in both summer and winter from the locations indicated by the red dots. August cores were incubated under aerobic conditions, while the January cores were incubated under both aerobic and anoxic conditions. Core locations are shown in the associated table. Location SGO-9 replaced SGO-8 in the winter survey.

Table IV-1 indicates the core incubation results. The summer aerobic core incubations generally show uptake of phosphorus by shallow (0-4 m) sediments, release of phosphorus in the middle depth (4-8 m) sediments and slight release of total phosphorus and slight uptake of ortho-P in the deep (8-14 m) sediments. This pattern is typical of lakes where the shallow waters tend to have more sandy nutrient-poor sediments because fine organic materials (plankton and detritus) are resuspended by wave action and winnowed toward deeper waters by in-lake circulation. The middle depths accumulate both the finer sediments (potentially enhanced by the mussel population) and some of the phosphorus released from the deep basins by anoxia, and therefore show the highest rates of release. Inorganic nitrogen (NO3-N and NH3-N) and total N both show increasing release with increasing depth. The temperature and dissolved oxygen profiles when these cores were collected generally showed cold deep temperatures (~10°C), lower dissolved oxygen throughout most of the water column, and shallower anoxia than average (up to 9 m).

In January 2012, another set of cores was collected and incubated for both aerobic and anaerobic conditions. As would be expected by the colder temperatures, the sediment oxygen demand is significantly reduced from summer conditions (10X less) and similar at all depth ranges during the winter. Shallowest sediments release inorganic nitrogen, total nitrogen, ortho-phosphorus, and total phosphorus at much higher aerobic rates during the winter than during the summer. Total nitrogen is released at roughly the same rate at intermediate depths between summer and winter, while twice as much is released from the deepest water sediments during the summer. Total and ortho-phosphorus are released at more than 10X higher rates in the intermediate depths during the summer than in the winter. In the deeper water sediments where water temperatures are more consistent between summer and winter, inorganic nitrogen release is similar between summer and winter conditions.

The results in **Table IV-1** are the gross sediment releases. In order to assess the true impact of the sediments, these gross releases must be adjusted to consider simultaneous deposition of nutrients from the overlying water column, as well as the area of the sediments. Adjusting the summer aerobic releases shows that the larger area of the 0-4 m sediments have a net uptake of total phosphorus (-0.10 kg/d), while the 4-8 m sediments have a net release of 0.14 kg/d. The net combination of these aerobic sediments in August 2010 is a 0.04 kg/d addition of total phosphorus from the water column to the sediments. This rate would equal an addition of approximately 4.6 kg over a four month summer period (June to September). Based on consideration of the watershed phosphorus loads and the average measured mass of phosphorus in the pond, this result appears to be reasonable.

During the winter, these shallower, aerobic sediments take up more phosphorus. The 0-4 m sediments roughly balance release and settling, while the 4-8 m sediments have a net uptake of 0.03 kg/d. The deep sediments (>8 m) more than double this uptake rate (0.08 kg/d). The overall net result is that the lake sediments are removing 0.1 kg of total phosphorus each day or 12 kg over a 4 month winter period (November to February).

Table IV-1. Scargo Lake Sediment Core Analysis.

Sediment cores collected at sites indicated in **Figure IV-7** at depths noted below. All values indicated as sediment release in milligrams per square meter per day under the specified redox conditions. Negative nutrient values indicate uptake from the water column by the sediments. Cores were incubated at water temperatures at the time of collection.

A. August 10, 2010 Aerobic

Core Sites	Depth Range	Sediment O2 Uptake		Inorganic Nitrogen		Ortho-Phosphate		Total Nitrogen		Total Phosphorus	
		(mg O2 m-2d-1)		(mg N m-2d-1)		(mg P m-2d-1)		(mg N m-2d-1)		(mg P m-2d-1)	
	(meters)	Mean	s.e.	Mean	s.e.	Mean	s.e.	Mean	s.e.	Mean	s.e.
4,8	0 - 4	1039	49	1.84	0.57	-1.04	0.01	1.88	1.34	-0.41	0.33
5,6,7	4 - 8	1283	219	4.52	1.09	2.17	1.62	28.94	0.55	3.79	0.53
1,2,3	8 - 14	1817	228	7.45	2.79	-0.31	0.39	36.27	7.59	0.15	0.37

B. January 11, 2012 Aerobic

Core Sites	Depth Range	Sediment O2 Uptake		Inorganic Nitrogen		Ortho-Phosphate		Total Nitrogen		Total Phosphorus	
		(mg O2 m-2d-1)		(mg N m-2d-1)		(mg P m-2d-1)		(mg N m-2d-1)		(mg P m-2d-1)	
	(meters)	Mean	s.e.	Mean	s.e.	Mean	s.e.	Mean	s.e.	Mean	s.e.
4	0 - 4	17.53	1.13	9.92	0.48	0.34	0.27	26.62	4.46	0.90	0.40
5,6,7,9	4 - 8	18.06	3.90	12.17	4.28	0.07	0.22	30.95	4.11	0.22	0.15
1,2,3	8 - 14	13.70	1.33	8.73	2.07	0.16	0.08	15.51	1.43	0.41	0.10

C. January 17, 2012 Anaerobic

Core Sites	Depth Range	Sediment O2 Uptake		Ammonium		Phase 2 P Release (chemical + anaerobic)		Anaerobic P Release		Chemical P Release		
		(mg O2 m-2d-1)		(mg N m-2d-1)		(mg P m-2d-1)		(mg P m-2d-1)		(mg P m^{-2}y-1)		
	(meters)	Mean	s.e.	Mean	s.e.	Mean	s.e.	Mean	s.e.	Mean	s.e.	Days
4	0 - 4	17.53	1.13	12.16	0.34	0.95	0.02	0.24	0.07	39.79	2.61	27
5,6,7,9	4 - 8	18.06	3.90	6.44	0.49	1.00	0.09	0.17	0.04	37.43	1.90	45.0
1,2,3	8 - 14	13.70	1.33	4.64	0.52	0.82	0.24	0.09	0.03	24.48	4.57	33.7

The net result of these aerobic sediment interactions would be annual retention of 7.5 kg of phosphorus in Scargo Lake in the upper portion of the lake. This calculation would assume that the two "shoulder" seasons (October and March/April) would essentially balance each other. This calculation would then need to adjusted to account for other factors removing phosphorus from the lake (*e.g.*, stream outflow and movement of phosphorus to deeper waters).

One way to begin to understanding the deeper waters is to look at summer anaerobic conditions. During the summer, anaerobic (or reducing) redox conditions develop in the sediments and the overlying water, which lead to the release of iron-bound phosphorus from the sediments (and the higher TP concentrations observed in the deepest water quality samples). The winter 2012 cores were collected when bottom temperatures were approximately 2 to 3°C cooler than during typical August temperatures. A rough rule of thumb is that sediment nutrient release rates double for every 10°C increase. During anaerobic conditions, iron-bound phosphorus is released first with anaerobic releases following until oxygen is reintroduced. In Table 1, the chemical release columns are the iron-bound release rates and the length of time (in days) that the release occurred during the incubation of the cores. It is noteworthy that the chemical release rate is 3-7X the anaerobic release rate of phosphorus and that these types of conditions would only typically be experienced in the deepest sediments (>9 m). Complete multiple dissolved oxygen profiles from the same summer are limited in the dataset, but the few available show that anaerobic conditions in deep Scargo Lake waters typically extended beyond the length of the chemical release phase indicated in the core incubation (34 days) meaning that all iron-bound phosphorus would be released and subsequent phosphorus release would occur at the anaerobic rate. Review of the estimated summer release information based on the core incubation shows that 1.1 to 1.3 kg is released from the sediments during the summer.

Water quality data provides an additional comparison for these estimates. Available data is typically limited to an August and September profiles; these show deep water additions of TP ranging between -1.1 and 1.9 kg. 2003 is the only year with June through September phosphorus concentrations at depth and the mass in the deep portion of the pond did not show an increase during the 2003 summer. Comparison of average TP water concentrations at 9 m and deeper show increases of 1.5 and 2.7 kg between April and August and April and September, respectively. These concentrations would also include settling phytoplankton, so these results generally agree with the sediment data.

Overall, the sediment core data shows that the sediments act as a source and sink for nutrients depending on the time of year. In August and September, the primary sediment source of phosphorus to Scargo Lake is not the deep sediments, but the intermediate sediments (4-8 m in depth). The deep sediments contribute 1.1 to 1.3 kg of TP during the summer, while the shallower sediments (primarily from the 4-8 m depths) contribute 4.6 kg of TP. Given that the deeper releases are generally prevented from impacting the shallower epilimnion waters, the mid-depth sediment TP releases play more of a role in the overall water quality of the lake. These sediment results are generally consistent with the average TP concentrations in the pond water. Compared to other ponds with low dissolved oxygen concentrations, the Scargo Lake deep sediments do not seem to be an overwhelming source of phosphorus; the annual phosphorus mass regenerated from the sediments is less than the annual contribution from wastewater or direct atmospheric contributions on the surface of the lake. The sediment data also collectively

shows that the Scargo Lake system is, as would be expected, retaining phosphorus. The natural retention of phosphorus means that more will be available as the lake ages. The rate of this retention and rate of its release during the summer will play an important role in determining the water quality and ecosystem status of Scargo Lake.

IV.D. Scargo Lake Mussel Survey

During July 2011, CSP/SMAST staff completed a visual mussel survey to determine the distribution of freshwater mussel habitat. Many of the freshwater mussel species on Cape Cod are listed by the Massachusetts Natural Heritage Program as endangered species or species of special concern, including the Tidewater Mucket (*Leptodea ochracea*) and Eastern Pondmussel (*Ligumia nasuta*) (www.mass.gov/dfwele/dfw/nhesp/species_info/mesa_list/mesa_list.htm). Staff recommended that a visual survey be completed due to experience in the Town of Barnstable, where an alum treatment was delayed for over a year in order to address issues associated with Massachusetts Endangered Species Act (WRS, 2011). Staff recommended the visual survey as a relatively lost cost approach to assess whether mussels would have to be a consideration in development of management strategies for Scargo Lake.

Staff completed the mussel survey by collecting underwater video recordings of the bottom sediments. The collected video was reviewed frame-by-frame for mussel valves and densities within each frame (**Figure IV-8**). Video tracks were not collected in depths greater than 12 m since mussels do not survive in these areas due to their regular seasonal anoxia. It is clear from this survey that there is an extensive freshwater mussel population in Scargo Lake. If management strategies are identified that involve disturbance of the bottom sediments, it is likely that a task to identify the freshwater mussel species will be needed.

V. Ecological and Regulatory Status: Data Synthesis and Nutrient Assessment

V.A. Limiting nutrient: Phosphorus Management is Key

Management of nutrients in freshwater lakes typically targets management of phosphorus. Phosphorus is targeted because it is typically the most limited of the key plant nutrients; nitrogen and potassium being the other two nutrients. If this key nutrient increases, the biomass in the lake will increase. This means that the key nutrient will spur plant population (typically phytoplankton) increases, clarity will drop, and more carbon will be retained in the lake. This latter step generally leads to greater sediment bacteria growth and increased sediment oxygen demand. Of course this general description often becomes more complex as the pond-specific details are considered, especially in deep lakes where conditions on the surface may be acceptable while deep water conditions are anoxic and degraded. In order to assess whether phosphorus is the key management nutrient, the balance between phosphorus and nitrogen in the pond water is reviewed. 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).

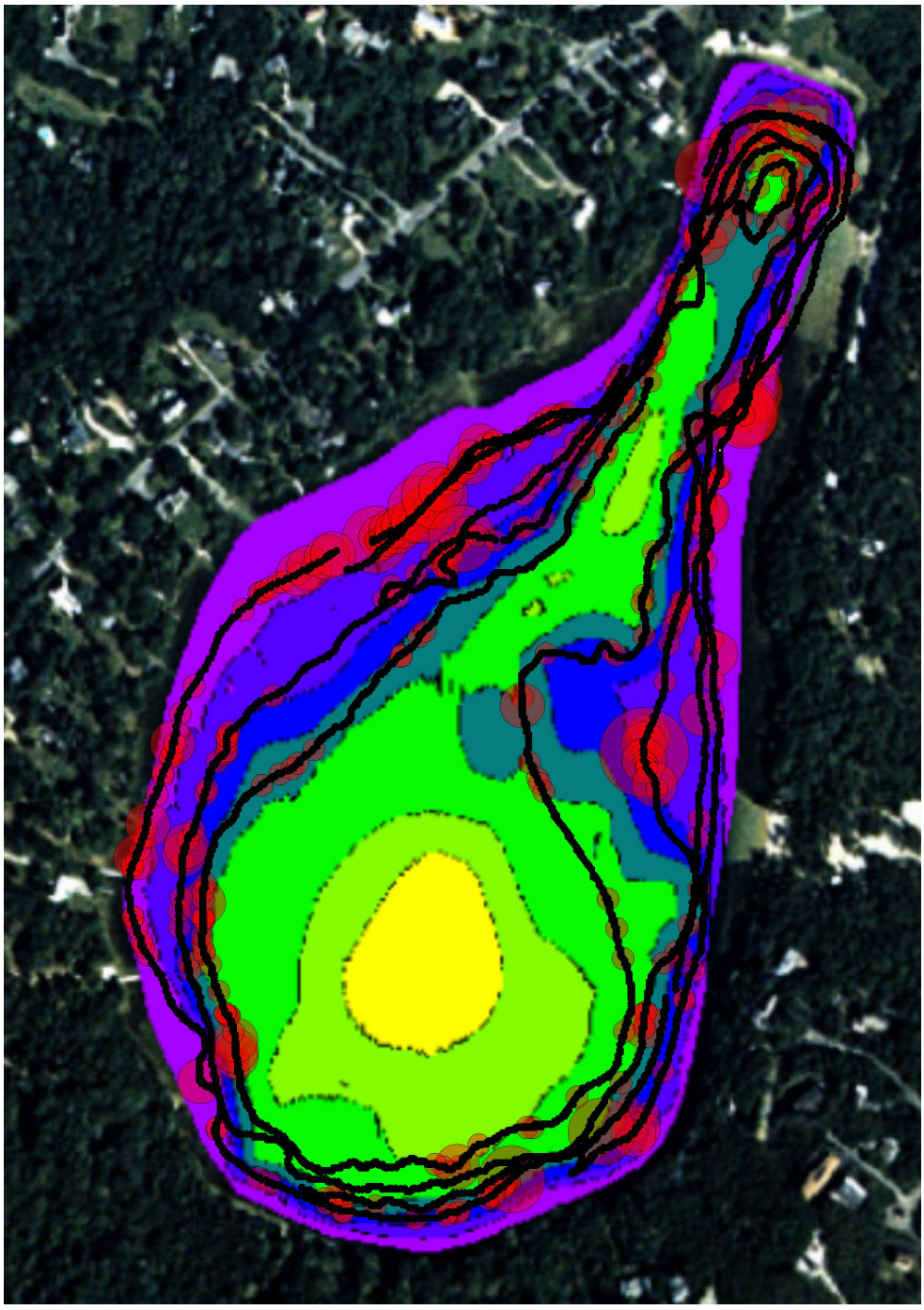


Figure IV-8. Scargo Lake Freshwater Mussel Survey.
The distribution of freshwater mussels throughout Scargo Lake was determined by video survey along transect lines (black lines). The video record was reviewed frame-by-frame and mussel numbers recorded. The sizes of the red circles indicate number of mussel valves per frame (1, 2, or 3). Bathymetric contours (colors) are 2 m increments. Speciation of mussels was not included in the project tasks as it would have required special permits given that most freshwater mussels in Massachusetts are listed as endangered species or species of special concern by Massachusetts Natural Heritage. Sediments deeper than 8 m were not assayed as seasonal anoxia excludes these areas as mussel habitat.

The average summer (August/September) N:P ratio in the upper waters (0.5 m, 3 m, and 9 m sampling depths) of Scargo Lake is 64. This is a slight drop from the limited (n=3) April readings where the average is 86 (**Figure V-1**). The change in the ratio is mostly due to a 18% decrease in total nitrogen (TN) concentrations, but is also accompanied by an slight (4%) increase in total phosphorus (TP). Deep readings also show phosphorus limitation (average summer N:P ratio is 71), but the relationships are slightly different. Deep summer TP concentrations increase by 67% compared to April reading and an 84% increase in TN concentrations. These changes suggest that TN in the upper waters is being transferred to the deeper waters, which would also be consistent with the high phaeophytin concentrations measured deep in the lake (see **Figure III-6**). The review of these ratios confirms that phosphorus is more limited than nitrogen in Scargo Lake and that management of phosphorus will directly impact water quality conditions.

V.B. Phosphorus Sources: Budget of Watershed, External, and Internal P inputs

Just as a water budget accounts for all the water coming into and leaving a pond, a phosphorus budget does the same for phosphorus and can be used to determine where management activities will have the most benefit to water quality and ecosystem function. 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).

The phosphorus loading assessment included in this report is an update of the assessment detailed in Eichner (2009) and benefits from the refinements completed by the Town (Eichner and Howes, 2012), as well as work in progress on the Massachusetts Estuaries Project assessment of Sesuit Harbor. This refined Scargo Lake-specific information allowed for a more refined understanding of phosphorus loads from these sources and, directly, a better set of water quality management options.

V.B.1. External Sources: Wastewater/Septic Systems Phosphorus

The Eichner (2009) loading assessment was completed with the assistance Dennis volunteers who reviewed town Board of Health records of properties within 300 ft of the pond shoreline to determine the distance from the pond shoreline to septic system leachfields, pits and cesspools. 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

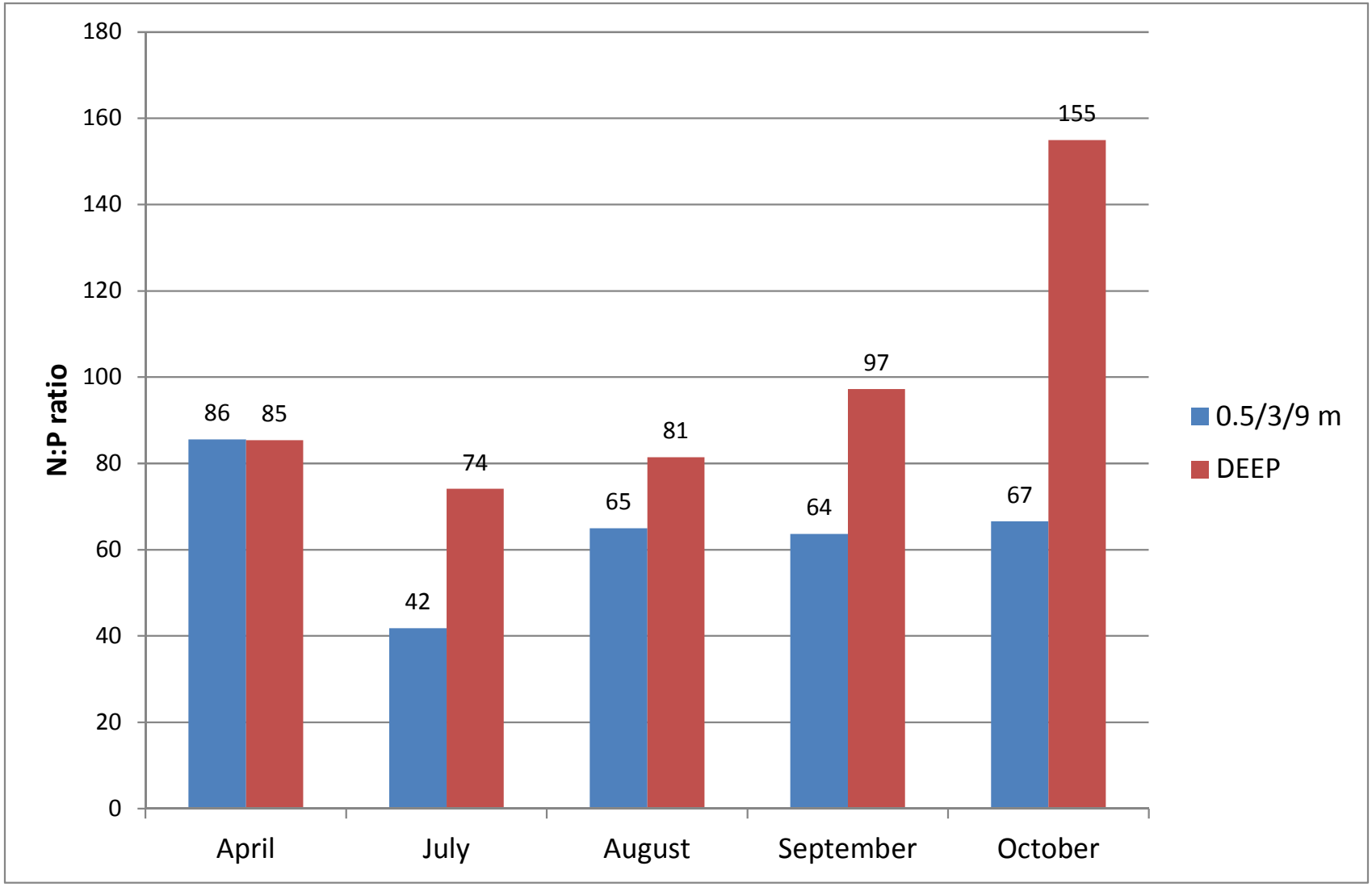


Figure V-1. Average Monthly Nitrogen to Phosphorus Ratios in Scargo Lake.
Readings are shown for April, July, August, September and October. All averages are based on at least two readings; August and September averages are based on 6-8 readings. All averages are multiples greater than the Redfield ratio of 16, indicating that the lake is consistently phosphorus limited and that control of phosphorus will restore water quality.

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.

Phosphorus loads were developed for each of the properties within 300 ft of the shoreline and located on the upgradient side of Scargo Lake. Aerial photographs of the properties were reviewed and non-wastewater loads were only assigned to developed properties with houses or other structures. 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. The wastewater phosphorus loading factors used in the assessment are listed in **Table V-1** and details of the development of the factors are discussed in Eichner (2009).

Based on this land use review, there are 21 properties within the watershed and along the upgradient shoreline of Scargo Lake (**Figure V-2**). Of the 21 properties, 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: Scargo Beach and Princess Beach. Nine of the 12 single family residences are connected to the municipal water supply and have 2007 water use from the Dennis Water District.

Table V-1. Watershed/External Phosphorus Loading Factors

Listed below are factors used in the development of the phosphorus budget for watershed and external phosphorus loading sources to Scargo Lake.

Factor	Value	Units	Source
Wastewater P load	1	lb P/septic system	MEDEP, 1989 load
Groundwater P retardation factor	25 - 37	velocity/solute velocity	Robertson, 2008
Road surface P load	0.02	kg TP/yr	Scargo Lake measured (Eichner and Howes, 2012)
Roof surface P load	0.6 - 1.5	kg/ha	Waschbusch, *et al*. (1999); CSN (2011)
Pond surface P load	0.05 - 0.14	kg/ha	Literature review detailed in Eichner (2009)
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
Lawn area	5,000	ft2 per residence	Eichner and Cambareri, 1992
Lawn fertilizer lawn load	0.02 - 0.3	lb P/ac	Literature review detailed in Eichner (2009)
Waterfowl net P load	0.57	kg/yr	Scargo Lake bird counts and Scherer, *et al*., 1995

Figure V-2. Scargo Lake Parcels within 300 ft Buffer.

The 300 ft buffer around Scargo Lake is shown in orange with parcel outlines also shown in orange. Based on phosphorus travel time, only parcels within the 300 ft buffer and within the southern purple lines are contributing phosphorus to the lake. These parcels were included in the Scargo Lake watershed phosphorus budget, which also includes a review of ages of house, ages of septic system, and distances of septic system leachfields to the pond shoreline. The only parcel on the northern side of the pond that is estimated to contribute measurable phosphorus is the town boat ramp off Route 6A (indicated by red circle).

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 the average age of the leachfields 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 5,280 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 currently 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 or assuming all septic systems are contributing phosphorus to the lake, septic systems are estimated to contribute 5.9 kg of phosphorus per year.

V.B.2. External Sources: Lawn Fertilizer Phosphorus

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 Scargo Lake using a range of rates: 0.02 to 0.3 lbs/ac. Using these rates, lawns within 300 ft of Scargo Lake annually add between 0.01 and 0.2 kg of phosphorus to the lake.

V.B.3. Other External Phosphorus Sources: Roofs, Precipitation, Birds, Roads

As detailed in Eichner and Howes (2012), part of the recent Town assessment activities have directly measured the Scargo Lake-specific phosphorus inputs from birds (Section IV.A) and stormwater road runoff (Section IV.B). The direct measurement of these sources indicates that they contribute 0.57 kg/yr and 0.02 kg/yr of phosphorus, respectively, to Scargo Lake.

Two other sources that must rely on available research are roof runoff and precipitation directly on the surface of the lake. These two sources are related because both are capturing precipitation, although the roof area is somewhat more complicated by whether the roof runoff is subject to any treatment, whether there is leach of phosphorus from the roofing material, and whether any additional phosphorus is deposited on the roof from birds or dry deposition. Previous pond phosphorus budgets on Cape Cod (*e.g.*, Eichner, 2008) have used a 0.14 kilogram per hectare (kg/ha) phosphorus load on the pond surfaces and 3.9 kg/ha based on MEDEP (1989) phosphorus loading guidance. The precipitation 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 Scargo Lake phosphorus budget uses a phosphorus load of between 0.05 and 0.14 kg/ha for phosphorus loading on the surface of the lake. Given the area of the lake, this range of loads results in an annual load on the surface of Scargo Lake of between 1.2 and 3.4 kg of TP.

Measurements of total phosphorus in roof runoff generally show very large ranges, which tends to confirm the role of a number of factors. However, more recent literature searches have indicated that the MEDEP (1989) guidance is likely too high. Waschbusch and others (1999) found median TP concentrations off pitched roofs varied between 0.06 mg/l and 0.15 mg/l. Chesapeake Bay draft guidance suggests that 0.12 mg/l TP is an appropriate concentration for roof runoff (Chesapeake Stormwater Network, 2011). In the development of the Scargo Lake phosphorus loading in this report, staff used the Waschbusch and others (1999) range since it seemed to include most of the reported concentrations that were reviewed; these translate to 0.61 to 1.52 kg/ha TP. Given the roof area of the houses within 300 feet of the lake and within its watershed, this range of loads results in an annual roof runoff load to Scargo Lake of between 0.07 and 0.17 kg of TP.

V.B.4. External Sources: Watershed Phosphorus Budget

Using the directly measured phosphorus data, watershed-specific information for Scargo Lake, and the factors in **Table V-1**, the total watershed/external phosphorus load to Scargo Lake is between 5.5 and 9.8 kg/yr (**Figure V-3**). Wastewater is the majority of this load, varying between 55% and 66% of the total load depending largely on the travel time of phosphorus from leachfields to the lake. The second largest load is from atmospheric deposition, which is largely uncontrollable for local management purposes.

These estimates agree very well with average measured phosphorus mass in the lake. Average late summer (August and September) phosphorus mass in the upper 9 m of Scargo Lake is 16 kg (±5 sd). In order to compare this number to the estimated watershed/external phosphorus load, the estimated load should be adjusted by the 2.4 year average residence time. This adjustment results in an estimated annual watershed load of 7 kg or roughly the mid-point of the external load. This comparison shows that, on average, the summer phosphorus concentrations are largely determined by watershed contributions, although some of the higher

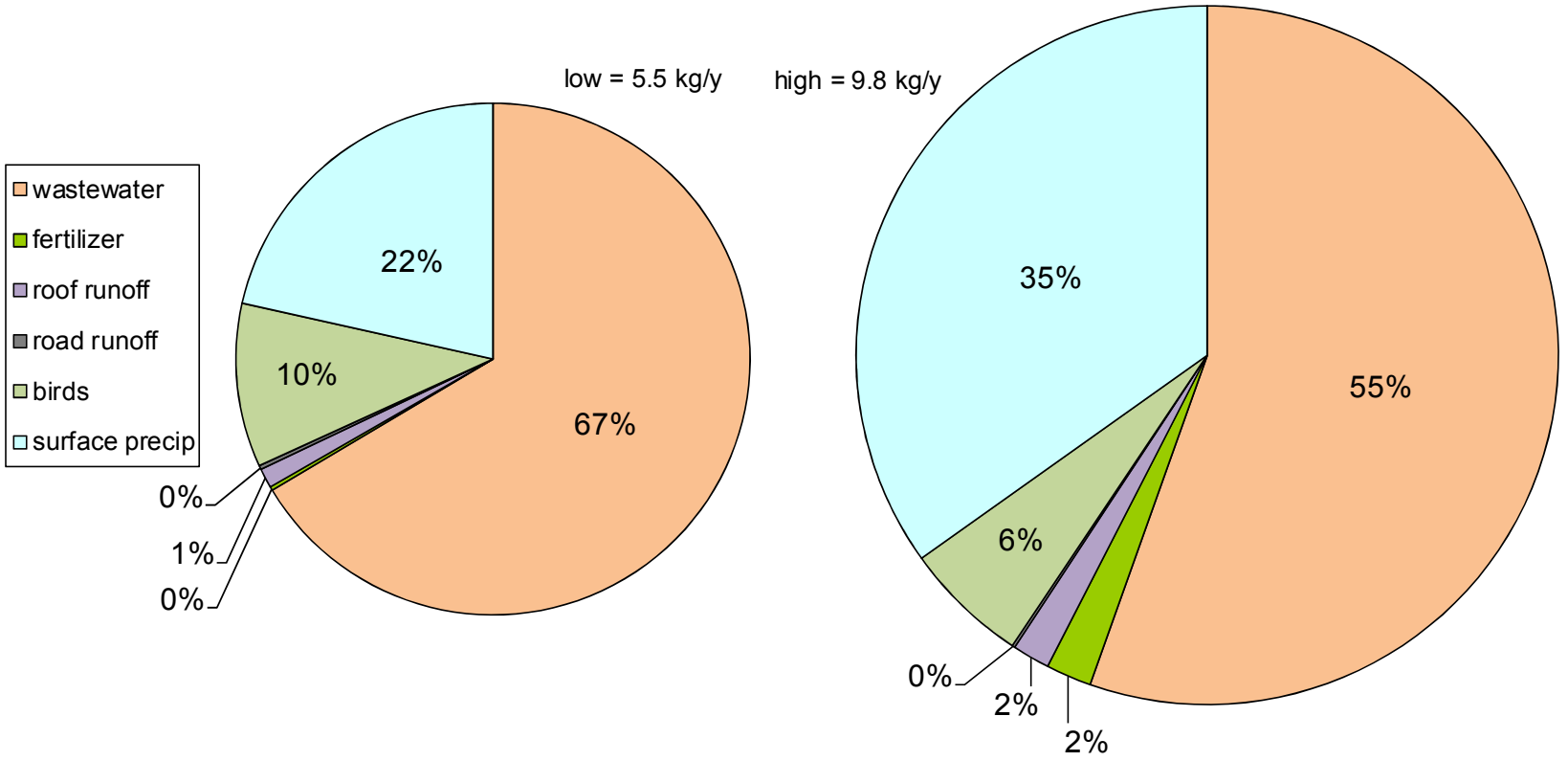


Figure V-3. Scargo Lake External/Watershed Phosphorus Budget.

The above pie diagrams show the high and low watershed estimates of external sources of phosphorus entering Scargo Lake. These estimates include the lake-specific measurements of road runoff and bird counts. Wastewater is the primary source of watershed phosphorus; wastewater loading estimates vary between 3.6 and 5.4 kg annually. Variations are based on age of leachfields and houses, as well as velocity of phosphorus travel in the groundwater system. Most of the rest of the variability is due to the range of phosphorus concentrations assigned to the surface precipitation.

masses of TP measured in the water column suggest that deep sediment regeneration occasionally impacts the surface waters.

V.C. Internal Phosphorus Inputs and Discharges: Sediment Nutrient Regeneration and Stream Outflow

As noted in Section IV.C., CSP/SMAST staff collected and incubated sediment cores to evaluate nutrient regeneration from the sediments under oxidizing and reducing conditions. Evaluations of the summer aerobic incubation results noted that shallow sediments have a net uptake of TP and intermediate sediments have a net release of TP, which cumulatively result in 4.6 kg addition to the pond during a four month summer. This rate fits within the observed variability of the summer phosphorus mass measured in the pond. Review of the anaerobic incubations, which would correspond to the deep water, low oxygen conditions, show that 1.1 to 1.3 kg is released from the deep sediments during the summer, but review of the DO and TP readings suggest that this release does not impact the upper waters during the summer. During the winter, the intermediate and deep sediments have a net uptake of TP, while the shallow sediments are in balance. Based on the core incubations, these sediments collectively adsorb 12 kg TP over a four month winter.

Based on the measured streamflow and average summer surface TP concentrations, 1.3 kg (±0.4 kg) leaves Scargo Lake during a four month summer. The streamflow information was gathered as part of the Massachusetts Estuaries Project (Howes and others, in preparation). The gauge is located on the east side of Route 6A, approximately 0.2 miles downstream of Scargo Lake. Flow corrections were made to determine the watershed between the gauge and the lake, so that outflow calculations account for only the flow leaving the lake. Winter water quality samples are very limited in the water quality dataset (*i.e.*, two November readings), so calculation of a year-round outflow is somewhat speculative. Average surface TP concentrations over the whole available dataset slightly increase a four month outflow mass to 1.4 kg.

V.D. Overall Phosphorus Budget

Collectively, the summer phosphorus loads appears to balance. Annual watershed inputs are estimated to be 5.5 to 9.8 kg, which are 1.8 to 3.3 kg for a four month summer. The stream outflow is 1.1 to 1.3 kg and the intermediate sediments are adding 4.6 kg (±14%). The sum of these loads range from 4.5 to 7.4, which balances with the range of masses in the epilimnion of the lake. Winter sediment core results suggest that phosphorus concentrations during the winter should be lower as the intermediate sediments adsorb phosphorus, but winter water quality data is not available to assess this. Absorption of phosphorus would be consistent the general idea that wetlands, including lakes, retain nutrients and, over time, gradually collect more phosphorus.

The phosphorus budget also establishes that the summer low oxygen conditions and phosphorus regeneration in the hypolimnion are somewhat separate from the upper epilimnion. However, the regular and pervasive deep anoxia establishes conditions where, if they worsen even slightly and begin to interact with the upper warm layer, they will provide a new source of phosphorus to the phytoplankton in that layer leading to decrease clarity and higher chlorophyll and total phosphorus concentrations.

V.E. Overall Scargo Lake Status and Discussion

Review of surface water conditions in Scargo Lake show conditions that are acceptable for swimming and other contact recreation. There has been no evidence of extensive algal blooms, blue-green algal blooms or fish kills; conditions that have impacted other Cape Cod ponds such as Hinckleys Pond in Harwich, Mystic Lake in Barnstable, and Long Pond in Brewster/Harwich. Total phosphorus and chlorophyll concentrations are a bit elevated, but not exceptionally high.

However, deeper in Scargo Lake are conditions that raise concerns about its quality and its future surface water quality. April data, the earliest in the year that is available, shows that sediment oxygen demand has already begun to consume oxygen from overlying waters. These conditions persist and slowly worsen throughout the summer, eventually reaching up to the bottom of the warm surface water layer and, on occasion, into the surface water layer. Review of collected water quality data shows that these low oxygen conditions release phosphorus, but that residual oxygen concentrations generally persist between the warm epilimnion and the cold hypolimnion. These DO concentrations are high enough in the upper portions of the cold layer that extensive algal blooms are not initiated. Sediments are a significant source of phosphorus to the pond, but there is no indication that deep low oxygen conditions and the deepest sediments seeping into the upper waters in a significant mass. Chlorophyll readings show that phytoplankton are growing more extensively at the low oxygen boundary, but these do not seem to be impacting concentrations in the waters above them. Review of sediment data shows that the pond is collecting more phosphorus each year and it is likely that this will gradually worsen dissolved oxygen conditions over time. There is, however, no discernible trend of worsening dissolved oxygen conditions over the past 10 years.

Review of potential next steps for the management of Scargo Lake largely depends on the regulatory criteria that are used to judge its water quality conditions and the advocacy to act proactively. Massachusetts regulatory standards for surface waters require dissolved oxygen concentrations in lakes with cold water fisheries to have dissolved oxygen (DO) concentrations of 6 ppm or above (314 CMR 4.05(3)(b)1). These waters are "designated as a 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." As shown in the DO profiles, the cold water fishery in Scargo Lake (*i.e.*, the hypolimnion) regularly has DO concentrations below 6 ppm throughout the summer. Water quality conditions in Scargo Lake meet all of the other provisions of the surface water regulations, including: temperature, pH, bacteria, solids, color and turbidity, oil and grease, and taste and color. Review of the Secchi readings show that the minimum recorded clarity is safe for swimming.

Based on the regulatory DO criterion, it is likely that MassDEP would require a TMDL for Scargo Lake under the Clean Water Act and, eventually, some sort of management actions to attain the TMDL. The oxygen demand in the sediments is driven by carbon loading, which is ultimately controlled by phosphorus loading. Given that phosphorus is the nutrient controlling water quality in the lake, the TMDL would likely be targeted at total phosphorus. What the target would be, however, would likely require some negotiations with MassDEP.

No TP TMDLs have been developed by MassDEP for deep water lakes within the Scargo Lake Ecoregion (*i.e.*, southern Plymouth, Cape Cod, Martha's Vineyard and Nantucket). The review of the 2001 PALS Snapshot data by the Cape Cod Commission (Eichner and others, 2003) suggested that a target TP concentration range for Cape Cod ponds should be between 7.5 and 10 ppb. Average late summer surface TP concentrations in Scargo Lake in the waters less than 9 m are 10.3 ppb, while the deepest waters average 22.9 ppb. The shallow concentration suggests that the TP should be lower than 10 ppb, but only one pond is listed by MassDEP as having a TMDL less than 10 ppb TP and that is based on a modeling exercise where MassDEP approved 28 TMDLs in the Millers River watershed (MassDEP, 2003). In order to achieve 7.5 ppb TP, the average mass of TP in the upper waters of Scargo Lake would need to be reduced from 16 kg to 9.8 kg. In order to meet 9.8 kg, the annual watershed load would need to be reduced by 3 kg.

The largest controllable load entering Scargo Lake from its watershed is wastewater (see **Figure V-3**). If wastewater alone was targeted for the potential phosphorus reduction, wastewater phosphorus loads would need to be reduced 55 to 83%. No other single controllable source could attain the 3 kg reduction. However, since wastewater phosphorus takes decades to reach Scargo Lake, immediate reductions in wastewater phosphorus would address the long term maintenance of appropriate TP loads, but would not address the MassDEP DO criterion.

The goal in addressing the MassDEP DO criteria can likely be met by establishing some stable trout habitat; not the whole the cold water layer, but some portion. If a layer of cold water with a stable DO concentration above 6 ppm can be sustained throughout the summer, it will provide some trout habitat, as well as providing added protection for the warm, upper waters of the lake from regenerated deep water phosphorus. A number of options could be deployed to attain the creation of this layer, but the ones most commonly considered and deployed are: 1) sediment removal, 2) phosphorus inactivation, and 3) injection of oxygen. Project staff reviewed each of these for their applicability to Scargo Lake.

Removal of the sediments would remove the sediment oxygen demand and restore the lake to conditions that existed before any monitoring occurred. However, sediment removal is technically complicated and difficult to permit. Sediment removal has not been used extensively in Massachusetts and does not appear to ever have been used on Cape Cod (MassDEP/ MassDCR, 2004). Removal of sediments in off-Cape lakes typically is accompanied by a drawdown in the level of the lake, so sediments can be more easily accessed. In an unconfined aquifer system like the Cape, the water level of a lake is typically an expression of the groundwater level, *i.e.* an open, exposed portion of the water table. As such, a drawdown of a lake on the Cape would have to be sustained by pumping large volumes of water, as the aquifer surrounding the lake would flow to the lake to try to match the surrounding water levels. For this reason, sediment removal in Scargo Lake would require dredging. Dredging is not typically considered in lakes deeper than 25 ft and development of a dredging plan would require at the very least securing a dewatering area, securing a sediment disposal location, testing of the sediments for metals and hydrocarbons, and accommodations to protect/restore the mussel population. This effort would also require difficult permitting with both state agencies and local boards. For these reasons, staff would not recommend dredging of Scargo Lake sediments.

Although phosphorus inactivation is not needed for the bottom sediments, the same techniques could be used to remove phosphorus from the water column and create a soft barrier over the sediments to limit oxygen demand. Phosphorus inactivation is typically attained by adding salts of aluminum, iron, or calcium that chemically bind with the phosphorus and form solid precipitates that sink to the bottom of the pond. Alum precipitates/solids are not sensitive to redox conditions, so it can be used in anoxic settings. Typically, iron is not added in Cape ponds with hypoxia because there is usually already sufficient iron present, but the low oxygen is preventing it from binding the phosphorus and forming solids; more iron will not resolve this solubility issue. Calcium is similarly not used because the low pHs naturally found in Cape ponds will prevent precipitation of calcium-phosphorus solids; calcium precipitates are more chemically favored at pH's above 8 (Stumm and Morgan, 1981). For these reasons, Cape Cod water conditions typically favor application of aluminum for phosphorus inactivation.

Alum applications, typically a mix of aluminum sulfate and sodium aluminate, have been used at a number of Cape Cod ponds: Ashumet Pond in Mashpee/Falmouth, Hamblin Pond and Mystic Lake in Barnstable, Long Pond in Brewster/Harwich, and Lovers Lake/Stillwater Pond in Chatham. Follow-up monitoring of each of these applications has generally showed reduced phosphorus regeneration and reduced sediment oxygen demand. The Hamblin Pond treatment, which occurred in May 1995, increased dissolved oxygen concentrations above the MassDEP 6 ppm threshold for 4 meters worth of water that was anoxic prior to the treatment and this restoration was sustained through at least 2006 (Eichner, 2008).

However, the characteristics of Scargo Lake and the goals of reducing phosphorus and improving dissolved oxygen do not appear to match well with an alum application. The Scargo Lake phosphorus budget more or less matches the phosphorus mass in the upper volume of the lake without any input of phosphorus from the colder hypolimnion. If an alum application could remove all the phosphorus in the upper volume, the phosphorus mass within these waters would return to current levels within approximately 2 years based on the input from the watershed. The alum application would form a barrier over the sediments and likely show some improvement in dissolved oxygen levels, but there have not been definitive forensic studies to evaluate the factors that lead to successful dissolved oxygen improvement after alum treatment or the length of time that the improvement is maintained. For these reasons, staff would not recommend an alum treatment for Scargo Lake.

Given the characteristics of Scargo Lake, the best option to address the sediment oxygen demand is aeration of the hypolimnion (**Figure V-4**). Hypolimnetic aeration can likely be confined to the deep basin in depths below 9 m and should done in a way that preserves the cold water layer and does not mix it with the warm upper layer. Since the layers do not begin to form until April, the system could be turned on in May and run through September. Deep dissolved oxygen concentrations naturally begin to recover in October, as rapid cooling of the lake begins to breakdown the layers.

Use of hypolimnetic aeration would be a long term solution that would need to be initiated and maintained each summer. If this is combined with reductions in watershed phosphorus inputs, the lake will gradually (over decades) reduce the mass of phosphorus in the sediments and the sources from the watershed will not replenish this mass. Performance of

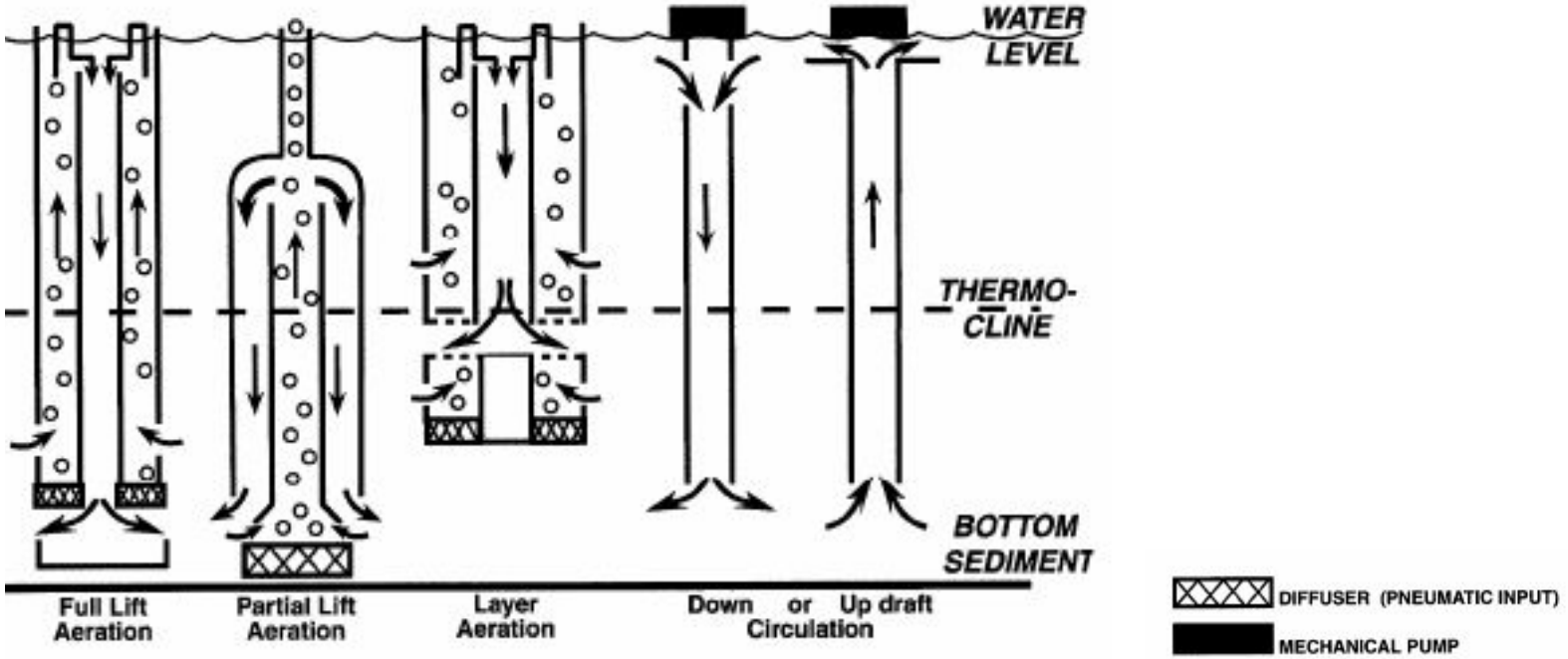


Figure V-4. Potential Hypolimnetic Aeration Options.

This figure, which is modified from Figure 3-1 in MassDEP/MassDCR (2004), shows the variety of general design options that have been developed to complete hypolimnetic aeration. This goal of this type of aeration is to maintain the thermal layers, keeping the warm water above the cold water, while adding oxygen to the cold water to address the sediment oxygen demand. Details to consider include the volume of water to be aerated, the shape of the basin, the amount of sediment oxygen demand, the siting and size of the compressor, and the amount of time that the aerator would operate. Preliminary recommendations are that the town target the sediment area deeper than 9 m in the large basin of Scargo Lake and that the aeration occurs from May through September. This area is 16 acres and has an average depth of 2 m. Sediment oxygen demand in these sediments is 1,817 mg/m2/d. Use of hypolimnetic aeration would be a long term solution that would need to be initiated and maintained each summer. If the town can accomplish reductions in wastewater phosphorus sources, it may be possible that the aeration could be re-evaluated after the remaining wastewater phosphorus is flushed from the aquifer.

aeration, both whole lake and hypolimnetic, has been somewhat mixed (MassDEP/MassDCR, 2004). Proper air/oxygen flows, mixing, and adequate characterization of the treated ponds are thought to have led to the most successful installations. Successful installations have no negative impacts on fish, shellfish, or plants. Unsuccessful installations present the opportunity to increase the transfer of phosphorus from deep waters to the more productive shallow waters and/or to destabilize the thermal layering and compromise the cold water fishery.

The area of the deep basin below 9 m is 16 acres and the average depth of this layer is 2 m. This volume and area is relatively small for the application of hypolimnetic aeration and great care would be necessary in the design to have an air flow that sustains the thermal layering. Based on ranges of cost presented in the MassGEIR (MassDEP/MassDCR, 2004) and updated to 2011 dollars, the likely cost range would be $10,000 to $60,000. Preliminary calculations of necessary air flow are small, so capital costs should be relatively small, but costs associated with design, energy, and regulatory approval would likely push the costs toward the higher estimate. Long term maintenance would also have to be factored into the cost estimates. There are a number of design options as indicated in **Figure V-4**.

Part of the long term success of in-lake treatment is going to be successful complementary reductions in watershed phosphorus inputs. As mentioned above, wastewater reductions would have the greatest impact. Wastewater is currently estimated to annually contribute 3.6 to 5.4 kg to Scargo Lake, which is greater than half of the watershed input. Removal of this whole load would reduce the mass in the lake to 34 to 44% of current levels and result in TP concentrations of 3.1 to 7.4 ppb without factoring in the sediment contributions.

Accomplishing this type of reduction, however, would present a number of challenges. The houses on the western edge of the lake are located in areas of significant elevation changes and wastewater collection to either neighborhood treatment facilities or a larger facility would have to address these changes with pumps that would add operation and design costs. In addition to these costs, wastewater facilities siting issues and costs would also be an issue. It might be possible to address these comprehensively during town-wide discussions of wastewater infrastructure to meet estuary TMDLs (*i.e.*, the comprehensive wastewater management plan (CWMP)).

VI. Summary

Scargo Lake is the largest (60 acres) and deepest (50 ft) freshwater pond in the Town of Dennis. It is located to the north of Scargo Hill and south of Route 6A and is largely surrounded by residential development except for the two public beaches (Scargo Beach and Princess Beach) on the south side and a public boat ramp located off Route 6A. A stream outlet in the northeast section connects the lake to Sesuit Harbor.

Over the past 10 years or so, citizen volunteers have worked through advocacy and sampling time to develop key information about the water quality of Scargo Lake. In 2009, with the guidance of the town Water Quality Advisory Committee and the town Natural Resource Department, staff from the Coastal Systems Program, School for Marine Science and Technology (SMAST), University of Massachusetts Dartmouth completed a review of available water quality data and assessed where key targeted information was necessary to develop a water

quality management plan (Eichner, 2009). The targeted data collection included collecting of Scargo Lake-specific measures of stormwater runoff, sediment nutrient regeneration, bird populations, and an updated bathymetric map (Eichner and Howes, 2012). This report utilizes this information to provide an assessment of steps needed to restore Scargo Lake.

Review of surface water conditions in Scargo Lake show conditions that are acceptable for swimming and other contact recreation. There has been no evidence of extensive algal blooms, blue-green algal blooms or fish kills; conditions that have impacted other Cape Cod ponds such as Hinckleys Pond in Harwich, Mystic Lake in Barnstable, and Long Pond in Brewster/Harwich. Total phosphorus and chlorophyll-a concentrations in this upper, warm layer, which extends down to 7-9 m, are elevated, but not exceptionally high.

However, deeper in Scargo Lake, in the colder waters deeper than 9 m, are conditions that impair this portion of the lake habitat and raise concerns the future surface water quality of the whole lake. During a given year, the earliest water quality data available is from April and this data shows that oxygen demand from the pond sediments has already begun to consume oxygen from overlying waters. These conditions persist and worsen throughout the summer, eventually reaching up to the bottom of the warm surface water layer and, on occasion, into the surface water layer. Review of collected water quality data shows that these low oxygen conditions release phosphorus, but close review of the dissolve oxygen readings show that there is usually enough residual oxygen in the upper portions of the cold layer that extensive algal blooms are not initiated in the warm upper layer.

These deep water diminishing oxygen concentrations are due to sediment oxygen demand, but there is no indication that the phosphorus released from these sediments is seeping into the upper waters in a significant mass. The sediment testing indicates that aerobic sediments in the 4-8 m depth range are the primary sediment phosphorus source during the summer. Collection of phosphorus in these sediments may be facilitated by an extensive freshwater mussel population. Chlorophyll-a readings show that phytoplankton are growing more extensively at the boundary between cold and warm waters (7-9 m), but these do not seem to be extensively impacting concentrations in the waters above them. Overall review of sediment data suggests that the pond is collecting more phosphorus each year and it is likely that this will gradually worsen dissolved oxygen conditions over time without intervention. There is, however, no discernible trend of worsening dissolved oxygen conditions or Secchi clarity over the past 10 years.

Review of potential next steps for the management of Scargo Lake largely depends on the criteria that are used to judge its water quality conditions, as well as advocacy to address the water quality problems. Massachusetts Department of Environmental Protection (MassDEP) regulatory standards for surface waters require dissolved oxygen concentrations in lakes with cold water fisheries to have dissolved oxygen (DO) concentrations of 6 ppm or above (314 CMR 4.05(3)(b)1). As shown in the DO profiles, the cold water fishery in Scargo Lake regularly disappears during the summer as sediment oxygen demand drops DO concentrations below 6 ppm throughout the whole cold water layer and with anoxic conditions (<1 ppm) in the deepest waters. Water quality conditions in Scargo Lake meet all of the other provisions of the surface water regulations, including: temperature, pH, bacteria, solids, color and turbidity, oil and

grease, and taste and color. Based on the DO criterion, it is likely that MassDEP would require a TMDL for Scargo Lake under the Clean Water Act and, eventually, some sort of management actions to attain the TMDL. What the TMDL would be, however, would likely require some negotiations with MassDEP, since no phosphorus TMDLs have been developed by MassDEP for deep water lakes within the Scargo Lake Ecoregion (*i.e.*, southern Plymouth, Cape Cod, Martha's Vineyard and Nantucket).

The review of the 2001 PALS Snapshot data suggested that a target TP concentration range for Cape Cod ponds should be between 7.5 and 10 ppb (Eichner and others, 2003). Average late summer surface TP concentrations in Scargo Lake in the waters less than 9 m are 10.3 ppb, while the deepest waters average 22.9 ppb. The shallow concentration and the deep DO impairments suggest that the TP should be lower than 10 ppb. In order to achieve 7.5 ppb TP, the average mass of TP in the upper waters of Scargo Lake would need to be reduced from 16 kg to 9.8 kg. In order to meet this lower mass, the annual watershed load would need to be reduced by 3 kg from the current annual load of 5.5 to 9.8 kg.

The largest controllable load entering Scargo Lake from its watershed is wastewater. If wastewater alone was targeted for the potential phosphorus reduction, wastewater phosphorus loads would need to be reduced 55 to 83%. No other single controllable source could attain the 3 kg reduction. However, since wastewater phosphorus takes decades to reach Scargo Lake, immediate reductions in wastewater phosphorus would address the long term maintenance of appropriate TP loads, but would not address the MassDEP dissolved oxygen criterion.

The goal in addressing the MassDEP DO criterion can likely be met by establishing some stable trout habitat; not the whole the cold water layer, but some portion. If a layer of high DO (>6 ppm), cold water can be sustained, it will provide some trout habitat, as well as protecting the warm, upper waters of the lake from regenerated deep water phosphorus. Project staff reviewed available options and recommend that the town consider implementing a hypolimnetic aeration project.

Hypolimnetic aeration is a process of controlled injection of air into the deep water in such a way that the cold water layer is maintained and oxygen levels are increased. It is recommended that this process be confined to the deep basin of Scargo Lake in depths below 9 m. Since the layers do not begin to form until April, the system could be turned on in May and run through September. Deep dissolved oxygen concentrations naturally begin to recover in October, as rapid cooling of the lake begins to breakdown the layers, so the system could be turned off at that point.

The area of the deep basin below 9 m is 16 acres and the average depth of this layer is 2 m. This volume and area is relatively small for the application of hypolimnetic aeration and great care would be necessary in the design to have an air flow that sustains the thermal layering. Based on ranges of cost presented in the MassGEIR (MassDEP/MassDCR, 2004) and updated to 2011 dollars, the likely cost range would be $10,000 to $60,000. Preliminary calculations of necessary air flow are small, so capital costs should be relatively small, but costs such as design, energy, and regulatory approval would likely push the costs toward the higher estimate. Long

term maintenance would also have to be factored into the cost estimates. There are a number of design options.

Use of hypolimnetic aeration would be a long term solution that would need to be initiated and maintained each summer. Proper air/oxygen flows, mixing, and adequate characterization of the treated ponds are key factors in the most successful installations. Successful installations have no negative impacts on fish, shellfish, or plants. Unsuccessful installations present the opportunity to increase the transfer of phosphorus from deep waters to the more productive shallow waters and/or to destabilize the thermal layering and compromise the cold water fishery. If this is combined with reductions in watershed phosphorus inputs, the lake will gradually (over decades) reduce the mass of phosphorus in the sediments and the sources from the watershed will not replenish this mass.

Part of the long term success of the proposed in-lake treatment is going to be successful complementary reductions in watershed phosphorus inputs. As mentioned above, wastewater reductions would have the greatest impact. Wastewater is currently estimated to annually contribute 3.6 to 5.4 kg to Scargo Lake, which is greater than half of the watershed input. Removal of this whole load would reduce the mass in the lake to 34 to 44% of current levels and result in TP concentrations of 3.1 to 7.4 ppb without factoring in the sediment contributions.

Accomplishing this type of reduction, however, would present a number of challenges. The houses on the western edge of the lake are located in areas of significant elevation changes and wastewater collection to either neighborhood treatment facilities or a larger facility would have to address these changes with pumps that would add operation and design costs. In addition to these costs, wastewater facilities siting issues and costs would also be an issue. It might be possible to address these comprehensively during town-wide discussions of wastewater infrastructure to meet estuary TMDLs.

VII. Recommended Next Steps

VII.1. Begin Review of Design Discussions for Hypolimnetic Aeration

Designing the hypolimnetic aeration system will require public discussions of design options. It is recommended that these discussions be facilitated through the Water Quality Advisory Committee and that the town consider development of a Request for Proposals to review options. SMAST staff could assist the WQAC and town in the development of the RFP, review of submittals and implementation of the selected proposal.

VII.2. Review Potential Options to Reduce Wastewater Phosphorus Sources

The above evaluation indicated that wastewater from sources within 300 ft of the pond shoreline and within the watershed is the primary watershed source of phosphorus to Scargo Lake. If some of these sources can be removed or reduced, the impacts of sediment phosphorus will be diminished and the need for hypolimnetic aeration will be diminished over time. It is recommended that existing work with the Town's comprehensive wastewater management plan (CWMP) be reviewed and updated based on the findings in this report.

VII.3. Continue 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. The current approach to sample once in April and once in August/September using PALS sampling protocols is invaluable in gauging the annual and long-term impact of sediment oxygen demand on the lake's water quality. It is recommended that this sampling continue and be adjusted as phosphorus mitigation options or sediment treatments are implemented.

VII.4. Initiate Discussions with MassDEP regarding TMDL guidance

As mentioned above, a total phosphorus TMDL has not been developed by MassDEP for deep water lakes within the Cape Cod ecoregion. A TMDL will provide the target criterion for any cleanup of Scargo Lake. It is recommended that the town proactively ask MassDEP for guidance regarding a TMDL to ensure that there is regulatory certainty regarding the target criteria and any follow-up compliance that may arise for implementation of phosphorus management activities.

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