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************************* Technical Memorandum *****************************

To: Virginia Esau, Chair, Water Quality Advisory Committee
Karen Johnson, Director of Natural Resources, Town of Dennis

From: Ed Eichner, Coastal Systems Program
Brian Howes, Director, Coastal Systems Program

RE: Scargo Lake Technical Support Project

Date: February 23, 2012

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Overview

Cape Cod has nearly 1,000 ponds and lakes of various sizes and depths. These ponds and lakes are important recreational areas (*e.g.*, swimming, fishing, boating) and natural habitat with important ecological and commercial services (*e.g.*, cranberry bog source water, herring spawning areas, nitrogen attenuation to protect estuaries). In 1999, the Cape Cod Pond and Lake Stewards (PALS) program was started to encourage development of basic knowledge about these resources as a basis for active and appropriate management.

CSP/SMAST staff were actively involved in the creation of the PALS program and its continued support, including citizen water quality monitoring programs, data review, and development of pond management strategies. In 2009, CSP/SMAST staff completed a review of citizen-collected data from 11 ponds in the Town of Dennis (Figure 1).[1] This review identified water quality problems in a number of the ponds and included a number of recommendations to complete basic assessment activities to establish a solid basis for future management plans. The Dennis Water Quality Advisory Committee has initiated an effort to address these recommendations and this technical memorandum details the results of initial work focused on Scargo Lake. Phase II of the present effort has begun, where the information in this technical memorandum will be used to create a Scargo Lake Water Quality Management Report.

The 2009 review of citizen-collected water quality data indicated that Scargo Lake currently has impaired water quality due to excessive phosphorus. This review identified three significant 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. Collection and synthesis of this data with previously collected citizen data would allow Town of Dennis to develop a management plan to restore Scargo Lake water quality. This project focuses on the development of the needed data, while a second project (Phase II),

[1] Eichner, E. 2009. Dennis Freshwater Ponds: Water Quality Status and Recommendations for Future Activities. Coastal Systems Program, School for Marine Science and Technology, University of Massachusetts Dartmouth and Cape Cod Commission. New Bedford and Barnstable, MA. 106 pp.

which is also underway, will synthesize this newly-collected data with the previously-collected data to provide phosphorus management options for Scargo Lake.

Four data gathering tasks were completed in and around Scargo Lake, during this current project:
(1) collection and incubation of lake sediments to characterize sediment nutrient regeneration rates,
(2) survey of stormwater discharges and associated nutrient loads to lake waters,
(3) survey of water bird populations associated with the lake (annual),
(4) mapping of lake depths (bathymetric map) and freshwater mussel distribution.

Details of the tasks and the results are as follows:

1. Scargo Lake Sediment Nutrient Regeneration:
CSP/SMAST staff were tasked with completing an evaluation of sediment nutrient regeneration in Scargo Lake. This evaluation consisted of collection and incubation of sediment cores to evaluate nutrient regeneration from the sediments under oxidizing and reducing conditions. Water quality samples were also collected during four runs to evaluate water quality conditions around the same time as the core collection. The sediment regeneration was undertaken based on the recommendation in Eichner (2009) to quantify nutrient inputs into the lake in order to better understand the relative contribution of the sediments to the phosphorus budget and their role in future water quality management of the lake.

Eight sediment cores were collected on August 20, 2010 and another eight cores were collected on January 10, 2012 (Figure 2). All the initial cores were analyzed for aerobic phosphorus regeneration, while the second set of cores were analyzed for both aerobic and anoxic regeneration. The second set of cores was necessary to determine the extent of phosphorus release at different depths in the lake should they become anoxic, as the anoxic zone rises to shallower depths as nutrient enrichment increases.

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. The laboratory followed standard methods for analysis and sediment geochemistry as currently employed by the Coastal Systems Analytical Facility at SMAST-UMassD.

Table 1 indicates the August core incubation results. Incubation of these cores under aerobic conditions 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. If the lake is deep and has anoxic bottom waters in summer (like Scargo Lake), much of the phosphorus from the fine deeper sediments is released during the anoxic period and ends up being deposited in other areas during fall mixing. The middle depths accumulate both the finer sediments and some of the phosphorus released from the deep basins, 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. Nitrogen, unlike phosphorus does not have the same regeneration from the deep basins, due to the differences in adsorption between N and P species. The January cores are still being incubated; anoxic incubation requires a minimum of 90 days.

Water quality data collected during four sampling runs accompanying the sediment sampling were generally consistent with past data although some indications of worse impairment than average. The four water quality sampling runs were on: August 30, September 15, October 28, and November 12. Lake water samples were analyzed 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, pH, alkalinity, chlorophyll *a*, and phaeophytin. Secchi depths on the four dates were 3.5 m, 3.85 m, 3.35 m, and 2.95 m, respectively, which are 25%, 29%, 24%, and 22% of the total depths on each date (Table 2). The average Secchi depth for Scargo Lake readings between 2001 and 2008 is 4.63 m with a relative Secchi depth of 34%.[2] A sampling run collected by town volunteers on April 26 had a Secchi depth of 5.0 m, which by comparison to the other readings shows the impact of the system warming during the late spring and the accompanying phytoplankton population growth (seen in the chlorophyll a and phaeophytin concentrations). Total phosphorus generally indicated lower concentrations than average except for the deepest waters, while total nitrogen concentrations were higher than average in all sampling rounds.

Aerobic and anoxic incubation results will be compared to water quality data from this year and past years to refine the phosphorus budget during the preparation of the Scargo Lake Water Quality Management Report, which will be completed during the current fiscal year.

2. Scargo Lake Stormwater Survey:

CSP/SMAST staff were also tasked with completing a Scargo Lake Stormwater Survey, which was defined as stormwater sampling at four locations during three storm events. This effort was undertaken based on the recommendation in Eichner (2009) to quantify stormwater nutrient inputs into the lake. Unlike groundwater inflows, stormwater discharges can contain high concentrations of phosphorus and have a disproportionate effect on the lake phosphorus balance. Therefore, to better understand the phosphorus budget and the relative contribution of stormwater and its role in future water quality management of the lake, a quantitative stormwater study was undertaken.

In order to complete the 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 3) and at the boat ramp on the north side of the lake (Figure 4). 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 5). 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 these channels have been obscured by regular water level fluctuations in the lake. Collectively, 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 example, staff were present during a small storm on May 18, but no runoff was generated. The runoff generated by the April 13 storm was significantly larger than either of the other two storm events (Figure 6); 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

[2] Eichner, E. 2009. Dennis Freshwater Ponds: Water Quality Status and Recommendations for Future Activities. Coastal Systems Program, School for Marine Science and Technology, University of Massachusetts Dartmouth and Cape Cod Commission. New Bedford and Barnstable, MA. 106 pp.

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 7). The load information showed that although the 4/13 storm was much larger than the other two measured storms and the loads typically followed this same pattern, there were locations where greater loads were measured during the other two storms. Further development and review of annual loads based on these storms will be completed during the development of the Scargo Lake Water Quality Management Report, which will be completed during the current fiscal year.

3. Scargo Lake Bird Population Survey:
CSP/SMAST staff were also tasked with developing and reviewing a Scargo Lake Bird Population Survey and developing phosphorus loads based on the year-long survey results. The survey was to be completed using volunteer bird counters and was undertaken based on the recommendation in Eichner (2009) to quantify bird nutrient inputs into the lake.

In order to complete the Scargo Lake Bird Population Survey, project staff divided the lake into quadrants (Figure 8). 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 4.7 and 26 (Figure 9). 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 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.[3] This study also provides a review of phosphorus contributions by a number species including Mallards and Gulls. In the study, the authors detail the weight of 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, staff determined the new bird phosphorus load in Scargo Lake on each day birds were counted. These loads were then averaged and a net annual load of 0.57 kg per year from birds was determined.

[3] Scherer, N.M., H.L. Gibbons, K.B. Stoops, and M. Muller. 1995. Phosphorus loading of an urban lake by bird droppings. *Lake and Reservoir Management*. 11(4): 317 - 327.

For comparison, Eichner (2009) used two approaches to determine a range of phosphorus load from birds for Scargo Lake.[4] The first approach was based on an areal loading rate developed by Scherer in the same study discussed above and the second approach was based on the range of birds per lake determined from the annual December snapshot of waterfowl conducted by the Cape Cod Bird Club.[5] The first approach resulted in an annual estimate of bird loading to Scargo Lake of 0.49 kg, while the second approach resulted in an annual range of 0.5 to 1.3 kg. These results resulted in a range of 3 to 6% of the external phosphorus load to Scargo Lake. Based on the results of the year-long counts documented in this technical memo, an appropriate estimate of phosphorus loading from birds to Scargo Lake is closer to 0.5 kg than 1.3 kg. Refinement of the phosphorus budget for Scargo Lake will be included in the Scargo Lake Water Quality Management Report.

4. Scargo Lake Bathymetry and Mussel Survey:

CSP/SMAST staff were tasked with completing a bathymetric survey to create a depth contour map and a mussel survey to determine the distribution of freshwater mussel habitat. Pond and lake volumes are critical for determining the impact of phosphorus inputs to these ecosystems. Previous work on other ponds has found that pond and lake volumes determined by new quantitative survey methods can be up to nearly 40% different than volumes based on the historic MADFW pond bathymetry.[6] Having a refined measurement of the pond volume is necessary to understand water quality conditions, but also to develop reliable management strategies. Staff recommended that a freshwater mussel survey be completed due to experience in other Cape towns with state permitting issues of management approaches due to the presence of endangered freshwater mussels.[7]

CSP/SMAST staff completed the bathymetric survey on June 28, 2011. Depth readings were sufficient to produce bathymetric contours of 5-ft intervals (Figure 10), which is an improvement over the 10-ft contour intervals previously available on the historic MADFW bathymetric map.[8] The survey was completed using a differential GPS for positioning mounted on a boat with a survey-grade fathometer. Project staff had intended to utilize an autonomous underwater vehicle (AUV) for the survey, but it was unavailable throughout the course of the project. Total volume for Scargo Lake based on the new contours is 1,563,037 m^3, 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). The impact of a larger volume on interpretation of phosphorus concentrations will be included in the Scargo Lake Water Quality Management Report.

During July 2011, CSP/SMAST staff also completed a survey of freshwater mussels. This survey used underwater video recordings of the bottom in the depths where mussels would be likely (Figure 11). The collected video was reviewed frame-by-frame for mussel valves and densities within each frame were developed as shown in Figure 11. Also as indicated, 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. Since many of the freshwater mussels in Cape Cod ponds are listed by the Massachusetts Natural Heritage Program as endangered or of special concern, species were not identified as this would require their removal from the sediments. Depending on selected management strategies, identification of mussel species may be

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[4] Eichner, E. 2009. Dennis Freshwater Ponds: Water Quality Status and Recommendations for Future Activities. Coastal Systems Program, School for Marine Science and Technology, University of Massachusetts Dartmouth and Cape Cod Commission. New Bedford and Barnstable, MA. 106 pp.

[5] www.capecodbirds.org/waterfowl.htm

[6] Eichner and Howes, in development

[7] Indian Ponds Newsletter. Fall 2009. Indian Ponds Association, Inc. Marstons Mills, MA.

[8] http://www.mass.gov/dfwele/dfw/habitat/maps/ponds/pdf/dfwscarg.pdf

required. It is clear from this survey that there is an extensive freshwater mussel population in Scargo Lake.

Summary/Conclusions

Scargo Lake is the deepest and largest freshwater pond in the Town of Dennis. Town volunteers from the town Water Quality Advisory Committee began collecting water quality data from Scargo Lake in 2001 through the guidance of the Cape Cod Pond and Lake Stewards (PALS) program.[9] Volunteers collected data throughout the 2000's and the data was reviewed in 2009 in the Dennis Pond Report.[10] The 2009 report recommended that the town consider development of key information to supplement the collected water quality data in order to provide a scientifically valid basis for management of water quality in Scargo Lake. Among the key information recommended for development were sediment nutrient regeneration measurements and measurements of stormwater nutrient inputs.

The Water Quality Advisory Committee discussed all the recommendations in the Dennis Ponds Report and has adopted a strategy of gradually addressing the recommendations in a considered manner over a period of years. This Technical Memo is the initial step in addressing some of the Scargo Lake recommendations and will be followed by a Scargo Lake Water Quality Management Report. The Scargo Lake Water Quality Management Report will use the information developed during this project and documented in this Technical Memorandum along with the previous measurements discussed in the Dennis Ponds Report to evaluate potential water quality management strategies for Scargo Lake.

In order to assist the Town of Dennis with developing key information for future management strategies for Scargo Lake, CSP/SMAST staff completed the following tasks for this project:
1) collection and incubation of Scargo Lake sediments to characterize sediment nutrient regeneration,
2) survey of stormwater flows and nutrient inputs to Scargo Lake,
3) bird population survey and associated phosphorus loads to Scargo Lake, and
4) bathymetric map to determine lake volume and freshwater mussel distribution.

Project staff collected a total of 13 sediment cores and incubated them in order to measure the phosphorus and nitrogen regeneration from Scargo Lake sediments under aerobic and anoxic conditions. This data will be used in the Scargo Lake Water Quality Management Report to detail the contribution of the lake sediments to measured phosphorus concentrations and whether sediment controls are advantageous to improve water quality in the lake.

Project staff measured stormwater runoff and nutrient loads into Scargo Lake from three storms at four locations identified as direct discharge locations. One of the locations does not appear to be a current direct discharge, but likely was one in the recent past. These measurements will be used in the Scargo Lake Water Quality Management Report to detail the contribution of direct stormwater discharges on measured phosphorus concentrations and whether stormwater controls are advantageous to improve water quality in the lake.

Project staff developed a bird population survey and two town volunteers (John Harper and Cliff Adams) diligently counted birds on the lake according to the survey protocols for one year. Project staff

[9] Eichner, E.M., T.C. Cambareri, G. Belfit, D. McCaffery, S. Michaud, and B. Smith. 2003. Cape Cod Pond and Lake Atlas. Cape Cod Commission. Barnstable, MA.
[10] Eichner, E. 2009. Dennis Freshwater Ponds: Water Quality Status and Recommendations for Future Activities. Coastal Systems Program, School for Marine Science and Technology, University of Massachusetts Dartmouth and Cape Cod Commission. New Bedford and Barnstable, MA. 106 pp.

developed phosphorus loads based on the species and number of individuals identified in the bird count. These loads will be used in the Scargo Lake Water Quality Management Report to detail the contribution of bird on measured phosphorus concentrations and whether bird controls are advantageous to improve water quality in the lake.

Project staff completed a new bathymetric map of Scargo Lake using refined measurement tools and conducted a spatial survey to determine the distribution of freshwater mussels. The bathymetric survey provided refinements to the contours of the bottom of the lake, including delineation of two previously unidentified deep holes. These refinements increased the volume of the lake by 8%. Freshwater mussels are typically listed by the Massachusetts Natural Heritage Program as endangered species or species of special concern. Recent lake management projects involving disturbance of sediments have encountered permitting difficulties associated with protection of freshwater mussels and it was recommended that a reconnaissance mussel survey be completed to evaluate whether this would be a consideration in the development of water quality management strategies for Scargo Lake. The freshwater mussel survey involved continuous transects recording of freshwater mussel populations using underwater video linked to dGPS. These records were then analyzed frame-by-frame to construct a spatial record of mussel density. It is clear from this survey that there is an extensive freshwater mussel population in Scargo Lake and that it will need to be a consideration in any water quality management options.

Next Steps

Working with the Town of Dennis Water Quality Advisory Committee, CSP/SMAST staff will use the measurements collected during this project and synthesize them with previously collected data. Collectively, all the data will be used to develop and review Scargo Lake water quality management options. This effort will be detailed in the Scargo Lake Water Quality Management Report, which will be released and reviewed by the Committee in late summer 2012.

References:

Eichner, E. 2009. Dennis Freshwater Ponds: Water Quality Status and Recommendations for Future Activities. Coastal Systems Program, School for Marine Science and Technology, University of Massachusetts Dartmouth and Cape Cod Commission. New Bedford and Barnstable, MA. 106 pp.

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

Howes, B.L. 1998. Sediment metabolism within Massachusetts Bay and Boston Harbor relating to rates and controls of sediment-water column exchanges of nutrients and oxygen in 1997. Boston: Massachusetts Water Resources Authority Report 1998-20. 80 p.

Jorgensen, B.B. 1977. The sulfur cycle of a coastal marine sediment (Limfjorden, Denmark). *Limnology Oceanograph*y. 22:814-832.

Klump, J. and C. Martens. 1983. Benthic nitrogen regeneration. In: *Nitrogen in the Marine Environment*, (Carpenter & Capone, eds.). Academic Press.

Scherer, N.M., H.L. Gibbons, K.B. Stoops, and M. Muller. 1995. Phosphorus loading of an urban lake by bird droppings. *Lake and Reservoir Management*. 11(4): 317 - 327.

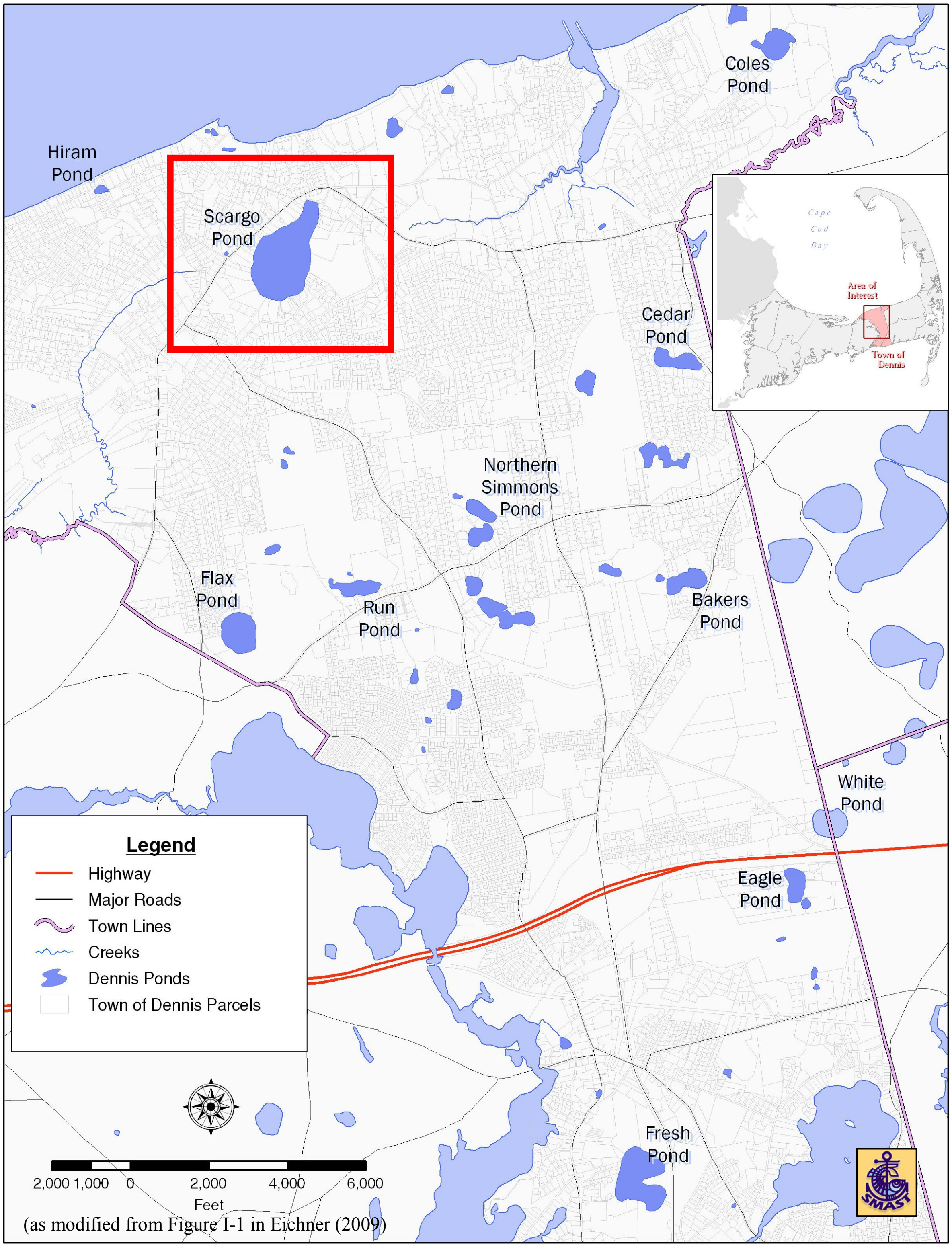
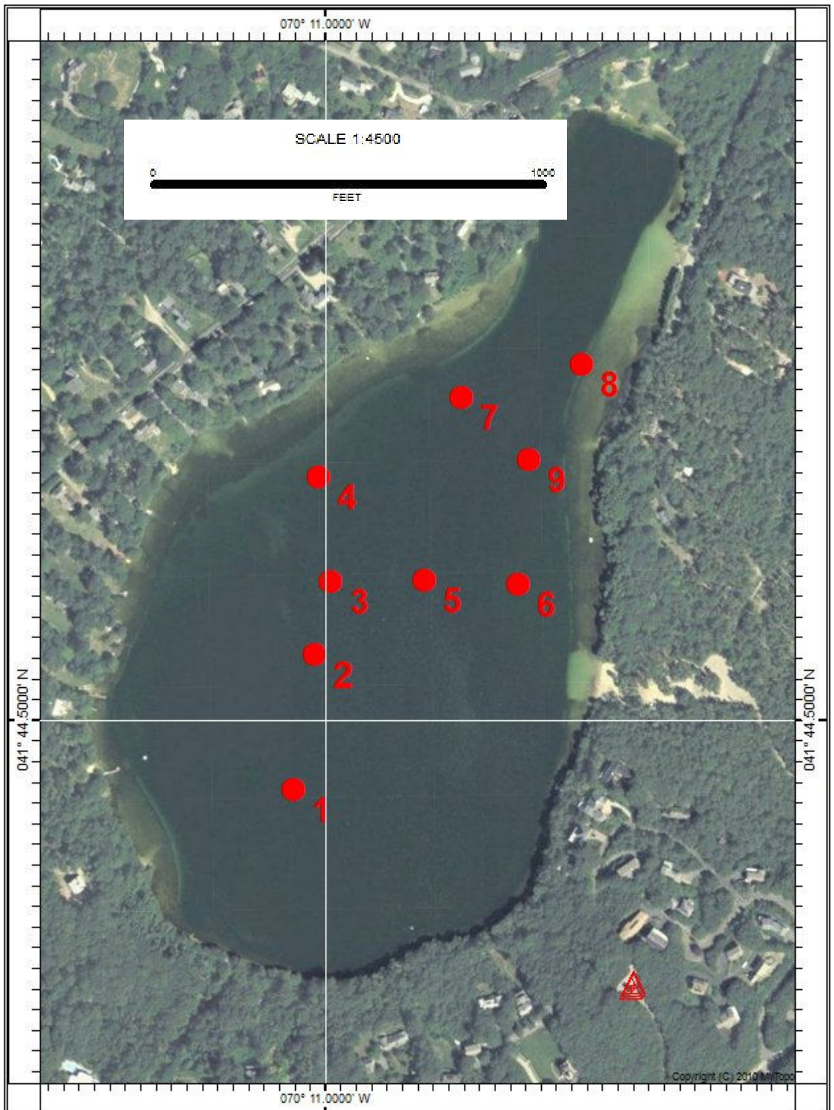


Figure 1. Ponds regularly sampled by Dennis volunteers.
The 11 ponds with name labels have been regularly sampled by Dennis volunteers with resulting water quality data reviewed by Eichner (2009). Scargo Lake, the focus of this Tech Memo, is indicated within the red box. The Town of Dennis has a total of 57 freshwater ponds (Eichner and others, 2003).



			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 2. 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. The January cores are still being incubated as of the date of this technical memorandum since the minimum time required for the anoxic cores to reach equilibrium is 90 days. Core locations are shown in the associated table. Location SGO-9 replaced SGO-8 in the winter survey.

Figure 3. 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 4. 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 5. 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.

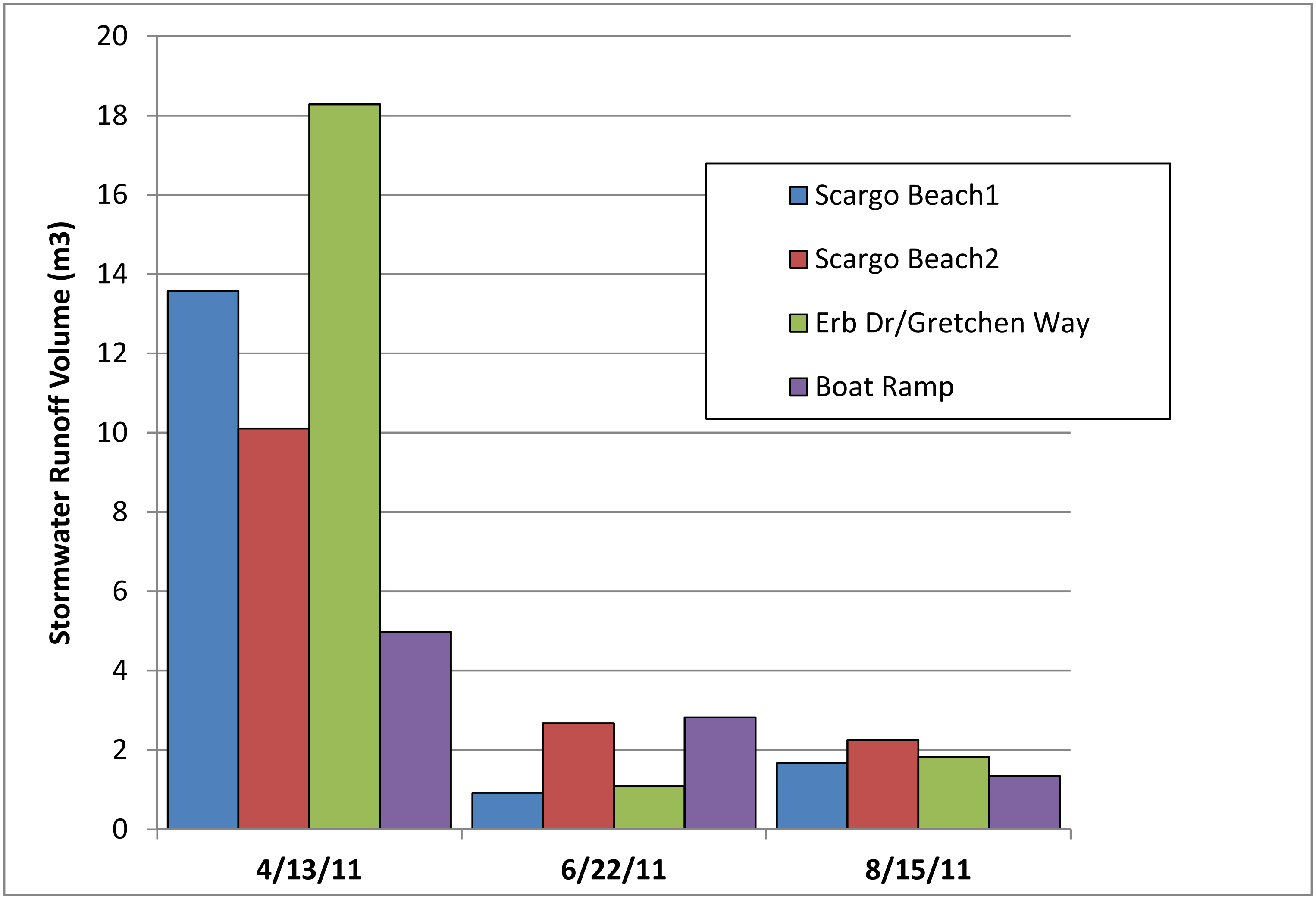


Figure 6. Measured 2011 Stormwater Runoff Volumes: Scargo Lake.

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.

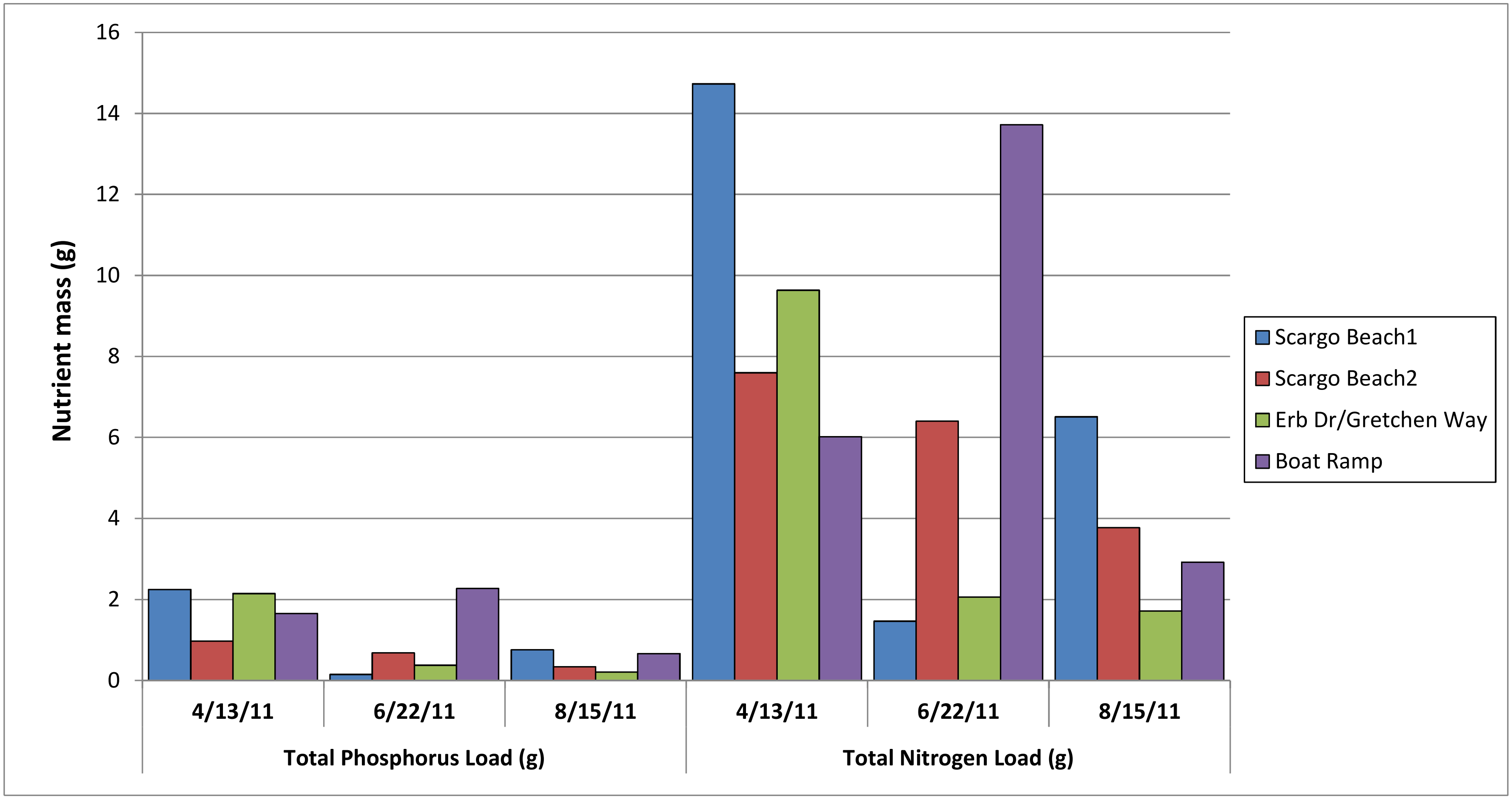


Figure 7. Measured Stormwater Nutrient Loads (Total Phosphorus and Total Nitrogen): 2011 Scargo Lake.
Nutrient loads are sum totals of each storm event. The April 13, 2011 storm cumulatively generated more nutrient inputs to Scargo Lake than either of the other two storms, but at selected locations higher 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.

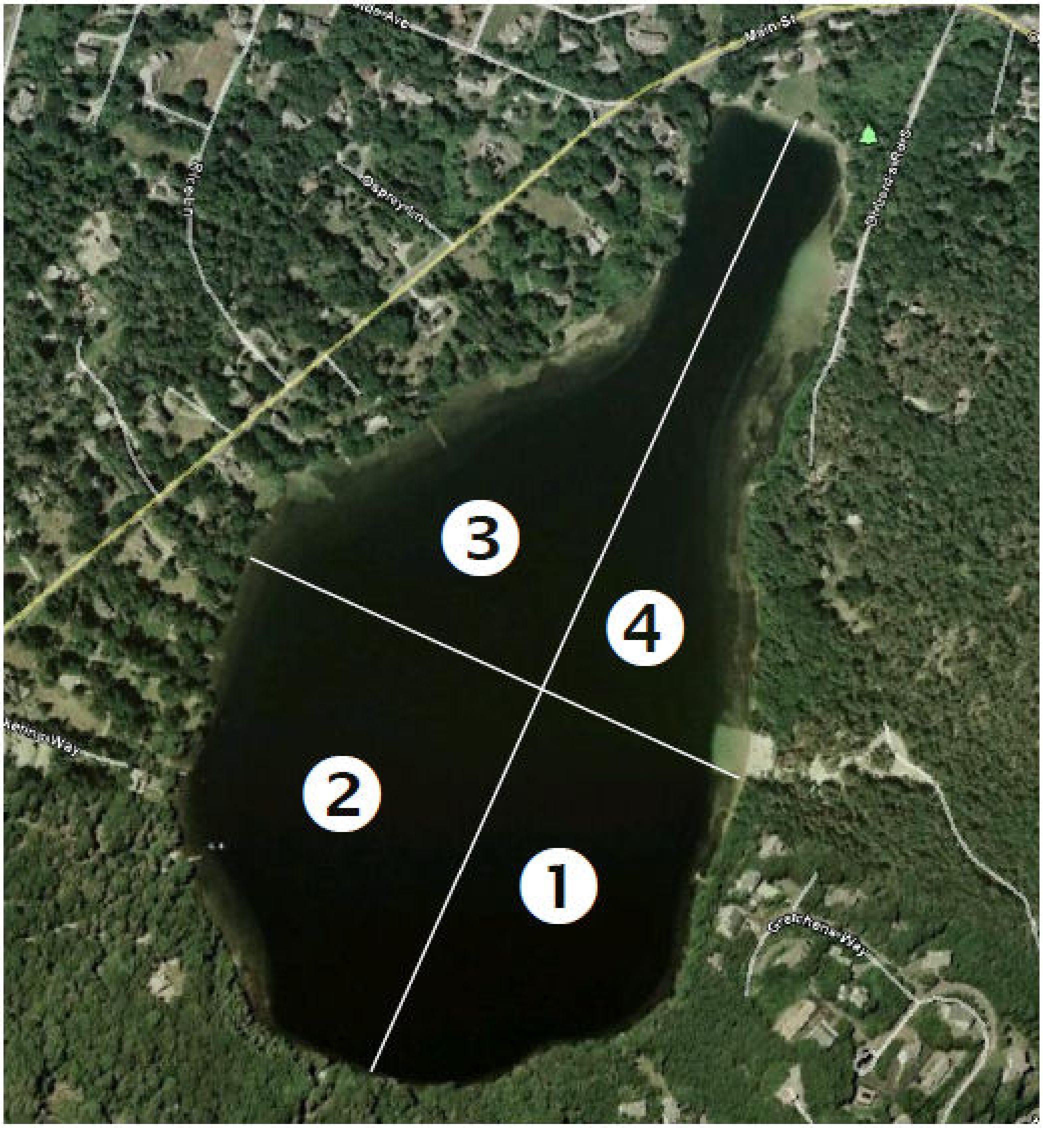


Figure 8. Scargo Lake Bird Counting Quadrants.
A volunteer team of John Harper and Cliff Adams conducted 54 bird counts of the Scargo Lake surface between October 10, 2010 and September 30, 2011. Birds were counted within each quadrant, their species noted, and their distance from shore (whether they were within or beyond 20 ft of the shoreline).

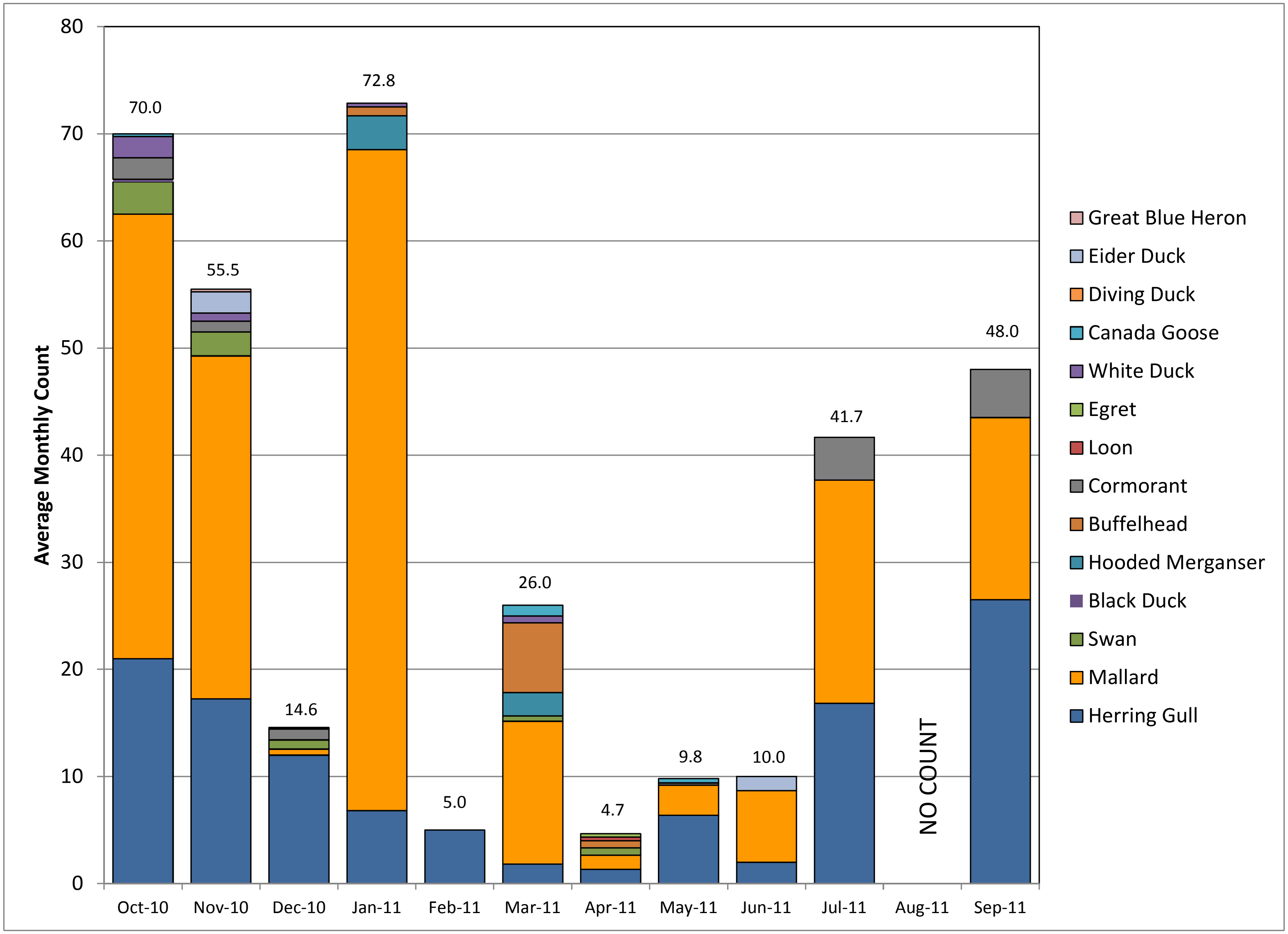


Figure 9. Average Monthly Bird Counts on Scargo Lake (October 10, 2010 and September 30, 2011).
Surveys per month ranged between 3 and 7. No readings were collected in August 2011. Overall average is 34 birds per month with a total count of 1,848 birds. Mallards and herring gulls are the most common birds observed.

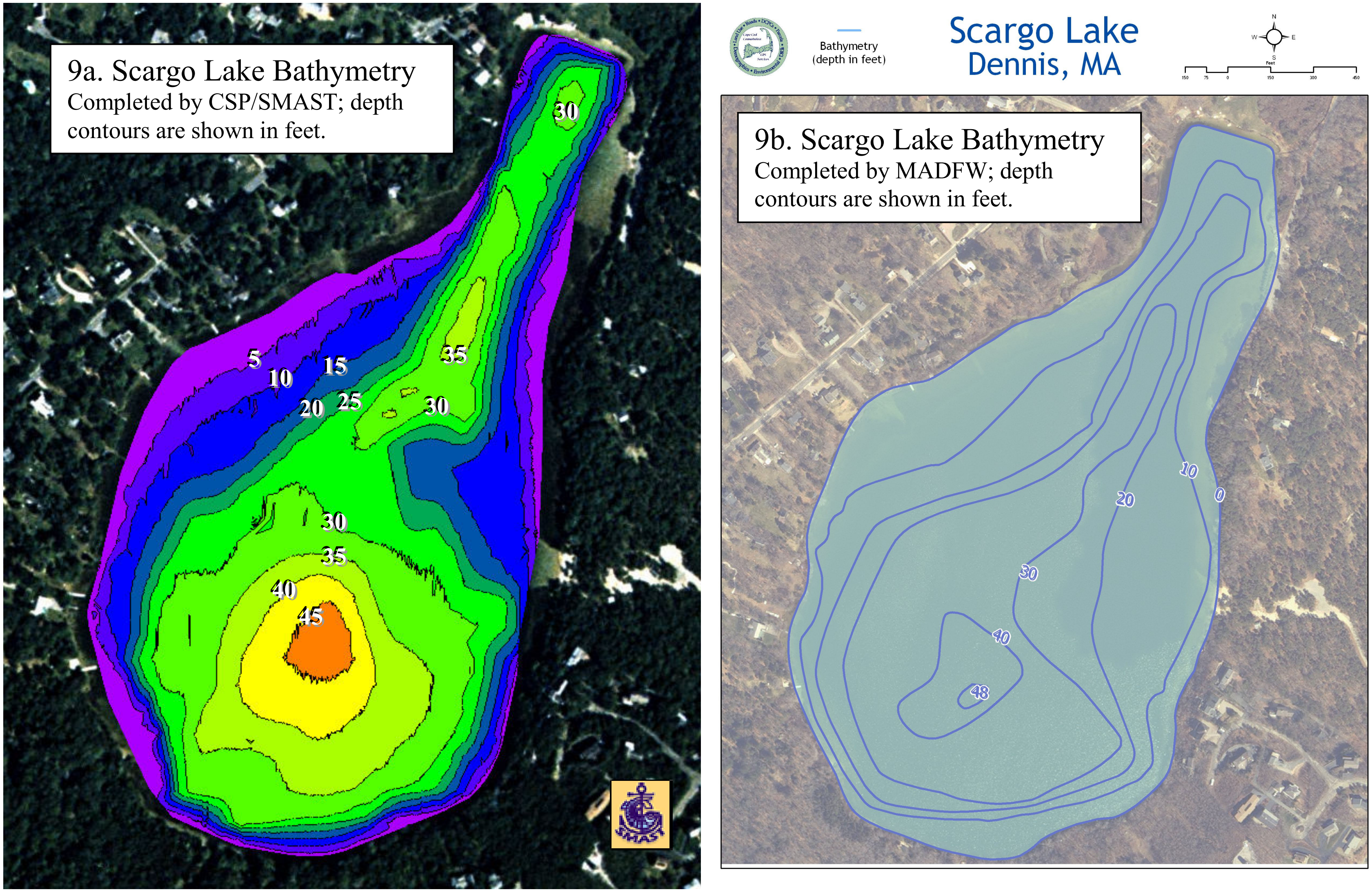


Figure 10. Comparison of Scargo Lake Bathymetry (CSP/SMAST and MADFW).
7a shows bathymetry developed by CSP/SMAST staff for this project, while 7b shows Massachusetts Division of Fish and Wildlife bathymetry (modified from Eichner (2009)). Project bathymetry has 5-ft contour intervals, which allows for a more refined volume calculation. Based on the CSP/SMAST bathymetry, the volume of Scargo Lake is 8% larger than the volume based on the MADFW bathymetry.

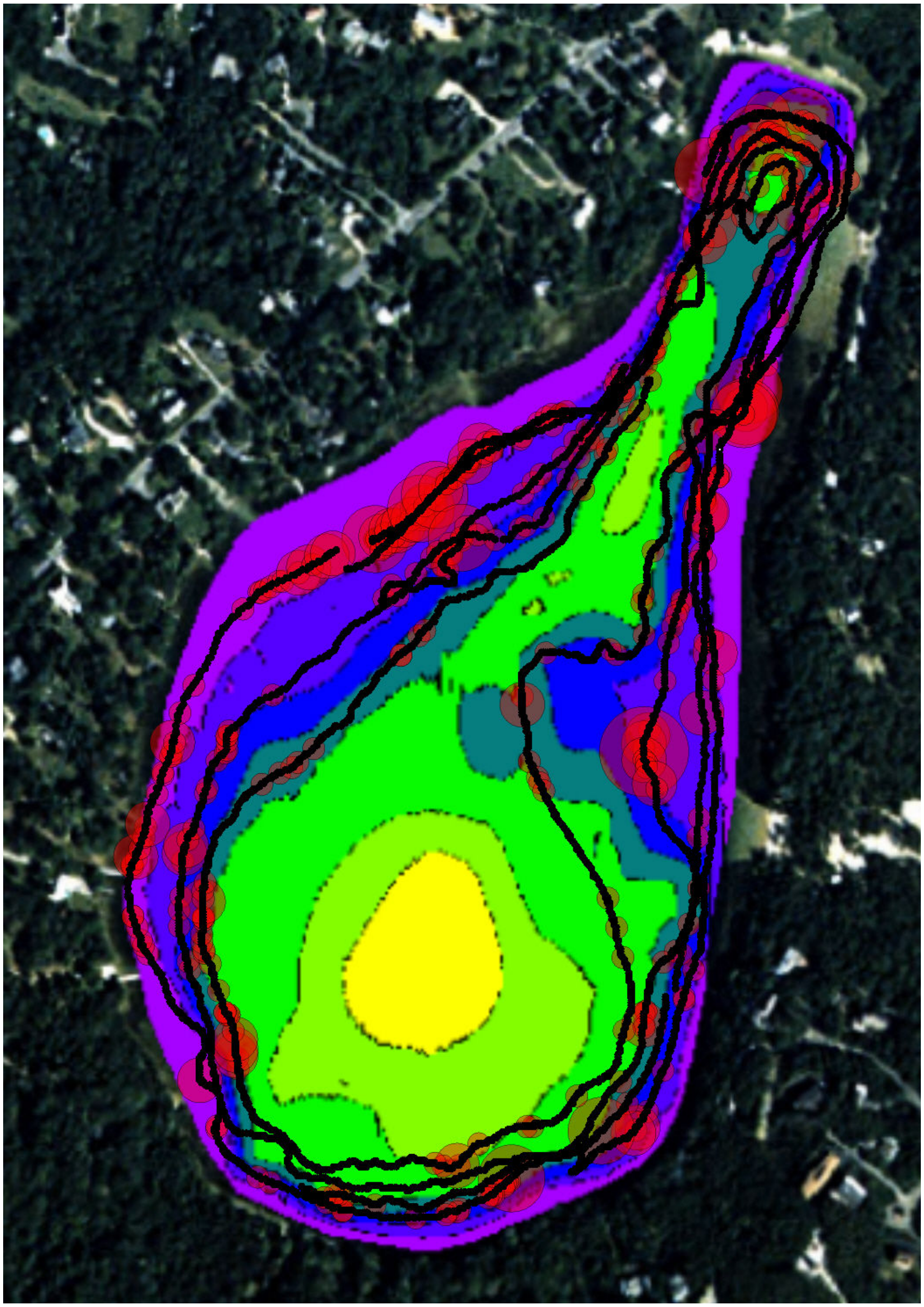


Figure 11. Scargo Lake Freshwater Mussel Survey.

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 size 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 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.

Table 1. Scargo Lake Sediment Efflux (August 10, 2010).

Sediment cores collected at sites indicated in Figure 2 at depths noted below. All values indicated as sediment release in milligrams per square meter per day under aerobic conditions. Negative nutrient values indicate uptake from the water column by the sediments. Average water quality data (Eichner, 2009) indicates that anoxic conditions can be found each summer at depths as shallow as 8 m. Cores collected in January 2012 at most of the same locations are in the process of being incubated for anoxic conditions, which requires 90 days for completion.

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 N 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

Table 2. Scargo Lake 2010 Water Quality Sampling Data.

Water quality samples and field measurements of Secchi depth, total depth, and temperature and dissolve oxygen profiles were collected on April 26, August 30, September 15, October 28, and November 12. Water quality samples were analyzed 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, pH, alkalinity, chlorophyll *a*, and phaeophytin. Key parameters are presented in this table.

Pond Name	Date	Sample Depth (m)	QC	Pond Depth (m)	Secchi Depth (m)	% Secchi	Temp °C	D.O. mg/L	pH	Alk mg/L CaCO3	TP (ppb)	TN (ppm)	Chl a ug/L	Phaeo ug/L
Scargo	4/26/10	0.5		15.1	5.02	33.2%	14.1	10.66	6.01	7.20	10.36	0.42	3.25	0.42
Scargo	4/26/10	1					14.1	10.6						
Scargo	4/26/10	2					14.1	10.67						
Scargo	4/26/10	3					14.1	10.63	6.12	7.30	14.63	0.42	2.58	1.08
Scargo	4/26/10	4					14.1	10.57						
Scargo	4/26/10	5					13.9	10.52						
Scargo	4/26/10	6					12.2	11.58						
Scargo	4/26/10	7					10.1	11.69						
Scargo	4/26/10	8					9	10.32						
Scargo	4/26/10	9					8.6	9.38	6.12	6.90	14.63	0.45	4.14	2.71
Scargo	4/26/10	10					8.3	8.23						
Scargo	4/26/10	11					8	7.01						
Scargo	4/26/10	12					7.9	5.22						
Scargo	4/26/10	13					7.8	4.93						
Scargo	4/26/10	14					7.7	4.24	6.12	6.50	15.65	0.66	5.89	3.69
Scargo	4/26/10	14.1					7.7	4.17						
Scargo	8/30/10	0.5		14.25	3.5	24.6%	23.5	8.35	7.08	8.4	10.25	0.46	2.51	1.15
Scargo	8/30/10	1					23.5	7.98						
Scargo	8/30/10	2					23.4	8.24						
Scargo	8/30/10	3					23.1	8.24	7.01	8.3	7.83	0.48	2.73	1.46
Scargo	8/30/10	4					22.8	8.15						
Scargo	8/30/10	5					22.3	7.98						
Scargo	8/30/10	6					22.0	6.89						
Scargo	8/30/10	7					21.7	6.52						
Scargo	8/30/10	8					19.8	3.23						
Scargo	8/30/10	9					14.4	ND	6.95	11.1	11.93	0.49	12.93	8.67
Scargo	8/30/10	10					12.4	ND						
Scargo	8/30/10	11					11.1	ND						
Scargo	8/30/10	12					10.3	ND	6.45	21.5	13.80	1.41	<0.05	87.19
Scargo	8/30/10	13					10.3	ND						
Scargo	8/30/10	13.2					10.3	ND	6.35	22.2	15.29	1.41	<0.05	53.43
Scargo	9/15/10	0.5		13.5	3.85	28.5%	21.3	7.65	7.08	8.3	10.81	0.36	3.35	<0.05
Scargo	9/15/10	1					21.3	7.62	7.06	8.2	11.62	0.41	4.56	<0.05
Scargo	9/15/10	2					21.3	7.57	NS	NS	NS	NS	NS	NS
Scargo	9/15/10	3	Sample				21.3	7.54	7.08	8.3	11.01	0.42	3.72	0.70
Scargo	9/15/10	3	FD				21.3	7.54	7.08	8.2	11.62	0.39	3.58	0.80
Scargo	9/15/10	4					21.3	7.53	7.04	8.1	9.99	0.45	3.78	0.48
Scargo	9/15/10	5					21.3	7.47	NS	NS	NS	NS	NS	NS
Scargo	9/15/10	6					21.3	7.31	7.08	8.3	6.12	0.42	1.78	0.10
Scargo	9/15/10	7					21.2	7.06	NS	NS	NS	NS	NS	NS
Scargo	9/15/10	8					21.1	6.75	6.84	8.5	8.77	0.48	6.13	1.51
Scargo	9/15/10	9					17.5	2.43	6.81	9.4	8.16	0.52	7.12	0.07
Scargo	9/15/10	10					13.7	1.17	6.76	11.4	22.94	0.54	14.32	10.31
Scargo	9/15/10	11					11.8	0.002	6.72	12.8	31.98	0.68	5.17	69.64
Scargo	9/15/10	12					10.5	0.002	6.88	22.5	45.02	1.20	<0.05	74.98
Scargo	9/15/10	12.5					10.0	0.002	6.91	26.0	34.85	1.57	<0.05	48.78

Table 2. Scargo Lake 2010 Water Quality Sampling Data.

Water quality samples and field measurements of Secchi depth, total depth, and temperature and dissolve oxygen profiles were collected on April 26, August 30, September 15, October 28, and November 12. Water quality samples were analyzed 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, pH, alkalinity, chlorophyll *a*, and phaeophytin. Key parameters are presented in this table.

Pond Name	Date	Sample Depth (m)	QC	Pond Depth (m)	Secchi Depth (m)	% Secchi	Temp °C	D.O. mg/L	pH	Alk mg/L CaCO3	TP (ppb)	TN (ppm)	Chl a ug/L	Phaeo ug/L
Scargo	10/28/10	0.5	Sample	13.75	3.35	24.4%	15.8	9.55	7.41	10.1	10.56	0.40	3.00	1.24
Scargo	10/28/10	0.5	FD				15.8	9.55	7.14	9.3	10.37	0.41	3.59	0.50
Scargo	10/28/10	1					15.8	9.54	7.12	9.5	10.75	0.43	4.21	0.59
Scargo	10/28/10	2					15.4	9.38	NS	NS	NS	NS	NS	NS
Scargo	10/28/10	3					15.2	9.34	7.12	9.7	12.29	0.42	4.43	0.36
Scargo	10/28/10	4					15.0	9.24	7.21	9.5	11.52	0.42	2.74	0.58
Scargo	10/28/10	5					14.6	9.07	NS	NS	NS	NS	NS	NS
Scargo	10/28/10	6					14.0	8.90	7.12	9.3	12.29	0.44	1.21	0.82
Scargo	10/28/10	7					13.8	8.64	NS	NS	NS	NS	NS	NS
Scargo	10/28/10	8					13.5	8.19	6.98	9.8	9.98	0.41	0.69	0.99
Scargo	10/28/10	9					13.5	8.09	7.22	11.3	8.45	0.52	0.56	1.19
Scargo	10/28/10	10					13.5	8.23	7.23	11.7	10.37	0.55	0.40	1.39
Scargo	10/28/10	11					13.4	7.35	7.22	11.7	11.52	0.62	0.53	1.49
Scargo	10/28/10	12					13.2	8.73	7.34	12.3	9.98	0.55	0.72	1.15
Scargo	10/28/10	12.75					ND	5.95	7.08	12.0	18.24	0.69	0.96	3.07
Scargo	11/12/10	0.5		13.7	2.95	21.5%	10.0	10.74	6.89	9.0	6.23	0.53	5.53	1.37
Scargo	11/12/10	1					9.9	10.70	7.05	9.0	13.65	0.55	4.77	1.42
Scargo	11/12/10	2					9.9	10.69	NS	NS	NS	NS	NS	NS
Scargo	11/12/10	3	Sample				9.9	10.68	7.00	9.1	11.45	0.57	5.25	1.84
Scargo	11/12/10	3	FD				9.9	10.68	7.01	9.6	12.65	0.92	4.90	1.89
Scargo	11/12/10	4					9.9	10.66	7.10	9.0	11.04	0.56	4.93	1.94
Scargo	11/12/10	5					9.9	10.69	NS	NS	NS	NS	NS	NS
Scargo	11/12/10	6					9.9	10.66	7.12	8.8	12.05	0.62	5.32	1.72
Scargo	11/12/10	7					9.9	10.66	NS	NS	NS	NS	NS	NS
Scargo	11/12/10	8					9.9	10.64	7.07	9.1	17.47	0.57	4.31	2.32
Scargo	11/12/10	9					10.0	10.63	7.09	9.1	11.45	0.59	5.03	1.24
Scargo	11/12/10	10					10.0	9.28	7.08	9.2	17.27	0.54	4.10	2.74
Scargo	11/12/10	11					10.0	10.61	7.19	9.4	12.45	0.54	4.99	1.46
Scargo	11/12/10	12					10.0	10.56	7.17	9.1	12.45	0.53	5.51	0.98
Scargo	11/12/10	12.7					10.1	10.34	7.26	9.6	14.66	0.62	4.68	1.98