Lake Wequaquet
Water Quality Assessment

FINAL REPORT
January, 2009

for the

Town of Barnstable
and
Cape Cod Commission

Prepared by:

Coastal Systems Group
School of Marine Science and Technology
University of Massachusetts Dartmouth
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New Bedford, MA 02744-1221

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This project was completed under a subcontract with the Cape Cod Commission from the Town of Barnstable

Acknowledgement: Special thanks to Gail Maguire, Gale Klun, and Roger Bodley of the Wequaquet Lake Protective Association, Rob Gatewood and Dale Saad of the Town of Barnstable, Tom Cambareri and Gabrielle Belfit of the Cape Cod Commission, Brian Howes, Dave White, and Betsy White of SMAST for all their help in completing this project.

Cover photo: Ed Eichner, Lake Wequaquet from Shootflying Hill Road Beach, 2008

Executive Summary

Lake Wequaquet
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Lake Wequaquet is the largest pond in the Town of Barnstable and the third largest on Cape Cod with a surface area of nearly 600 acres. Water quality concerns in the lake have become an increasingly frequent discussion among lakeside residents, users of the lake, and town officials. Town officials have worked with the Wequaquet Lake Protective Association, Inc. (WLPA), which was formed in 1993, to address a number of lake-specific issues, including high water levels in 1996 (Eichner and others, 1998) and a proposal for public sewers around the lake (Tighe & Bond, 2004). However, the last extensive sampling of water quality in the lake was completed over 20 years ago (IEP/KV, 1989). In order to help the town evaluate current water quality conditions in the lake and the connected basins of Bearses Pond and Gooseberry Pond, the Town of Barnstable contracted with the Coastal Systems Program, School of Marine Science and Technology (SMAST), University of Massachusetts Dartmouth through the Cape Cod Commission (CCC) to update the understanding of water quality in Lake Wequaquet.

Working in partnership with the Town of Barnstable Conservation Division and members of the WLPA, project staff collected water quality data during the summer of 2007. This data collection included water samples, measurements of the outlet stream, and collection of phytoplankton and periphyton samples. SMAST staff have reviewed and interpreted the resulting data and provide an assessment of the current water quality in Lake Wequaquet, as well as a comparison to the 1986 conditions. This report documents the sampling results and their interpretation, as well as an evaluation of the relationship of the lake to its watershed through water, nitrogen, and phosphorus budgets.

This review of Lake Wequaquet includes information developed as part of a review of all available water quality data for all Barnstable ponds that was also completed this year (Eichner, 2008). The comprehensive review of all Barnstable pond data found that most ponds in town have excessive phosphorus and chlorophyll-*a* concentrations and about half have average dissolved oxygen concentrations failing to meet state standards. This town-wide review recommends that the town consider:

a) an expanded annual monitoring program,
b) continued prioritization and detailed assessment of individual ponds,
c) developing bathymetric and watershed delineation information for all ponds,
d) development of pond specific nutrient thresholds equivalent to TMDLs, and
e) review local regulations to ensure that proper pond protection best management practices are incorporated.

The review of 2007 water quality data indicates that water quality in Lake Wequaquet and it subbasins are not impaired based on state surface water regulatory criteria. The lake and all its basins met the state's dissolved oxygen concentration limit of 5 ppm during the 2007 sampling season. The lake and its basins also met this criterion 20 years ago and there is essentially no difference in dissolved oxygen conditions between the 1985-86 and 2007 datasets. Further, there is also no indication that the lake is failing to meet the state regulatory standards for recreational or habitat uses.

While the lake is meeting state regulations, data indicates that other water quality measures in the lake have worsened significantly between 1986 and 2007. Total phosphorus concentrations and Secchi readings are significantly worse. In addition, total phosphorus, total nitrogen, and chlorophyll-*a* concentrations are all above recommended Cape Cod-specific standards (Eichner and others, 2003). Other ponds in Barnstable with similar conditions fail to meet state regulatory standards, but the individual characteristics of Lake Wequaquet suggest that it may be somewhat resistant to falling below state thresholds. It is recommended that the town institute a long term monitoring plan as part of an overall management strategy to keep track of conditions in the lake.

Review of the phosphorus budget and the 2007 water quality data indicates that there are two likely sources of the rise in total phosphorus concentrations: 1) wastewater from houses that existed in 1986, but had not yet impacted the lake and 2) an apparent loss of rooted aquatic plants since 1986. A refined plant survey is recommended to evaluate which of these is the primary source. Depending on the results of this sampling, the management of the phosphorus concentrations could target nearshore houses, the in-lake plant community, or some combination of both. Evaluation of phosphorus and nitrogen concentrations show that management of phosphorus is the key to managing the water quality of Lake Wequaquet.

Sediment sampling shows that the lake and all its basins have a significant buildup of phosphorus in bottom sediments since the last sampling in 1986. Because these samples are somewhat limited and these sediments could significantly impact the water quality in the lake, it is recommended that the town consider collecting sediment cores and testing the cores to see what conditions are required to mobilize this increased phosphorus.

The Wequaquet Lake Protective Association, Inc. has the potential to be a more active participant in providing information to assist in resolving the identified issues and monitoring the condition of the lake. The WLPA has collected field data in the past similar to those reviewed in this report (*i.e.*, Secchi, dissolved oxygen and temperature). A volunteer monitoring program formed from a Town/WLPA partnership would provide a better sense of the water quality fluctuations, as well as providing a regular gauge of whether conditions are failing to meet state surface water regulations. A refined version of the annual WLPA plant survey could be part of this program.

Based on the data review, SMAST staff recommends that the Town consider the following next steps to ensure that Lake Wequaquet continues to meet state water quality standards and meet community goals:

1. Collect and test sediment cores to establish dissolved oxygen thresholds and evaluate the potential for phosphorus release from the sediment that would prompt higher algal density and decreased clarity,

2. Conduct a refined aquatic plant survey of the lake to establish whether management of phosphorus loads to the lake is best targeted at wastewater from nearshore properties or aquatic plant management,
3. Establish a regular monitoring program to ensure that water quality conditions do not worsen and remain in compliance with state surface water standards,
4. Develop a management plan for the lake that includes water quality thresholds and goals, water level management, best management practices for land uses on abutting properties, and water sheet management for activities on the lake.

School of Marine Science and Technology (SMAST) staff are available to elaborate on these recommendations and assist the town in the development of strategies to address the long term management and protection of Lake Wequaquet.

Recommended Citation
Eichner, E. 2008. Lake Wequaquet Water Quality Assessment. Completed for the Town of Barnstable and the Cape Cod Commission. Coastal Systems Program, School of Marine Science and Technology, University of Massachusetts Dartmouth. 81 p.

Table of Contents

Lake Wequaquet Water Quality Assessment

Final Report
January, 2009

List of Figures and Tables

Lake Wequaquet Water Quality Assessment

Final Report
January, 2009

Figures

Tables

I. Introduction

Lake Wequaquet is the largest pond in the Town of Barnstable and the third largest on Cape Cod (Figure I-1). The lake has a surface area of nearly 600 acres. Over the last few years, lake water quality concerns have been a much discussed topic among lakeside residents, users of the lake, and town officials. The last comprehensive review of lake water quality was nearly 20 years ago (IEP, 1989). Much has changed over those 20 years: 1) citizens formed the Wequaquet Lake Protective Association, Inc. (WLPA) in 1993, 2) high water levels in 1996 raised public concerns and were the subject of a water level analysis (Eichner and others, 1998), 3) public sewers were proposed around the lake (Tighe & Bond, 2004) 4) the town began a nuisance aquatic plant program and 5) the regional Pond and Lake Stewards (PALS) program was started. In order to account for all these efforts, changes, and growing concerns, the Town of Barnstable contracted with the Coastal Systems Program at the School of Marine Science and Technology (SMAST), University of Massachusetts Dartmouth through the Cape Cod Commission (CCC) to update the understanding of water quality in Lake Wequaquet.

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This review of Lake Wequaquet includes information developed as part of a review of all available water quality data for all Barnstable ponds that was also completed this year (Eichner, 2008). The comprehensive review of Barnstable pond data found that most ponds in town have excessive phosphorus and chlorophyll *a* concentrations and about half have average dissolved oxygen concentrations failing to meet state standards. This review recommends that the town consider a) an expanded annual monitoring program, b) continued prioritization and detailed assessment of individual ponds, c) developing bathymetric and watershed delineation information for all ponds, d) development of pond or pond group specific nutrient thresholds equivalent to TMDLs, and e) review local regulations to ensure that proper pond protection best management practices are incorporated. This assessment of Lake Wequaquet is an example of the type of detailed assessment recommended for individual ponds, as is 2006 assessment completed for the Indian Ponds (Eichner and others, 2006).

II. History and Characteristics of Lake Wequaquet

Lake Wequaquet is located within the Barnstable Outwash deposits and within the Sagamore groundwater flow cell, the largest of the Cape's groundwater aquifer lenses (see Figure I-1). The outwash deposits are sand and gravel deposited by meltwater flowing off the southern face the retreating glaciers approximately 15,000 years ago at the end of the last ice age or the end of the late Wisconsinan Glacial Stage of the Pleistocene Epoch (Oldale, 1992). Just to the north of Lake Wequaquet is the Sandwich Moraine, which was formed by the readvance of

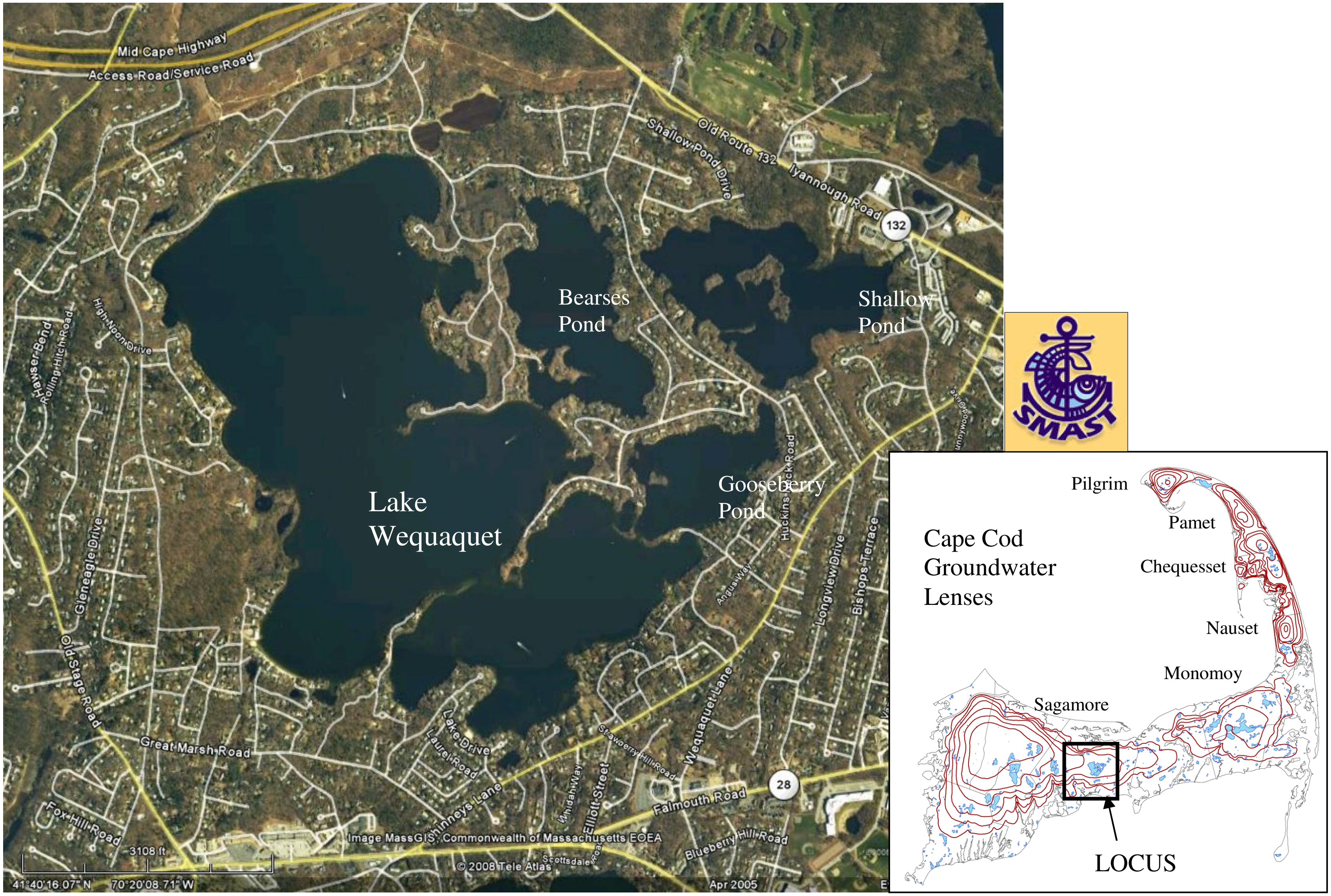


Figure I-1. Lake Wequaquet Locus Map and Cape Cod Groundwater Lenses
Lake Wequaquet is part of the Sagamore Groundwater Lens. Lake Wequaquet area map is from Google Earth and shows Route 132 to the northeast, Route 6/Mid-Cape Highway to the north, Old Stage Road to the west, and Phinney's Lane to the south.

glaciers into previously deposited materials; pushing them into a large mound somewhat like a large bulldozer. Route 6 generally runs along the top of this moraine.

The sandy outwash deposits around the lake are highly permeable and capable of storing a vast amount of water in their pore spaces; water that fills these spaces is referred to as groundwater. The Cape's groundwater system was designated as the Cape Cod Sole Source Aquifer by the U.S. Environmental Protection Agency in 1982; this designation acknowledges that the aquifer system is Cape Cod's only source of potable water. The aquifer is bounded by the water table at its surface, the surrounding marine waters at it margins, and bedrock below (LeBlanc and others, 1986). The aquifer within the Barnstable outwash is approximately 250 feet thick and the average groundwater flow rate is approximately one foot per day (Masterson and others, 1996).

The deeper basins of Lake Wequaquet (Figure II-1) were formed by one or more large ice blocks left by retreating glaciers; outwash deposits eventually buried these blocks and when they melted the land surface collapsed into the resulting holes leaving the depressions that eventually became the lake (Strahler, 1966). Other ice blocks in the area created the depressions that have become Bearses Pond and Shallow Pond. Based on pollen collected from pond sediments in outer Cape Cod (Winkler, 1985), it is likely that these Barnstable ponds are at least 12,000 years old. Groundwater levels rose in response to the post-glacial rise in sea level, which is estimated to have attained its modern level approximately 6,000 years ago, (Ziegler and others, 1965).

Lake Wequaquet, which includes the portions called Bearses Pond and Gooseberry Pond, has an overall average depth of 3.7 meters (12.2 feet), a maximum measured depth of 10.4 meters (34 feet), and holds an average of 10.5 million cubic meters (2.7 billion gallons). The herring run that is the only surface water discharge from Wequaquet connects the lake to Long Pond and eventually to the Centerville River estuary system. The herring run is 131 years old; it was dug in 1867 by unemployed veterans of the Civil War (Hays and Ranta, 1976).

III. Watershed Delineation and Water Budget

A pond water budget accounts for the volume of water in the pond and the balance of flows of water entering and leaving the pond. In Cape ponds, groundwater typically enters the pond along one shoreline from its watershed (*i.e.*, the upgradient side) and a similar amount of pond water discharges from the pond and reenters the aquifer system along the opposite shoreline (*i.e.*, the downgradient side). Occasionally, there are also surface water inputs or outputs from connecting streams that alter how water enters or leaves the lake. Lake Wequaquet has some additional unique features because of its morphology and its location on the regional divide of the Sagamore Lens.

III.1. Watershed Delineation

Watershed delineations on the Cape are largely determined by groundwater elevations and the topography of the water table (Cambareri and Eichner, 1988). In order to organize all of the hydrogeologic information that has been developed over the past few decades for the Sagamore Lens, the US Geological Survey (USGS) created a regional groundwater model, the most recent iteration of which is described in Walter and Whealan (2004).

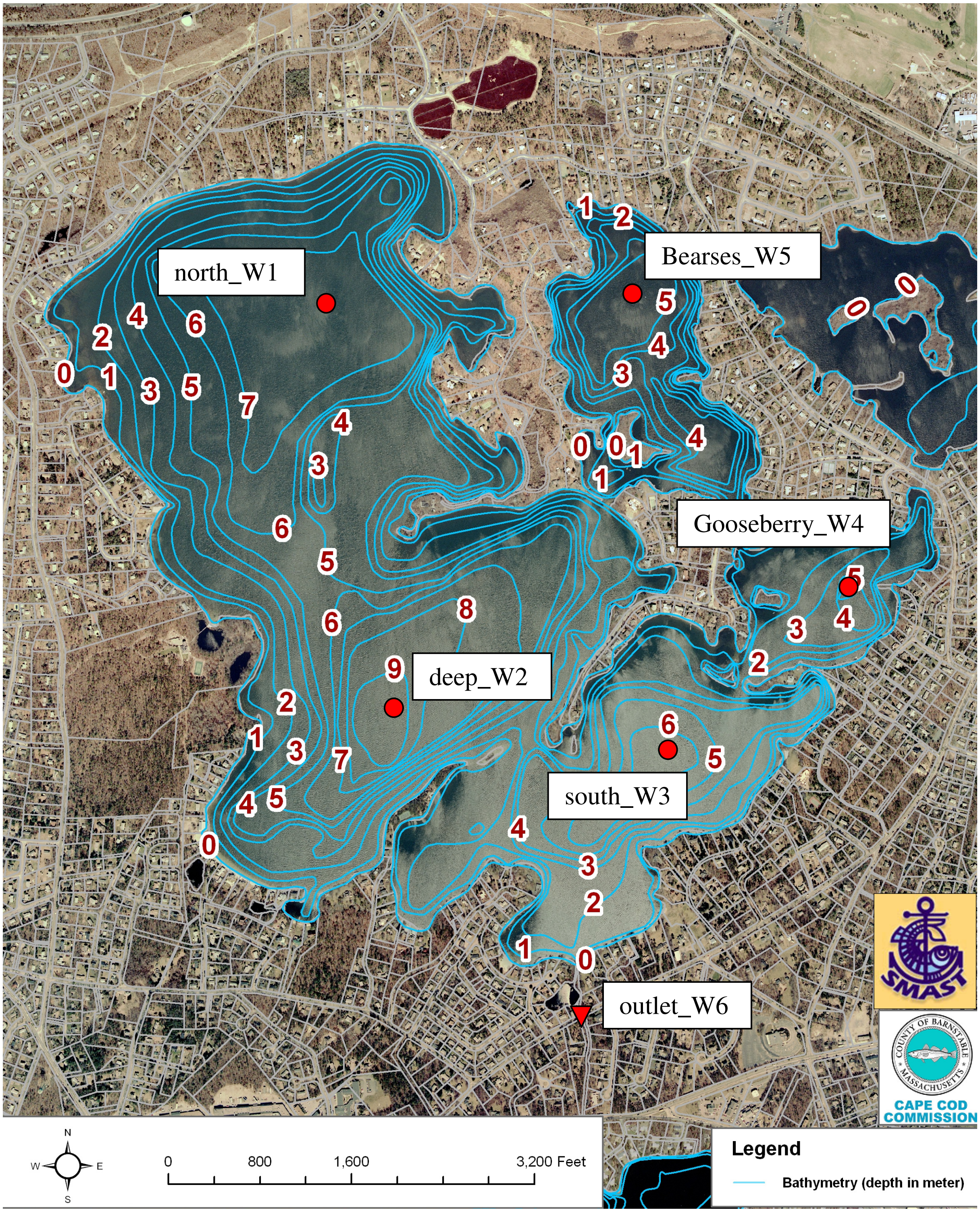


Figure II-1. Lake Wequaquet Bathymetry and Water Quality Sampling Stations
Red circles indicate five in-pond sampling locations where shallow and deep samples were collected for this assessment. Red triangle at outlet_W6 is located on the southern side of the herring run culvert under Phinney's Lane.

This model incorporates information characterizing groundwater levels, municipal drinking water supply pumping, stream flow measurements, and geologic information developed over a number of decades. The model relies on the USGS three-dimensional, finite-difference groundwater model MODFLOW-2000 (Harbaugh and others, 2000) and the USGS particle-tracking program MODPATH4 (Pollock, 1994). MODPATH4 uses output files from MODFLOW-2000 to track the simulated movement of water in the aquifer and can be used to delineate the contributing areas or watersheds to wells, streams, ponds, and coastal water bodies.

The USGS is part of the technical team working on the Massachusetts Estuaries Project (MEP) and the USGS Sagamore Lens model was used to delineate a watershed to the Centerville River estuary system during its MEP assessment (Howes and others, 2006). The MEP watershed to the Centerville River estuary includes a number of subwatersheds, including a single, combined watershed to Lake Wequaquet, Bearses Pond, and Shallow Pond. This initial MEP watershed is the basis for the watershed analyses in this report. The watershed delineation for this project modifies MEP/USGS watershed by adding internal subwatersheds to each of the pond basins (Figure III-1). These dividing lines between Lake Wequaquet's basins are largely based on results from previous water table evaluations in the study area (Eichner and others, 1999) and water table exploration in other parts of the Cape, specifically looking at isthmuses between two surface waters (*e.g.*, Seacoast Shores, Falmouth; Ashumet/Johns Ponds).

Previous watershed delineations have included one done in 1988 and another in 1998 (Figure III-2). The IEP/KVA (1988) watershed delineation places the regional groundwater divide for the Sagamore Lens approximately 300 feet north of the northern shoreline to the lake and Bearses Pond, but has a much more limited upgradient watershed to both the east and west than the current project watershed. Water table measurements collected throughout the area of the lake by the CCC in 1998 (Eichner and others, 1998) resulted in an expanded watershed delineation, but continued to place the regional divide so that discharge from Wequaquet only flowed toward Nantucket Sound; the regional divide in this delineation is approximately 1,200 feet north of the northern shoreline. The 1998 delineation also has a much larger upgradient watershed to the west than the 1988 delineation and an eastern upgradient watershed that extends to a groundwater mound near the Hyannis Water Pollution Control Facility. The current project's watershed places the lake on the regional divide, which means that downgradient discharge out of the lake occurs through portions of both the northern and southern shorelines; northern flow from both Lake Wequaquet and Bearses Pond toward Cape Cod Bay and southern flow from both Lake Wequaquet and Gooseberry Pond toward Vineyard/Nantucket Sound (see Figure III-1).

In order to complete a water budget, the groundwater input into the lake and its basins is determined by the annual recharge rate within each basin watershed, precipitation that falls on its surface, and flow out of the basin back into groundwater. One of the keys in these estimates is the determination of annual precipitation and recharge (*i.e.*, precipitation that reaches the groundwater). Walter and Whealan (2005) evaluated precipitation between 1941 and 1995 at Hatchville, MA, which has the longest term precipitation reading is southeastern Massachusetts. This evaluation showed annual precipitation ranging between 26 inches in 1965 and 74 inches in 1972 with an annual average of 44 inches. Since water table elevations are a function of precipitation and the portion that reaches the water table (*i.e.*, recharge), USGS modeling

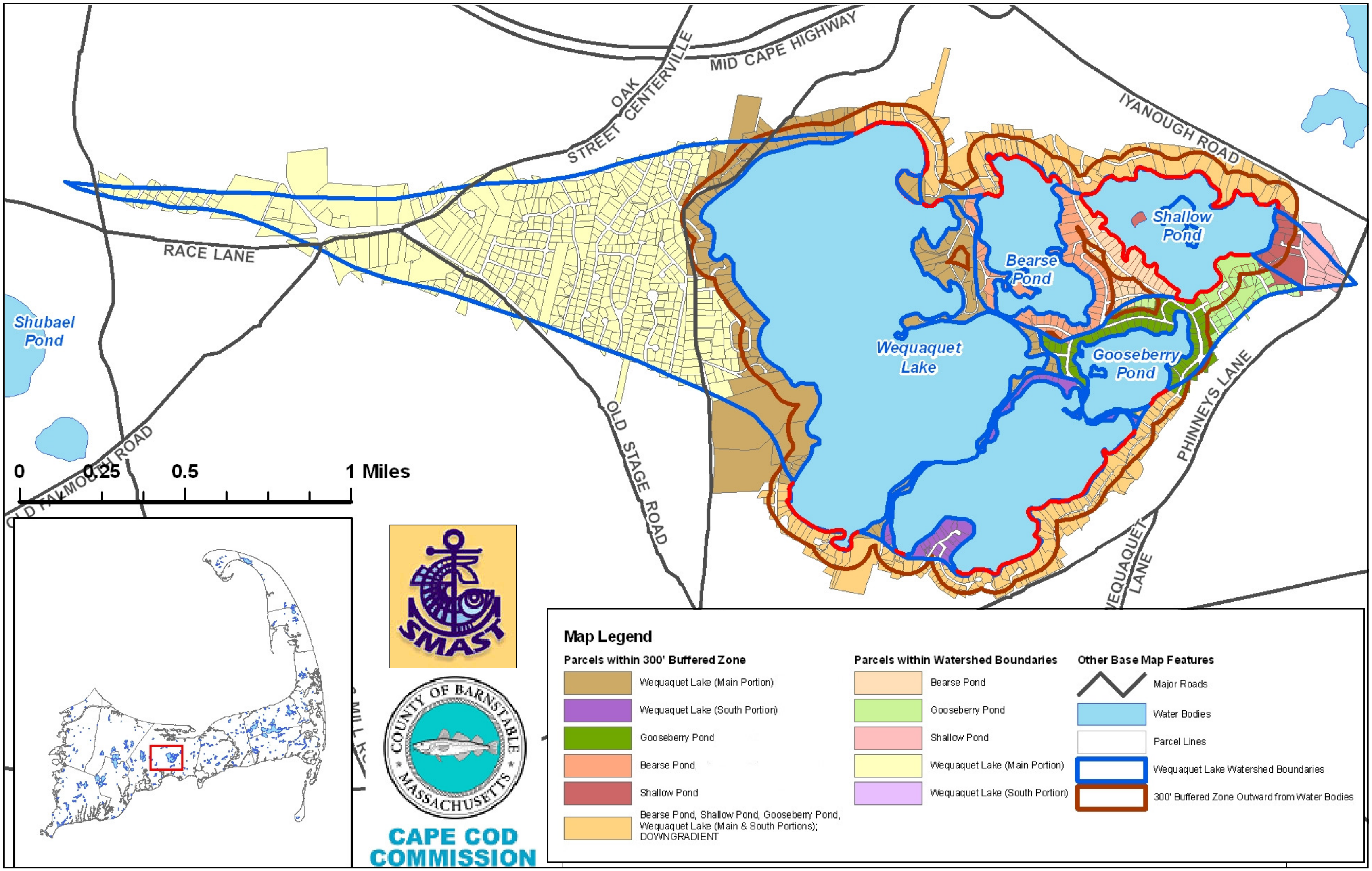


Figure III-1. Lake Wequaquet Watershed Delineation

Outer boundaries of delineation are based on the Massachusetts Estuaries Project delineation for the Centerville River (Howes and others, 2006). Interior basin subwatersheds are based on previous analyses in the area (*e.g.*, Eichner and others, 1998), evaluation of similar land forms on Cape Cod and best professional judgment. Parcels within 300 ft of the shoreline and within the watershed of each basin are assigned darker colors, while the other parcels in the watershed are assigned a lighter version of the same color. Parcels within 300 ft, but on downgradient or discharging shorelines (indicated by red), are all assigned the same color regardless of basin.

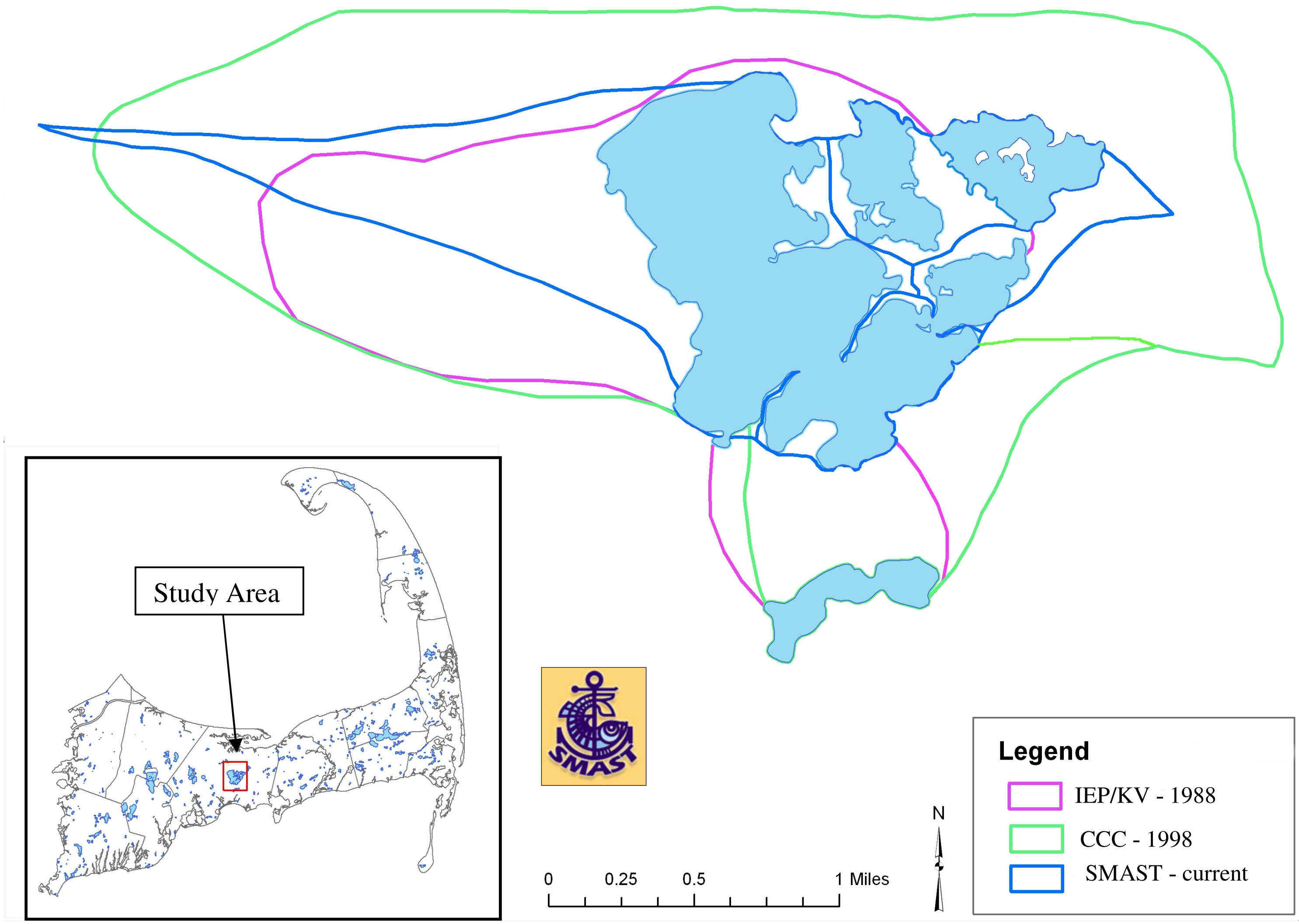


Figure III-2. Historic and Current Watershed Delineations for Lake Wequaquet
Previous and current watershed delineations for Lake Wequaquet are shown: 1988 delineation from the diagnostic/feasibility study (IEP/KV, 1988), 1998 Cape Cod Commission version from Lake Wequaquet water level study (Eichner and others, 1998) and the current delineation for this report.

compared recharge rates with long term average water table elevations. USGS modeling found that an overall recharge rate of 27.25 inches per year best matched the long term average water table elevations. USGS staff also reviewed evapotranspiration rates and determined that recharge rates of 15.8 inches per year on pond surfaces and no net recharge on wetland surfaces best matched the available data. Table III-1 shows the area of each subwatershed and pond and the corresponding recharge volumes.

III.2. Phinney's Lane Stream Outflow

Aside from lake water discharging back to groundwater along downgradient shorelines of the lake, discharge out of Lake Wequaquet also occurs through the Phinney's Lane culvert/herring run on the southern shoreline (see Figure II-1). During the current project, streamflow was measured on the south side of the Phinney's Lane culvert approximately monthly between May and October 2007 using a Pygmy current meter (Figure III-3). The initial flow reading of 13.1 cubic feet per second in early May 2007 was followed by declining flows throughout the summer with only a slight recovery in November. Although water was present in the culvert under Phinney's Lane in August and September, the water was quiescent and no current was measured. Annualized streamflow through the Phinney's Lane culvert is 2.6 million cubic feet based on 2007 data. The water budget in Table III-1 uses the water flow readings from 2007.

Figure III-3 also shows the streamflow measurements collected during 1998 for the Lake Wequaquet water level study (Eichner and others, 1998). Streamflow measurements during this study were collected approximately twice a month between January and September 1998. At the time of this study, groundwater levels around the lake were on average two feet higher than the lake level, but the lake level only increased 0.5 ft. It was hypothesized at the time that the large surface area of the lake restrains water level increases and that the increased pressure of higher surrounding water levels was relieved by increased discharge through the herring run and downgradient shorelines. Annualized streamflow based on this data is 7.5 million cubic feet or nearly three times the annualized flow during 2007.

The fluctuation in streamflow during changes in regional groundwater levels has the potential to impact water quality because the residence time of water and nutrients in the lake would be reduced during high groundwater conditions and increased during low groundwater conditions. Water levels during 2007 approximate average conditions based on an approximately 30 year period of record at a nearby monitoring well (A1W 254); water levels during 1998 were just short of the historic high for the same period of record. Water levels during the IEP/KV diagnostic study were approximately the same as those during 2007. Unfortunately, streamflow measurements were not collected during the IEP/KV (1989) study; streamflow was calculated by difference from groundwater discharge readings. Therefore, the impact of water levels on water quality conditions can only be qualitatively assessed when comparing the 1985-86 and 2007 water quality datasets. Differences between the 1989 study results and the current project are discussed in the water quality sections of this report.

Table III-1 Lake Wequaquet Water Budget and Residence Times

Lake Wequaquet is divided into the various basins that are consistent with the sampling locations shown in Figure II-1. Basin volumes are based on the bathymetry in Figure II-1. Watershed areas are based on the areas shown in Figure III-1. Watershed groundwater inflow and pond surface recharge based on rates from Walter and Whealon (2004). Streamflow out of the south basin is based on 2007 data. Groundwater outflow is based on length of downgradient/discharging shoreline and balance with inflow. In-lake movement of water is estimated based on net inflow and groundwater outflow. In order to maintain water budget balance, no flow to groundwater occurs through the downgradient shoreline of the south basin.

	Watershed area		Pond area		Volume	Residence Time
Basin Name	m2	acres	m2	acres	m3	yrs
MAIN BASIN	1,894,238	468	1,724,386	426	7,633,786	3.37
BEARSES POND	252,220	62	267,551	66	780,568	2.26
SOUTH BASIN	336,460	83	518,621	128	1,476,463	0.56
GOOSEBERRY POND	235,948	58	165,751	41	318,064	1.20
TOTAL LAKE WEQ	2,718,867	672	2,676,309	661	10,208,881	1.86

	NET INFLOW						OUTFLOW				
	Watershed GW In	Watershed Inflow from		Pond Surface Recharge	In-Lake Flow	TOTAL INFLOW	GW Out	In-Lake Outflow to		Streamflow	TOTAL OUTFLOW
Basin Name	m3/y	Basin	m3/y	m3/y	m3/y	m3/y	m3/y	Basin	m3/y	m3/y	m3/y
MAIN BASIN	1,311,097			692,031	263,322	2,266,450	336,174	South	1,930,277		2,266,450
BEARSES POND	238,535	Shallow	63,960	107,374		345,908	82,586	Main	263,322		345,908
SOUTH BASIN	232,881			208,133	2,179,816	2,620,830				2,654,099	2,654,099
GOOSEBERRY POND	198,086	Shallow	34,775	66,519		264,606	15,066	South	249,539		264,606
TOTAL LAKE WEQ	1,980,599		98,735	1,074,056	2,443,138	5,497,793	433,826		2,443,138	2,654,099	5,531,063

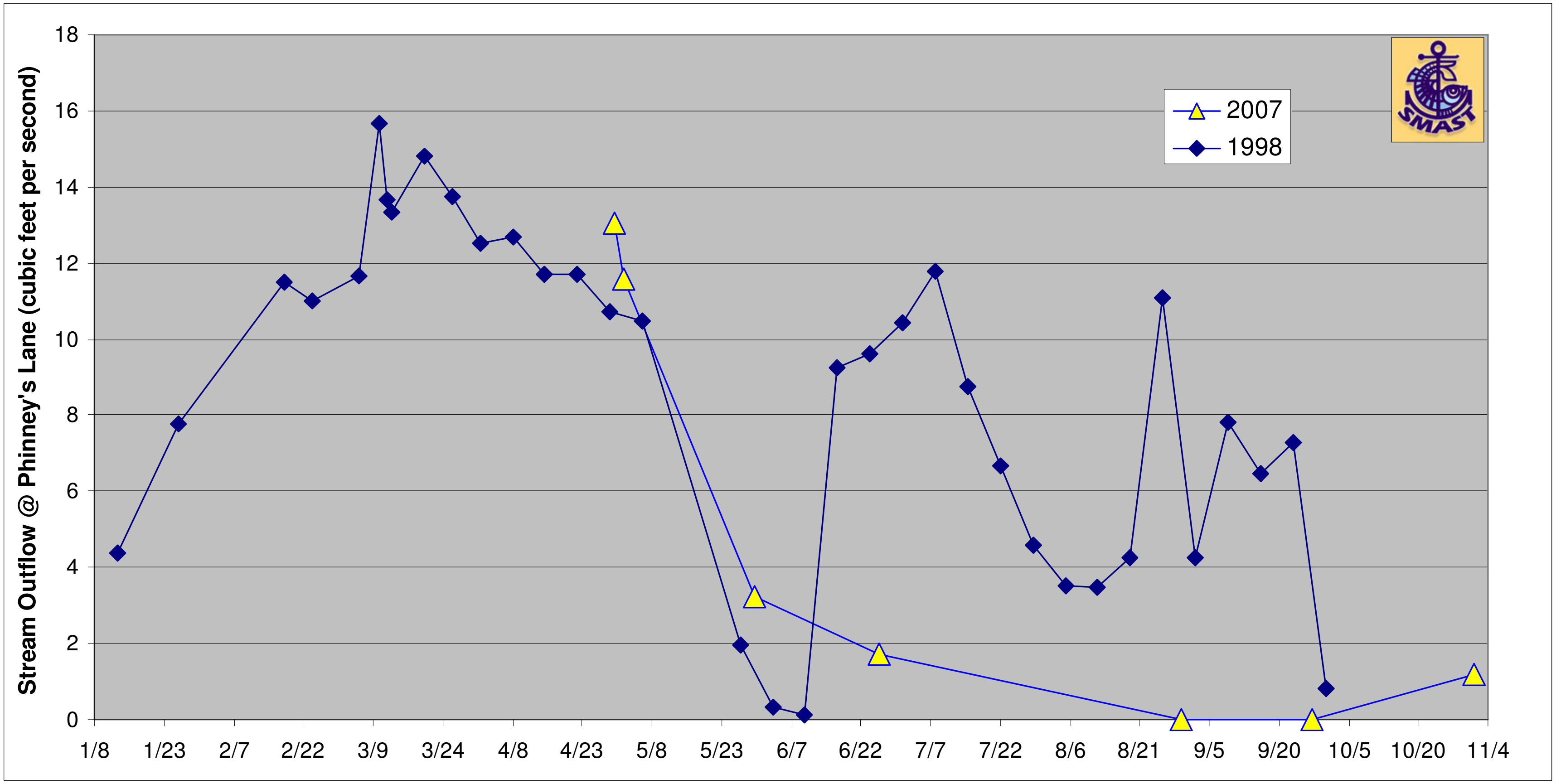


Figure III-3. Streamflow out of Lake Wequaquet: 1998 and 2007

All data collected on the southern side of the culvert under Phinney's Lane. 1998 streamflow data is from Eichner and others (1998). 2007 data collected for this study. No streamflow readings were collected during the diagnostic/feasibility study (IEP/KV, 1989).

III.3. Lake Volume

Lake volumes are usually based on bathymetric maps and are assumed to be at steady state in the calculation of most water budgets. In order to refine the analysis of the various basins within Lake Wequaquet, project staff determined the volumes for Bearses Pond, Gooseberry Pond, the two major basins of the lake, and Shallow Pond (see Table III-1). These volumes are based on the bathymetry prepared by IEP/KV (1989) and areas of the pond are based on 1994 aerial photos.

Eichner and others (1998) established that the water level of the pond fluctuated within a two foot range in 1998. Therefore, it is clear the volume and, thus, the water budget of the pond does change. However, quantifying this change would require refined recording of water levels, a detailed survey of shoreline geometry, and regular recording of outflows; data collection of this type was beyond the scope of this project and has also not been done in the past. Based on the current area of Lake Wequaquet, a two foot rise in water level would increase the volume of the lake by approximately 16%.

III.4. Lake Residence Time

Residence time is how long water remains in a water body before it is replaced by an equivalent volume of water from the combined sources of its watershed, recharge on its surface, and any streams flowing into it. Calculation of the residence time, therefore, depends on both the incoming flow and the volume of the lake and is determined by dividing the annual inflow by the volume. Residence time is also important for understanding not only the balance of water in a lake, but also how much water is available to dilute contaminants that enter a lake. Table III-1 shows the residence times for Bearses Pond, Gooseberry Pond, and the two major basins of the Lake Wequaquet (Main and South).

Complete exchange of the water volume in the Main basin of Lake Wequaquet takes over three years to occur, while it takes just over half a year for the South basin to be exchanged. The volume in Bearses Pond takes over two years to be exchanged and Gooseberry Pond's volume is exchanged in slightly more than one year.

III.5. Water Budget Discussion

The water budget assumes that water levels are constant and this is a reasonable assumption for 2007. Development of the water budget shown in Table III-1 began with the determination of the watersheds contributing to each of the basins (see Figure III-1). Once these areas were determined, recharge volumes from the watershed and upon the pond surface were determined based on annual recharge rates developed for the regional groundwater model (Walter and Whealon, 2004). Groundwater inflow is the primary source of input into most basins, with a range of 58 to 75% of inflow from groundwater for all basins except the South basin which receives only 9% of its inflow from groundwater. Although this relatively straightforward, the contributions of Shallow Pond, groundwater outflows and internal water movement add some additional considerations to the water budget development.

Shallow Pond is upgradient of both Bearses Pond and Gooseberry Pond (see Figure III-1). The recharge inputs into Shallow Pond must be divided among these two basins, as well as a portion discharged along its northern shoreline. Project staff determined the total length of downgradient/discharging shoreline and determined the volume of recharge to each downgradient area based on the percentage of shoreline discharging to each area. Thirty-one percent (31%) of Shallow Ponds outflow is discharged to Lake Wequaquet with 20% going to Bearses Pond and 11% to Gooseberry Pond. The volumes of Shallow Pond recharge discharging to Bearses and Gooseberry are shown in Table III-1.

A similar approach was applied to each of the basins of Lake Wequaquet, although these calculations also needed to account for the measured stream outflow. Groundwater outflow was determined based the length of downgradient shoreline as a percentage of the total shoreline for each of the basins, including Gooseberry and Bearses. Twenty-four percent (24%) of Bearses outflow is discharged to groundwater along its northern shoreline, while 15% of the Main basin outflow is discharged to both the north and to the south.

After accounting for discharge from the individual basins back to groundwater, the remaining inflow was assumed to be transferred within the lake to the adjacent basin; these flows are labeled "in-lake flow" in Table III-1. This approach is consistent with the need to provide balance for the stream outflow, as well as results from the internal drifter/circulation analysis completed for by IEP/KV (1988). This analysis found the predominant annual outflow from each of the basins toward the herring run outlet. The primary recipient of this in-lake flow is the South basin of Lake Wequaquet, which receives 83% of its inflow from its adjacent basins.

In order to balance the annual water budget for Lake Wequaquet, no groundwater outflow can occur along the southern side of the South basin; all outflow from this basin needs to leave the pond through the herring run outlet. This would be consistent with basic physics since there is less resistance to flow through the herring run compared to surface water entering the pore spaces and becoming groundwater. The large influence of stream outflows on water budgets has also been observed in other Cape Cod ponds (*e.g.*, Stillwater Pond/Lovers Lake system in Chatham) (Howes and others, 2003).

Overall, the water budget for Lake Wequaquet and each of its basins is in balance between inflows and outflows. This result appears to confirm that the watershed and subwatershed delineations, recharge rates, and the measured streamflow are reasonable. Of the lake-wide inflow, only 8% flows out of the pond and into the groundwater; the remaining 92% flows out through the herring run at the Phinney's Lane culvert. From the available data, it is also clear that these results do change on a seasonal basis and from year to year as groundwater levels fluctuate. Streamflow readings indicate that little or no flow is discharged from the lake during the summer. During these periods or during low groundwater conditions, outflow would predominately occur via groundwater outflow along the southern side of the South basin. More refined water table, streamflow, and shoreline discharge readings would be necessary to more fully explore these issues and related issues, such as the subwatershed boundaries between the basins.

IV. Pond Water Quality

Understanding how water moves within an aquatic ecosystem is an important component of determining the factors that cause water quality conditions. Diminishing water quality in surface waters generally follow a relatively simple progression that begins with higher nutrient concentrations and ends with low oxygen conditions: more nutrients create more plants (either algae or rooted plants), which in turn create more decaying material falling to the pond bottom, where bacteria consume oxygen while decomposing the dead plants. Low oxygen conditions produces chemical changes in the sediment materials that allow nutrients in the sediments to be regenerated back into the water, creating the opportunity to enhance cycle with additional nutrients. Of course this general description often becomes very complex as the details that are specific to each pond are considered. However, because water quality impacts follow this progression, regular low dissolved oxygen conditions are generally more of a terminal state, while diminishing clarity/Secchi depth and elevated nutrient concentrations are generally the initial stages.

In order to characterize current water quality conditions and compare these conditions to 1985-1986 conditions measured in the IEP/KV diagnostic study, project staff worked with town staff and Wequaquet Lake Protective Association (WLPA) volunteers to develop a sampling plan for 2007 that fit within the available budget. Laboratory and field data results from 2007 and comparison to 1985-1986 results are discussed in this section.

IV.1. 2007 Water Quality Sampling Plan

The Lake Wequaquet sampling plan included collection of two water quality samples over the deepest point at each of the following locations: Bearses Pond, Gooseberry Pond, Lake Wequaquet South basin, Lake Wequaquet North, and Lake Wequaquet Deep (main) basin. Samples were collected at 0.5 m and one meter off the bottom at each location. The sampling locations match the IEP/KV (1998) sampling locations, while the sampling depths are the same as utilized in the annual Cape Cod Pond and Lake Stewardship (PALS) snapshots. Using the same depths as the PALS Snapshots allows previous snapshot results to be compared to results from the samples collected during this project. Samples were also collected on the southern side of the Phinney's Lane outflow culvert with a regular second sample at this location functioning as the quality assurance/quality control sample for each sampling run.

Water quality samples were collected on the following dates in 2007: May 2, May 30, June 26, July 25, August 30, September 27, and November 1. Water quality samples were collected with Niskin samplers and stored in dark brown, acid-washed, Nalgene bottles, which were transported in coolers with ice packs to ensure that samples achieved a temperature of 4°C. Samples were delivered on the same day as they were collected to the Coastal Systems water quality lab at the School of Marine Science and Technology (SMAST), University of Massachusetts Dartmouth in New Bedford. Laboratory procedures are described in the SMAST Coastal Systems Analytical Facility Laboratory Quality Assurance Plan (2003). These are the same procedures that are followed for the Cape Cod Pond and Lake Stewardship (PALS) snapshots that have been completed annually between 2001 and 2008.

Aside from the water quality samples delivered to the SMAST lab, project staff also collected field readings: measurement of Secchi depth and profile readings of dissolved oxygen and temperature recorded at every meter in the water column at each sampling station. Dissolved oxygen and temperature readings were recorded using a YSI-85 meter calibrated prior to each sampling event. Membranes on the probe were changed according to recommendations in the YSI operations manual. Field readings were collected on the same days as water quality samples, as well as on June 19, August 13, and September 13. Laboratory and field data collected, along with analyte detection limits, measurement ranges, and accuracy measurements, are shown in Table IV-1.

Table IV-1. Field and laboratory reporting units and detection limits for data collected during the 2007 Lake Wequaquet assessment

Parameter	Matrix	Reporting Units	Detection Limit	Accuracy (+\-)
Field Measurements				
Temperature	Water	ºC	0.5°C	± 0.3 ºC
Dissolved Oxygen	Water	mg/l	0.5 ppm	± 0.3 mg/l or ± 2% of reading, whichever is greater
Secchi Disk Water Clarity	Water	meters	NA	20 cm
Laboratory Measurements – SMAST				
Alkalinity	Water	mg/l as $CaCO_3$	0.5	80-120% Std. Value
Chlorophyll-*a*	Water	µg/l	0.05	80-120% Std. Value
Nitrogen, Total	Water	µM	0.05	80-120% Std. Value
pH	Water	standard units	NA	80-120% Std. Value
Phosphorus, Total	Water	µM	0.1	80-120% Std. Value
Laboratory Measurements – Spectrum Analytical, Inc.				
% solids	Sediment	%		
Phosphorus as P	Sediment	mg/kg dry	0.25	80-120% Std. Value
Iron bound P	Sediment	mg/kg dry	0.25	80-120% Std. Value
Loosely-sorbed P	Sediment	mg/kg dry	0.25	80-120% Std. Value
Laboratory Measurements – PhycoTech, Inc.				
Phytoplankton - Tow	Water	Genus level identification and biovolume calculations		
Periphyton - Total	Areal	Genus level identification and biovolume calculations		
Note: All SMAST laboratory measurement information from SMAST Coastal Systems Analytical Facility Laboratory Quality Assurance Plan (January, 2003); all other laboratory measurement information from laboratory results and method listings.				

In addition to standard water quality samples, project staff also collected plankton, periphyton, and sediment samples. Sediment samples were collected on May 2 and August 30 using an Ekman dredge and were analyzed for various forms of phosphorus to gauge the potential for release to overlying waters. One-time plankton and periphyton samples were collected on September 27. These samples were collected to provide a point of comparison to much more extensive plankton readings collected during the IEP/KV (1989) diagnostic/ feasibility study.

IV.2. Field Collected Water Quality Data

IV.2.1. Dissolved Oxygen and Temperature

Pond and lake ecosystems are controlled by interactions among the physical, chemical, and biological factors within a given lake. Light availability, water transparency, and food availability can control the distribution of plants. The availability of oxygen often determines distributions of various animal species living within a lake; some require higher concentrations, while others are more tolerant of occasional low oxygen concentrations. Oxygen concentrations also determine the solubility of many inorganic elements; elevated 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 (*e.g.*, higher temperature water holds less dissolved oxygen).

Oxygen concentrations are also related to the amount of biological activity in a pond and its physical characteristics, such as depth, surface area, and its orientation to predominant winds. Since oxygen is one of the main byproducts of plants gathering energy from the sun (*i.e.*, photosynthesis), a vigorous algal population can produce dissolved oxygen concentrations that are greater than the concentrations that would be expected based simply on temperature interactions alone. 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 sediment and near-sediment water conditions and the release of recycled nutrients back into the pond water from the sediments.

The state surface water regulations (314 CMR 4) have numeric standards for both dissolved oxygen and temperature. Under these regulations, ponds that are not drinking water supplies are required to have a dissolved oxygen concentration of not less than 6.0 mg/l in cold water fisheries and not less than 5.0 mg/l in warm water fisheries. These regulations also require that temperature not exceed 68^0F (20^0C) in cold-water fisheries or 83^0F (28.3^0C) in warm water fisheries. There are additional provisions in the regulations that allow lower concentrations or higher temperatures if those are natural background conditions. Given its depth and temperature regime, Lake Wequaquet would be classified by the state as a warm water fishery and, thus, would have a minimum dissolved oxygen concentration of 5.0 mg/l as its regulatory limit.

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

Shallow Cape Cod ponds [less than 9 meters (~30 ft) deep] tend to have well mixed water columns because ordinary winds blowing across the Cape have sufficient energy to move deeper waters up to the surface. In these ponds, both temperature and dissolved oxygen readings tend to be constant from surface to bottom; 2007 data from all of Lake Wequaquet basins tend to have this characteristic (Figure IV-1). In deeper ponds on Cape Cod, 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 and the water column stratifies into a warmer, upper layer and a colder, deeper layer. These temperature conditions appear to occur temporarily in Lake Wequaquet (see the May 30 temperature profile at W-2), but the water column tends to return to a relatively uniform temperature profile throughout the water column within a month; these temporary conditions are likely due to relatively quiescent periods. Continuous monitoring through the use of a moored data collection device would be necessary in order to better measure the range and time frames associated with these temporary events.

As would be expected, similar temporary conditions also occur in the 2007 dissolved oxygen profiles. The 7/25 and 8/13 profiles over the deepest station (W2) both have deep concentrations below the state regulatory standard of 5 ppm (see Figure IV-1a). A dissolved oxygen concentration of zero ppm was recorded at the deepest station in the 7/25 profile, while two weeks later a concentration of 1.6 ppm was recorded. Another two weeks later, on 8/30, the deepest concentration is again above 5 ppm. Between June and September of 2007, the average DO concentration at the deepest station at the depth just above the sediments is 4.2 ppm (n=4) with a range of 0 to 7.75 ppm.

Bearses Pond, on the other hand, shows relatively consistent low dissolved oxygen at its deepest station (see Figure IV-1c). From the 6/19 to 8/13 profiles, the deepest station is less than the state 5 ppm standard and the 8/30 reading is just above the standard (5.68 ppm). Between June and September of 2007, the average DO concentration at the Bearses Pond station at the depth just above the sediments is 4.9 ppm (n=7) with a range of 2.1 to 7.75 ppm. The difference in the readings at Bearses and the deep station in the main basin of Lake Wequaquet suggest that the deep basin has higher oxygen demand, but the larger surface area allows that demand to be tempered by more regular mixing of atmospheric oxygen. None of the other basins in Lake Wequaquet (north, Gooseberry, or south) had DO concentrations measured in 2007 that were less than state dissolved oxygen standards.

The June through September surface temperature and dissolved oxygen conditions measured in 2007 are generally similar to those measured by IEP/KV during 1985-1986 at the four Lake Wequaquet stations. Surface temperature readings in 1985-1986 are generally significantly lower ($\rho<0.05$) than in 2007 although it is difficult to say whether this is just part of regular natural fluctuations in Cape temperatures or part of a larger trend related to global warming. The higher temperatures in 2007 lower the dissolved oxygen capacity of the water and, as expected, dissolved oxygen concentrations are lower in 2007 than in 1986, although not at a statistically significant level ($\rho<0.21$). When dissolved oxygen concentrations are corrected for the impact of temperature differences, the surface DO concentrations are essentially the same between the two datasets.

Comparisons between deep, near-sediment dissolved oxygen concentrations in 1986 and 2007 is only possible at the deepest station (W2) since only surface DO readings were collected all the other stations in 1985-86. The lowest concentration recorded at the deep station at deep-W2 in 1986 was 4.8 ppm on August 4, which is 55% saturation based on the temperature. As noted above, readings of 0 and 1.6 ppm were recorded at the same location in 2007, which are

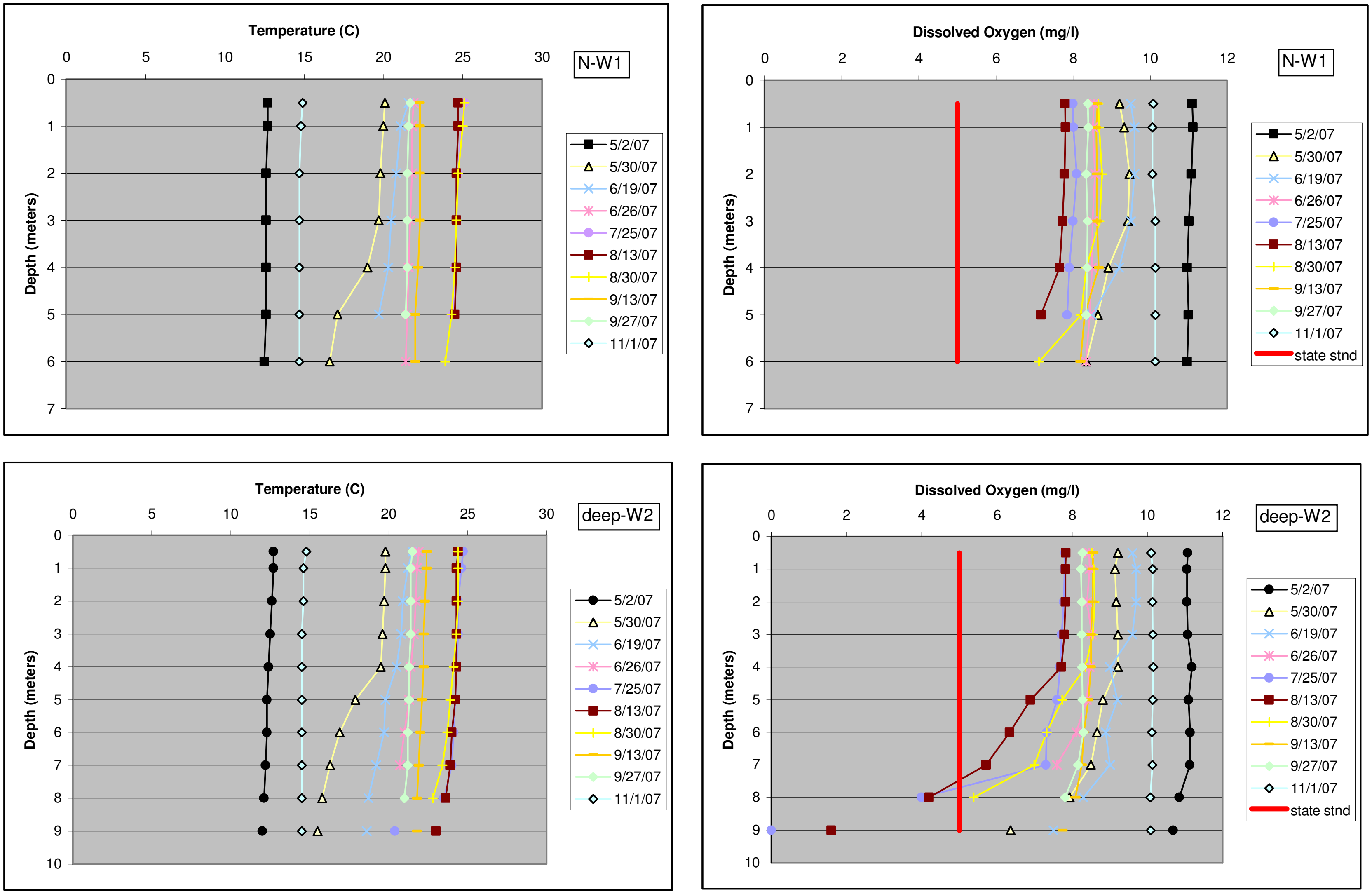


Figure IV-1a. Temperature and Dissolved Oxygen Profiles: Lake Wequaquet 2007 (N-W1 and deep-W2 stations)

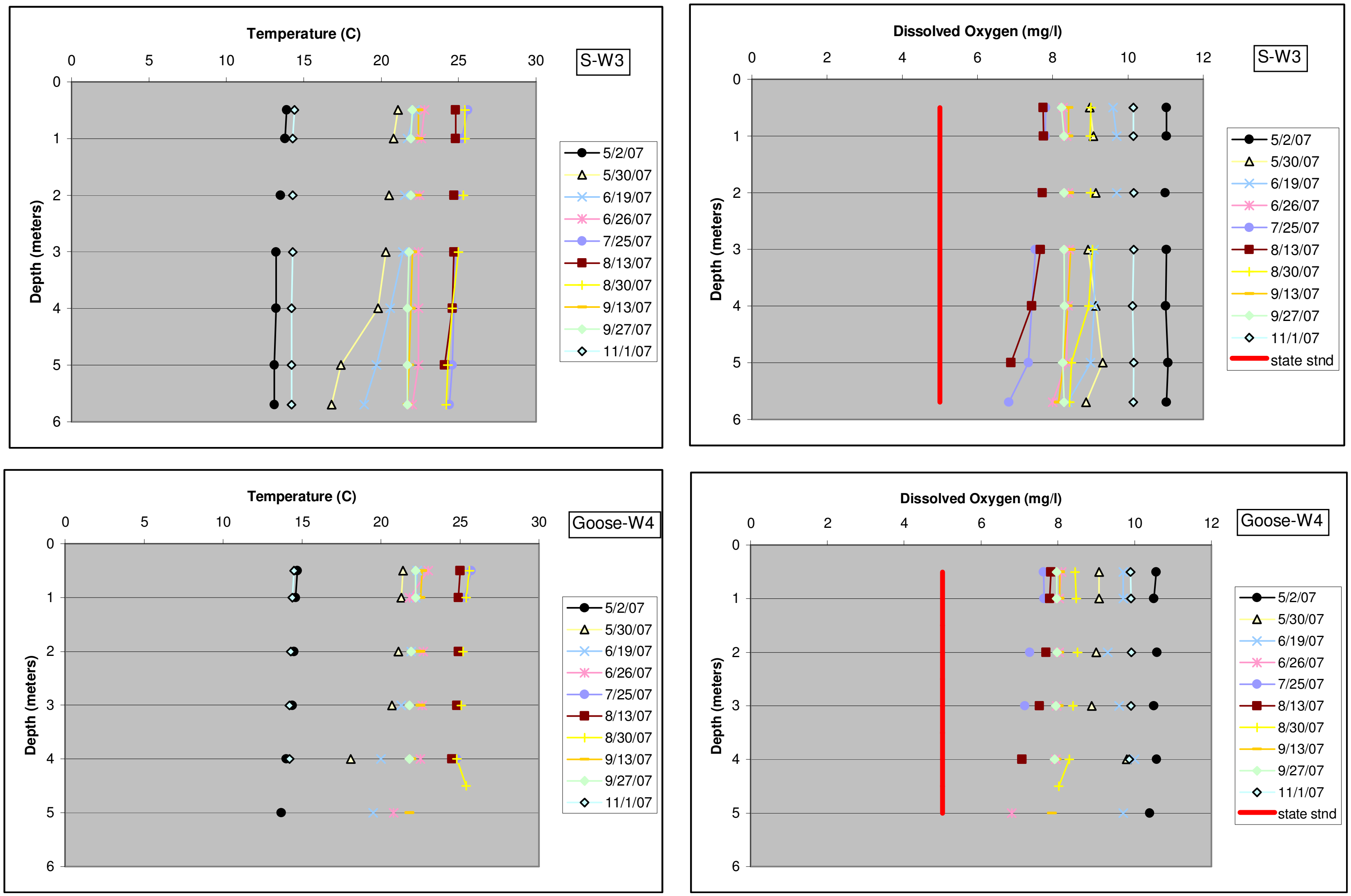


Figure IV-1b. Temperature and Dissolved Oxygen Profiles: Lake Wequaquet 2007 (S-W3 and Goose-W4 stations)

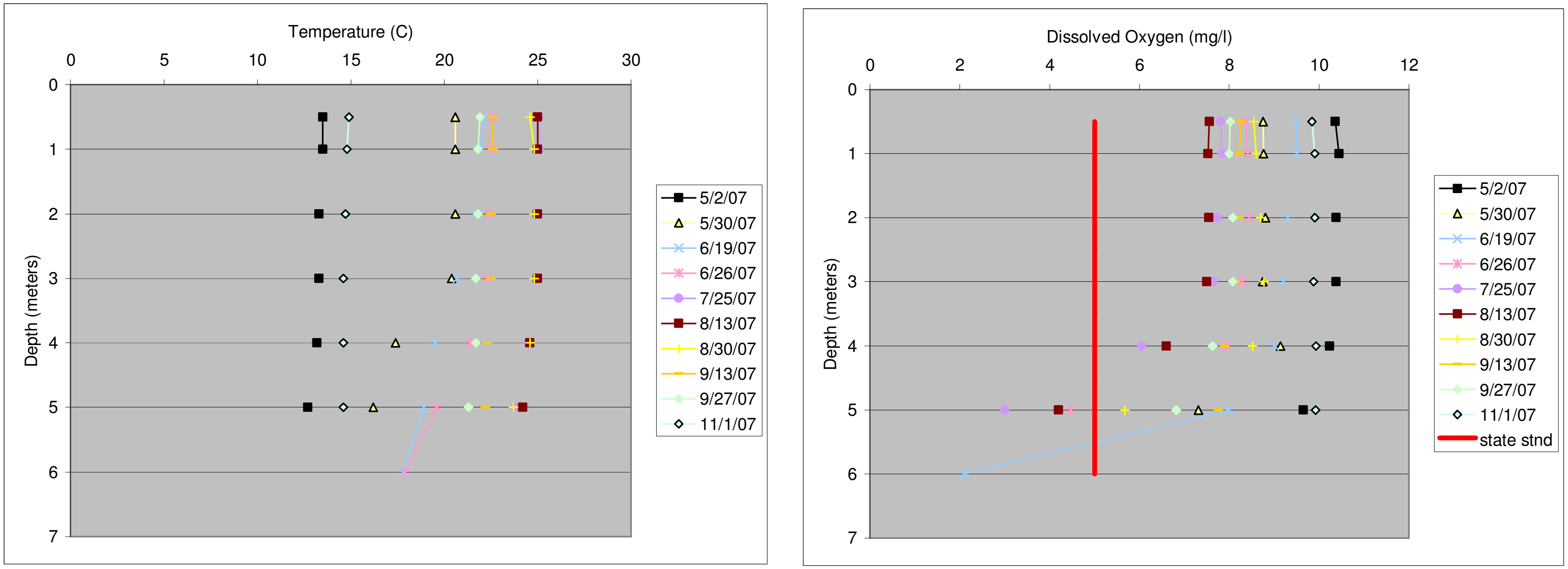


Figure IV-1c. Temperature and Dissolved Oxygen Profiles: Lake Wequaquet 2007 (Bearses Pond)
Dissolved oxygen figures show state standard for dissolved oxygen in warm water fisheries (5 mg/l) (314 CMR 4.05). All measurements recorded using a YSI-85 meter.

0% and 19% saturation, respectively. Although this finding seems to indicate worsening conditions, the 0 ppm reading is a statistical anomaly; it would be eliminated under standard analysis techniques. Removal of this result results in insignificant differences between average deep dissolved oxygen conditions in the 1986 and 2007 datasets.

These findings suggest that dissolved oxygen concentrations near the sediments in the main basin of Lake Wequaquet are a cause for concern, but available data are not sufficient to discern how much of an ecological impact is occurring. More definitive characterization of conditions could be made by collecting other data, such as a benthic fauna evaluation and/or installation of a continuous monitoring device to measure DO concentrations more frequently.

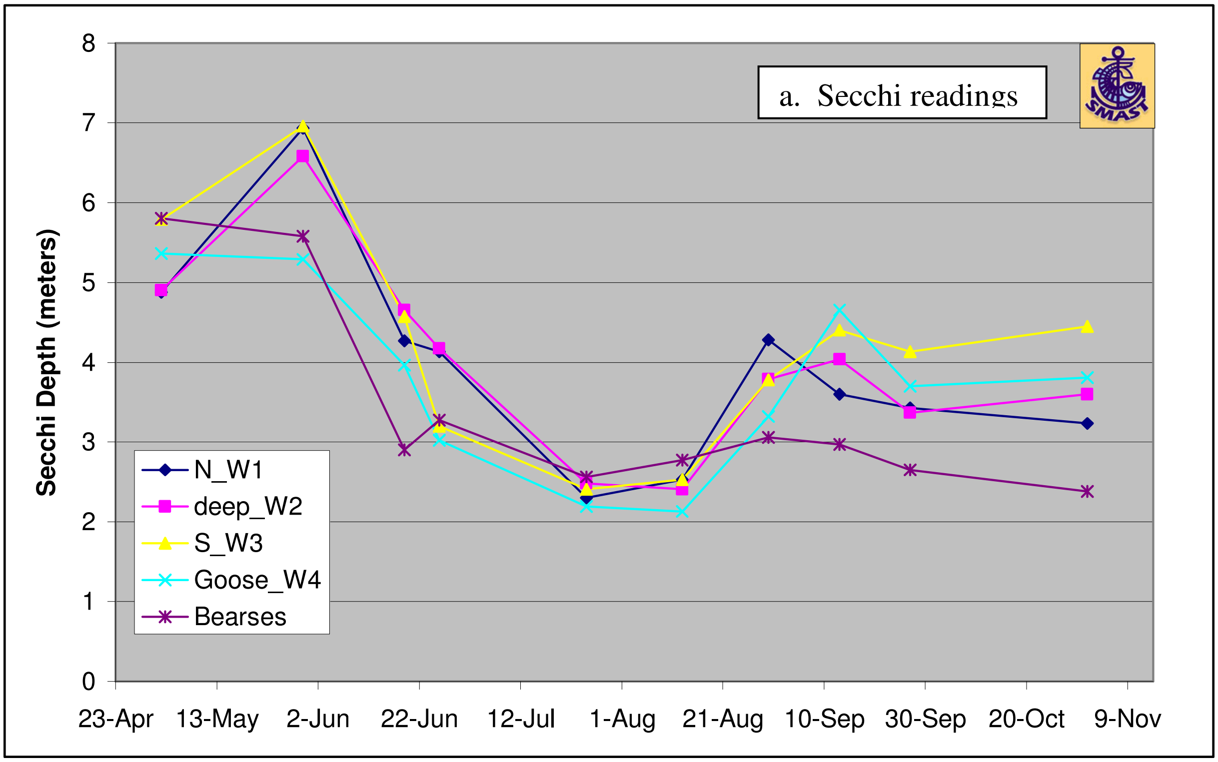
IV.2.2. Secchi Depth

A Secchi disc is used to evaluate transparency, or light penetration, of water. Since fluctuations in Secchi depths are linked to fluctuations in concentrations of plankton or inorganic particles, a Secchi reading is an aggregate, general measure of ecosystem condition and is especially useful if data is collected over multiple years. Because of its ease of collection and its generalized nature, Secchi readings have been linked through a variety of analyses to trophic status of lakes (Carlson, 1977). Secchi depth is also related to the overall depth of a pond; if the pond is relatively shallow, the disk may be visible on the bottom even with significant algal densities. Relative Secchi readings, which compare the Secchi depth to total depth at the sampling location, have also been used to assess the condition of a pond ecosystem. Since Cape Cod ponds generally have very limited inorganic particles, Secchi readings on the Cape tend to be directly linked to algal populations, which are, in turn, linked to nutrient levels.

The state does not have transparency standards related to the ecological condition of surface waters. The only state regulation related to water clarity is a state safe swimming clarity limit of 4 feet (105 CMR 435). None of the recorded Secchi readings in 2007 or 1986 were less than 4 feet (1.22 m); the minimum recorded Secchi depth in the 2007 dataset is 7.55 ft (or 2.3 m on July 25 at the north_W1 station).

Average Secchi readings collected between June and September 2007 at the Lake Wequaquet stations generally ranged between 3 and 3.5 m, although they did fluctuate significantly throughout the year (Figure IV-2). Secchi depth readings were generally much higher in the early spring, before the phytoplankton populations are actively growing, decline during the summer, and then recover as phytoplankton populations senesce. Readings in November were still lower than early May readings suggesting that additional clarity recovery occurs during the winter.

Absolute Secchi readings shown in Figure IV-2a indicate that transparency in all basins of Lake Wequaquet are generally the same. Relative Secchi readings in Figure IV-2b show that the lowest readings are generally found at the deepest station, where the average between June and September is 40%, and the greatest readings are in Gooseberry Pond where average readings during the same period are 68%. By way of comparison, Joshua Pond, which is located in Osterville, is relatively pristine because it is largely surrounded by undeveloped land and has a maximum depth of 9.5 meters, has an average relative Secchi reading of 86% (Eichner, 2008).



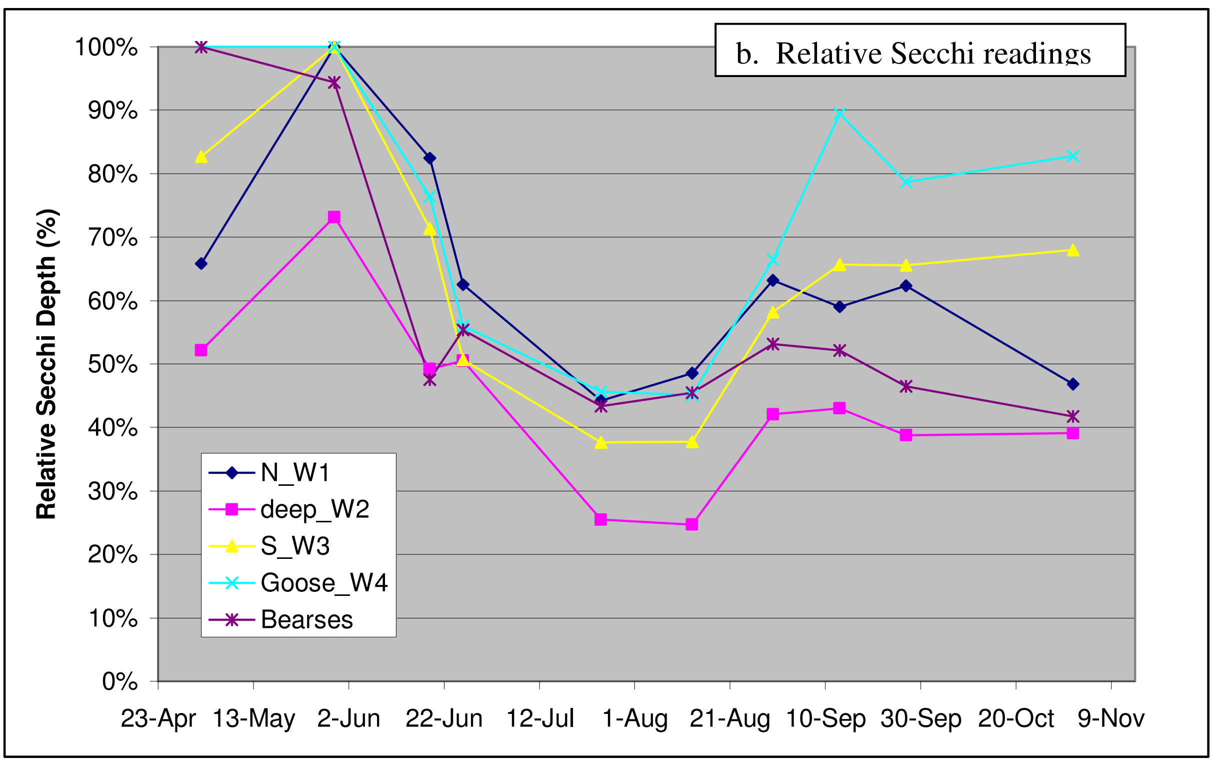


Figure IV-2. Secchi Readings: Lake Wequaquet 2007
All readings recorded with standard 20 cm disk with black and white quadrants. Relative Secchi readings are the percentage of station depth.

Comparison of average Secchi readings between June and September from the 1986 IEP/KV evaluation to the same time period during 2007 generally show a reduction in transparency and, in some cases, statistically significant reductions (Figure IV-3). In the southern basin of the Lake (S_W3 station), Gooseberry Pond (Goose_W4 station) and Bearses Pond, average Secchi readings declined significantly ($\rho<0.004$, $\rho<0.0003$, and $\rho<0.05$, respectively). The readings at the northern station (N_W1) and main deepest station (deep_W2) show a slight decline, but they are not statistically significant.

The WLPA also collected some Secchi readings at selected locations between 1997 and 2007. The most extensive dataset of these readings are at the Bearses Pond and the deep_W2 locations. If these data are included with the 2007 data and data collected from the PALS Snapshots between 2001 and 2006, the declines and the statistical comparisons to the 1986 dataset are maintained.

Since decreasing Secchi readings in Cape Cod ponds are generally the result of increases in algal populations and accompanying nutrient concentrations, these statistically significant decreases in Secchi readings suggest that there has been an increase in nutrients entering Lake Wequaquet since 1986.

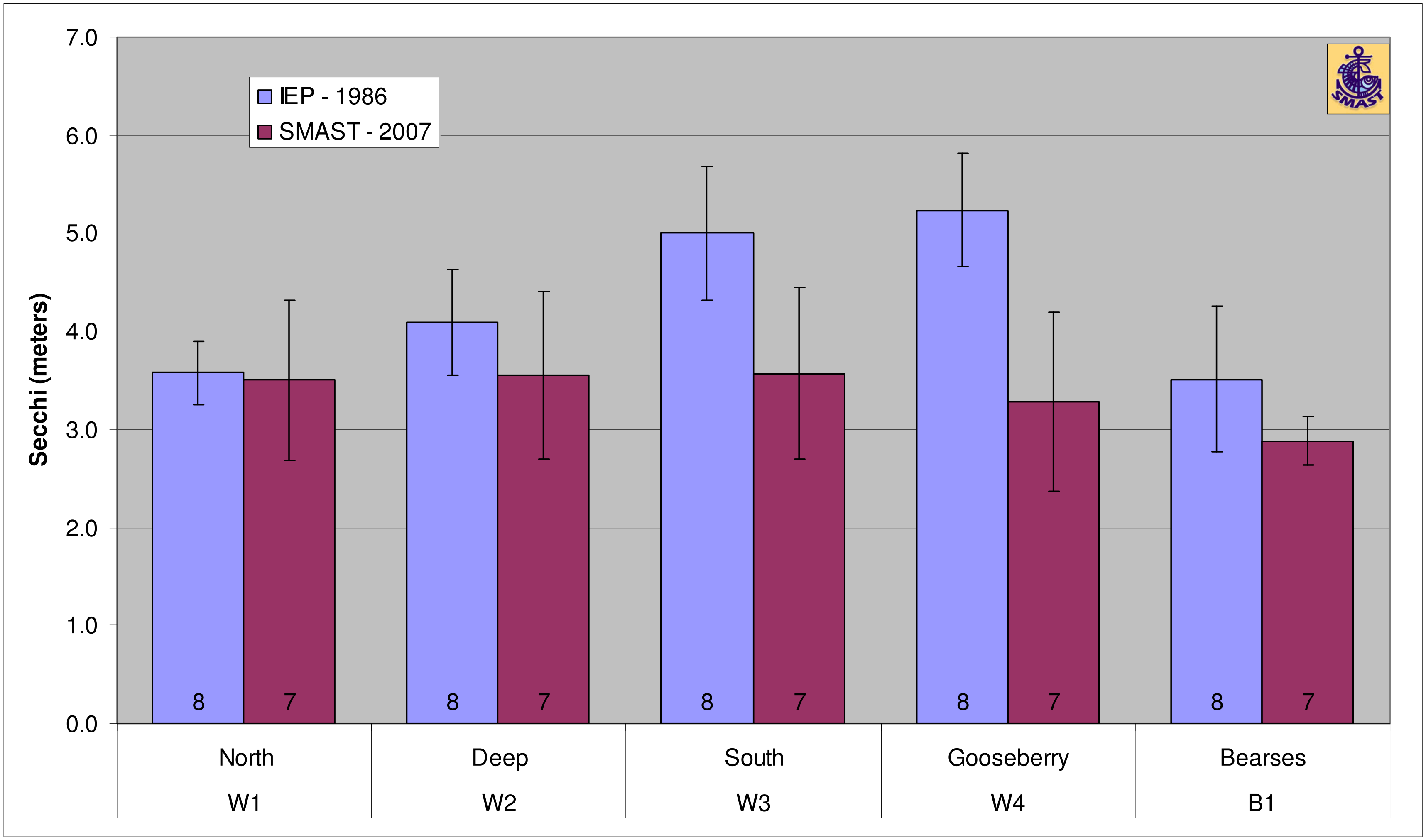


Figure IV-3. Comparison of Average Lake Wequaquet Secchi Readings between 1986 and 2007
Averages are based on June thorough September Secchi readings collected in 1986 for IEP/KV (1989) and 2007 readings collected for this assessment. Error bars are one standard deviation. 2007 averages at South (W3), Gooseberry Pond (W4) and Bearses Pond stations are significantly lower than 1986 using a t-test ($\rho<0.004$, $\rho<0.0003$, and $\rho<0.05$, respectively). Number of readings used to calculate the averages are shown in the base of each bar.

IV.3. Laboratory Water Quality Data

As mentioned above, unfiltered water samples were collected in the ponds at depths specified under the sampling plan. These depths match the protocols developed for the PALS Snapshot, so comparisons between data collected under prior years' Snapshots and data collected as part of this analysis are facilitated. Water samples were analyzed at the SMAST Coastal Systems Analytical Facility Laboratory at UMASS Dartmouth for the following constituents: total phosphorus (TP), total nitrogen (TN), pH, alkalinity, and chlorophyll *a*. The comparative analysis below focuses on the June through September measurements.

IV.3.1. Total Phosphorus (TP)

Phosphorus is the key nutrient in ponds and lakes because it is usually more limited in freshwater systems than nitrogen. Typical plant organic matter contains phosphorous, nitrogen, and carbon in a ratio of 1 P:7 N:40 C per 500 wet weight (Wetzel, 1983). Therefore, if the other constituents are present in excess, phosphorus, as the limiting nutrient, can theoretically produce 500 times its weight in algae or phytoplankton. Because it is more limited, 90% or more of the phosphorus occurs in organic forms (plant and animal tissue or plant and animal wastes) and any available inorganic phosphorus [mostly orthophosphate (PO_4^{-3})] is quickly reused by the biota in a lake. Extensive research has been directed towards trying to determine the most important phosphorus pool for determining the overall productivity of lake ecosystems, but to date, most of the work has found that a measure of total phosphorus is the best predictor of productivity of lake ecosystems (*e.g.*, Vollenweider, 1968). The laboratory analysis techniques for total phosphorus (TP) include ortho-phosphorus and all phosphorus incorporated into organic matter, including phytoplankton.

Most Cape Cod lakes have low phosphorus concentrations due to the lack of phosphorus in the surrounding glacially-derived sands that make up Cape Cod. The median surface concentration of TP in 175 Cape Cod ponds sampled during the 2001 Pond and Lake Stewards (PALS) Snapshot is 16 ppb (or µg/l) (Eichner and others, 2003). A more limited sampling of 60 Cape Cod lakes in 1997 and 1998 found a mean TP concentration in surface waters of 14 ppb (Ahrens and Siver, 2000). Using the US Environmental Protection Agency (2000) method for determining nutrient thresholds and the data from ponds and lakes sampled during the 2001 PALS Snapshot, the Cape Cod Commission determined that healthy freshwater ponds on Cape Cod should generally have a surface TP concentration no higher than 10 ppb (Eichner and others, 2003).

All of the Lake Wequaquet stations sampled between June and September during 2007 have average concentrations exceeding the 10 µg/l total phosphorus threshold (Figure IV-4). All 1986 averages also exceed the 10 ppb threshold except for the South (W3) station, which had an average TP concentration of 7.75 ppb. Five of the nine stations have average 2007 total phosphorus concentrations between June and September that are significantly higher than 1986 averages [t-test ($\rho<0.05$)]; averages at the shallow and deep stations at North (W1) and the deep station at Deep (W2) are not significantly different.

No statistically significant differences exist between surface and deep stations in either the 1986 or the 2007 datasets, except for Bearses [t-test ($\rho<0.05$)]. This result suggests that all basins except Bearses have well mixed water columns and limited regeneration of TP from the sediments. The Bearses difference is not significant in the limited 2007 dataset (n=4), but inclusion of PALS data makes the difference statistically significant. This difference does not appear in the IEP/KV dataset, which suggests that conditions have worsened in Bearses during the last 20 years. The station that has the largest difference between surface and deep concentrations is the 1986 results from the Deep (W2) station; statistical significance using a t-test is $\rho=0.06$. Given that the differences between the deep concentration in 1986 and 2007 are not significantly different, this result is likely due to the significant rise in the surface concentrations. In other words, the upper TP concentrations have risen more than the deep concentrations at W2.

One potential complication in the comparison of the 1986 and the 2007 datasets is that historic laboratory detection limits for phosphorus in lake samples often have been too high for the low concentrations generally found, especially in relatively low nutrient Cape Cod ponds and lakes. As might be expected, the 1986 TP data from IEP/KV has a number of datapoints during June through September that are less than the laboratory detection limit (10 ppb). As a point of comparison, the current TP detection limit for water samples at the SMAST laboratory is 3 ppb (see Table IV-1). Using a data analysis convention usually used for samples with concentrations below detection limits, project staff assigned these "non-detection" results a concentration of half the detection limit or 5 ppb. Because of the relatively small number of data points in 1986 that exceed the detection limit, this convention has a relatively large impact on the averages for the 1986 dataset. For example, among the surface sample concentrations at the South (W3) station, five of the 8 sampling dates have concentrations that are the below detection limit. Staff checked the impact of assigning a higher concentration to these below-detection-limit results and found that although statistical relationships were somewhat weakened, all statistically significant relationship were maintained.

Although there is a concern related to the laboratory methods in the 1986 dataset, the increase in TP concentrations from 1986 to 2007 is observed in both the shallow and the deep stations. In addition, all average TP concentrations in Lake Wequaquet are above the recommended 10 ppb Cape Cod limit. As would be expected, the increase in TP concentrations matches the decreases in Secchi transparency discussed above.

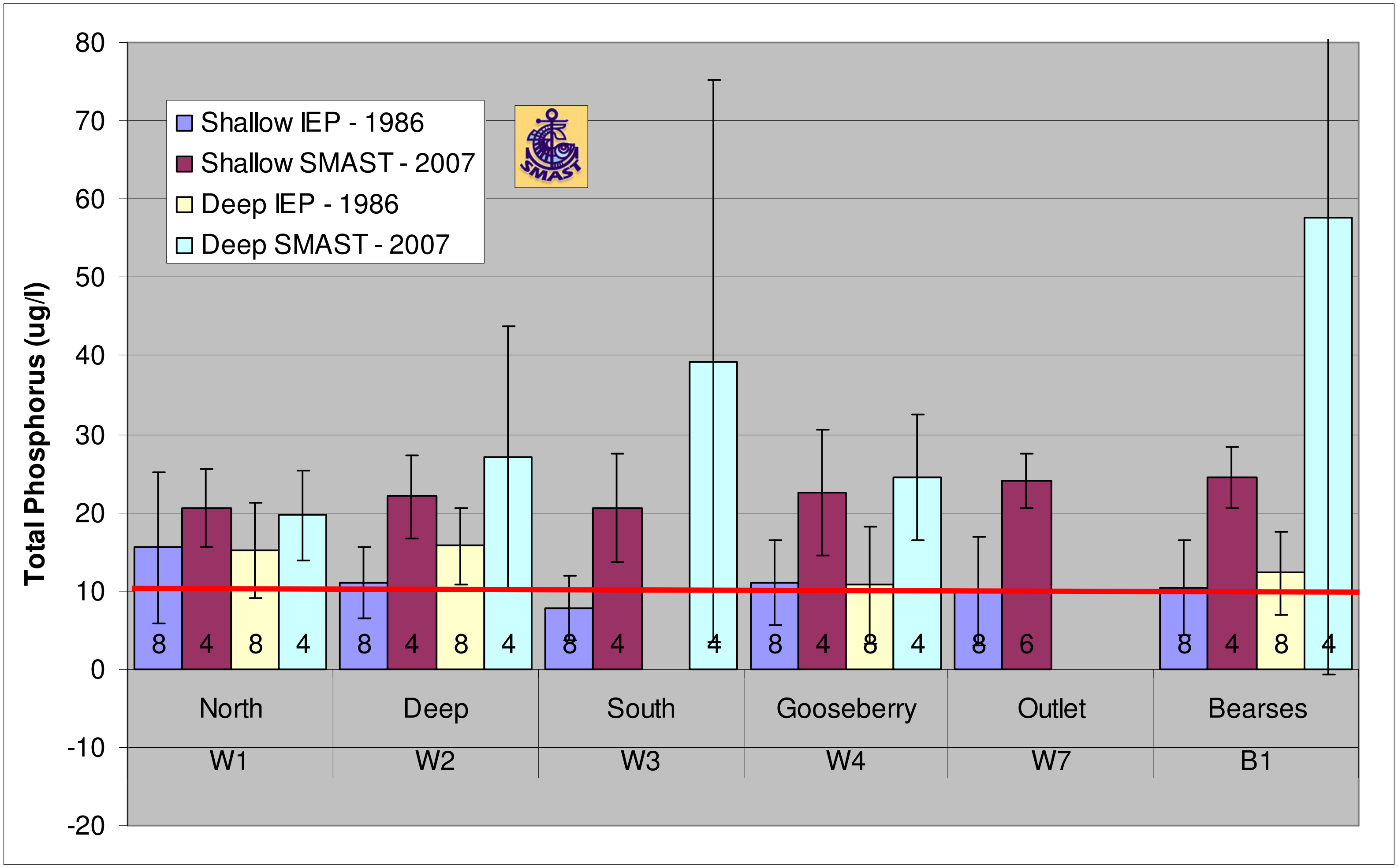


Figure IV-4. Average total phosphorus concentrations in Lake Wequaquet: 1986 and 2007.
Averages are based on June thorough September total phosphorus concentrations collected in 1986 for IEP/KV (1989) and 2007 readings collected for this assessment. Error bars are one standard deviation. 2007 averages at all locations except the shallow and deep at North (W1) and the deep at Deep (W2) are significantly higher than 1986 averages using a t-test ($\rho<0.05$). The number of readings used to calculate the averages are shown in the base of each bar. Red line shown on figure indicates Cape Cod-specific TP threshold of 10 ppb (Eichner and others, 2003). The upper standard deviation for Bearses, Deep CCC – 2007 is 115.8 µg/l.

IV.3.2. Total Nitrogen (TN)

Nitrogen is one of the primary nutrients in surface water systems (phosphorus and potassium being the other two). Nitrogen switches between a number of chemical species (nitrate, nitrite, ammonium, nitrogen gas, and organic nitrogen) depending on a number of factors, including dissolved oxygen, pH, and biological uptake (Stumm and Morgan, 1981). Nitrate-nitrogen is the fully oxidized form of nitrogen, while ammonium-nitrogen is the fully reduced (*i.e.*, low oxygen) form. Inorganic nitrogen generally enters ponds in the nitrate-nitrogen form, is incorporated into algae, forming organic nitrogen, and then is converted back to inorganic forms (nitrate- and ammonium-nitrogen) in the excreta from algae or organisms higher up the food chain or from bacteria decomposing dead algae in the sediments. Total Kjeldahl nitrogen (TKN) is a combined measure of organic nitrogen and ammonium forms. Total nitrogen (TN) is generally reported as the addition of TKN and nitrate-nitrogen concentrations.

Nitrogen is not usually the nutrient that limits growth in freshwater ponds, but ecosystem changes during the course of a year or excessive phosphorus loads can create conditions where it is the limiting nutrient. In very productive or eutrophic lakes, phytoplankton that can extract nitrogen directly from the atmosphere, which is approximately 75% nitrogen gas, often have a strong competitive advantage and tend to dominate the pond ecosystem. These blue-green algae, more technically known as cyanophytes, are generally indicators of excessive nutrient loads.

Nitrogen is a primary pollutant associated with wastewater. Septic systems, the predominant wastewater treatment technology on Cape Cod, generally introduce treated effluent to the groundwater with total 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, 2006). Because septic systems are abundant sources of nitrogen, Cape Cod ponds and lakes tend to have relatively high concentrations of nitrogen; the 184 ponds with TN concentrations sampled during the 2001 PALS Snapshot had an average surface water TN concentration of 0.58 ppm. Using the US Environmental Protection Agency (2000) method for determining nutrient thresholds and the data from the 2001 PALS Snapshot data, the Cape Cod Commission determined that healthy freshwater ponds on Cape Cod should generally have a surface TN concentration no higher than 0.31 ppm (Eichner and others, 2003).

All of the stations in Lake Wequaquet sampled during 2007 have average concentrations between June and September exceeding the 0.31 mg/l total nitrogen threshold (Figure IV-5). All 1986 average concentrations between June and September also exceed the 0.31 ppm threshold except for the shallow South (W3) station and the shallow and the deep stations in Gooseberry Pond (W4); these stations had average TN concentrations of 0.30 ppm, 0.28 ppm, and 0.28 ppm, respectively. These same stations are also the only ones with statistically higher concentrations in 2007 than in 1986 ($\rho<0.05$). No statistically significant differences exist between measured surface and deep concentrations in either 1986 or 2007. All results from both datasets are above laboratory detection limits.

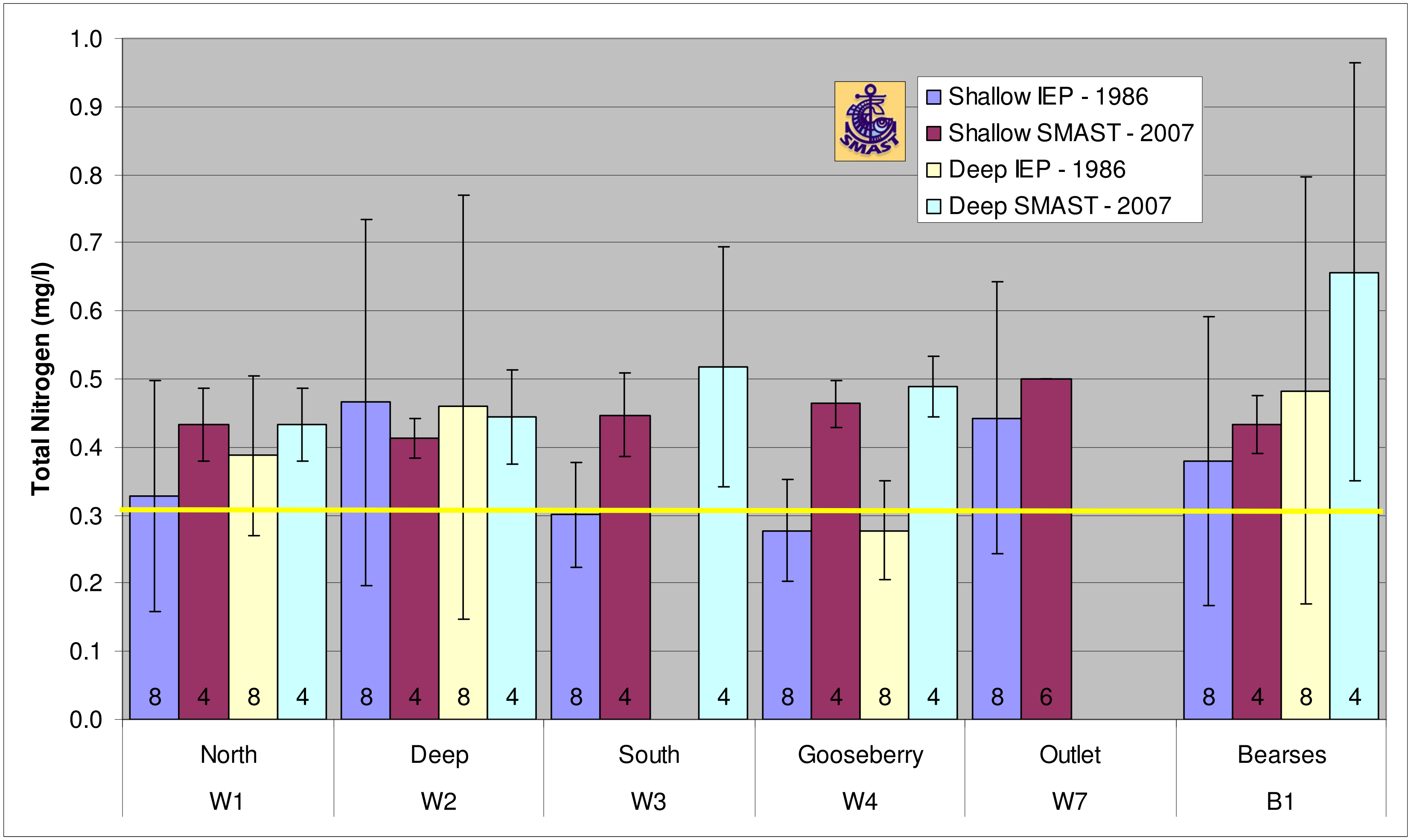


Figure IV-5. Average total nitrogen concentrations in Lake Wequaquet: 1986 and 2007.
Averages are based on June thorough September total nitrogen concentrations collected in 1986 for IEP/KV (1989) and 2007 readings collected for this assessment. Error bars are one standard deviation. 2007 averages at the shallow station at South (W3) and both depth stations at Gooseberry Pond (W4) are the only averages that are significantly higher than 1986 averages using a t-test ($\rho<0.05$). Number of readings used to calculate the averages are shown in the base of each bar. Yellow line shown on figure indicates Cape Cod-specific TN threshold of 0.31 ppm (Eichner and others, 2003).

IV.3.3. Alkalinity and pH

pH is a measure of acidity; pH values less than 7 are considered acidic, while pH values greater than 7 are considered basic. pH is the negative log of the hydrogen ion concentration in water (*e.g.*, water with a H^+ concentration = $10^{-6.5}$ has a pH of 6.5). pH is determined by the interaction of all of the ions with carbon species, like carbon dioxide, carbonate, and bicarbonate, having the most direct effect (Stumm and Morgan, 1981). The natural pH of rainwater, in equilibrium with carbon dioxide in the atmosphere, is 5.65. Photosynthesis takes carbon dioxide and hydrogen ions out of the water causing pH to increase, so more productive, higher nutrient lakes will tend to have higher pH measurements. Alkalinity is a measure of the compounds that shift pH toward more basic values, is mostly determined by the concentrations of bicarbonate, carbonates, and hydroxides, and is a measure of the capacity of waters to buffer acidic inputs. Since both alkalinity and pH are related to the same chemical species, pH and alkalinity are linked values.

Since the sand deposited as Cape Cod during the last glacial period does not have carbonate minerals, Cape soils have low alkalinity and little capacity to buffer the naturally acidic rainwater that falls on the Cape. Available groundwater data shows this; groundwater pH on Cape Cod is generally 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. The average surface pH of 193 ponds sampled in the 2001 PALS Snapshot is 6.16 with a range of 4.38 to 8.92, while the average alkalinity is 7.21 mg/L as $CaCO_3$ with a range of 0 to 92.1 (Eichner and others, 2003).

Average pH in the five surface stations collected between June and September range between 6.38 and 6.44 during 2007, while the deep stations range between 6.14 and 6.42 (Figure IV-6). These readings are generally lower than readings at the same stations in 1986; IEP/KV (1989) readings generally ranged between 6.5 and 6.6. In some cases, the lower pH's in 2007 are significantly lower; the shallow station at N_W1 and the deep stations at South_W3 and Bearses have significantly ($\rho<0.05$) lower readings in 2007 than 1986. All of the stations except Bearses Pond exhibit insignificant differences between shallow and deep readings in either 1986 or 2007; which again suggests well-mixed water column conditions and insignificant impact of sediments on the overlying waters. Bearses had insignificant differences between shallow and deep pH readings in 1986, but significantly ($\rho<0.05$) higher surface readings than deeper readings in 2007. Since the deeper readings are also significantly lower in 2007 than in 1986, this finding suggests that this basin was not as well mixed in 2007 as it was in 1986 or that sediment chemistry is having a greater impact on the overlying waters in 2007.

Average alkalinity concentrations in the five surface stations collected between June and September range between 6.05 and 7.00 mg/L as $CaCO_3$ during 2007, while the deep stations range between 6.23 and 7.63 mg/L as $CaCO_3$ (Figure IV-7). These readings are generally higher than readings at the same stations in 1986; IEP/KV (1989) readings at surface stations ranged between 5.06 and 5.98 mg/L as $CaCO_3$, while deep stations concentrations ranged between 5.25 and 5.63 mg/L as $CaCO_3$. All concentrations at the various stations in 2007 are significantly higher than 1986 except for Gooseberry Pond (both shallow and deep) and the shallow station in Bearses Pond. None of the stations has significant differences between shallow and deep concentrations in 1986 or 2007, which also reinforces the generally well mixed characteristics

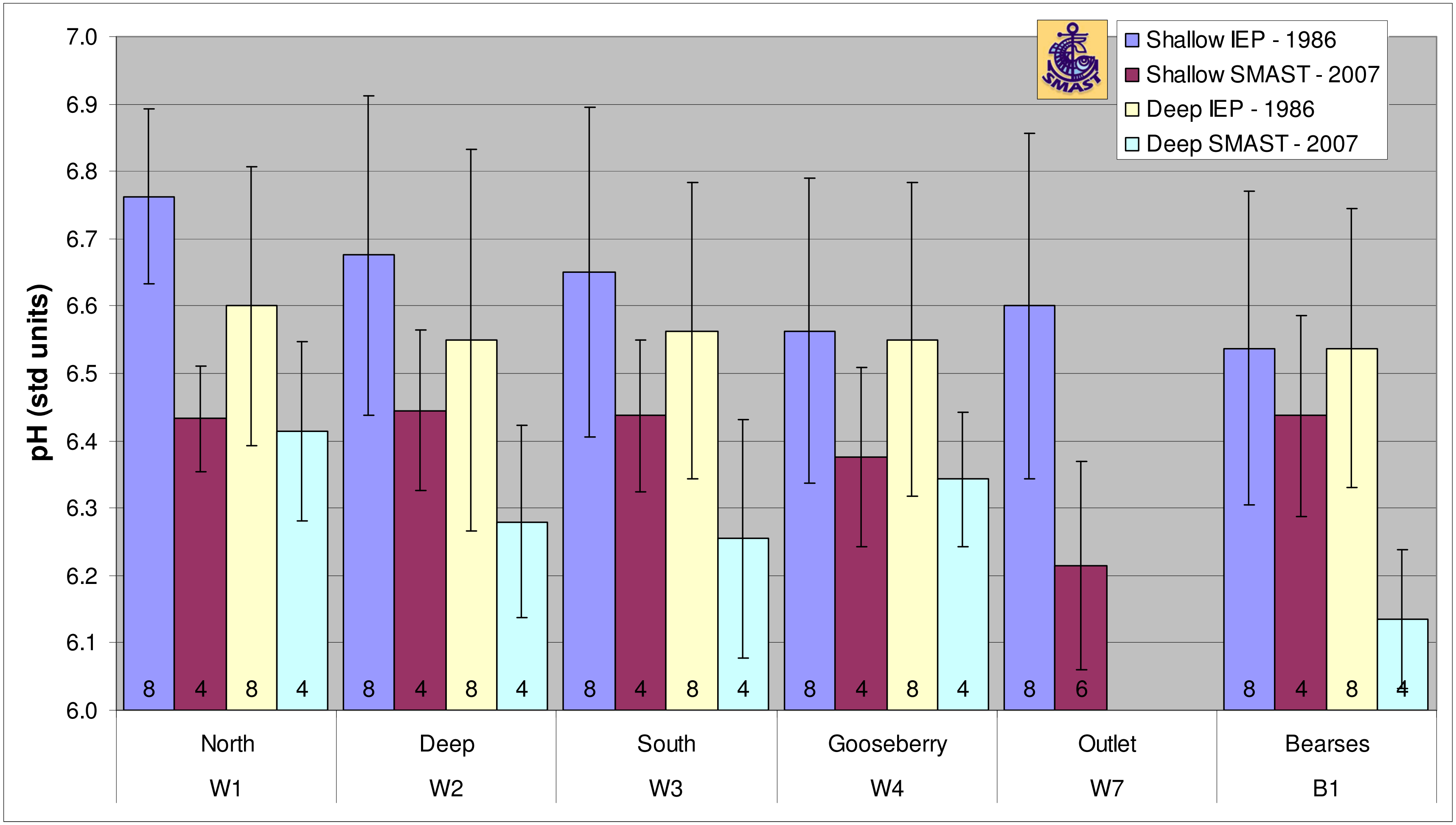


Figure IV-6. Average pH readings in Lake Wequaquet: 1986 and 2007.

pH readings collected between June and September in 1986 for IEP/KV (1989) and 2007 readings collected for this assessment. Error bars are one standard deviation. 2007 averages at the shallow station at North (W1) and the deep stations at South (W3) and Bearses (B1) are the only averages that are significantly lower than 1986 averages using a t-test ($\rho<0.05$). Number of readings used to calculate the averages are shown in the base of each bar.

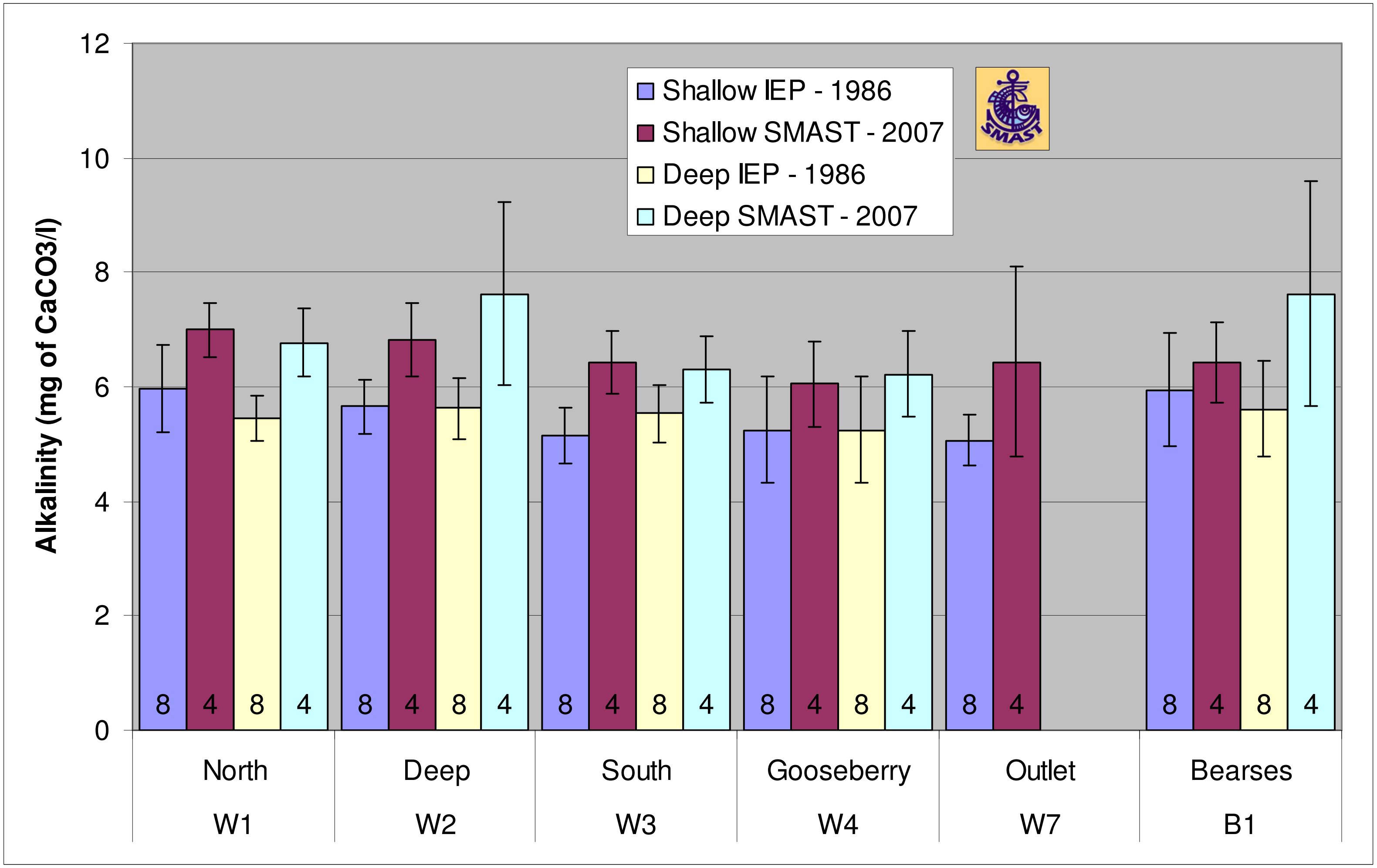


Figure IV-7. Average alkalinity concentrations in Lake Wequaquet: 1986 and 2007.
Alkalinity concentrations collected between June and September in 1986 for IEP/KV (1989) and 2007 readings collected for this assessment. Error bars are one standard deviation. 2007 averages at all stations except both depth stations at Gooseberry Pond (W4) and the shallow station at Bearses Pond (B1) are significantly higher than 1986 averages using a t-test ($\rho<0.05$). Number of readings used to calculate the averages are shown in the base of each bar.

of the water column in each basin and the relatively insignificant impact of the sediments on water column concentrations.

Based on both the 1986 and the 2007 pH and alkalinity readings, Lake Wequaquet would be classified as an acidic, low alkalinity lake, but the opposite directions of change in the alkalinity and pH readings suggest that other factors should be evaluated. Because Cape Cod lakes do not tend to have an inherent alkalinity due to the surrounding geology, most of the alkalinity in these ponds and lakes tends to be the result of hydrogen ion consumption during photosynthesis. Recent regional reviews of Cape Cod ponds and lakes have shown that waters with higher chlorophyll and phosphorus concentrations tend to have higher pH and alkalinity than those with lower chlorophyll and phosphorus concentrations (*e.g.*, Eichner, 2007).

One potential explanation for the declining pH and elevated alkalinity might be increasing concentrations of atmospheric carbon dioxide. Because the total mass of carbon in Cape's ponds and lakes is generally low, changes in atmospheric pressure of carbon dioxide could have a significant impact on the carbonate concentrations and, thus, on the alkalinity and pH. Aquatic carbonate balance equations predict that each 10% increase in atmospheric CO2 concentrations would result in an approximately 1% increase in soluble carbon dioxide concentrations and an accompanying 10% increase in hydrogen ion concentrations (Stumm and Morgan, 1981).

In order to explore this hypothesis, project staff looked at reviews of recent worldwide long term atmospheric datasets. These reviews place the annual increase in atmospheric carbon dioxide over the last 40 years at between 1.4 and 2 parts per million by volume (ppmv) with higher rates in the last few years (IPCC, 2007). Using an initial rate of 350 ppmv and the range of annual increases, the atmospheric concentrations on Cape Cod would have increased 8 to 11% between 1986 and 2007. Surface alkalinity concentrations in Lake Wequaquet increased 8 to 27% between 1986 and 2007, while hydrogen ion concentrations increased 2.5 to 6.6 times the alkalinity increases. While these results are suggestive, more refined sampling and analysis and comparison to results from other lakes would be necessary to fully resolve why pH is declining and alkalinity is rising in Lake Wequaquet and these conditions have not been observed in other Cape Cod ponds with similar datasets.

IV.3.4. Chlorophyll *a* (CHL-a)

Chlorophyll is the primary photosynthetic pigment in plants, both algae and macrophytes (*i.e.*, any aquatic plants larger than microscopic phytoplankton, including rooted aquatic plants). Because of its prevalence, measurement of chlorophyll can be used to estimate how much algae is present in collected water samples. Chlorophyll-*a* is a specific pigment in the chlorophyll family and plays a primary role in photosynthesis (USEPA, 2000).

Laboratory procedures for chlorophyll can be somewhat complicated because its breakdown products have very similar characteristics; for this reason SMAST labs also quantify phaeophytin, the primary initial breakdown product of chlorophyll. Since chlorophyll-*a* is a measure of active photosynthetic pigment, phaeophytin is sometime characterized as "dead" chlorophyll.

Since most Cape Cod lakes have relatively low phosphorus inputs, rooted plant populations tend to be small and algal populations are sparse. Because the algal populations are sparse and are the source of chlorophyll in pond waters, chlorophyll concentrations also tend to be low. The median surface concentration in the 191 Cape Cod ponds sampled for chlorophyll-*a* during the 2001 Pond and Lake Stewards (PALS) Snapshot is 3.6 ppb (or µg/l) with a range from below detection limit to 86 ppb (Eichner and others, 2003). A more limited sampling of 60 Cape ponds found a mean chlorophyll-*a* concentration of 3.07 ppb with a range of 0.51 to 19.25 µg/l (Ahrens and Siver, 2000).

As with TP and TN, Cape Cod Commission staff also used the US Environmental Protection Agency (2000) method for determining nutrient thresholds and the 2001 PALS Snapshot data to determine that healthy freshwater ponds on Cape Cod should generally have a surface chlorophyll concentrations no higher than 1.7 ppb. This same analysis also found that the most protected or pristine ponds on Cape Cod have surface chlorophyll concentrations of no higher than 1.0 ppb (Eichner and others, 2003). Phaeophytins were not considered in this analysis.

All of the Lake Wequaquet stations sampled during 2007 have average concentrations between June and September exceeding the 1.7 ppb chlorophyll-*a* threshold except for the outlet, which has an average concentration of 1.0 ppb (Figure IV-8). All 1986 average concentrations between June and September also exceed the threshold. Although all of the 2007 average concentrations are higher than the 1986 averages, none of the concentrations are significantly ($\rho<0.05$) higher in 2007 than in 1986. Although Bearses Pond shallow and deep average concentrations, in particular, have a large difference, no statistically significant differences exist between measured surface and deep concentrations in 2007. This generally reinforces the well mixed nature of each of the basins in Lake Wequaquet, but also is reflective of the wide range of measured concentrations. Deep chlorophyll samples were not analyzed in 1986. Combined phaeophytin/chlorophyll a concentrations generally have the same relationships as those described for chlorophyll alone. Results from both 2007 and 1986 datasets are above laboratory detection limits.

IV.3.5. Other Laboratory Data

In addition to data determined from collected water samples, project staff also collected a limited number of additional samples to qualitatively assess conditions in Lake Wequaquet in 2007. Collected samples included sediment, algae/phytoplankton, and periphyton.

IV.3.5.1. Sediments

As plants and animals die within a lake, they fall to the bottom and become part of the sediments. As such, the sediments are a reflection of the history of a pond ecosystem, collecting information on conditions both within the pond and within its watershed. Since bacterial decay processes can release the nutrients stored in these dead plants and animals, these nutrients can be released or regenerated back into the water column if chemical conditions are suitable. Once back in the water column, these nutrients can prompt the creation of more plants and animals. Given a significant source of regenerated sediment nutrients, algal populations can increase substantially and cause worse water quality conditions than if only the watershed is the predominant source of nutrients.

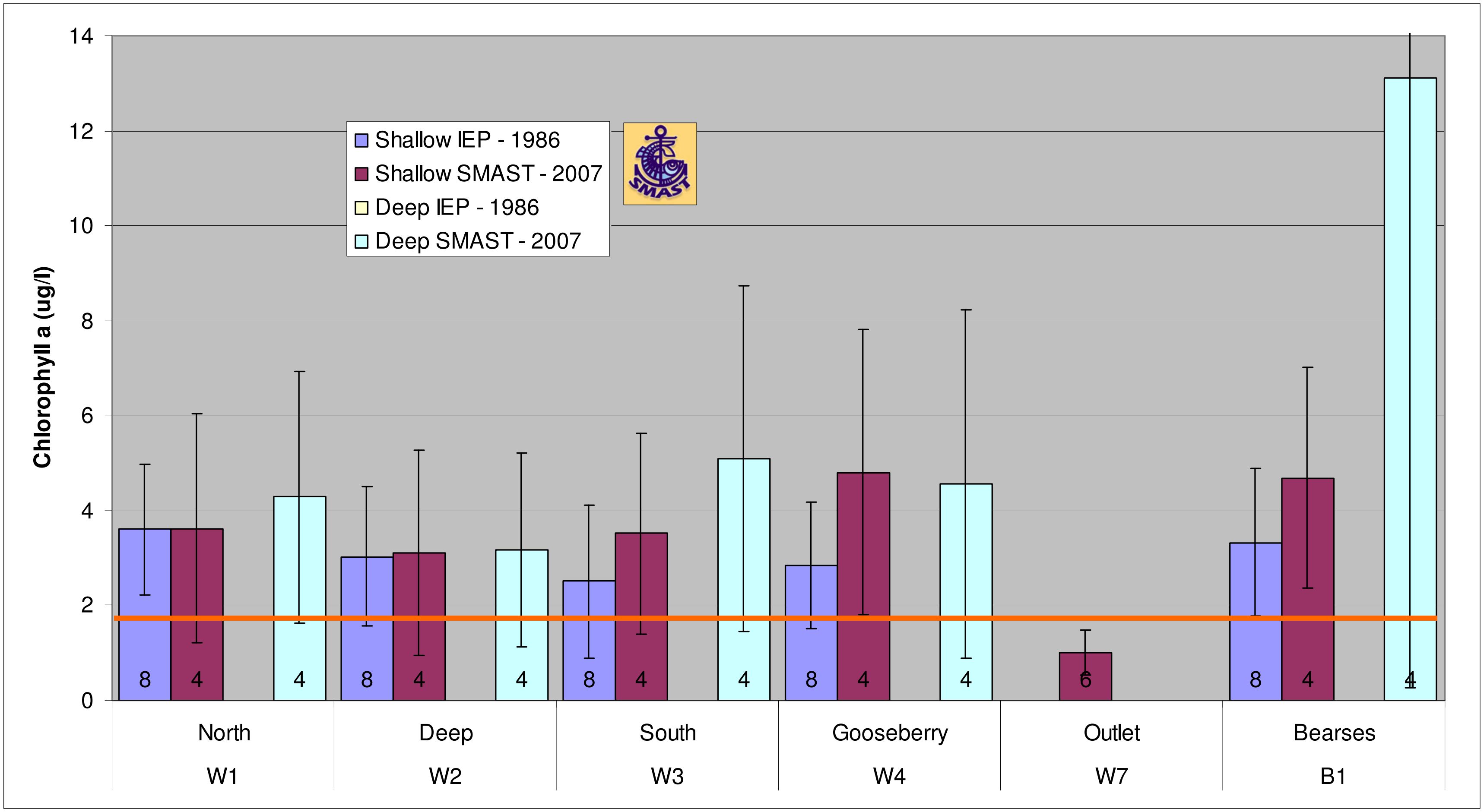


Figure IV-8. Average chlorophyll-*a* concentrations in Lake Wequaquet: 1986 and 2007.
Chlorophyll-*a* concentrations collected between June and September in 1986 for IEP/KV (1989) and 2007 readings collected for this assessment. Error bars are one standard deviation. None of the stations have significantly higher averages in 2007 than 1986 using a t-test ($\rho<0.05$), although most 2007 averages are higher than 1986 averages. Number of readings used to calculate the averages are shown in the base of each bar. No chlorophyll-*a* concentrations were determined at deep stations during the IEP/KV (1989) study. Orange line shown on figure indicates Cape Cod-specific chlorophyll a threshold of 1.7 ppb (Eichner and others, 2003).

Unfortunately, pond sediment sampling is not consistently done in lake assessments and data, especially historic data, is usually limited.

Project funding during 2007 was sufficient to collect sediment samples during two periods: May and August. Samples were collected using an Ekman dredge, transferred to 8 ounce amber glass soil jars, stored on ice at 4°C, and shipped on the same day to Spectrum Analytical, Agawam, MA. Sediment temperatures and chain of custody procedures were checked at the lab to ensure proper handling.

Since phosphorus is the key nutrient in determining water quality conditions in most ponds, staff limited the 2007 sediment analysis to total phosphorus, iron-bound phosphorus, and loosely-sorbed phosphorus. While total phosphorus analysis is relatively common, the other two analyses were developed to assess the portion of the total phosphorus pool that are most likely to be regenerated from the sediments during low oxygen conditions. Iron-bound phosphorus would be the most easily released as iron is highly soluble in low oxygen conditions (Stumm and Morgan, 1981). Loosely-sorbed phosphorus is generally released from sediments at lower oxygen concentrations or more sustained low oxygen concentrations than iron-bound phosphorus. An alternative regeneration analysis method is to collect a sediment column, subject it to various specified conditions, and measure the amount of nutrients released; this type of analysis is part of the estuary analysis protocol for the Massachusetts Estuaries Project. IEP/KV (1989) collected one run of sediment samples; sediment samples collected on 2/27/86 were analyzed for total phosphorus and metals.

Table IV-2 shows the phosphorus related results for the 1986 and 2007 sediment samples. Because the number of samples is limited, quantitative conclusions are difficult, but the results are suggestive that sediment conditions have changed significantly over the last 20 years. The 2007 samples have dramatically higher total phosphorus concentrations at all stations, except Bearses Pond, while maintaining approximately the same solids content. This suggests that more phosphorus is entering the main portions of the lake, but that Bearses Pond loads have not changed. The iron-bound and loosely-sorbed phosphorus results, however, generally show that most of the total phosphorus pool is not actively available. This result suggests that while more phosphorus is entering the lake, the sediments are still generally a sink for the nutrient and little is available for regeneration during low oxygen events. It is recommended that the town consider collecting some sediment cores and evaluating what conditions will cause the release of these apparently increasing pools. Potential impacts of the more available, labile phosphorus in the sediments will be discussed below.

IV.3.5.2. Phytoplankton, Periphyton, and Macrophytes

Available nutrients in a pond water column are going to be initially used and incorporated into biological material by various types of plants, which generally fall into three categories: 1) free-floating phytoplankton or algae, 2) attached algae or periphyton, and 3) rooted plants, often referred to as macrophytes. While it was well beyond the available project budget to duplicate the sampling completed by IEP/KV (1989), project staff did collect phytoplankton tows at three locations (deep station, Bearses, and Gooseberry), one periphyton sample on the northern shore of the main basin near the public boat ramp, and reviewed plant survey information collected by Wequaquet Lake Protective Association volunteers.

Table IV-2. Lake Wequaquet Sediment Phosphorus: 1986 and 2007

Sediment analysis of total phosphorus, % solids, and phosphorus fractions are from IEP/KV (1989) and this project. Iron-bound phosphorus and loosely-sorbed phosphorus analyses were not completed on samples collected in 1986. No sample was collected at W_3 on 8/30/07.

		Sampling Station				
		Deep	South	Gooseberry	Bearses	
		W_2	W_3	W_4	B_1	Lab Method
IEP/KV		2/27/86	2/27/86	2/27/86	2/27/86	2/27/86
% Solids	%	38	20	17	22	not specified
Total P	mg/kg dry	21	88	5	943	not specified
SMAST/CCC		5/2/07	5/2/07	5/2/07	5/2/07	5/2/07
% Solids	%	29.1	29.6	45.9	17.8	SM2540 G Mod
Total P	mg/kg dry	900	691	585	812	ASTM D515-88(A)
Fe-bound P	mg/kg dry	31.6	BRL	BRL	BRL	ASTM D515-88(A)
Loosely sorbed P	mg/kg dry	BRL	BRL	BRL	BRL	ASTM D515-88(A)
SMAST/CCC		8/30/07	8/30/07	8/30/07	8/30/07	8/30/07
% Solids	%	21.7		22	14	SM2540 G Mod
Total P	mg/kg dry	1580		1460	1740	EPA 200.7
Fe-bound P	mg/kg dry	60.5		BRL	12.9	ASTM D515-88(A)
Loosely sorbed P	mg/kg dry	BRL		BRL	BRL	ASTM D515-88(A)

Phytoplankton samples were collected as net tows throughout the photic zone as measured by a Secchi reading on September 27, 2007. Samples were placed in brown bottles, stored at 4°C, and shipped overnight to Phytotech, Inc., where they were preserved and analyzed. Samples were analyzed at genus level for units per milliliter and volume per milliliter and grouped into various algal divisions. Summary results from all three sites are shown in Figure IV-9.

The dominant phytoplankton population on September 27, 2007 in all collected samples by cells (natural units) is Cyanophyta, also known as blue-green algae, while the dominant population by cellular volume is Bacillariophyta, also known as diatoms. The total number of cellular natural units/ml was 156 at the main basin/deep station, 108 at the Gooseberry station, and 270 at the Bearses station. These concentrations are at the low end of the ranges measured by IEP/KV during the October 1985 to September 1986 sampling period; phytoplankton counts during this period ranged between 118 and 1,900 natural units/ml (IEP/KV, 1989). The high end of this range was due to a bloom of a colonial alga named *Volvox*, which is a green algae.

Although IEP/KV collected over 72 phytoplankton samples, the analysis of the results is most limited to total counts. The original analysis sheets, including species breakdowns, are included in the appendix of the diagnostic/feasibility study. A quick review of the analysis sheets generally do not show significant Cyanophyta. Since significant blue-green algae populations are generally associated with diminished water quality conditions, the large presence in the 2007 sample is indicative that ecosystem conditions have worsened over the past 20 years, but more extensive sampling would be necessary to confirm how representative the 9/27/07 sampling tow is of general or average phytoplankton populations in Lake Wequaquet since phytoplankton populations tend to fluctuate and 9/27/07 would tend to be worst case conditions.

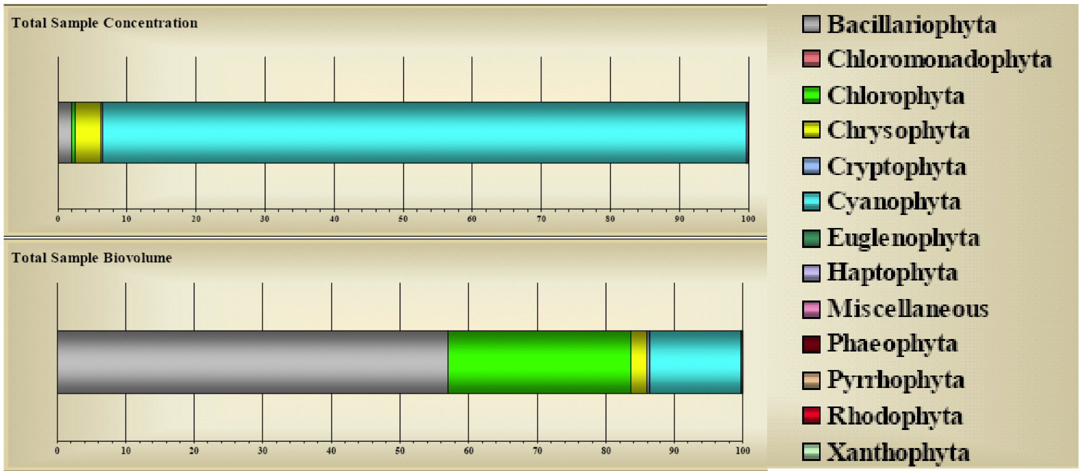
Periphyton was observed growing on all exposed cobbles in the area to the west of the Shootflying Hill public boat ramp during the September 27, 2007 sampling; no periphyton was observed growing on sandy substrates. The periphyton sample had more or less the same balance of algal divisions as the phytoplankton at LW-1 (deep station) with blue green algae as the dominant cell division and diatoms as the predominant cell volume. Total cell count in the sample from 0.5 m2 is 1.8 million natural units/ml. Four samples in the appendix of IEP/KV (1989) showed a range of 240 to 385 cells/mm2 in Lake Wequaquet and one sample with a cell count of 1,171 cells/mm2 in Bearses. Because the sampling protocols are not discussed in the text of the IEP/KV diagnostic/feasibility report, it is unclear whether the apparent increase in periphyton count is reflective of changes in the lake or differences in sampling protocols.

For the past five years, volunteers from the Wequaquet Lake Protective Association (WLPA) have been collecting information on the plant coverage and generalized species identification around the margins of the lake. All the WLPA maps are included in Appendix A. Although it is beyond the scope of the contracted activities, project staff reviewed the maps resulting from these activities to provide some comparison to the more detailed data collection conducted by IEP/KV. IEP/KV (1989) reviewed macrophyte density (as % of bottom coverage) and identified all macrophyte species.

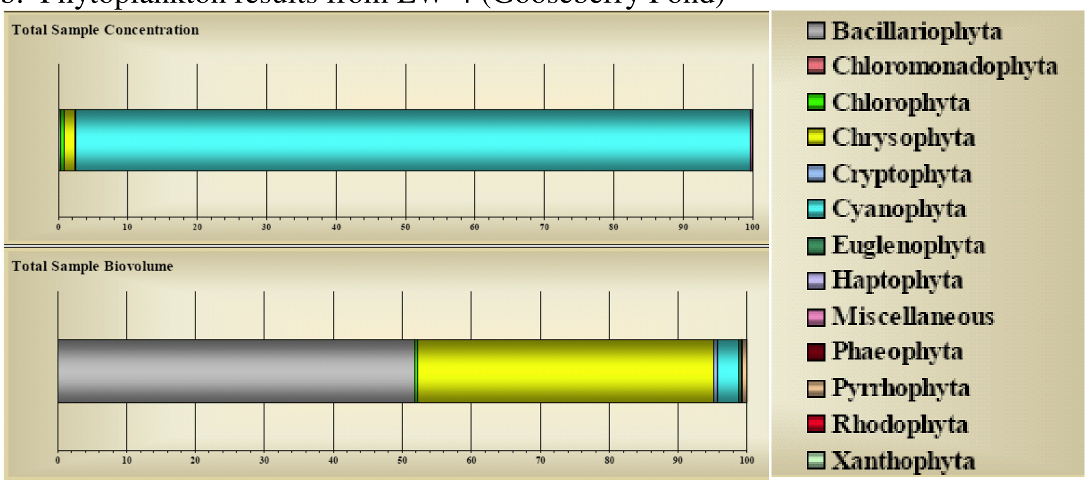
Figure IV-10 shows the macrophyte density throughout Lake Wequaquet based on a boat survey between August 29 and September 8, 1987 (IEP/KV, 1989). IEP/KV scientists cataloged density and identified plant species via a viewing box as a boat trolled along the shoreline. The most common plants in shallow waters were *Sagittaria teres* (slender arrowhead) and *Isoetes* species (various forms of quillwort), with a transition toward *Elodea nuttallii* (western waterweed), *Potamogeton pusillus* (small pondweed), and *Myriophyllum humile* (low watermilfoil) as waters deepen, and finally to *Vallisneria americana* (American eelgrass or wild celery) as the dominant plant in the deepest waters (12 to 15 feet deep). *Brasenia schreberi* (watershield), *Nymphaea odorata* (American white waterlily), and *Nuphar variegate* (varigated yellow pond-lily) were the most common plants in the coves and protected areas of the lake and various *Nitella* species (stoneworts, which are not vascular plants, but large algae) were recovered from anchors at Stations 3 (South) and 4 (Gooseberry). Macrophytes were generally sparse or absent in areas with sand or gravel bottoms and all species were observed in areas with organic bottom substrates. All common names were researched by project staff from the US Department of Agriculture Plant Database (http://plants.usda.gov).

Figure IV-11 shows the aquatic plant information collected by WLPA volunteers in 2007. The WLPA plant information varies from year to year based on the amount of the pond shoreline that could be surveyed, but the most striking difference is the apparent loss of plant coverage compared to the 1987 IEP/KV survey. If this apparent plant loss is confirmed, it would help to explain the decline in Secchi readings and rise in total phosphorus and chlorophyll-*a* concentrations. Given the importance of this factor toward understanding the function and management of water quality in the lake, it is recommended that the town consider a more detailed aquatic plant survey.

a. Phytoplankton results from LW-1 (Lake Wequaquet deep station)



b. Phytoplankton results from LW-4 (Gooseberry Pond)



c. Phytoplankton results from LW-5 (Bearses Pond)

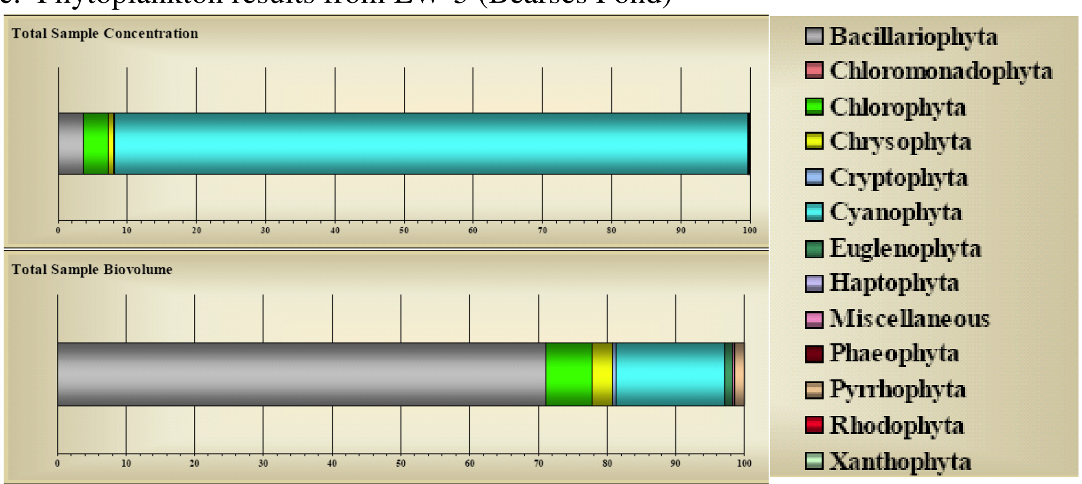


Figure IV-9. Phytoplankton Concentrations from Lake Wequaquet 9/27/07

Samples taken at the deep station in the (a) main basin, (b) Gooseberry Pond, and (c) Bearses Pond. Top bar is relative (%) sample concentration of cells per milliliter by algal division, while bottom bar is the relative (%) volume of each algal division. All samples show a dominant number of Cyanophyta (blue green algae), while Bacillariophyta (diatoms) are the dominant division by volume.

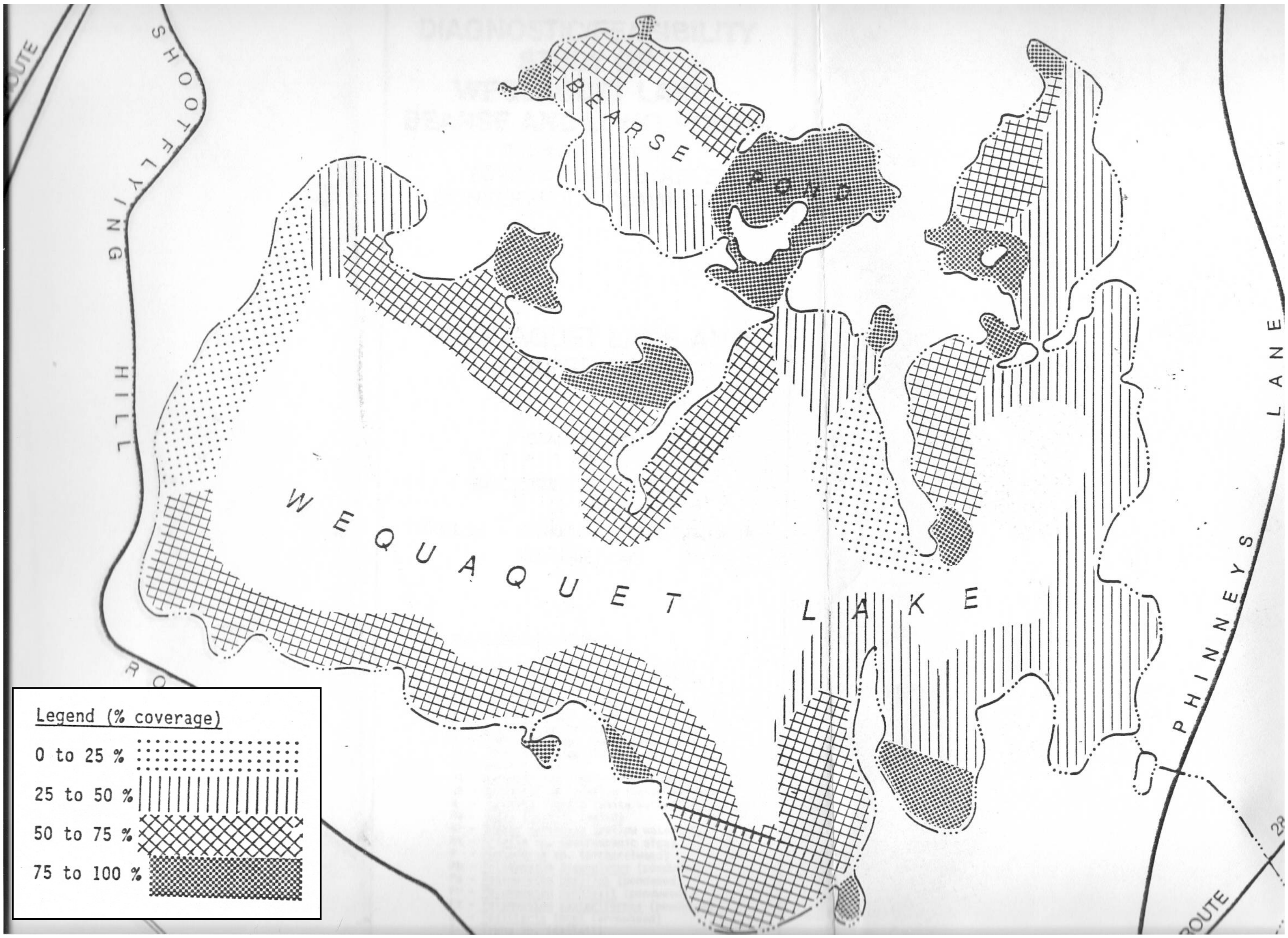


Figure IV-10. IEP/KV (1989) Macrophyte coverage map for Lake Wequaquet

Survey data collected August 29 to September 8 using a viewing box from a trolling boat. Predominate species were also identified.

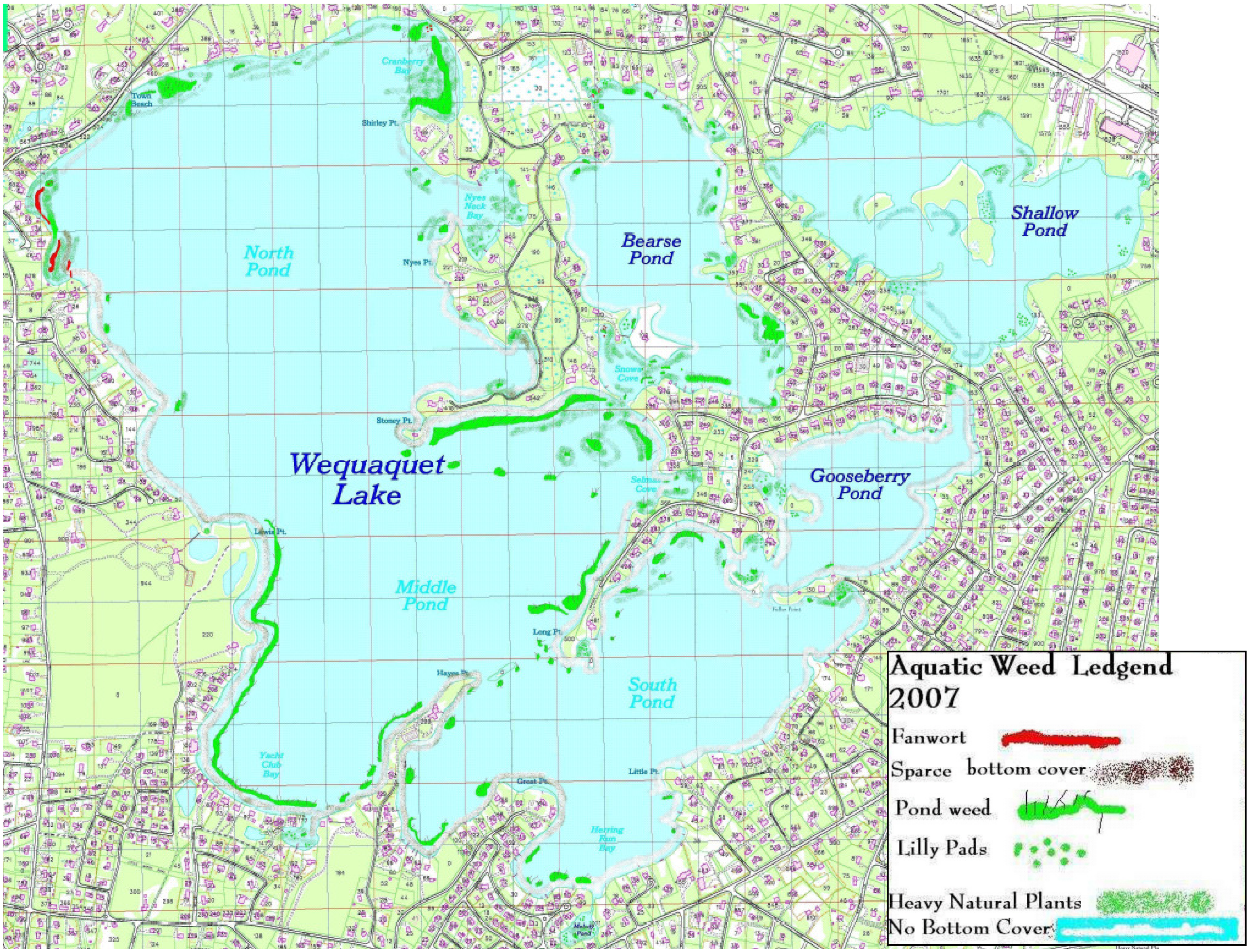


Figure IV-11. Wequaquet Lake Protective Association Aquatic Plant Map for 2007

Survey data during 2007 by WLPA volunteers via boating around the lake; plant coverage interpretation completed in the field.

V. Overall Assessment

V.1. Ecosystem Status/Carlson Index

Assessing the ecosystem status of a lake or pond usually starts from trying to develop an understanding what the system would be like if it did not have the impacts of development within its watershed and surrounding land uses. This understanding usually has to be developed by looking at similar, unimpacted ponds and historic water quality measurements from the same pond, if available. On Cape Cod, developing this understanding by comparing monitoring results to other ponds is hindered a bit more than in other portions of the country since the Cape's geology and climatic environment are relatively unique.

Carlson (1977) developed a trophic status index based on water quality monitoring from ponds in Wisconsin and Minnesota. The trophic state of a pond is the total amount of living biological material (*i.e.*, biomass) in the ecosystem and Carlson's index uses various measures to provide a single index number that places ponds in various trophic categories (Table V-1). Carlson designed the system to utilize a selected measure to classify the trophic state index (TSI) of a pond or lake on a scale of 0 to 100 (Carlson and Simpson, 1996). Although the Carlson indices were developed for use in northern temperate lakes and do not work well in lakes where macrophytes (*i.e.*, rooted aquatic plants) dominate the ecosystem, these indices have been extensively used and use of this index provides a common touchstone for comparing Lake Wequaquet to other ponds.

Use of the Carlson Index on average chlorophyll-*a* readings generally place the main basin of Lake Wequaquet on the lower edge of the mesotrophic classification with Bearses and Gooseberry somewhat elevated in 2007, but still within the mesotrophic range (Figure V-1). The classification of the main portion is essentially the same in 1986 as it is in 2007. Use of Secchi disk readings result in similar index classifications in 1986 and just slightly higher in 2007. Total phosphorus concentrations result in index readings mostly on the oligotrophic side of the oligotrophic/mesotrophic boundary, while 2007 readings result in indices approaching the mesotrophic/eutrophic boundary.

Data from the 2001 PALS Snapshot indicated that a "healthy" freshwater pond on Cape Cod would have a threshold concentration of 1.7 µg/l for chlorophyll-*a*, which translates to a TSI of 35.8, while the cleanest, and presumably pristine, Cape Cod ponds have a TSI of 30.6 (Eichner and others, 2003). This TSI level is classified as oligotrophic (see Table V-1 for generalized conditions). Lake Wequaquet stations have average 2007 chlorophyll-*a* TSI readings of between 42 and 46 and 1986 TSI readings of between 40 and 43.

V.2. Limiting Nutrient

Biomass in pond and lake ecosystems is usually limited by a key nutrient; if more of the nutrient is available the biomass will increase. In ponds and lakes, the key nutrient is usually phosphorus; rapid introduction of phosphorus usually leads to algal blooms, while more gradual increases can prompt the change in the dominant plant community from one dominated by algae to one dominated by rooted plants. In ponds and lakes that are phosphorus limited, addition of phosphorus begins a cascade of events that leads to excessive oxygen demand and failure to meet state water quality standards. Phosphorus additions increase available concentrations, causing an increase in algal biomass, which, in turn, leads to additional organic loading to the sediments, which eventually overwhelms natural bacterial regeneration processes and leads to anoxic

Table V-1. – Carlson Trophic State Index (TSI)					
TSI Calculations					
TSI(SD) = 60 - 14.41 ln(SD)				SD = Secchi disk depth (meters)	
TSI(CHL) = 9.81 ln(CHL) + 30.6				CHL = Chlorophyll *a* concentration (µg/l)	
TSI(TP) = 14.42 ln(TP) + 4.15				TP = Total phosphorus concentration (µg/l)	
TSI Values	Chl a (µg/l)	SD (m)	TP (µg/l)	Pond Attributes	Fisheries & Recreation
<30	<0.95	>8	<6	Oligotrophy: Clear water, oxygen throughout the year in the hypolimnion	Salmonid fisheries dominate
30-40	0.95-2.6	8-4	6-12	Hypolimnia of shallower lakes may become anoxic	Salmonid fisheries in deep lakes only
40-50	2.6-7.3	4-2	12-24	Mesotrophy: Water moderately clear; increasing probability of hypolimnetic anoxia during summer	Hypolimnetic anoxia results in loss of salmonids.
50-60	7.3-20	2-1	24-48	Eutrophy: Anoxic hypolimnia, macrophyte problems possible	Warm-water fisheries only. Bass may dominate.
60-70	20-56	0.5-1	48-96	Blue-green algae dominate, algal scums and macrophyte problems	Nuisance macrophytes, algal scums, and low transparency may discourage swimming and boating.
70-80	56-155	0.25-0.5	96-192	Hypereutrophy: (light limited productivity). Dense algae and macrophytes	
>80	>155	<0.25	192-384	Algal scums, few macrophytes	Rough fish dominate; summer fish kills possible
after Carlson and Simpson (1996); Note: Carlson TSI developed in algal dominated, northern temperate lakes					

sediment conditions (Wetzel, 1983).

One way to assess whether a lake is limited by phosphorus is to review the balance between phosphorus and nitrogen. As a rule of thumb, if the ratio between nitrogen and phosphorus is greater than 16, phosphorus is the limiting nutrient (Redfield and others, 1963). Generally, phosphorus-limited systems have N to P ratios that are multiples of 16.

Lake Wequaquet surface samples in 1986 generally had N to P ratios between 63 and 121, which are indicative of a phosphorus-limited system (Figure V-2). These ratios are likely somewhat inflated because of the high number of phosphorus results in 1986 that were below laboratory detection limits, but the 2007 ratios, while lower, also indicate phosphorus limitation. Surface samples from 2007 have N to P ratios of between 39 and 49, which are still 2-3 times the Redfield ratio of 16. Bottom samples generally have similar ratios as the surface samples, as would be indicative of a well-mixed water column, although some of the deep samples in both 1986 and 2007 are at or below the Redfield ratio. These lower ratios are consistent with sediment regeneration and the deep, low dissolved oxygen conditions observed during what are likely quiescent periods.

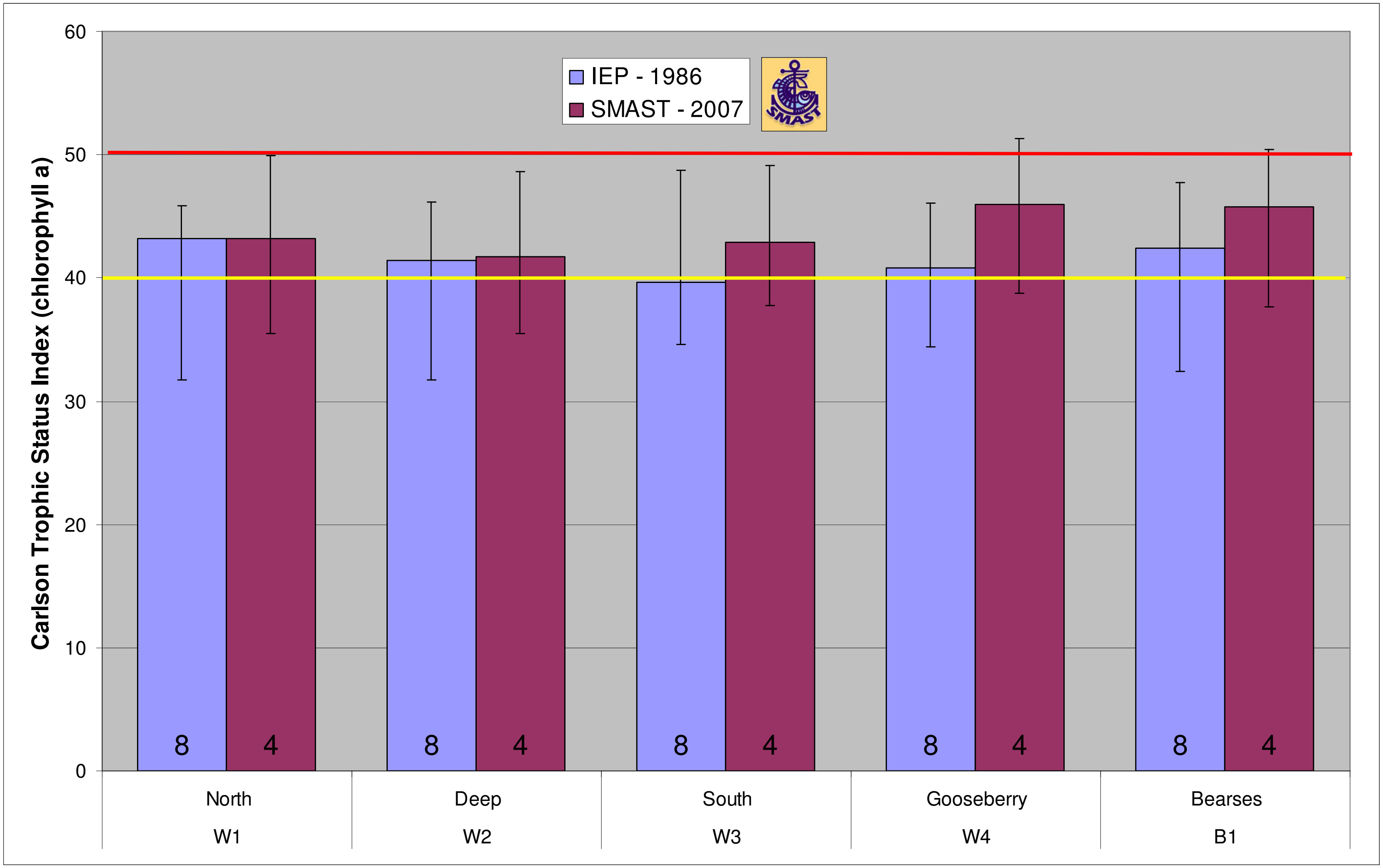


Figure V-1. Average Carlson Trophic Status Index in Lake Wequaquet: 1986 and 2007.
Carlson TSI (Carlson, 1996) based on chlorophyll a concentrations from surface samples collected between June and September in 1986 for IEP/KV (1989) and 2007 readings collected for this assessment. Error bars are maximum and minimum readings. Number of readings used to calculate the averages are shown in the base of each bar. Yellow line shown on figure indicates oligotrophic/mesotrophic boundary, while the red line indicates the mesotrophic/eutrophic boundary.

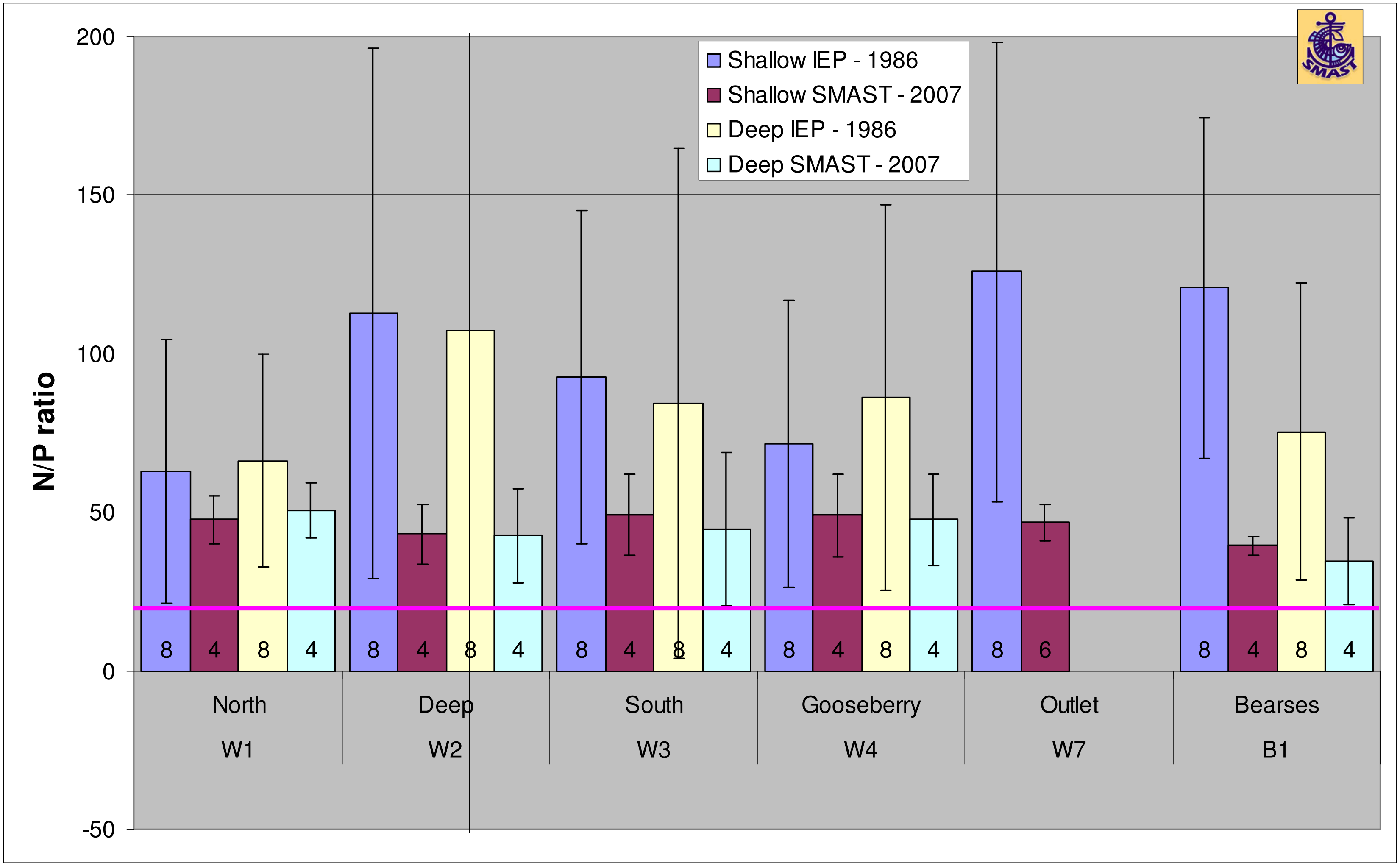


Figure V-2. Average Nitrogen to Phosphorus Ratios in Lake Wequaquet: 1986 and 2007.
Bars indicate average nitrogen to phosphorus ratios based on samples collected between June and September in 1986 for IEP/KV (1989) and 2007 readings collected for this assessment. Error bars are one standard deviation; Deep_W2, IEP standard deviation values are -68 and +282. Number of readings used to calculate the averages are shown in the base of each bar. Pink line is the Redfield ratio of 16 and above which systems are more limited by phosphorus than nitrogen.

V.3. Nutrient Budget Development: Phosphorus and Nitrogen

Because phosphorus and nitrogen are key nutrients in determining the ecosystem health of Lake Wequaquet, project staff developed budgets for each nutrient. Because phosphorus is limiting nutrient in Lake Wequaquet and, therefore largely determines the water quality of the system, a phosphorus budget accounts for each of the primary sources of phosphorus, which include wastewater, road runoff, and internal sediment regeneration. If phosphorus reduction strategies are desired, determining which of the sources contributes the most allows the development of targeted strategies to reduce the loads in the most cost effective fashion.

Although phosphorus is the key for determining water quality in Lake Wequaquet, it should also be noted that the lake is also a component of the Centerville River estuary watershed. This estuary has been identified as being impaired by excessive nitrogen by the Massachusetts Estuaries Project (Howes and others, 2006) and the MEP-prepared nitrogen limits have been approved as TMDLs under the Clean Water Act by the US Environmental Protection Agency (USEPA, 2007). Although nitrogen is not the limiting nutrient for the lake, it is for the estuary and the lake plays an important role in removing a portion of nitrogen that enters the lake from its watershed. The MEP assumed that the lake removed 50% of the watershed nitrogen based on the PALS data available at the time; the data collected during this project and the development of a revised nitrogen budget allow this assumption to be reviewed based on a more extensive dataset.

Development of the nutrient budgets for each of the Lake Wequaquet basins begins with the watershed delineation described in Section III and the Massachusetts Estuaries Project (MEP) land use database developed as part of the evaluation of the Centerville River/East Bay system (Howes and others, 2006). Digital parcels and land use/assessors data in the MEP database are from 2004 and were obtained from the Town of Barnstable Geographic Information Systems Department. This data includes traditional information regarding tax assessor's land use classifications (MADOR, 2002), which are a key factor for determining land use. In order to complete the MEP watershed analysis, these parcels and their accompanying database were joined with available water use information from 2001 through 2005 from the Centerville, Osterville, Marstons Mills (COMM) Water District. Water use volume is adjusted to account for consumptive use and is used as a proxy for wastewater generation in MEP analyses. All GIS work for this portion of the MEP analysis was completed using the Cape Cod Commission Geographic Information System (GIS). For this Lake Wequaquet project, lawn areas were also determined based on aerial photographs and this information was also linked to the land use database.

V.3.1. Nitrogen Budget

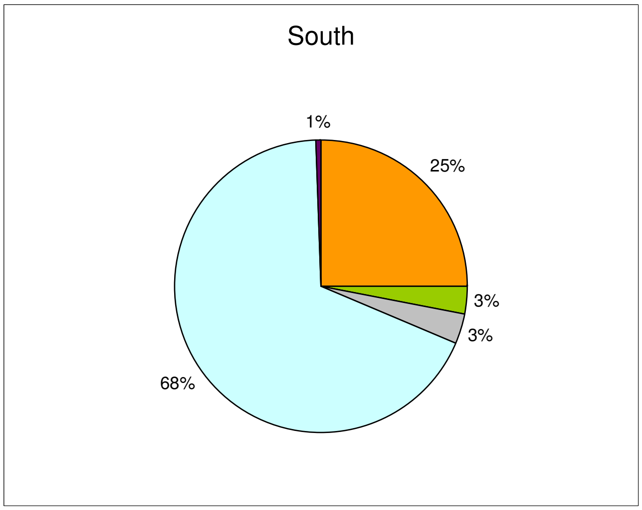
In order to develop nitrogen loading estimates for each of the basin watersheds, parcels and their accompanying information from this enhanced MEP database were assigned to each of basin watersheds shown in Figure III-1. Nitrogen loads were then determined for each individual parcel using its information and the nitrogen loading factors shown in Table V-3. The loading factors are generally the same as the ones used by the MEP for the Centerville River analysis (Howes and others, 2006).

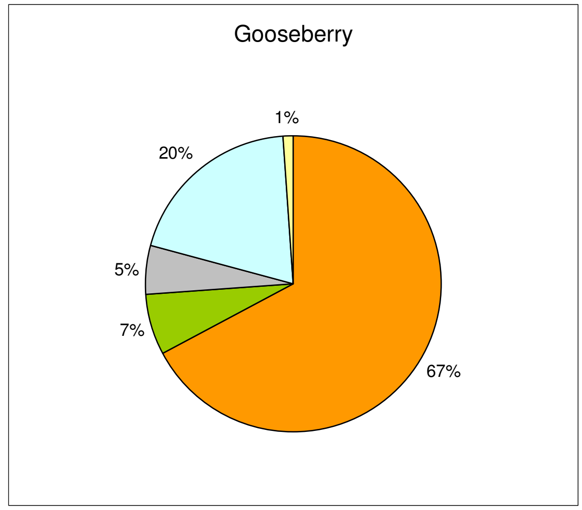
Table V-3. Nitrogen Loading Factors for Lake Wequaquet Nitrogen Budget.
All factors used in the Centerville River/East Bay MEP analyses (Howes and others, 2006).

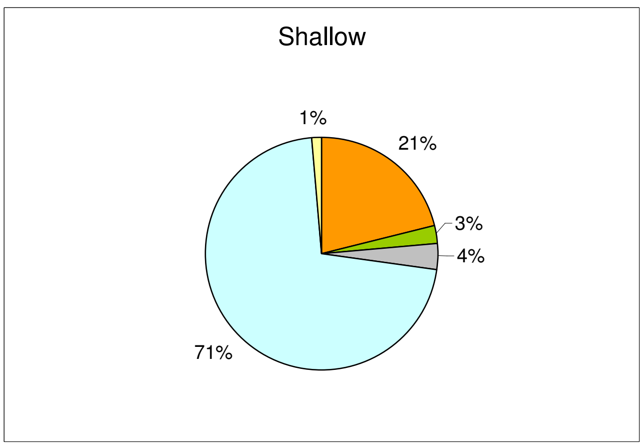
Nitrogen Concentrations:	**mg/l**	**Recharge Rates:**	**in/yr**
Road Run-off	1.5	Impervious Surfaces	40
Roof Run-off	0.75	Natural and Lawn Areas	27.25
Direct Precipitation on Embayments and Ponds	1.09	**Water Use/Wastewater:**	
Natural Area Recharge	0.072	Existing developed residential parcels without water accounts (average watershed flow):	203 gpd
Wastewater Coefficient	23.63		
Fertilizers:			
Residential Lawn Area (sq ft)	5,000		
Residential Watershed Nitrogen Rate (lbs/lawn)	1.08	Existing developed parcels w/water accounts:	Measured annual water use
Cranberry Bogs nitrogen application (lbs/ac)	31	Commercial and industrial parcels without water accounts and buildout additions:	21 gpd/1,000 ft2 of building
Cranberry Bogs nitrogen attenuation	34%		
		Commercial and industrial building coverage for parcels without water accounts and buildout additions:	28%

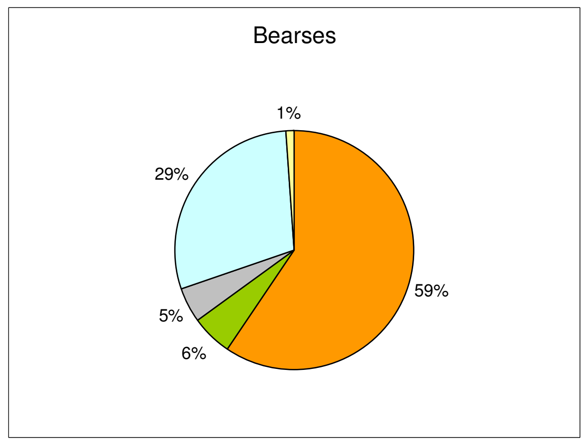
The estimated annual nitrogen loads for each of the Lake Wequaquet basin watersheds plus Shallow Pond are shown in Figure V-3. Wastewater is the major nitrogen source in the subwatersheds to Gooseberry, Bearses, and the Main basin. Atmospheric deposition on the pond surface is the major source for the South basin and Shallow Pond, which should be expected given their relatively small watershed areas. Shallow Pond estimates were developed since Shallow is a significant portion of the Bearses Pond watershed.

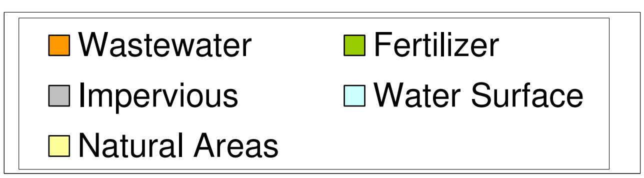
In order to develop the final nitrogen budget for the Lake Wequaquet basins, there are a number of factors that must be addressed. The budget needs to account for the portion of the nitrogen load within each basin that is discharged out of the system and downgradient to groundwater; these loads were addressed using the portions of the shoreline that were identified in the water budget as discharging water back to groundwater (see Figure III-1). The budget must also account for nitrogen that is transferred between basins with the internal flow of water, which was also identified in the water budget (see Table III-1). In the case of Bearses Pond, Shallow Pond is a significant portion of its watershed and the portion of the attenuated mass of Shallow Pond nitrogen that stays within the Bearses Pond watershed must be included in the budget. Once all these adjustments are addressed for each of the basins, the total annual nitrogen load to each basin can be determined. The use of the same nitrogen loading factors in all the MEP analyses completed to date and the subsequent validation of the results compared to estuary water quality data provides a high degree of confidence that the nitrogen loading rates determined with the same nitrogen loading factors in this analysis are reasonable.

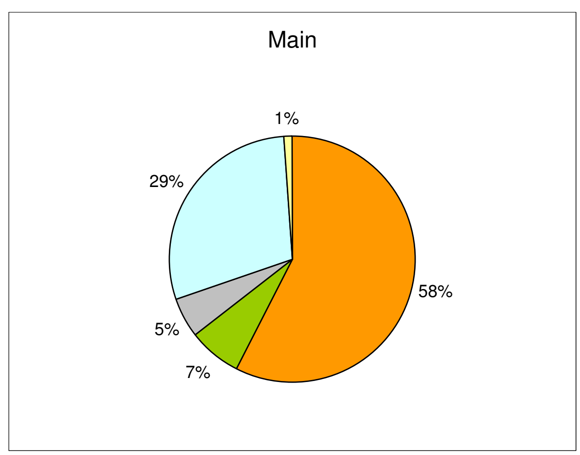












Nitrogen Load (kg/yr)						
	Wastewater	Fertilizer	Impervious	Water Surface	Natural Areas	TOTAL
Gooseberry	625	64	49	184	9	931
Bearses	599	56	48	296	11	1009
Main	3758	456	340	1910	81	6544
South	212	25	28	574	4	843
Shallow	103	12	18	350	7	490
System Total	5296	613	482	3314	112	9817

Figure V-3. Nitrogen Loading Estimates for Lake Wequaquet Basins
Percentages of each nitrogen source within each of the basin subwatersheds are displayed; wastewater is the major source for Gooseberry, Bearses, and the Main basin, while atmospheric deposition on the pond surface is the major source for the South basin and Shallow Pond. Shallow Pond estimates were developed since Shallow is a significant portion of the Bearses Pond watershed.

Figure V-4 shows the adjusted nitrogen loading budget for each basin of Lake Wequaquet, including the adjustments from the loads presented in Figure V-3. The overall system annual load is 10,418 kg, which is 12% higher than the unattenuated load determined for Lake Wequaquet by the MEP (Howes and others, 2006). A nitrogen budget was not completed by IEP/KV (1989). The higher load in this report is largely due to an assumption that was not made in the MEP analysis. In the current analysis, road areas within 300 feet of the lake are assumed to contribute runoff to the lake, regardless of whether they are upgradient or downgradient. This assumption was made after reviewing many of the roads within the Lake Wequaquet study during rainstorms. Detailed assessment of all stormdrains, including review of available design plans, within the study area could refine this assumption, but such an activity was beyond the scope of this project. Figure V-4 also shows the average mass of nitrogen that occurs in each basin of the lake. The mass is based on average measured total nitrogen concentrations and the volume of the basin.

The mass in each basin is a product of the external nitrogen loads from the watershed and the amount of time it takes to completely exchange the water volume in each basin (*i.e.*, the residence time). If the residence time is more than a year, the measured nitrogen mass will represent more than a year's worth and this must be accounted for in the nitrogen budget calculations.

After accounting for the water residence times, project staff determined the nitrogen attenuation rates for each basin. Nitrogen removed in the basins generally ranges between 84 and 87% except for 34% estimated in the South Basin. The lower percentage in the South basin is the result of its relatively short residence time (0.61 yr), which is largely due its function as the primary basin for discharge from the entire lake system, and its receipt of external loads from the Main Basin and Gooseberry Pond. Overall, the system-wide nitrogen attenuation rate is 75%.

Although a buildout assessment of the watershed was not part of the scope for this project, staff did review the Massachusetts Estuaries Project buildout of the combined Lake Wequaquet/Bearses Pond/Gooseberry Pond watershed, which was part of the Centerville River estuary analysis (Howes and others, 2006). This analysis, which was based on existing zoning at the time, identified the potential for 53 additional single family residences. Since there are 774 residences identified in this watershed by the MEP analysis, 53 additional residences would be an increase of approximately 7%. The percentage increase in the overall nitrogen load would be somewhat less given the fixed loads associated with the pond surface.

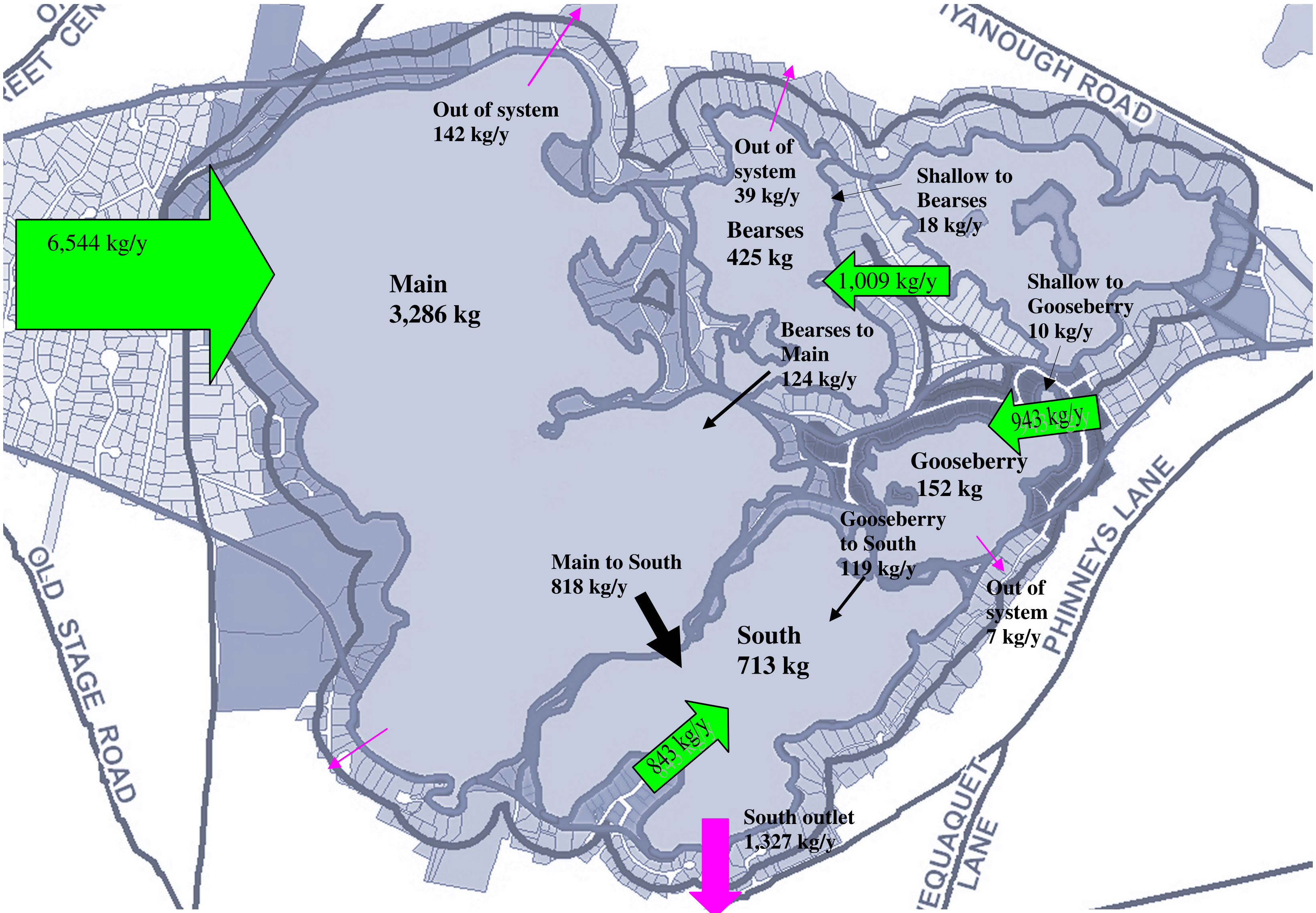


Figure V-4. Nitrogen Loading Budget for Lake Wequaquet

Mass of nitrogen in each basin is shown in kilograms and is based on average total nitrogen concentrations. Green arrows indicate annual watershed load and surface deposition based on nitrogen loading analysis. Black arrows indicate transfers from basins based on water budget flows and average total nitrogen concentrations. Basin nitrogen attenuation rates range between 84-87% except for South basin which has a rate of 34%. The whole system nitrogen attenuation rate is 75%.

V.3.2. Phosphorus Budget

As groundwater flows into Cape Cod ponds along the upgradient shoreline, it brings phosphorus, as well as nitrogen, from the pond watershed. Phosphorus move differently in the groundwater system than nitrogen because its chemistry favors bound rather than soluble forms in well-oxygenated waters (Stumm and Morgan, 1981). One of the most common binding partners for phosphorus is iron and because iron particles tend to coat the sands of Cape Cod, phosphorus introduced into the groundwater system tends to create insoluble iron/phosphorus complexes (Walter and others, 1996). Still, once a iron binding site has bound with phosphorus, the next phosphorus ion traveling with the groundwater bypasses this site and is bound by the next iron ion. In this way, phosphorus moves with the groundwater away from its source, but very slowly. Phosphorus associated with small sources, like septic systems, typically moves approximately one meter per year in groundwater systems, like the Cape (*e.g.*, Robertson and others, 1998). By contrast, a general groundwater flow rate for Cape Cod is approximately 100 times faster: one ft/day (or 111 meters/year). Because of the slow movement of phosphorus, most of the sources of phosphorus entering Cape Cod ponds is from properties abutting the pond shoreline; previous analysis of Cape Cod ponds have focused on properties within 250 to 300 ft of the shoreline (*e.g.*, Eichner and others, 2001; Eichner and others, 2006).

For Lake Wequaquet, project staff began the development of the watershed portion of the phosphorus budget by looking at properties within 300 ft of the pond shoreline based on the same database used in the nitrogen loading analysis. The list of these properties was then adjusted to review properties only if they were on the upgradient side (see Figure III-1). Aerial photographs of the properties were reviewed and loads were only assigned to developed properties with houses or other structures within the 300 ft boundary. Properties included in the loading calculations were adjusted, as described below, based on best professional judgment of likely groundwater flow characteristics near the various basins of the lake. Watershed phosphorus loads were developed based on the factors in Table V-4. Review of selected factors is also discussed below.

Table V-4. Phosphorus Loading Factors for Lake Wequaquet Phosphorus Budget

Factor	Value	Units	Source
Wastewater P load	1	lb P/septic system	MEDEP, 1989
Road surface P load	5.3	lb P/ac	MEDEP, 1989
Roof surface P load	3.5	lb P/ac	MEDEP, 1989
Natural Areas P conc.	0.014	mg P/l	BEC, 1993
Recharge Rate	27.25	in/yr	Walter and Whealan, 2005
Precipitation Rate	44	in/yr	Walter and Whealan, 2005
Building Area	2,000	ft2	Eichner and Cambareri, 1992
Road Area	Actual value	ft2	Mass. Highway Information
Lawn Factors			
Area per residence	Actual area	ft2	Based on aerial observation
Fertilizer lawn load	0.3	lb P/ac	MEDEP, 1989
Waterfowl Factors			
P load	0.156	g/m2/yr	Scherer, *et al.*, 1995
New P load	13	%	Scherer, *et al.*, 1995

V.3.2.1 Wastewater Phosphorus Loading Factor

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

Because of phosphorus' chemical characteristics, field studies of phosphorus loads have typically had varied results that are very dependent on the individual characteristics of the resource being evaluated. Evaluation of available studies have shown that phosphorus loads range from 1.1 (*e.g.*, Reckhow and others, 1980; Panuska and Kreider, 2002) to 1.8 pounds per capita per year (*e.g.*, Garn and others, 1996). When the soil range of potential phosphorus soil retention factors (0.5 to 0.9) are applied (Robertson and others, 2003), the resulting annual per capita load ranges between 0.11 and 0.9 lb. As a point of comparison, KV/IEP (1989) assumed an annual per capita load of 0.25 lb and a per house load of 0.75 lbs in their buildout calculations. If one uses the average occupancy in the Town of Barnstable during the 2000 Census (2.44 people per house), the per capita range results in an average septic system load range of 0.3 to 2.2 lbs. Given that the MEDEP load falls into the range, project staff proceeded with this factor as the initial phosphorus load for septic systems.

V.3.2.2 Lawn Fertilizer Phosphorus Loading Factor

Lawn fertilizers are nutrients designed to prompt growth from the plants that make up a lawn. Reviews of fertilizer application rates on Cape Cod have generally found that homeowners do not fertilize lawns as frequently as recommended by lawn care guidelines unless commercial companies tend the lawns [see Howes and others (2007) for summary]. In addition, these surveys have found that many Cape Codders do not use lawn fertilizers at all. Because of these findings, project staff continued to use the standard phosphorus loading factor listed in Table V-4, but also reviewed aerial photographs on individual parcels within a 300 ft buffer of the pond to identify and quantify lawn areas that appeared to active management. In conducting the phosphorus loading analysis, all lawn areas in the buffer zone identified during this review, regardless of whether they are upgradient and in the watershed or downgradient, were assumed to add phosphorus to the pond. Downgradient lawns were included with the thought that lawns on these adjacent parcels would have the potential to have overland stormwater runoff directly to the pond. Further review of this assumption could be accomplished via a boat survey of all shoreline properties, a survey of lawn care practices, and/or testing of lawn nutrient concentrations.

V.3.2.3 Bird Phosphorus Loading Factor

Phosphorus loading from birds has been a difficult factor to resolve for Cape Cod ponds. Previous analyses completed by SMAST staff have relied on the factors shown in Table V-4 that are derived from a highly detailed study of birds and pond water quality from Seattle, Washington (Scherer and others, 1995). This study evaluated bird counts for a large pond (259 acres), determined the load per species, and the percentage of the phosphorus load from each species that was new addition to the pond and how much was reworking of existing phosphorus sources already in the pond. The results from Scherer and others (1995) found that the annual average phosphorus load from birds is 0.156 grams of P per square meter with 13% of the load as new P addition to the lake. Because this load is determined by the area of the pond, applying this factor would result in larger ponds having greater bird loading.

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

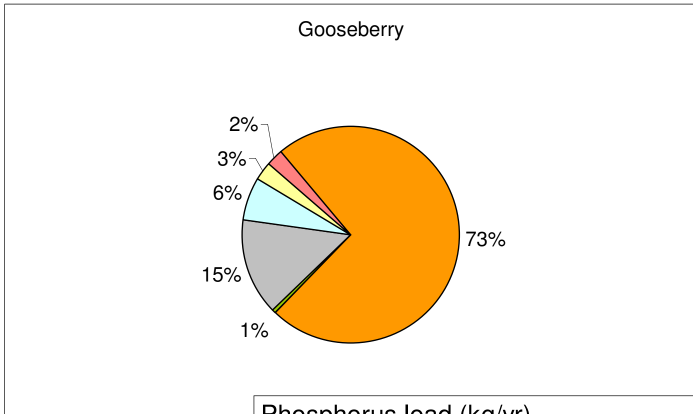
This estimated Cape Cod-specific per pond load is 3 to 27% of the load determined from the areal rate for the Lake Wequaquet basins. Although not comprehensive, staff observations during the 2007 water quality samplings of the Wequaquet basins generally resulted in total populations of 30 to 40 birds, most of which were gulls; these observations seem to support the use of the 0.9 kg/y loading rate for Lake Wequaquet. In order to address some of the uncertainty in this factor, project staff assigned the 0.9 kg/y loading factor to each of the Lake Wequaquet basins.

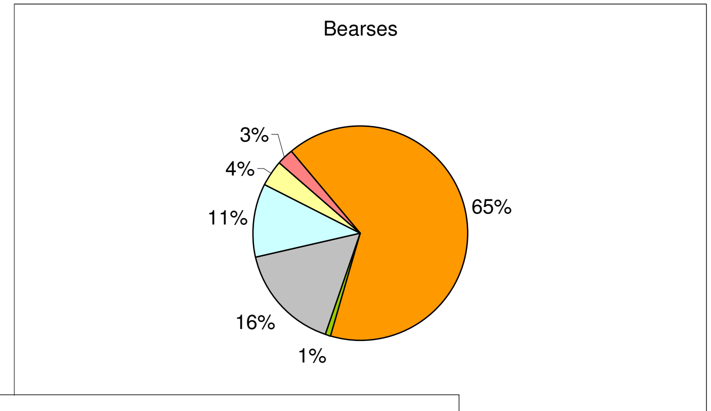
As a point of comparison, IEP/KV (1989) estimated that the waterfowl/gull phosphorus loading for the entire Wequaquet/Bearses system was 9 kg/y. This load was based on an estimated year-round population of 100 birds. Further refinement of this factor could be accomplished through a more comprehensive survey of bird populations around the lake; this should include species and should occur over at least one year.

V.3.2.4 Overall Phosphorus Loading Results

The estimated annual phosphorus loads for each of the basin watersheds are shown in Figure V-5. Wastewater is generally the major phosphorus source to each of the basins although it varies from 50 to 78% of the annual load. Given the relative large surface areas compared to the watersheds for the Main and South basins, surface deposition is the second largest source for these basins. Impervious surfaces are the second largest source for the Gooseberry and Bearses basins. Shallow Pond estimates were developed since Shallow is a significant portion of the Bearses Pond watershed.

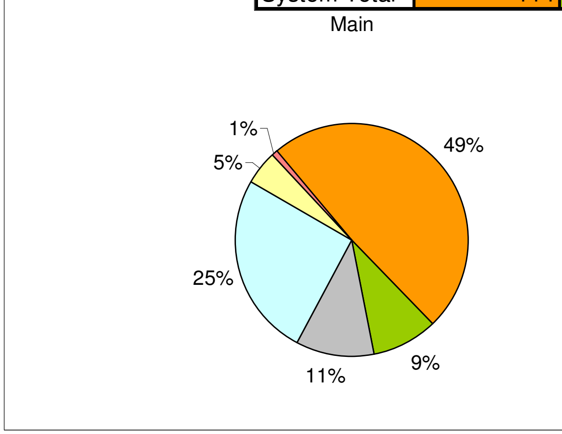
As with the nitrogen budget, the final phosphorus budget for the Lake Wequaquet basins must address phosphorus that flows out of the system and internal transfers of phosphorus between the basins. The loads within each basin that are discharged out of the system are addressed the same way as the nitrogen budget: volumes identified in the water budget as being discharged along portions of the shoreline (see Figure III-1) are assigned average basin total phosphorus concentrations and the resulting mass is assumed to be removed from the system. The budget also accounts for phosphorus that is transferred between basins with the internal flow





Phosphorus load (kg/yr)

	Wastewater	Fertilizer	Impervious	Water Surface	Natural Areas	Birds	TOTAL
Gooseberry	27	0	5	2	1	1	37
Bearses	23	0	6	4	1	1	35
Main	47	9	10	25	4	1	96
South	17	0	5	7	1	1	31
System Total	114	10	26	38	8	4	199



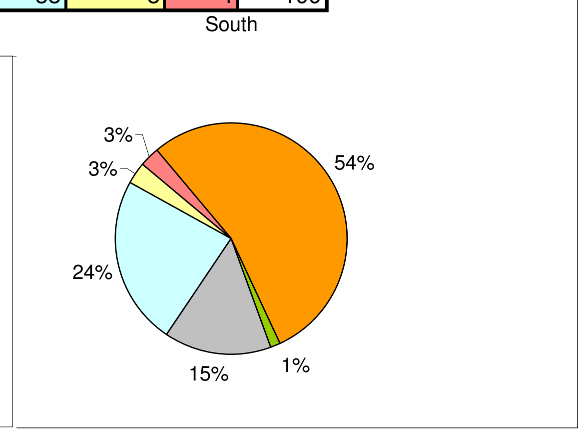


Figure V-5. Phosphorus Loading Estimates for Lake Wequaquet Basins

Annual phosphorus loading estimates and resulting percentages by source within each of the basin subwatersheds are displayed; wastewater is the major source to all basins. Annual loads are rounded to whole numbers. Shallow Pond is estimated to add approximately 6 kg/y to the Lake Wequaquet system.

of water in the same way: volumes from the water budget (see Table III-1) are multiplied by average basin concentrations to determine a load transfer. Once all these adjustments are addressed for each of the basins, the total annual phosphorus load to each basin can be determined. These loads are then compared to the calculated mass in each basin, which is determined from the 2007 water quality data.

Figure V-6 shows the adjusted phosphorus loading budget for each basin of Lake Wequaquet, including the adjustments from the loads presented in Figure V-5. The overall system annual load is 205 kg, which is approximately the same as total load of 190 kg/y estimated by IEP/KV (1989). The current analysis includes the same assumption about road runoff that was made for the nitrogen loading analysis. Figure V-6 also shows the average mass of phosphorus that occurs in each basin of the lake. This mass is based on average measured total phosphorus concentrations and the volume of the basin.

The total system phosphorus budget calculated in this project and the IEP/KV budget are compared in Figure V-7. Although the overall loads calculated by IEP/KV and this project are similar, the components of the load are different. The primary difference is the loads determined for the septic inputs and the atmospheric loading. IEP/KV (1989) assumed a background TP concentration of 50 ppb based on the average TP concentration measured from Cape-wide groundwater monitoring (Frimpter and Gay, 1979) and used this concentration with the recharge from the entire watershed to determine a septic phosphorus load. This load was then added to loads from lawns, cranberry bogs, waterfowl, and stormwater to estimate a total load. In the phosphorus budget for this project, the phosphorus load from individual properties within 300 ft is the basis for the septic load. Given that IEP/KV (1989) uses a buildout wastewater loading factor that is based on the number of houses and a per capita phosphorus load, this loading analysis essentially assumes that, under the current conditions of the time, none of the wastewater loading from nearshore septic systems had reached the pond.

For the atmospheric loading, IEP/KV (1989) assumed an areal loading rate of 0.35 kg of P per hectare per year (based on an analysis from Ontario: Scheider and others, 1979). For the current project, phosphorus loading from precipitation is based on a concentration used in a phosphorus loading analysis of Hamblin Pond by Baystate Environmental Consultants (1993); 0.014 ppm is equivalent to 0.14 kg P/ha/yr. Further research has found little data on total phosphorus concentrations in precipitation on Cape Cod; however one readily available resource is the Northeast AVGWLF Nonpoint Source Pollution, Watershed Model, which uses available regional data from the USGS National Water Information System. The loading rate in this model for atmospheric TP inputs is 0.05 kg P/ha/yr. Although the Northeast AVGWLF model does not have any Cape Cod-specific data, its calibration techniques tend to support a lower natural phosphorus load than the value used by IEP/KV (1989). Given the historic use in Barnstable of the 0.014 ppm concentration, staff utilized this in phosphorus loading analysis for this project.

The mass in each basin is a product of the external phosphorus loads from the watershed and the amount of time it takes to completely exchange the water volume in each basin (*i.e.*, the residence time). If the residence time is more than a year, the measured phosphorus mass will

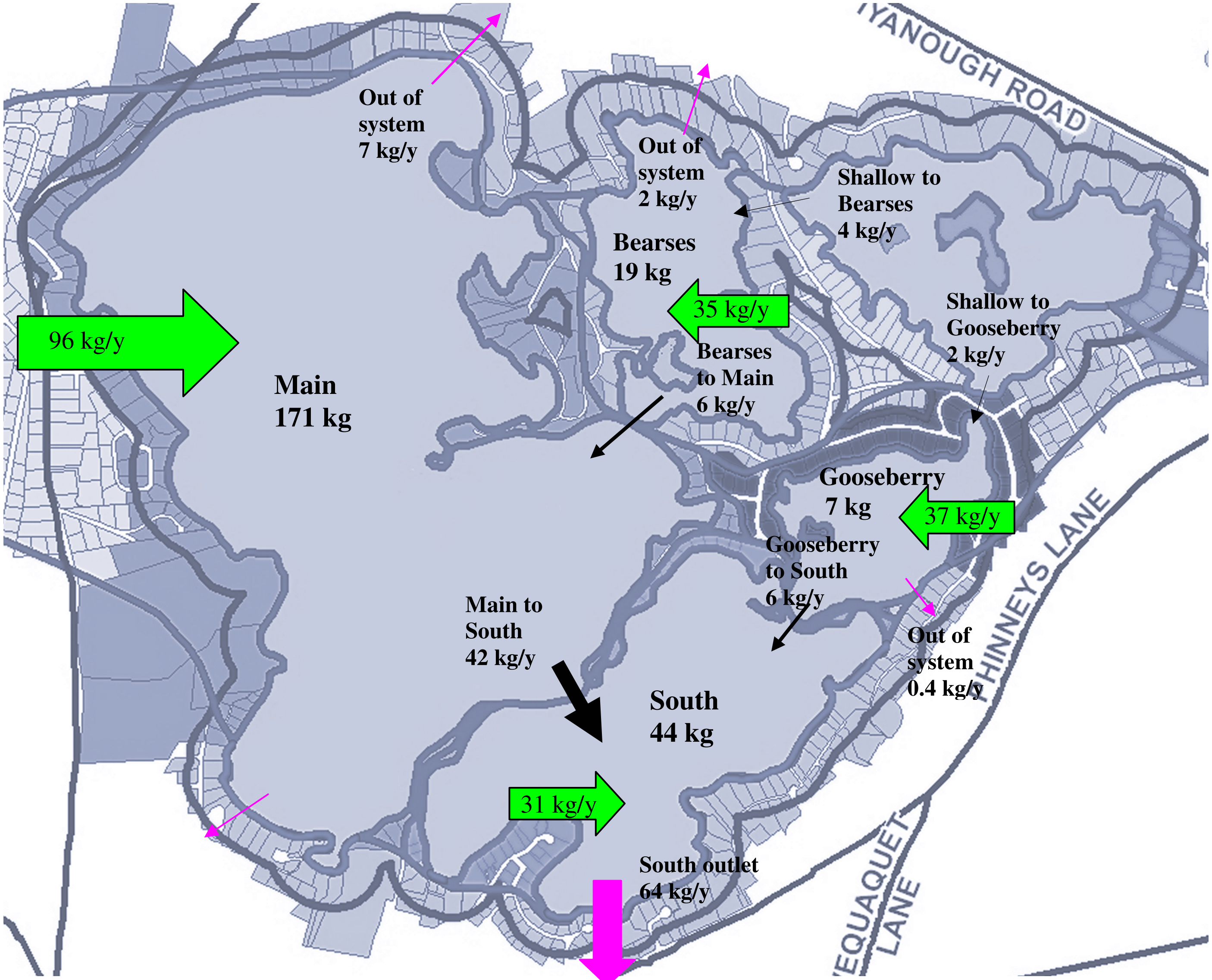


Figure V-6. Phosphorus Loading Budget for Lake Wequaquet

Mass of phosphorus in each basin is shown in kilograms and is based on average total phosphorus concentrations. Green arrows indicate annual watershed load and surface deposition based on phosphorus loading analysis. Black arrows indicate transfers from basins based on water budget flows and average total phosphorus concentrations. Basin phosphorus attenuation rates are: Bearses 81%, Gooseberry 84%, Main basin 51%, and South basin 9%. The whole system phosphorus attenuation rate is 52%.

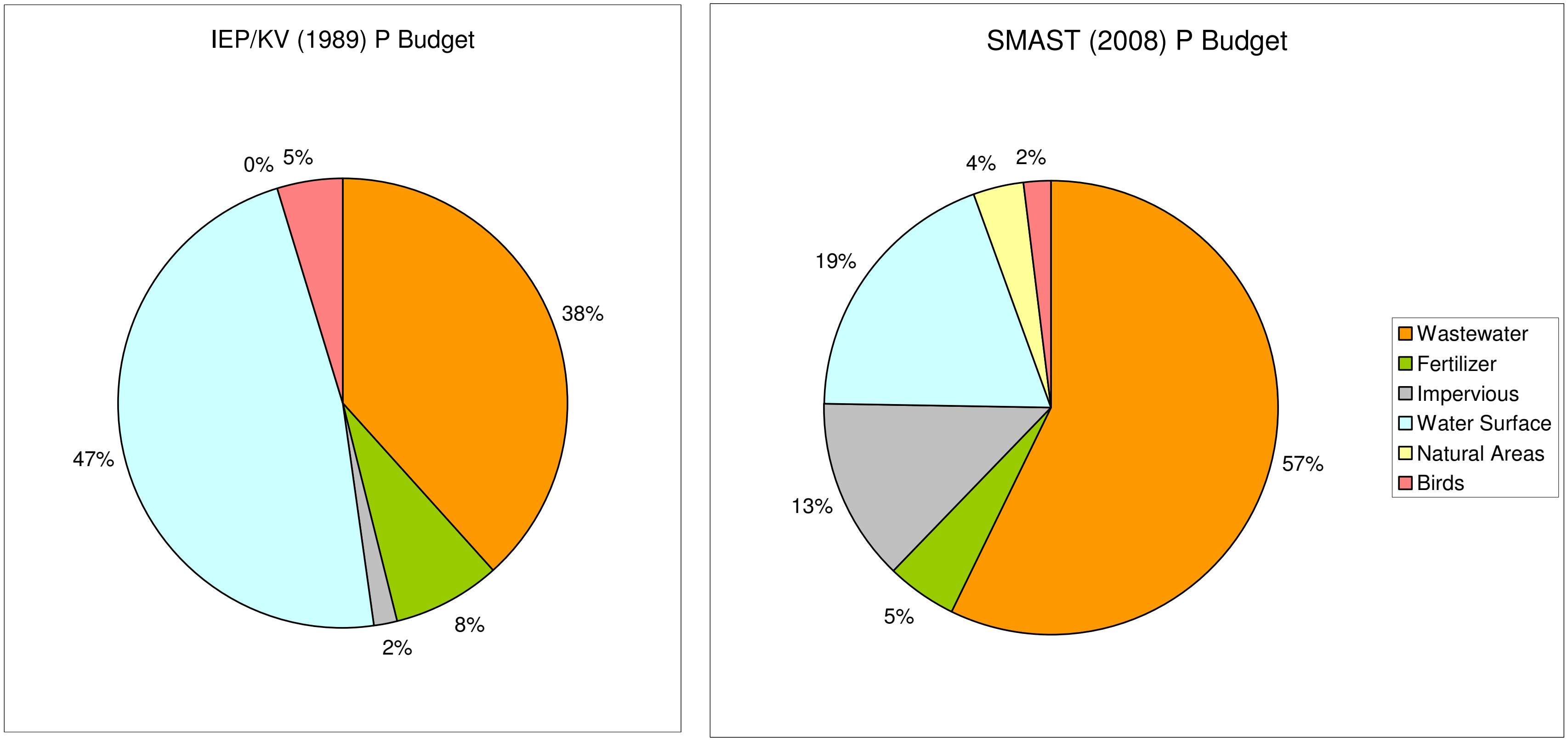


Figure V-7. Comparison of Current and Historic Phosphorus Loading Estimates for Lake Wequaquet System
IEP/KV (1989) loading estimates are based on different loading factors than those used in the current assessment. The primary differences are in the atmospheric and wastewater loading. IEP/KV uses an atmospheric loading rate that is approximately twice the rate used in the current assessment; available current data supports the use of the current rate. The IEP/KV analysis essentially assumes that none of the septic systems adjacent to the pond are having any greater impact than any other septic systems in the watershed, while the current analysis focuses on the properties adjacent to the pond. The overall budgets have similar annual rates for the entire system: 190 kg for IEP/KV (1989) and 205 kg for the current project.

represent more than a year's worth and this must be accounted for in the calculations of the phosphorus budget.

After accounting for the water residence times, project staff determined the phosphorus attenuation rates for each basin. Phosphorus percentages retained in the basins are highest in the basin without surface water inputs: Bearses 81% and Gooseberry 84%. The Main basin retains 51% of its external loads, while the South basin only retains 9%. Overall, the system-wide phosphorus attenuation rate is 52%, which is similar to the 55% estimated by IEP/KV (1989).

Although a buildout assessment was not included in the project scope, staff did review the number of parcels within the 300 ft buffer zone that are classified by the town assessor as available for residential development (*i.e.*, state class code 130 or 131). There are only five parcels classified with this code in the combined upgradient buffer zones for Lake Wequaquet/Bearses Pond/Gooseberry Pond. There are also a number of properties classified as undevelopable, which occasionally end up being developed and reclassified. However, the total number of potential new residences is likely less than 20. Since the assessor's classification of the current properties lists 232 single family residences in this combined buffer zone, the potential exists to increase the number of residences and, concurrently, the phosphorus load by less than 10%.

V.4. Cumulative Assessment and Discussion

Gauging the condition of an ecosystem is about both the conditions that exist in the system and what measures are compared to those conditions. For Lake Wequaquet and its basins, there are two general measures for comparison: regulatory standards and ecological benchmarks. Regulatory standards are defined as an interpretation of a federal, state, or local law and, as such, usually have more power to compel action to meet those standards. Ecological gauges are generally based on comparisons to similar systems in similar settings or to historic information about the ecosystem under review. Community actions to address these gauges are usually based on the local value of the resource.

It is clear that Lake Wequaquet is impacted and that ecological conditions have worsened since the sampling completed in 1987 (IEP/KV, 1989). The ecological factors that generally see the first impacts of additional nutrients in freshwater pond ecosystems are worse now than they were in 1986: total phosphorus concentrations and chlorophyll *a* concentrations are higher and Secchi readings are lower. However, the key regulatory standard, dissolved oxygen, is approximate the same as measured in 1986 except for some slight worsening in the deep, near-sediment station in the Main basin.

Lake Wequaquet and its basins are classified as "Class B" waters under Massachusetts Surface Water Quality Standards regulations (314 CMR 4). According to these regulations, Class B waters must have "consistently good aesthetic value" and have the following designated uses: "habitat for fish, other aquatic life, and wildlife, including for their reproduction, migration, growth and other critical functions, and for primary and secondary contact recreation" [314 CMR 4.05(3)(b)]. These regulations have been written to interpret the Massachusetts Clean Water Act (Massachusetts General Law c. 21, §§ 26 through 53) and the Massachusetts' role in implementing the federal Clean Water Act.

These regulations have a lower limit for dissolved oxygen, which is one of three ecological numeric water quality standards in the regulations; temperature and pH are the other two. According to the regulations, dissolved oxygen concentrations "shall not be less than 6.0 mg/l in cold water fisheries and not less than 5.0 mg/l in warm water fisheries" [314 CMR 4.05(3)(b)1.]. All the numeric standards have provisions to allow "natural" readings outside of the specified ranges; for example, pH readings in Lake Wequaquet are lower than the state 6.5 limit, but a strong case is available that most Cape Cod and Town of Barnstable ponds have natural pH readings less than 6.5 (Eichner and others, 2003; Eichner, 2008, respectively).

Since the state numeric regulatory standards are met in Lake Wequaquet and its basins, the next state compliance threshold is whether the lake is supporting all designated uses. There is another portion of the regulations that states that: "Unless naturally occurring, all surface waters shall be free from nutrients in concentrations that would cause or contribute to impairment of existing or designated uses…Human activities that result in the nonpoint source discharge of nutrients to any surface water may be required to be provided with cost effective and reasonable best management practices for nonpoint source control" [314 CMR 4.05(5)(b)3.].

Because this nutrient criterion is based on support of "designated uses", the review of compliance is then based on whether recreation and habitat features are sustained. Given the observation of the number of boats on the lake, the number of boat trailers parked along Shootflying Hill Road, rowers on the lake, and swimmers on the beaches, anecdotal evidence suggests that recreational features are sustained by current water quality conditions. The remaining question, as far as compliance with state water quality regulations, is then whether current conditions support the various habitat functions and this largely is a question of ecological assessment of the Lake and its basins.

When pond ecosystems start to get higher nutrient loads, water quality samples will generally contain increased concentrations of the primary nutrients (phosphorus and nitrogen). Pond phytoplankton populations will rapidly respond to these nutrients and grow, which usually leads to coincident increased chlorophyll-*a* concentrations and reduced clarity/Secchi readings. If these nutrient increases are sustained rather than a brief, one time burst, such as would be associated with a bloom, the pond ecosystem will gradually reach a new equilibrium with these impacts becoming permanent. If the increases are significant enough and sustained, the increased detritus from dying phytoplankton will increase sediment oxygen demand as the bacterial population grows and adjusts to recycle this detritus load. This oxygen demand can change the chemical environment in the sediments and lead to release of nutrients that would otherwise remain buried in the sediments. Of course this simplified description above can become complicated when factors particular to an individual pond are added to the mix, such as the depth, volume, watershed geology, stream inputs or outputs, and existing rooted plant population.

Since this progression of ecosystem impacts begins with measurement of nutrient concentrations, review of the phosphorus and nitrogen concentrations is the first step to assess whether concentrations are high enough to affect any of the habitat issues mentioned in the state regulations. All average total phosphorus concentrations in Lake Wequaquet are statistically significantly higher in 2007 than 1986, except for the shallow readings at the Main basin northern station and deep readings at the Main basin deep station (see Figure IV-4). All of the 2007 TP average concentrations are at least double the Cape Cod recommended limit of 10 ppb (Eichner and others, 2003).

Notably, only three of the average total nitrogen concentrations at the eleven depth stations are significantly higher in 2007 than 1986: the shallow South basin station and both depth stations in Gooseberry Pond. Because of the difference in how nitrogen and phosphorus travel in groundwater, the relative lack of change in total nitrogen concentrations suggests that watershed land uses and/or land use nitrogen loads have changed very little since 1987. Review of year-built date in the assessor's database helps to explain why Gooseberry is different than the other three basins. The average year-built for residences in the Gooseberry buffer zone is significantly younger (1970) than the average year-built for any of the other basins, which are generally in the early 1960's. This difference would mean that nitrogen equilibrium in the Gooseberry basin has been achieved later than the other basins, more than likely during the period between the 1987 IEP/KV sampling and 2007 sampling for this project.

The increase in the nitrogen concentration of the South basin matches the increase observed in all the other basins. Although there is statistically insignificant change in the concentrations in most of the basins, the calculated loads do increase slightly in 2007 as compared to 1986. The sum of these load increases closely approximates the measured increase in concentration in the South basin; the total increase in measured mass of nitrogen in the South basin is 269 kg, while the total measured increase in all the other basins, which feed into South basin, is 308 kg. Since these are very close, it appears to confirm the estimated transfers of nitrogen between the basins based on the water budget (see Figure V-4).

If watershed land uses have generally not changed significantly, the increase in the total phosphorus concentrations is likely to be due to either phosphorus that was in transit finally reaching the pond basins or some internal change leading to greater phosphorus availability. Given the average age of the residences and their distances to the pond shoreline, it is likely that most of houses within the 300 ft buffer zone are now currently contributing wastewater phosphorus to the pond. Conversely, it appears to be unlikely that the majority of these same residences were contributing wastewater phosphorus to the pond in 1986. One way to more closely evaluate this would be to review the setbacks for individual septic system leachfields from the pond shoreline. Project staff consulted with Town of Barnstable GIS staff and found that a large portion of this information is still in paper files and a search of these files was beyond the scope of this project. Given the currently available information, however, more wastewater phosphorus reaching the pond in 2007 from the same houses that were not contributing in 1986 is a plausible cause of the increased phosphorus concentrations in the pond.

An alternative or complementary explanation for the increase in phosphorus concentrations is the apparent loss of rooted plants in the lake. Comparison of pond plant coverage data prepared by IEP/KV and those prepared by the WLPA (see Figures IV-10 and IV-11, respectively) suggest that Wequaquet and its basins have lost a large portion of the rooted plant community that existed in 1986. If the plants have died off, it is unlikely that that the phosphorus contained in them would have left the lake ecosystem, especially given its role as a limiting nutrient. A portion of this phosphorus would have been returned to the water column following digestion of the plants and would then be available to the phytoplankton community and cause a rise in total phosphorus concentrations. As mentioned previously, a comprehensive plant survey with species identification would be necessary to confirm the status of the current rooted plant community.

Regardless of the cause, the increased phosphorus concentrations in 2007 have led to increased chlorophyll-*a* concentrations (see Figure IV-8) and decreased Secchi readings (see Figure IV-3) compared to the conditions that existed in 1986. Both chlorophyll and Secchi readings are directly tied to greater phytoplankton populations; chlorophyll-*a* is a proxy for phytoplankton growth since it is the primary photosynthetic pigment in phytoplankton and increases in phytoplankton populations are the principle cause of Secchi/clarity loss in Cape Cod ponds. The impact on these measures means that the Lake Wequaquet ecosystem has adapted to the higher phosphorus loads by growing more phytoplankton. Some of the WLPA members have suggested that there are more rooted plants based on the results from their plant surveys. Although the plant population appears to have shrunk compared to the 1986 data, it is possible that more phosphorus is being shifted into rooted plants over the last few years. While a comprehensive plant survey is recommended, WLPA volunteers could help to resolve these questions and others, such as year to year fluctuations, with some slight refinements in their current survey techniques.

Ecologically, the next step of increased nutrient impacts is decreased dissolved oxygen concentrations. As mentioned, this usually originates in the bottom of the pond, where sediment oxygen demand overwhelms available supplies in the sediments and starts taking oxygen from the overlying water. Sediment oxygen demand increases because more phytoplankton is falling to the bottom of the pond and the bacterial population that recycles these plants increases in response to this increasingly abundant food source. As they eat and the population grows, more oxygen is consumed by their respiration.

In other lakes in Barnstable with similar total phosphorus, chlorophyll-*a* concentrations, and approximately the same depth (*e.g.* Neck, Micah), average dissolved oxygen concentrations near the sediments are less than state standards (Eichner, 2008). It is thought that Lake Wequaquet, because of its relatively large surface area, will be somewhat resistant to even significant sediment oxygen demand because its surface area captures enough wind energy to keep the lake well mixed and this mixing replenishes whatever sediment oxygen demand there is with regular additions of new atmospheric oxygen to the water column.

The limited sediment samples (see Table IV-2) appear to show that phosphorus concentrations in the lake sediments have increased significantly, which would be consistent with increasing water column phosphorus concentrations. Based on the lab analyses, little of the current concentrations are soluble, but it is recommended that the town consider some refined sediment sampling, including the collection of cores to confirm this. Collection and testing of sediment cores will determine what dissolved oxygen conditions would mobilize these nutrients and allow them to mix into the overlying water. This type of testing should allow the town to establish a threshold concentration where additional management steps would be taken if dissolved oxygen concentrations dropped below the threshold.

Based on the 2007 sampling, the Lake Wequaquet appears to be providing adequate habitat support required under the state surface water regulations. However, the same data indicates that the lake, especially in the Main basin and Bearses Pond, is moving toward conditions that will not meet the regulations. Conditions have worsen significantly since 1986, the last check on the water quality/habitat of the lake. Given that there has not been regular monitoring, except for the PALS monitoring that started in 2001, it is unclear whether the conditions in 2007 are a steady-state endpoint or a point assessment on a trend of worsening conditions that will be twice as bad in twenty more years.

Based on monitoring completed in 2007, there are a number of recommendations to provide better understanding of the pond ecosystem and water quality/ecosystem trends, as well as providing for more reasoned management of water quality in the lake. These recommendations include: 1) collecting and testing sediment core samples to gauge the potential phosphorus contribution from the sediments and the conditions that are likely to trigger significant releases, 2) a detailed plant survey of the lake to help understand the extent of plant coverage and resolve the rooted plant contribution to the measured increase in phosphorus concentrations, 3) work with the WLPA to refine their annual plant surveys to gauge year-to-year variations, 4) institute a regular monitoring program of the lake, and 5) develop a mitigation/management strategy that establishes, among other things, water quality thresholds and planned actions if the thresholds are exceeded.

The recommendation to establish a management strategy presents the opportunity to work out a number of issues associated with the long term management of Lake Wequaquet, including issues that are not related to water quality management. These issues include topics that have arisen in the past, including water level management and management of activities on the watersheet or surface of the lake. It is recommended that the town consider developing a comprehensive management strategy that addresses all aspects of the use and quality of Lake Wequaquet.

Details for all these recommendations are listed below in the Recommendations summary. SMAST staff are available to assist the town in addressing these recommendations.

VI. Lake Wequaquet Water Quality Assessment Conclusions

1. Based on state surface water regulatory criteria, Lake Wequaquet and it subbasins are not impaired. The primary numeric criterion in state regulations is a dissolved oxygen concentration of 5 ppm and all basins met this limit during the 2007 sampling season. The lake and its basins also met this criterion in 1986 (IEP/KV, 1989) and there is essentially no difference in dissolved oxygen conditions between the 1986 and 2007 datasets.

2. Other water quality measures besides dissolved oxygen have worsened significantly between 1986 and 2007. Total phosphorus concentrations and Secchi readings are significantly worse. It is unclear because of the relative lack of interim sampling whether current conditions are likely to continue to worsen or whether they represent equilibrium or near-equilibrium conditions. Other lakes with similar water quality conditions often fluctuate in and out of conditions that fail to meet state regulatory standards.

3. Total phosphorus, total nitrogen, and chlorophyll-*a* concentrations are all above recommended Cape Cod-specific standards developed based on the first Pond and Lake Stewards water quality snapshot sampling of 195 ponds (Eichner and others, 2003).

4. Evaluation of phosphorus and nitrogen concentrations show that the ecosystem conditions of the lake and its basins are largely determined by phosphorus availability; so management of phosphorus is the key to managing water quality.

5. Review of the phosphorus budget and the 2007 water quality data indicates that there are two potential sources of the elevated total phosphorus concentrations: 1) wastewater from houses that existed in 1986, but had not yet impacted the lake and 2) an apparent loss of rooted aquatic plants since 1986. A refined plant survey is recommended to evaluate which of these is the primary source. Depending on the results of this sampling, the management of the phosphorus concentrations could target nearshore houses, the in-lake plant community, or some combination of both.

6. Very limited sediment sampling shows that the lake and all its basins have a significant buildup of phosphorus in bottom sediments since the last sampling in 1986. It is recommended that the town consider collecting sediment cores and testing the cores to see what conditions are required to mobilize this increased phosphorus. Significant release of phosphorus from the sediments could occur due to increased sediment oxygen demand, which is possible with the nutrient levels that currently exist in the pond; testing of the cores would allow the town to establish monitoring thresholds for dissolved oxygen. Dissolved oxygen concentrations below these thresholds would cause the sediments to become a significant internal source of phosphorus for the lake and its basins, which would prompt additional algal growth and accompanying decrease in water clarity.

VII. Recommendations for Future Activities

Listed below are a summary of recommendations to ensure that water quality in the lake and its basins meets state regulatory standards and community goals. Project staff have developed approximate cost ranges for each of these recommendations based on School of Marine Science and Technology (SMAST) staff completing these tasks; there are likely to be cost savings associated with completing a number of tasks together. SMAST staff are available to discuss these recommendations with town staff and can develop refined cost proposals that will detail the tasks, appropriate schedules and the resulting reports.

VII.1. Collect and test lake sediment cores

Sediment sampling in 2007 shows that total phosphorus concentrations have generally increased ten fold since 1987 in every basin except Bearses (see Table IV-2). The sampling conducted for this project shows that only a small amount of this phosphorus is potentially available to be regenerated, but this is based on limited grab samples of the upper sediment layers. It is recommended that the town consider collecting at least three core samples in each basin of the lake and analyze these cores to accurately establish how much phosphorus could be released from the sediments and what conditions would cause this release. This type of analysis would allow the town to establish a monitoring threshold for dissolved oxygen in each of the basin and use this threshold as the basis to determine mitigation steps if the threshold is exceeded. Estimated cost for evaluation and reporting on the sediment cores including threshold dissolved oxygen concentrations would be $25,000 to $30,000.

This analysis could also benefit from determining the extent and thickness of sediment, which was only partially completed in 1986. If this information was obtained, the town would have a comprehensive evaluation of potential nutrient regeneration along with a gauge of whether sediment accretion has increased due to the increased phosphorus concentrations. Given the large area of the lake and the potential difficulties associated collecting thickness measurements in the deep basins, the estimated cost for completing a sediment map of the lake and all its basins would be $45,000 to $50,000. If the town wished to refine the bathymetric map at the same time, this task could be accomplished for an estimated cost of $15,000 to $20,000.

VII.2. Conduct a refined aquatic plant survey of the lake

The phosphorus budget for the lake and its basins indicates that the increase in total phosphorus concentrations since the 1986 sampling is either due to wastewater phosphorus from developed nearshore properties finally reaching the lake or a significant loss of rooted aquatic plants since 1986. Shoreline measures of nutrient inputs are fraught with difficulties related to representativeness of sampling sites and completeness of results, so it is not recommended that this approach be pursued. A refined aquatic plant survey conducted in a similar fashion to the 1986 survey, including the identification of plant species, offers a more appropriate measure of the potential impact of the plants on the increased phosphorus concentrations and help to better define phosphorus management strategies. Estimated cost for completing an updated macrophyte survey and the resulting map would be $50,000 to $90,000.

VII.3. Establish a regular monitoring program

Although detailed pond sampling has been completed in 1986 and, now, in 2007, the lack of information between these samplings does not allow an evaluation of how the conditions that are observed in 2007 developed. Simple field data, such as Secchi readings or dissolved oxygen profiles, can provide information about water quality trends and the natural range of fluctuations. Given the elevated phosphorus concentrations, decreased Secchi readings, increased chlorophyll-*a* concentrations and their exceedance of Cape Cod-specific thresholds, it is recommended that the town closely monitor water quality conditions in Lake Wequaquet and its basins. A monitoring program will allow the town to better understand whether the trend between 1987 and 2007 is continuing to worsen these key ecological measures or whether 2007 represents an ecological endpoint and near steady-state conditions. A natural partner in such a monitoring program would be the Wequaquet Lake Protective Association, Inc.; the WLPA has collected similar data in the past and use of volunteer help in the monitoring program would lower costs.

The recommended monitoring program would consist of water quality samples collected twice a year (April and August/September) in each of the stations and at the same depths as sampled in 2007. Samples would be analyzed for standard PALS analytes, at a minimum, with laboratory detection limits of at least the same at those attained during the PALS Snapshot. These samples would be accompanied by collection of Secchi and station depth readings and dissolved oxygen and temperature profiles, which would also be collected monthly in May, June, July, August or September, and October. If WLPA is willing to provide volunteers to maintain this program, total estimated costs would be approximately $5,000 annually. Estimated costs include training, quality assurance/quality control procedures, and regular staff support. Data could be reviewed annually and it is further recommended that a more comprehensive review occur every 3-5 years.

VII.4. Develop a management plan for the lake

The above recommendations suggest ideas to help the town develop better management strategies for the water quality of Lake Wequaquet. It is clear from past discussions with town officials and WLPA members that there are other, non-water quality issues that are also management issues for Lake Wequaquet. These issues have included conflicts between users of the watersheet or surface of the lake and discussions about appropriate water level of the lake. Given the large number of residents living around the lake and its importance for recreational uses, it is recommended that the town consider developing a comprehensive management plan for the lake that addresses the variety of issues that have arisen, including water quality management, land use best management practices, water levels, use of the boat ramp, and watersheet management. Public discussions about such a plan would offer the opportunity to reach community consensus on each of these factors. Costs for developing a management plan are largely dependent on the number of meetings necessary to complete the plan; estimated cost for developing a management plan for the lake would be $20,000 to $25,000.

VIII. References

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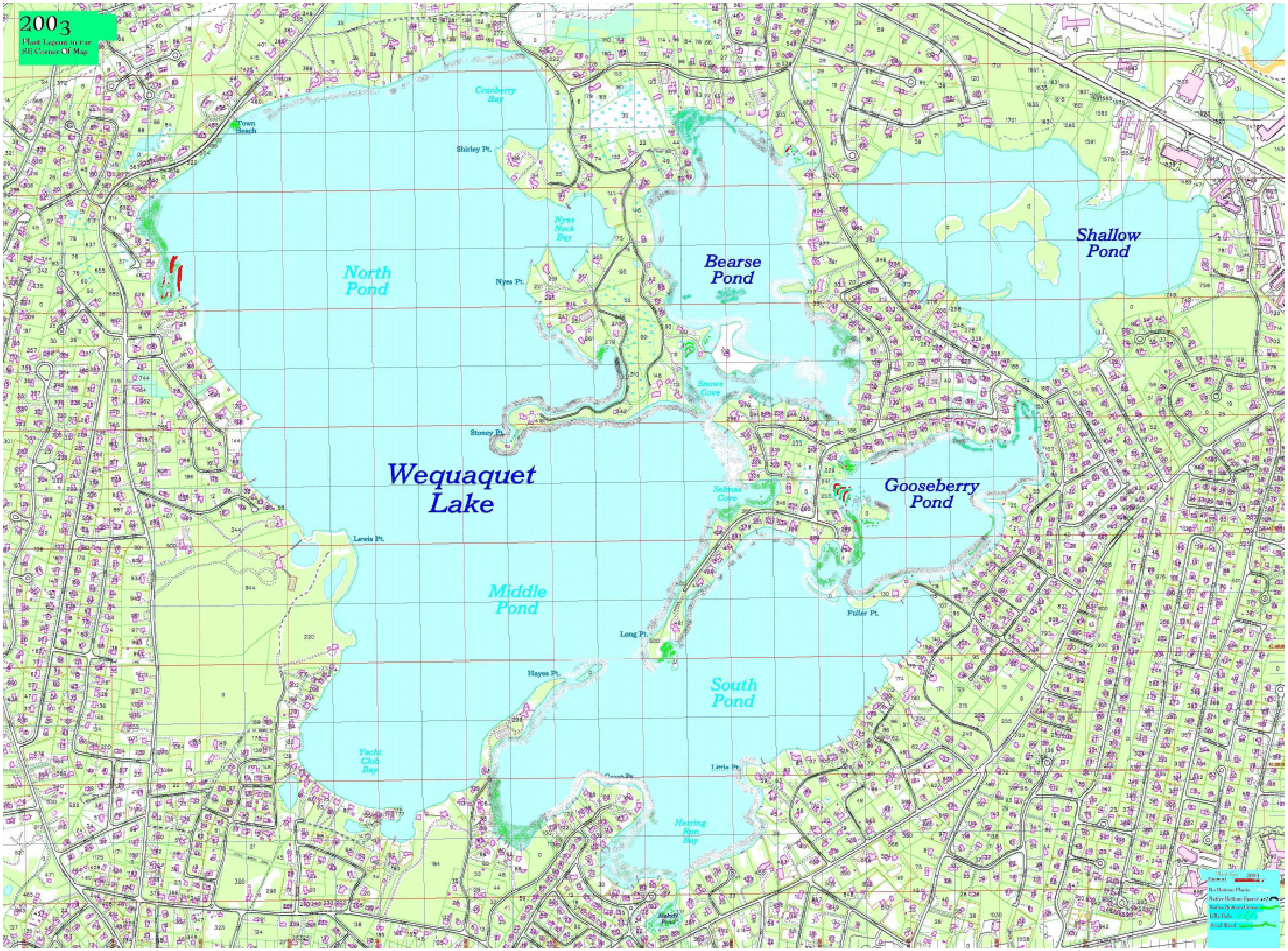
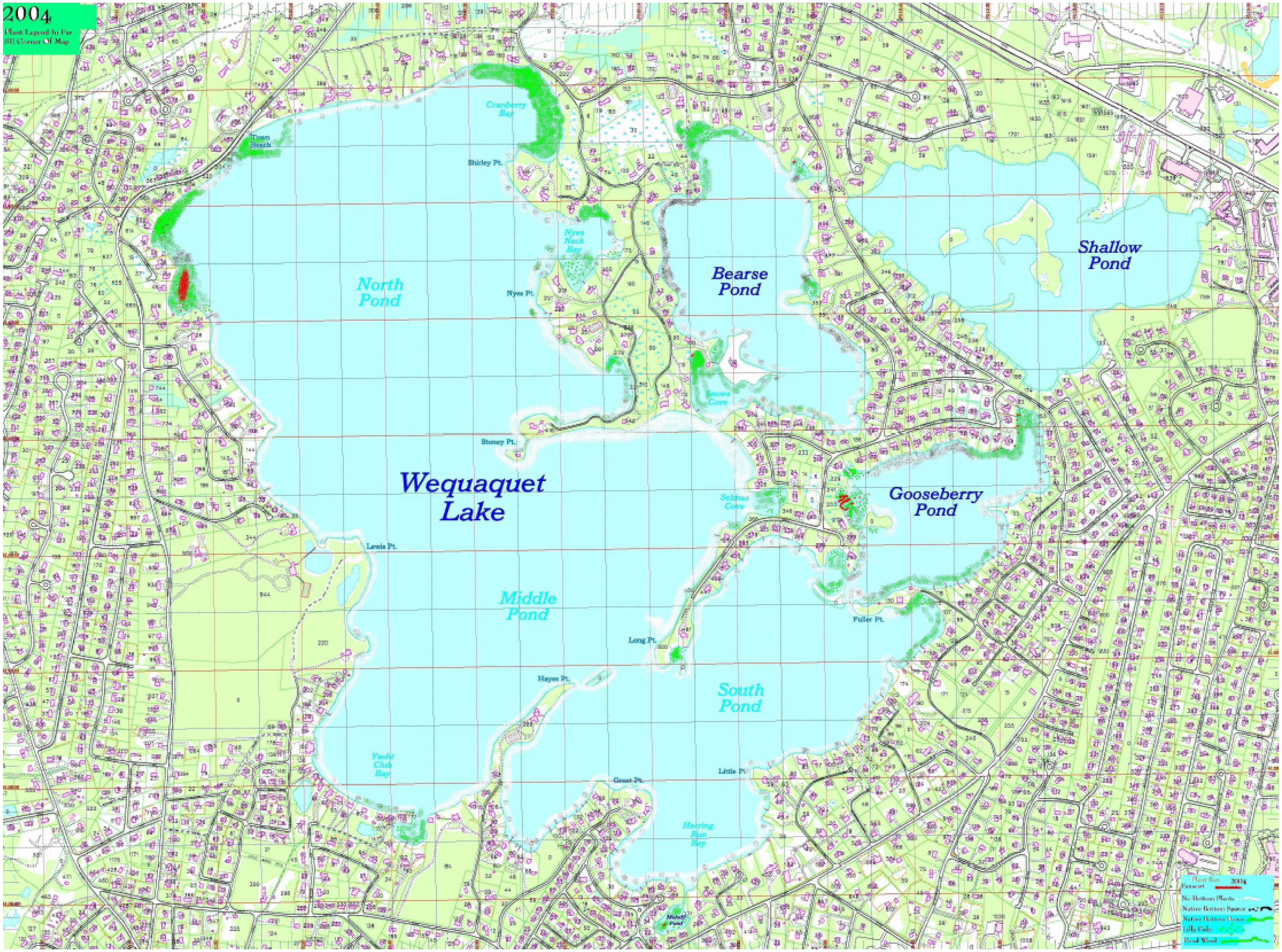
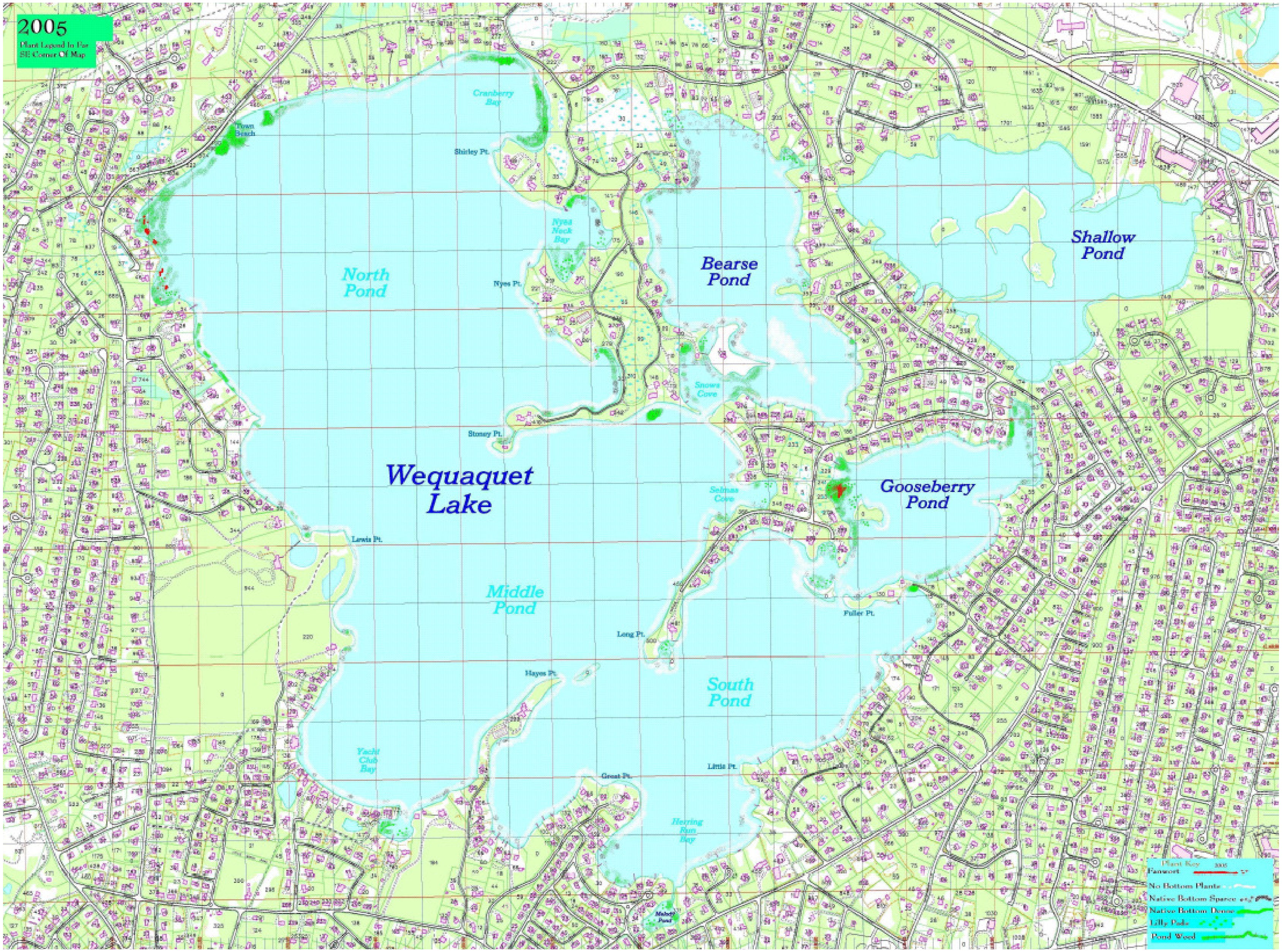
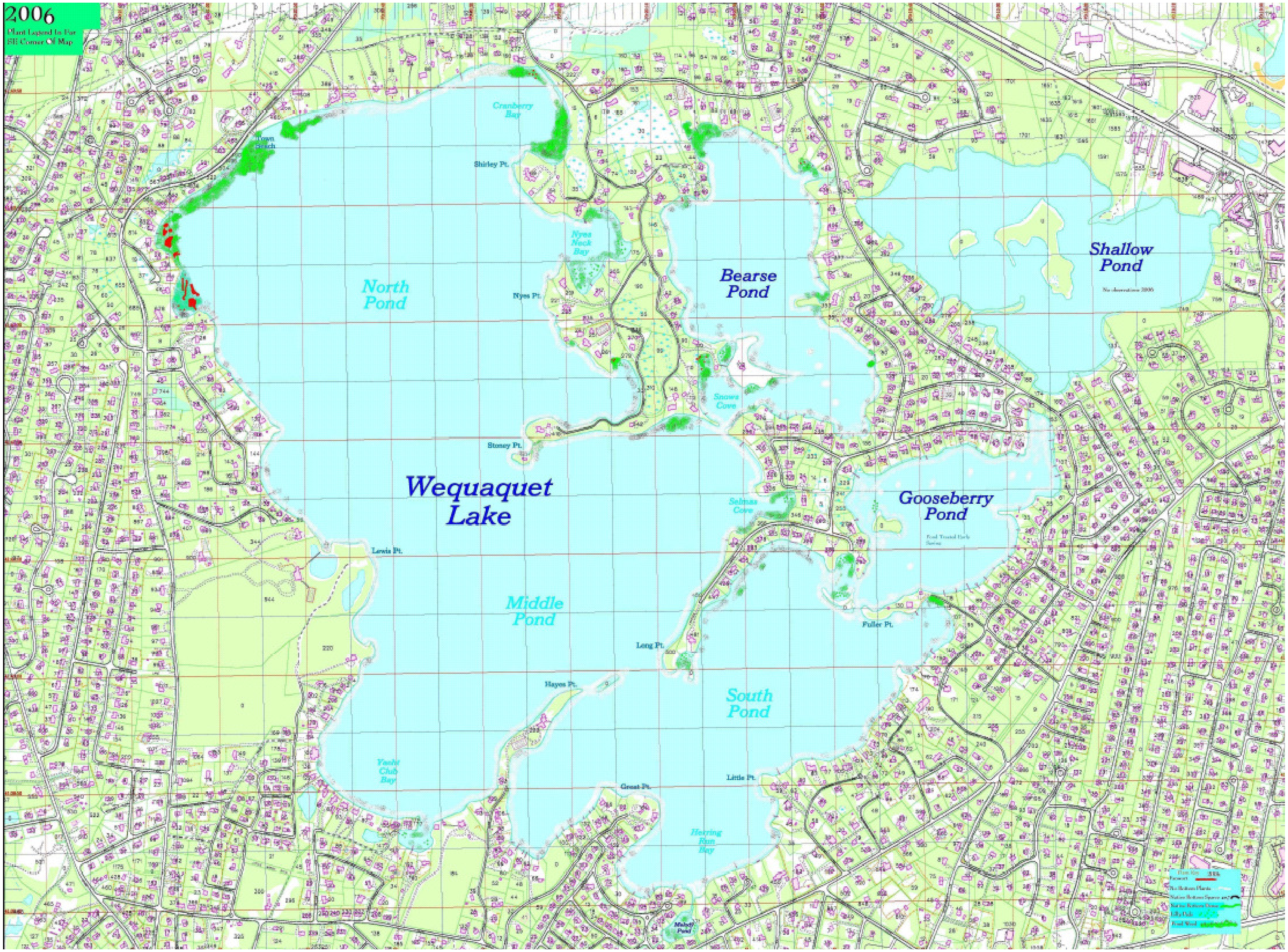
Appendix A

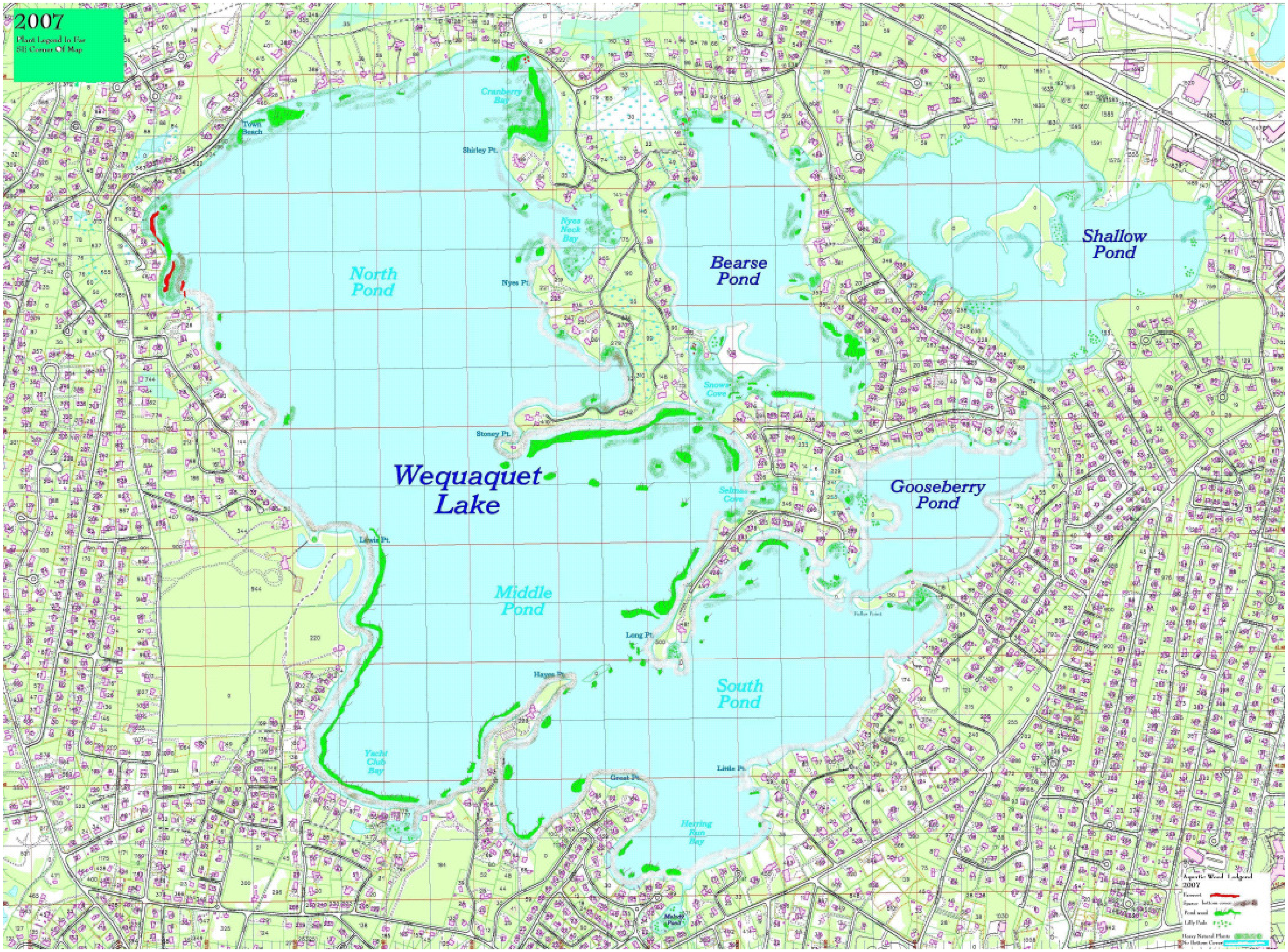
Wequaquet Lake Protective Association, Inc.
Plant Survey Maps
2003-2007


2003
Plant Legend in the SE Corner Of Map
North Pond
Bearse Pond
Shallow Pond
Wequaquet Lake
Gooseberry Pond
Middle Pond
South Pond
Cranberry Bay
Shirley Pt.
Nyes Neck Bay
Nyes Pt.
Snows Cove
Stoney Pt.
Selmas Cove
Lewis Pt.
Long Pt.
Fuller Pt.
Hayes Pt.
Yacht Club Bay
Little Pt.
Herring Run Bay
Town Beach


2004
Plant Legend In Far SE Corner Of Map
Cranberry Bay
Town Beach
Shirley Pt.
Nyes Neck Bay
North Pond
Nyes Pt.
Bearse Pond
Shallow Pond
Snows Cove
Stoney Pt.
Wequaquet Lake
Selmas Cove
Gooseberry Pond
Lewis Pt.
Middle Pond
Fuller Pt.
Long Pt.
Hayes Pt.
South Pond
Yacht Club Bay
Great Pt.
Little Pt.
Herring Run Bay


2005
Plant Legend In Far SE Corner Of Map
Cranberry Bay
Town Beach
Shirley Pt.
Nyes Neck Bay
Nyes Pt.
North Pond
Bearse Pond
Shallow Pond
Snows Cove
Stoney Pt.
Wequaquet Lake
Gooseberry Pond
Selmas Cove
Lewis Pt.
Middle Pond
Fuller Pt.
Long Pt.
Hayes Pt.
South Pond
Yacht Club Bay
Great Pt.
Little Pt.
Herring Run Bay
Plant Key
Fanwort
No Bottom Plants
Native Bottom Sparse
Native Bottom Dense
Lilly Pads
Pond Weed


2006
Plant Legend In Far SE Corner Of Map
Cranberry Bay
Town Beach
Shirley Pt.
Nyes Neck Bay
North Pond
Nyes Pt.
Bearse Pond
Shallow Pond
Snows Cove
Stoney Pt.
Wequaquet Lake
Selmas Cove
Gooseberry Pond
Lewis Pt.
Middle Pond
Fuller Pt.
Long Pt.
Hayes Pt.
South Pond
Yacht Club Bay
Great Pt.
Little Pt.
Herring Run Bay
Melody Pond



2007
Plant Legend In Far SE Corner Of Map
Town Beach
Cranberry Bay
Shirley Pt.
Nyes Neck Bay
Nyes Pt.
North Pond
Bearse Pond
Shallow Pond
Snows Cove
Stoney Pt.
Wequaquet Lake
Selmas Cove
Gooseberry Pond
Lewis Pt.
Middle Pond
Long Pt.
Hayes Pt.
South Pond
Yacht Club Bay
Great Pt.
Little Pt.
Herring Run Bay