Barnstable Ponds: Current Status, Available Data, and Recommendations for Future Activities

FINAL REPORT

July 2008

for the

Town of Barnstable Conservation Division

Prepared by:

Cape Cod Commission
Water Resources Program
3225 Main St., PO Box 226
Barnstable, MA 02632

Coastal Systems Group
School of Marine Science and Technology
University of Massachusetts Dartmouth
706 South Rodney French Blvd.
New Bedford, MA 02744-1221

Barnstable Ponds: Current Status, Available Data, and Recommendations for Future Activities

FINAL REPORT

July 2008

Prepared for

Town of Barnstable Conservation Division

Prepared By

Ed Eichner, Water Research Scientist/Project Manager
COASTAL SYSTEMS GROUP
SCHOOL OF MARINE SCIENCE AND TECHNOLOGY
UNIVERSITY OF MASSACHUSETTS DARTMOUTH
706 South Rodney French Blvd., New Bedford, MA 02744-1221

with the assistance of:
Thomas C. Cambareri, Program Manager
Donna McCaffery, Project Assistant
Gabrielle Belfit, Hydrologist
Xiaotong Wu, GIS Assistant
Scott Michaud, Hydrologist
CAPE COD COMMISSION
WATER RESOURCES PROGRAM
3225 Main Street, Barnstable, MA 02630

This project was completed using funding from the Town of Barnstable via the Cape Cod Commission

Acknowledgement: Special thanks to Rob Gatewood and Dale Saad from the Town of Barnstable for their assistance in gathering available pond reports and to town staff, volunteers, and advocacy groups that collect pond water samples and continue to be advocates for Barnstable's ponds.

Cover photo: Hathaway Pond (Ed Eichner, August 1993)

Executive Summary

Barnstable Ponds:
Current Status, Available Data, and Recommendations for Future Activities

FINAL REPORT

July 2008

The Town of Barnstable has 182 freshwater ponds, 93 of which are one acre or more. Twenty-five ponds are greater than 10 acres and are considered "Great Ponds" under state regulations. Collectively, ponds occupy 1,856 acres within the town.

The Town of Barnstable asked the Cape Cod Commission to review available freshwater pond water quality data in order to gauge their status and provide recommendations regarding future pond monitoring, protection, and remediation activities. With the assistance of town Conservation Division staff, Cape Cod Commission and School of Marine Science and Technology (SMAST) University of Massachusetts Dartmouth staff gathered, organized, and reviewed available pond monitoring data collected from Barnstable ponds between 1948 and 2006. Data from 38 ponds was identified.

Data from the 38 ponds is generally focused on two sources: 1) individual pond studies with intensive year-long data collection and 2) data collect through the Pond and Lake Stewardship (PALS) Snapshots conducted through the CCC and the SMAST between 2001 and 2007. Half of the ponds only have water quality data through the PALS Snapshots and another eight have more data collected through the Snapshots than through other sources. Since the data available for the majority of ponds is from the PALS Snapshots, which are designed to gauge worst-case conditions for regional comparison of pond state, the available datasets for Barnstable's ponds are generally insufficient for definitive conclusions about causes of conditions in individual ponds, but they are sufficient to compare conditions between ponds.

For the review of the data, SMAST staff focused on nutrient and dissolved oxygen conditions in the comparisons between ponds. Minimum dissolved oxygen concentrations are specified in state surface water regulations, but nutrient concentrations are not. Staff developed average concentrations for dissolved oxygen, total phosphorus, total nitrogen, chlorophyll *a*, and pH at depths determined through the PALS Snapshot sampling protocol. Staff also developed average Secchi transparency readings. Ponds were divided among three different groups based on maximum depth: ultrashallow ponds (maximum depth <1.5 m), shallow ponds (maximum depths between 2.1 and 8.3 m) and deep ponds (maximum depth >9.3 m).

Development of water quality impacts in surface waters generally follow a progression from higher nutrient concentrations to 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 decompose the dead plants. Since the bacteria consume oxygen, more decomposing plant material can remove oxygen for the water, which in turn produces chemical conditions that allow nutrients in the decomposing plant to be regenerated back into the water, creating the opportunity to start the cycle all over again by prompting more plant growth.

The review of available data generally creates a consistent picture that most ponds in Barnstable are ecologically impacted or impaired. More of the ponds show impacts in nutrient levels and less meet the state definition of impaired, which is based on dissolved oxygen concentrations. This pattern is consistent with the progression of nutrient impacts and suggests that impacts in a number of ponds can be addressed through less intensive measures that will halt the progression to extensive low oxygen conditions and regeneration of sediment nutrients.

Overall, Cape Cod-specific threshold concentrations for total phosphorus and chlorophyll *a* are exceeded in 84% and 88% of the pond depth stations; these percentages are fairly consistent across the three depth groups. Six of the 15 shallow ponds and eight of the 10 deep ponds have at least one depth station that has an average DO less than state limits. All ultrashallow ponds, which would be easily mixed by available winds, meet the state DO limits. Three ponds that appear to be relatively pristine are: Little Hathaway, Mary Dunn, and Joshua.

After reviewing the average nutrient and DO conditions, it is not surprising that most of Barnstable's ponds have higher trophic classifications than would be expected. Review of the most protected Cape ponds show that most are oligotrophic or have a naturally low nutrient content. Among Barnstable's ultrashallow ponds, the average trophic classification according to the Carlson Trophic Status Index is mesotrophic (or a step above oligotrophic), while in the shallow ponds the average classification is eutrophic (or two steps above oligotrophic). In the deep ponds, which have greater volume to dilute impacts, the average trophic classification is on the oligotrophic side of the oligotrophic/mesotrophic boundary. For comparison, the average classification of protected ponds on the Cape is the low end of the oligotrophic range.

As a result of the data review, SMAST and Commission staff developed a series of recommendations for future pond activities to address the impairments and provide the town with a better basis for proactive, rather than reactive, pond management. These recommendations, which build on the results in this report, are:

1) Develop an integrated long term pond monitoring program,
2) Continue to prioritize detailed individual pond projects,
3) Develop additional Town-wide physical data about the ponds, including bathymetry and watershed delineations,
4) Set water quality targets for individual ponds or groups of ponds, and
5) Review local regulations to better protect pond water quality.

These recommendations and others are described in more detail in this report. SMAST and Commission staff are available to assist the town in discussion of these types of activities, the pond analysis results, and recommendations contained in the report.

Suggested Citation: Eichner, E. 2008. Barnstable Ponds: Current Status, Available Data, and Recommendations for Future Activities. School of Marine Science and Technology, University of Massachusetts Dartmouth and Cape Cod Commission. New Bedford and Barnstable, MA.

Table of Contents

Barnstable Ponds:
Current Status, Available Data, and Recommendations for Future Activities
FINAL REPORT
July 2008

Figures and Tables

Barnstable Ponds:
Current Status, Available Data, and Recommendations for Future Activities

FINAL REPORT
July 2008

FIGURES

TABLES

Appendices

I. Introduction

As the population of the Town of Barnstable has grown, more development has occurred around the freshwater ponds and lakes of the town. Residents around these ponds have the potential to be regular observers of water quality conditions and, in some cases, advocates for protective or remedial activities to maintain water quality that supports all of the uses desired by the residents. These uses include recreational activities, such as swimming, boating, and fishing, and recently developed information indicates that these ponds also provide nitrogen attenuation capacity that protects water quality in the town's bays and harbors (*e.g*., Howes, *et al*., 2006a). Review and correction of the Cape Cod Pond and Lake Atlas database based on work completed in this project, shows that the Town of Barnstable has 182 ponds that collectively occupy 1,856 acres. Figure I-1 shows all identified ponds and lakes in the Town of Barnstable.

Pond concerns in Barnstable mirror concerns that are being raised Cape-wide. The Cape Cod Commission and other community partners, including the Community Foundation of Cape Cod, the state Executive Office of Environmental Affairs, and the University of Massachusetts Dartmouth School of Marine Science and Technology (SMAST), developed the Pond and Lake Stewards (PALS) program to respond to these concerns. Initial PALS activities included a number of accomplishments, including the production of the Cape Cod Pond and Lake Atlas (Eichner, *et al*., 2003), a number of "Ponds in Peril" workshops where pond concerns and solutions could be shared among all towns and volunteers, and participation of volunteers in the National Secchi Dip-In using Secchi disks provided by the Commission to measure transparency in their ponds. Volunteers who participated in the Dip-In wanted to know more about the water quality in their ponds and, with SMAST's offer of free laboratory analysis of water samples, the Commission, SMAST, and the towns created the first PALS Snapshot water quality sampling in 2001.

The successful participation of volunteers in pond water quality monitoring led many communities and pond groups to seek Cape Cod Commission assistance with more refined, locally or pond-focused sampling programs. In Barnstable, Commission staff assisted the Indian Ponds Association and the town with a water quality study of Mystic, Middle, and Hamblin ponds (Eichner, *et al*., 2006). Commission staff also discussed refined sampling and analysis with representatives of the Wequaquet Lake Protective Association and with concerned citizens around Round Pond and Hinckley Pond. Town of Barnstable staff recognized that the increasing interest in pond water quality would benefit from a more formal review of past activities within the town, including recent water quality monitoring. The town, working through the Conservation Commission, approved funding for such a review, which is documented in this report, as well as a more refined review of Wequaquet Lake, which will be documented in a subsequent report. Working with town staff, Cape Cod Commission and SMAST staff have organized and reviewed available pond water quality data for ponds in Barnstable. This report reviews this data and presents a series of recommendations for future pond activities within the Town of Barnstable.

II. Available Pond Data Sources

Of the 182 ponds in the Town of Barnstable ponds, 49% of them are greater than one acre and 25 of them are greater than ten acres (Table II-1). Ponds of 10 acres or greater are called

Figure I-1. Freshwater Ponds and Lakes in the Town of Barnstable
All ponds in Cape Cod Commission database are shown; those with names in the database have labels.

“Great Ponds” under Massachusetts law and are considered public ponds (MGL, ch. 91,§35). The 25 Great Ponds in Barnstable are 84% of the total pond acreage in the town.

The acreage of each of the ponds is based on Cape Cod Commission delineations from a Spring 1994 orthophoto. Given that the ponds on the Cape are connected to the underlying groundwater and are considered “windows on the aquifer”, the area of a pond may fluctuate considerably depending on the surrounding water levels. For example, intensive water level measurements of Lake Wequaquet in 1998 found that its water level fluctuated 2.2 feet during the course of the year (Eichner, *et al*., 1998). Because Spring 1994 was a relatively high groundwater period based on Cape Cod Commission water level databases, it is likely that most ponds are slightly smaller during average water level conditions.

Watershed delineations are available for 21 ponds (Figure II-1). These delineations are based on groundwater modeling completed by the US Geological Survey for the Massachusetts Estuaries Project (Walter and Whealan, 2005). The outer boundary of the estuary watershed delineations are shown in Figure II-1; only ponds included in the regional groundwater model have watershed delineations. In order to complete additional watershed delineations, a subregional model based on the USGS regional model would likely be required along with some additional localized data collection of hydrogeology and bathymetry to provide more refined results.

Bathymetric or comprehensive depth information is available for 18 ponds. Bathymetric maps for these ponds are included in Appendix A. Bathymetric information is generally required to complete a detailed assessment of water quality problems within a pond. Bathymetry allows a water scientist to determine the volume of the pond, how long water from a watershed takes to completely exchange water within the pond, and how pollutants and impairments change with depth and volume within the pond. Bathymetric information can be developed by volunteers with appropriate guidance; volunteers in the Town of Orleans collected bathymetric data for 18 ponds and Cape Cod Commission staff used this data to develop bathymetric maps for the town (Eichner, 2007).

Most of the focus of this project is the water quality data available for Barnstable ponds. Over the course of nearly sixty years, water quality data has been collected from 38 ponds in the Town of Barnstable (Table II-2). All the sampled ponds are greater than one acre and 23 are greater than 10 acres. Table II-2 also lists the number of sampling events for each year in which a pond is sampled. Sampling events are defined as the collection of any water quality monitoring data. Years listed as having ten or more sampling events generally indicate that a more substantive study was completed on the pond during that year. The list of pond studies reviewed during this project is included in Appendix B.

Table II-2 also separately lists each time samples were collected from a pond during any of the seven PALS Snapshots. These are included as a separate section in the table because sampling under this program has generally been more consistent and comprehensive than the other sampling projects. The same laboratory generates all PALS Snapshot water quality

Table II-1. Summary of Town of Barnstable Pond and Lake Areas

Cape Cod Commission GIS databases indicate that the Town of Barnstable has a total of 182 ponds and lakes with a cumulative area of 1,856 acres. Listed below are ponds by name and PALS ID number within three size groups: >10 acres, 3.1<acres<10, and 1<acres<3.1. In the CCC GIS database there are 93 ponds of less than one acre, which have a cumulative area of 39 acres.

Area: >10 acres		
Pond Name	PALS_ID	Area acres
Wequaquet	BA-605	596.3
Mystic	BA-584	148.4
Hamblin	BA-668	115.4
Middle	BA-640	104.6
Shallow	BA-626	78.4
Bearse	BA-617	66.8
Lovells	BA-759	55.5
Shubael	BA-664	55.1
Long (MM)	BA-675	54.8
Long (Cville)	BA-737	51.0
Garretts	BA-510	27.9
Muddy	BA-694	24.6
Hathaway (North)	BA-565	20.9
Mary Dunn	BA-646	18.0
Mill (WB)	BA-391	16.7
Micah	BA-797	16.0
Joshua	BA-807	14.7
Neck	BA-874	13.6
Hathaway (South)	BA-594	12.6
Lamson	BA-596	12.3
Fawcetts	BA-748	11.9
Parker	BA-875	10.9
Hinckley	BA-411	10.3
Crystal	BA-878	10.1
West	BA-764	10.1
	TOTAL ACRES	1556.9
	NUMBER	25

Area: 3.1<acres<10		
Pond Name	PALS_ID	Area acres
Coleman	BA-819	9.9
Round (MM)	BA-691	9.8
Lumbert	BA-719	9.7
Little/Stoney	BA-564	9.7
Eagle	BA-815	8.5
Pattys	BA-731	8.3
Israel	BA-585	8.1
Simmons	BA-789	7.8
Bog	BA-802	7.2
Flowing	BA-733	7.2
Aunt Bettys	BA-756	7.1
Sandy Hill	BA-542	6.6
Elizabeth	BA-795	6.3
Flint Rock	BA-614	6.3
	BA-750	6.1
Mill (MM)	BA-746	6.0
North (Cville)	BA-752	5.8
	BA-382	5.6
	BA-673	5.6
Sam	BA-820	5.1
	BA-799	5.1
Spruce	BA-535	5.0
North (Ost)	BA-816	4.9
	BA-864	4.8
	BA-662	4.7
Lewis	BA-881	4.6
	BA-699	4.5
Red Lily	BA-782	4.5
	BA-771	4.3
Schoolhouse	BA-806	3.6
Dunns	BA-723	3.6
Lewis	BA-670	3.5
Campground	BA-574	3.5
	TOTAL ACRES	203.3
	NUMBER	33

Area: 1<acres<3.1		
Pond Name	PALS_ID	Area acres
	BA-533	3.0
	BA-636	3.0
	BA-372	2.8
Fresh	BA-701	2.7
	BA-843	2.7
	BA-373	2.5
	BA-370	2.5
Round (Bar)	BA-587	2.5
Flax	BA-473	2.4
	BA-655	2.0
	BA-633	1.9
	BA-747	1.9
	BA-708	1.8
No Bottom	BA-523	1.8
	BA-772	1.8
	BA-813	1.8
	BA-450	1.7
	BA-696	1.7
	BA-727	1.7
	BA-732	1.5
Naomi	BA-812	1.4
	BA-800	1.3
Little Parker	BA-841	1.3
	BA-735	1.2
	BA-624	1.2
	BA-773	1.2
	BA-672	1.2
	BA-791	1.1
Little Israel	BA-608	1.1
	BA-743	1.1
	BA-862	1.1
	TOTAL ACRES	56.9
	NUMBER	31

Figure II-1. Watershed Delineations for Ponds and Lakes in the Town of Barnstable. These delineations are the pond delineations created by the USGS for the Massachusetts Estuaries Project Technical Reports for Popponesset Bay (Howes, *et al.*, 2004), Three Bays (Howes, *et al.*, 2006b), Centerville River (Howes, *et al.*, 2006a), and the draft report for Lewis Bay (Howes, *et al.*, 2007). Ponds within these watersheds without delineations are not included in the regional groundwater model (Walter and Whealan, 2005).

Table II-2. Summary of Pond and Lake Sampling Events in Town of Barnstable (1948-2007)

Number of sampling events is shown for each pond between 1948 and 2006. In years with two numbers listed (e.g., "3/2"), the first number is the total number of sampling events, while the second number is the number of events between June and September of that year. If only a single number is shown, all data was collected between June and September. Years with 10 or more events listed generally reflect a pond-specific study completed during that year. Cape Cod Pond and Lake Stewards Snapshot samples between 2001 and 2007 are shown on the far right; these are shown separately since they were completed with a consistent volunteer-supported sampling protocol and use of a consistent laboratory (*i.e.*, UMASS Dartmouth, SMAST) for water quality analysis.

Pond or Lake Name	PALS ID	Area	Bathy	SAMPLING EVENTS PER YEAR																								PALS Snapshot						
		acres		48	75	78	79	80	82	83	84	85	86	87	88	89	90	91	92	95	96	97	98	00	04	05	06	01	02	03	04	05	06	07
Aunt Bettys	BA-756	7.1	N		1																							1	1	1				1
Bearse	BA-617	66.8	Y							1	1	3/0	16/8									4	2					1	1	1		1	1	
Bog	BA-802	7.2	N																									1	1	1		1	1	
Coleman	BA-819	9.9	N																									1						
Crystal	BA-878	10.1	N																									1	1	1		1	1	1
Dunns	BA-723	3.6	N																									1						
Eagle	BA-815	8.5	Y																									1	1	1			1	1
Elizabeth	BA-795	6.3	N			1/0	1/0					11/4																1	1	1				
Fawcetts	BA-748	11.9	N																									1	1	1				
Garretts	BA-510	27.9	Y					1																				1	1	1				
Hamblin	BA-668	115.4	Y	1								1							14/8	6/4	5/3	5	5/4	3/2	10/9	7		1	1	1	1	1	1	1
Hathaway N	BA-565	20.9	Y	1																								1	1	1				
Hathaway S	BA-594	12.6	N																									1						
Hinckley	BA-411	10.3	N																											1			1	1
Joshua	BA-807	14.7	N					1		1																		1	1	1		1	1	1
Lewis	BA-881	4.6	N																									1	1	1		1	1	
Little Parker	BA-841	1.3																														1	1	1
Little/Stoney	BA-564	9.7	N																									1	1			1	1	1
Long Cville	BA-737	51.0	Y	1				1	1	1		3/0	16/8															1	1	1		1	1	1
Long MM	BA-675	54.8	N	1				1																				1	1	1				
Lovells	BA-759	55.5	Y	1				1		1											16/8							1	1	1		1	1	
Lumbert Mill	BA-719	9.7	N																									1	1	1				1
Mary Dunn	BA-646	18.0	Y																									1		1				
Micah	BA-797	16.0	N					1																				1	1	1		1	1	1
Middle	BA-640	104.6	Y	1																					10/8	7		1	1	1	1	1	1	1
Mill MM	BA-391	16.7	N																					3				1	1	1		1	1	1
Mill W Bar	BA-746	6.0	N					1																					1	1				
Muddy	BA-694	24.6	N																									1	1	1				1
Mystic	BA-584	148.4	Y	1				1																	10/8	7		1	1	1	1	1	1	1
Neck	BA-874	13.6	N																									1	1	1		1	1	1
No Bottom	BA-523	1.8	N																										1	1				
Parker	BA-875	10.9	N																									1	1	1		1	1	1
Red Lily	BA-782	4.5	Y			1/0	1/0		1			12/4																2	2	2				
Round	BA-691	9.8	N																									1	1	1		1		1
Schoolhouse	BA-806	3.6	N																									1	1	1				1
Shallow	BA-626	78.4	Y	1				1		1		3/0	16/8															1	1	1				
Shubael	BA-664	55.1	Y	1									2/1	2/1	2/1	2/1	1	1										1	1	1				1
Wequaquet	BA-605	596.3	Y	1					1			3/0	16/8									1	2		2	3	3	4	1	1		1	1	1

concentration results and both field data and lab samples are collected using a consistent sampling protocol. This consistency allows for reasonable comparison between ponds and among sampling years.

The PALS Snapshots provide free laboratory analyses provided by the SMAST Coastal Systems Analytical Facility Laboratory at University of Massachusetts Dartmouth. Snapshot water samples are collected from individual ponds from mid-August through September. The PALS sampling protocol calls for a shallow (0.5 m) sample and then generally a deep sample 1 m off the bottom for all ponds of 9 m total depth or less; ponds less than 1.5 m should have two samples from the surface collected. Ponds that are deeper than 5 m will have a third sample collected at 3 m (*i.e.*, 0.5 m, 3 m, and one meter off the bottom) and ponds greater than 10 m will have a fourth sample collected at 9 m (*i.e.*, 0.5 m, 3 m, 9 m, and one meter off the bottom). Samples are collected as whole water and transferred to the SMAST lab within 24 hours. The PALS Snapshot program is directed toward measuring ponds when water quality is expected to be at its worst, so interpretation of this data must keep this limitation in mind.

Field sampling procedures under the PALS Snapshot protocol include water column profile measurements (at 0.5 m, 1 m, 2 m, etc.) of dissolved oxygen and temperature, and Secchi disk transparency. Laboratory analysis and sample handling procedures are described in the SMAST Coastal Systems Analytical Facility Laboratory Quality Assurance Plan (2003). Laboratory analysis of PALS Snapshot samples include the following parameters: total nitrogen, total phosphorus, chlorophyll *a*, pH, and alkalinity.

Detection limits for laboratory analytes and field data collection under the PALS Snapshot are listed in Table II-3. The laboratory detection limits represent minimum detection limits that are recommended for all pond water quality analysis on Cape Cod. Higher detection limits, especially for nitrogen and phosphorus, are likely to produce concentration results that are below the detection limit. So, for example, if a pond has a total phosphorus concentration of 15 µg/l and the analysis is conducted with a test with a 1.3 µg/l detection limit, the accurate concentration will be reported. If, on the other hand, the test detection limit is 20 µg/l, the reported result will be “below detection limit” (BDL). BDL results means the pond concentration is within the range of 0 to 20 µg/l and this wide range means interpretation of the results has to be limited in its conclusions. Many of the older data collected from Barnstable ponds had detection limits that produced numerous BDL results.

III. Overview of Available Pond Water Quality Data

In order to complete the town-wide data review, Commission, SMAST, and Town Conservation Division staff collected all available pond studies, reports, and town and Commission-collected data. This data spanned the years 1948 through 2006. Cape Cod Commission staff organized all of the pertinent data, focusing on nutrient, nutrient-related (*e.g.,* dissolved oxygen), and physical (*e.g.*, temperature) data. Once organized, the data was reviewed to determine consistency of sampling and laboratory analysis techniques. Data was included unless the review of accompanying reports suggested that it should be excluded due to laboratory analysis concerns. Data was then analyzed to determine mean, standard deviation, maximum, minimum concentrations of all available data. Data was then screened to remove outliers (± two standard deviations). Selected data stations, largely based on the PALS sampling depths, was then organized to produce the comparison of data between ponds that is described below. The

Table II-3. Field and laboratory reporting units and detection limits for data collected for the Barnstable Ponds under the PALS Snapshots			
Parameter	**Matrix**	**Reporting Units**	**Detection Limit**
Field Measurements			
Temperature	Water	ºC	0.5°C
Dissolved Oxygen	Water	mg/l	0.5
Secchi Disk Water Clarity	Water	meters	NA
Laboratory Measurements - SMAST			
Alkalinity	Water	mg/l as $CaCO_3$	0.5
Chlorophyll-*a*	Water	µg/l	0.05
Nitrogen, Total	Water	µg/l	0.7
pH	Water	standard units	NA
Phosphorus, Total	Water	µg/l	3.1
Information from SMAST (2003)			

analysis also focuses on average concentrations between June through September. Data outside of this period helps in understanding how the ecosystems are set prior to the primary period of ecosystem activity or how they reset following this period, but the time between June and September is the most ecologically significant, as well as when most residents spend time in or on Cape Cod ponds.

Available data for most ponds in Barnstable is limited. Other than the PALS Snapshots and sampling following the alum treatment at Hamblin Pond, sampling of most of the ponds has been sporadic. High frequency sampling associated with detailed pond assessments has been completed, mostly in the 1980's, but most of these have not had regular follow-up sampling other than the PALS Snapshots. Pond sampling during the 1990's was almost exclusively for detailed pond assessments. Given the sporadic available data and since the PALS Snapshots are designed to sample ponds during what is likely to be their worst water quality conditions, interpretation of available data must be approached with an understanding of these limitations.

III.1. Field Collected Water Quality Data

III.1.1 Dissolved Oxygen and Temperature

Pond and lake ecosystems are controlled by interactions among the physical, chemical, and biological factors within a given lake. The availability of oxygen determines distributions of various species living within a lake; some species require higher concentrations, while others are more tolerant of occasional low oxygen concentrations. Oxygen concentrations also determine the solubility of many inorganic elements; higher concentrations of phosphorus, nitrogen, and iron, among other constituents, can occur in the deeper portions of ponds when anoxic conditions convert bound, solid forms in the sediments into soluble forms that are then released into the water column. Temperature is inversely related to dissolved oxygen (DO) concentrations (*i.e.*, higher temperature water holds less dissolved oxygen).

Oxygen concentrations are also related to the amount of biological activity in a pond. Since one of the main byproducts of photosynthesis is oxygen, a vigorous algal population can produce DO concentrations that are greater than the concentrations that would be expected based simply on temperature interactions alone. These instances of "supersaturation" usually occur in lakes with high nutrient concentrations, since the algal population would need readily available nutrients in order to produce these conditions. Conversely, as the algal populations die, they fall to the sediments where bacterial populations consume oxygen as they degrade the dead algae. Too much algal growth can thus lead to anoxic conditions and the release of recycled nutrients back into the pond from the sediments potentially leading to more algal growth.

Shallow Cape Cod ponds [less than 9 meters (29.5 ft) deep] tend to have well mixed water columns because ordinary winds blowing across the Cape have sufficient energy to move deeper waters up to the surface. In these ponds, both temperature and dissolved oxygen readings tend to be relatively constant from surface to bottom; this would be the expected condition in all but the deepest ponds in Barnstable.

In deeper Cape Cod ponds, mixing of the water column tends to occur throughout the winter, but rising temperatures in the spring heat upper waters more rapidly than winds can mix the heat throughout the water column. This leads to stratification of the water column with warmer, upper waters continuing to be mixed and warmed throughout the summer and the isolation of cooler, deeper waters. The upper layer is called the epilimnion, while the lower layer is called the hypolimnion; the transitional zone between them is called the metalimnion. Among Barnstable's ponds, only Crystal, Hamblin, Hathaway, Lovells, and Mystic develop significant stratification and among these only Hamblin, Hathaway, and Mystic develop a clearly defined hypolimnion.

Since the lower layer in a stratified pond is cut off from the atmosphere by the epilimnion, there is no mechanism to replenish oxygen consumed by sediment bacterial populations as they consume organic matter (*e.g.*, algae, fish) that has sunk to the bottom. If there is extensive organic matter falling to the sediments, as one would expect with lakes with higher amounts of nutrients, the bacterial respiration can consume all of the oxygen before the lake mixes the whole water column again in the fall.

The state surface water regulations (314CMR4) 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 (*e.g.*, Hamblin) and not less than 5.0 mg/l in warm water fisheries (*e.g.*, Wequaquet). 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 these are natural background conditions.

Dissolved oxygen and temperature concentrations are the most extensive dataset collected for Barnstable's ponds. Readings were generally collected following the PALS protocol with an initial reading at a depth of 0.5 meter and then 1 m increments below that (*e.g.*, 0.5 m, 1 m, 2 m, etc.). In order to simplify comparison between ponds, staff separated the ponds into three groups based on their depth and reviewed dissolved oxygen concentrations at the water sample collection depths specified by the PALS protocol. The three groups are labeled "ultra-shallow", "shallow", and "deep." The ultra-shallow ponds have a maximum depth of 1 m or less, shallow ponds have a maximum depth of 9 m, but greater than 1 m, and deep ponds have a maximum depth greater than 9 m. There are 13 ponds in the ultra-shallow group, 15 in the shallow group, and 10 in the deep group. Maximum depths are largely based on station depths determined during PALS Snapshots.

Among the 38 ponds in Barnstable with available data, there are 81 station depths where both water quality samples for lab analysis were collected and dissolved oxygen concentrations were measured between 1948 and 2006. These station depths have between 1 (a number of ponds) and 42 (Hamblin) dissolved oxygen readings. Among the 38 ponds, only Hamblin, Hathaway, and Mystic clearly meet the state criteria for a cold-water fishery. Crystal and Lovells have occasional conditions that match the cold-water fishery criteria, while the remainder of the ponds would be considered warm water fisheries.

Of the 13 station depths in the 13 "ultra-shallow" ponds, average concentrations from the available monitoring data between June and September all except Dunns Pond exceed the state 5-ppm DO standard for warm water fisheries (Figure III-1a). This should be expected since all of these ponds would be easily mixed by available wind energy and, thus, would either have an equilibrium concentration with the atmosphere or, if a very productive system, a concentration above equilibrium. Dunns Pond has only one reading, while the other ponds have between two and eight readings.

Of the 33 station depths in the 15 "shallow" ponds, six stations in six different ponds had average concentrations less than the state 5-ppm DO standard (Figure III-1b). The six stations were the deepest stations in the following ponds: Elizabeth, Hinckley, Long (Centerville), No Bottom, Parker, and Schoolhouse. These ponds generally should be shallow enough to have frequent mixing of the water column and sufficient atmospheric oxygen to replenish sediment oxygen consumption. This group contains ponds with maximum depths between 2.1 and 8.6 m. One might think that the deepest ponds would be most likely to have the low oxygen stations because winds would need to circulate a larger water volume, but the six low oxygen stations are in ponds with maximum depths of 2.2 to 6.6 m. Although it is beyond the scope of the current review, most of the ponds that meet the state DO standard at their deepest station appear to either be shallow enough to have regular mixing (*e.g.*, Shallow Pond) or are largely surrounded by undeveloped or protected land (*e.g.*, Joshua or Eagle Pond).

Although Massachusetts has adopted regulatory limits for dissolved oxygen, the occurrence of concentrations less than these limits can have profound impacts on fish and other animals in pond ecosystems even if they occur very infrequently. For example, studies of fish populations have shown decreased diversity, totals, fecundity, and survival at low dissolved oxygen concentrations (*e.g.*, Killgore and Hoover, 2001; Fontenot, *et al*., 2001; Thurston, *et al.*, 1981; Elliot, 2000; Wu, *et al*., 2003). Concentrations of less than 1 ppm are generally lethal, even on a temporary basis, for most species (Wetzel, 1983; Matthews and Berg, 1997). With this in mind, staff also identified stations where dissolved oxygen concentrations of 1 ppm or less had been measured. All six of the stations in the "shallow" ponds that have averages less than the state standards also have dissolved oxygen minima of less than 1 ppm; no other stations have minima less than 1 ppm.

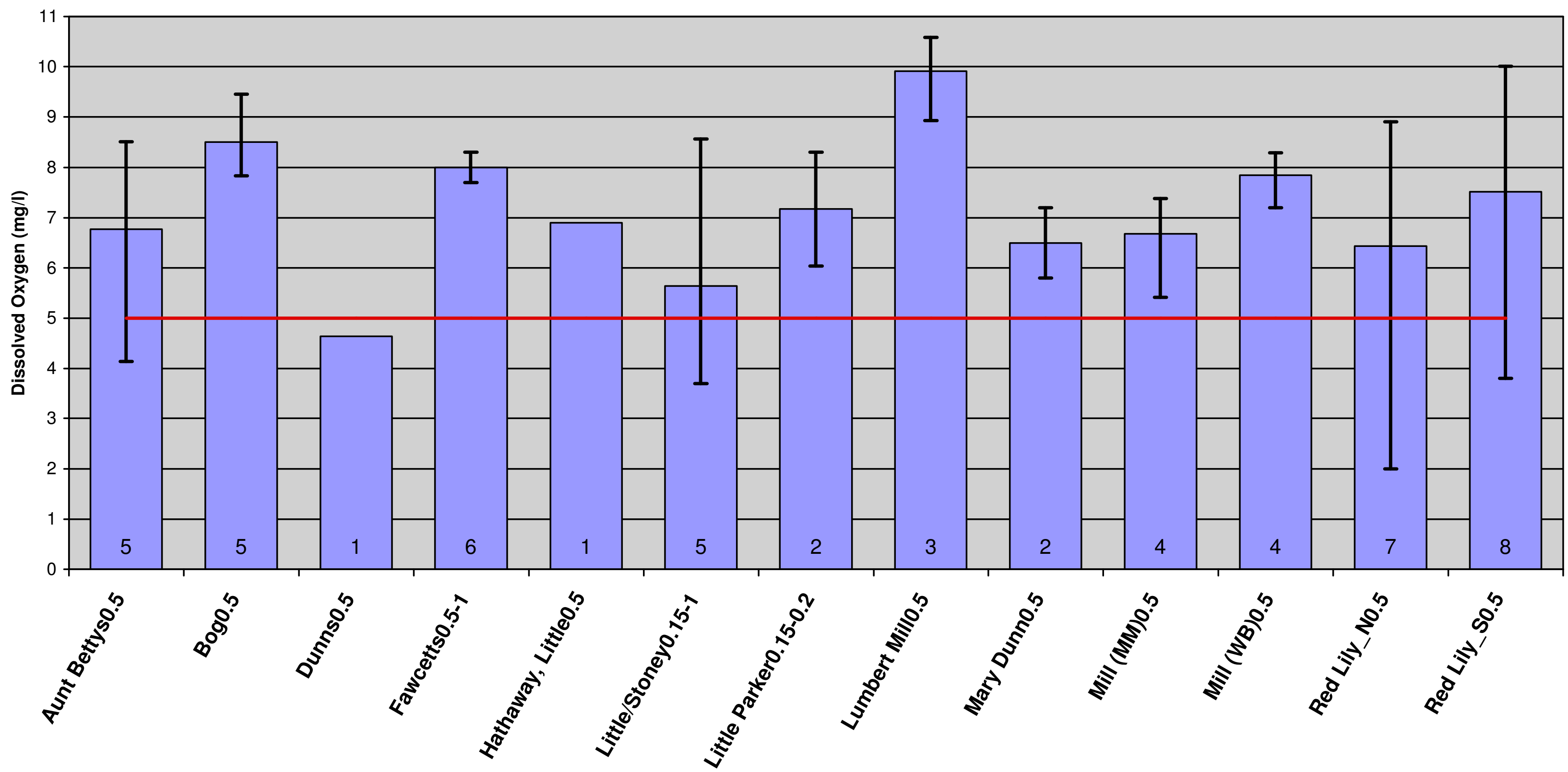


Figure III-1a. Dissolved Oxygen Concentrations in Barnstable Ponds: Ultrashallow Ponds
Average dissolved oxygen concentrations based on available pond data between June and September for ponds that have depths between 0.5 and 1.2 m. Pond names have the depths in meters at which readings were collected (*e.g.*, "Bog0.5" is Bog Pond readings collected at 0.5 m). Error bars show maximum and minimum recorded concentrations; all values are corrected for outliers (>±two standard deviations). The red line is the MassDEP regulatory threshold (5 milligrams per liter of dissolved oxygen) for warm water fisheries (314CMR4). Numbers shown at the base of each bar indicate the number of readings used to calculate the average concentration for each pond.

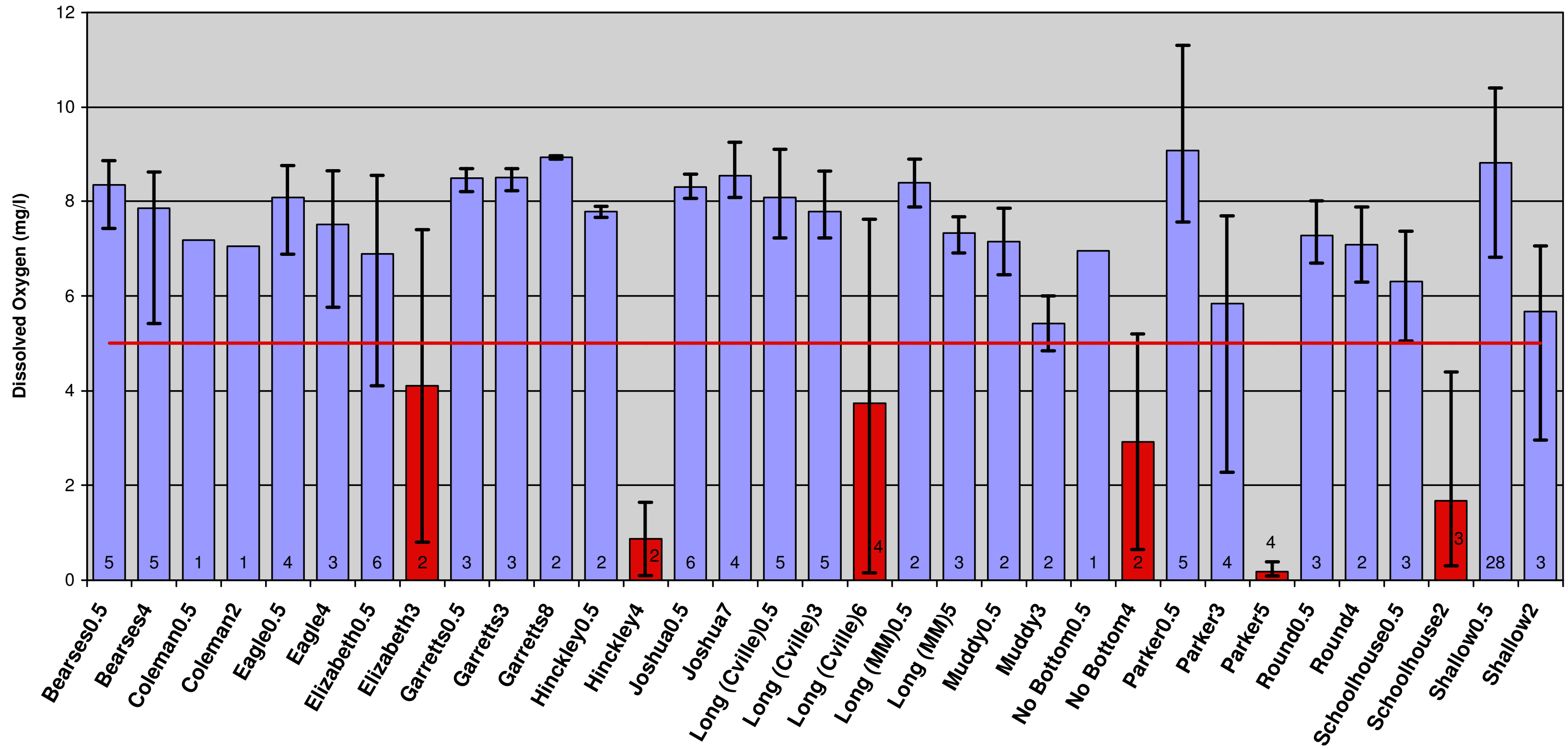


Figure III-1b. Dissolved Oxygen Concentrations in Barnstable Ponds: Shallow Ponds
Average dissolved oxygen concentrations based on available pond data between June and September for ponds that have depths between 2.1 and 8.6 m. Pond names have the depths in meters at which readings were collected (*e.g.*, “Eagle0.5” is Eagle Pond readings collected at 0.5 m). Error bars show maximum and minimum recorded concentrations; all values are corrected for outliers (>±two standard deviations). The red line is the MassDEP regulatory threshold (5 milligrams per liter of dissolved oxygen) for warm water fisheries (314CMR4). Bars that are colored red are stations with average concentrations less than 5 mg/l. Numbers shown near the base of each bar indicate the number of readings used to calculate the average concentration for each pond.

Of the 35 station depths in the ten "deep" ponds, eleven stations in nine ponds had average concentrations less than both the state 5 ppm warm water fisheries and 6 ppm cold water fisheries DO standards (Figure III-1c). The 11 stations were in the following ponds at the listed depths: Crystal (9 m), Hathaway (14 m), Hamblin (17 m), Lovells (9 and 11 m), Micah (9 m), Middle (9 m), Mystic (9 and 13 m), Neck (9 m), and Shubael (11 m). Of these ponds, Wequaquet, Middle, Crystal, Micah, and Neck should likely be classified as warm water fisheries, while the others could likely sustain a cold water fishery if sufficient oxygen concentrations were maintained. In the deepest of these ponds, bottom waters have the potential to be cutoff from atmospheric oxygen replenishment. On Cape Cod, waters in ponds deeper than 9 m tend to stratify into layers during the summer; upper waters warm much quicker than wind can mix the warmth into the rest of the water column and deeper waters become trapped below an shallower, warm, upper layer.

Available data from a 1948 state fisheries survey (MassDFG, 1948) shows that DO conditions in all these ponds, except for Hamblin, have worsened significantly. Hamblin is significantly improved due to the 1995 alum treatment. All eleven of the stations that have averages less than the state standards also have dissolved oxygen minima of less than 1 ppm except for Neck, which only had one reading. No other stations have minima less than 1 ppm.

Well-oxygenated conditions favor binding of phosphorus with iron, which is readily available in lake sediments. When oxygen concentrations drop, the chemical bonds between iron and phosphorus break and phosphorus is released. Once in the water column, this phosphorus, which generally entered the pond in previous years, is available once again to potentially prompt more algal growth. The only pond among the "deep" ponds in Barnstable where this lack of oxygen does not appear to be significant is Lake Wequaquet. This is likely due to three factors: 1) being relatively shallow, 2) having a large surface area that captures significant wind energy to keep it well mixed, and 3) having a large volume relative to its nutrient inputs. Wequaquet is currently the subject of a more detailed evaluation that the SMAST and the Cape Cod Commission are conducting in coordination with the Town Conservation Division and the Wequaquet Lake Protection Association. Results and a report on this evaluation should be available during the summer of 2008.

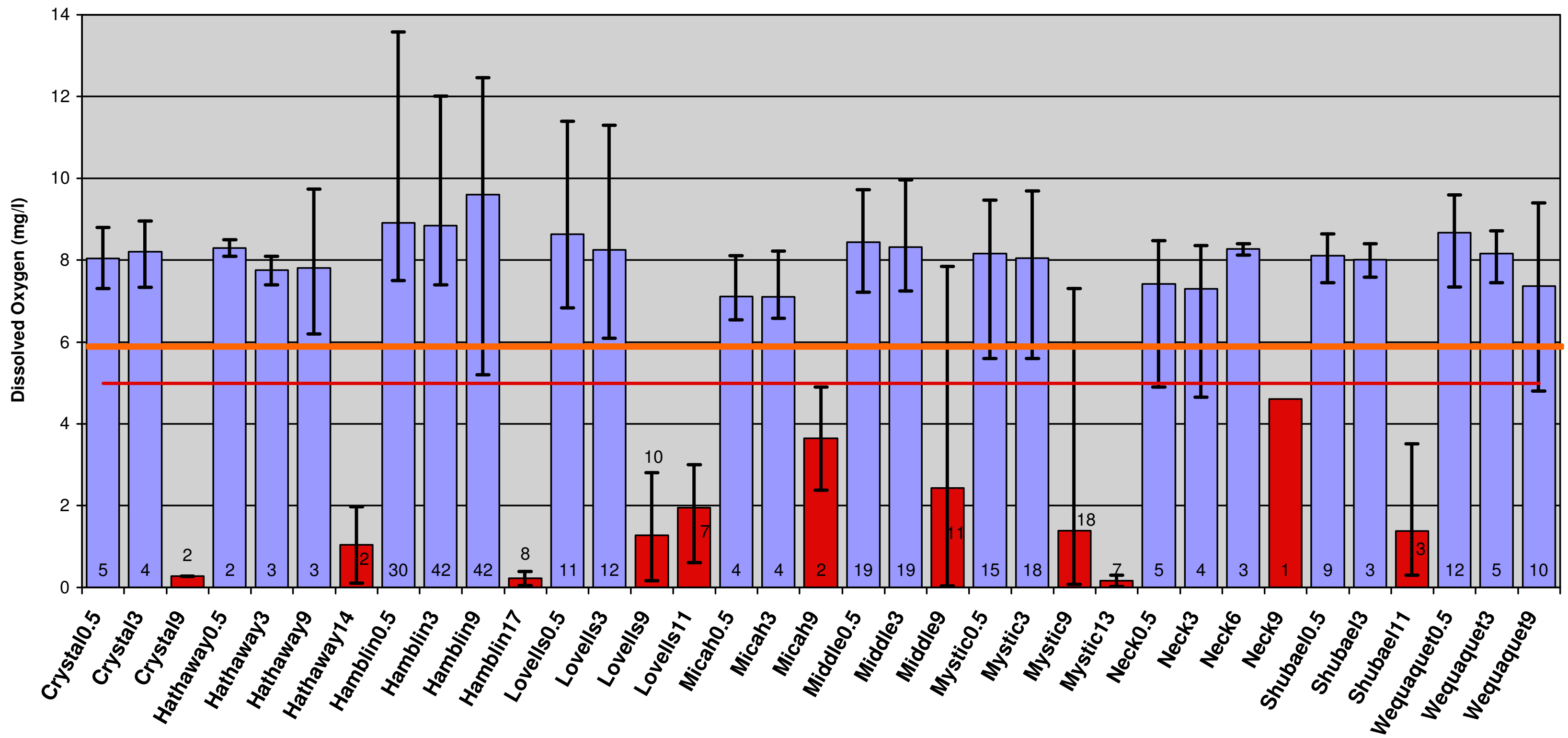


Figure III-1c. Dissolved Oxygen Concentrations in Barnstable Ponds: Deep Ponds
Average dissolved oxygen concentrations based on available pond data between June and September for ponds that have depths between 9.3 and 17.3 m. Pond names have the depths in meters at which readings were collected (*e.g.*, "Neck0.5" is Neck Pond readings collected at 0.5 m). Error bars show maximum and minimum recorded concentrations; all values are corrected for outliers (>±two standard deviations). The red line is the MassDEP regulatory threshold (5 milligrams per liter of dissolved oxygen) for warm water fisheries, while the orange line is the 6-mg/l threshold for cold-water fisheries (314CMR4). Bars that are colored red are stations with average concentrations less than 5 mg/l. Numbers shown near the base of each bar indicate the number of readings used to calculate the average concentration for each pond.

III.1.2 Secchi Depth

A Secchi disc is an eight-inch disk with black and white quadrants that is used to evaluate water transparency. Since fluctuations in Secchi depths are linked to fluctuations in concentrations of plankton or inorganic particles, a Secchi reading is an aggregate measure of ecosystem condition. Because of this, Secchi readings have been linked through a variety of analyses to trophic status or nutrient levels of lakes (*e.g.*, 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 comparing the Secchi depth to total depth of the sampling location have also been used to assess the condition of a pond ecosystem. Secchi readings collected over a long period are useful for reviewing water quality trends.

Secchi readings for Barnstable ponds are less extensive than dissolved oxygen readings, which is somewhat surprising given the ease of collection of Secchi readings compared to DO readings. Most ponds in Barnstable have between two and five readings available through the review of collected data and reports except for the Mystic, Middle, and Hamblin, which have datasets extensively supplemented by the 2006 study of the Indian Ponds (Eichner, *et al.*, 2006).

Although there is no state regulatory standard for Secchi depth, there is a state safe swimming clarity limit of 4 feet (105CMR435). As such, this review focused on the average Secchi depth reading while presenting average relative depths as well. All of the ultrashallow ponds, except for Mary Dunn, have total depths of less than 4 feet, so these were not reviewed for the swimming standards. Average relative Secchi depth in these thirteen ponds ranged between 57 and 100% and the number of readings varied between 1 (Dunns) and 4 (Bog and Mill (MM))(Figure III-2a).

Of the 15 ponds in the shallow ponds group, Parker in Osterville and Schoolhouse in Hyannis are the only ponds that have average transparency depths of less than four feet (Figure III-2b). Five others have at least one reading that is less than the four foot swimming clarity standard: Elizabeth, Long (Centerville), Long (MM), Muddy, and Round. Readings in this group are also fairly limited with a range of readings between 1 (Coleman) and 6 [Long (Centerville)]. Average relative Secchi depth in these ponds ranged between 14 (Parker) and 95% (Shallow).

None of the ten ponds in the deep ponds group have average transparency depth of less than four feet (Figure III-2c). Readings in this group are somewhat more extensive than the other groups with a range of readings between 2 (Hathaway) and 38 (Hamblin). Average relative Secchi depth in these ponds ranged between 22 (Lovells) and 58% (Neck).

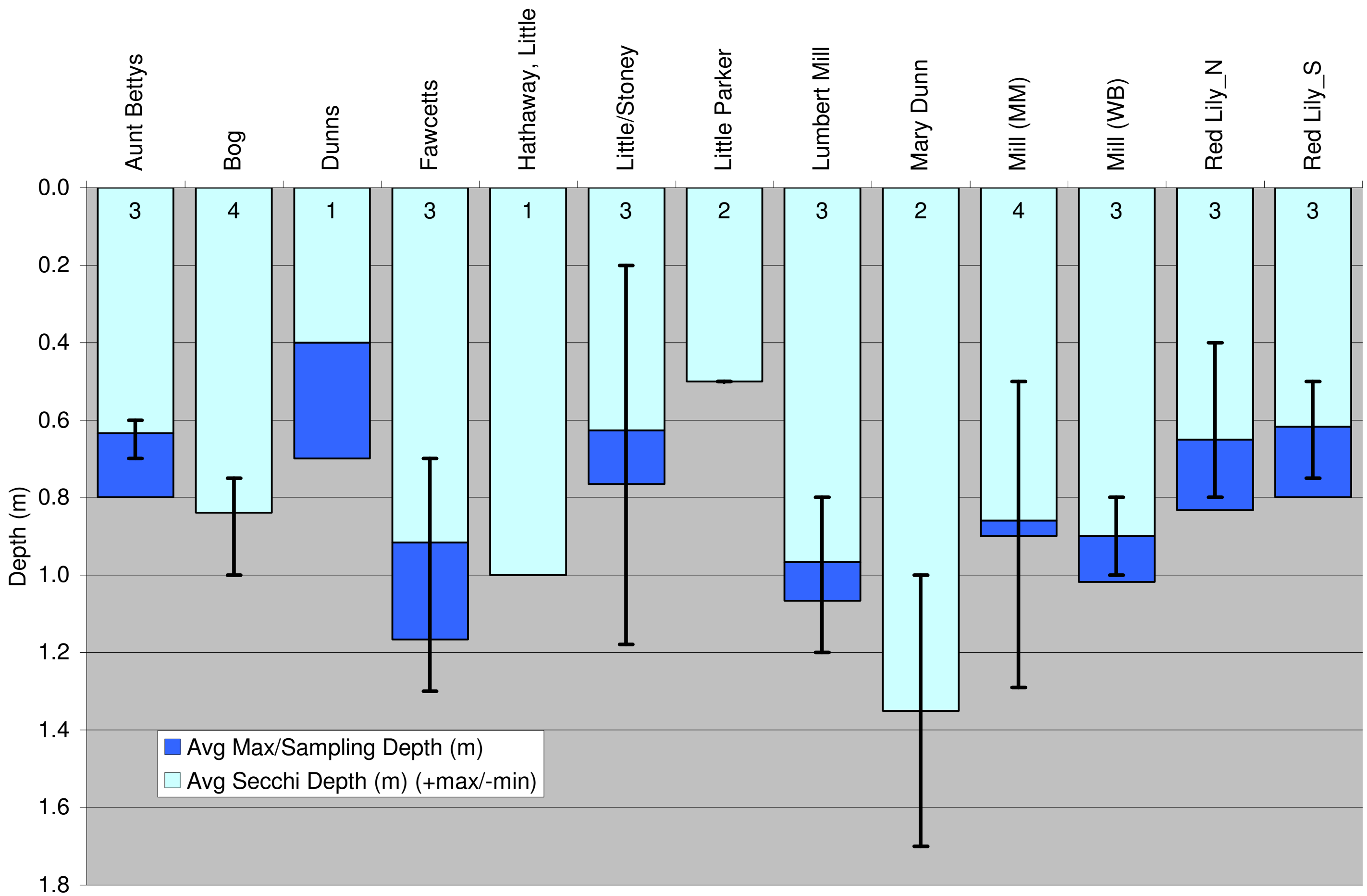


Figure III-2a. Secchi Transparency Readings in Barnstable Ponds: Ultrashallow Ponds
Average Secchi transparency and station depths based on available pond data between June and September for ponds that have depths between 0.5 and 1.2 m. Error bars show maximum and minimum recorded depths; all values are corrected for outliers (>±two standard deviations). Numbers shown near the base of each bar indicate the number of readings used to calculate the averages for each pond.

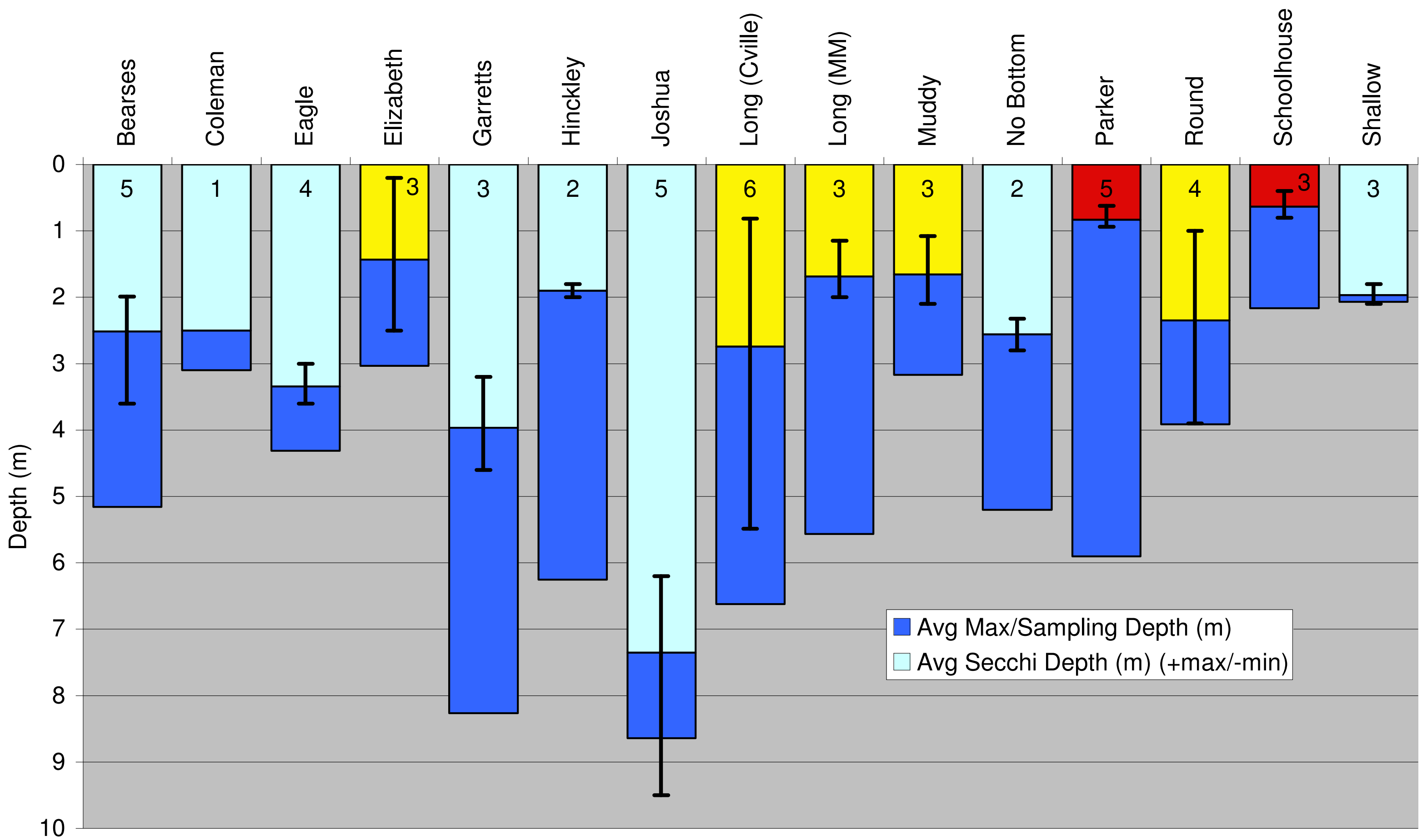


Figure III-2b. Secchi Transparency Readings in Barnstable Ponds: Shallow Ponds
Average Secchi transparency and station depths based on available pond data between June and September for ponds that have depths between 2.1 and 8.6 m. Error bars show maximum and minimum recorded depths; all values are corrected for outliers (>±two standard deviations). Numbers shown near the base of each bar indicate the number of readings used to calculate the averages for each pond. Ponds with red bars have average Secchi depths that are less than the state safe swimming clarity limit of four feet, while ponds with yellow bars have shallowest recorded readings that are less than the four-foot limit.

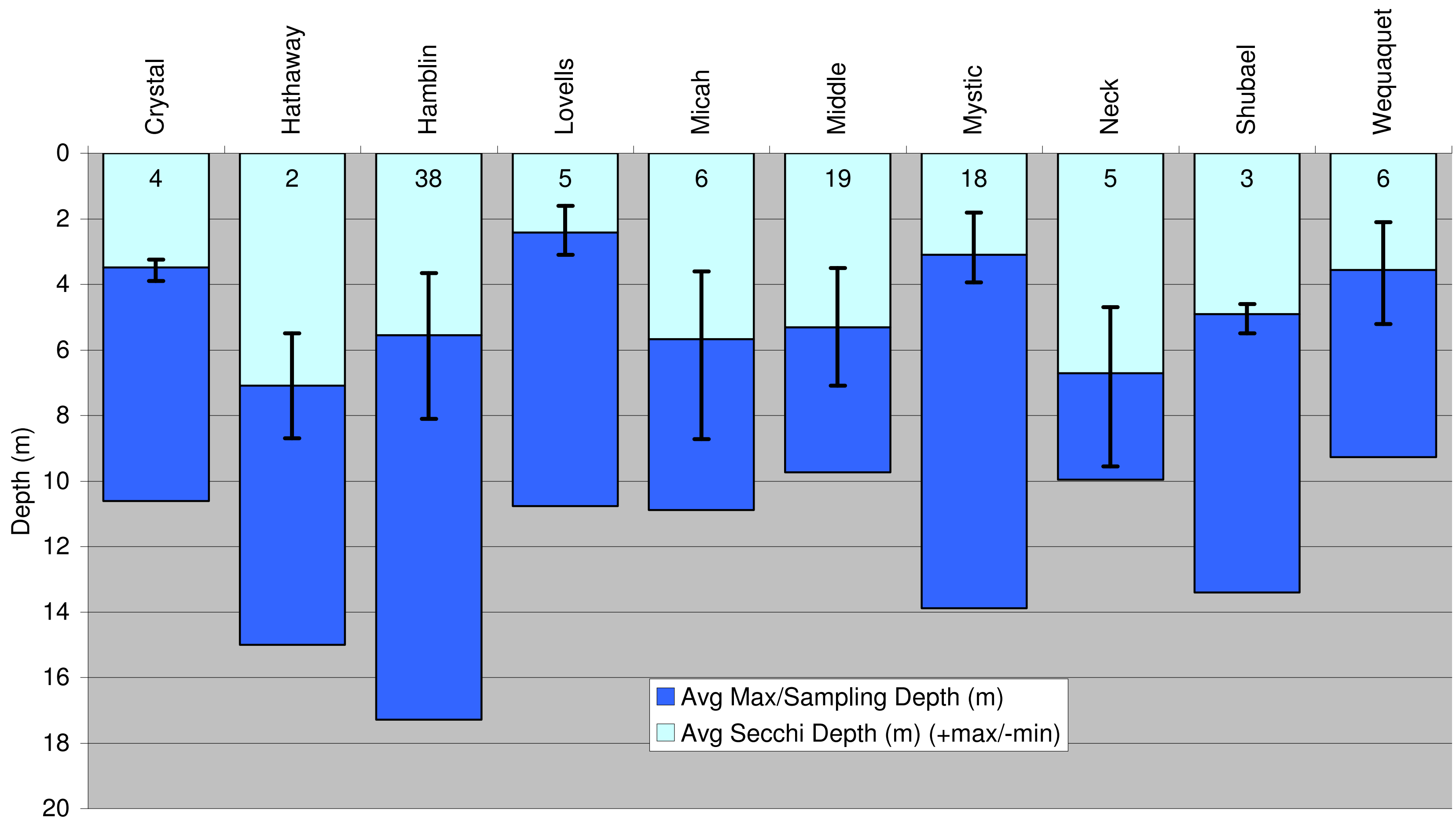


Figure III-2c. Secchi Transparency Readings in Barnstable Ponds: Deep Ponds
Average Secchi transparency and station depths based on available pond data between June and September for ponds that have depths between 9.3 and 17.3 m. Error bars show maximum and minimum recorded depths; all values are corrected for outliers (>±two standard deviations). Numbers shown near the base of each bar indicate the number of readings used to calculate the averages for each pond.

III.2 Laboratory Water Quality Data

While dissolved oxygen and Secchi transparency readings are usually recorded in the field, at the lake being monitored, other information about a given lake's ecological condition is usually determined from lake water that is collected and analyzed in a laboratory. Laboratory analyses are usually done for a variety of constituents depending on what questions about the pond are being asked. Although selected ponds have more extensive datasets, SMAST staff focused the analysis below on data that is meaningful for determining the general ecological condition of each of the ponds and are common enough that most of the ponds will have had these analyses done in the past. This set of data will also allow the analysis to make comparisons between ponds.

This analysis of laboratory data focuses on the following constituents: total phosphorus (TP), total nitrogen (TN), pH, and chlorophyll *a*. In addition, although pre-PALS Snapshot sampling events used a variety of sampling protocols and labs, the PALS Snapshot database is the most consistent long-term pond database in Barnstable and staff utilized the depths specified in the PALS sampling protocol for organizing the data. The PALS Snapshot protocol specifies a 0.5 m sampling depth in all ponds and a deep sampling depth (1 m off the bottom) for any pond greater than 2 m deep. Additional sampling depths of 3 and 9 m are added as the depth of the pond increases. This protocol anticipates that there should be some variability in the sampling depth, especially the deepest station, because of fluctuations in the water table/surface of the pond. The average concentrations also focus on measurements collected between June and September, which is the time of most activity in the ecosystem and also the period of most recreational activity for Cape Cod ponds.

The 2001 PALS Snapshot provided the most comprehensive sampling of pond water quality completed at the time of Cape Cod ponds and lakes; over 175 ponds were sampled. In order to understand the potential status of Cape Cod ponds, Cape Cod Commission staff analyzed the 2001 data to determine Cape Cod-specific nutrient thresholds (Eichner, *et al.*, 2003). These thresholds were developed using an approach recommended by the US Environmental Protection Agency (USEPA, 2000). In general, the EPA developed a method to assist states in developing regulatory thresholds or targets to identify impacted ponds that could be listed on a state's list of impaired waters. Under the federal Clean Water Act, which is administered by the states, waters listed as impaired are required to have a limit developed under the Total Maximum Daily Load (TMDL) provisions of the Act. Massachusetts currently has numeric thresholds for dissolved oxygen, temperature, and pH in surface waters, but does not have numeric thresholds for any nutrients (314CMR4). Commission staff used the EPA method to develop two sets of nutrient, chlorophyll, and pH thresholds: 1) one set based on data from all the ponds sampled and 2) another set based on those ponds that are generally surrounded by natural, undeveloped lands (Table III-1). The thresholds for the largely pristine ponds were developed to try to understand what water quality conditions might be expected in Cape ponds without anthropogenic influences. The specific thresholds developed by the Commission for each of the laboratory constituents are discussed in each of the following sections.

Table III-1 Cape Cod Ponds Reference Criteria					
		chl-*a*	TP	TN	pH
category	*measure*	µg/l	µg/l	mg/l	std units
2001 PALS Snapshot	# of ponds sampled	191	175	184	193
2001 PALS Snapshot (all ponds)	median	3.6	16	0.44	6.28
2001 PALS Snapshot (all ponds)	threshold	1.7	10	0.31	5.62
2001 PALS Snapshot (protected ponds)	threshold	1.0	7.5	0.16	5.19
Note: Reference criteria were developed using USEPA (2000) methods applied to sampling results from the 2001 Pond and Lake Stewards (PALS) Snapshot sampling. These results and methods are more fully discussed in the Cape Cod Pond and Lake Atlas (Eichner, *et al*., 2003).					

III.2.1 Total Phosphorus (TP)

Phosphorus is the key nutrient in ponds and lakes because it is usually more limited in freshwater systems than nitrogen. Typical plant organic matter contains phosphorous, nitrogen, and carbon in a ratio of 1 gram of P:7 grams of N:40 grams of C per 500 grams of 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 in freshwater systems. Because it is usually 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 understanding 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 algae.

Most Cape Cod lakes have relatively low phosphorus concentrations due to the lack of phosphorus in the surrounding glacially-derived sands. The median surface concentration of TP in 175 Cape Cod ponds sampled during the 2001 Pond and Lake Stewards (PALS) Snapshot was 16 ppb (or µg/l) (Eichner, *et al*., 2003). Using the US Environmental Protection Agency (2000) method for determining a nutrient criteria and the 2001 PALS Snapshot data, the Cape Cod Commission determined that "healthy" pond ecosystems on Cape Cod should have a surface TP concentration no higher than 10 ppb, while "unimpacted" ponds should have a surface TP concentration no higher than 7.5 ppb. There is no state regulatory standard for total phosphorus.

Among the 38 ponds in Barnstable with available data, there are 81 station depths where total phosphorus concentrations were measured. These station depths have between 1 (a number of ponds) and 29 (Shallow) total phosphorus readings. Overall, 84% of the stations have average TP concentrations greater than the Cape Cod 10 ppb "healthy" criteria.

Of the 13 station depths in the 13 "ultra-shallow" ponds, average concentrations for all but Mary Dunn and Little Hathaway exceed 10 ppb (Figure III-3a). The number of available concentration readings range from 1 (Dunns, Little Hathaway) to 11 [Mill (MM)]. Since Mary Dunn and Little Hathaway are largely surrounded by undeveloped forest and both have average

TP concentrations of 8 ppb, this suggests that the threshold concentration developed from the PALS data for "unimpacted" systems (7.5 ppb) is reasonable. It also suggests that the average concentrations for the other ponds in this category, which are two or more times this threshold, are indicative of impaired ecosystems. Comparing TP concentrations with other measures (*e.g.*, chlorophyll *a*, dissolved oxygen, etc.) help to further understanding of the ecological status of these ecosystems. The highest average TP concentrations for ponds in this category are: 206 ppb at Dunns (n=1) and 114 ppb at Little Parker (n=4).

Of the 33 station depths in the 15 "shallow" ponds, 30 stations have average TP concentrations greater than 10 ppb (Figure III-3b). The three stations with concentrations less than the 10 ppb threshold are Joshua and Eagle, which are largely surrounded by undeveloped forest, and Long (Centerville), which has an extensive rooted plant community that is likely consuming most of the phosphorus in the pond. All of the ponds, except for Schoolhouse, which has exceptionally high concentrations, have higher average TP concentrations in their deeper stations. These higher concentrations are likely due to low oxygen conditions in the sediments of these ponds, even in cases where the overlying water is well-oxygenated, releasing TP back into the water column during the summer. The highest average concentrations are at stations in Schoolhouse [195 ppb at 0.5 m (n=3) and 166 ppb at 1-1.5 m (n=3)] and Elizabeth [138 ppb at 2.5-3.5 m (n=3)].

Of the 35 station depths in the ten "deep" ponds, 27 stations have average TP concentrations greater than 10 ppb (Figure III-3c). The 27 stations include at least one station in every pond, except for Middle, which has three stations with average TP concentrations less than 10 ppb. Surface concentration in three ponds (Crystal, Middle, and Neck) have averages less than 10 ppb. All of the ponds, except for Micah and Middle, have higher average TP concentrations in their deeper stations. As with the "shallow" ponds, this is due to regeneration of phosphorus from the sediments, which in some cases, like Mystic, is magnified by low oxygen in the water overlying the sediments. Deep stations at Lovells and Mystic have the highest average TP concentrations: [217 ppb at 9 m (n=5) and 406 ppb at 9.3-10 m (n=4)] and [424 ppb at 11.9-14 m (n=13)], respectively.

These high TP concentrations at the deep stations have the possibility to mix into the upper waters and impact concentrations through the water column depending on the depth of the pond and the temperature regime. In Hamblin Pond, for example, the average TP concentration at the deepest station is 79 ppb, but the next shallowest station has an average of 7 ppb. This difference occurs because the alum treatment has allowed a layer of well oxygenated cold water to return. This oxygenated layer causes any phosphorus that is regenerated from the bottom sediments to bind with iron and precipitate, returning it to the sediments and not allowing it to prompt algal growth in the warmer waters that mix with surface waters. In Mystic, all oxygen is consumed in this cold layer once it is established in May or June and surface TP concentrations suggest that regenerated bottom TP is mixing into the upper, warmer layer of the lake (Eichner, *et al*., 2006).

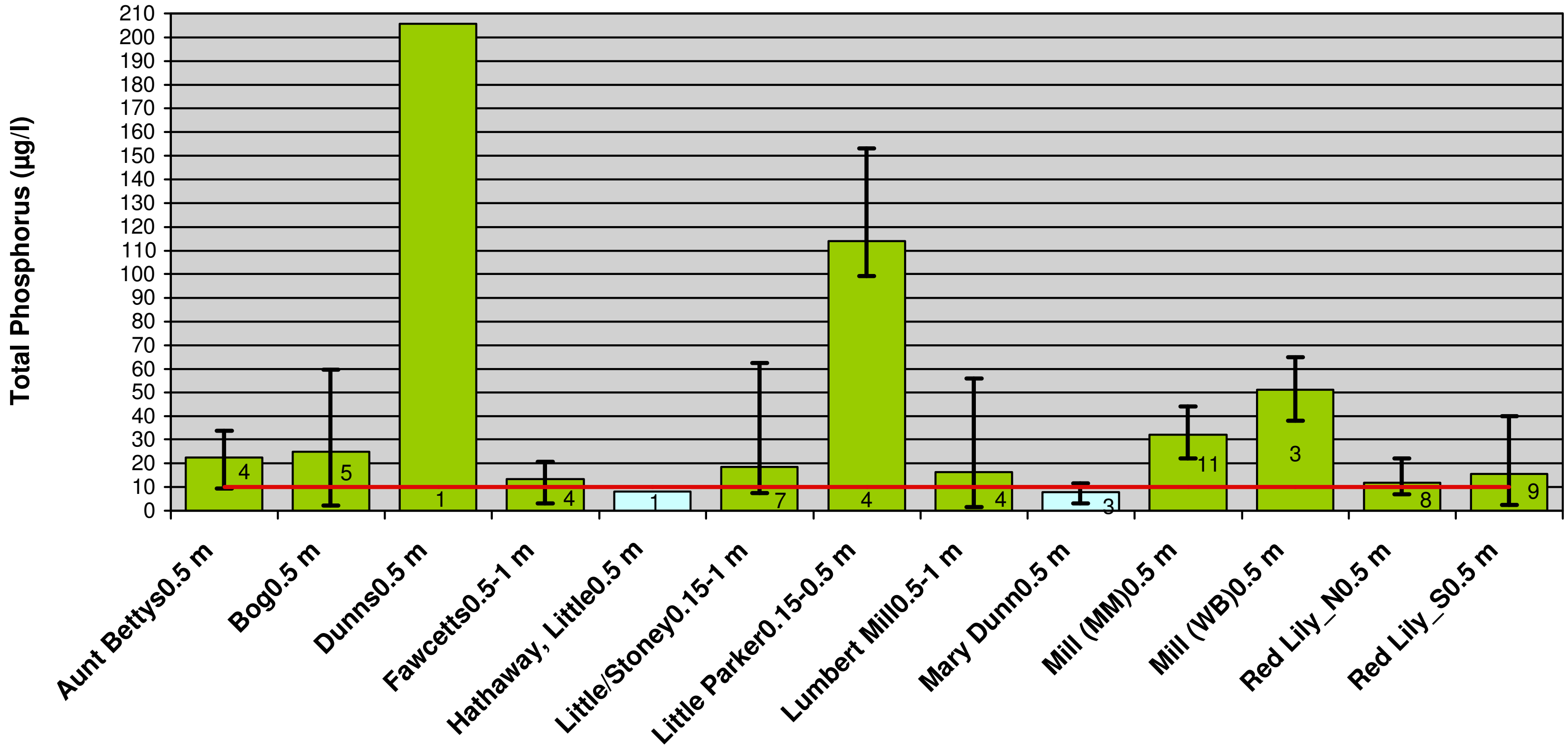


Figure III-3a. Total Phosphorus Concentrations in Barnstable Ponds: Ultrashallow Ponds
Average total phosphorus concentrations based on available pond data between June and September for ponds that have depths between 0.5 and 1.2 m. Pond names have the depths in meters at which readings were collected (*e.g.*, "Bog0.5 m" is Bog Pond readings collected at 0.5 m). Error bars show maximum and minimum recorded concentrations; all values are corrected for outliers (>±two standard deviations). The red line is the Cape Cod threshold for healthy pond ecosystems (10 micrograms per liter of TP from Eichner, *et al.*, 2003); bars for ponds with an average TP concentration less than 10 µg/l are colored light blue. Numbers shown at the base of each bar indicate the number of readings used to calculate the average concentration for each pond.

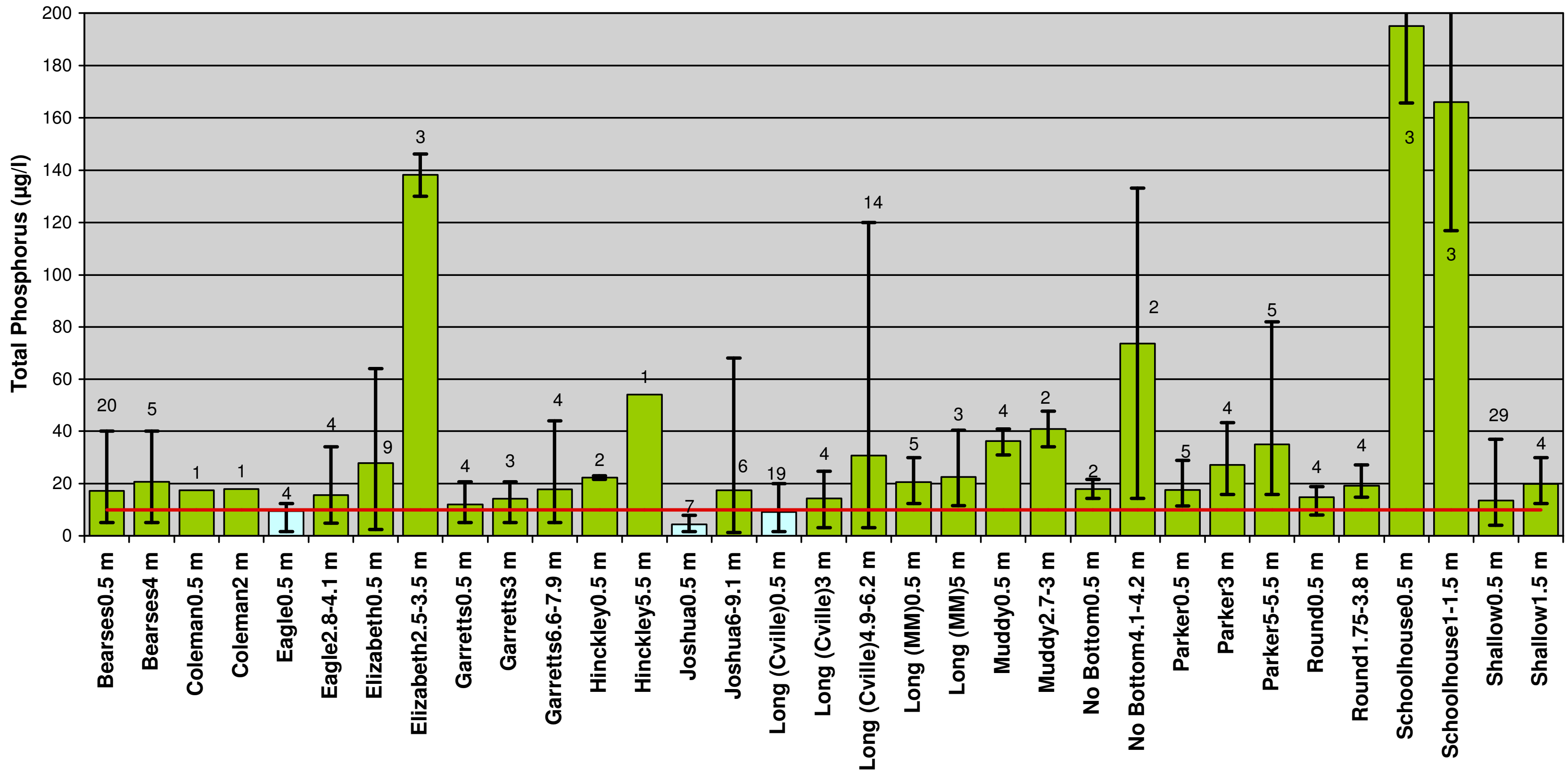


Figure III-3b. Total Phosphorus Concentrations in Barnstable Ponds: Shallow Ponds
Average total phosphorus concentrations based on available pond data between June and September for ponds that have depths between 2.1 and 8.6 m. Pond names have the depths in meters at which readings were collected (*e.g.*, "Eagle0.5 m" is Eagle Pond readings collected at 0.5 m). Error bars show maximum and minimum recorded concentrations; all values are corrected for outliers (>±two standard deviations). The red line is the Cape Cod threshold for healthy pond ecosystems (10 micrograms per liter of TP from Eichner, *et al.*, 2003); bars for ponds with an average TP concentration less than 10 µg/l are colored light blue. Numbers shown at above each bar indicate the number of readings used to calculate the average concentration for each pond. Maximum readings for Schoolhouse 0.5m and 1-1.5m are 238 and 211 µg/l TP, respectively.

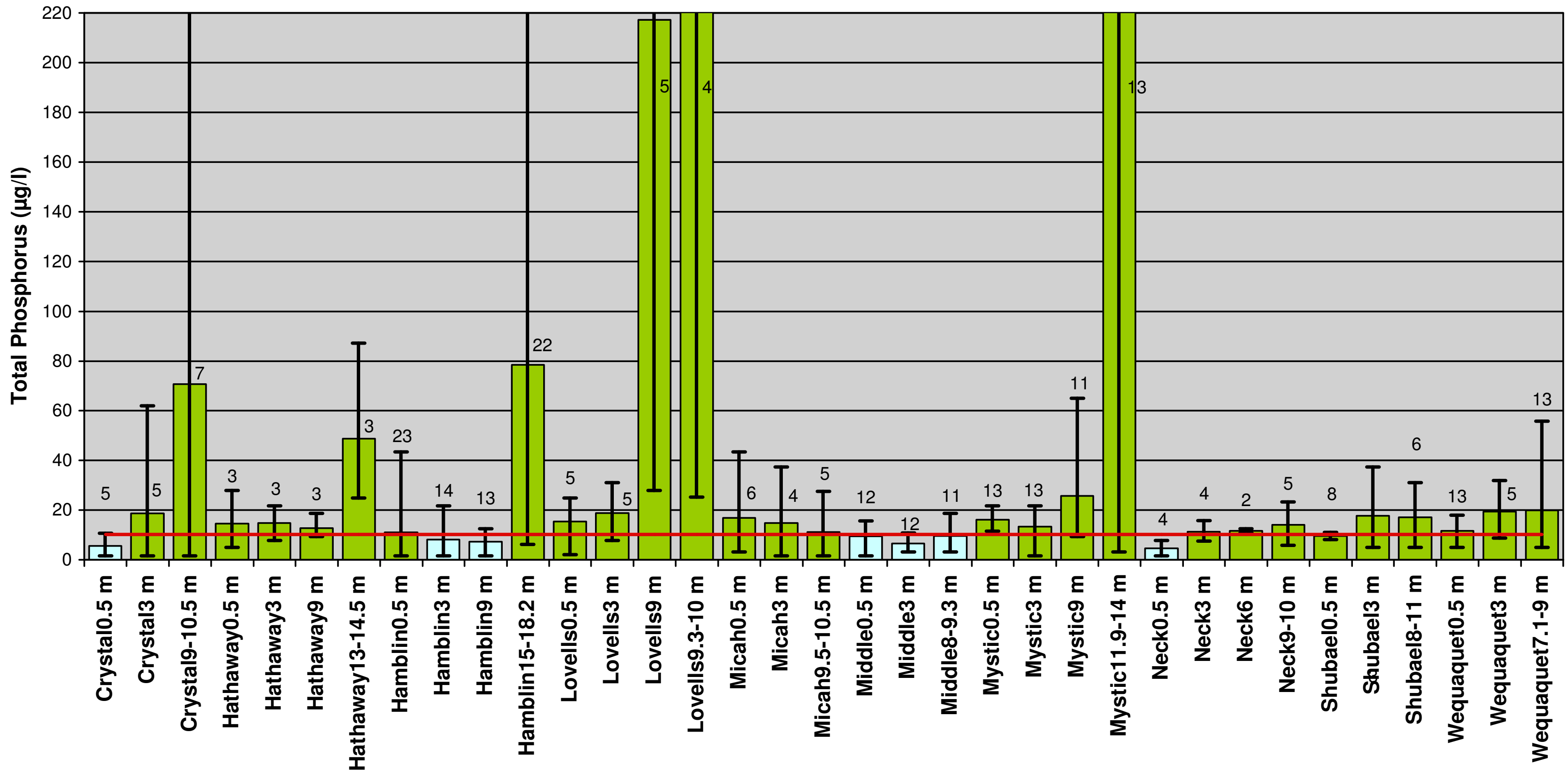


Figure III-3c. Total Phosphorus Concentrations in Barnstable Ponds: Deep Ponds
Average total phosphorus concentrations based on available pond data between June and September for ponds that have depths between 9.3 and 17.3 m. Pond names have the depths in meters at which readings were collected (*e.g.*, "Neck0.5 m" is Neck Pond readings collected at 0.5 m). Error bars show maximum and minimum recorded concentrations; all values are corrected for outliers (>±two standard deviations). The red line is the Cape Cod threshold for healthy pond ecosystems (10 micrograms per liter of TP from Eichner, *et al.*, 2003); bars for ponds with an average TP concentration less than 10 µg/l are colored light blue. Numbers shown at above each bar indicate the number of readings used to calculate the average concentration for each pond. Maximum readings for Crystal 9-10.5 m, Hamblin 15-18.2 m, Lovells 9 m and 9.3-10 m, and Mystic 11.9-14 m are 241, 431, 471, 903, and 1140 µg/l TP, respectively.

III.2.2 Total Nitrogen (TN)

Nitrogen is one of the primary nutrients for plants (phosphorus and potassium being the other two). Nitrogen switches between a number of chemical species (nitrate, nitrite, ammonium, nitrogen gas, and organic nitrogen) depending on a number of factors, including dissolved oxygen, pH, and biological uptake (Stumm and Morgan, 1981). Nitrate-nitrogen is the fully oxidized form of nitrogen, while ammonium-nitrogen is the fully reduced (*i.e.*, low oxygen) form. Inorganic nitrogen generally enters Cape Cod ponds 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 waste from organisms higher up the food chain or by bacteria decomposing dead algae in the sediments. Total Kjeldahl nitrogen (TKN) is a laboratory 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 can be the limiting nutrient. In very productive or eutrophic lakes, blue-green algae that can extract nitrogen directly from the atmosphere, which is approximately 75% nitrogen gas, often have a strong competitive advantage and tend to dominate the pond ecosystem. These algae, more technically known as cyanophytes, are generally indicative of excessive nutrient loads.

Nitrogen is a primary pollutant associated with wastewater. Septic systems, the predominant wastewater treatment technology on Cape Cod, generally introduce treated effluent to the groundwater with nitrogen concentrations between 20 and 40 ppm: Massachusetts Estuaries Project watershed nitrogen loading analyses use 26.25 ppm as an effective TN concentration for septic system wastewater (*e.g.*, Howes, *et al*., 2006b). Because so much nitrogen is introduced to the groundwater system by the septic systems, Cape Cod ponds and lakes tend to have relatively high concentrations of nitrogen; the 184 ponds sampled during the 2001 PALS Snapshot had an average surface water TN concentration of 0.58 ppm. Review of these sampling results established that unimpacted ponds have concentration limit of 0.16 ppm, while the "healthy" threshold concentration is 0.31 ppm (Eichner, *et al*., 2003).

Monitoring nitrogen is important because ponds remove or "attenuate" nitrogen from the groundwater system of the Cape. That means that the septic, fertilizer, and runoff loads from land uses can be reduced if groundwater carrying the nitrogen flows through a pond (or wetland). The groundwater nitrogen is converted to nitrogen gas through interaction with the biota and sediments in the pond and is released to the atmosphere. This action of the ponds provides a natural source of nitrogen reduction and protection for the salt-water estuaries, which are susceptible to excessive nitrogen additions. Current Massachusetts Estuaries Project watershed nitrogen loading models generally use a 50% attenuation rate for freshwater ponds unless a more detailed study supports a higher rate (*e.g*., Howes, *et al*., 2006a). The Three Bays MEP analysis used higher attenuation rates for Mystic, Middle, and Hamlin based on the detailed analysis of the Indian Ponds (Eichner, *et al*., 2006).

Among the 38 ponds in Barnstable with available data, there are 81 station depths where total nitrogen concentrations have been measured. These station depths have between 1 (a number of ponds) and 25 (Shallow) total nitrogen readings. Overall, 74% of the stations have average TN concentrations greater than the Cape Cod 0.31 ppm "healthy" criteria.

Of the 13 station depths in the 13 "ultra-shallow" ponds, average TN concentrations for all but Little Hathaway exceed the 0.31 ppm "healthy" threshold (Figure III-4a). The number of available concentration readings range from 1 (Dunns, Little Hathaway) to 9 [Red Lily (S)]. All of the ponds have average TN concentrations exceeding the 0.16 ppm "unimpacted" concentration developed from the 2001 PALS Snapshot data (Eichner, *et al*., 2003). The highest average TN concentrations for ponds in this category are: 2.38 ppm at Lumbert Mill (n=4) and 1.95 ppm at Red Lily N (n=7).

TN to TP ratios are generally an appropriate measure of which nutrient is more limiting for growth in surface water bodies; as a rule of thumb, if the ratio between nitrogen and phosphorus molar concentrations is greater than 16, phosphorus is the limiting nutrient (Redfield, *et al*., 1963). All of the ultra-shallow ponds have TN:TP ratios based on the average concentrations that exceed 16 and all but Dunns and Mill (WB) have ratios that are two or more times greater than 16. This analysis suggests that ecosystem productivity and water quality in all of the ponds in this size category is largely determined by the amount of available phosphorus. Comparing TN concentrations with other measures (*e.g*., chlorophyll *a*, dissolved oxygen, etc.) helps to further understanding of the ecological status of these ecosystems.

Of the 33 station depths in the 15 "shallow" ponds, 28 stations have average TN concentrations greater than the 0.31 ppm "healthy" threshold (Figure III-4b). The five stations with average concentrations less than the TN threshold are in two ponds: Joshua and Garretts. As mentioned in the TP discussion, Joshua is largely surrounded by undeveloped land and has limited development within its watershed (Howes, *et al*., 2006b). Garretts has some significant development around it, but much of it is on its downgradient side and much of its likely watershed is within a mostly undeveloped electrical line right of way. All of the ponds, except for Round and Schoolhouse, have higher average TN concentrations in their deeper stations. These higher concentrations are likely due to low oxygen conditions in the sediments of these ponds, even in cases where the overlying water is well-oxygenated, releasing TN back into the water column during the summer. The highest average concentrations are at stations in Parker [1.73 ppm at 5-5.5 m (n=5)] and Elizabeth [1.70 ppm at 2.5-3.5 m (n=3)]. All stations have TN:TP ratios exceeding the Redfield limit of 16, indicating likely phosphorus limitation.

Of the 35 station depths in the ten "deep" ponds, 20 stations have average TN concentrations greater than the 0.31 ppm "healthy" threshold (Figure III-4c). The 15 stations with average concentrations less than the TN threshold are in five ponds: Hathaway, Hamblin, Micah, Middle, and Mystic. In all but Middle and Micah, the deeper stations in these five ponds have average TN concentrations greater than 0.31 ppm. Hathaway and Micah have largely undeveloped watersheds, while Middle and Hamblin are somewhat protected from nitrogen loads by their relatively small watersheds and the upgradient placement of Mystic removing nitrogen prior to it reaching either pond (Eichner, *et al*., 2006). Mystic was identified in the Three Bay Massachusetts Estuaries Project analysis as having a nitrogen attenuation rate of 87%, while Middle and Hamblin have nitrogen attenuation rates of 40% and 52%, respectively (Howes, *et al*., 2006b). The differences between these attenuation rates suggest that Cape freshwater ponds with impaired ecosystem conditions might do a better job of attenuating nitrogen entering from their watersheds. Further analysis would be necessary to evaluate this suggestion. All of the ponds, except for Micah and Shubael, have higher average TN concentrations in their deeper stations. Micah has fairly consistent low concentrations at all station depths, while Shubael has exceptionally high concentrations at both the shallow and deep stations.

As with the “shallow” ponds, the higher concentrations generally measured at the deepest stations in the other ponds is due to regeneration of nitrogen from the sediments, which in some cases, like Mystic, is magnified by low oxygen in the water overlying the sediments. Deep stations at Lovells and Mystic have the highest average TN concentrations: 2.12 and 3.29 ppm at 9 m (n=4) and 9.3-10 m (n=3), respectively, in Lovells and 2.10 ppm at 11.9-14 m (n=11) in Mystic. As with phosphorus, these high concentrations at the deep stations have the possibility to mix into the upper waters and impact concentrations through the water column depending on the depth of the pond and the temperature regime. Exceptionally high TP concentrations in deeper waters can create conditions where the usual phosphorus limited conditions within freshwater ponds shift to nitrogen limited conditions (TN:TP ratio less than 16). This occurs at the deepest station in Mystic, where the TN:TP ratio based on average concentrations is 10.9.

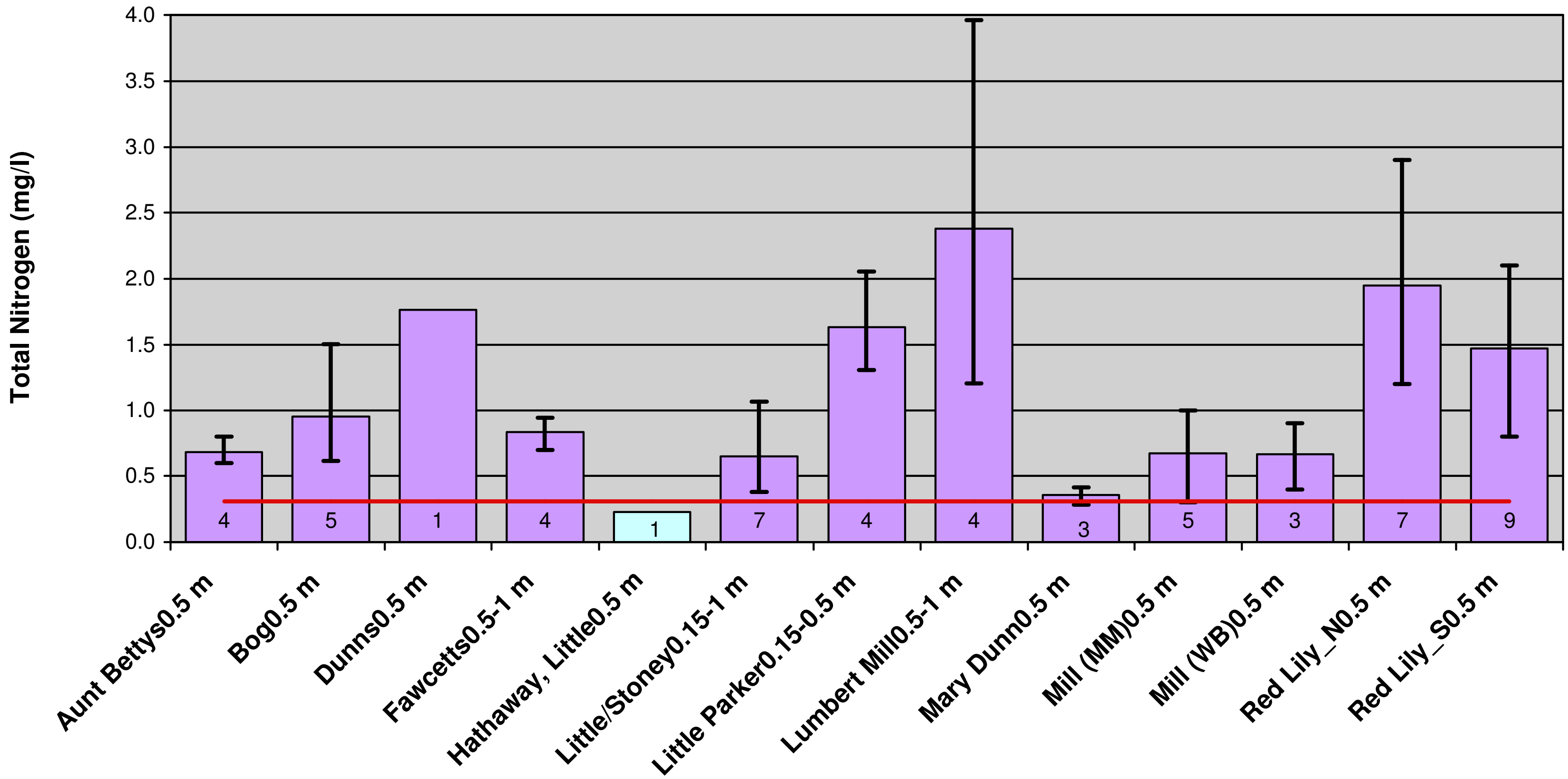


Figure III-4a. Average Total Nitrogen Concentrations in Barnstable Ponds: Ultrashallow Ponds
Average total nitrogen concentrations based on available pond data between June and September for ponds that have depths between 0.5 and 1.2 m. Pond names have the depths in meters at which readings were collected (*e.g.*, "Bog0.5 m" is Bog Pond readings collected at 0.5 m). Error bars show maximum and minimum recorded concentrations; all values are corrected for outliers (>±two standard deviations). The red line is the Cape Cod threshold for healthy pond ecosystems (0.31 milligrams per liter of TN from Eichner, *et al.*, 2003); bars for ponds with an average TN concentration less than 0.31 mg/l are colored light blue. Numbers shown at the base of each bar indicate the number of readings used to calculate the average concentration for each pond.

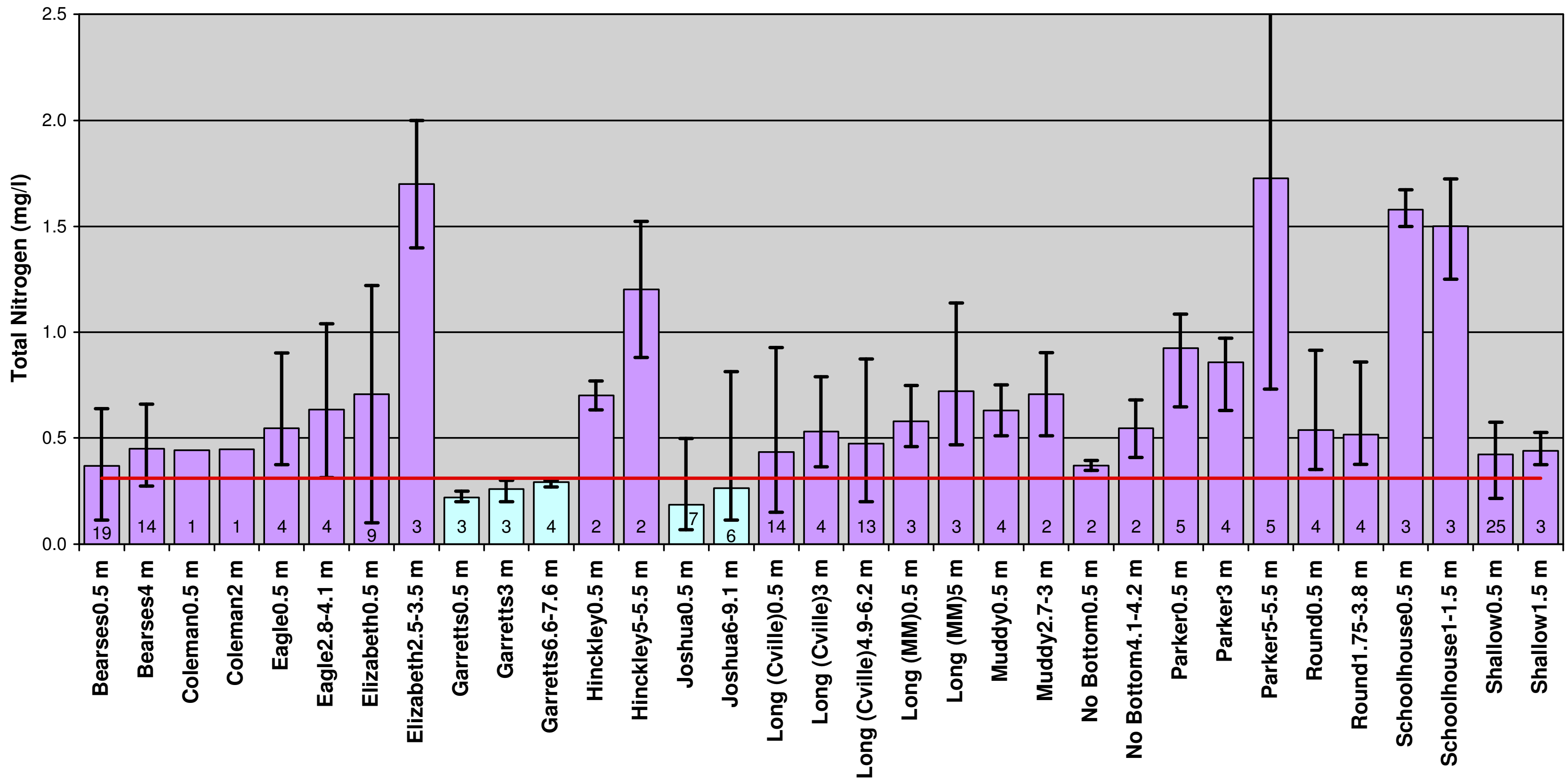


Figure III-4b. Average Total Nitrogen Concentrations in Barnstable Ponds: Shallow Ponds
Average total nitrogen concentrations based on available pond data between June and September for ponds that have depths between 2.1 and 8.6 m. Pond names have the depths in meters at which readings were collected (*e.g.*, "Eagle0.5 m" is Eagle Pond readings collected at 0.5 m). Error bars show maximum and minimum recorded concentrations; all values are corrected for outliers (>±two standard deviations). The red line is the Cape Cod threshold for healthy pond ecosystems (0.31 milligrams per liter of TN from Eichner, *et al.*, 2003); bars for ponds with an average TN concentration less than 0.31 mg/l are colored light blue. Numbers shown at above each bar indicate the number of readings used to calculate the average concentration for each pond. Maximum TN reading for Parker 5-5.5 m is 5.2 mg/l.

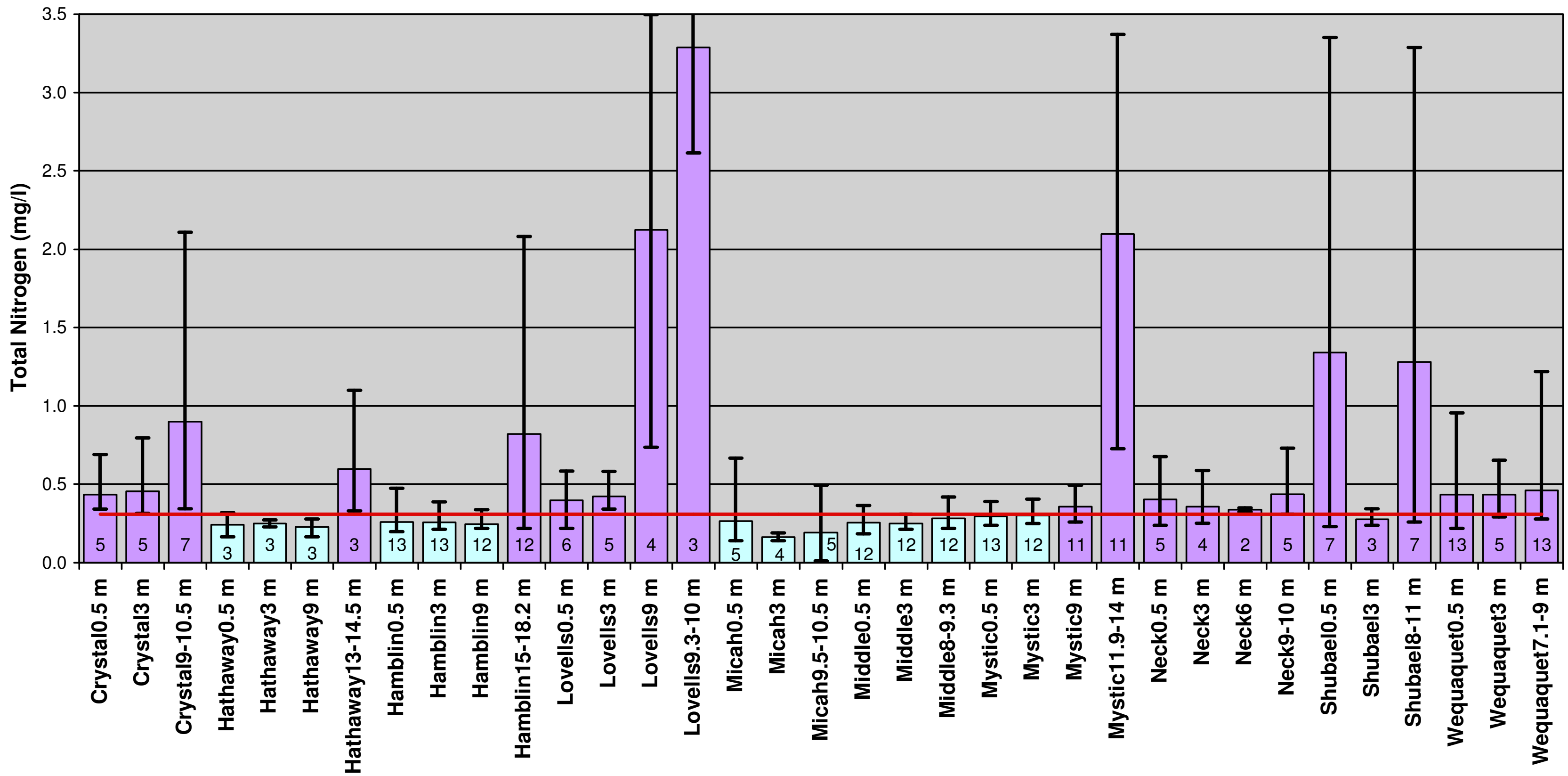


Figure III-4c. Average Total Nitrogen Concentrations in Barnstable Ponds: Deep Ponds
Average total nitrogen concentrations based on available pond data between June and September for ponds that have depths between 9.3 and 17.3 m. Pond names have the depths in meters at which readings were collected (*e.g.*, "Neck0.5 m" is Neck Pond readings collected at 0.5 m). Error bars show maximum and minimum recorded concentrations; all values are corrected for outliers (>±two standard deviations). The red line is the Cape Cod threshold for healthy pond ecosystems (0.31 milligrams per liter of TN from Eichner, *et al.*, 2003); bars for ponds with an average TN concentration less than 0.31 mg/l are colored light blue. Numbers shown at above each bar indicate the number of readings used to calculate the average concentration for each pond. Maximum TN readings for Lovells 9 m and 9.3-10 m are 3.5 and 4.4 mg/l, respectively.

III.2.3 pH

pH is a measure of acidity; pH values less than 7 are acidic, while pH values greater than 7 are basic. pH is the negative log of the hydrogen ion concentration in water (*e.g.*, water with an H^+ concentration = $10^{-6.5}$ has a pH of 6.5). The 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 lakes will tend to have higher pH measurements. Because of this relationship, pH is important to consider when reviewing pond water quality, but is somewhat of an indirect measure of ecological status and, thus, does not have a threshold concentration. Analysis is provided here to help provide another tool for understanding which ponds in Barnstable are most and least impacted by nutrients.

Since the sand deposited as the Cape Cod peninsula during the last glacial period does not have carbonate minerals, Cape soils generally have low alkalinity and little capacity to buffer the naturally acidic rainwater that falls on the Cape. Available groundwater data generally shows pH on Cape Cod 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. Cape Cod ponds tend to have pH readings close to the groundwater average, while the least impacted ponds have pH close to average rain pH of 5.65 (water in equilibrium with carbon dioxide in the atmosphere). 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 (Eichner, *et al*., 2003). The pH threshold established for the least impacted ponds from the 2001 PALS Snapshot data is 5.62.

Among the 38 ponds in Barnstable with available data, there are 81 station depths where pH readings have been measured. These station depths have between 1 (a number of ponds) and 30 (Shallow) pH readings. Overall, 86% of the stations have average pH readings greater than 5.65.

Of the 13 station depths in the 13 "ultra-shallow" ponds, eleven have average pH readings greater than 5.65 (Figure III-5a). The number of available concentration readings range from 1 (Dunns, Little Hathaway) to 9 [Red Lily (S)]. The weighted average of readings in this category is 6.53. The highest average pH reading for ponds in this category is 7.7 at Aunt Bettys (n=4), while the lowest is 4.4 at Little Hathaway (n=1).

Of the 33 station depths in the 15 "shallow" ponds, 28 stations have average pH readings greater than 5.65 (Figure III-5b). The five stations with average readings less than 5.65 are in three ponds: Joshua, Muddy, and Shallow. As mentioned in the TP and TN discussion, Joshua is largely surrounded by undeveloped land and has limited development within its watershed (Howes, *et al*., 2006), so it has limited watershed nutrient inputs and, as such, likely has a small algal population to impact pH. Lower pH readings in Shallow are somewhat surprising given its average TP concentrations; further evaluation of the watershed and biota in the pond might help explain this relationship better. Muddy's low reading is a single reading at the deepest station; the shallower station has an average reading of 6.2 and this suggests that the deep reading is an anomaly. The weighted average of pH readings of all stations in the shallow pond category is 6.23 with surface stations averaging 6.15. The highest average pH reading for ponds in this category is 7.9 at Parkers 0.5 m (n=5), while the lowest is 3.1 at Muddy 2.7-3 m (n=1).

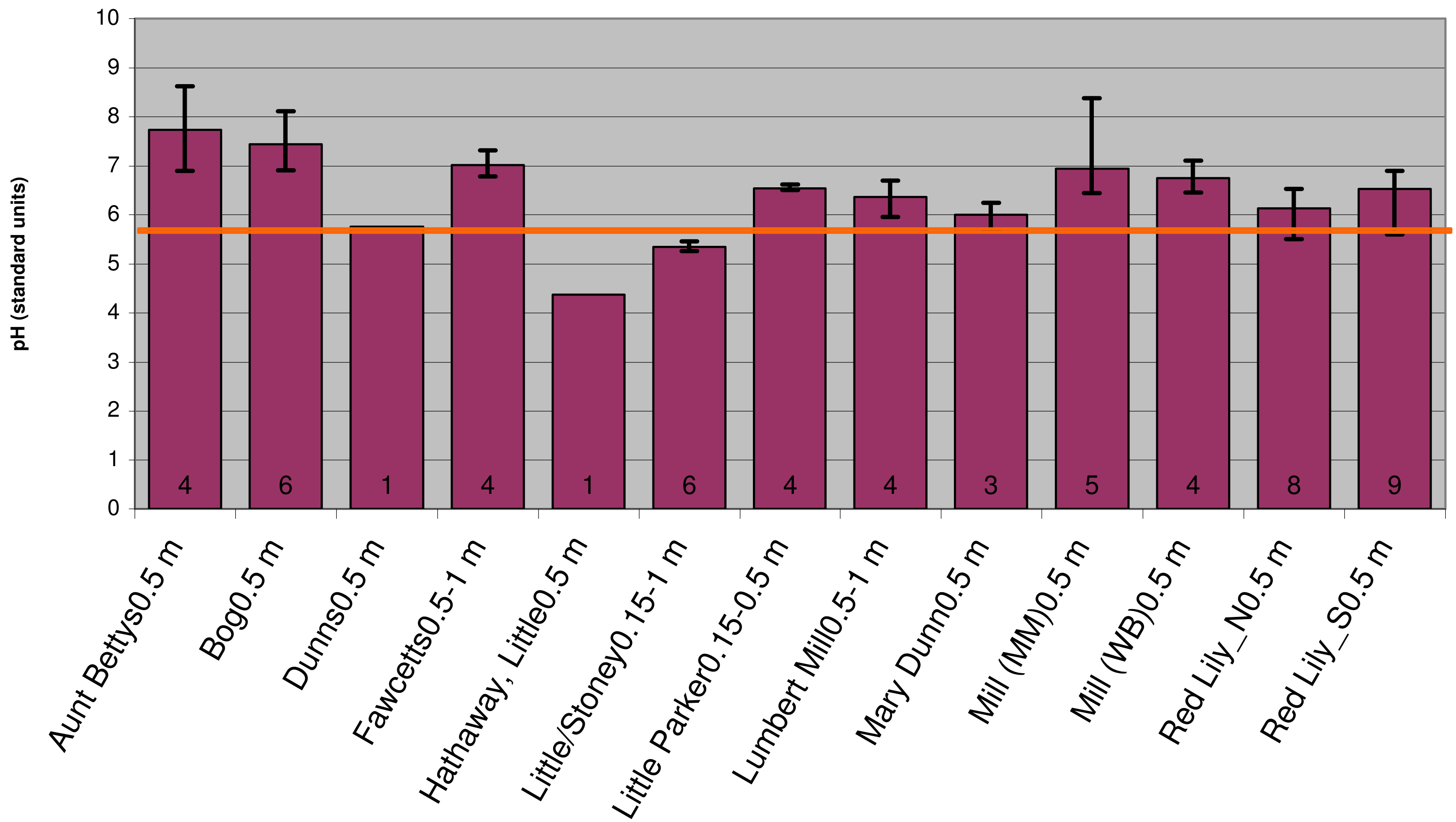


Figure III-5a. Average pH readings in Barnstable Ponds: Ultrashallow Ponds
Average pH readings based on available pond data between June and September for ponds that have depths between 0.5 and 1.2 m. Pond names have the depths in meters at which readings were collected (e.g., "Bog0.5 m" is Bog Pond readings collected at 0.5 m). Error bars show maximum and minimum recorded readings; all values are corrected for outliers (>±two standard deviations). The orange line is 5.65, which is the pH of natural rainwater in equilibrium with carbon dioxide in the atmosphere. Numbers shown at the base of each bar indicate the number of readings used to calculate the average pH for each pond.

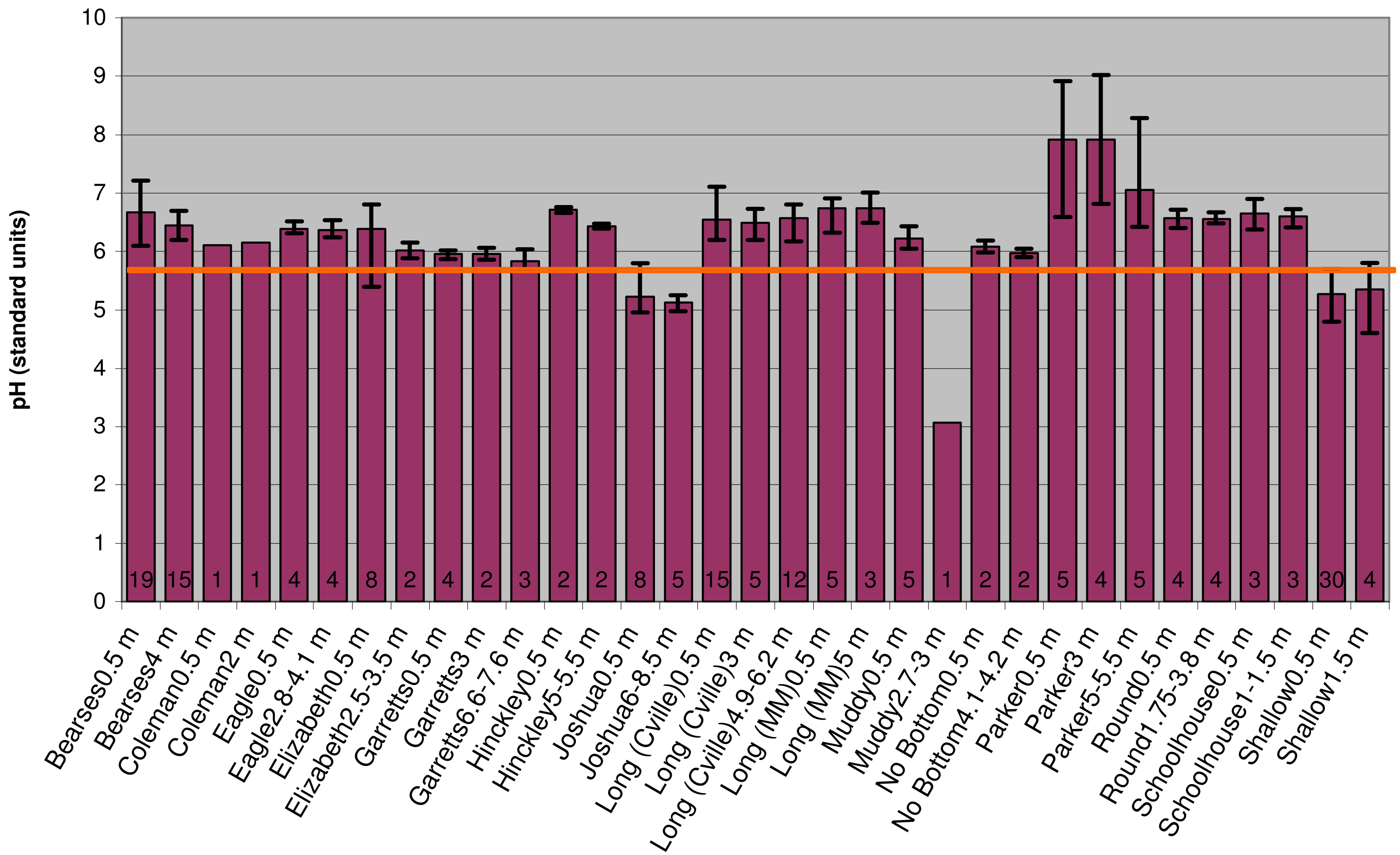


Figure III-5b. Average pH readings in Barnstable Ponds: Shallow Ponds
Average pH readings based on available pond data between June and September for ponds that have depths between 2.1 and 8.6 m. Pond names have the depths in meters at which readings were collected (e.g., "Eagle0.5 m" is Eagle Pond readings collected at 0.5 m). Error bars show maximum and minimum recorded concentrations; all values are corrected for outliers (>±two standard deviations). The orange line is 5.65, which is the pH of natural rainwater in equilibrium with carbon dioxide in the atmosphere. Numbers shown at the base of each bar indicate the number of readings used to calculate the average pH for each pond.

Of the 35 station depths in the ten "deep" ponds, 31 stations have average pH readings than 5.65 (Figure III-5c). The four stations with average concentrations less than 5.65 are in two ponds: Hathaway and Micah. As might be expected, both of these ponds are largely surrounded by undeveloped land and both have average surface TP concentrations in the 15 to 17 ppb range (see Figure III-3c). The weighted average of pH readings of all stations in this category is 6.52 with surface stations averaging 6.63. The highest average pH reading for ponds in this category is 6.96 at Shubael 0.5 m (n=9), while the lowest is 5.46 at Micah 3 m (n=4).

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

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

Because phosphorus, the limiting nutrient in most Cape Cod ponds, is needed for the growth of both algae and macrophytes, the available phosphorus pool can be divided unequally between these two groups of plants. Because of this relationship, the relationship between chlorophyll *a* and phosphorus measurements in water samples can sometimes be slightly askew, especially in ponds where the dominant plant community is macrophytes. Anecdotal evidence from Cape Cod ponds with undeveloped land around them suggests that "natural" Cape ponds are algal dominated and, therefore, should have a strong relationship between chlorophyll *a* and total phosphorus concentrations. Ponds, such as Long in Centerville, where extensive macrophyte growth exists (IEP and KVA, 1989), appear to be the product of excessive nutrient loads and largely unrepresentative of the ecology in most Cape Cod ponds.

During the 2001 PALS Snapshot sampling, 191 ponds had surface CHL-a samples. The average of concentration of these samples is 8.44 µg/l (or ppb) with a range from 0.01 to 102.9 µg/l. Review of the PALS 2001 sampling results established that unimpacted Cape Cod ponds have a CHL-a threshold concentration of 1.0 µg/l, while the "healthy" threshold concentration is 1.7 µg/l (Eichner, *et al*., 2003).

Among the 38 ponds in Barnstable with available data, there are 81 station depths where CHL-a concentrations have been measured. These station depths have between 1 (a number of ponds) and 21 (Hamblin) CHL-a readings. Overall, 88% of the stations have average CHL-a concentrations greater than the Cape Cod 1.7 ppb "healthy" criteria.

Of the 13 station depths in the 13 "ultra-shallow" ponds, average CHL-a concentrations for all but Little Hathaway exceed the 1.7 ppb "healthy" threshold (Figure III-6a). The number of available concentration readings range from 1 (Dunns, Little Hathaway) to 8 [Red Lily (N)]. Little Hathaway's single reading also is the only CHL-a concentration lower than the 1.0 ppb "unimpacted" threshold. The highest average CHL-a concentrations for ponds in this category are: 340.2 ppb at Little Parker (n=4) and 22.5 ppb at Mill (WB) (n=3).

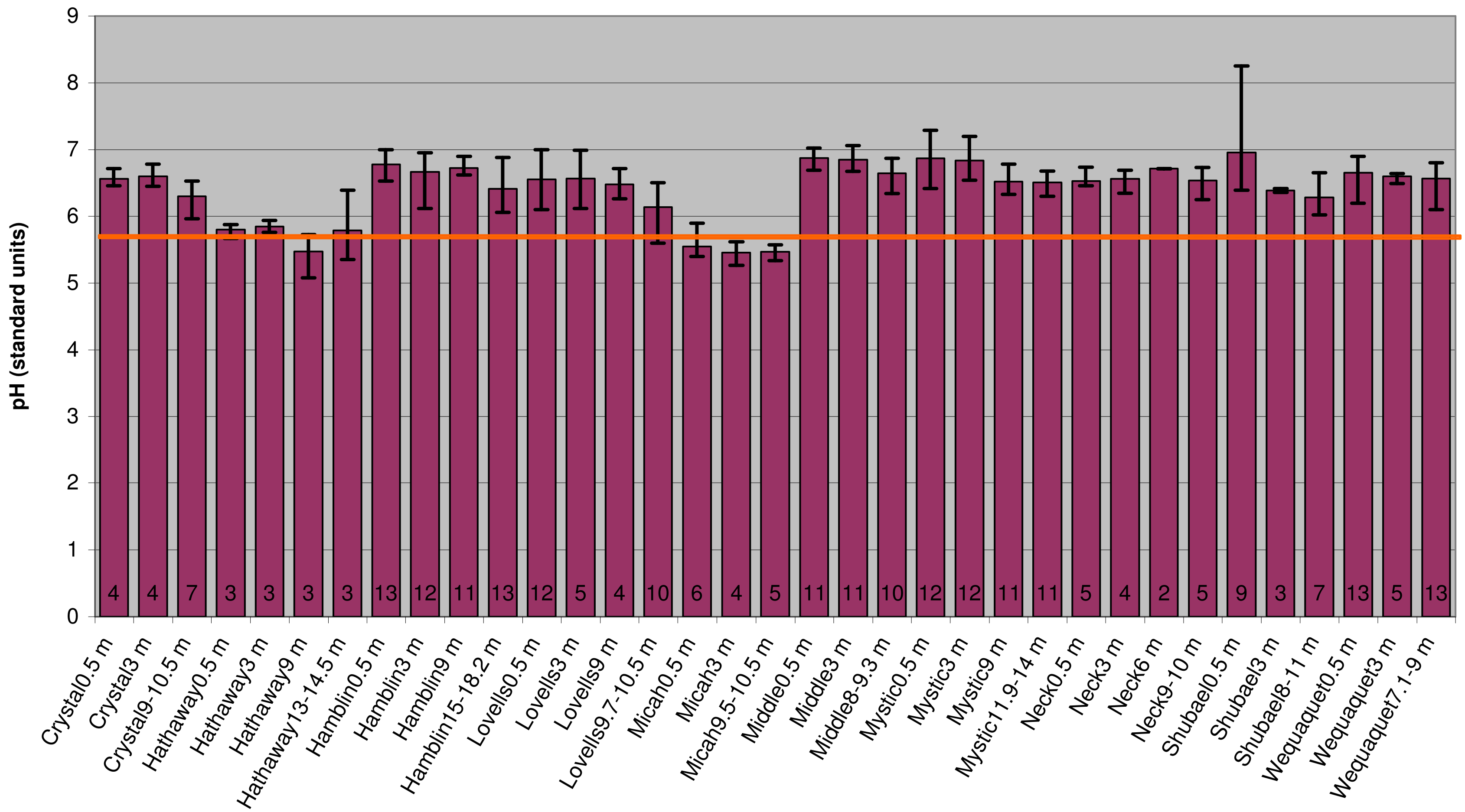


Figure III-5c. Average pH readings in Barnstable Ponds: Deep Ponds
Average pH readings based on available pond data between June and September for ponds that have depths between 9.3 and 17.3 m. Pond names have the depths in meters at which readings were collected (e.g., "Neck0.5 m" is Neck Pond readings collected at 0.5 m). Error bars show maximum and minimum recorded concentrations; all values are corrected for outliers (>±two standard deviations). The orange line is 5.65, which is the pH of natural rainwater in equilibrium with carbon dioxide in the atmosphere. Numbers shown at the base of each bar indicate the number of readings used to calculate the average pH for each pond.

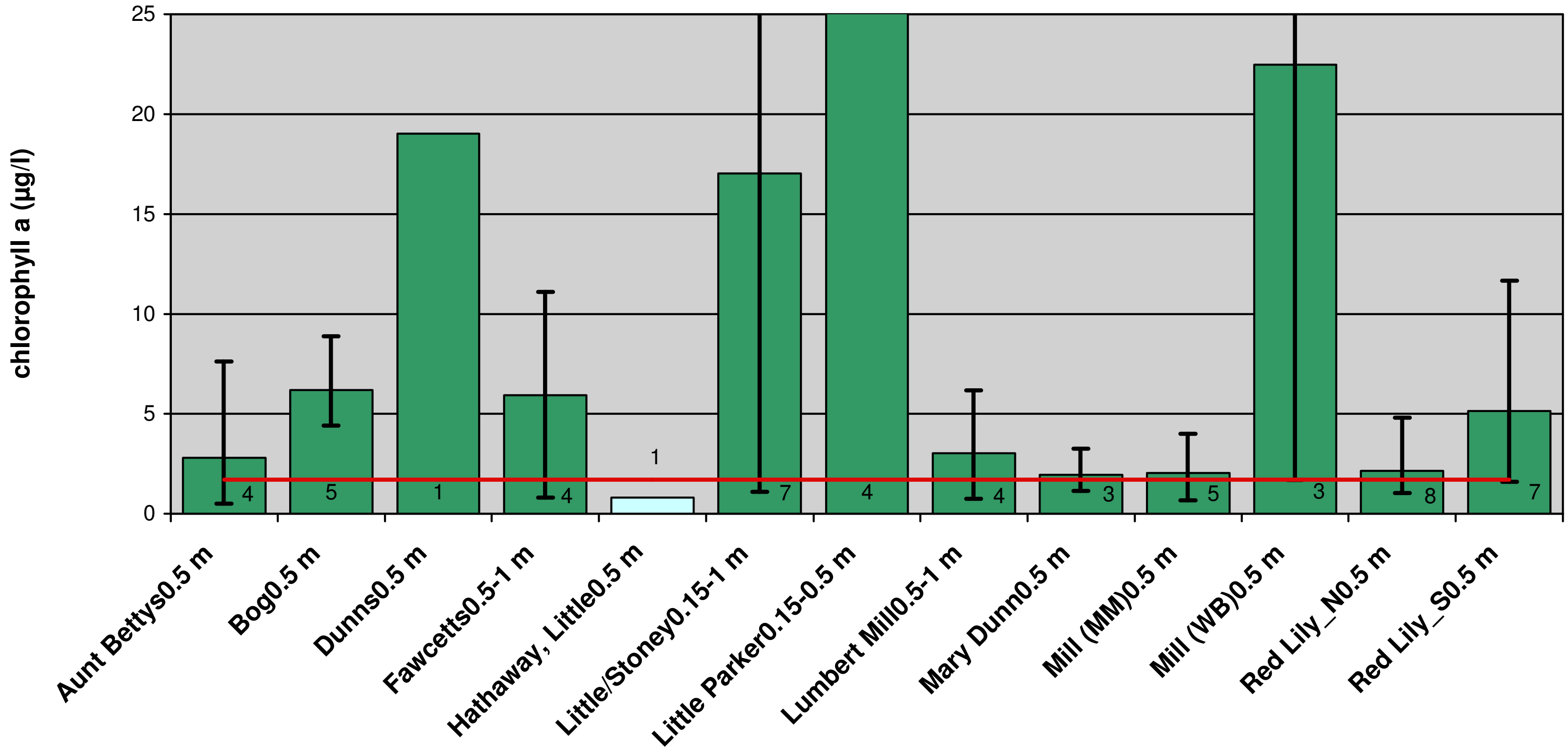


Figure III-6a. Average Chlorophyll *a* Concentrations in Barnstable Ponds: Ultrashallow Ponds
Average chlorophyll *a* concentrations based on available pond data between June and September for ponds that have depths between 0.5 and 1.2 m. Pond names have the depths in meters at which readings were collected (*e.g.*, "Bog0.5 m" is Bog Pond readings collected at 0.5 m). Error bars show maximum and minimum recorded concentrations; all values are corrected for outliers (>±two standard deviations). The red line is the Cape Cod threshold for healthy pond ecosystems (1.7 micrograms per liter of chlorophyll *a* from Eichner, *et al.*, 2003); bars for ponds with an average CHL-a concentration less than 1.7 µg/l are colored light blue. Numbers shown near the base of each bar indicate the number of readings used to calculate the average concentration for each pond. The average concentration for Little Parker is 340.2 µg/l, while the maximum concentrations for Little/Stoney, Little Parker, and Mill (WB) are 101.3, 886.6, and 55 µg/l, respectively.

Of the 33 station depths in the 15 "shallow" ponds, all but the shallow station (0.5 m) at Joshua exceed the 1.7 ppb CHL-a "healthy" threshold (Figure III-6b). None of the stations have average concentrations less than the 1.0 ppb "unimpacted threshold. As mentioned in the TP and TN discussion, Joshua is largely surrounded by undeveloped land and has limited development within its watershed (Howes, *et al*., 2006b). As algae die and fall to the bottom sediments, chlorophyll *a* begins to breakdown thereby reducing the CHL-a concentrations, but depending on deeper circulation and settling patterns, the overall magnitude of surface concentrations, and sediment regeneration, deep concentration of CHL-a can sometimes be either higher or lower than surface concentrations. As might be expected, CHL-a concentration data from deeper stations among the "shallow" ponds are not consistently higher or lower than surface concentrations. Understanding these relationships would require more refined sampling of each of the individual ponds. The highest average concentrations in this group of ponds are at the two stations in Schoolhouse: 134.1 ppb at 0.5 m (n=3) and 128.3 ppb at 1-1.5 m (n=3).

Of the 35 station depths in the ten "deep" ponds, 27 stations have CHL-a concentrations greater than the 1.7 ppb CHL-a "healthy" threshold (Figure III-6c). The eight stations with average concentrations less than the 1.7 ppb threshold are in four ponds: Hathaway, Hamblin, Micah, and Neck. These are among the same ponds that are listed as being below the thresholds for other constituents. The deepest station average concentrations in all of these ponds except Wequaquet are greater than the surface concentrations. The highest average concentrations in this group of ponds are at the deep stations in Crystal and Lovells: 19.5 ppb at 9-10.5 m (n=7) and 10.5 ppb at 9.3-10.5 m (n=5), respectively.

Since the shallow CHL-a concentrations are more representative of ecological conditions in these ponds than deeper readings, average concentrations among the different depth groups were compared, as were concentrations for those ponds surrounded by undeveloped land. Average CHL-a concentrations among the four groups, after accounting for outliers, are very similar: 7.4 ppb, 8.1 ppb, and 10.0 ppb for the ultrashallow, shallow, and deep ponds, respectively. This suggests that, on average, these pond ecosystems respond similarly to nutrient inputs. It also suggests that those ponds at the lowest and highest average concentrations reflect what Cape Cod pond water quality can be if we reduce nutrient inputs and what future conditions might be if we do not adopt protective strategies, respectively,

Project staff took a step toward further clarification of this issue by comparing those ponds that are surrounded by largely protected/undeveloped land and the rest of the ponds. This type of analysis reveals the impact of development around ponds. Joshua, Micah, Hathaway, Little Hathaway, Middle, and Eagle are largely surrounded by undeveloped land. Among this group, Eagle has an average CHL-a concentration that is exceptionally high and is considered an outlier. Once this is removed, the average CHL-a concentration for this group is 1.3 ppb, which is slightly lower than the 1.7 ppb threshold determined from the 2001 PALS Snapshot data. The rest of the ponds have an average surface CHL-a concentration of 11.2 ppb. This result suggests that most of Barnstable ponds have excessive CHL-a concentrations.

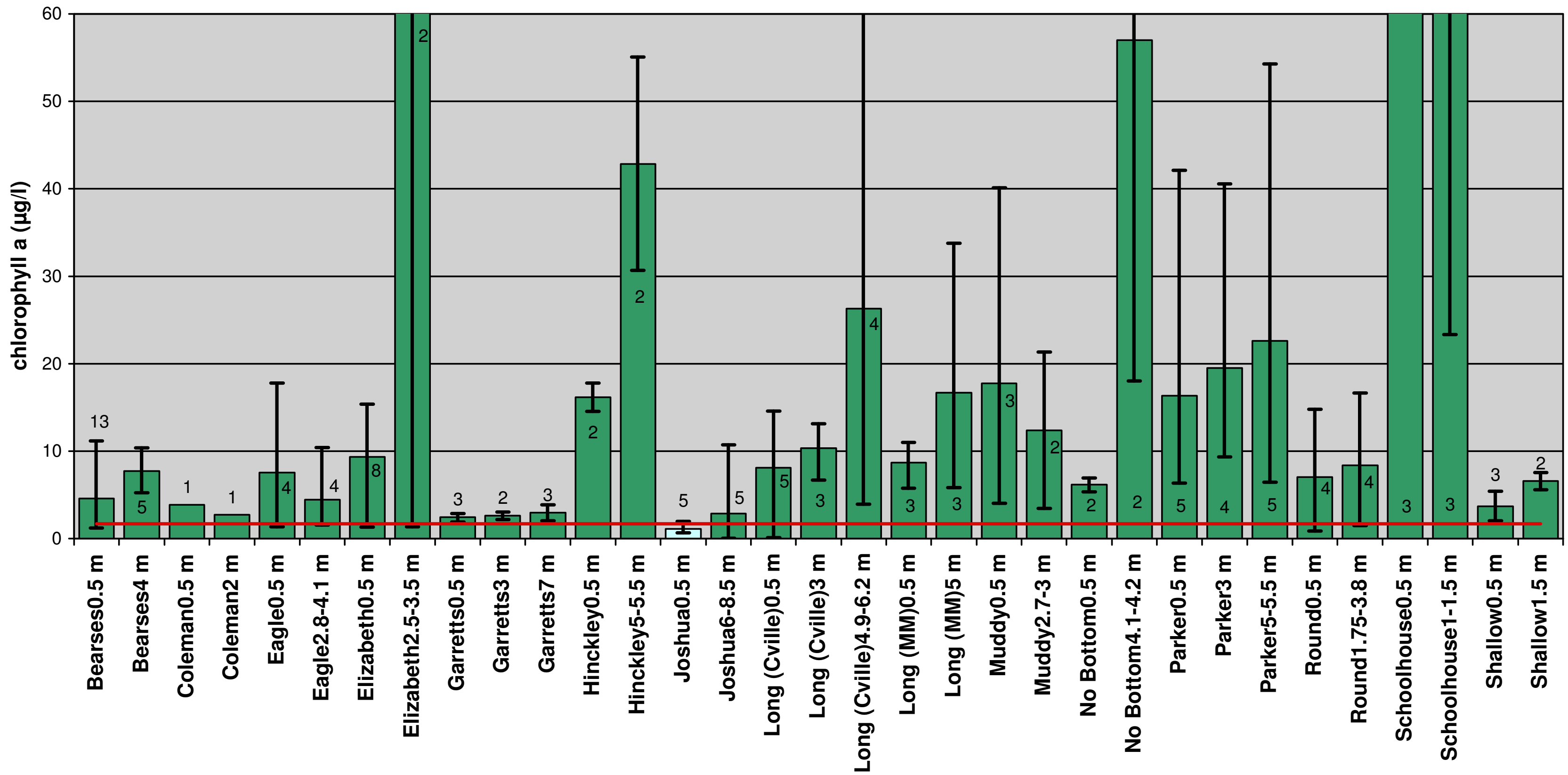


Figure III-6b. Average Chlorophyll-*a* Concentrations in Barnstable Ponds: Shallow Ponds
Average chlorophyll *a* concentrations based on available pond data between June and September for ponds that have depths between 2.1 and 8.6 m. Pond names have the depths in meters at which readings were collected (*e.g.*, "Eagle0.5 m" is Eagle Pond readings collected at 0.5 m). Error bars show maximum and minimum recorded concentrations; all values are corrected for outliers (>±two standard deviations). The red line is the Cape Cod threshold for healthy pond ecosystems [1.7 micrograms per liter of chlorophyll *a* from Eichner, *et al.*, 2003(; bars for ponds with an average CHL-a concentration less than 1.7 µg/l are colored light blue. Numbers shown near the base of each bar indicate the number of readings used to calculate the average concentration for each pond. The average concentration for deep Elizabeth and two Schoolhouse stations are 108.1, 134.1, and 128.3 µg/l, respectively, while the maximum concentrations for the deep stations in Elizabeth, Long (Centerville), and No Bottom and the two Schoolhouse stations are 214.8, 77.2, 96.0, 210.3 and 205.4 µg/l, respectively.

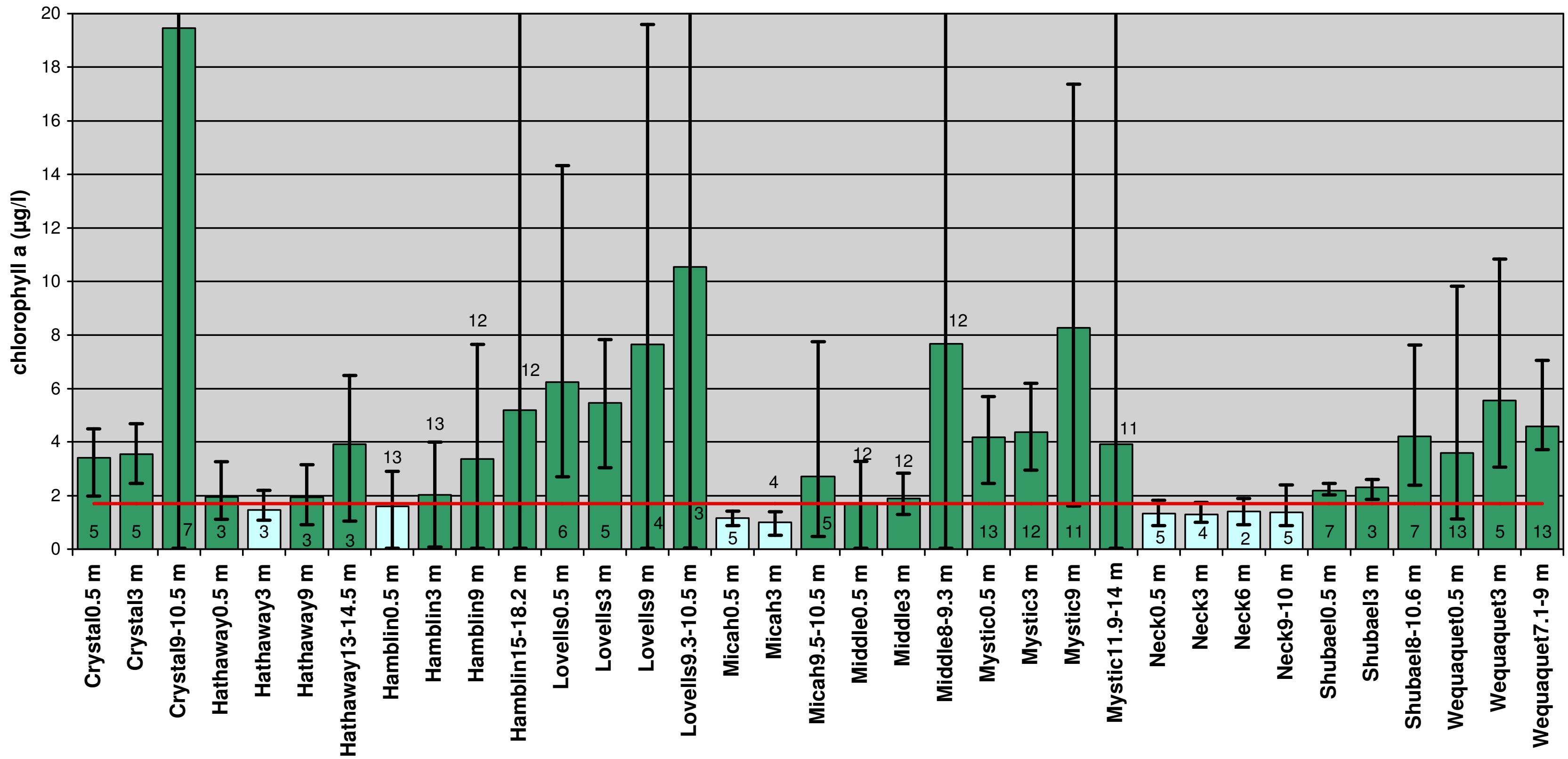


Figure III-6c. Average Chlorophyll-*a* Concentrations in Barnstable Ponds: Deep Ponds
Average chlorophyll *a* concentrations based on available pond data between June and September for ponds that have depths between 9.3 and 17.3 m. Pond names have the depths in meters at which readings were collected (*e.g.*, "Neck0.5 m" is Neck Pond readings collected at 0.5 m). Error bars show maximum and minimum recorded concentrations; all values are corrected for outliers (>±two standard deviations). The red line is the Cape Cod threshold for healthy pond ecosystems (1.7 micrograms per liter of chlorophyll *a* from Eichner, *et al.*, 2003); bars for ponds with an average CHL-a concentration less than 1.7 µg/l are colored light blue. Numbers shown near the base of each bar indicate the number of readings used to calculate the average concentration for each pond. The maximum concentrations for the deep stations in Crystal, Hamblin, Lovells, Middle, and Mystic are 65.4, 24.9, 34.3, 20.8 and 21.2 µg/l, respectively.

IV. Trophic Status Classification

Trophic status of a surface water body is generally based on the amount of biomass (or more generally "life") that is contained in the lake or pond. Developing a trophic index usually incorporates an understanding of the regional geologic or climate setting, including what constitutes a "healthy" pond, and some proxy measure or measures of the biomass. One of the better known pond trophic classification strategies is the one developed by Carlson (1977). Carlson's strategy looks at algal biomass and relates it to separate measures of total phosphorus, chlorophyll *a*, and Secchi disk depth. Carlson designed the system to utilize one or another of the measures to classify the trophic state index (TSI) of a pond or lake on a scale of 0 to 100 (Carlson and Simpson, 1996). The equations for producing the various TSI values and the likely ecosystem characteristics are presented in Table IV-1.

Subsequent evaluation of Carlson's Index has found that one measure or another is better

Table IV-1. – Carlson Trophic State Index (TSI)

TSI Calculations

TSI(SD) = 60 - 14.41 ln(SD)	SD = Secchi disk depth (meters)
TSI(CHL) = 9.81 ln(CHL) + 30.6	CHL = Chlorophyll a concentration (µg/L)
TSI(TP) = 14.42 ln(TP) + 4.15	TP = Total phosphorus concentration (µg/L)

TSI values and likely pond attributes

TSI Values	Chl a (µg/L)	SD (m)	TP (µg/L)	Attributes	Fisheries & Recreation
<30	<0.95	>8	<6	Oligotrophy: Clear water, oxygen throughout the year in the hypolimnion	Salmonid fisheries dominate
30-40	0.95-2.6	8-4	6-12	Hypolimnia of shallower lakes may become anoxic	Salmonid fisheries in deep lakes only
40-50	2.6-7.3	4-2	12-24	Mesotrophy: Water moderately clear; increasing probability of hypolimnetic anoxia during summer	Hypolimnetic anoxia results in loss of salmonids.
50-60	7.3-20	2-1	24-48	Eutrophy: Anoxic hypolimnia, macrophyte problems possible	Warm-water fisheries only. Bass may dominate.
60-70	20-56	0.5-1	48-96	Blue-green algae dominate, algal scums and macrophyte problems	Nuisance macrophytes, algal scums, and low transparency may discourage swimming and boating.
70-80	56-155	0.25-0.5	96-192	Hypereutrophy: (light limited productivity). Dense algae and macrophytes	
>80	>155	<0.25	192-384	Algal scums, few macrophytes	Rough fish dominate; summer fish kills possible

after Carlson and Simpson (1996);
Carlson TSI developed in algal dominated, northern temperate lakes

for use at various times of year (*e.g.*, total phosphorus may be better than chlorophyll *a* at predicting summer trophic state), but the best overall predictor of algal biomass is chlorophyll *a* concentrations (Carlson, 1983). Subsequent uses of the Carlson Index by other investigators have included combining and averaging the various TSI values based on all the measures (*i.e.*, chlorophyll *a*, TP, Secchi depth). Carlson (1983) regards this as a misuse of the indices and states "There is no logic in combining a good predictor with two that are not."

Trophic indices are appropriate for first order comparison among ponds; further detailed pond by pond analysis of other measures (*e.g.*, total phosphorus, dissolved oxygen, macrophyte cover, etc.) should be evaluated to assess the "health" of an individual lake. It should also be further noted that higher Carlson values do not necessarily mean that the water quality in a pond is "poor"; although water quality and biomass levels are linked, higher biomass levels are valuable for warm water fisheries (*e.g.*, bass). Similarly, it should also be noted that Carlson index is based largely on lakes and ponds in Minnesota and Wisconsin that have higher pH and alkalinity; a similar index has not been developed for soft water lakes like those on Cape Cod.

Figure IV-1 shows the trophic categories based on the average surface chlorophyll *a* concentrations in the Barnstable ponds, as well as error bars showing one standard deviation. The width of the error bars show the variability in the data and how much conditions fluctuate within individual ponds. For example, Bearses Pond on average is classified under this index as a mesotrophic pond, but chlorophyll concentrations fluctuate enough to place it on occasion in the oligotrophic or eutrophic categories. This finding reinforces the need for adequate sampling of ponds prior to assessment or remediation.

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, *et al*., 2003). This lower TSI level fits into the lowest nutrient oligotrophic category of Carlson's index (see Table 4 for generalized conditions). Based on the average TSIs, twelve of the 38 Barnstable ponds with chlorophyll *a* data are classified as oligotrophic, 13 are classified as mesotrophic, 11 are classified as eutrophic, and two are classified as hypereutrophic. Among the size groups, ultrashallow ponds have an average TSI of 49 (mesotrophic), shallow ponds have an average TSI of 51 (eutrophic), and deep ponds have an average TSI of 39 (oligotrophic).

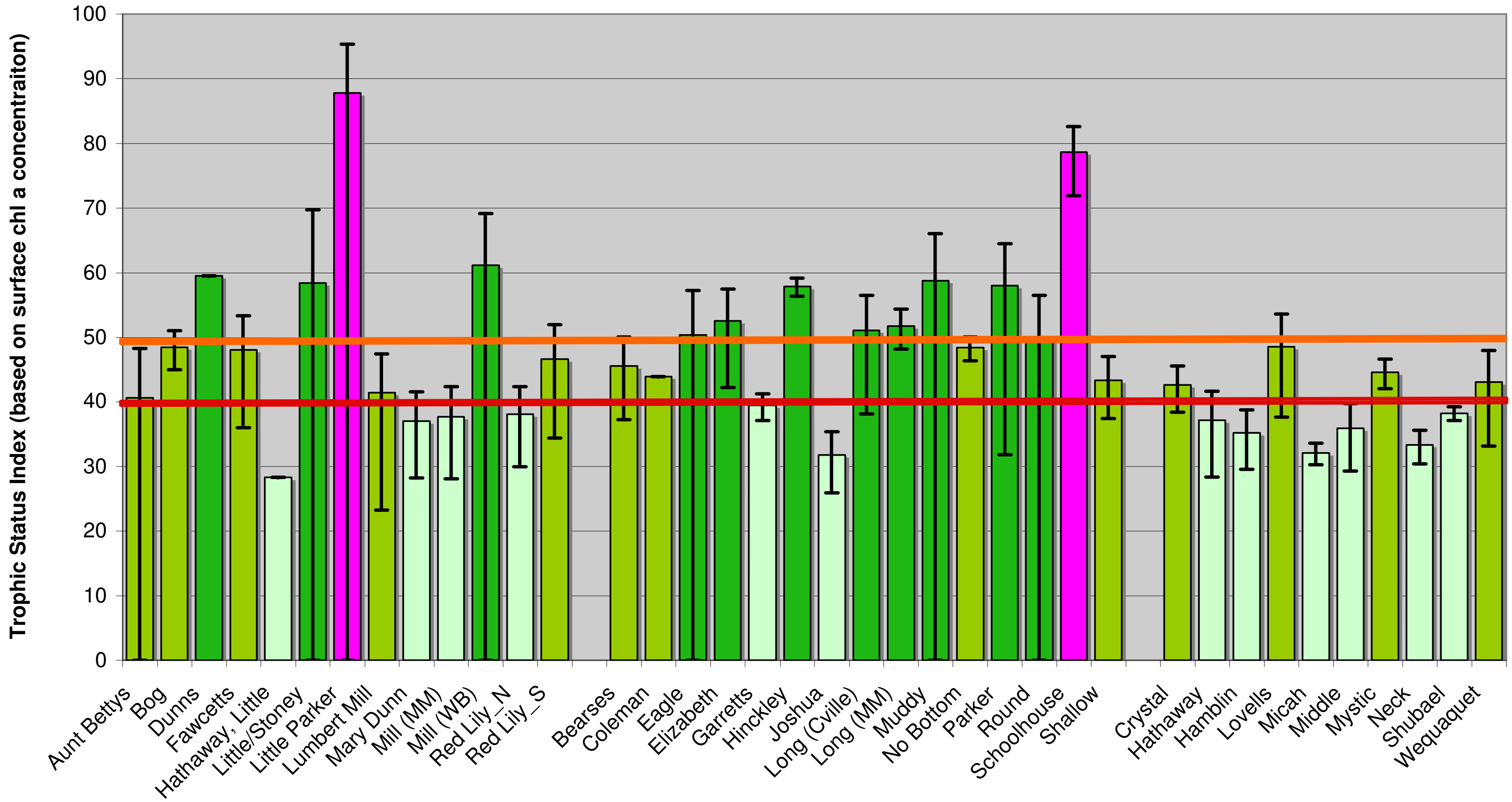


Figure IV-1. Trophic Status Index (TSI) in Barnstable Ponds
TSI values are based on average surface chlorophyll *a* concentrations from data collected between June and September. Concentrations were corrected for outliers (>±2 std dev); error bars show one standard deviation. TSI based on Carlson and Simpson (1996) for chlorophyll *a*. Orange line is boundary between oligotrophic and mesotrophic classifications; red line is boundary between mesotrophic and eutrophic classifications. Oligotrophic ponds are shown by light green bars, mesotrophic by lime green bars, eutrophic by dark green bars, and hypereutrophic by pink bars. Trophic classifications are described in Table IV-1.

V. Summary and Conclusions

The above review of the available data shows that almost all of Barnstable's ponds have water quality concerns. In order to discuss potential prioritization of these concerns, it is useful to look at the key datasets: total phosphorus, chlorophyll a, and dissolved oxygen. It is also useful to understand that these datasets reflect a progression of impacts: total phosphorus and chlorophyll *a* concentrations rise and over a period of time the resulting plant growth causes the sediment bacteria digesting all the dead plants to consume more oxygen than is available in the water column. As a result, a pond with low oxygen conditions has more severe water quality problems than one with high total phosphorus concentrations.

Since most Cape Cod ponds are algal dominated and plants are the primary base of an ecosystem, the amount of algae, as measured by chlorophyll *a*, provides a sense of how productive an ecosystem is. Phosphorus is the key nutrient for determining algal growth. Data from the Cape Cod Pond and Lake Atlas presents concentrations of total phosphorus and chlorophyll *a* that should be found in unimpacted or pristine Cape ponds, as well as those that are "healthy" (Eichner, *et al*., 2003). The above analyses compared the available Barnstable pond data to these concentrations and found that almost all of Barnstable's ponds have average concentrations exceeding the "healthy" levels (Table V-1).

Dissolved oxygen is somewhat different because Massachusetts has adopted regulatory limits that define "impaired" waters. State surface water regulations (314CMR4) require that ponds 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. Fourteen of the 38 Barnstable ponds have average dissolved oxygen concentrations that are less than these standards (see Table V-1). Since low dissolved oxygen is caused by excessive growth, ponds that are failing to meet these standards have already passed through a phase of only having elevated phosphorus and chlorophyll *a* concentrations.

When looking at all of this data, there are two significant factors that must also be considered: all of these characterizations are based on very limited data and there are a number of Barnstable ponds that do not have any data. Except for Mystic, Middle, and Hamblin, the rest of the ponds have not had water quality samples collected since 1986 except for PALS Snapshots. The PALS Snapshot data is useful for what it was designed for, a Cape-wide picture of pond water quality, but it is not sufficient for definitively stating the status of individual ponds or designing remedial strategies.

Table II-1 lists all Barnstable ponds within various area ranges. Among the 89 ponds of greater than one acre, data is available for 38. All but Lamson and West in the 10 acre or greater category have samples, while only one pond in the greater than 1 acres, but less than 3.1 acre category (No Bottom) has water quality data. The above analyses and conclusions generally assume that these 38 ponds are representative of pond conditions in Barnstable, but this could not be definitively known without a more comprehensive sampling program.

With these caveats in mind, the available data is sufficient for prioritizing which ponds the town might want to consider looking at in greater detail. But even this must be considered with other information about the ponds. In consideration of this, project staff prepared the following briefs on each of the pond depth groups.

V.1. Ultrashallow Ponds: Conclusions

Since these 13 ponds are shallow, they are well mixed and have dissolved oxygen concentrations above state regulatory standards. Four of the ponds in this category are greater than 10 acres and, thus, meet the state definition of "Great Ponds" and are public waters: Mary Dunns, Mill (West Barnstable), Little Hathaway, and Fawcetts. All of the ultrashallow ponds except Little Hathaway, which has been sampled only once, have total phosphorus and chlorophyll *a* concentrations higher than "healthy" concentrations. Little Hathaway and Mary Dunn are generally surrounded by undeveloped land, so development activities near them should consider that these have relatively pristine conditions and should be protected. Although individual pond-specific characterization of their watersheds, potential nutrient sources, and more extensive water quality sampling would be necessary to develop pond-specific strategies to return these ponds to "healthy" levels, standard best management practices could help to improve the existing conditions. These practices would include maintaining natural buffers of at least 25 feet, limiting the disturbance or alteration of these buffer areas, removing or treating any direct stormwater discharges, and limiting fertilized areas on upgradient sides. Because of the shallow depths of these ponds, it may be possible in some cases to remove bottom sediments to return these ponds to "healthy" or even "unimpacted" TP and chlorophyll a concentrations. This type of activity might also provide potential natural nitrogen attenuation for remediating estuary water quality; for example, Mill in Marstons Mills is a headwater for the impaired waters of Prince Cove and removing sediments from the pond would increase the retention time and may provide greater nitrogen removal for loads coming down the Marstons Mills River. Pond specific analysis, including more detailed sampling, would be necessary to explore remedial possibilities.

V.2. Shallow Ponds: Conclusions

All 15 ponds in this category, except Joshua, have either excessive average total phosphorus or chlorophyll *a* concentrations and six have average dissolved oxygen concentrations at their deep station that are less than state standards: Elizabeth, Hinckley, Long (Centerville), No Bottom, Parker, and Schoolhouse. The following ponds in this category are greater than 10 acres and, thus, meet the state definition of "Great Ponds" and are public waters: Shallow, Bearse, Long (Marstons Mills), Long (Centerville), Garretts, Muddy, Joshua, Parker, and Hinckley.

Among the ponds with DO impairments, water quality in Elizabeth was last reviewed in detail in 1984 and this analysis had only limited samples collected between June and September (KV and IEP, 1988). Long (Centerville) has been the subject of numerous aquatic plant control activities, specifically targeted at hydrilla, but its last detailed review was in 1986 (IEP and KV, 1989). Hinckley, No Bottom, Parker, and Schoolhouse have water quality data available only through the PALS Snapshots.

Pond-specific water quality sampling of the other 8 ponds with excessive TP and chlorophyll a concentrations, but without DO impairments, would be necessary to characterize strategies to return these concentrations in these ponds to "healthy" levels. Of these, Bearse and Shallow were last sampled in detail in 1986 (IEP and KV, 1989; KV and IEP, 1993, respectively), although Bearse is currently being sampled through a Conservation Division study with the SMAST and the Cape Cod Commission. The majority, and in most cases, all, of the data from the remaining ponds is from the PALS Snapshots.

As with the Ultrashallow ponds, adopting best management practices around these ponds would have the potential to improve the water quality in these ponds. However, further characterization of deep water quality and the sediments in these ponds would likely be necessary to develop strategies to completely return these ponds to “healthy” total phosphorus and chlorophyll *a* concentration levels and remove the DO impairments. These more refined characterizations would likely also offer opportunities to explore enhanced nitrogen attenuation opportunities to improve estuary water quality.

As with other relatively pristine ponds in town, ensuring that Joshua maintains existing water quality should also be a priority. Aside from the benefits of preserving the recreational uses and ecological condition of the pond, the preservation of this system will continue to provide a reference condition for comparison and remedial activities in other ponds. Development activities near the pond should ensure that ecosystem conditions in Joshua are preserved.

V.3. Deep Ponds: Conclusions

All 10 ponds in this category have either excessive average total phosphorus or chlorophyll *a* concentrations and eight have average dissolved oxygen concentrations at their deep station that are less than state standards. Micah and Wequaquet are the only two ponds in this category that meet state DO standards. All of the ponds in this category are also greater than 10 acres and, thus, are defined as “Great Ponds” and public waters under state regulations.

Among the ponds with both DO impairments and excessive TP and chlorophyll *a* concentrations, Hamblin, Middle, and Mystic were last reviewed in detail in 2004 (Eichner, *et al*, 2006), while Lovells was reviewed in 1996 (AE, 1997). Crystal, Hathaway, Neck, and Shubael water quality data is predominately available through the PALS Snapshots.

As with the ponds in the other two categories, adopting best management practices around these ponds would have the potential to improve the water quality in these ponds. However, further characterization of deep water quality and the sediments in these ponds would likely be necessary to develop strategies to completely return these ponds to “healthy” total phosphorus and chlorophyll *a* concentration levels and remove the DO impairments. These more refined characterizations would likely also offer opportunities to explore enhanced nitrogen attenuation opportunities to improve estuary water quality.

All of the ponds in this category have water quality characteristics that suggest some concern; none of the ponds fit easily fit a “pristine” label. Some of the ponds, however, have characteristics that suggest they have only recently begun to express some water quality impairments. Among these ponds are: Micah, Middle, and Neck. Hamblin also generally fits within this group, but its on-going concerns are still a significant improvement over conditions that existed prior to the 1995 alum treatment.

VI. Recommendations

VI.1. Develop an integrated long term pond monitoring program

The only data from half of the ponds (19 of 38) reviewed in this project report came from the PALS Snapshots. If the PALS Snapshots are excluded, another eight ponds have less than 5 sampling events between 1948 and 2006. While project staff have used this information to review the status of the ponds, the limitations of the available dataset prevent firm conclusions about the status of many of the ponds. If the town developed a long term monitoring program for ponds, the water quality changes over the years could be fairly assessed, the benefits of remediation and protective strategies could be more clearly stated, more ponds could be assessed, and pond management within Barnstable could move toward a more proactive approach.

This type of program would be relatively low cost if it is created through a volunteer monitoring network. In other Cape communities, volunteers are the core of monitoring programs with town staff providing logistics support for transfer of samples to labs, training, maintenance of monitoring equipment, and organization of data. In most cases, SMAST staff can provide assistance with initial startup, interpretation of collected data and guidance on quality control/quality assurance procedures.

If the 81 sampling station identified for the 38 ponds reviewed in this project were sampled once in spring and then again during the traditional PALS Snapshot period, the annual laboratory cost would be approximately $16,200. The town has already invested in the purchase of dissolved oxygen meters (mostly for estuary monitoring), so a monitoring program featuring the measurement of DO and temperature profiles would only require maintenance and replacement of these meters. Program directors, in conjunction with volunteers, could also evaluate the benefits of monitoring additional ponds. A small cost would likely be incurred for staff time to coordinate volunteers and organize data, as well as another relatively small cost for occasional interpretation of the data. Interpretation could be designed to provide yearly updates with a more extensive review every five years.

The town has generally pursued a pond management strategy that targets specific ponds. While this produces a detailed analysis of an individual pond, the targeting of only one year means that results may or may not be representative of the average conditions in the pond. Drought, high groundwater levels, precipitation, temperature extremes can skew the results of a single year assessment. While this type of detailed assessment is necessary, it is recommended that selection of individual ponds be integrated with long term monitoring and prioritization that results from review of long term monitoring results.

Integrating long term pond monitoring program with the likely estuary Total Maximum Daily Load (TMDL) compliance monitoring that the town will face would likely result in cost savings. Other potential cost savings might be realized if estuary and pond monitoring is coordinated with neighboring towns, each of which will have TMDL compliance monitoring of their own. Development of long term monitoring program of the freshwater ponds would also provide the town with background information for any strategies that are implemented and, eventually, the benefits of the wastewater improvements that the estuary TMDL compliance will require. It will also provide support information for any natural attenuation modifications that the town may want to pursue in lieu of sewer systems for meeting the estuary TMDLs.

For an annual budget of $20,000 to $25,000, the town would be able to develop an integrated pond-monitoring program that meets all these goals. SMAST and Commission staff are available to discuss this recommendation and other potential monitoring strategies.

VI.2. Continue to prioritize detailed individual pond projects

As mentioned above, the town has generally pursued a pond management strategy that targets specific ponds for detailed year-long monitoring projects. While it is recommended that this be integrated with a more comprehensive town-wide monitoring program, there is still going to be a need for detailed, focused studies of individual ponds. Further, it is clear from the available data that detail studies should be considered for a number of ponds in order to more clearly define the sources of their current impairments and define the range of potential solutions to address those impairments.

Long term, volunteer-based monitoring programs are generally designed to gauge the general ecosystem health of a pond. Detailed pond studies, often referred to as diagnostic/feasibility studies, develop information that is generally outside of standard volunteer monitoring programs and are designed to develop solutions to address a particular problem in a selected pond. Types of information gathered during detailed assessments often include bottom sediment sampling and measurement of thickness, streamflow measurements, collection of algal samples, and measurement of contaminants in fish.

It is recommended that budgets for these types of detailed analysis be developed as a result of discussions between town staff and pond assessment professionals. These discussions can focus on the problem or potential problem identified as a result of available monitoring and develop a cost proposal to develop the necessary information to frame potential solutions to address the problem.

As a result of the analysis in this report, it is recommended that the town consider prioritizing Muddy, Hinckley, and/or Parker for a detailed pond project. It is pretty clear that almost all of the ponds in town have ecological issues. The worst ponds generally have already been or will be addressed by alum treatments (Hamblin, 1995; Mystic, in development) or aeration (Lovells, in development). Muddy, Parker, and Hinckley have the highest surface chlorophyll a concentrations, are among the top five in surface total phosphorus concentrations, are among the ponds with the worst dissolved oxygen issues, and are all public ponds (>10 acres). Given that almost all of the ponds in Barnstable have water quality issues, it is suggested that the town could pick any number of ponds for detailed assessment, but Muddy, Parker, and Hinckley seem to the among those most in need of attention.

Detailed pond assessments generally will cost between $25,000 and 35,000 depending on the amount of pre-existing information and the types of information that needs to be collected. If a problem were identified, a similar amount of funding would generally be necessary to develop a list of potential solutions and a preferred option. SMAST and Commission staff are available to assist the town in discussion of potential strategies for prioritizing individual pond assessments, as well as discussion of scopes of work to complete and fund the assessments and subsequent feasibility studies to solve identified problems.

VI.3. Develop additional Town-wide physical data about the ponds

In addition to a town-wide water quality-monitoring program, the town should consider developing bathymetric information and modeling capability to delineate watersheds to ponds. Bathymetric information will provide important base data that will be necessary to put water quality data into context for individual ponds.

Volunteers can collect the necessary information with proper training and equipment. Equipment needs generally consist of a sounding line, a GPS unit, and a boat. Once data is collected, it will need to be interpreted in order to develop bathymetric contours. SMAST and Cape Cod Commission staff can assist the town with all aspects of this effort.

Bathymetric information will also be necessary for modeling/delineation of pond watersheds. The USGS regional model for the Sagamore Lens generally includes ponds of 10 acres or more. This size range was developed in concert with the rest of the Massachusetts Estuaries Technical Team and is largely based on the balance necessary to allow the groundwater model run and what size is meaningful at a regional scale.

In order to move toward more localized scale of pond management, watersheds will be necessary and the best way to facilitate their delineation is with the creation of a subregional groundwater model that focuses on Barnstable. This model will use the USGS regional model as a starting point and then incorporate localized information about geology, pond bathymetry, wetlands, etc. Aside from the delineation of pond watersheds, a Barnstable-focused model would also be useful for evaluation of potential wastewater, estuary, and drinking water management strategies as the town moves ahead with the Nutrient Management Program.

VI.4. Set water quality targets for individual ponds or groups of ponds

Although the Massachusetts Department of Environmental Protection is currently focused on developing TMDLs for estuaries, eventually their attention will turn toward ponds. The federal Clean Water Act, which is administered by MassDEP, requires that a TMDL be developed for any waters that are listed as "impaired". The latest impaired waters list from MassDEP only lists nine freshwater ponds on Cape Cod (MassDEP, 2005). Red Lily is the only pond in Barnstable on this list.

As with the estuaries, which had a limited set of listed waters prior to the creation of the Massachusetts Estuaries Project, as more water quality data is developed, the list of potential freshwater pond candidates for the state impaired list will grow. For example, a recent Cape Cod Commission evaluation of pond water quality in the Town of Orleans found 16 of the 18 ponds reviewed met the definition of impaired under state regulations (Eichner, 2007).

Based on what is know about other ponds on the Cape and the data reviewed through this project, it is recommended that the Town of Barnstable consider establishing pond-specific or pond class-specific water quality targets/goals. SMAST and Cape Cod Commission staff are available to assist the town in developing the scope of work for such an effort and, if desired, to complete such a project.

VI.5. Review local regulations to better protect pond water quality

Water quality in ponds is generally a product of the form and type of development around their shorelines. How this development addresses potential nutrient sources is often related to the rules and regulations that help shape how wastewater and stormwater are treated, whether natural buffers between the pond and land disturbance are required, and whether roads can discharge stormwater into ponds. These rules and regulations generally fall within purview of the Conservation Commission (natural buffers), Board of Health (septic systems), and Department of Public Works (roads and stormwater).

It is recommended that the Town of Barnstable consider reviewing existing land use and development rules and regulations to identify potential changes that would provide better protection of pond water quality. Cape Cod Commission staff completed a similar review in 2004 for the Town of Brewster and Commission and SMAST staff are available to assist the town in the completion of this effort.

VII. References

Ambient Engineering, Inc. 1997. Diagnostic/Feasibility Study, Lovell's Pond, Barnstable, Massachusetts. Prepared for Town of Barnstable.

Carlson, R.E. 1977. A trophic state index for lakes. *Limnology and Oceanography.* 22: 361-369.

Carlson, R.E. 1983. Discussion on "Using differences among Carlson's trophic state index values in regional water quality assessment", by Richard A. Osgood. *Water Resources Bulletin*. 19: 307-309.

Carlson, R.E. and J. Simpson. 1996. *A Coordinator's Guide to Volunteer Lake Monitoring Methods*. North American Lake Management Society. 96 pp. (summarized at http://dipin.kent.edu/tsi.htm#A).

Eichner, E.M. 2007. Review and Interpretation of Orleans Freshwater Ponds Volunteer Monitoring Data. Final Report to the Town of Orleans Marine and Fresh Water Quality Task Force and Barnstable County. Cape Cod Commission. Barnstable, MA.

Eichner, E.M., S. Michaud, and T.C. Cambareri. 2006. First Order Assessment of Indian Ponds (Mystic Lake, Middle Pond, and Hamblin Pond). Cape Cod Commission. Barnstable, MA.

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

Eichner, E.M., T.C. Cambareri, V. Morrill, and B. Smith. 1998. Lake Wequaquet Water Level Study. Cape Cod Commission. Barnstable, MA.

Elliot, J.M. 2000. Pools as refugia for brown trout during two summer droughts: trout responses to thermal and oxygen stress. *Journal of Fish Biology*. 56(4): 938.

Frimpter, M.H. and F.B. Gay. 1979. Chemical Quality of Ground Water on Cape Cod, Massachusetts. Water Resources Investigations 79-65. US Geological Survey. Boston, MA.

Fontenot, Q.C., D.A. Rutherford, and W.E. Kelso. 2001. Effects of Environmental Hypoxia Associated with the Annual Flood Pulse on the Distribution of Larval Sunfish and Shad in the Atchafalaya River Basin, Louisiana. *Transactions of the American Fisheries Society*. 130: 107-116.

Howes B., H.E. Ruthven, J. S. Ramsey, R. Samimy, D. Schlezinger, J. Wood, E. Eichner. 2006a. Linked Watershed-Embayment Model to Determine Critical Nitrogen Loading Thresholds for Centerville River System, Barnstable, Massachusetts. Massachusetts Estuaries Project, Massachusetts Department of Environmental Protection. Boston, MA.

Howes B.L., H.E. Ruthven, E.M. Eichner, J. S. Ramsey, R.I. Samimy, and D.R. Schlezinger. 2007. DRAFT Linked Watershed-Embayment Model to Determine Critical Nitrogen Loading Thresholds for the Lewis Bay System, Towns of Barnstable and Yarmouth, MA. SMAST/DEP Massachusetts Estuaries Project, Massachusetts Department of Environmental Protection. Boston, MA.

Howes, B., S. Kelley, J. Ramsey, R. Samimy, E. Eichner, D. Schlezinger, and J. Wood. 2004. Linked Watershed-Embayment Model to Determine Critical Nitrogen Loading Thresholds for Popponesset Bay, Mashpee and Barnstable, Massachusetts. Commonwealth of Massachusetts, Department of Environmental Protection, Massachusetts Estuaries Project, 138 pp. + Executive Summary, 10 pp.

Howes B., S. W. Kelley, J. S. Ramsey, R. Samimy, D. Schlezinger, and E. Eichner. 2006b. Linked Watershed-Embayment Model to Determine Critical Nitrogen Loading Thresholds for Three Bays, Barnstable, Massachusetts. Massachusetts Estuaries Project, Massachusetts Department of Environmental Protection. Boston, MA.

IEP, Inc. and K-V Associates, Inc. 1989. Diagnostic/Feasibility Study of Wequaquet Lake, Bearse, and Long Pond. Prepared for Town of Barnstable, Conservation Commission. Sandwich and Falmouth, MA.

Killgore, K.J. and J.J. Hoover. 2001. Effects of Hypoxia on Fish Assemblages in a Vegetated Waterbody. *Journal of Aquatic Plant Management*. 39: 40-44.

K-V Associates, Inc. and IEP, Inc. 1988. Red Lily Pond Diagnostic/Feasibility Study. Prepared for Town of Barnstable. Falmouth and Barnstable, MA.

K-V Associates, Inc. and IEP, Inc. 1993. Shallow Pond Diagnostic - Feasibility Study. Prepared for Town of Barnstable, Conservation Commission. Falmouth and Barnstable, MA.

Massachusetts Department of Environmental Protection. 2005. Massachusetts Year 2004 Integrated List of Waters, Final listing of the condition of Massachusetts' waters pursuant to Sections 303(d) and 305(b) of the Clean Water Act. Available at: www.state.ma.us/dep/water/resources/2004il4.pdf).

Massachusetts Division of Fisheries and Game. 1948. Fisheries Report – Lakes of Plymouth, Berkshire and Barnstable Counties.

Matthews, K.R. and N.H. Berg. 1997. Rainbow trout responses to water temperature and dissolved oxygen stress in two southern California stream pools. *Journal of Fish Biology*. 50: 50-67.

School of Marine Science and Technology, University of Massachusetts Dartmouth. 2003. Coastal Systems Program, Analytical Facility, Laboratory Quality Assurance Plan. New Bedford, MA.

Stumm, W. and J.J. Morgan. 1981. *Aquatic Chemistry*. John Wiley & Sons, Inc., New York, NY.

Thurston, R.V., G.R. Phillips, R.C. Russo, and S.M. Hinkins. 1981. Increased Toxicity of Ammonia to Rainbow Trout (Salmo Gairdneri) Resulting from Reduced Concentrations of Dissolved Oxygen. *Canadian Journal of Fisheries and Aquatic Sciences*. 38(8): 983-988.

Vollenweider, R.A. 1968. Scientific Fundamentals of the Eutrophication of Lakes and Flowing Waters, with Particular Reference to Nitrogen and Phosphorus as Factors in Eutrophication. Paris, Rep. OECD, DAS/CSI/68.27.

United States Environmental Protection Agency. 2000. Nutrient Criteria Technical Guidance Manual: Lakes and Reservoirs. First Edition. EPA-822-B00-001. US Environmental Protection Agency, Office of Water, Office of Science and Technology. Washington, DC.

Walter, D.A. and A.T. Whealan. 2005. Simulated Water Sources and Effects of Pumping on Surface and Ground Water, Sagamore and Monomoy Flow Lenses, Cape Cod, Massachusetts. U.S. Geological Survey Scientific Investigations Report 2004-5181.

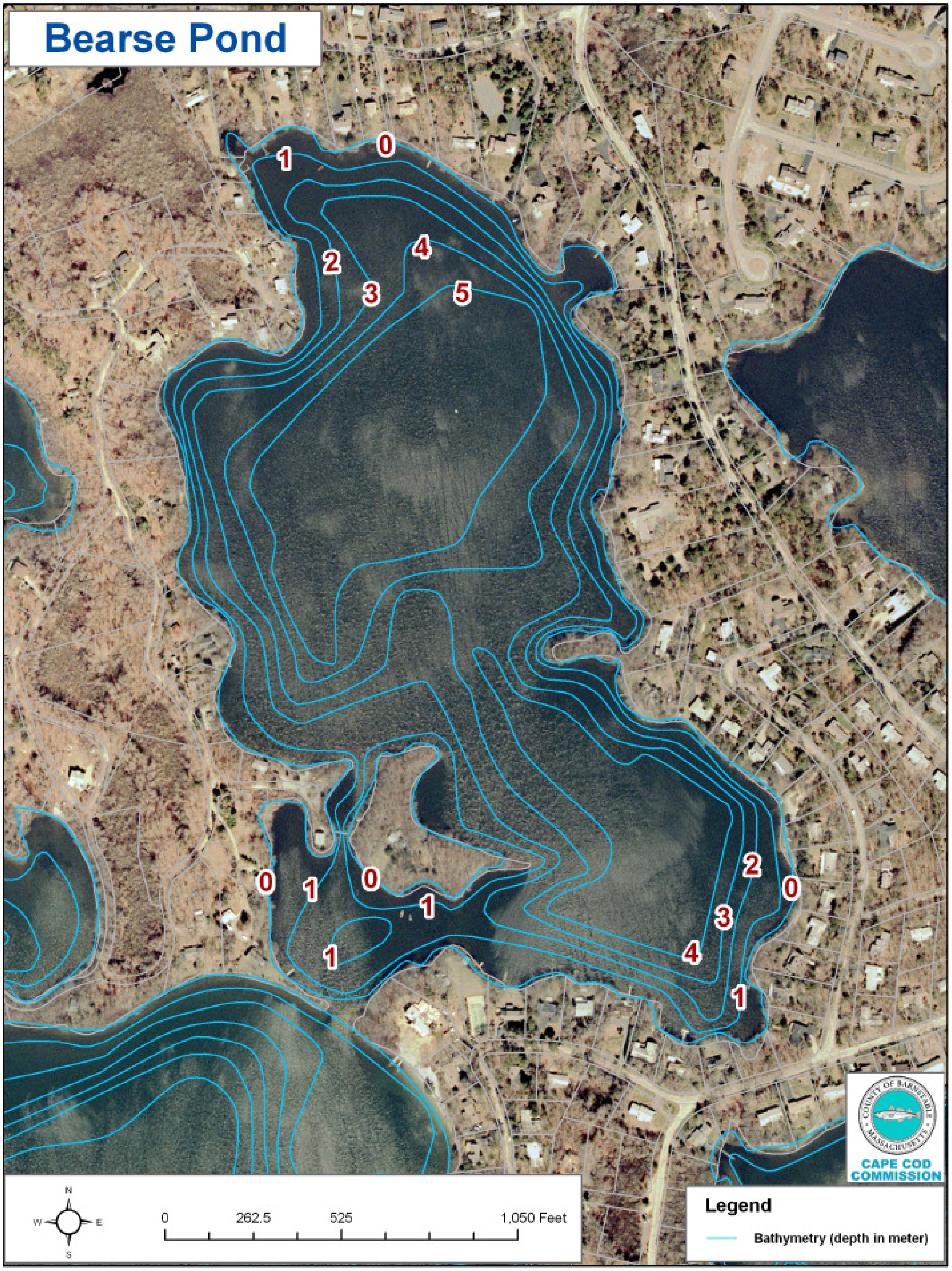
Wetzel, R. G. 1983. *Limnology*. Second Edition. CBS College Publishing, New York.

Wu, R.S.S., B.S. Zhou, D.J. Randall, N.Y.S. Woo, and P.K.S. Lam. 2003. Aquatic Hypoxia is an Endocrine Disruptor and Impairs Fish Reproduction. *Environmental Science and Technology*. 37(6): 1137-1141.

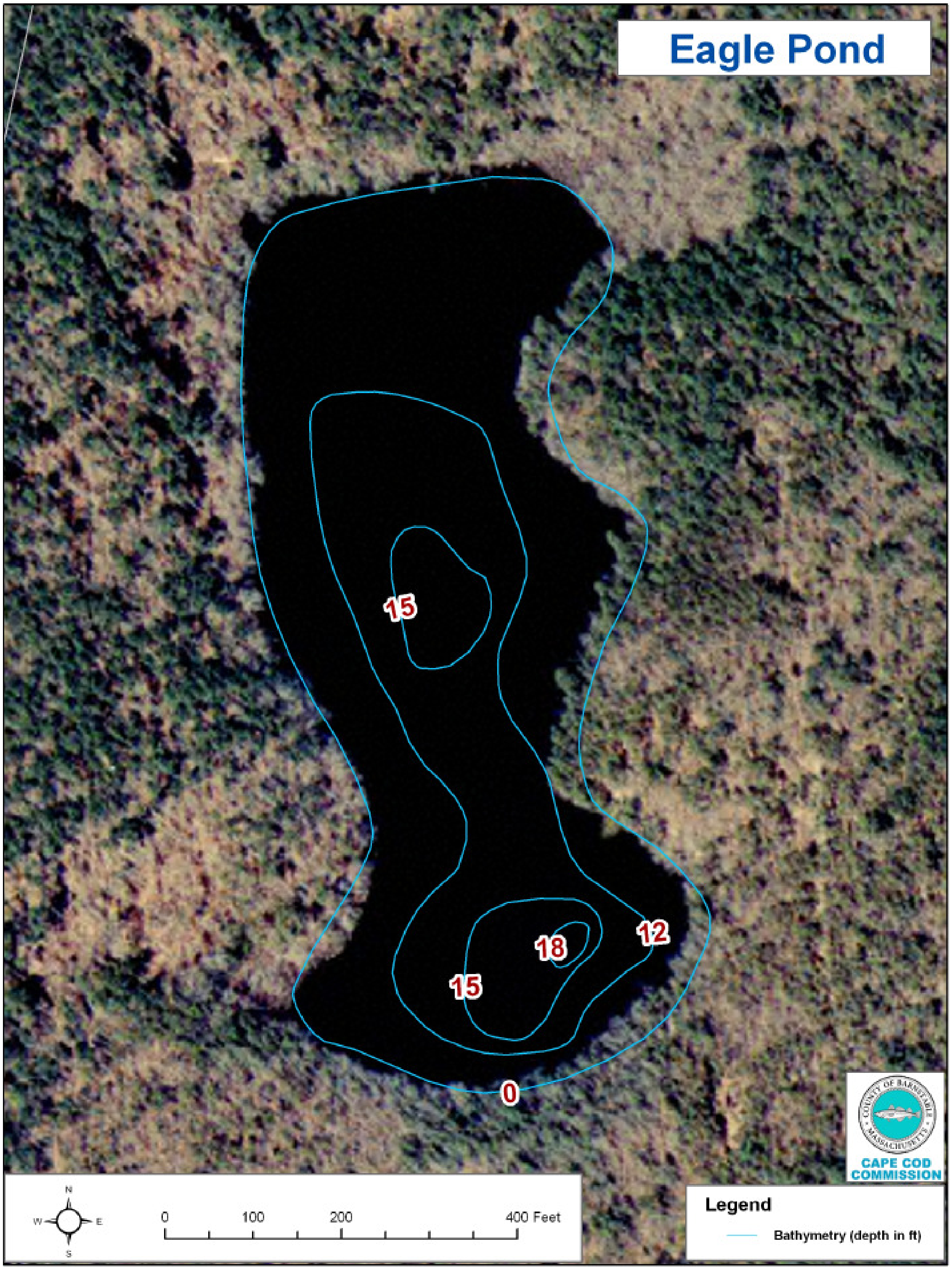
Appendix A

Bathymetric Maps Available for Barnstable Ponds

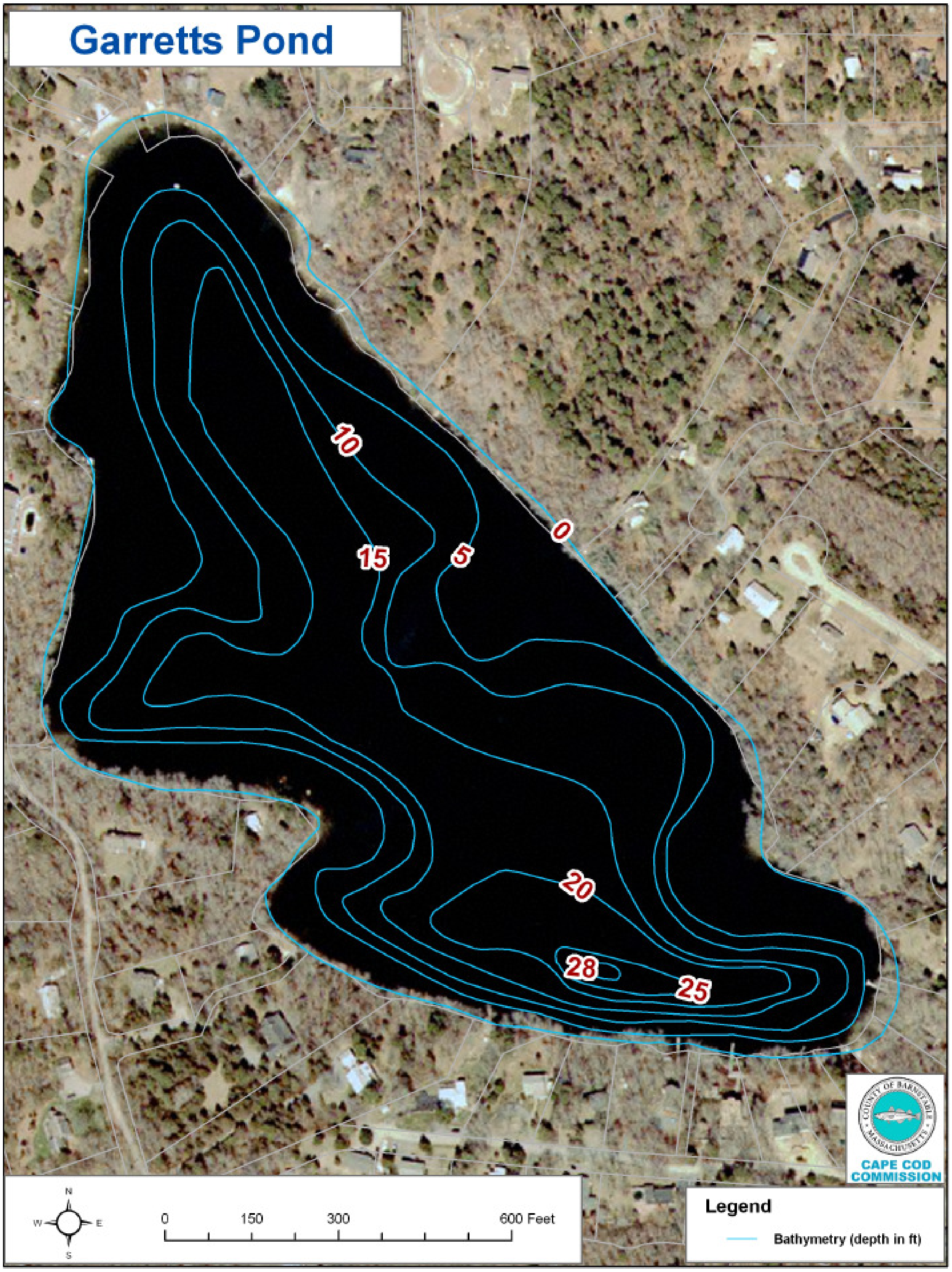
The source of the bathymetric information for each pond is listed. The base of each map is a 2002 color orthophoto. Also shown on the maps are parcel boundaries from 2006. Since shoreline delineations were completed at the time of the development of the bathymetric contours and water levels in most of these ponds fluctuate (up to 4 feet), shoreline contours may not match the shorelines in the orthophotos.



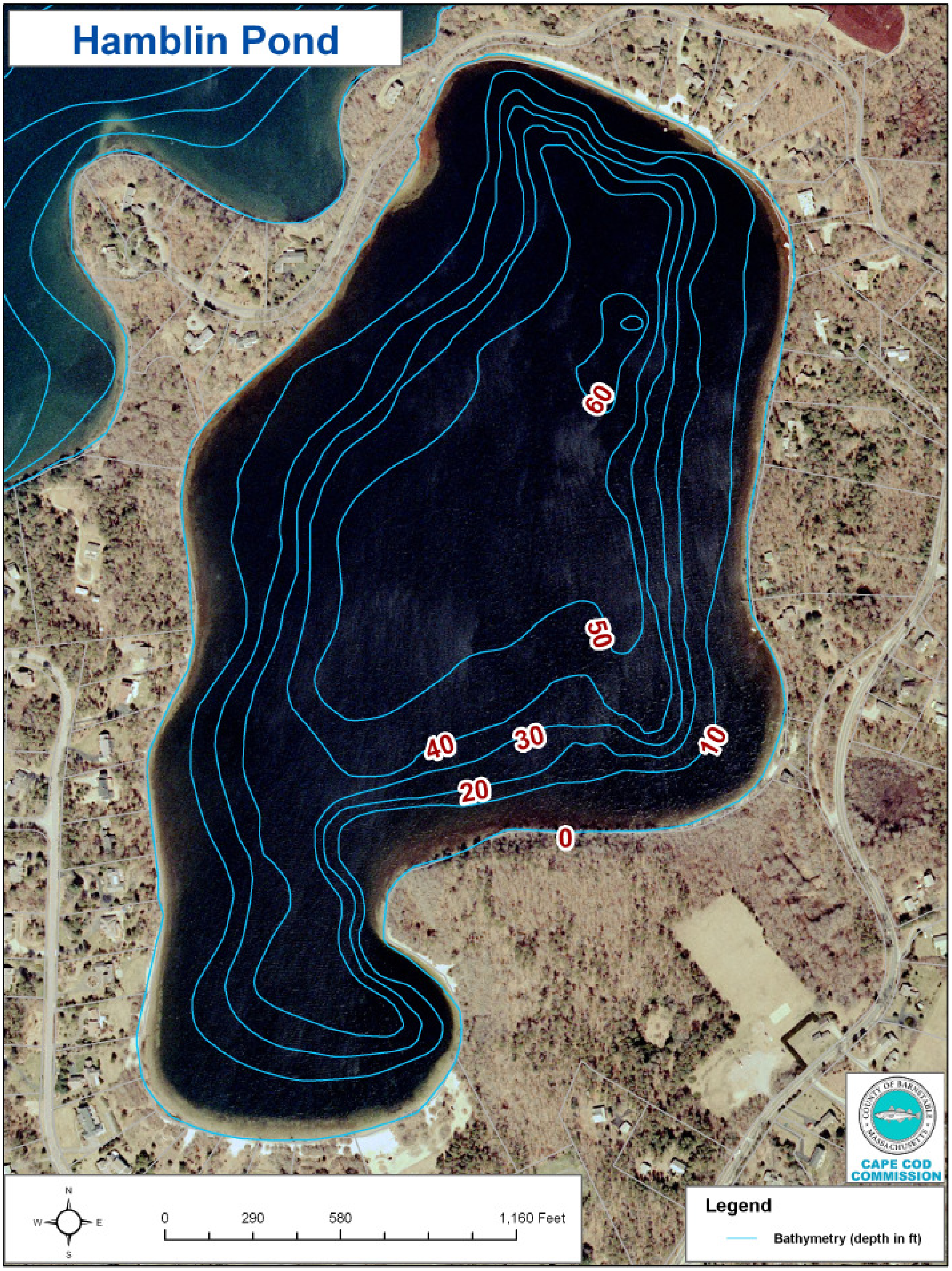
Bathymetric contours data source: IEP, Inc. and K-V Associates, Inc. 1989.



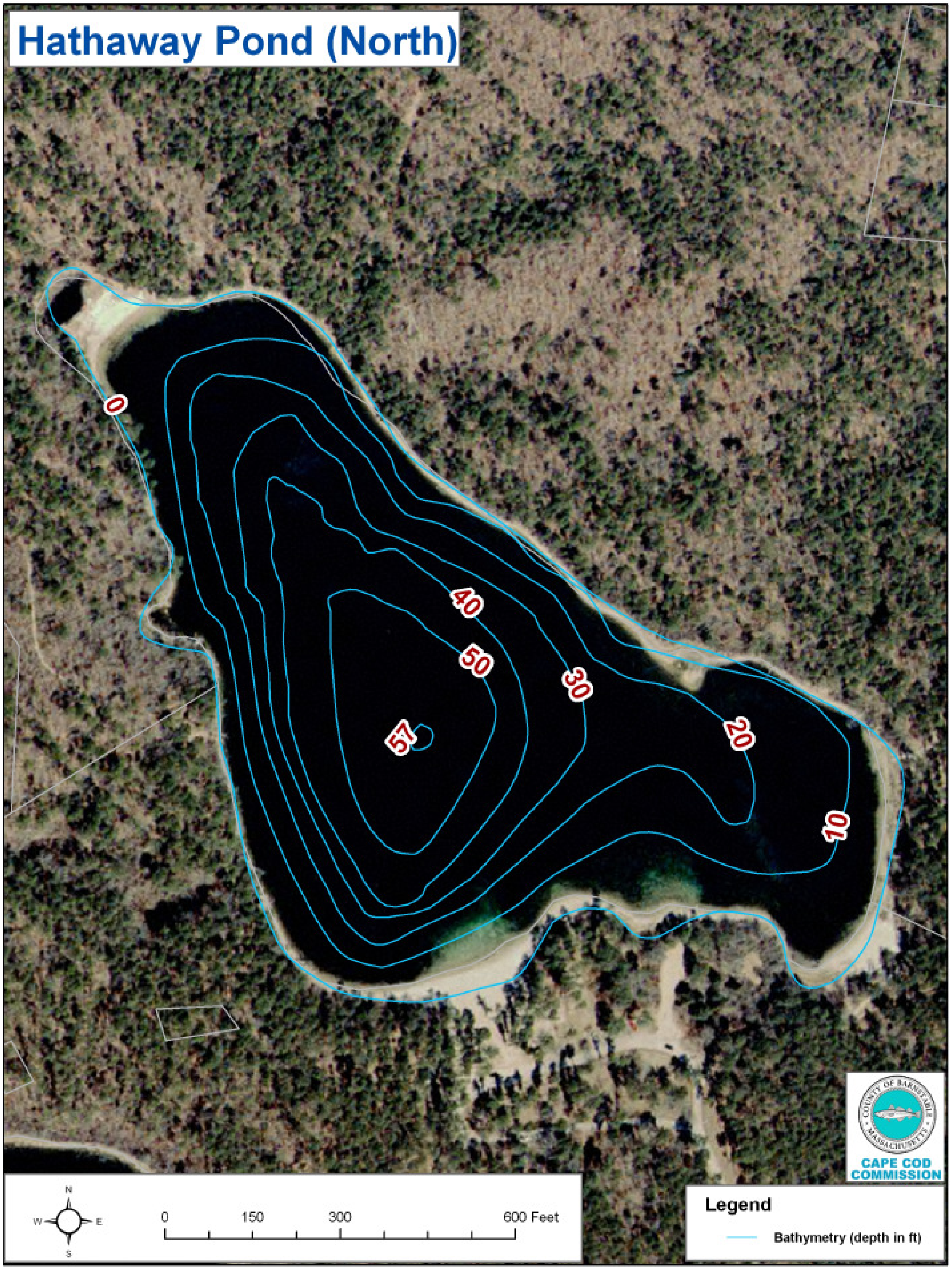
Bathymetric contours data source: Romark Limnological Assessments, Inc. (1983)



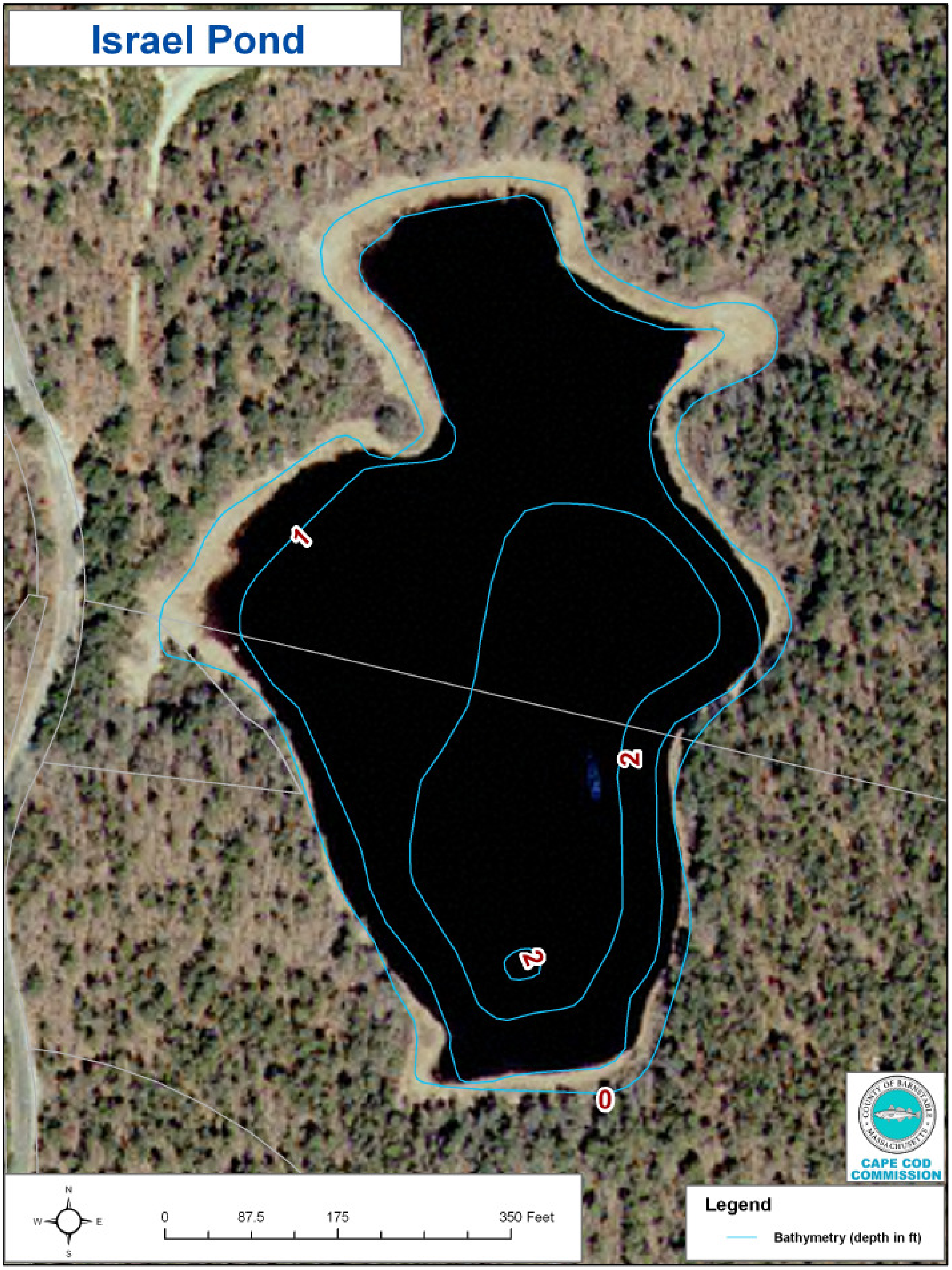
Bathymetric contours data source: IEP, Inc. 1980.



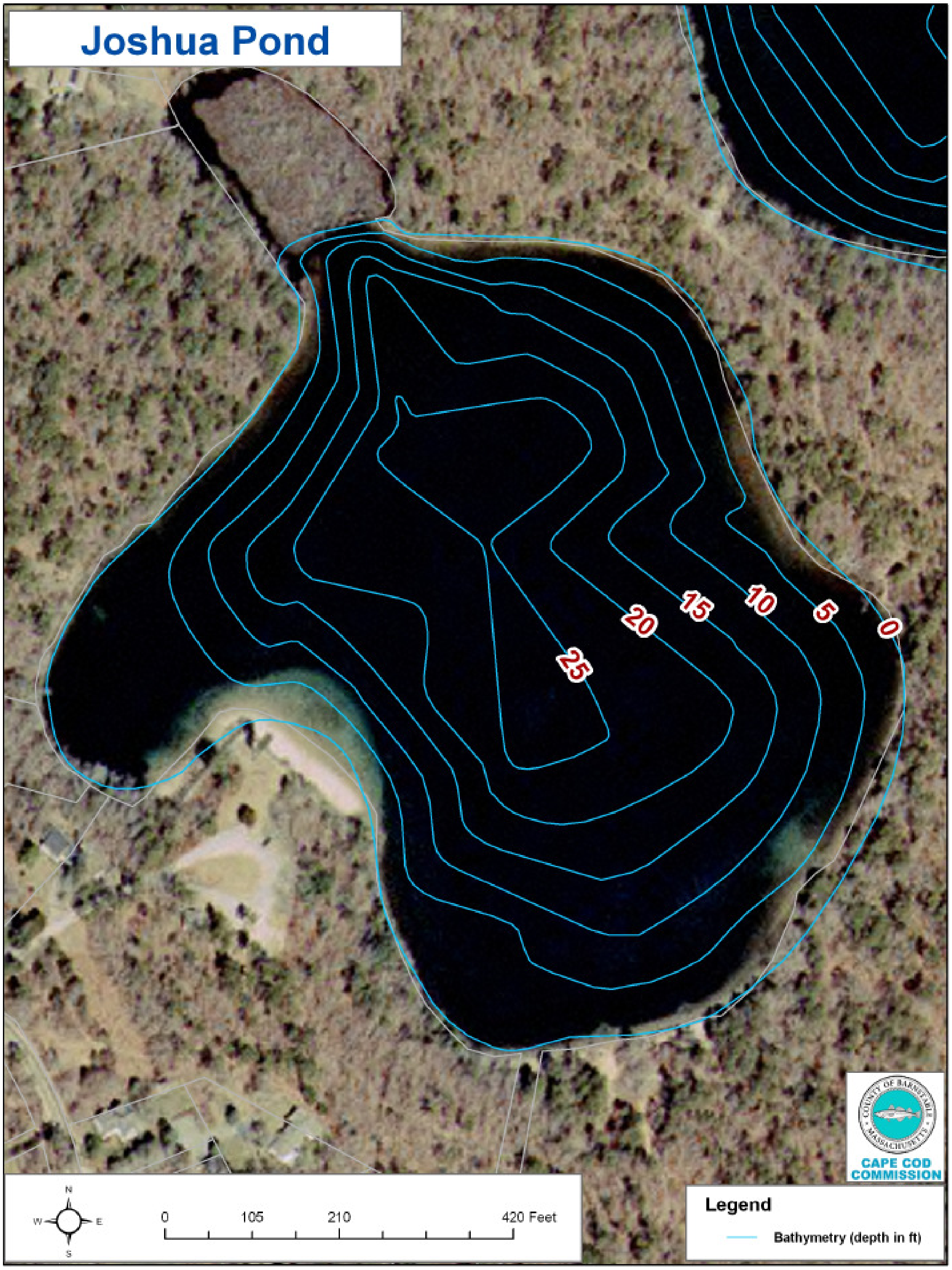
Bathymetric contours data source: MassDFW (available at: http://www.mass.gov/dfwele/dfw/habitat/maps/ponds/pond_maps.htm); reviewed by BEC, Inc. 1993.



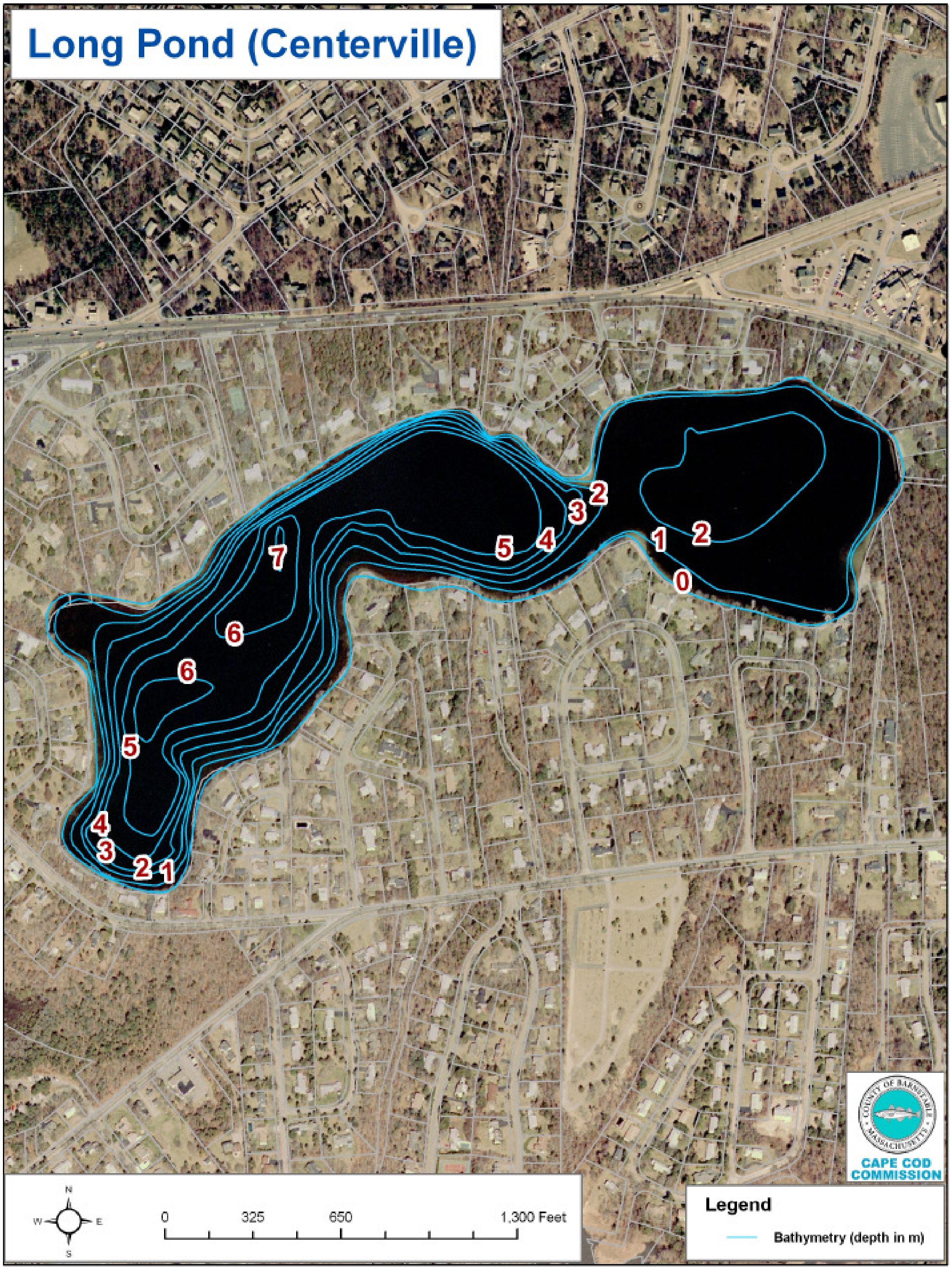
Bathymetric contours data source: MassDFW (available at: http://www.mass.gov/dfwele/dfw/habitat/maps/ponds/pond_maps.htm)



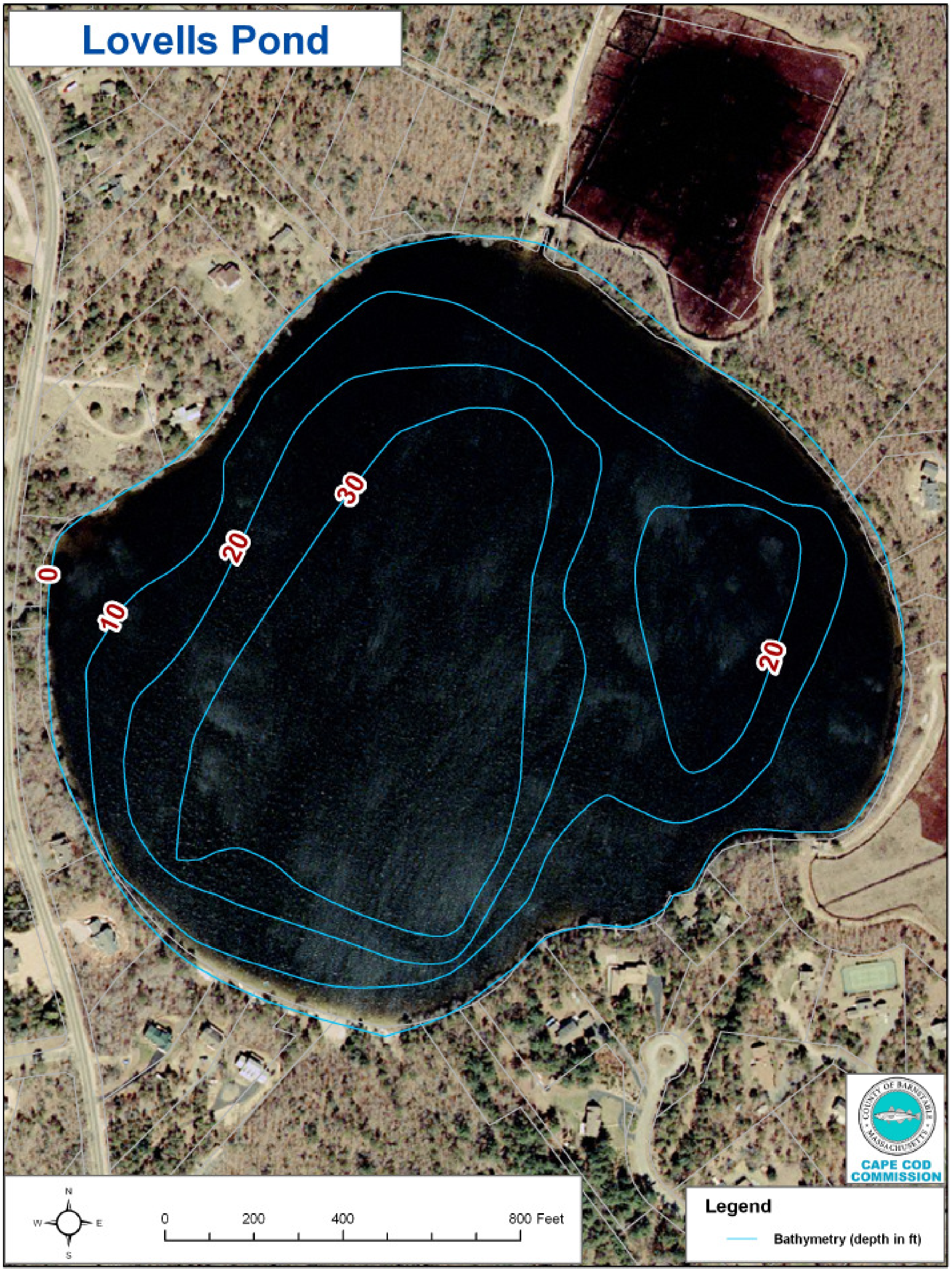
Bathymetric contours data source: IEP, Inc (1990) (Independence Park EIR)



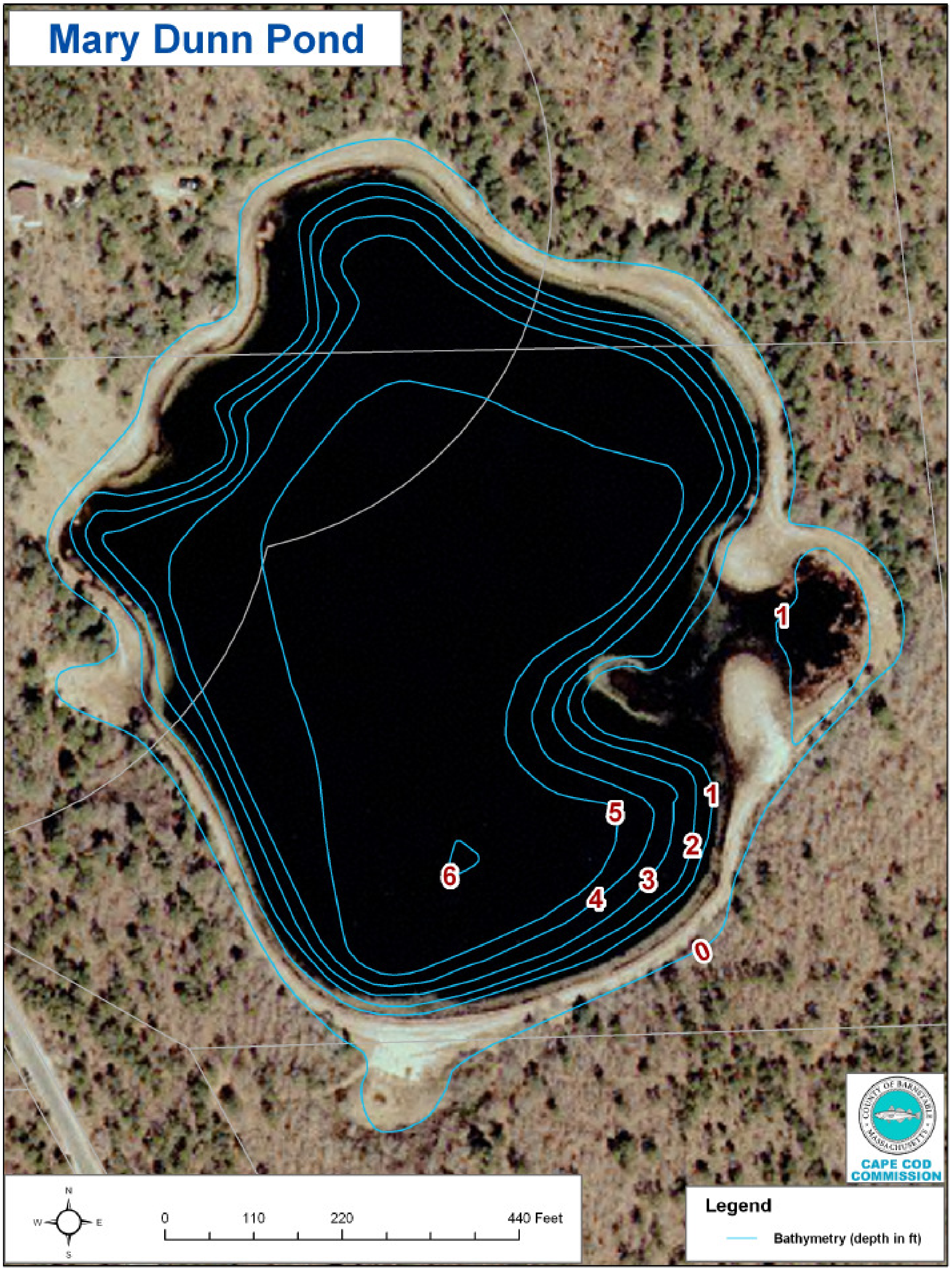
Bathymetric contours data source: MassDFW (available at:
http://www.mass.gov/dfwele/dfw/habitat/maps/ponds/pond_maps.htm)



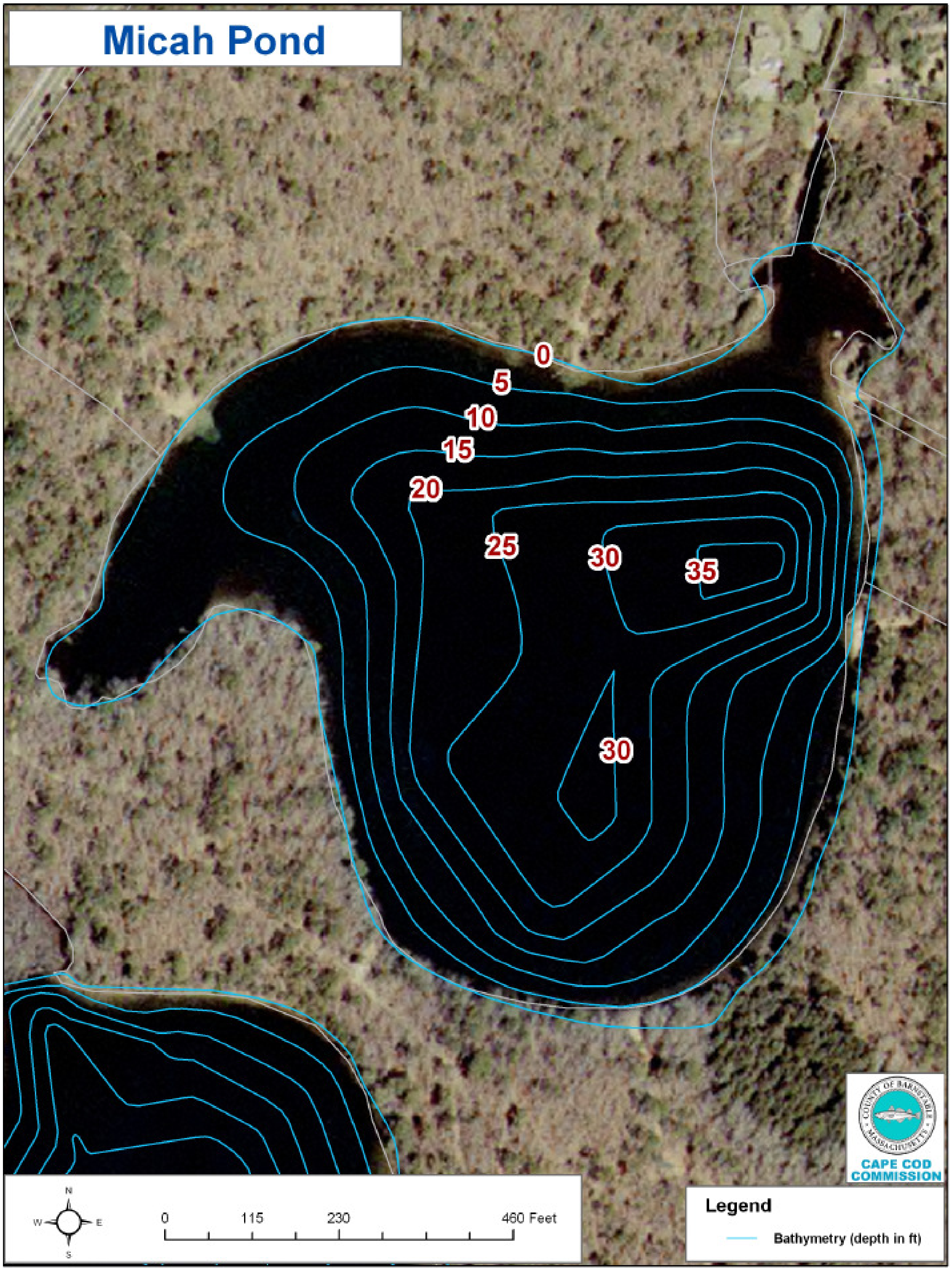
Bathymetric contours data source: IEP, Inc. and K-V Associates, Inc. 1989.



Bathymetric contours data source: MassDFW (available at: http://www.mass.gov/dfwele/dfw/habitat/maps/ponds/pond_maps.htm)

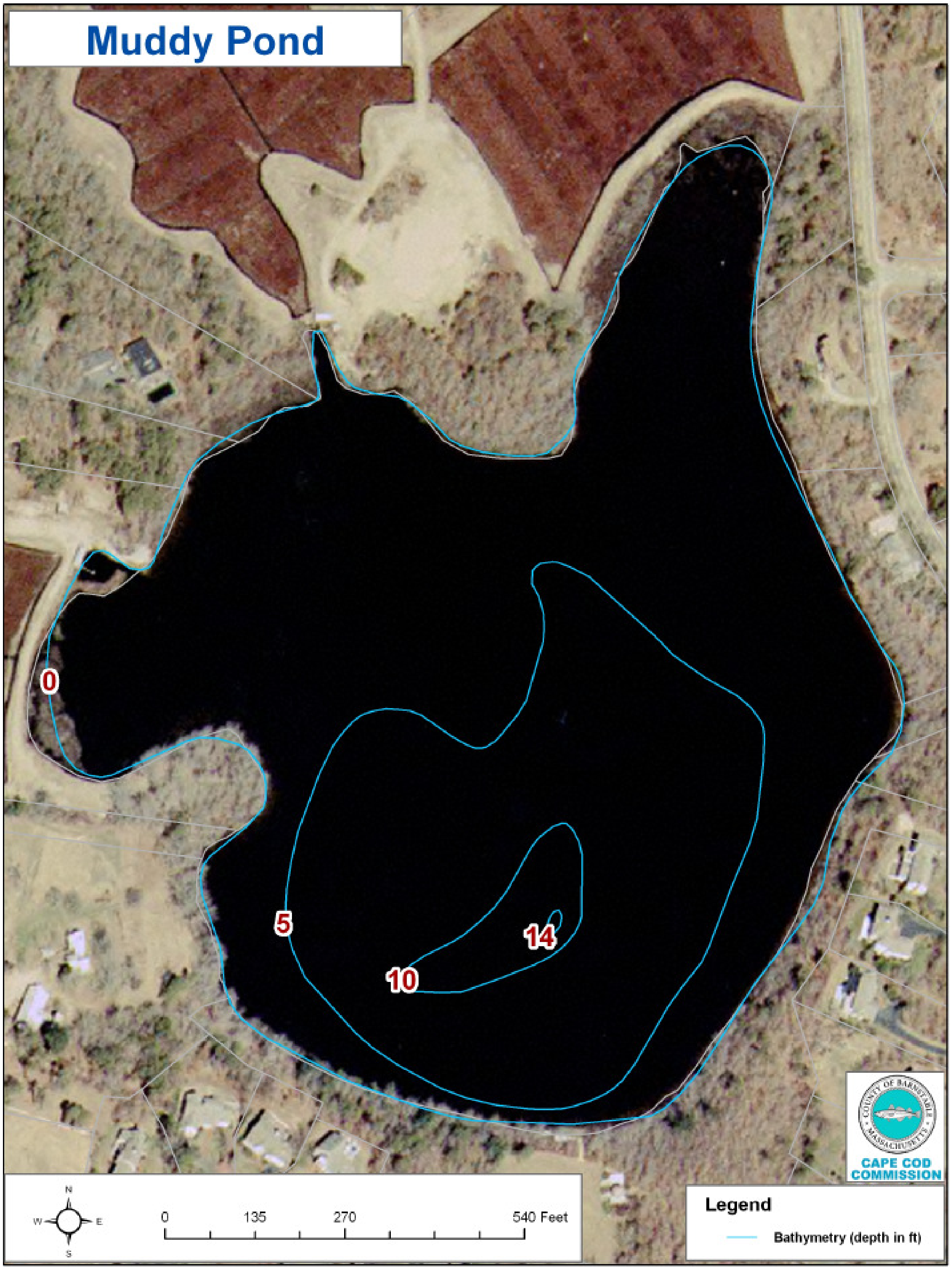


Bathymetric contours data source: IEP, Inc (1990) (Independence Park EIR)

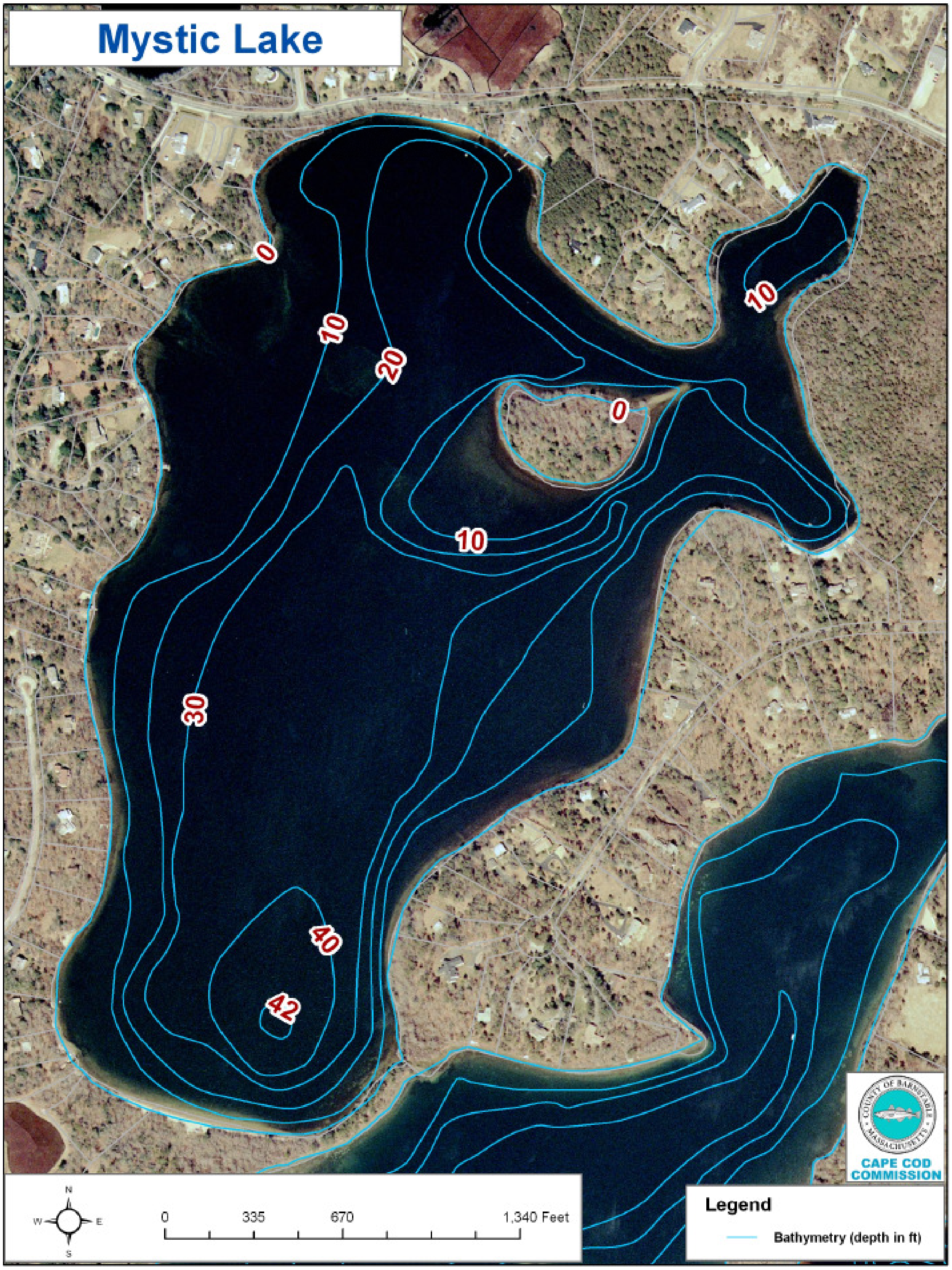


Bathymetric contours data source: MassDFW (available at: http://www.mass.gov/dfwele/dfw/habitat/maps/ponds/pond_maps.htm)

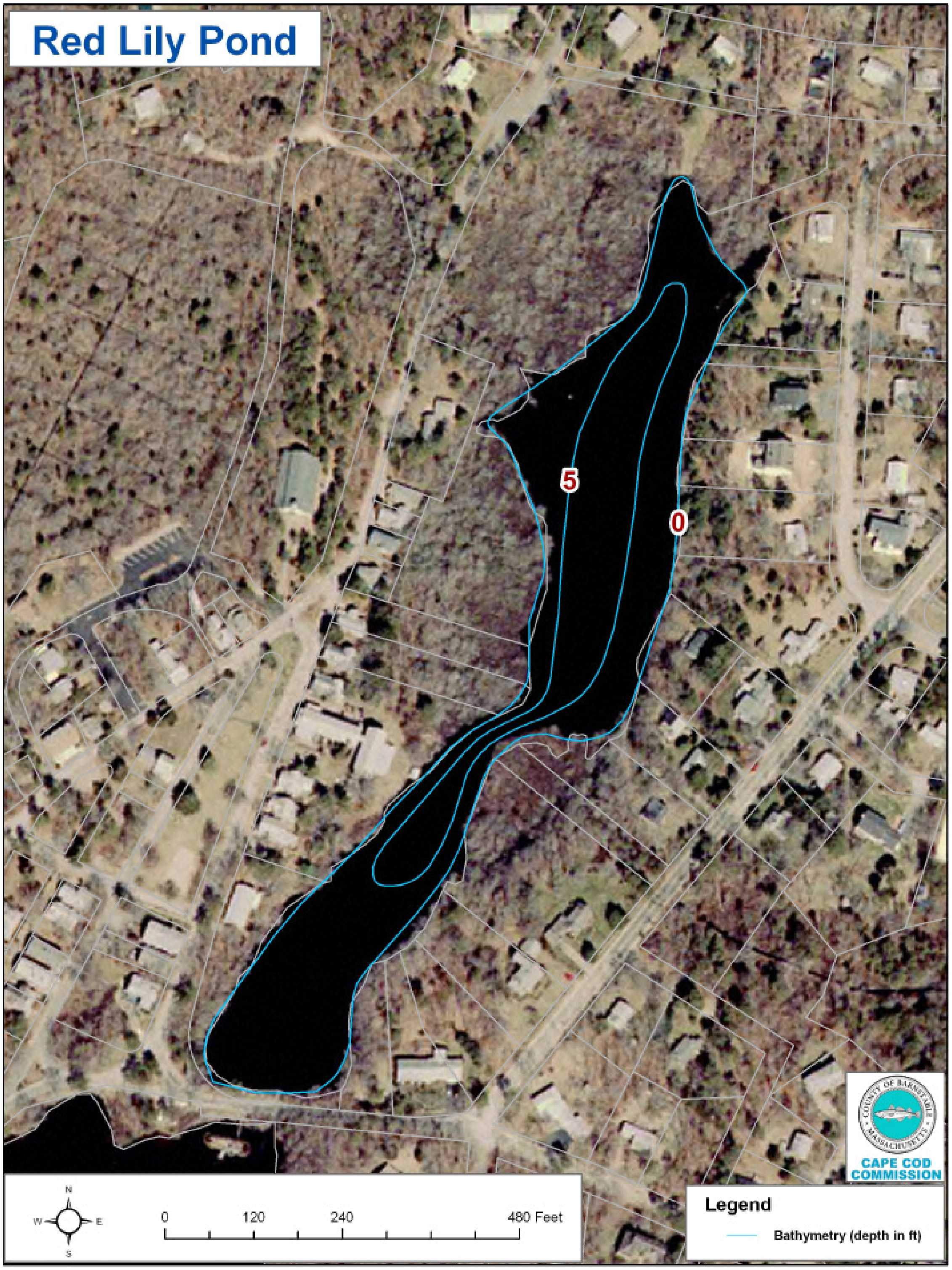
Bathymetric contours data source: MassDFW (available at: http://www.mass.gov/dfwele/dfw/habitat/maps/ponds/pond_maps.htm)



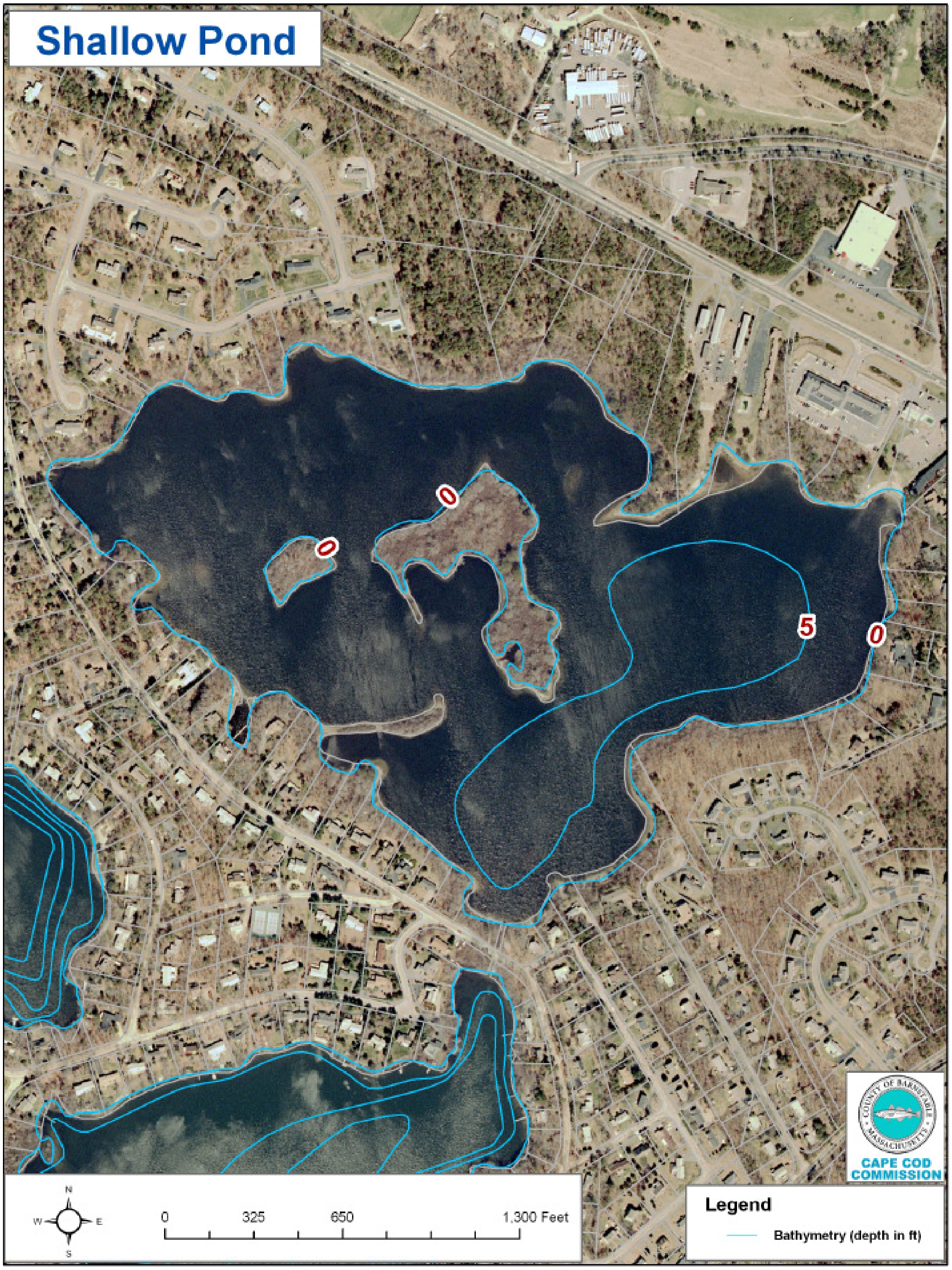
Bathymetric contours data source: ???



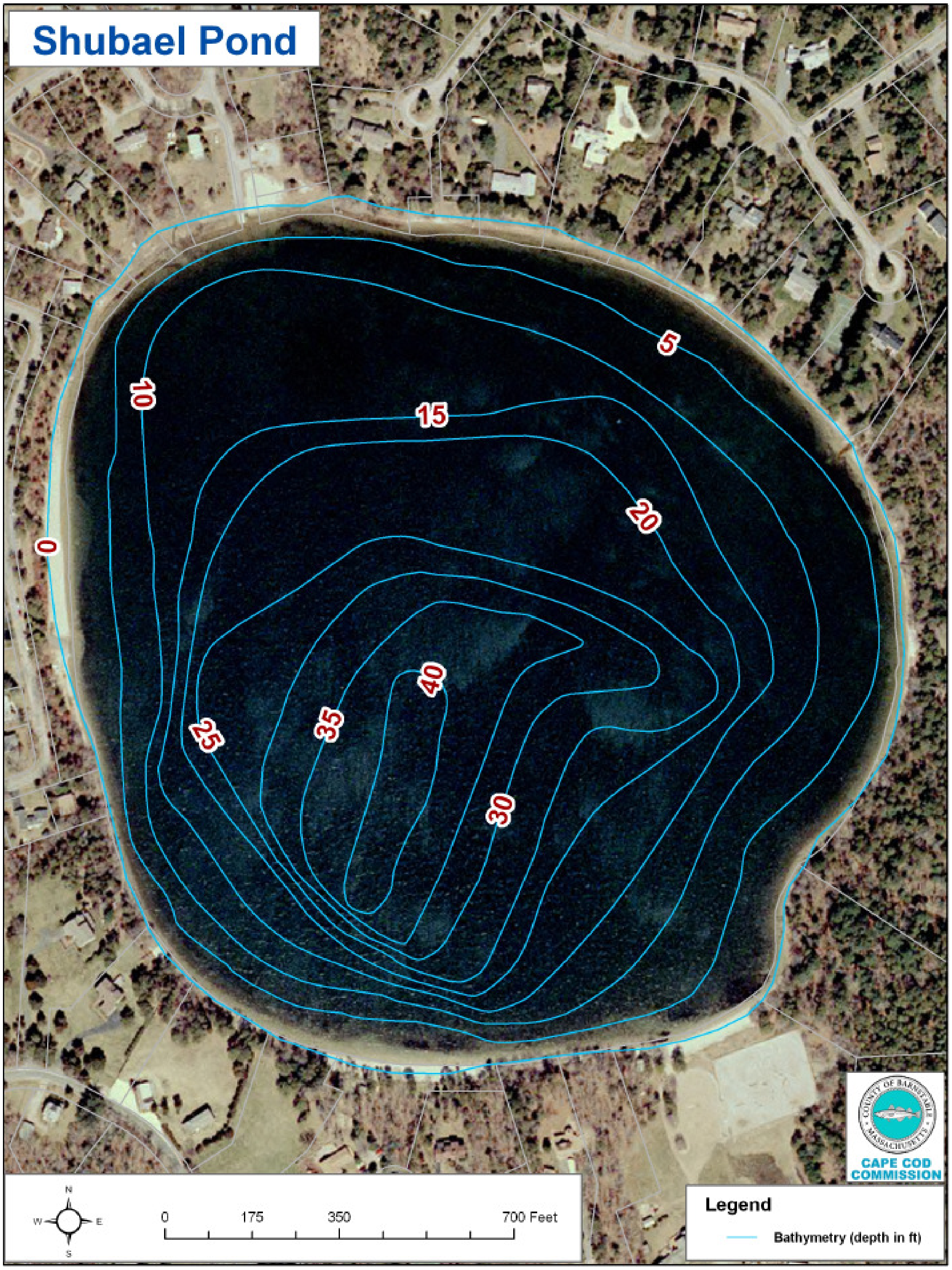
Bathymetric contours data source: MassDFW (available at: http://www.mass.gov/dfwele/dfw/habitat/maps/ponds/pond_maps.htm)



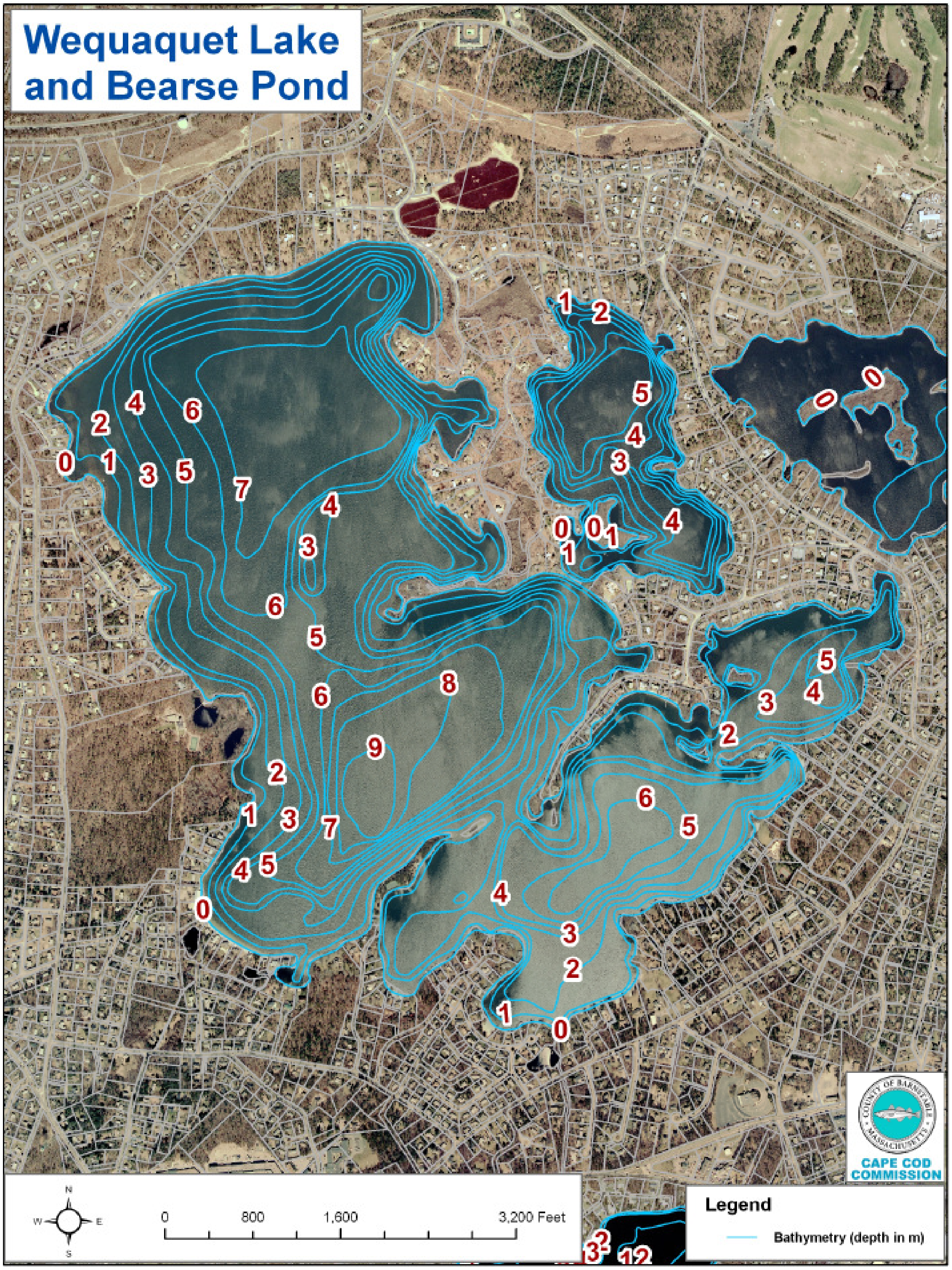
Bathymetric contours data source: K-V Associates, Inc. and IEP, Inc. 1988.



Bathymetric contours data source: K-V Associates, Inc. and IEP, Inc. 1993.



Bathymetric contours data source: MassDFW (available at: http://www.mass.gov/dfwele/dfw/habitat/maps/ponds/pond_maps.htm)



Bathymetric contours data source: IEP, Inc. and K-V Associates, Inc. 1989.

Barnstable Ponds:
Current Status, Available Data, and Recommendations for Future Activities
FINAL REPORT
July 2008

Appendix B

List of Pond Water Quality Data Sources Reviewed

List of pond reports and other sources used to develop the water quality information discussed within this report. Additional sources of data were used to develop some of the physical information about the ponds; these sources are listed in the text of the report.

CODE	Pond	author	year	title
AB77	Aunt Betts	Cullinan Engineering	1977	A Study of the sedimentation of Aunt Betts Pond, Hyannis, Barnstable, MA
IEP89	Bearse	IEP, Inc. and KV Associates	1989	Diagnostic/Feasibility Study, Wequaquet Lake, Bearse and Long Pond, Barnstable, MA
KV85	Bearse	KV Associates	1985	Ltr Report re: Recharge areas for Micah Pond and Bearses Pond taking into account seasonal variation
IEP80	Garrett's	IEP	1980	Baseline Water Quality/Aquatic Biological Studies fo Selected Ponds and Lakes
BEC93	Hamblin	Baystate Environmental Consultants	1993	Diagnostic/Feasibility Study, Hamblin Pond, Barnstable, MA
KV83	Hamblin	KV Associates	1983	Water Quality Evaluation and Recharge Areas Assessment for Lovells, Joshua, and Hamblin Ponds, Barnstable County, MA
BAH	Hamblin	Town Monitoring		Followup WQ monitoring on Alum Treatment since 1995
CCC06	Hamblin	Cape Cod Commission	2006	First Order Assessment of the Indian Ponds
IEP80	Joshua	IEP	1980	Baseline Water Quality/Aquatic Biological Studies fo Selected Ponds and Lakes
KV83	Joshua	KV Associates	1983	Water Quality Evaluation and Recharge Areas Assessment for Lovells, Joshua, and Hamblin Ponds, Barnstable County, MA
IEP79	Lake Elizabeth	IEP	1979	Environmental Assessment Red Lilly Pond/Lake Elizabeth
ACT05	Long	Aquatic Control Technology, Inc	2005	2005 Project Completion Report, Sonar Herbicide Treatment, Hydrilla Control Project, Long Pond, Barnstable, MA
IEP80	Long	IEP	1980	Baseline Water Quality/Aquatic Biological Studies fo Selected Ponds and Lakes
IEP89	Long	IEP, Inc. and KV Associates	1989	Diagnostic/Feasibility Study, Wequaquet Lake, Bearse and Long Pond, Barnstable, MA
KVL82	Long	KV Associates	1982	Environmental Assessment Management Plan for Long Pond (Centerville), Barnstable, MA
KV82	Long	KV Associates	1982	Water Quality Assessment of Six Groundwater Lakes in Barnstable, MA
CCC98	Long	Cape Cod Commission	1998	Lake Wequaquet Water Level Study
IEP80	Long (MM)	IEP	1980	Baseline Water Quality/Aquatic Biological Studies fo Selected Ponds and Lakes
AE97	Lovell's	Ambient Engineering	1997	Diagnostic/Feasibility Study, Lovell's Pond, Barnstable, MA
IEP80	Lovell's	IEP	1980	Baseline Water Quality/Aquatic Biological Studies fo Selected Ponds and Lakes
KV83	Lovell's	KV Associates	1983	Water Quality Evaluation and Recharge Areas Assessment for Lovells, Joshua, and Hamblin Ponds, Barnstable County, MA
BA05	Lovell's	Town appl for EOEA grant	2005	Design and associated material for aeration trmt
IEP80	Micah	IEP	1980	Baseline Water Quality/Aquatic Biological Studies fo Selected Ponds and Lakes
KV85	Micah	KV Associates	1985	Ltr Report re: Recharge areas for Micah Pond and Bearses Pond taking into account seasonal variation
IEP80	Middle	IEP	1980	Baseline Water Quality/Aquatic Biological Studies fo Selected Ponds and Lakes
KV82	Middle	KV Associates	1982	Water Quality Assessment of Six Groundwater Lakes in Barnstable, MA
CCC06	Middle	Cape Cod Commission	2006	First Order Assessment of the Indian Ponds
LA00	Mill	Lycott Associates	2000	Recommendation for treatment for the elimination of rampant aquatic macorphyte growth at Mill Pond, Marstons Mills
IEP80	Mill (West BAR)	IEP	1980	Baseline Water Quality/Aquatic Biological Studies fo Selected Ponds and Lakes
IEP80	Mystic	IEP	1980	Baseline Water Quality/Aquatic Biological Studies fo Selected Ponds and Lakes
KV82	Mystic	KV Associates	1982	Water Quality Assessment of Six Groundwater Lakes in Barnstable, MA
CCC06	Mystic	Cape Cod Commission	2006	First Order Assessment of the Indian Ponds
IEP79	Red Lilly	IEP	1979	Environmental Assessment Red Lilly Pond/Lake Elizabeth
KV88	Red Lilly	KV Associates and IEP, Inc.	1988	Red Lilly Pond Diagnostic/Feasiblity Study
IEP80	Shallow	IEP	1980	Baseline Water Quality/Aquatic Biological Studies fo Selected Ponds and Lakes
KV82	Shallow	KV Associates	1982	Water Quality Assessment of Six Groundwater Lakes in Barnstable, MA
KV93	Shallow	KV Associates and IEP, Inc.	1993	Shallow Pond Diagnostic - Feasibility Study
KV82	Shubael	KV Associates	1982	Water Quality Assessment of Six Groundwater Lakes in Barnstable, MA
LL92	Shubael	Living Lakes, Inc.	1992	Living Lakes Final Report Shubael Pond
CCC98	Wequaquet	Cape Cod Commission	1998	Lake Wequaquet Water Level Study
IEP89	Wequaquet	IEP, Inc. and KV Associates	1989	Diagnostic/Feasibility Study, Wequaquet Lake, Bearse and Long Pond, Barnstable, MA
KV82	Wequaquet	KV Associates	1982	Water Quality Assessment of Six Groundwater Lakes in Barnstable, MA
WLPA	Wequaquet			Field data collected by Wequaquet Lake Protective Association

PALS	Multiple ponds	PALS data		collected between 2001 and 2006; Field data from volunteers; lab data from SMAST, UMASS Dartmouth