Review and Interpretation of Orleans Freshwater Ponds Volunteer Monitoring Data

DRAFT FINAL REPORT

May 2007

for the
Town of Orleans Marine and Fresh Water Quality Task Force
and Barnstable County

Prepared by:

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Prepared By

WATER RESOURCES PROGRAM

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This project was completed using funding from the Barnstable County Growth Management Initiative

Cover photo: Crystal Lake, Orleans (Judy Scanlon, September 2006)

Executive Summary

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The Cape Cod Commission has completed a review of pond monitoring data collected by Town of Orleans monitoring volunteers from 18 ponds between 2000 and 2005. This review has included a detailed review of five ponds selected by the Orleans Marine and Fresh Water Quality Task Force (WQTF): Bakers, Boland, Cedar, Crystal, and Pilgrim. The detailed review included interpretation of available data through the delineation of pond watersheds, development of water and phosphorus budgets, and characterization of the ponds ecological status. This effort included use of revised bathymetric maps that were developed by staff for all 18 ponds based on data collected by WQTF volunteers. The overall project was completed using funding to the Pond and Lake Stewardship (PALS) program from Barnstable County's Growth Management Initiative.

The initial review of data from 18 ponds monitored in Orleans found that 16 of the ponds have ecological impairments and average dissolved oxygen conditions during June through September that are worse than state surface water quality thresholds. In addition, every pond has total phosphorus concentrations exceed the 10 ppb "healthy" Cape Cod threshold developed by the Cape Cod Commission (Eichner, *et al*., 2003).

The detailed review completed for the five selected ponds more thoroughly defined and quantified the extent of the impairments found in the initial review. Detailed review included delineation of watersheds and review of phosphorus loading, as well as more refined reviews of dissolved oxygen and temperature profiles, Secchi transparency readings, and phosphorus concentrations. Development of the watersheds allowed Commission staff to review current and future sources of phosphorus loads. Because phosphorus becomes bound to sand as it travels through the aquifer, phosphorus does not reach a pond until all binding sites are between its source and the pond are used. Therefore, it can take decades for loads from a nearby septic system, for example, to reach a pond shoreline.

The detailed review of the five individual ponds shows that these ponds span a continuum of ecological conditions. Bakers Pond is relatively pristine, although it has some deep-water conditions that warrant additional monitoring. Crystal Lake is relatively impaired, but most of the impairment is deeper in the pond and only occasionally are the impairments seen at the surface. Pilgrim Lake and Boland Pond are impaired with regular mixing of internal sediment-regenerated phosphorus prompting algal growth and near eutrophic conditions. Cedar Pond is significantly impaired, but it has ecological conditions more typical of an estuary and should be addressed following the completion of the Massachusetts Estuaries Project review of Rock Harbor. All ponds, except Bakers, have dissolved oxygen concentrations that are worse than

state surface water minimums. In addition, existing conditions in the four freshwater ponds represent only a fraction of the nutrient loads coming from watershed development; water quality will worsen in time as systems move closer to steady state.

Since the results from the detailed and town-wide data reviews consistently show impairments in almost all of Orleans' ponds, it is recommended that the Town of Orleans consider development of an integrated pond remediation and monitoring program. This program would be tasked with addressing the existing impairments and prevent future impairments of each pond, develop ways to ensure the long term health of these ecosystems, and integrate on-going monitoring to assess long term water quality trends and efficacy of remedial projects.

In order to facilitate the prioritization of Town pond management activities, project staff have developed a series of recommendations regarding each aspect of this proposed effort, including:

1) cutting back monitoring on all 18 ponds that have data to twice a year,
2) completing a detailed review of the data from remaining 13 ponds,
3) reviewing whether any of the additional 40 ponds in Orleans warrant monitoring or additional characterization,
4) developing a process to review remedial options for Crystal, Pilgrim, and Boland,
5) combining the Cedar Pond review in this report with Rock Harbor MEP findings and then developing management and remedial options, and
6) reviewing existing town regulatory and land use regulations to determine whether changes could be made that would benefit the water quality in ponds throughout Orleans.

These recommendations and others are described in more detail in this report. Cape Cod 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.

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I. Introduction

The Town of Orleans has 63 ponds that collectively occupy 220 acres (Eichner, *et al*., 2003). Of these ponds, 40% of them are greater than one acre and four of them are greater than ten acres: Bakers, Cedar, Crystal, and Pilgrim. As population has grown in the town, public concerns about pond water quality have also increased.

These local pond concerns 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 sampling in 2001.

Many towns took the opportunities presented by the annual PALS Snapshots, which have continued from 2001 through 2005, to create, or in the case of Orleans, expand volunteer pond monitoring programs. Orleans volunteers began freshwater pond monitoring in 2000. The Orleans monitoring program has included funding for laboratory analysis of water samples, training of volunteers, and coordination through the town Marine and Fresh Water Quality Task Force (WQTF). The Orleans program uses the PALS sampling protocol as guidance and the collection of samples from 18 of the town's ponds (Figure I-1). Citizen interest in pond water quality has also led to the creation of the Orleans Pond Coalition, an 800-member umbrella organization representing "Friends Of" groups from over 15 salt and fresh water ponds.

During the 2005 discussions of Barnstable County's Growth Management Initiative (GMI), a number of towns requested assistance from the Cape Cod Commission to provide interpretation of the pond water quality data that has been collected by volunteers over the previous years. The Commission and the Town worked together to develop a project to review this data using GMI funding. The project scope included an overall review and interpretation of all volunteer collected pond water quality data and detailed review, including water and phosphorus budgets, of five ponds selected by the Town.

With the assistance of the WQTF, all of the volunteer data was compiled, organized, and reviewed by Commission water resources staff. A preliminary summary of this review was presented at a Task Force meeting on May 17, 2006. In mid-June, the WQTF, in consultation with other concerned citizens and staff, selected the following ponds for the more detailed review: Bakers, Boland, Cedar, Crystal, and Pilgrim (see Figure I-1). The information presented below details the overall review of the volunteer monitoring data, followed by the detailed review of the selected ponds.

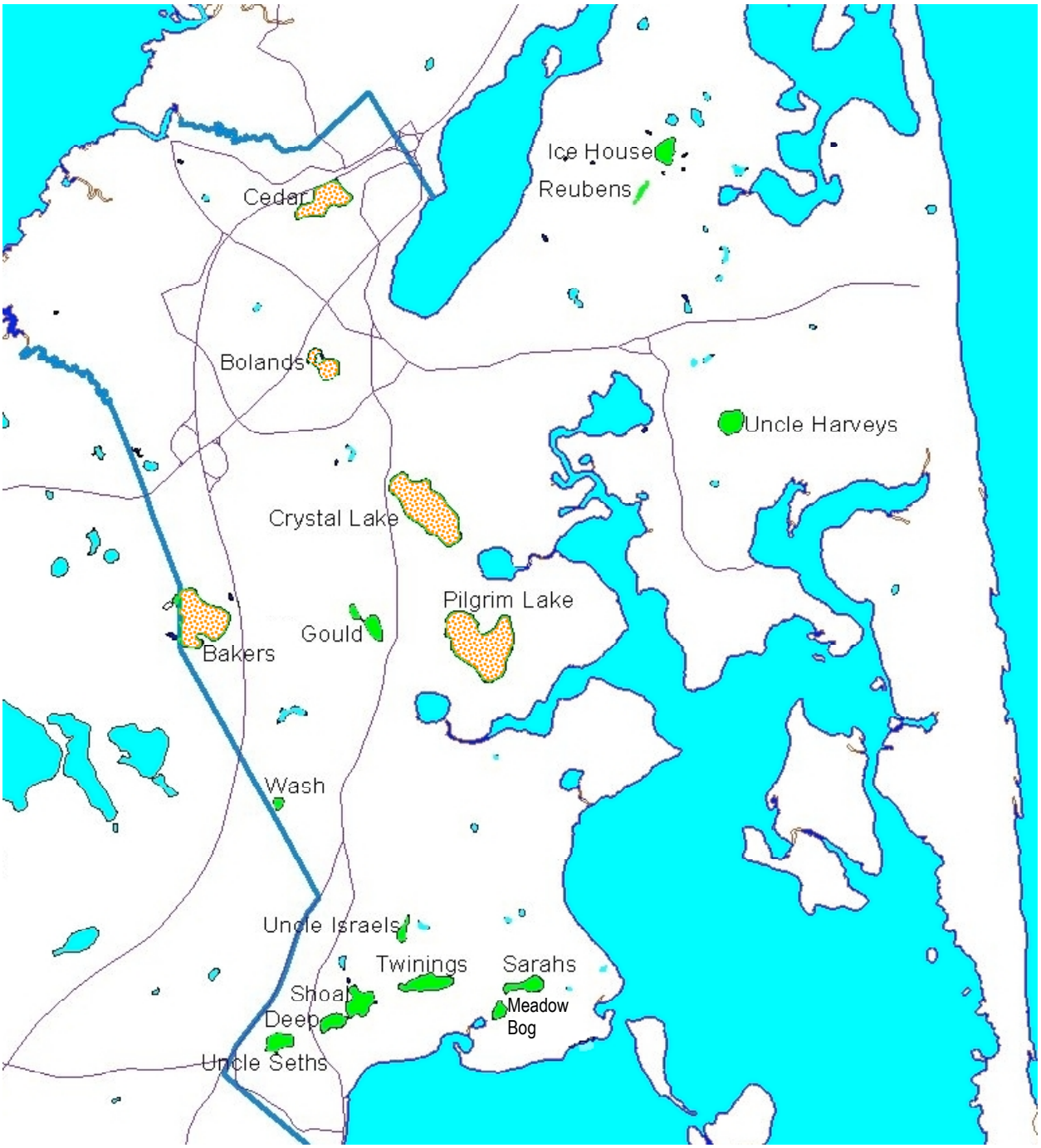


Figure I-1. Ponds regularly sampled by Orleans volunteers
(ponds shown in orange/patterned are the ponds selected for detailed analysis; named ponds have data reviewed in the town-wide analysis)

II. Pond Data Sources

During the initial 2001 PALS Snapshot, Orleans volunteers collected data from 16 ponds. Data for all the ponds has been generally been collected at least twice a year since the initial 2001 PALS sampling with one of the samplings each year being the annual PALS Snapshot. The PALS Snapshots provide free laboratory analyses provided by the SMAST Coastal Systems Analytical Facility Laboratory. Water samples are collected from individual ponds from mid-August through September during the Snapshots. The PALS pond water sampling protocol calls for a shallow (0.5 m) sample and then generally a deep sample 1 m off the bottom for all ponds of 9 m total depth or less; ponds less than 1.5 m should have two samples from the surface collected. Ponds that are deeper than 5 m will have a third sample collected at 3 m (*i.e.*, 0.5 m, 3 m, and one meter off the bottom) and ponds greater than 10 m will have a fourth sample collected at 9 m (*i.e.*, 0.5 m, 3 m, 9 m, and one meter off the bottom). Samples are collected as whole water and transferred to the SMAST lab within 24 hours.

Field sampling procedures under the PALS Snapshot protocol include water column profile measurements of dissolved oxygen and temperature, and Secchi disk transparency. 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 are listed in Table II-1.

Table II-1. Field and laboratory reporting units and detection limits for data collected for the Orleans Ponds under the PALS Snapshots

Parameter	Matrix	Reporting Units	Detection Limit	Accuracy (+\-)	Measurement Range
Field Measurements					
Temperature	Water	ºC	0.5°C	± 0.3 ºC	-5 to 45
Dissolved Oxygen	Water	mg/l	0.5	± 0.3 mg/l or ± 2% of reading, whichever is greater	0 – 20
Secchi Disk Water Clarity	Water	meters	NA	20 cm	Disappearance
Laboratory Measurements - SMAST					
Alkalinity	Water	mg/l as $CaCO_3$	0.5	80-120% Std. Value	NA
Chlorophyll-*a*	Water	μg/l	0.05	80-120% Std. Value	0-145
Nitrogen, Total	Water	μM	0.05	80-120% Std. Value	NA
pH	Water	Standard Units	NA	80-120% Std. Value	0 - 14
Phosphorus, Total	Water	µM	0.1	80-120% Std. Value	NA

Note: All laboratory measurement information from SMAST Coastal Systems Analytical Facility Laboratory Quality Assurance Plan (January, 2003)

In addition to the PALS Snapshots, the Orleans volunteers also benefited from laboratory services provided by the North Atlantic Coastal Laboratory at Cape Cod National Seashore (CCNS). Analysis of samples taken to the CCNS lab includes the following parameters: total nitrogen, total phosphorus, chlorophyll *a*, nitrate-nitrogen, ammonia-nitrogen, and ortho-phosphate. These laboratory services were funded through grants and allowed monthly and bimonthly sampling during the summers of 2002 and 2003. Sampling depths and field data collection procedures generally followed PALS protocols so data could be compared.

Table II-2 shows the ponds sampled and the frequency of sampling events for all the Orleans ponds between 2001 and 2005, including both SMAST and CCNS-supported lab analyses. The data collected during this time period was used for the initial overview of all the ponds that is discussed in Section III. Data collected prior to this period is included in the analyses of the ponds selected for more detail review as discussed in Section V.

III. Town-wide Water Quality Data

In order to complete the town-wide data review, Commission staff organized the data by sampling station according to the PALS sampling protocol. Thus, a pond like Deep Pond that is approximately 6 m deep would have a shallow sampling station at 0.5 m and a deep sampling station that is one meter off the bottom. The deep stations depth would vary due to slight changes in the sampling location and fluctuations in the pond's water level. This review allows comparison between the ponds at the same depth. The analysis also generally 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 ecological significant, as well as when most residents spend time in or on Cape Cod ponds.

III.1. Field Collected Water Quality Data

III.1.1 Dissolved Oxygen and Temperature

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

Oxygen concentrations are also related to the amount of biological activity in a pond. Since one of the main byproducts of photosynthesis is oxygen, a vigorous algal population can produce DO concentrations that are greater than the concentrations that would be expected based simply on temperature interactions alone. These instances of "supersaturation" usually occur in lakes with high nutrient concentrations, since the algal population would need readily available

Table II-2. Ponds sampled for laboratory samples and number of sampling events for Orleans Ponds (2001-2005)

	2001	2002 2002 NPS WQ Sampling								TOTAL 2002	2003 2003 NPS WQ Sampling									TOTAL 2003	2004 NPS			TOTAL 2004	2005 NPS		TOTAL 2005	01-05 TOTAL
POND	PALS Snapshot	PALS Snapshot	May	Jun	Jul	Aug	Sep	Oct	Nov		PALS Snapshot	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov		PALS Snapshot*	Jun	Jul		PALS Snapshot*	May		
Bakers	√	√	1	2	2	2	1	1		10	√			1	2	2	2	2	1	11	√			2	√		1	25
Bolands	√	√		2	2	3	1	1		10	√				1	1	1	1	1	6	√			2	√		2	21
Cedar	√	√		2	2	2	1	1	1	10	√			1			1	1		4	√			2	√		2	19
Chigger										0										0	√			1	√		1	2
Crichetts										0										0	√			1	√		1	2
Crystal	√	√		1	2	2	1		1	8	√		1	1	2	1	1		2	9	√	1	1	4	√	1	3	25
Deep	√	√		1	2	3	1	1		9	√			1	1	1	1	1		6	√			2	√		2	20
Gould	√	√				1				2	√					1				2	√			2	√		2	9
Ice House	√	√		1		1	1			4	√			1	1	1	1	1	1	7	√			2	√		2	16
Kettle							1			2	√			1						2	√			2	√		1	7
Meadow Bog	√	√		1	1	1				4	√	1		1	1	1	1	1		7	√			2	√		2	16
Pilgrim	√	√		1	1	2	1	1		7	√			1	1	1		1	1	6	√			2	√		1	17
Reubens		√				1	1			3	√			1		1				3	√			1	√		1	8
Sarahs	√	√			2	2	1			6	√			1	1	1	1	1		6	√			2	√		2	17
Shoal	√	√		1	2	2	1			7	√			1	1	1	1	1		6	√			2	√		2	18
Twinings	√	√		1	2	2	1			7	√			1	1	1	1	1	1	7	√			2	√		2	19
Uncle Harveys	√	√		1	2	2	1			7	√			1	1	1	1	1		6	√			2	√		2	18
Uncle Israels	√	√			1	1	2			5	√			1			1			3	√			1	√		1	11
Uncle Seths	√	√			2	2	1			6	√			1	1	1	1	1		6	√			2	√		2	17
Wash	√	√				1				2	√					1				2	√			1	√		1	7
# of ponds	16	17	1	11	13	17	15	5	2	109	19	1	1	15	12	15	13	12	6	99	20	1	1	37	20	1	33	294

*Note: Ponds were generally sampled twice during the PALS Snapshot in 2004 and 2005. Additional collection of field measurements (dissolved oxygen and temperature profiles and Secchi transparency readings) without collection of lab samples occurred in 2004, 2005 and 2006. Volunteers also collected water quality data from Bakers Pond in 2000 and 2001 (Eichner, et al., 2001) and Pilgrim and Crystal in 2000 and 2001 (Scanlon and Meservey, 2001).

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 most of the Orleans ponds reviewed in this report.

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 the Orleans Ponds, only Bakers and Crystal are deep enough to have strong stratification of temperature and dissolved oxygen; Pilgrim also develops some stratification, but without 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 throughout the 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.*, like Crystal) and not less than 5.0 mg/l in warm water fisheries (*e.g.*, like Boland). These regulations require that temperature not exceed 68^0F (20^0C) in cold water fisheries or 83^0F (28.3^0C) in warm water fisheries. There are additional provisions in the regulations that allow lower concentrations or higher temperatures if those are natural background conditions.

Dissolved oxygen and temperature concentrations are the most extensive dataset collected by volunteers for the Orleans 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.). For the initial town-wide overview, staff reviewed dissolved oxygen concentrations at the water sample collection depths specified by the PALS protocol. More refined review of the dissolved oxygen and temperature concentrations are detailed for the ponds selected for more in-depth review (see Section V).

Among the 18 ponds in Orleans with volunteer data selected for the town-wide overview, there are 38 station depths where both water quality samples for lab analysis were collected and

dissolved oxygen concentrations were measured between 2001 and 2005. These station depths have between 4 (Wash) and 38 (Bakers) dissolved oxygen readings. Among the 18 ponds, only Bakers, Crystal, and, possibly, Pilgrim would meet the state criteria for a cold water fishery; the remainder of the ponds would be considered warm water fisheries.

Of the 30 station depths in the 16 warm water fishery ponds (including Pilgrim), 15 had average concentrations between June and September less than the state 5 ppm standard for warm water fisheries (Figure III-1). Every warm water pond has a station depth, usually the deepest one, which has average dissolved oxygen concentration less than the state standard except for Meadow Bog. The deep station in Bakers and the two deepest stations in Crystal have average concentrations less than the state 6-ppm cold-water fisheries standard.

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 a pond ecosystem if they occur even once. For example, study 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). 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 15 of the depth stations 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 (see Figure III-1).

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 general 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 were generally collected by Orleans volunteers each time dissolved oxygen and temperature readings were collected; the number of readings ranged between 5 (Wash) and 38 (Bakers). As shown in Figure III-2, among ponds deeper than four feet average readings generally met the state safe swimming clarity limit of 4 feet except for: Kettle (average 0.9 ft Secchi reading), Shoal (2 ft avg), Meadow Bog (2.8 avg), and Cedar (3.36 avg). Six other ponds had at least one reading (*i.e*, minimum reading) less than 4 feet: Uncle Seth, Wash, Boland, Deep, Sarah's, and Twinings. Relative average readings varied between 19% (Kettle) and 78% (Uncle Israel).

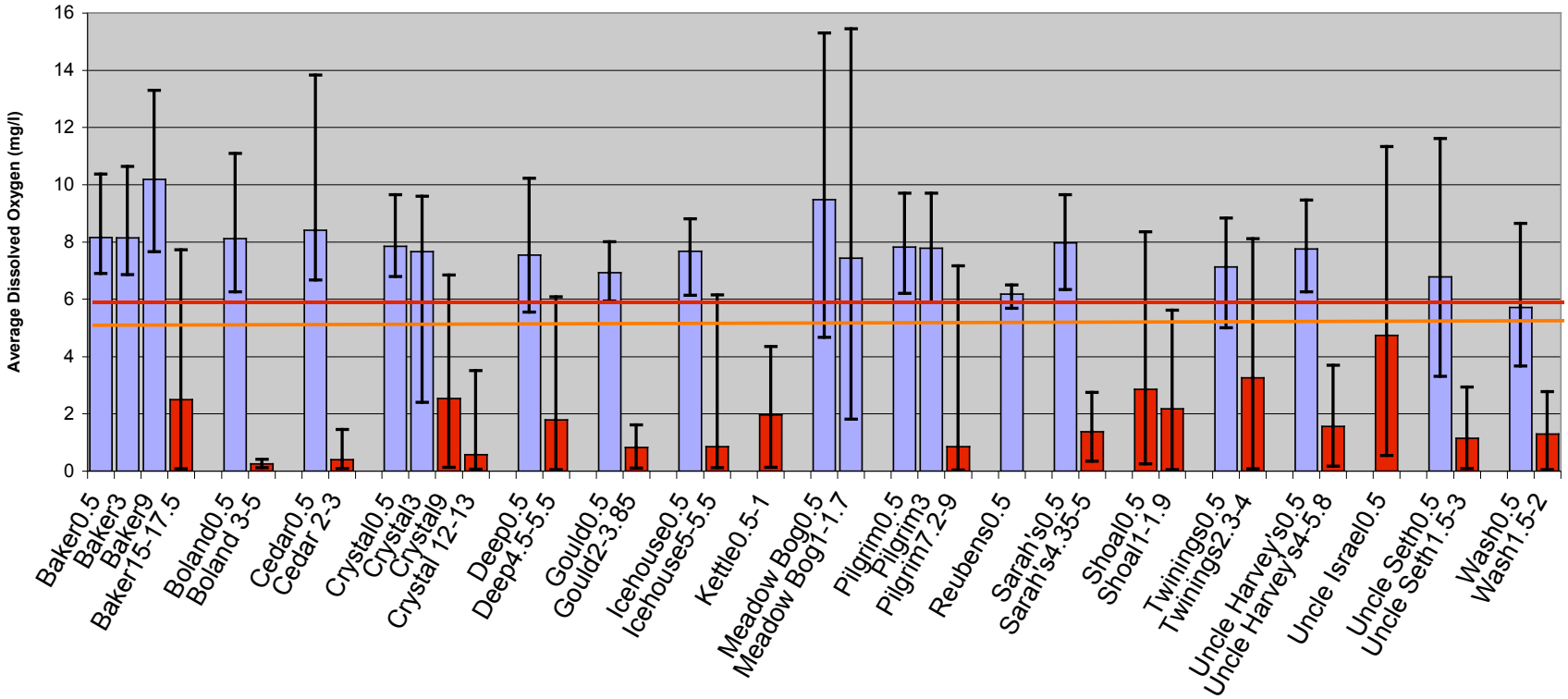


Figure III-1. Average Dissolved Oxygen Concentrations in Orleans Ponds 2001-2005*
Source data is field measurements collected by Orleans volunteers. Station depths (in meters) are same depths where laboratory water samples were collected. Averages are based on data collected between June and September; maximum and minimum concentrations are also identified for each station using error bars. Bars colored red identify stations with average concentrations less than the Massachusetts surface water standards, which are 5 ppm for warm water fisheries and 6 ppm for cold water fisheries. Lines at these concentrations also indicate the state DO standards. *Averages for Bakers, Crystal, and Pilgrim include data from 2000.

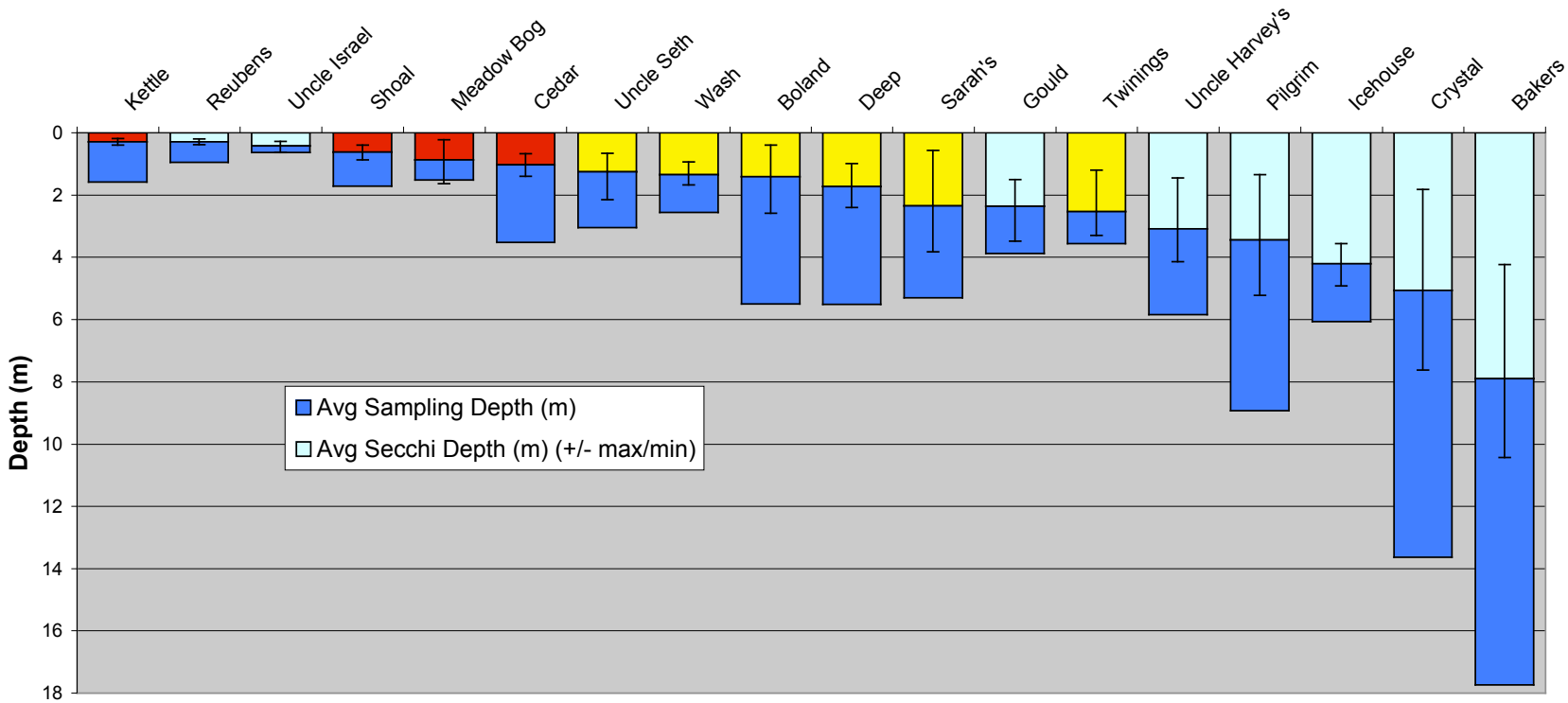


Figure III-2. Average Secchi Transparency Readings in Orleans Ponds 2001-2005*
Source data is field measurements collected by Orleans volunteers. Averages are from data collected between June and September and are corrected for outliers (>±2 std dev); maximum and minimum depths are also identified for each pond using error bars. Bars colored red identify ponds deeper than four feet that have averages less than the state safe swimming standard of 4 ft. Bars colored yellow identify ponds with minimum readings less than four feet. *Averages for Bakers, Crystal, and Pilgrim include data from 2000.

III.2 Laboratory Water Quality Data

As mentioned above, water samples were collected in the ponds at depths generally specified by the PALS Snapshot protocol. The PALS Snapshot protocol specifies a 0.5 m sampling depth in all ponds and a deep sampling depth (1 m off the bottom) for any pond greater than 2 m deep. Additional sampling depths of 3 and 9 m are added as the depth of the pond increases. This protocol anticipates that there should be some variability in the sampling depth, especially the deepest station, because of fluctuations in the water table/surface of the pond. Water samples were generally analyzed at the SMAST Coastal Systems Analytical Facility Laboratory at UMASS, Dartmouth or at the North Atlantic Coastal Laboratory at CCNS. Data from pre-2001 samples used a variety of sampling protocols and labs. Review of laboratory results focused on the following constituents: pH, total nitrogen (TN), total phosphorus (TP), alkalinity, and chlorophyll *a*.

III.2.1 Total Phosphorus (TP)

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

Average TP concentrations at the 38 Orleans pond station depths range between 5.1 (0.5 m station in Bakers) and 459.8 ppb (deep station in Cedar) (Figure III-3). Average surface concentrations in 15 of the 18 ponds exceed the 10 ppb TP regional limit; the three ponds with average surface concentrations less than 10 ppb TP are: Bakers, Crystal, and Icehouse. Two additional station depths in Bakers and one more in Crystal average less than 10 ppb TP. Overall, 32 of the 38 stations have average TP concentrations exceeding 10 ppb while the six stations that are less than 10 ppb also have averages less than the unimpacted 7.5 ppb threshold. These deeper exceedances are likely tied to low oxygen conditions releasing TP from the

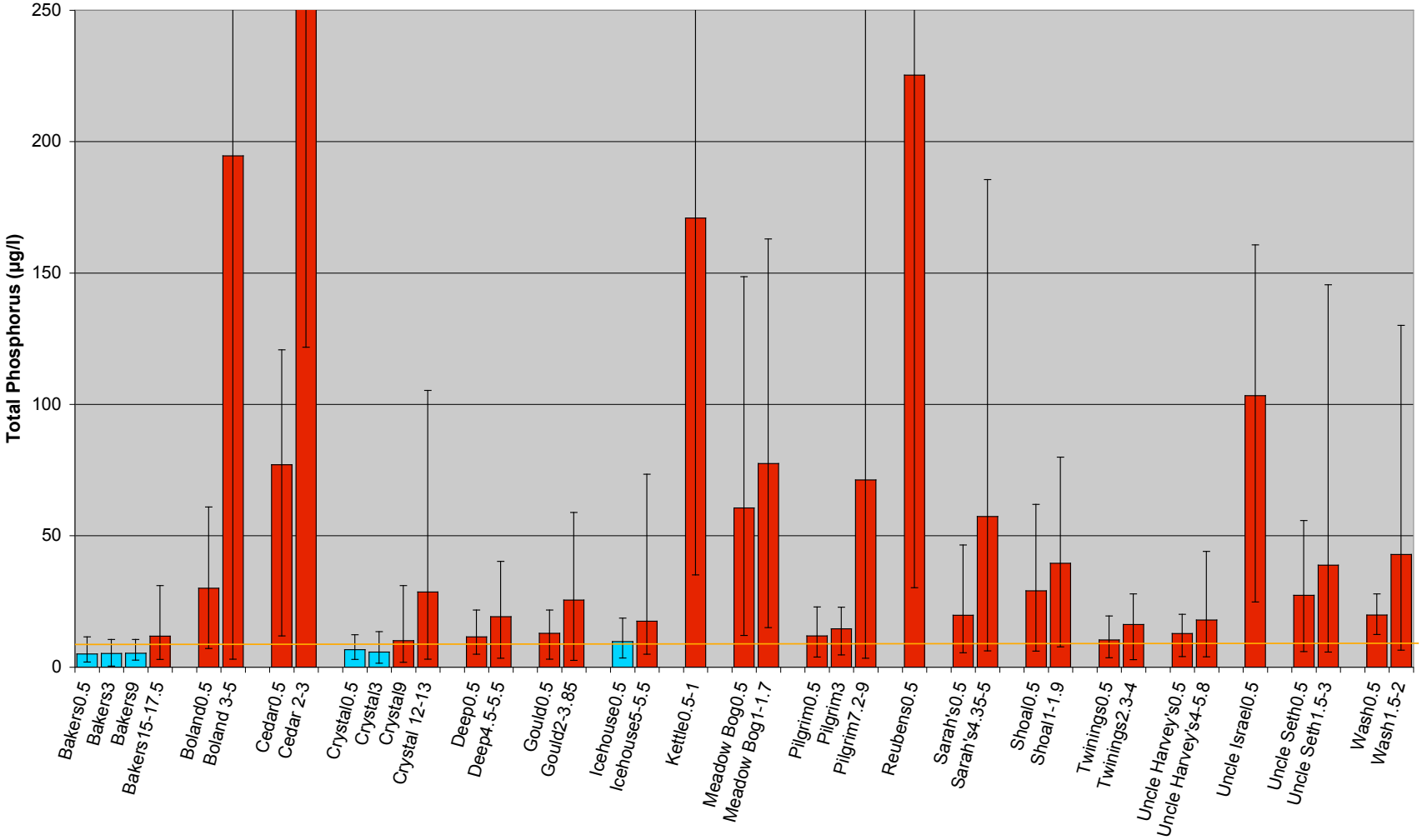


Figure III-3. Average Total Phosphorus Concentrations in Orleans Ponds 2001-2005
Averages are from data collected between June and September and are corrected for outliers (>±2 std dev); maximum and minimum concentrations are identified for each pond depth station using error bars. Cedar Pond deep station average is 460 µg/l with a maximum of 1,291 µg/l; scale is reduced to better show other ponds. Bars colored red identify depth stations with average concentrations exceeding the Cape Cod 10 µg/l TP "healthy" threshold concentration (Eichner, *et al.*, 2003), which is also identified with an orange line. Bars colored blue identify depth stations with average concentrations less than the 10 µg/l TP threshold.

sediments, which in turn are mixed throughout the water column in the ponds that do not thermally stratify.

III.2.2 Total Nitrogen (TN)

Nitrogen is one of the primary nutrients in surface water systems (phosphorus and potassium being the other two). Nitrogen switches between a number of chemical species (nitrate, nitrite, ammonium, nitrogen gas, and organic nitrogen) depending on a number of factors, including dissolved oxygen, pH, and biological uptake (Stumm and Morgan, 1981). Nitrate-nitrogen is the fully oxidized form of nitrogen, while ammonium-nitrogen is the fully reduced (*i.e.*, low oxygen) form. Inorganic nitrogen generally enters 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 measure of organic nitrogen and ammonium forms. Total nitrogen (TN) is generally reported as the addition of TKN and nitrate-nitrogen concentrations.

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

Nitrogen is a primary pollutant associated with wastewater. Septic systems, the predominant wastewater treatment technology on Cape Cod, generally introduce treated effluent to the groundwater with nitrogen concentrations between 20 and 40 ppm: Massachusetts Estuaries Project watershed nitrogen loading analyses use 26.25 ppm as an effective TN concentration for septic system wastewater (*e.g.*, Howes, *et al.*, 2004). As such, 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).

Average TN concentrations at the 38 Orleans pond depth stations range between 0.18 (3 m station in Bakers) and 2.41 ppm (0.5 m station in Reubens) (Figure III-4). The number of surface TN samples among the ponds range from 8 (Reubens and Wash) to 18 (Bakers); surface stations have 14 readings available on average in the June to September analysis period. Average surface concentrations in 16 of the 18 ponds exceed 0.31 ppm; only Bakers and Crystal average TN concentrations are less than the "healthy" limit. The two deeper stations in Bakers and Crystal (3 m and 9 m) have average TN concentrations less than 0.31 ppm. None of the station depths have an average concentration less than the 0.16 ppm TN "unimpacted" threshold. Overall, average concentrations at 32 of the 38 station depths exceed the "healthy" 0.31 ppm TN limit.

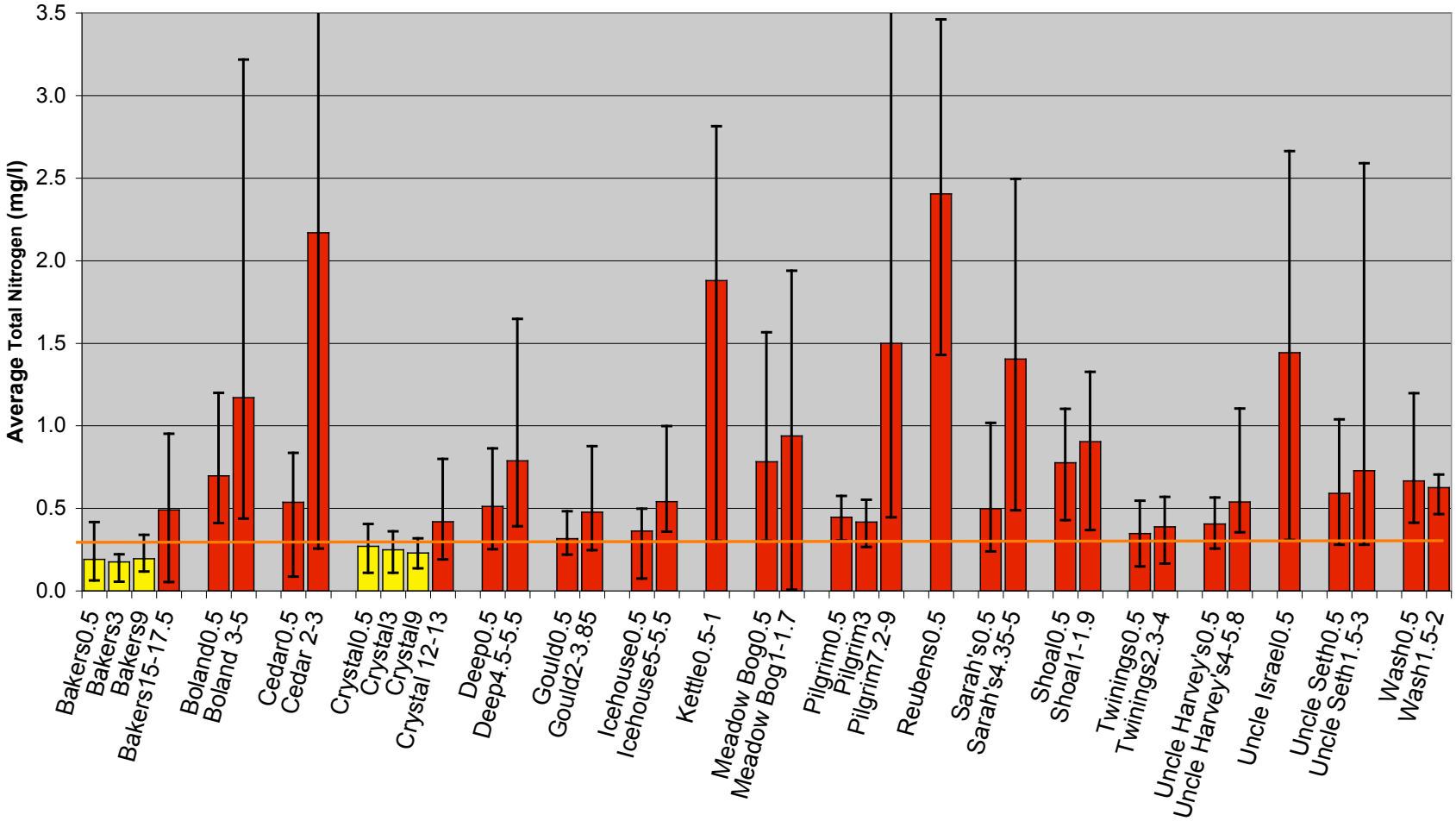


Figure III-4. Average Total Nitrogen Concentrations in Orleans Ponds 2001-2005
Averages are from data collected between June and September and are corrected for outliers (>±2 std dev); maximum and minimum concentrations are identified for each pond depth station using error bars. Bars colored red identify depth stations with average concentrations exceeding the Cape Cod 0.31 ppm TN "healthy" threshold concentration, (Eichner, *et al*., 2003), which is also identified with an orange line. Bars colored yellow identify depth stations with average concentrations exceeding the Cape Cod 0.16 ppm TN "unimpacted" threshold concentration.

III.2.3 Alkalinity and pH

pH is a measure of acidity; pH values less than 7 are acidic, while pH values greater than 7 are basic. pH is the negative log of the hydrogen ion concentration in water (*e.g.*, water with an H^+ concentration = $10^{-6.5}$ has a pH of 6.5). The 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. Alkalinity is a measure of the compounds that shift pH toward more basic values, is mostly determined by the concentrations of bicarbonate, carbonates, and hydroxides, and is a measure of the capacity of waters to buffer acidic inputs (Stumm and Morgan, 1981). Consequently, pH and alkalinity are linked values.

Since the sand deposited as Cape Cod during the last glacial period does not have carbonate minerals, Cape soils 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. The average surface pH of 193 ponds sampled in the 2001 PALS Snapshot is 6.16 with a range of 4.38 to 8.92, while the average alkalinity is 7.21 mg/L as $CaCO_3$ with a range of 0 to 92.1 (Eichner, *et al*., 2003). The lower 25th percentile, or the least impacted ponds, among pH readings from the 2001 Snapshot is 5.62.

Average pH at the 38 Orleans pond depth stations range between 4.9 (0.5 m station in Kettle) and 7.6 (0.5 m station in Meadow Bog) (Figure III-5). Since pH readings tended to only be measured samples taken to the SMAST lab, the number of readings tend to be smaller than readings reported for other constituents; the number of surface pH readings among the ponds range from 5 (Shoal, Wash) to 13 (Bakers). Average surface pH readings in 15 of the 18 ponds exceed 5.62; average surface pH readings below 5.62 are in: Kettle, Shoal, and Wash. Overall 34 of the 38 stations have pH averages exceeding 5.62.

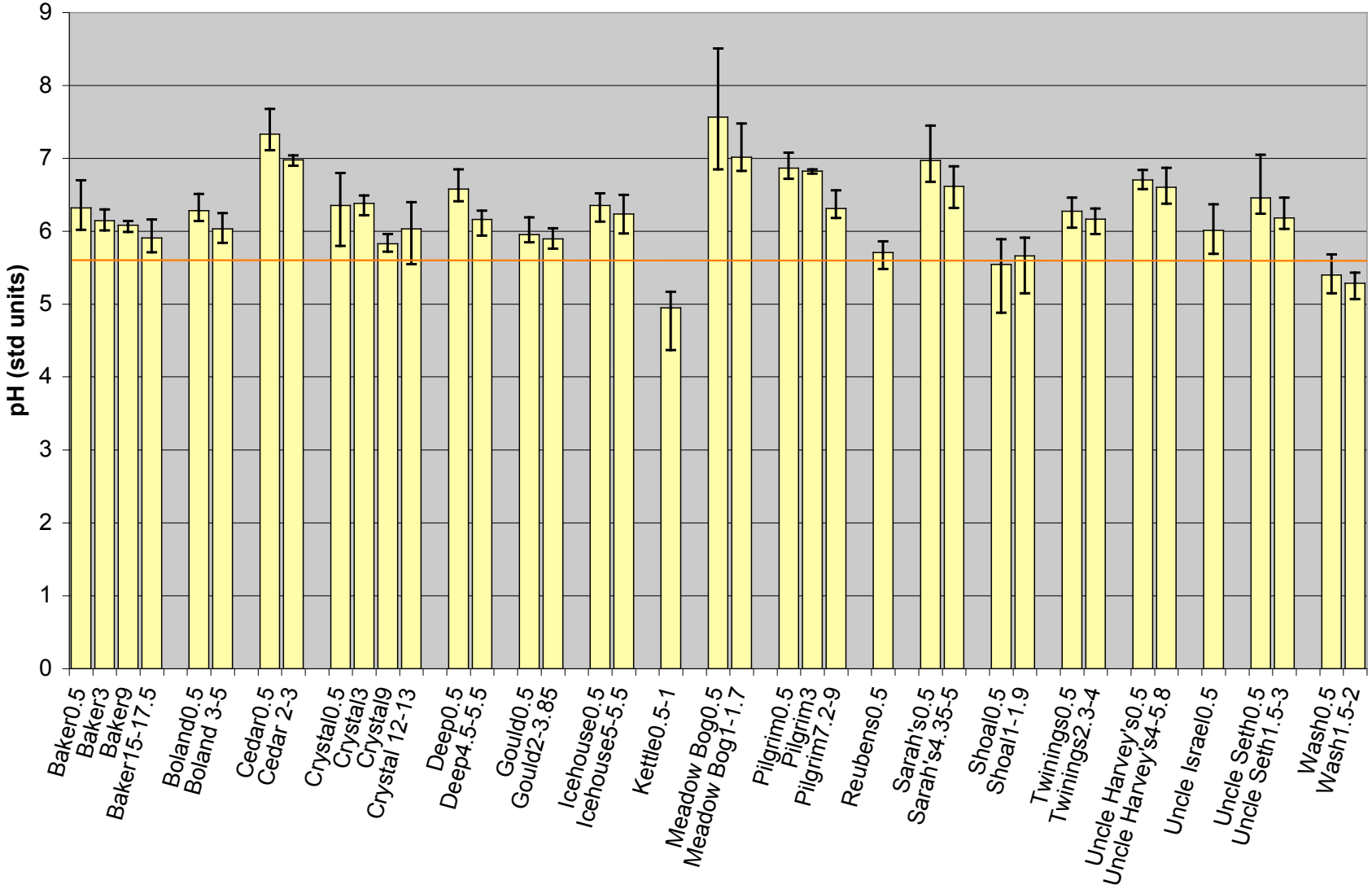


Figure III-5. Average pH in Orleans Ponds 2001-2005

Averages are from data collected between June and September and are corrected for outliers (>±2 std dev); maximum and minimum concentrations are identified for each pond depth station using error bars. Orange line is 5.65, which is the pH of natural rainwater.

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

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

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 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).

Average CHL-a concentrations at the 38 Orleans pond depth stations range between 0.8 (0.5 m station in Bakers) and 111.3 ppb (0.5 m station in Reubens) (Figure III-6). The number of surface CHL-a samples among the ponds range from 7 (Gould and Wash) to 14 (Cedar); surface stations have 10 readings available on average for the June to September analysis period between 2001 and 2005. Average surface concentrations in 17 of the 18 ponds exceed the "healthy" threshold concentration of 1.7 μg/l; the only pond with an average surface CHL-a concentration below 1.7 μg/l is Bakers. The two upper depth stations in Bakers are both below the 1.0 μg/l "unimpacted" threshold concentration. Overall 34 of the 38 depth stations have average CHL-a concentrations greater than 1.7 μg/l with another 3 stations with average concentrations greater than 1.0 μg/l.

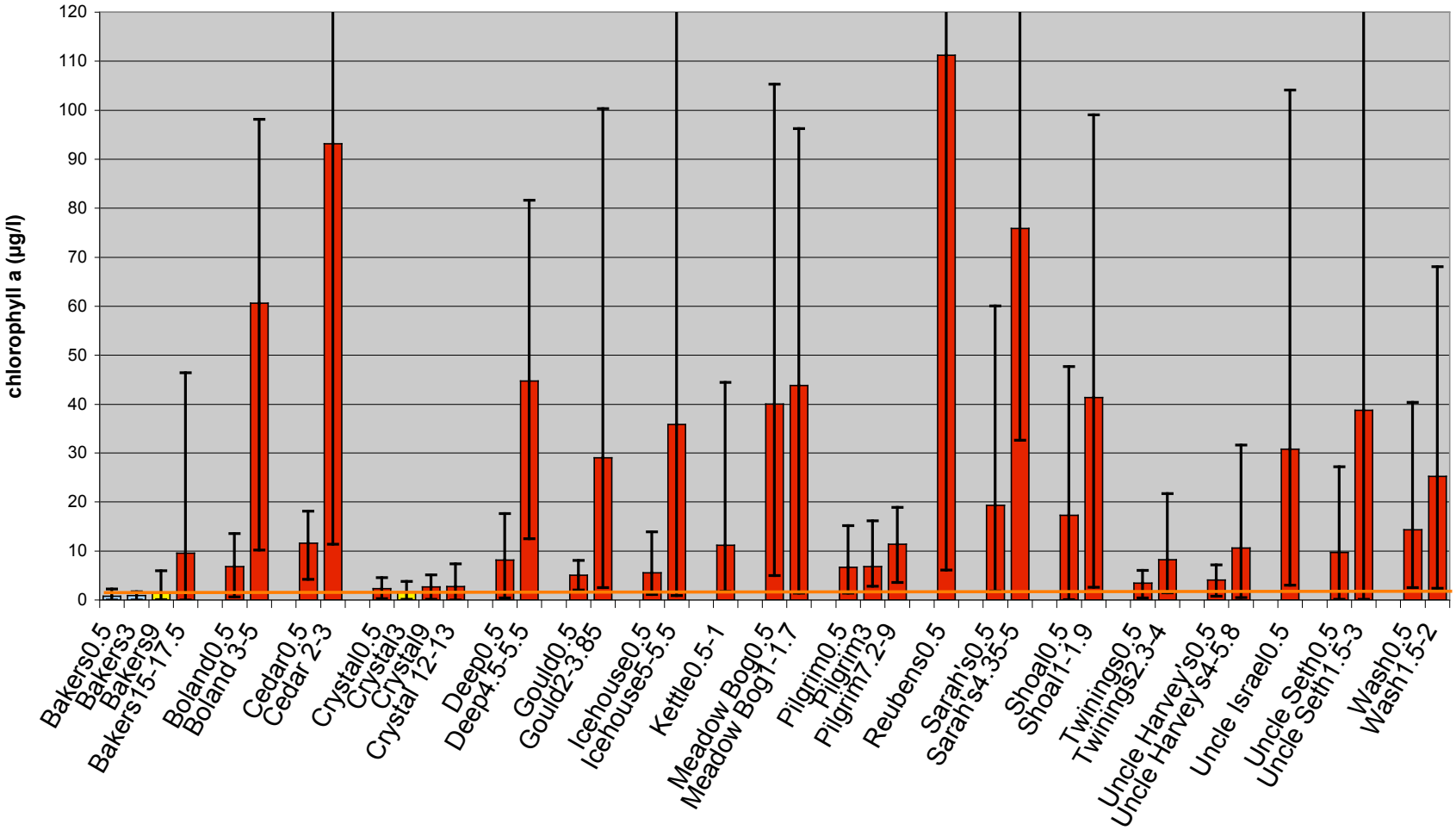


Figure III-6. Average Chlorophyll-*a* Concentrations in Orleans Ponds 2001-2005
Averages are from data collected between June and September and are corrected for outliers (>±2 std dev); maximum and minimum concentrations are identified for each pond depth station using error bars. Scale on y-axis is adjusted to better show detail. Bars colored red identify depth stations with average concentrations exceeding the Cape Cod 1.7 μg/l chlorophyll *a* "healthy" threshold concentration, (Eichner, *et al.*, 2003), which is also identified with an orange line. Bars colored yellow bars identify pond stations with concentrations exceeding the Cape Cod 1.0 μg/l chlorophyll *a* "unimpacted" threshold concentration, while bars colored blue are less than the 1.0 μg/l threshold.

IV. Water Quality Town-wide Overview

IV.1 Trophic Status

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.

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

Subsequent evaluation of Carlson's Index has found that one measure or another is better for use at various times of year (*e.g.*, total phosphorus may be better than chlorophyll at predicting summer trophic state), but the best overall predictor of algal biomass is chlorophyll *a* concentrations (Carlson, 1983). Subsequent uses of the Carlson Index by other investigators have included combining and averaging the various TSI values. Carlson (1983) regards this as a misuse of the indices and states "There is no logic in combining a good predictor with two that are not."

Trophic indices are appropriate for first order comparison among ponds; 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) and may be appropriate for shallow, more naturally productive pond ecosystems.

Figure IV-1 shows the trophic categories based on the average surface chlorophyll *a* concentrations in the Orleans 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, Pilgrim Lake 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. 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 TSI level is classified as oligotrophic (see Table 4 for generalized conditions). Based on the average TSIs, Bakers and Crystal are the only sampled Orleans ponds that are oligotrophic. The remainder is classified as either mesotrophic or eutrophic except for Reubens, which is classified as hypereutrophic.

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

In May 2006, Commission staff presented information on the overview of town-wide data at a regular meeting of the Orleans Marine and Fresh Water Quality Task Force. This presentation included a review of the information presented in the previous section, as well as a comparison among the ponds in order to provide some guidance for the selection of five ponds for more detailed analysis including development of water and phosphorus budgets.

The comparison among the ponds included a review of each of the parameters above and a weighting scheme based on whether the average concentrations exceed the parameter-specific Cape Cod thresholds in the Pond and Lake Atlas (Eichner, *et al.*, 2003). The primary criterion for each of these measures (*e.g.*, average TP concentration greater than 10 ppb) was assigned a value of two in the weighting scheme, while the secondary criterion (*e.g.*, average TP concentration greater than 7.5 ppb) was assigned a value of one. The criteria were reviewed for each sampling station depth and resulting values were summed. Because deeper ponds have more depth stations, this scheme assigns higher potential scores to deeper ponds than shallow ponds.

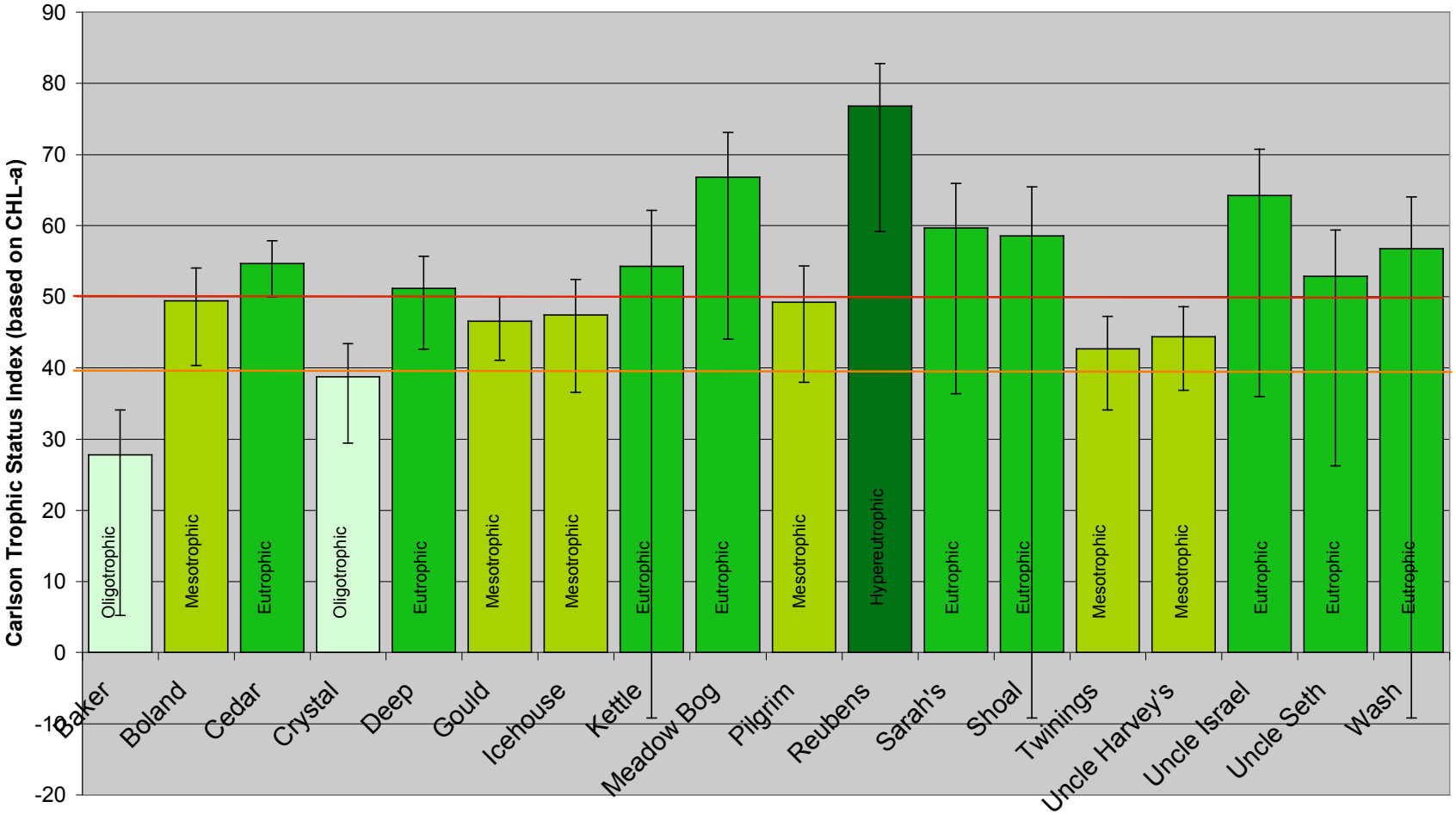


Figure IV-1. Average Trophic Status Index (TSI) in Orleans Ponds 2001-2005
TSI averages are based on chlorophyll *a* data collected between June and September that are corrected for outliers (>±2 std dev); error bars show one standard deviation. TSI based on Carlson and Simpson (1996) for chlorophyll *a*. Trophic classification labels are based on averages; descriptions of labels are detailed in Table IV-1. Orange line is boundary between oligotrophic and mesotrophic classifications; red line is boundary between mesotrophic and eutrophic classifications.

This analysis resulted in a relatively small range and limited differences among the 18 ponds largely because so many of the concentrations exceed the parameter thresholds. The results of this analysis reinforce the conclusion that all of the ponds are impacted. Total phosphorus, total nitrogen, and chlorophyll *a* concentrations show that all of the ponds are impacted. Secchi disk results show that visibility has been a concern for swimming in 11 of the 18 ponds at one time or another. Close review of the dissolved oxygen results show that average conditions in the deep portion of almost every pond are lower than state limits and have regular occurrences of anoxic conditions.

Since most of the ponds are impaired in one way or another, the selection of five ponds for more detailed evaluation could not be based strictly on water quality criteria. Since the Task Force and other Orleans residents could bring additional insights into selection of the ponds, Commission staff worked with the Task Force to select the five ponds for more detailed evaluation.

V. Detailed Pond Evaluations

Following a May 2006 meeting of the Orleans Marine and Fresh Water Quality Task Force, the WQTF selected Bakers, Boland, Cedar, Crystal, and Pilgrim for more detailed review of their water quality (see Figure I-1). The detailed evaluations include delineation of watersheds, incorporation of historic water quality data, development of phosphorus and water budgets, and more refined interpretation of the available water quality data. These evaluations are described in the following sections.

V.1. Setting and Physical Characteristics of Bakers, Boland, Cedar, Crystal, and Pilgrim ponds

The five ponds selected for more detailed review are located in glacial outwash plain referred to as the Harwich Outwash (Oldale, 1977). The outwash plain is mostly sand and gravel, which is overlaid in some areas to the north of the lakes with lake deposits from the proglacial lake that occupied the southern portion of what is now Cape Cod Bay (Oldale, 1971). The glacial sediments were deposited during the last deglaciation of Wisconsinan Stage of the Pleistocene Epoch that occurred in New England approximately 15,000 years ago.

The ponds are groundwater-flooded kettle holes. As the glacial ice sheets melted and receded from southern New England, remnant "dead" ice blocks were buried beneath the sandy outwash deposits from the glacial melt water (Strahler, 1966). When these ice blocks later melted, the overlying sediments collapsed and left large depressions in the landscape. Pollen records from ponds on outer Cape Cod show lake sediments were forming approximately 12,000 years ago (Winkler, 1985). Groundwater levels rose in response to the post-glacial rise in sea level, which is estimated to have attained its modern level approximately 6,000 years ago, (Ziegler, *et al*., 1965).

The Orleans ponds are located in the Monomoy Lens, the second largest of six independent groundwater flow cells that comprise the Cape Cod aquifer. The Cape's groundwater system was designated as the Cape Cod Sole Source Aquifer, by the U.S. Environmental Protection Agency; this designation explicitly acknowledges that the aquifer system is Cape Cod's only source of potable water and somewhat implicitly indicates how all freshwater on the Cape is linked together. The aquifer system is bounded by the water table at its surface, the surrounding marine waters at it margins, and bedrock below (LeBlanc, *et. al.* 1986). The aquifer in the area of the five ponds is up to 400 feet thick and the average groundwater flow rate is approximately one foot per day (Walter and Whealan, 2005).

Pilgrim Lake is the largest (43.3 acres) of the five ponds selected for detailed review. It is situated to the east of Bakers and Crystal and south of Boland and Cedar. Bakers Pond is 28.9 acres, is the deepest of the five ponds, and straddles the town boundary between Orleans and Brewster. Crystal is the second largest of the lakes (37 acres), while Cedar is 15.1 acres and Boland is 4.7 acres.

Bathymetric information was developed by Orleans pond volunteers during 2005-2006 using integrated depth and GPS recording. The raw depth and GPS data were forwarded to the Cape Cod Commission and refined by staff using GIS techniques and Surfer graphing software to develop depth contours. These depth contours are the basis for the pond volumes shown in Table V-1 and the bathymetric maps and volume calculation results are included in Appendix A.

Table V-1. Physical Characteristics of Bakers, Boland, Cedar, Crystal, and Pilgrim ponds

Pond	PALS Pond unique ID	Area	Volume	Residence Time	Deepest Point
		Acres	Cubic meters	Years	Feet
Bakers	OR-167	28.9	809,172	1.18	64
Boland	OR-136	4.7	41,378	0.35	21
Cedar	OR-122	15.1	113,371	0.18	15
Crystal	OR-153	37.0	976,344	1.15	49
Pilgrim	OR-176	43.3	770,730	0.51	34

Notes: 1) Volume and areas developed by Cape Cod Commission staff based on data collected by Orleans volunteers using integrated depth and GPS, 2) PALS ID is a unique identification assigned to each pond by the Cape Cod Commission under the Pond and Lake Stewardship (PALS) program (Eichner, *et al*., 2003).

Water quality in Bakers Pond was reviewed as part of a water quality assessment completed for the Town by the Cape Cod Commission (Eichner, *et al*., 2001) and this data was incorporated into a similar review that also looked as water quality in Pilgrim and Crystal later in the same year (Scanlon and Meservey, 2001). Data from these analyses are reviewed in the detailed review of these ponds.

V.2. Watershed Delineation and Water Budgets

A pond water budget accounts for the volume of water in the pond and the flows of water entering and leaving the pond. In kettle hole ponds, typically groundwater enters the pond along one shoreline (*i.e*., the upgradient side) and pond water reenters the aquifer system along the opposite shoreline (*i.e*., the downgradient side). Bakers Pond functions in this way. In some cases, kettle ponds have small streams entering or leaving them; Cedar Pond has a tidally-influenced stream under Route 6 on its downgradient side. Generally, a pond surface on Cape Cod is a reflection of the level of the water table. Groundwater flows according to the regional hydraulic gradient starting at the top of the Monomoy Lens near Long Pond where it is 32 feet above mean sea level to Pilgrim Lake at 8 feet.

On Cape Cod, groundwater flow lines may be projected upgradient from ponds, perpendicular to these water table contours, to delineate recharge areas to the ponds or estuaries (*e.g*., Cambareri and Eichner, 1998). Assuming uniformly distributed groundwater recharge across watersheds, watershed areas are directly proportional to the flux of water through those watersheds. Therefore, the areal extent of the upgradient watershed is a function of how much water is flowing into a pond. Using these basic understandings of the system, hydrologists can organize site-specific information about a groundwater system to develop a model to help develop a more refined understanding of interactions between ponds, estuaries, public water supplies, and the groundwater system.

The United States Geological Survey (USGS) has recently released a revised version of a regional Cape Cod groundwater model that includes the Orleans area (Walter and Whealan, 2004). This model incorporates information characterizing groundwater levels, municipal drinking water supply pumping, stream flow measurements, and geologic information developed over a number of decades. The model relies on the USGS three-dimensional, finite-difference

groundwater model MODFLOW-2000 (Harbaugh, *et al*., 2000) and the USGS particle-tracking program MODPATH4 (Pollock, 1994). MODPATH4 uses output files from MODFLOW-2000 to track the simulated movement of water in the aquifer and was used to delineate the area at the water table that contributes water to wells, streams, ponds, and coastal water bodies. The model simulates steady state, or long-term average, hydrologic conditions including a long-term average recharge rate of 27.25 inches/year and the pumping of public-supply wells at average annual withdrawal rates for the period 1995-2000 with a 15% consumptive loss. This recharge rate is based on the most recent USGS information. Average pumping rates (1995 to 2000) for the public water wells in Orleans and Brewster area are used as part of the dataset for the development of the model.

This USGS regional groundwater model incorporates selected ponds and can reasonably model their "flow-through" characteristics. With this in mind, the USGS model was used to delineate watersheds to four of the five ponds selected for more detailed review and model results were then refined to better reflect shoreline configuration and measured streamflow information. Boland Pond was not specifically incorporated into the groundwater model; its watershed delineation is based on best professional judgment about its size, depth, position in the aquifer, and delineations from similar size ponds (Figure V-1). Watersheds to Bakers, Crystal and Pilgrim were previously reviewed as part of the Massachusetts Estuaries Project Technical Report on Pleasant Bay (Howes, *et al*., 2006).

As indicated in Figure V-1, ponds closer to the edge of the aquifer (in this case, the shore of Pleasant Bay) often receive flow from an upgradient pond. A portion of the flow from these upgradient ponds (*e.g*., Little Cliff Pond) can discharge into the watershed of a downgradient pond (*e.g*., Bakers Pond), while another portion can flow into another watershed (*e.g*., Higgins Pond). In order to calculate the amount of recharge or annual flow out of each pond, project staff determined the length of the downgradient shoreline of each pond. Discharge out of the pond was then split among all the downgradient watersheds receiving flow based on the percentage of the total shoreline length. For example, 21% of the shoreline and groundwater flow from Little Cliff Pond is discharged to the watershed to Bakers Pond, while 49% of the flow is to Higgins Pond, 13% to the Cliff Pond wellfield in Orleans and the remainder flows out of the Pleasant Bay watershed.

Since recharge drives movement of groundwater within the aquifer system, annual recharge within each watershed is equivalent to the flow of groundwater discharge out of each watershed. This recharge was then compared with the volume of each pond and a residence time for water in each of the ponds was determined. This data is then compared to observed nutrient concentrations as a check on its reliability.

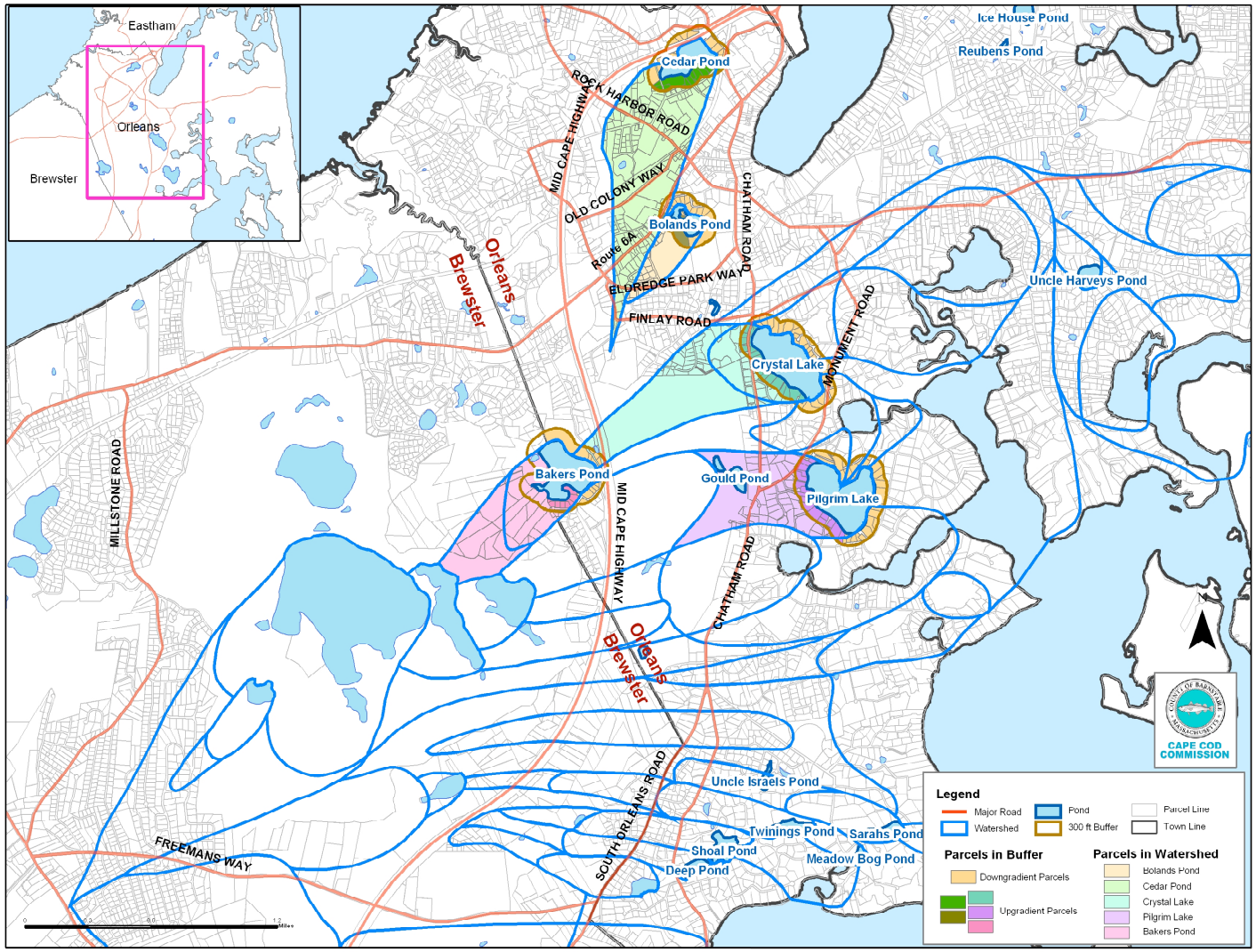


Figure V-1. Orleans Pond Watersheds: Bakers, Boland, Cedar, Crystal, and Pilgrim
Watersheds to ponds based on refinements of US Geological Survey model outputs; watersheds corrected to better address pond shorelines. Watersheds to Bakers, Crystal, and Pilgrim were developed as part of the Massachusetts Estuaries Project Technical Report for Pleasant Bay (Howes, *et al.*, 2006). Other subwatersheds to the Pleasant Bay system are also shown.

The preceding analyses are based on output from the USGS groundwater flow model as it is currently configured. Parameters and assumptions imposed on the model result in a simulation that suggests that water does not underflow Bakers, Crystal or Pilgrim, *i.e.,* all upgradient groundwater flows into the pond system, while upgradient water flows under Boland. In the case of Bakers, Crystal, and Pilgrim, this scenario would mean that groundwater at bedrock, hundreds of feet below the water table, would surface into the ponds. Addition of new water supply wells in the area would have the potential to alter watershed delineations and these alterations could be evaluated using the model. Additional wells in the area or better streamflow information would also add additional site-specific data that can be used to refine the watershed delineations presented in this report.

This report's revision of the watershed to Crystal Lake is an example of how new data helps to alter characterizations of these systems. An earlier watershed delineation for Crystal Lake was completed by the Cape Cod Commission (Scanlon and Meservey, 2001) using an annual depression rate method and water table information developed by the Commission for the town (Leab, *et al.*, 1995). The annual depression rate method uses the maximum or average depth of a pond and available water table information to determine a flowpath that would intersect the selected depth. The upgradient location at which this flowpath intersects the top of the water table is the maximum extent of the watershed to the pond. Flowpaths from the lateral extents of the pond are drawn back to this point and the land area between the maximum extent and the pond is the estimated watershed. Comparison of watersheds determined using this method and those developed by USGS modeling have generally shown that the modeled watersheds tend to be significantly larger. Subsequent comparisons of residence times based on these watersheds to available water quality data have also shown that the groundwater modeling results provide better match (Eichner, *et al.*, 2006). Additional site-specific hydrogeologic data collection would be necessary to further refine groundwater flowpaths in this area.

A water budget summarizes all the water inputs and outputs of a pond and, because the pond volume is relatively stable, makes sure that the inputs and outputs balance. In the case of the Orleans Ponds selected for more detailed evaluation, the predominant input and output is groundwater with additional inputs from precipitation and additional outputs from evaporation. Streamflow is an additional component for selected ponds (*e.g.* Pilgrim), but this data has generally not been collected. In equation form, a water budget is typically represented as:

$$IN = OUT + \Delta S, \qquad (1)$$

Where,
IN = groundwater inflow + precipitation
OUT = groundwater discharge + stream flow + evaporation
ΔS = the amount of water storage gained or lost as water levels increase or decrease, respectively.

As mentioned above, groundwater levels and pond levels of Cape Cod ponds tend to fluctuate together; so long-term decreases in the volume of a pond tend to be accompanied by equivalent changes in the amount of groundwater inflow and outflow. Shorter term events, such as individual storms, can change the storage, but in a way that is quickly assimilated by the

aquifer and has little impact on the overall annual water budget. Because of this relationship, the storage component of the water budget equation is removed and equation (1) is simplified to:

$$IN = OUT \qquad (2)$$

Groundwater is generally greater than 80% of the inflow portion of the water budget for all the ponds (Table V-2). The "IN" portion of the budget is determined by the recharge within the watersheds shown in Figure V-1, precipitation on the surface of the ponds, and precipitation on road surfaces that are generally inside a 300 ft buffer to the pond, but outside of the watershed. The precipitation on roads outside of the watershed is included because available, albeit not comprehensive, evaluations of stormwater systems around these ponds generally show road drainage systems are designed to discharge into the ponds (*e.g.*, Town of Orleans, 2003).

Recharge and precipitation rates are based on the recent USGS review in support of the regional groundwater model development (Walter and Whealan, 2004). This evaluation showed annual precipitation ranging between 26 inches in 1965 and 74 inches in 1972 with an average of 44 inches. Using available hydrogeologic data, Walter and Whealan (2004) estimated annual recharge to groundwater through land surfaces to be 27.25 inches and through ponds to be 15.8 inches. Ponds have higher evapotranspiration because of the exposure of the water surface to sunlight and wind, as well as plant biota transpiration.

In the preparation of the "OUT" portion of the budget, the difference between precipitation (44 in/y) and the net pond recharge (15.8 in/y) is the amount of evapotranspiration. Stream outflows are based on stream measurements collected as part of the Massachusetts Estuaries Project evaluations of Pleasant Bay (Howes, *et al*., 2006) and the draft information for Rock Harbor (in development, Roland Samimy, SMAST, personal communication). Groundwater outflow is determined by subtracting the sum of evaporation and streamflows from the sum of the "IN" portions of the budget.

Results from the water budget estimates generally show that groundwater is the dominant component of both inflow and outflow from the ponds, except for Cedar Pond. The estimate for Cedar shows that all of inflow into the pond except for evapotranspiration flows out through the stream into Rock Harbor. This finding is consistent with the presence of salinity in Cedar; it functions more as a terminal discharge area and part of the estuary system than as a freshwater pond. For the other ponds, estimated groundwater outflow is approximately the same as groundwater inflow, which is consistent with the general concept that these ponds are flow-through portions of the groundwater aquifer system. Pilgrim is a slight except because it has a stream flowing out of it, but even in its case, groundwater is the dominant portion of the outflow out of the system.

Table V-2. Estimated water budgets for Orleans Ponds selected for detailed review.

Water Budget

Pond	PALS #	Area	IN		OUT			Storage Volume
			GW	Precipitation	GW	Evaporation	Stream	
		m2	m3/y	m3/y	m3/y	m3/y	m3/y	m3
Baker	OR-167	116,741	605,513	130,469	652,363	83,619		809,172
Boland	OR-136	19,034	110,918	25,598	122,882	13,634		41,378
Cedar	OR-122	61,015	592,475	76,671	(9,265)	43,704	634,706	113,371
Crystal	OR-153	149,676	739,856	174,568	807,214	107,210		976,344
Pilgrim	OR-176	175,272	1,374,173	198,484	1,089,048	125,544	358,065	770,730

Pond	PALS #	Area	IN		OUT		
			GW	Precipitation	GW	Evaporation	Stream
		m2	m3/y	m3/y	m3/y	m3/y	m3/y
Baker	OR-167	116,741	82%	18%	89%	11%	
Boland	OR-136	19,034	81%	19%	90%	10%	
Cedar	OR-122	61,015	89%	11%	-1%	7%	95%
Crystal	OR-153	149,676	81%	19%	88%	12%	
Pilgrim	OR-176	175,272	87%	13%	69%	8%	23%

note: PALS# is unique identifier developed for each pond on Cape Cod by the Cape Cod Commission under the Pond and Lake Stewardship (PALS) program. Precipitation portions of the "IN" budget include estimated runoff from road areas within 300 ft, but outside of the watershed. Streamflow information is based on Massachusetts Estuaries Project data: a) Pilgrim flow is likely high since the gauge was far enough downstream that additional groundwater input was captured, b) Cedar flow is based on preliminary data from Rock Harbor analysis; groundwater outflow is shown to be negligible.

V.3. Phosphorus Budget Factors

Just as a water budget accounts for all the water coming into and leaving a pond, a phosphorus budget does the same for phosphorus. Biomass in pond and lake ecosystems is usually limited by a key nutrient; if more of the nutrient is available the biomass will increase. In ponds and lakes, the key nutrient is usually phosphorus; rapid introduction of phosphorus usually leads to algal blooms, while more gradual increases can prompt the change in the dominant plant community from one dominated by algae to one dominated by rooted plants. Overall, addition of phosphorus increases the biomass in a lake and excessive phosphorus leads to excessive plant growth the decay of which in the sediments overwhelms natural regeneration and burial processes and leads to anoxic sediment conditions (Wetzel, 1983). One way to assess whether a lake is limited by phosphorus is to review the balance between phosphorus and nitrogen; as a rule of thumb, if the ratio between nitrogen and phosphorus is greater than 16, phosphorus is the limiting nutrient (Redfield, *et al.*, 1963). Because phosphorus is usually the key nutrient, lake scientists usually develop a phosphorus budget to quantify the primary sources and, if there are water quality problems, to develop targeted strategies to reduce the loads from these sources.

As groundwater flows into Cape Cod ponds along the upgradient shoreline, it brings with it contaminants from the pond watershed, including phosphorus. Phosphorus is chemically more stable in well-oxygenated waters if it is bound with iron (Stumm and Morgan, 1981). Because of this, phosphorus associated with small sources, like septic systems, moves very slowly (~1 m/yr) in groundwater systems, like the Cape, where iron coats sand particles that make up most of our aquifer (*e.g.*, Robertson, *et al.*, 1998). By contrast, nitrogen, which is generally present in the Cape's groundwater system in its nitrate form, flows with the groundwater, which generally moves 1 ft/d (or 111 m/yr). Because of the slow movement for phosphorus, most of the sources

of phosphorus entering Cape Cod ponds is from properties abutting the pond shoreline; previous analysis of Cape Cod ponds have focused on properties within 250 to 300 ft of the shoreline (*e.g.*, Eichner, *et al*., 2001; Eichner, *et al*., 2006).

For the five Orleans ponds selected for more detailed review, project staff began the development of the watershed portion of the phosphorus budget by asking Orleans Marine and Fresh Water Quality Task Force (WQTF) members and other volunteers to review town Board of Health records to determine the distance from the pond shorelines to septic system leachfields, pits and cesspools on properties within 300 ft of the pond shorelines. Volunteers were also asked to determine the age of the wastewater systems and the age of the buildings connected to these systems. The Town Planning Department and Board of Health staff assisted the volunteers during the review of the records and by preparing maps and accompanying spreadsheets listing all parcels within or partially within the 300 ft buffer. Project staff also encouraged volunteers to note large potential nutrient sources outside of the 300 ft buffer area, as well as seeking out historic information on past land uses that might still have some impacts on the currently observed water quality in the five selected ponds.

The lists of properties within 300 ft of the shorelines were then adjusted to focus on properties on the upgradient sides of the ponds (Figures V-2 and V-3). Aerial photographs of the properties were reviewed and non-wastewater loads were only assigned to developed properties with houses or other structures within the 300 ft buffer and upgradient, or within the watersheds, to the ponds. For the purposes of reviewing wastewater sources, all discharge structures on upgradient properties within or partially within the 300 ft buffer were included in the calculations. Properties included in the loading calculations were adjusted, as described below, based on best professional judgment of likely groundwater flow characteristics near the ponds. Phosphorus loads were developed based on the factors in Table V-3. Details of the phosphorus loading are discussed in the individual pond sections below.

Table V-3. Watershed Loading Factors for Phosphorus Budget

Factor	Value	Units	Source
Wastewater P load	1	lb P/septic system	MEDEP, 1989
Road surface P load	5.3	lb P/ac	MEDEP, 1989
Roof surface P load	3.5	lb P/ac	MEDEP, 1989
Natural Areas P conc.	0.014	mg P/l	BEC, 1993
Recharge Rate	27.25	in/yr	Walter and Whealan, 2005
Precipitation Rate	44	in/yr	Walter and Whealan, 2005
Building Area	2,000	ft2	Eichner and Cambareri, 1992
Road Area	Actual value	ft2	Mass. Highway Information
Lawn Factors			
Area per residence	5,000	ft2	Eichner and Cambareri, 1992
Fertilizer lawn load	0.3	lb P/ac	MEDEP, 1989
Waterfowl Factors			
P load	0.156	g/m2/yr	Scherer, *et al*., 1995
New P load	13	%	Scherer, *et al*., 1995

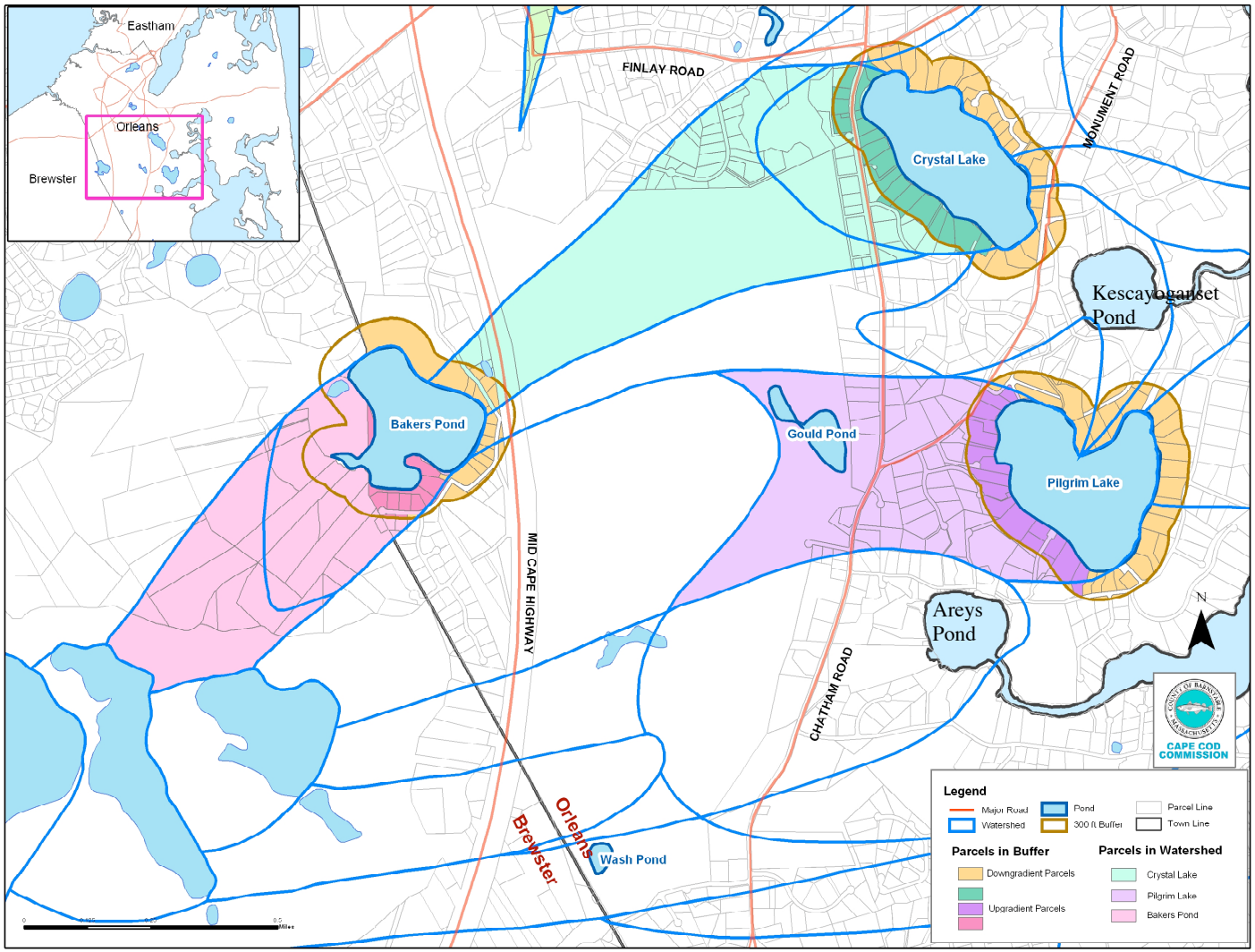


Figure V-2. Parcels considered in pond watershed phosphorus loading estimates: Bakers, Crystal, and Pilgrim. Properties upgradient of the ponds are shown in darker versions of the watershed colors; these parcels are included in the watershed phosphorus loading estimates. Parcels on the downgradient side of the ponds, but within a 300 ft buffer are colored tan; these parcels are not included in the watershed phosphorus loading estimates except for stormwater loads from roads in these areas. Parcel information was supplied by the towns.

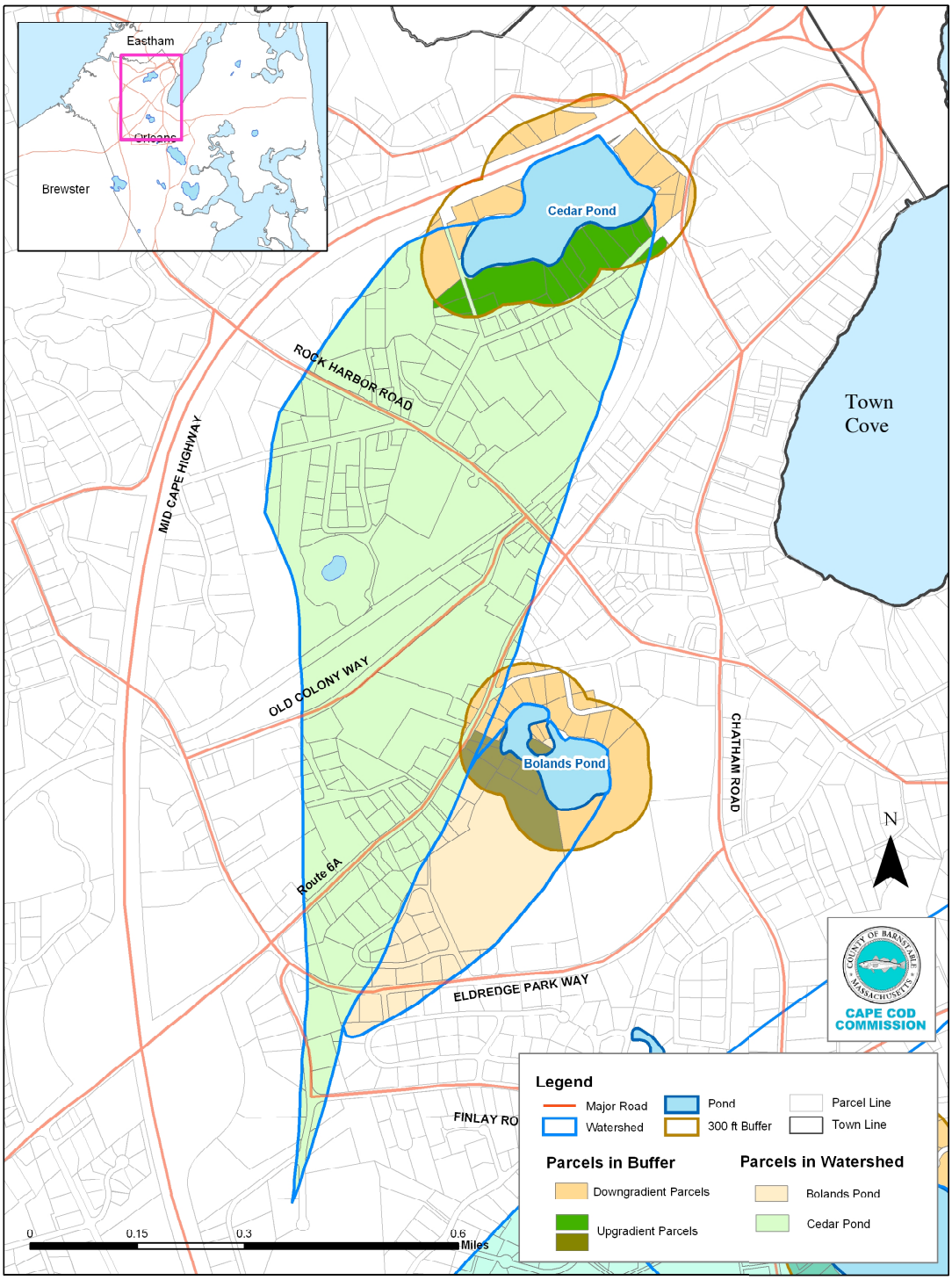


Figure V-3. Parcels included in pond watershed phosphorus loading estimates: Boland and Cedar.

Properties upgradient of the ponds are shown in darker versions of the watershed colors; these parcels are included in the watershed phosphorus loading estimates. Parcels on the downgradient side of the ponds, but within a 300 ft buffer are colored tan; these parcels are not included in the watershed phosphorus loading estimates except for stormwater loads from roads in these areas. Parcel information was supplied by the towns.

VI. Individual Pond Reviews

VI.1. Bakers Pond

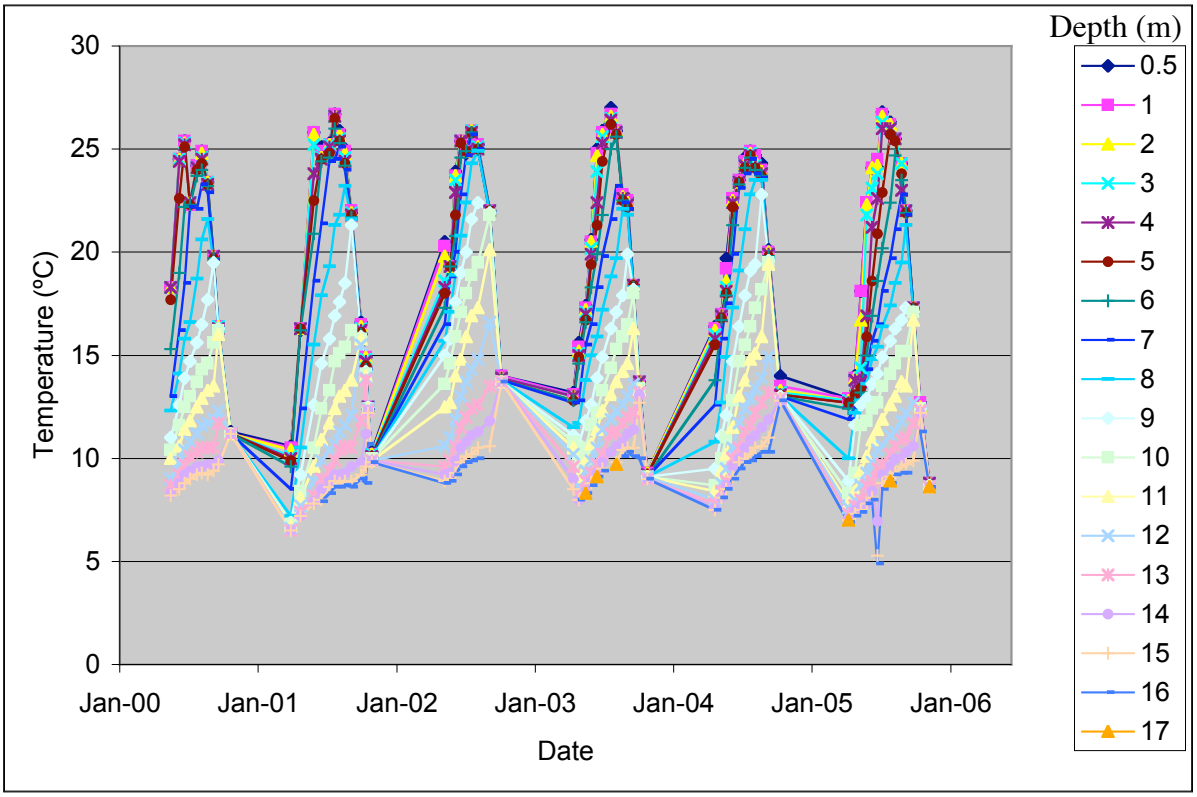
Bakers Pond is a 28-acre pond that straddles the border between Orleans and Brewster (see Figure V-2). It is the deepest of the ponds selected from detailed review; its deepest point is 64 ft. Bakers Pond had previous monitoring during 2000 (Eichner, *et al.*, 2001). Given its depth, it thermally stratifies usually starting in late May/early June (Figure VI-1). The upper layer continues to warm throughout the summer and this warmth is mixed into the upper layer (*i.e.*, the epilimnion). This warmer layer gradually thickens and deepens, generally starting with the upper 4 m in June and extending to 7 or 8 m by September. Once stratification sets up, oxygen consumption from the sediments regularly creates anoxic (<1 ppm) conditions in the lower layer (*i.e.*, the hypolimnion). By the end of September/early October, when thermal stratification begins to breakdown, anoxic conditions can reach as high as 12 m in depth.

Since Bakers Pond thermally stratifies, it has the potential to sustain a cold-water fishery. State surface water regulations (314CMR4) require cold-water fisheries to attain a 6 ppm dissolved oxygen standard. State standards also define cold-water fisheries as having temperatures less than 20ºC.

Based on average conditions for June through September on data collected between 2000 and 2005, the 6-ppm standard is usually met down to a depth of 10 m (Figure VI-2). Waters 12 m and deeper are less than the 6 ppm standard the majority of the time between June and September. On average, approximately 6% of the pond volume fails to meet the 6-ppm DO standard (Figure VI-3). Since temperatures on average exceed 20ºC at depths at 7 m and above, the potential cold water fishery is depth 8 m and below. Between the temperature and dissolved oxygen standards, the average cold water fishery is between depths of 8 and 10 m. This volume is approximately 69% of the potential cold-water fishery.

Dissolved oxygen conditions have definitely worsened since the 1948 sampling done by the Massachusetts Division of Fisheries and Game (MADFG, 1948). Figure VI-2 also shows an August 18, 1948 dissolved oxygen profile that was collected by during a survey of 51 Cape Cod ponds and lakes by MADFG. The 1948 profile shows dissolved oxygen conditions meeting state standards (>6.0 ppm) to a depth of 45 ft (13.7 m). As noted in Figure VI-2, the average DO concentration between June and September between 2000 and 2005 at 14 m is 2.6 ppm.

Secchi readings average 7.4 m between June and September (n=44) during the 2000-2005 dataset (Figure VI-4). Average sampling station depth is 17.73 m and on average 44% of the overall water depth is clear enough at the sampling station to see a Secchi disk. Both Secchi and station depth have upward trends; these trends match the increasing groundwater levels during the same time (Cape Cod Commission files). Increasing groundwater levels would tend to increase the pond volume, dilute phosphorus loads and algal populations, and lead to greater transparency. The rise in water levels would also result in deeper station readings. Secchi readings have an overall range from 3.27 to 10.43 m.



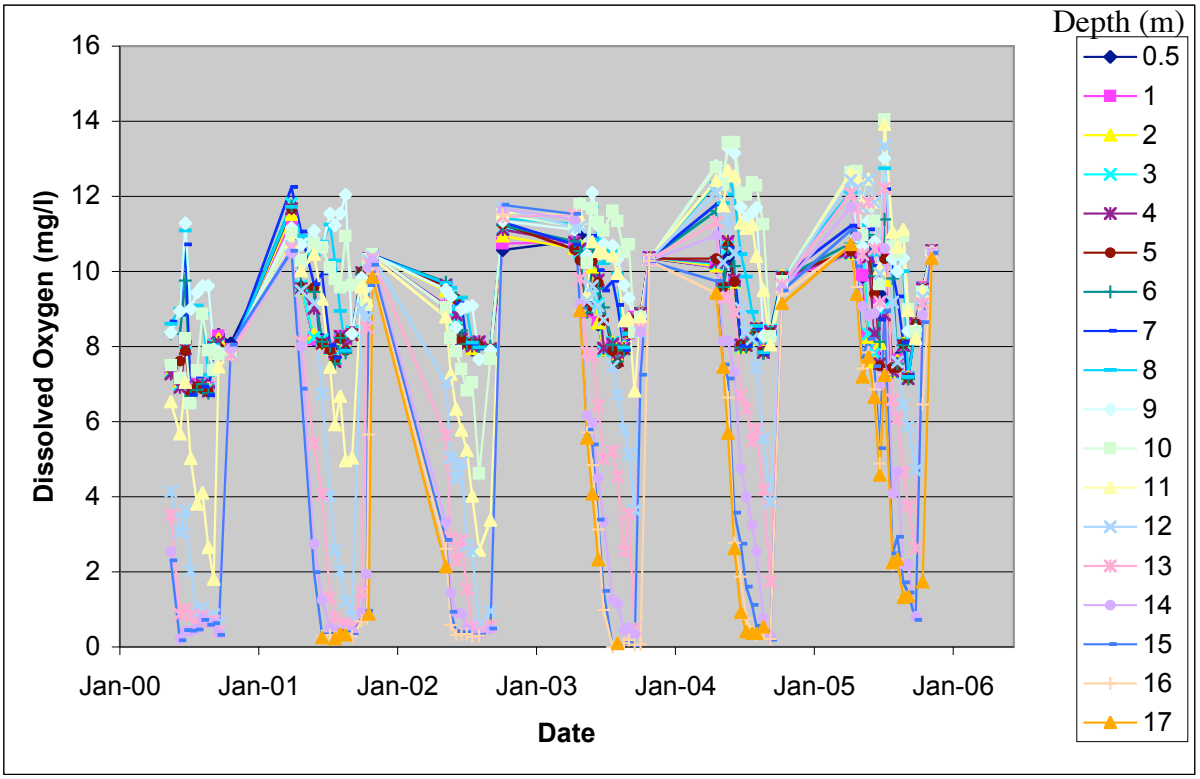


Figure VI-1. Bakers Pond Temperature and Dissolved Oxygen Measurements 2000-2005
Data collected by Orleans volunteers. These graphs include data documented in Eichner, *et al.* (2001) and PALS Snapshots from 2001 to 2005.

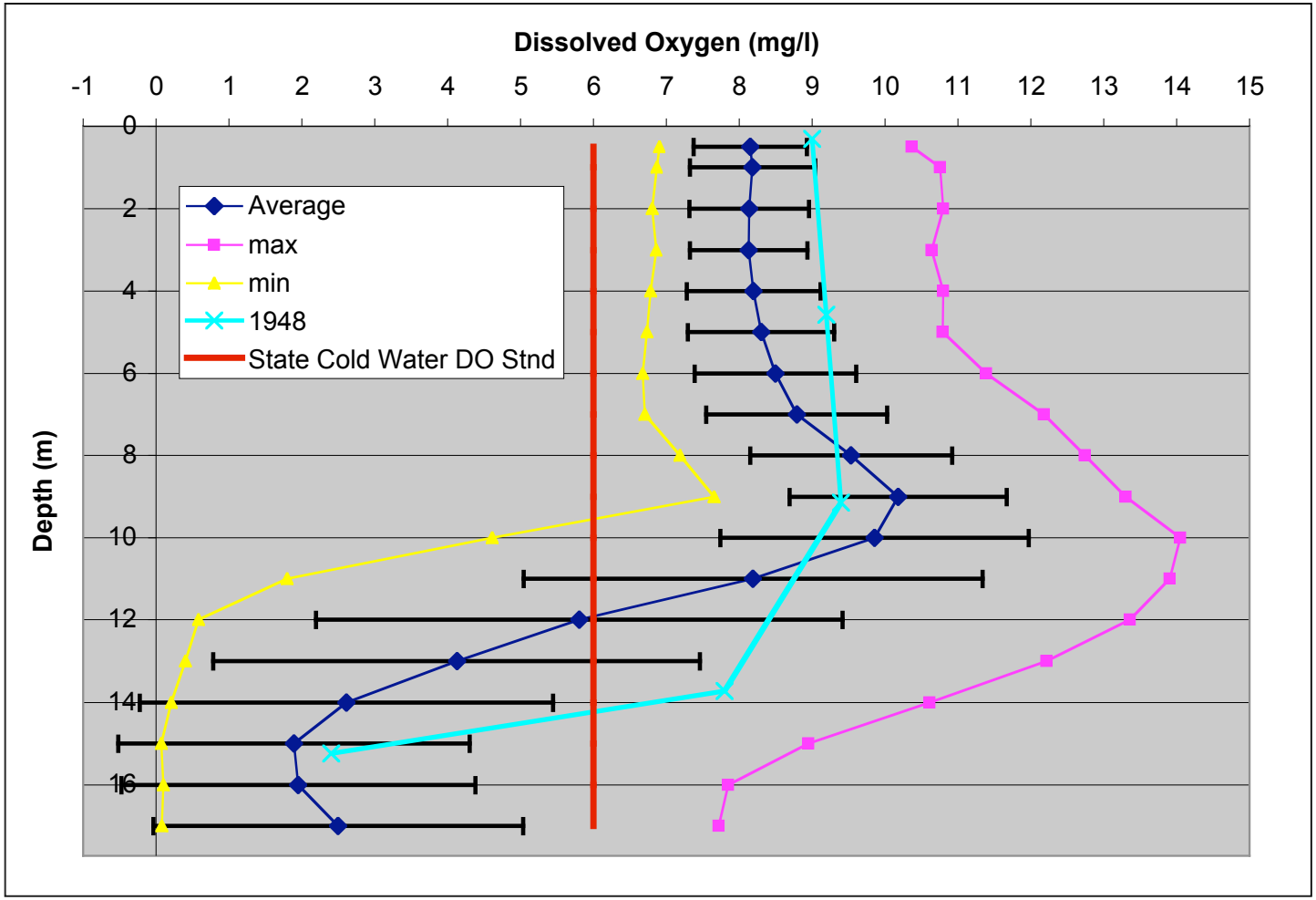


Figure VI-2. Average dissolved oxygen concentrations in Bakers Pond June through September 2000-2005
Graph shows average DO profile with error bars (±1 standard deviation) plus maximum and minimum readings for each depth. Also shown is August 19, 1948 profile and the state surface water 6-ppm DO standard for cold water fisheries. Most depths have 46 readings.

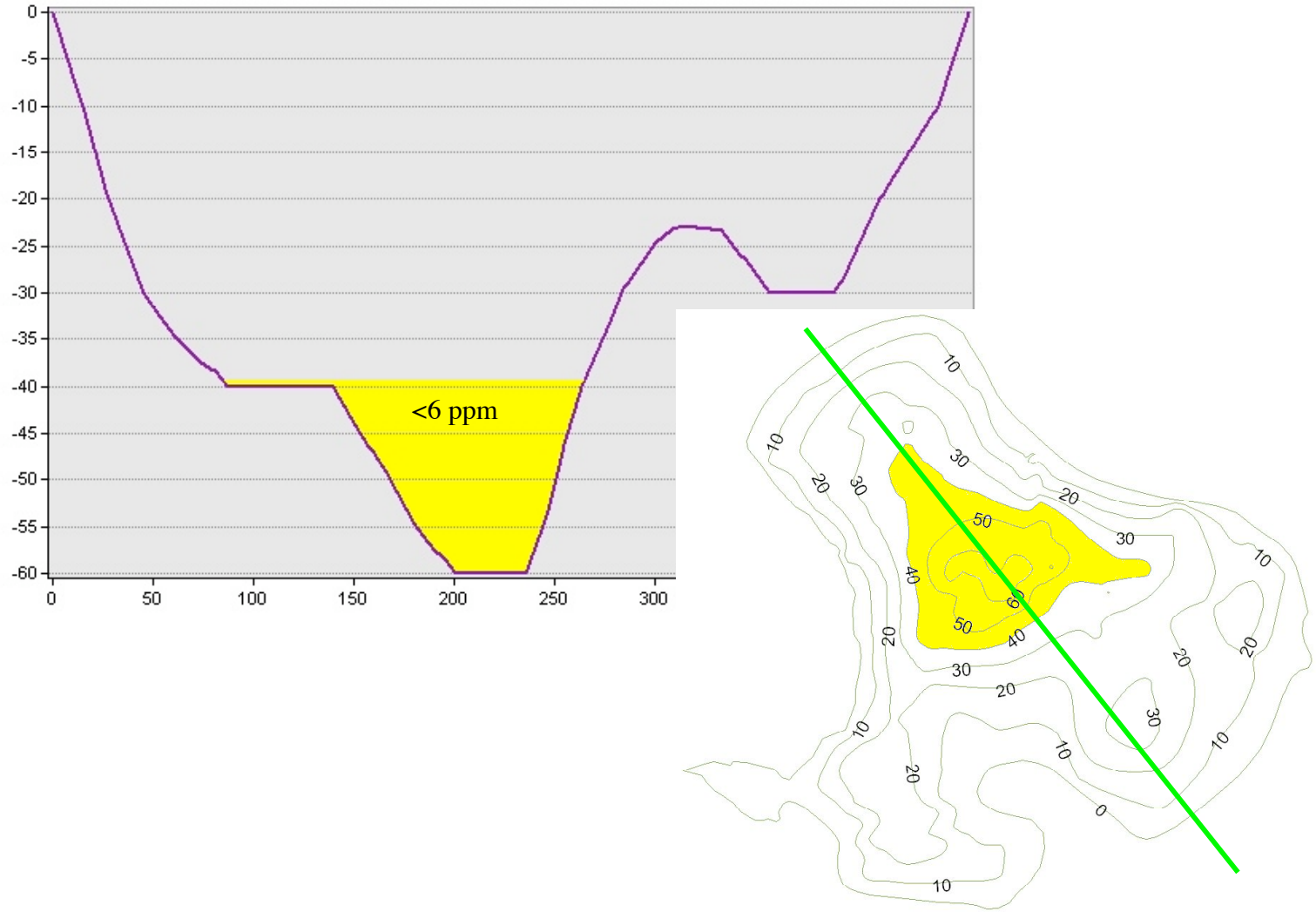


Figure VI-3. Baker Pond Average Dissolved Oxygen and State Surface Water Standards
Depth profile and map show portion of Baker Pond that averages between June and September less than the state surface water 6-ppm DO standard for cold water fisheries. Green line on map shows depth profile track through the pond.

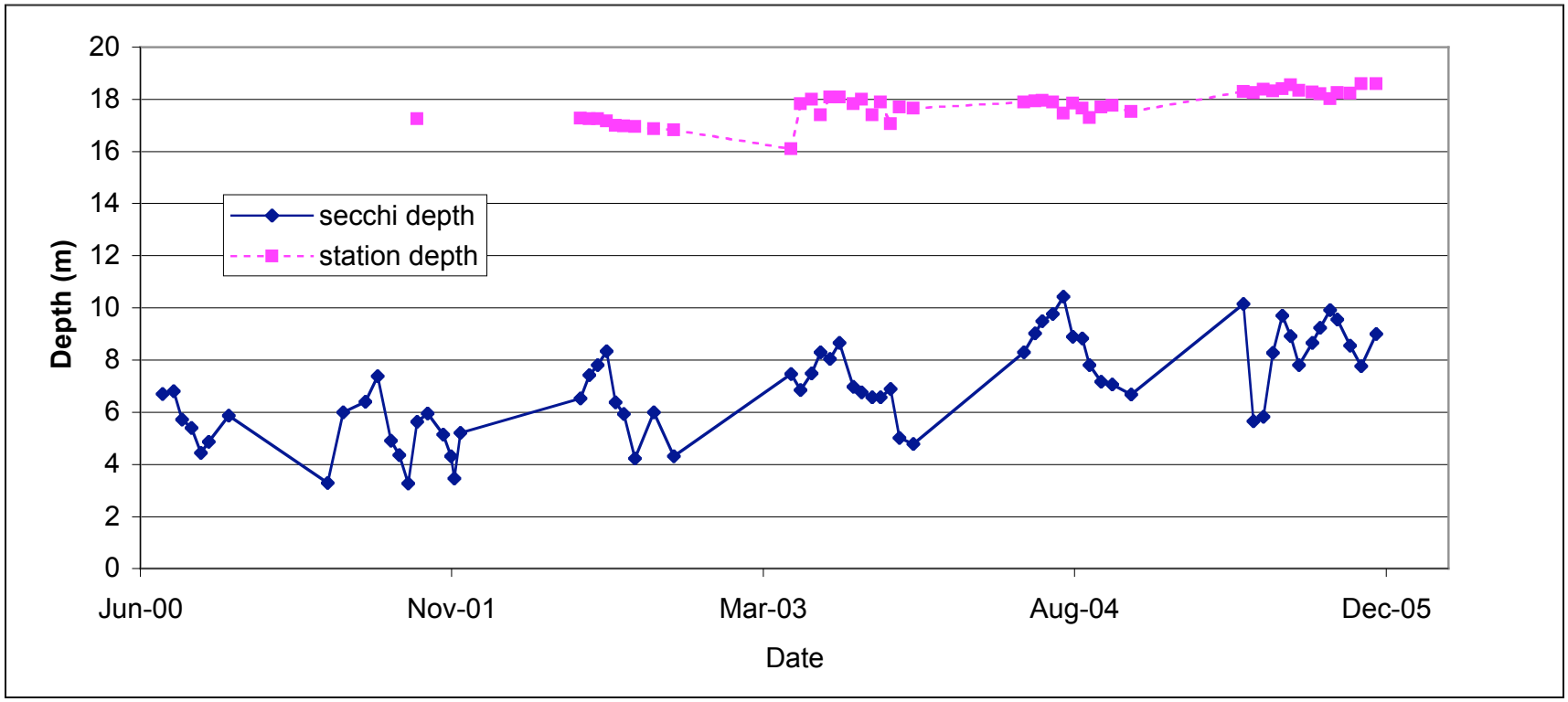


Figure VI-4. Secchi transparency readings in Bakers Pond 2000-2005
Blue data points are Secchi depth readings collected by Orleans volunteers. Station depth (shown in pink) was not consistently collected before 2001. Both station depth and Secchi depth have increasing trends over the sampling period. These trends match increasing regional water levels experienced during this same period and the rise in water levels is likely increasing pond volumes, which would dilute algal populations and increase Secchi transparency.

Average total phosphorus concentrations in Bakers Pond are less than the Cape Cod 7.5 ppb "unimpacted" threshold at the three upper stations: 5.1 ppb at 0.5 m (n=18), 5.2 ppb at 3 m (n=19), and 5.4 at 9 m (n=16). The average concentration at the deepest station is 11.8 ppb (n=16). The elevated concentration in the deep station is due to the regular low oxygen concentrations causing the release of nutrients from sediments that would otherwise be bound if overlying waters had higher DO concentrations. Although the hypolimnion has elevated total phosphorus concentrations, the layer of well-oxygenated cold water that is located above the low DO deep waters appears to generally prevent significant transfer of phosphorus from the deep waters into the warmer upper layer.

The total mass of phosphorus in the pond between June and September averages 5.1 kg (n=19). Of this mass, 83% is contained in the well-mixed upper layer. Since this load is such a high percentage and concentrations at the upper three stations are comparable, this also reinforces the hypothesis that little of the phosphorus released from the sediments reaches the epilimnion and that the load in the upper waters is largely determined by watershed sources. Total phosphorus to total nitrogen ratios average 119 in the upper waters. Since this is more than seven times the Redfield ratio of 16, on average the pond is phosphorus limited.

A phosphorus-loading estimate was determined by reviewing nearby properties in the watershed shown in Figure V-2 and applying the factors in Table V-3. This effort results in a steady state annual load of 20 kg. This load is from 11 upgradient single-family residences, municipal land, road areas, and undeveloped properties. One developable property exists among the undeveloped properties and development on this property will increase the steady state annual load to 21 kg.

Based on review of Board of Health records by town volunteers, septic system leachfields, leaching pits, and cesspools on the watershed properties are located on average 267 ft from the pond edge and the average age of these systems is 15 years. On average the properties have been residences for 25 years with a range of 9 to 96 years.

Since phosphorus from residential-sized septic systems takes approximately 91 years to travel 300 ft (*e.g.*, Robertson, *et al.*, 1998), the load from the Bakers Pond residences can be adjusted by both the average distance from the pond shoreline and the age of the wastewater systems and/or the age of the houses. Given an average of 267 ft to the pond shore, it will take approximately 81 years for the average load from all the existing houses to reach the pond. Given that the average age of the wastewater systems is 15 years, only 19% of the existing phosphorus load would have reached the pond. A similar analysis completed based on the age of the residences shows that 31% of the load would have reached the pond. If an alternative approach is taken and only residences of old enough to have phosphorus loads reach the pond are counted along with load from other sources, the total mass is approximately the same (4.67 kg) as the average measured mass in the epilimnion (4.15 kg). This analysis suggests that the load equivalent to only one residence is currently reaching the pond.

Although further review of travel times and loading factors should be considered, the comparison between the projected loads and the observed concentrations suggest that there are significant loads that are in transit toward the pond. These loads may take decades to arrive, but

once they arrive the potential impact is a cause for concern. Steady state loads added to the pond will result in total phosphorus concentrations of 16 to 17 ppb, which are above the 10 ppb "healthy" threshold and triple those currently measured. Cape Cod ponds with TP concentrations in this range typically have impaired water quality, extensive hypolimnetic anoxia, and shallow Secchi depths (*e.g.*, Eichner, *et al.*, 2006).

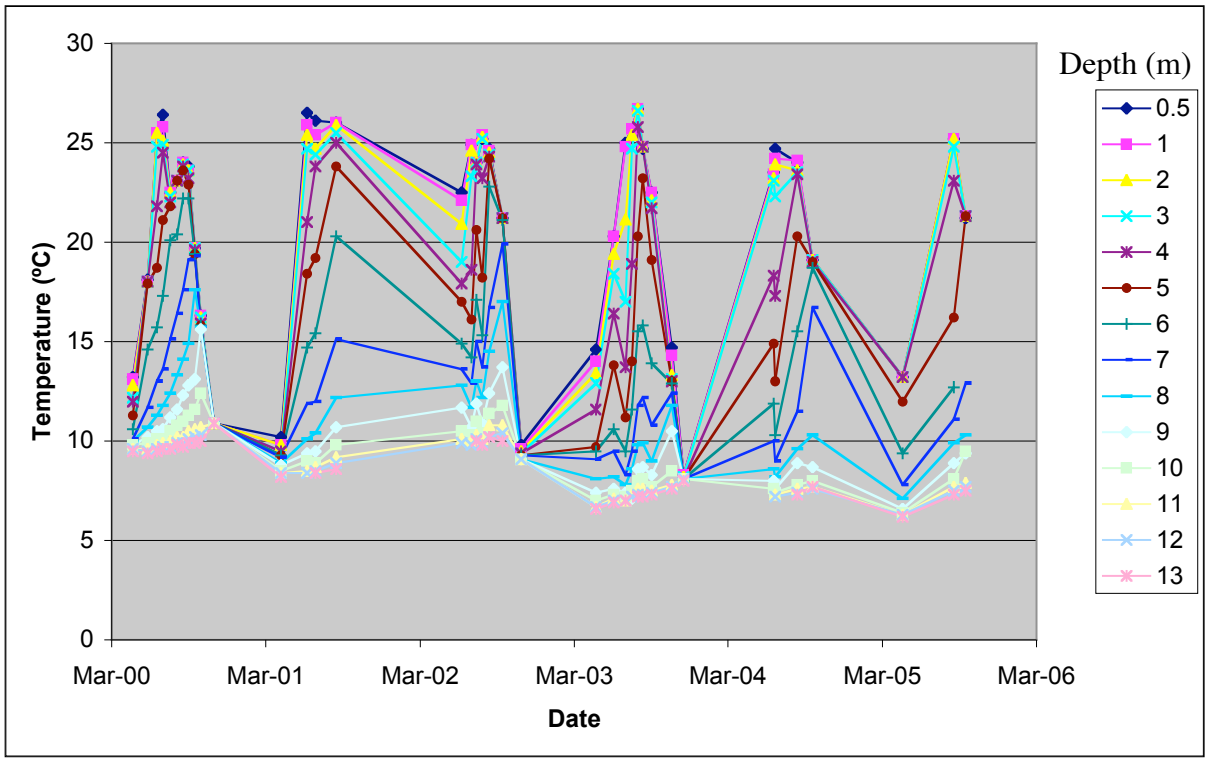
Aside from the phosphorus-in-transit concern, both Figure VI-1 and VI-2 document regular anoxia and DO conditions that have worsened over the past 50 years. Anoxic conditions never occurred at 11 m during the sampling periods (n=46), but they did occur seven times at 12 m depth, fourteen times at 13 m, and half of the time at 14 m. The state 6-ppm DO limit was rarely attained below 14 m during June through September for six years of volunteer monitoring. The average and maximum dissolved oxygen profiles in Figure VI-3 show positive heterograde profiles with DO maxima near the top of the hypolimnion. This type of DO profile generally only occurs in ponds with nutrients being released from the hypolimnion into the epilimnion; nutrients prompt algal growth and there is sufficient light to allow photosynthesis and resulting excessive or supersaturated DO conditions. Positive heterograde DO profiles also tend to be measured in ponds that have ecosystem impairments. This type of profile suggests that some of the deeper impairments will eventually impact upper waters.

At this point, Bakers Pond is relatively healthy, oligotrophic Cape Cod pond with some signs for concern and bottom impairments that should be monitored on a regular basis. Surface total phosphorus concentrations are similar to a pristine Cape Cod pond, but the bottom anoxia and DO profiles suggest that this pond is headed toward worsening conditions. The current signs of concern appear to have developed over the last 60 years, so additional long-term monitoring is warranted. During the development of monitoring protocols, the town should consider what are appropriate thresholds for management changes and what management activities will be undertaken. Monitoring recommendations are discussed in a subsequent section.

VI.2. Crystal Lake

Crystal Lake is a 37-acre pond that is the second largest pond in the Town of Orleans after Pilgrim Lake. It is located to the northeast of Kescayogansett Pond estuary (see Figure V-2). It is the second deepest of the ponds selected from detailed review after Bakers Pond; its deepest point is 49 ft. Crystal Lake had previous monitoring during 2000 (Scanlon and Meservey, 2001). Given its depth, it thermally stratifies usually starting in late May/early June (Figure VI-5). The upper layer continues to warm throughout the summer and this warmth is mixed into the upper layer (*i.e.*, the epilimnion) that gradually thickens and deepens. Once stratification sets up, oxygen consumption from the sediments regularly creates anoxic (<1 ppm) conditions in the lower layer (*i.e.*, the hypolimnion). By the end of September/early October, when thermal stratification begins to breakdown, anoxic conditions can reach as high as 5 m in depth.

Since Crystal Lake thermally stratifies, it has the potential to sustain a cold-water fishery and, as such, should maintain a 6 ppm dissolved oxygen standard as required by state surface water regulations (314CMR4). Because it is shallower than Bakers, however, it has a thinner



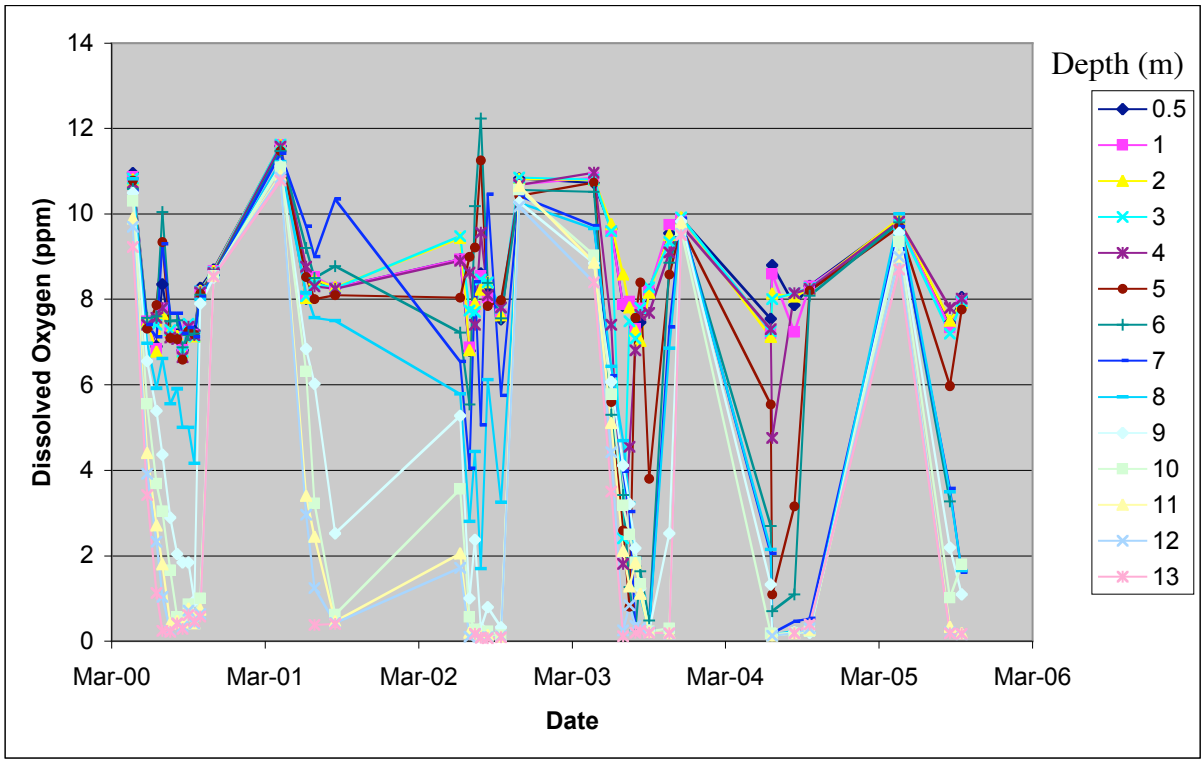


Figure VI-5. Crystal Lake Temperature and Dissolved Oxygen Measurements 2000-2005
Data collected by Orleans volunteers. These graphs include data documented in Scanlon and Meservey (2001) and PALS Snapshots from 2001 to 2005.

hypolimnion and greater opportunity for deep anoxic conditions to impact the well-mixed epilimnion. Based on average conditions for June through September on data collected between 2000 and 2005, the state fisheries 6-ppm standard is usually met down to a depth of 6 m (Figure VI-6).

However, average conditions below 3 m show the impact of oxygen demand from the sediments. Average percent saturation is below 90% at 3 m and below. Average DO concentrations at 7 m and below are less than 6 ppm and the two bottom meters have average anoxic conditions (<1 ppm). Concentrations less than 6 ppm have been measured as high as 3 m in depth. Because oxygen demands can, on average, reach up into the well mixed upper layer of the lake, the nutrients that accompany the lower oxygen water can mix into the upper waters and prompt algal growth and/or blooms. On average, approximately 31% of the pond volume fails to meet the state 6-ppm DO standard (Figure VI-7).

Dissolved oxygen conditions have definitely worsened since the 1948 sampling done by the Massachusetts Division of Fisheries and Game (MADFG). Figure VI-6 also shows an August 18, 1948 dissolved oxygen profile that was collected by during a survey of 51 Cape Cod ponds and lakes by MADFG. The 1948 profile shows dissolved oxygen conditions meeting state standards (>6.0 ppm) to a depth of at least 25 ft (7.6 m). As shown in Figure VI-6, the average DO concentration at 8 m between June and September between 2000 and 2005 is 4.1 ppm. Approximately 3 m worth of the lake profile has dropped below the 6 ppm DO limit in the last 30 years or so.

Secchi readings average 5.4 m between June and September (n=25) during the 2000-2005 dataset (Figure VI-8). Based on an average station depth of 13.63 m, an average of 37% of the water column is clear enough to see a Secchi disk. Secchi readings have an overall range from 3.65 to 7.61 m between June and September. Station depths have a slight upward trend, as would be expected due to increasing groundwater levels (Cape Cod Commission files), but the trend is not as significant as seen in Bakers Pond. This is likely due to Crystal being closer to the coast and, thus, experiencing lower groundwater fluctuations due to the dampening of the ocean. Secchi readings have a slight downward trend over the six years; this appears to be consistent with the low DO concentrations measured higher in the water column.

Average total phosphorus concentrations in Crystal Lake are less than the Cape Cod 7.5 ppb "unimpacted" threshold at the two upper depth stations: 6.7 ppb at 0.5 m (n=16) and 5.8 ppb at 3 m (n=18). Both the deeper stations exceed the 10 ppb TP "healthy" threshold: the 9 m depth station has an average concentration of 10.2 ppb (n=18) and the deep station has an average of 28.6 ppb (n=18). The elevated deep concentrations are consistent with the observed oxygen concentrations; low oxygen conditions are freeing phosphorus bound in the sediments and releasing it to the overlying waters. Since the average concentrations in the upper layers are still healthy, this suggests that, on average, a relatively small amount of phosphorus is making its way to the upper waters. Maximum concentrations at the upper stations between June and September show that the 10 ppb limit was exceed three times at 0.5 m and four times at 3 m. These results show that sufficient phosphorus occasionally makes its way into the upper waters to prompt algal blooms and to change the system from an oligotrophic to a mesotrophic/eutrophic state (see Figure IV-1).

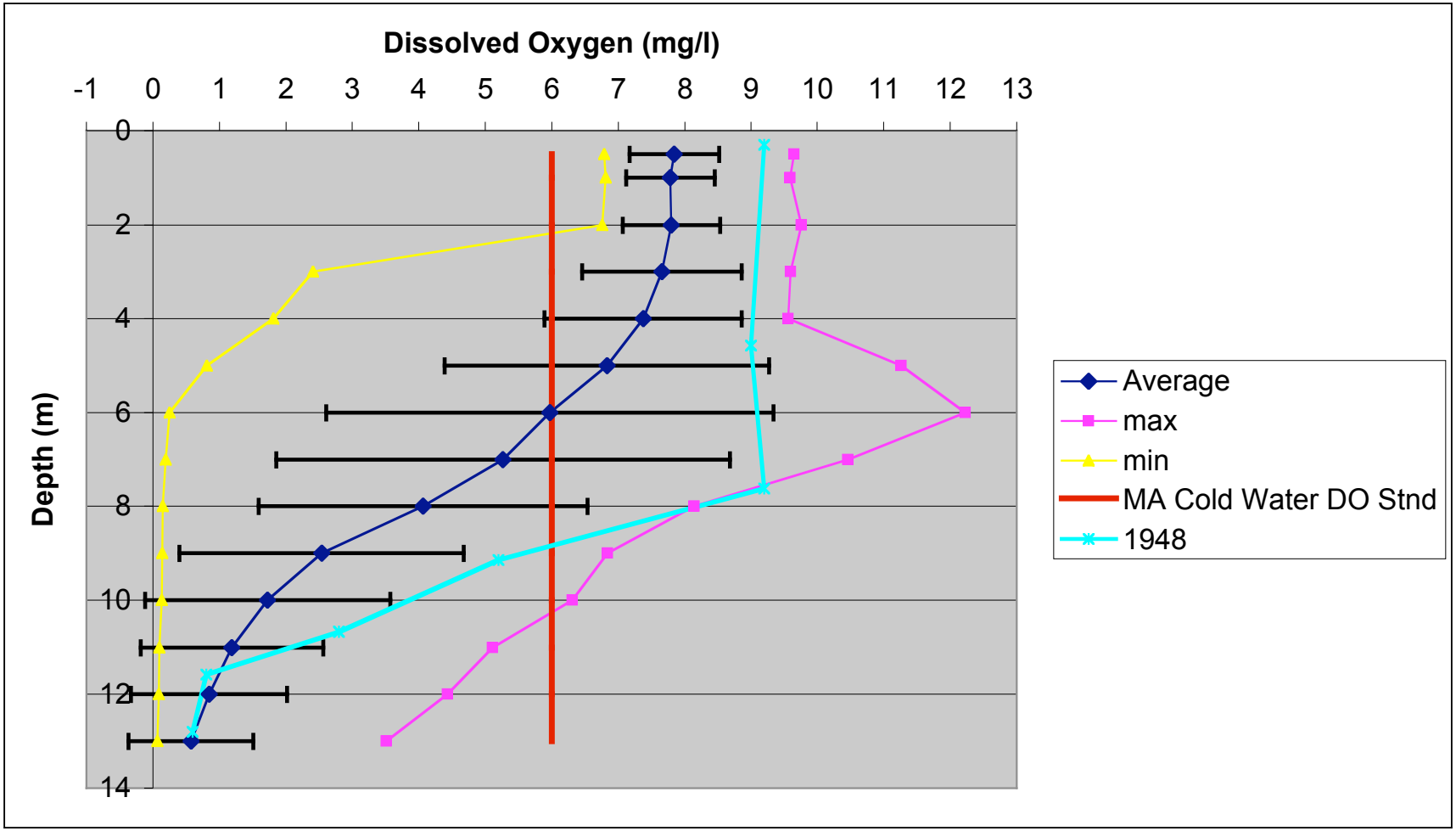


Figure VI-6. Average dissolved oxygen conditions in Crystal Lake June through September 2000-2005
Graph shows average DO profile with error bars (±1 standard deviation) plus maximum and minimum readings for each depth. Also shown is August 19, 1948 profile and the state surface water 6-ppm DO standard for cold water fisheries. Most depths have 29 readings.

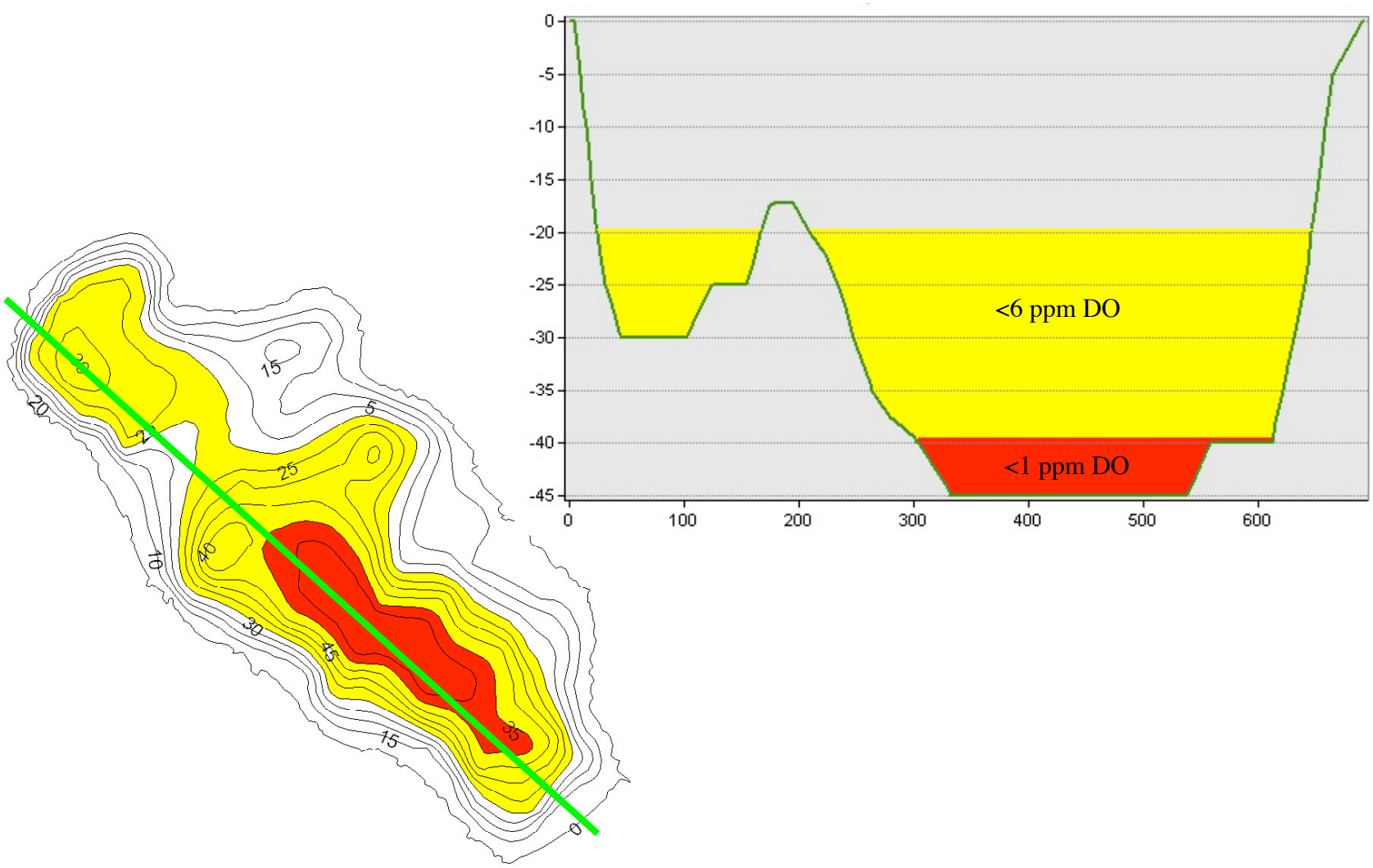


Figure VI-7. Crystal Lake Average Dissolved Oxygen and State Surface Water Standards
Depth profile and map show portion of Crystal Lake that averages less than surface water 6-ppm DO standard for cold water fisheries (shaded yellow) between June and September; areas shaded red have average anoxic concentrations (<1 ppm). Green line on map shows depth profile track through the pond.

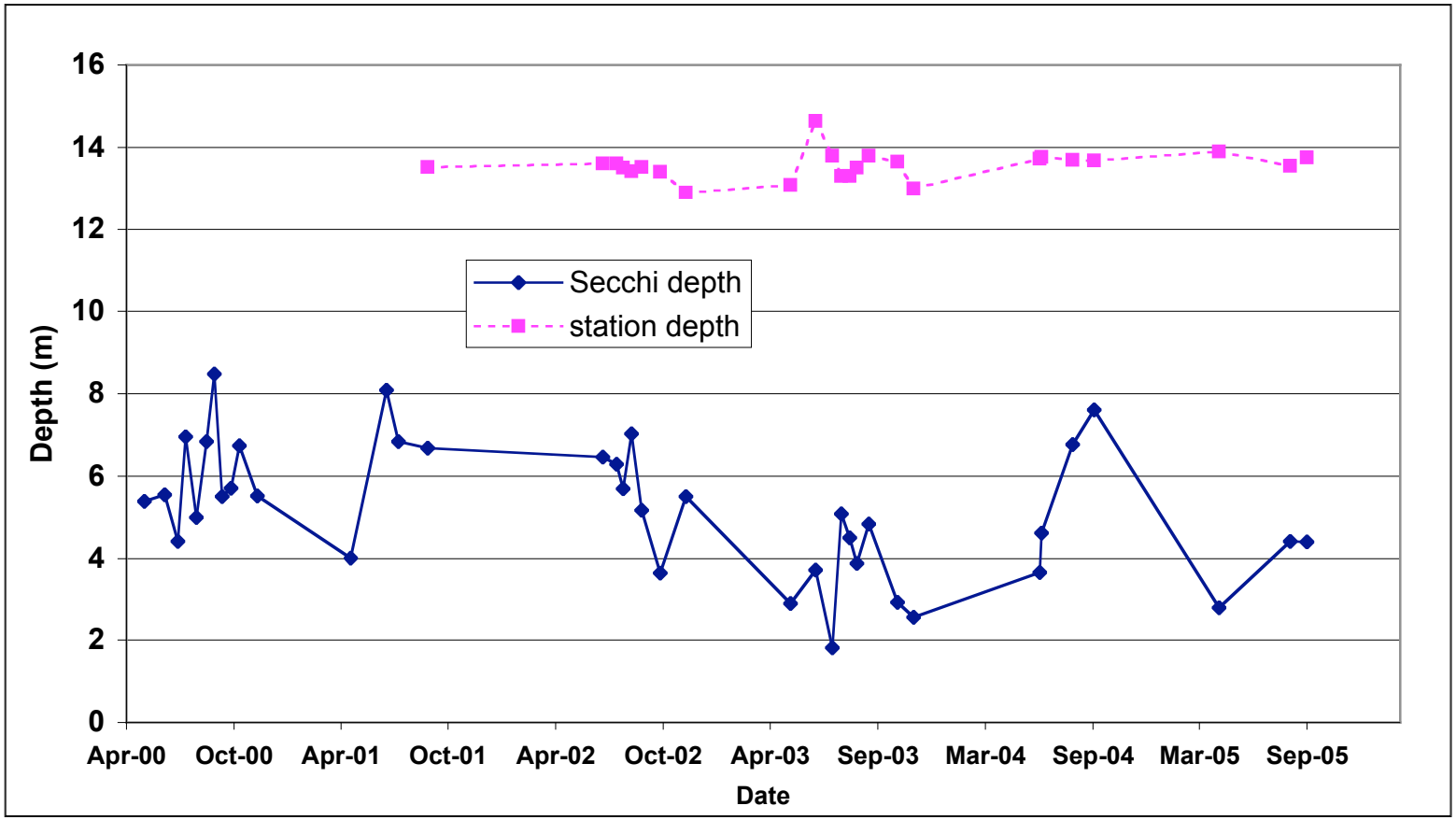


Figure VI-8. Secchi transparency readings in Crystal Lake 2000-2005
Blue data points are Secchi depth readings collected by Orleans volunteers. Station depth (shown in pink) was not consistently collected before 2001. Station depth readings have a slight upward trend, while Secchi depths have a slight downward trend. The upward trend in station depth is consistent with regional groundwater increases during the same time, but slightly reduced likely due to the proximity of the lake to the ocean. The downward trend in Secchi readings is consistent with apparent worsening conditions in the lake.

The total mass of phosphorus in the pond averages 8.7 kg with 56% of the load contained in waters deeper than 7 m. Since the average concentrations in the upper two stations are similar, they can reasonably be combined. Because the 9 m and the deep stations show impacts from sediment release, it is more appropriate to group the 9 m station with the deep station. Unanswered is how much of the 9 m concentration is representative of the watershed loads and how much is due to internal loading from the sediments. The observed average mass in the upper two stations is 4.9 kg, some portion of the 2.0 kg average mass at the 9 m station is likely due sediment sources with the rest from the watershed. Total phosphorus to total nitrogen ratios average 115 in the upper waters (0.5 and 3 m stations). Since this is more than seven times the Redfield ratio of 16, on average the pond is phosphorus limited.

Applying the phosphorus loading factors in Table V-3 to the adjacent properties within the watershed results in a steady state annual load of 22.5 kg for Crystal Lake. The properties included in the loading estimate are: 17 upgradient single family residences, four multifamily residences, municipal land, road areas, and one undeveloped residential property and one undeveloped industrial property (see Figure V-2). Development of the currently undeveloped properties will increase the steady state annual load to 23.6 kg.

Based on review of Board of Health records by town volunteers, septic system leachfields, leaching pits, and cesspools on the developed properties within the watershed are located on average 194 ft from the pond edge and the average age of these systems is 21 years. On average the properties have been residences for 40 years with a range of 7 to 81 years.

Since phosphorus from residential-sized septic systems takes approximately 91 years to travel 300 ft (*e.g.*, Robertson, *et al.*, 1998), the load from the Crystal Lake residences can be adjusted by both the average distance from the pond shoreline and the age of the wastewater systems and/or the age of the houses. Given an average of 194 ft to the pond shore, it will take approximately 59 years for the average load from all the existing watershed development to reach the pond. Given that the average age of the wastewater systems is 21 years, this analysis suggests that only 36% of the existing wastewater phosphorus load could have reached the pond (total load of 14.9 kg). If a similar analysis is completed based on the age of the residences, 67% of the wastewater load could have reached the pond (total load of 18.7 kg). If an alternative approach is taken and only the two residences with wastewater systems old enough to have phosphorus loads reach the pond are counted, the total mass is 8.2 kg. This last alternative is the best match for the monitoring data and suggests that wastewater is currently a relatively small component of the phosphorus load reaching the pond; the highest percentage of the watershed load under this scenario is from stormwater runoff.

Although further review of travel times and loading factors should be considered, the comparison between the projected loads and the observed concentrations suggest that there are significant loads that are in transit toward the pond. These loads may take decades to arrive, but once they arrive the potential impact is an additional cause for concern. Steady state loads added to the pond will result in total phosphorus concentrations of 26 to 28 ppb, which are more than twice the 10 ppb "healthy" threshold. Cape Cod ponds with TP concentrations in this range typically have impaired water quality, extensive hypolimnetic anoxia, and shallow Secchi depths (*e.g.*, Eichner, *et al.*, 2006).

At this point, Crystal Lake is a pond given to fairly large fluctuations in ecosystem health. Upper waters tend to be oligotrophic, but oxygen demand and accompanying nutrient release from the sediments maintain a ready internal source of nutrients, which are occasionally mixed into the upper waters and shift the whole system into the mesotrophic category. In addition to these concerns, there is sufficient phosphorus in transit to the lake that average trophic conditions in the lake will likely slowly shift toward more eutrophic conditions and the regular fluctuations may on occasion push it into hypereutrophic conditions.

The overall assessment of Crystal Lake shows an impaired ecosystem that generally presents as healthy based on surface conditions, but can rapidly display its impairments when existing internal sources of nutrients are mixed into the upper waters. Projections of watershed nutrient loads suggest that the eutrophication will accelerate and worsen. It is recommended that management/remedial strategies be developed to address the internal sources of nutrients, existing watershed loads and future potential watershed loads that will eventually reach the pond. Existing data are sufficient to develop management/remedial strategies.

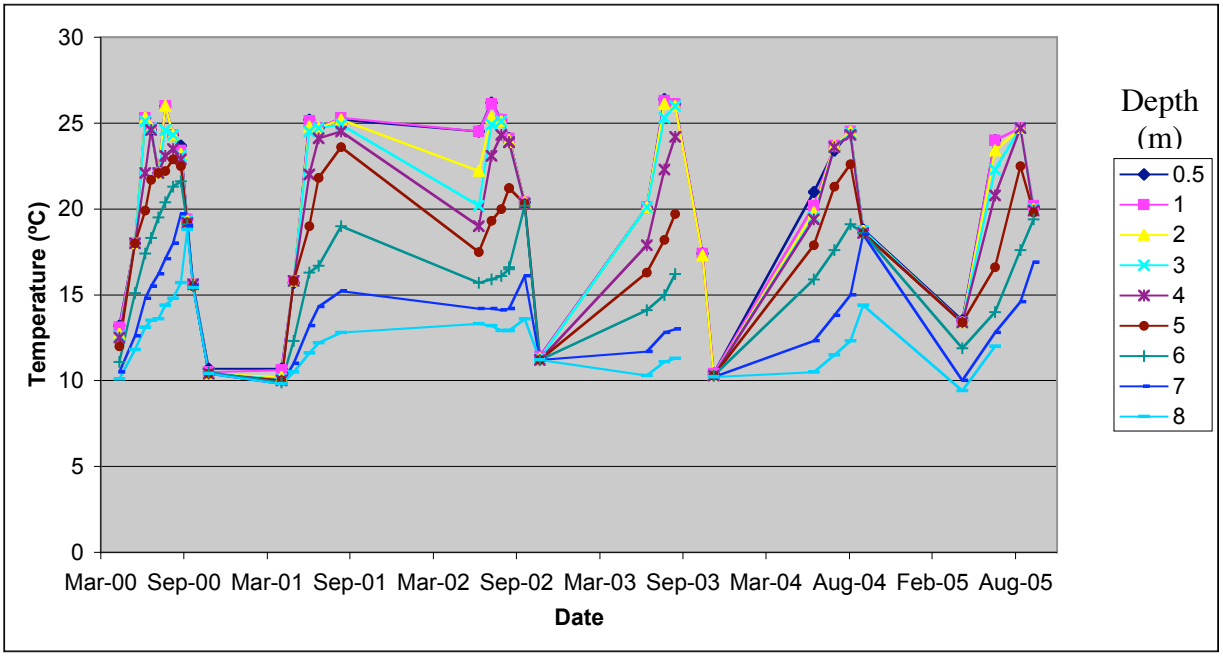
Long term monitoring of Crystal Lake should continue, but at a reduced rate until management strategies are implemented. Monitoring recommendations are discussed greater detail in a subsequent section.

VI.3. Pilgrim Lake

Pilgrim Lake is a 43-acre pond that is the largest pond in the Town of Orleans. It is located between the Kescayogansett Pond estuary to the north and the Areys Pond estuary to the south (see Figure V-2). Pilgrim Lake had previous monitoring during 2000 (Scanlon and Meservey, 2001). It is 34 ft deep (10.4 m) at its deepest point, which places it in a somewhat different category than Crystal and Bakers, which develop relatively thick, well-defined hypolimnions. Given its depth, Pilgrim Lake develops a well mixed upper layer down to 5 to 6 m, a transition zone of 1 to 3 m, and thin, ~1 m thick hypolimnion (Figure VI-9). The upper layer continues to warm throughout the summer and this warmth is mixed into the upper layer (*i.e.*, the epilimnion) that gradually thickens and deepens. As this happens, the bottom layer gets compressed and generally retains a temperature close to May or June's surface temperature. Anoxic conditions in the deepest layer impact concentrations up through 5 m in depth.

Although Pilgrim Lake thermally stratifies, the lack of a significant hypolimnion raises questions whether it should be considered a cold-water fishery. As such, a question exists whether it should maintain a 6 ppm dissolved oxygen standard required by state surface water regulations (314CMR4) of cold-water fisheries or 5 ppm required of warm water fisheries. Based on average conditions for June through September on data collected between 2000 and 2005, it really does not matter which standard is applied; concentrations are below both standards in more than half the readings at 6 m and below.

Average conditions at and below 6 m show the impact of oxygen demand from the sediments. Since these impaired waters rise up to the bottom of the well mixed upper layer and the average difference in temperature between the 4 and 5 m depths is a less than 2ºC, the barrier to mixing the deeper oxygen demand and accompanying nutrient loads is relatively small.



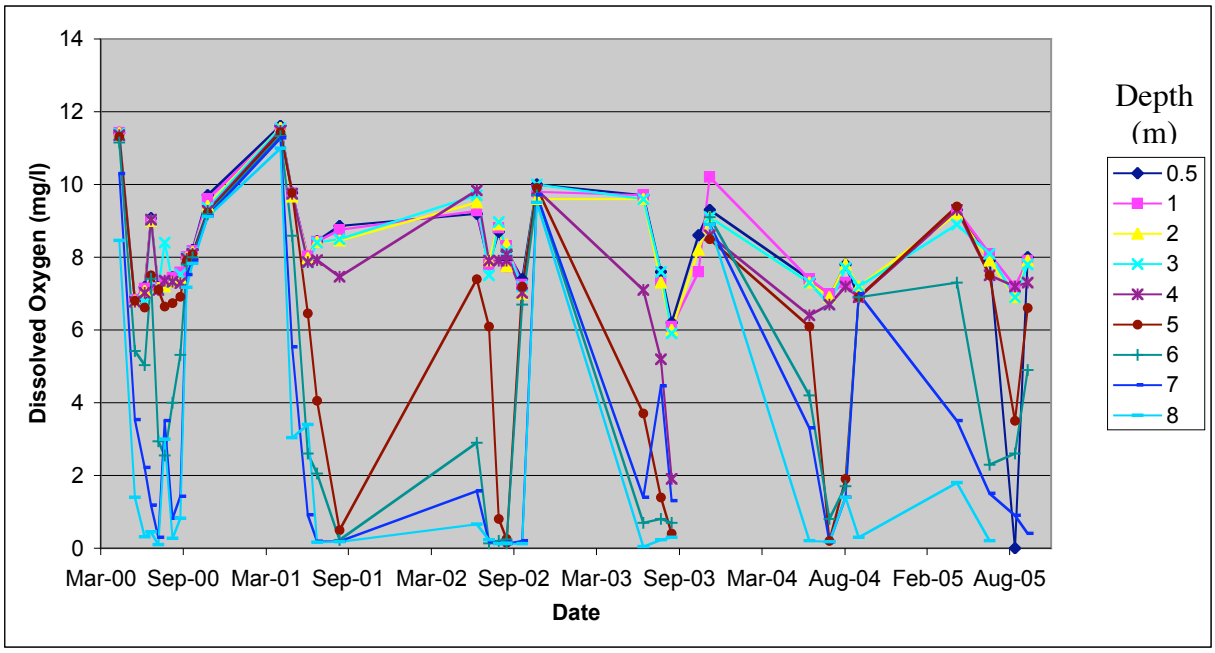


Figure VI-9. Pilgrim Lake Temperature and Dissolved Oxygen Measurements 2000-2005
Data collected by Orleans volunteers. These graphs include data documented in Scanlon and Meservey (2001) and PALS Snapshots from 2001 to 2005.

Results of this can be seen in the minimum DO concentrations in the upper waters, which are 5.9 to 6.2 ppm (Figure VI-10). On average, approximately 16% of the pond volume fails to meet either a 5 or 6 ppm DO surface water standard (Figure VI-11).

Secchi readings average 4.0 m between June and September (n=24) during the 2000-2005 dataset (Figure VI-12). Based on an average station depth of 8.93 m, an average of 38% of the water column is clear enough to see a Secchi disk. Secchi readings have an overall range from 1.76 to 5.58 m. Station depths have a slight upward trend, as would be expected due to increasing groundwater levels (Cape Cod Commission files), but the trend is not as significant as seen in Bakers Pond. This is likely due to Pilgrim being closer to the coast, similar to Crystal, and, thus, experiencing lower groundwater fluctuations due to the dampening of the ocean. Secchi readings have a slight downward trend over the six years; this appears to be consistent with the low DO concentrations measured higher in the water column.

Average total phosphorus concentrations in Pilgrim Lake are greater than the Cape Cod 10 ppb "healthy" threshold at all the monitoring station depths: 11.8 ppb at 0.5 m (n=14), 14.6 ppb at 3 m (n=12) and 71.2 ppb (n=13) at the deepest station. The elevated deep concentration and increase in average concentration with depth are consistent with the observed oxygen concentrations; deep low oxygen conditions are freeing phosphorus bound in the sediments and releasing it to the overlying waters. These results show that sufficient phosphorus is readily available to prompt algal blooms and rapidly change the conditions in the lake.

Based on monitoring data between June and September, the total mass of phosphorus in the pond averages 15.9 kg with 46% of the load contained in waters deeper than 6 m. It is clear from the TP averages that the deepest station is significantly impacted by the sediment regeneration, but is not clear how much of the 3 m station is representative of the watershed loads and how much is due to internal loading from the sediments. The observed average TP mass in the upper station is 3.8 kg, 4.8 kg at the middle station and 7.3 kg at the deep station. Total phosphorus to total nitrogen ratios average 107 at the upper station and 78 at the 3 m station. Since these are a minimum of 4.9 times the Redfield ratio of 16, on average the pond is phosphorus limited.

Applying the phosphorus loading factors in Table V-3 to the adjacent properties within the watershed results in a steady state annual load of 18.0 kg for Pilgrim Lake. The properties included in the loading estimate are: 17 upgradient single-family residences, two multifamily residences, tax-exempt land, road areas, and six undeveloped residential properties, one of which is classified as undevelopable by the town assessing department (see Figure V-2). Development of the currently undeveloped properties will increase the steady state annual load to 20.2 kg.

In order to refine the phosphorus loads to get closer to actual loading and account for phosphorus lag time, project staff requested assistance from town volunteers. Volunteers reviewed of Board of Health records in order to determine the distance from the lake shoreline to septic system leachfields, leaching pits, and cesspools on adjacent and nearby developed properties within the watershed. On average, these structures and the phosphorus they are adding to the groundwater are 242 ft from the pond edge and the average age of these systems is

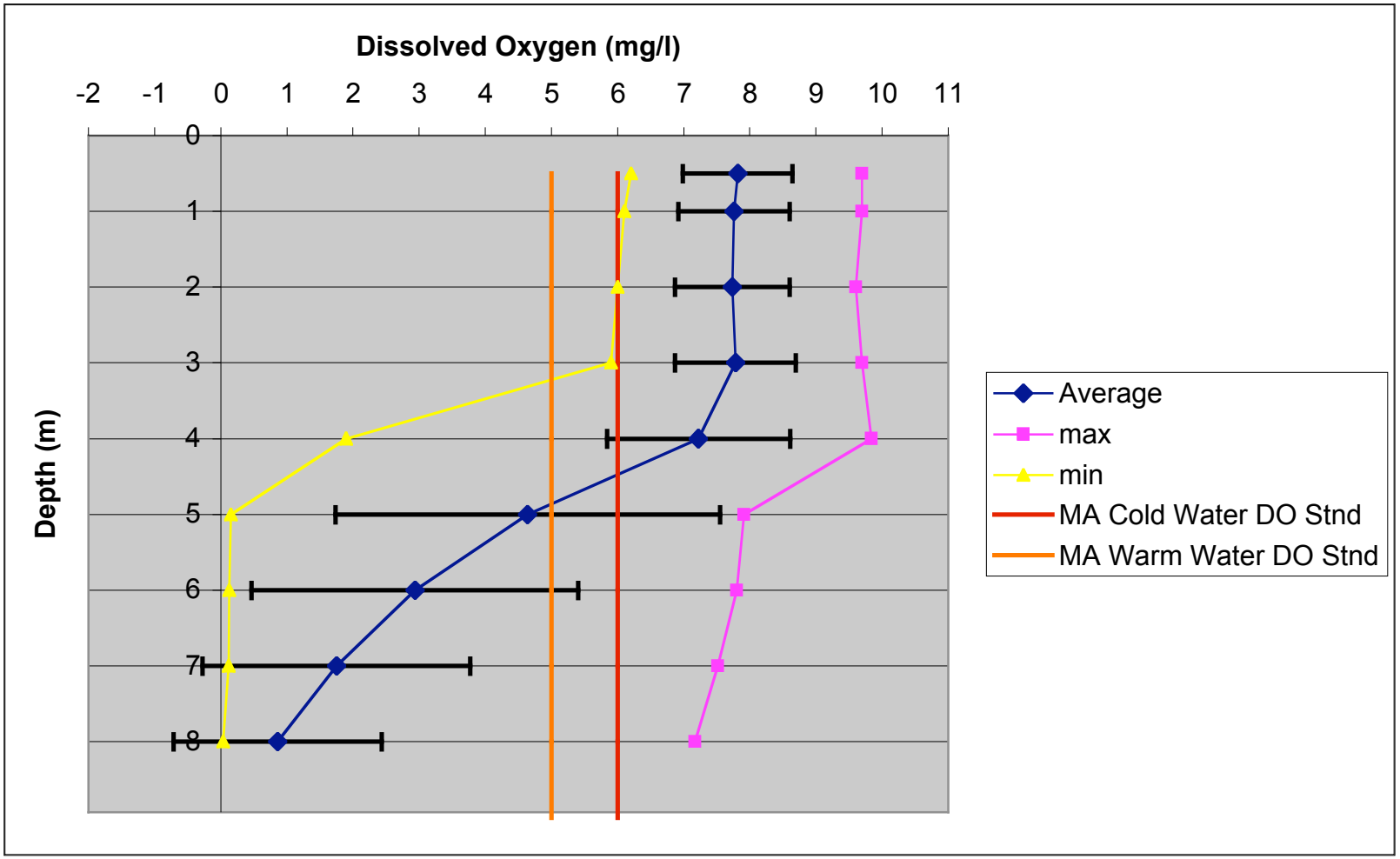


Figure VI-10. Average dissolved oxygen conditions in Pilgrim Lake June through September 2000-2005
Graph shows average DO profile with error bars (±1 standard deviation) plus maximum and minimum readings for each depth. Also shown are the state surface water 6-ppm DO standard for cold-water fisheries and the state surface water 5-ppm DO standard for warm water fisheries. Most depths have 26 readings.

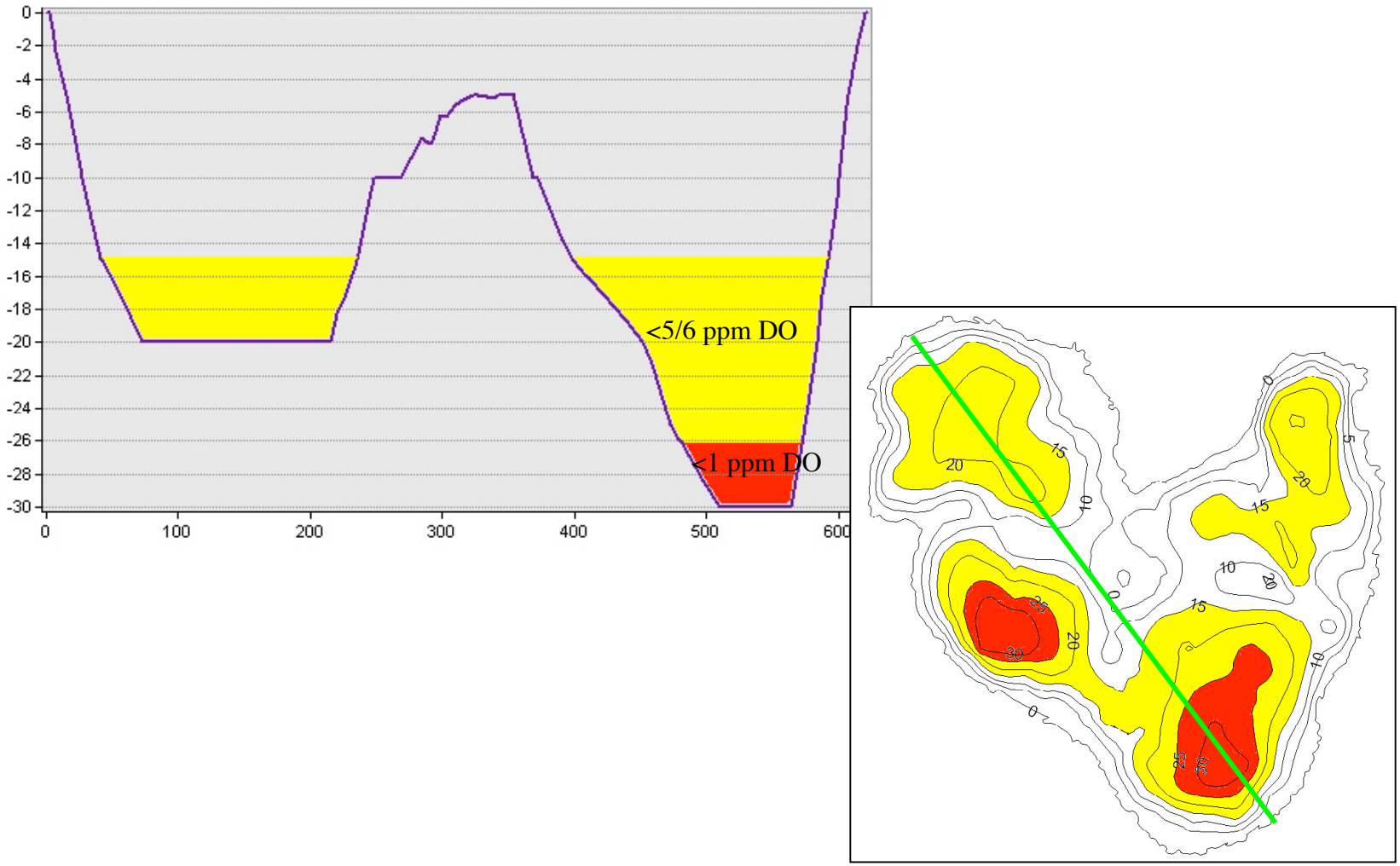


Figure VI-11. Pilgrim Lake Average Dissolved Oxygen and State Surface Water Standards
Depth profile and map show portion of Pilgrim Lake that averages less than either the state surface water 6-ppm DO standard for cold water fisheries or 5-ppm standard for warm water fisheries (shaded yellow) between June and September; areas shaded red have average anoxic concentrations (<1 ppm). Green line on map shows depth profile track through the pond.

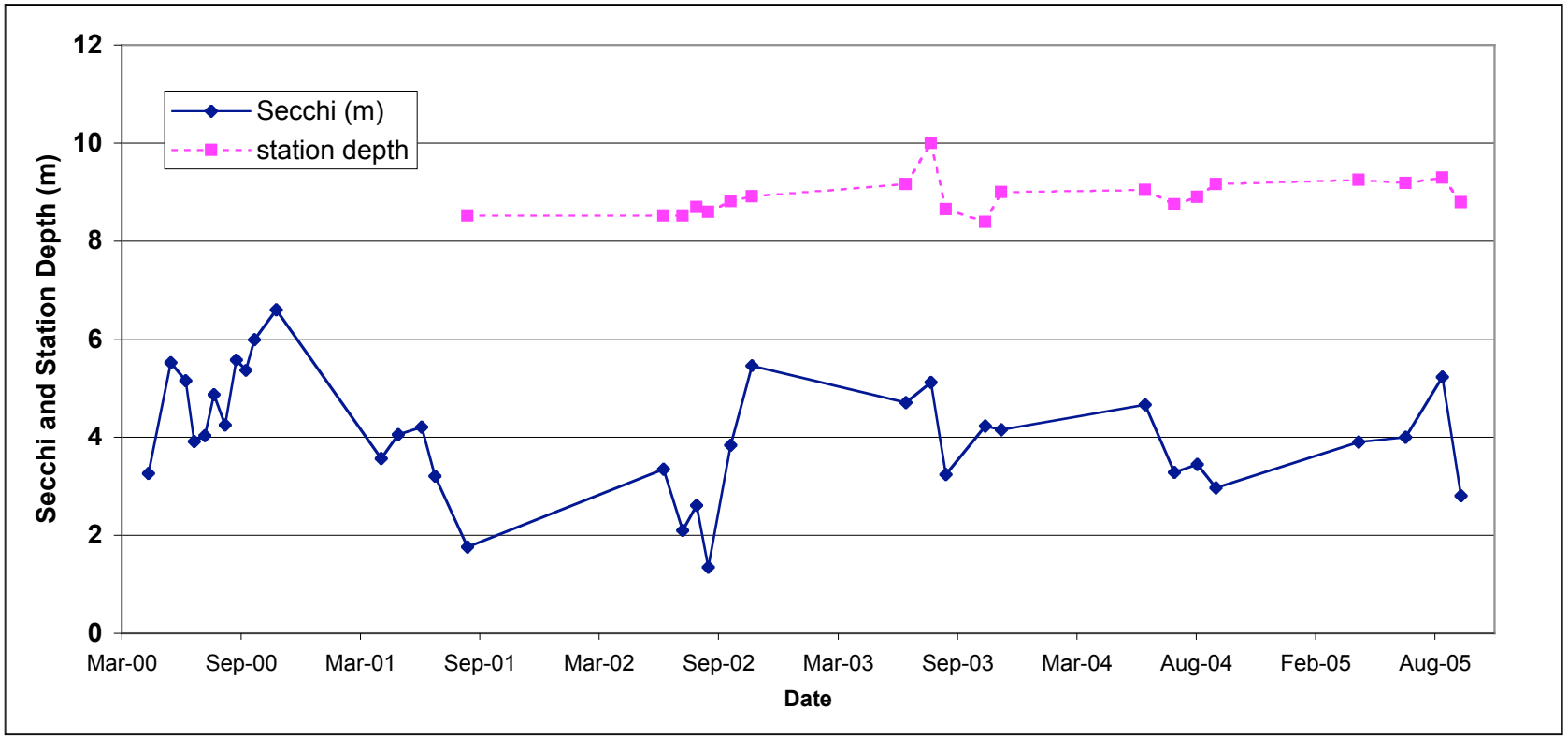


Figure VI-12. Secchi transparency readings in Pilgrim Lake 2000-2005
Blue data points are Secchi depth readings collected by Orleans volunteers. Station depth (shown in pink) was not consistently collected before 2001. Station depth readings have a slight upward trend, while Secchi depths have a slight downward trend. The upward trend in station depth is consistent with regional groundwater increases during the same time, but slightly reduced likely due to the proximity of the lake to the ocean. The downward trend in Secchi readings is consistent with apparent worsening conditions in the lake.

15 years. The properties have been developed as residences for an average of 33 years with a range of 2 to 66 years.

Since phosphorus from residential-sized septic systems takes approximately 91 years to travel 300 ft (*e.g.*, Robertson, *et al.*, 1998), the load from the Pilgrim Lake residences can be adjusted by both the average distance from the pond shoreline and the age of the wastewater systems and/or the age of the houses. Given an average of 242 ft to the pond shore, it will take approximately 73 years from the average load from all the existing watershed development to reach the pond. Given that the average age of the wastewater systems is 15 years, this analysis suggests that only 21% of the existing wastewater phosphorus load could have reached the pond (overall load of 10.7 kg). If a similar analysis is completed based on the age of the residences, 45% of the current wastewater load could have reached the pond (overall load of 12.9 kg). If an alternative approach is taken and only the one residence with a wastewater systems old enough to have phosphorus loads reach the pond is counted, the total annual phosphorus mass reaching the lake is 6.3 kg. A reasonable estimate is that the actual annual load from the watershed to the lake is between 6 and 11 kg. The average mass in the upper waters (8.6 kg) is between these two estimates.

The watershed loading analysis shows that under current conditions the average TP concentration in the upper waters of Pilgrim Lake should be 7.5-8 ppb. As mentioned above, average concentrations in the upper depth stations are 11.8 and 14.6 ppb. This comparison suggests that sediment regeneration is consistently adding approximately 5 kg of phosphorus to the upper waters. This analysis also suggests that if remedial activities effectively address sediment regeneration that concentrations in Pilgrim Lake will be reduced below the regional 10 ppb "healthy" threshold.

The watershed loading analysis also shows that additional loading from the watershed will increase concentrations above the 10 ppb threshold even if sediment regeneration is addressed. These loads may take decades to arrive, but once they arrive the likely potential impact is an additional cause for concern. Steady state loads added to the pond will add 5 to 7 ppb to existing TP concentrations without considering the potential for increases in sediment regeneration rates. Projected total phosphorus concentrations could then reach 17 to 21 ppb, roughly twice the 10 ppb "healthy" threshold, and bring maximum concentrations to approximately 30 ppb. Cape Cod ponds with TP concentrations in this projected average range typically have significantly impaired water quality, extensive anoxia, and shallow Secchi depths (*e.g.*, Eichner, *et al.*, 2006). These factors would also likely shift Pilgrim Lake from mesotrophic to eutrophic category (see Figure IV-1).

The overall assessment of Pilgrim Lake shows an impaired ecosystem with anoxic conditions and a weak stratification allowing internal regenerated phosphorus to sustain total phosphorus concentrations higher than the 10 ppb "healthy" Cape Cod threshold. Projections of watershed nutrient loads suggest that the eutrophication will accelerate and worsen. It is recommended that management/remedial strategies be developed to address the internal sources of nutrients, existing watershed loads and future potential watershed loads that will eventually reach the pond. Existing data are sufficient to develop management/remedial strategies.

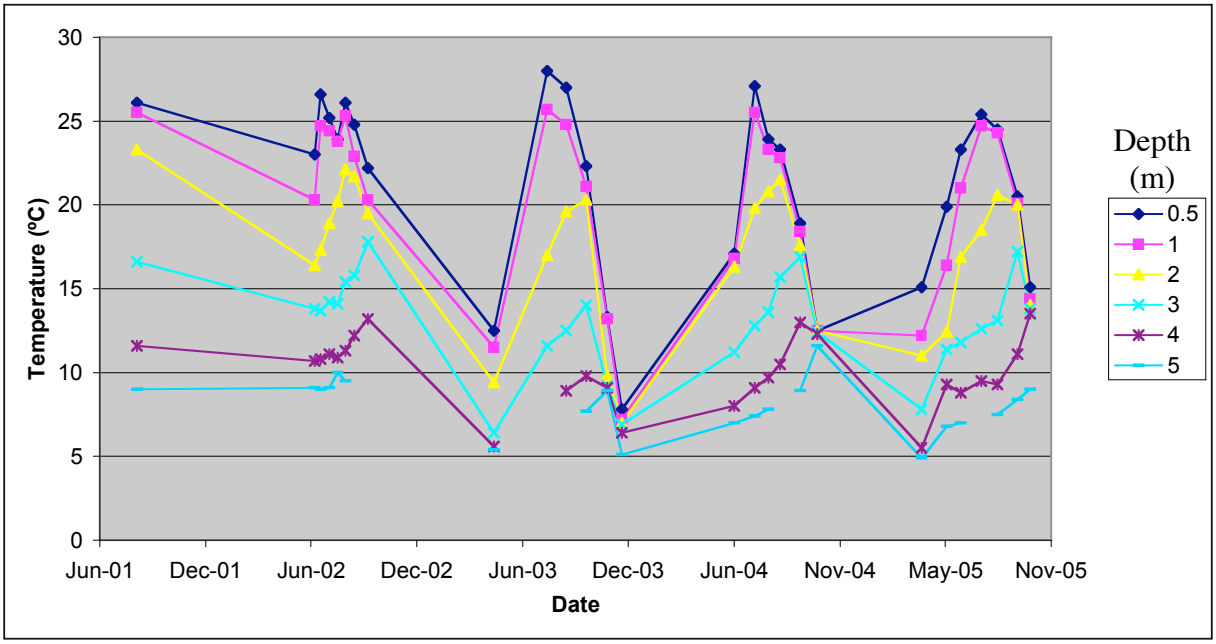
Long term monitoring of Pilgrim Lake should continue, but at a reduced rate until management strategies are implemented. Monitoring recommendations are discussed greater detail in a subsequent section.

VI.4. Boland Pond

Boland Pond is the smallest of the ponds selected for more detailed review. At 4.7 acres, it is not considered a public pond under Massachusetts law. It is 21 ft (6.4 m) deep at its deepest point and is located to the south of Route 6A, west of Route 28 and north of Eldridge Parkway (see Figure V-3). Since Boland is relatively shallow, it would not be expected to thermally stratify, but its average temperatures between June and September show that it is well mixed down to 2 m and then has a decline of 5.2ºC, 3.7ºC, and 2.1ºC for each subsequent meter. The deepest average temperature (8.4ºC) is equivalent to the average temperature at 17 m in Bakers Pond. This temperature profile is likely caused by a combination of factors: 1) the pond is likely in a selective groundwater discharge area and is receiving more than groundwater discharge than would be expected for a pond of its size and depth and 2) it is surrounded by relatively higher ground elevations adjacent to the pond protecting it from winds that would otherwise keep it well mixed. Further field evaluations would be necessary to evaluate the relative contribution of these factors. Dissolved oxygen patterns match the apparent stratification with well-oxygenated conditions existing in the 0.5 m and 1 m depths with extensive fluctuation at the 2 and 3 m depths and reduced fluctuations and regular anoxic (<1 ppm) conditions at 4 and 5 m depths (Figure VI-13).

Because Boland Pond thermally stratifies and temperatures at 3 m and below are consistently below the 20ºC required by the state (314CMR4), it could qualify as a cold-water fishery, but given its small size it is unclear whether it would support anything other than a small amount of biomass. For the purposes of comparing its dissolved oxygen concentrations to either the 6 ppm cold water standard or 5 ppm warm water standard, it does not matter which standard is used; concentrations are below both standards at roughly the same percentage. Dissolved oxygen concentrations at 3 m are anoxic (<1 ppm) in 90% of the June through September readings and 100% are anoxic at both 4 and 5 meters (Figure VI-14). Since even 25% of the 2 m readings are anoxic, it is clear that the sediments in Boland Pond have a significant oxygen demand. On average between June and September, approximately 35% of the pond volume fails to meet either a 5 or 6 ppm DO standard and 21% is anoxic (Figure VI-15).

Secchi readings average 1.4 m between June and September (n=20) during the 2001-2005 dataset (Figure VI-16). Based on an average station depth of 5.5 m, an average of 26% of the water column is clear enough to see a Secchi disk. Secchi readings have an overall range from 0.4 to 2.58 m. The minimum reading is less than the state visibility limit of 4 ft for swimming. Station depths have a slight upward trend, as would be expected due to increasing groundwater levels (Cape Cod Commission files), but the trend is not as significant as seen in Bakers Pond. This is likely due to Boland being closer to the coast, similar to Crystal and Pilgrim, and, thus, experiencing lower groundwater fluctuations due to the dampening of the ocean. Secchi readings have a slight upward trend over the six years that closely matches the trend for the station depth; this suggests that the increase in Secchi depth is due to the increase in the water level of the pond.



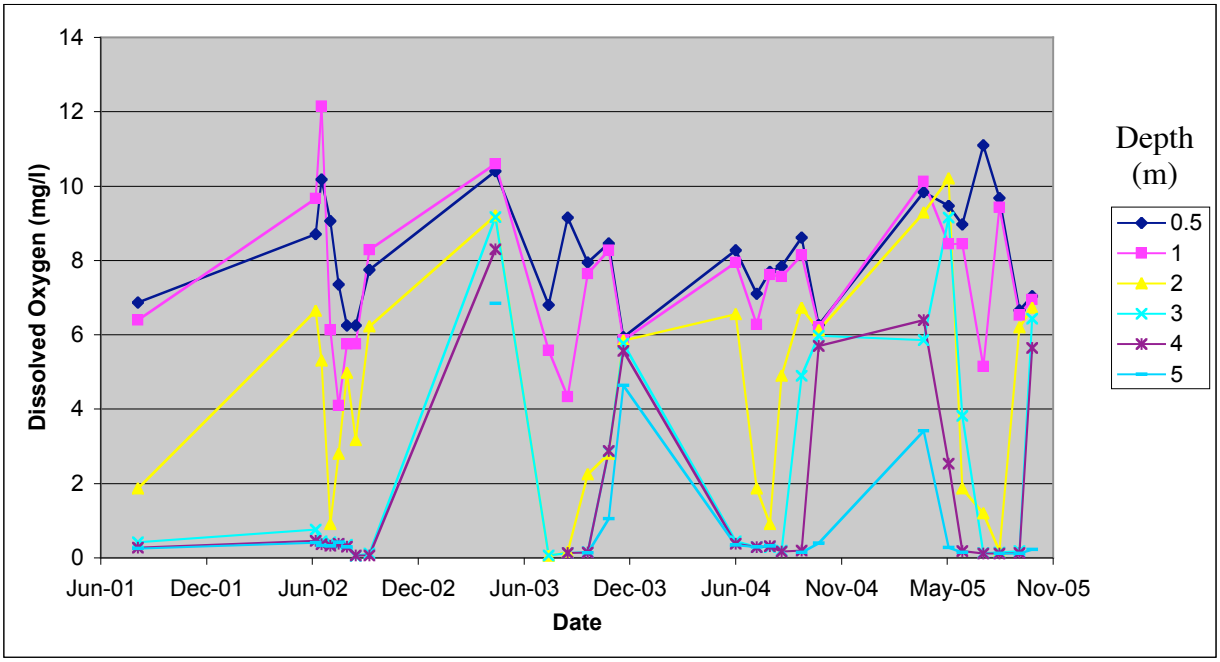


Figure VI-13. Boland Pond Temperature and Dissolved Oxygen Measurements 2001-2005
Data collected by Orleans volunteers. These graphs include data from PALS Snapshots from 2001 to 2005.

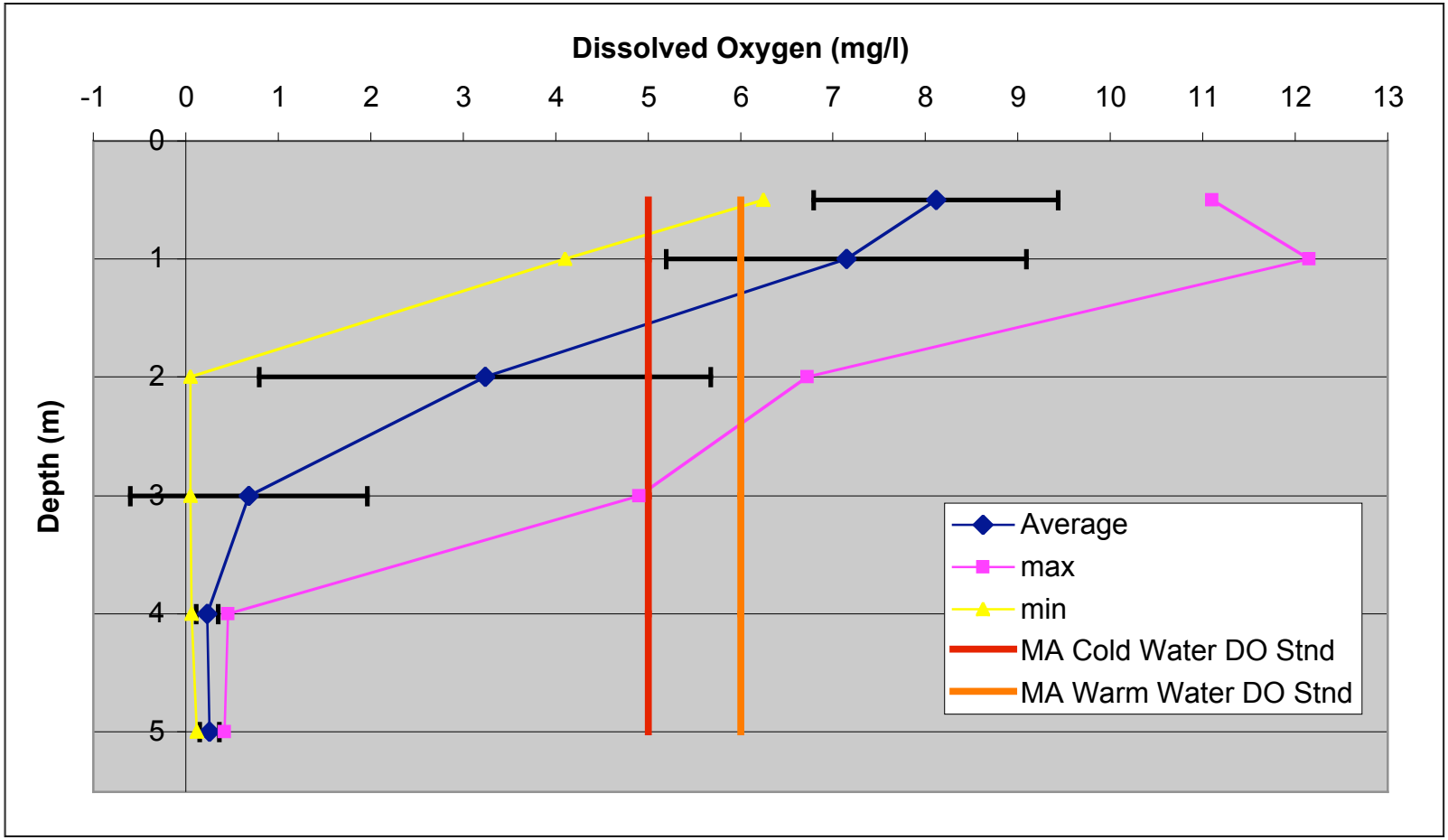


Figure VI-14. Average dissolved oxygen conditions in Boland Pond June through September 2001-2005
Graph shows average DO profile with error bars (±1 standard deviation) plus maximum and minimum readings for each depth. Also shown are the state surface water 6-ppm DO standard for cold-water fisheries and the state surface water 5-ppm DO standard for warm water fisheries. Most depths have 20 readings.

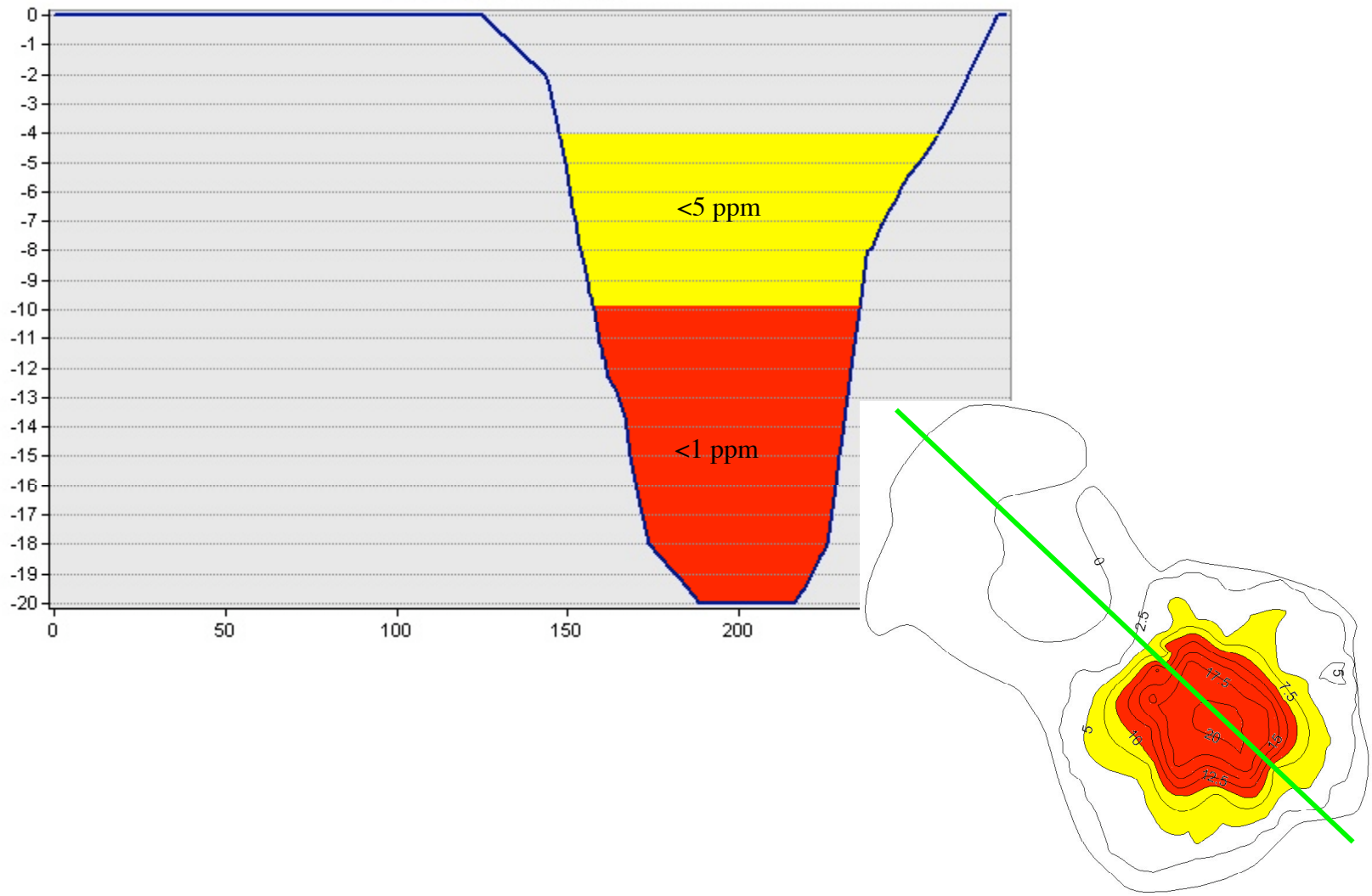


Figure VI-15. Boland Pond Average Dissolved Oxygen and State Surface Water Standard
Depth profile and map show portion of Boland Pond that averages less than the state surface water 5-ppm standard for warm water fisheries (shaded yellow) between June and September; areas shaded red have average anoxic concentrations (<1 ppm). Green line on map shows depth profile track through the pond.

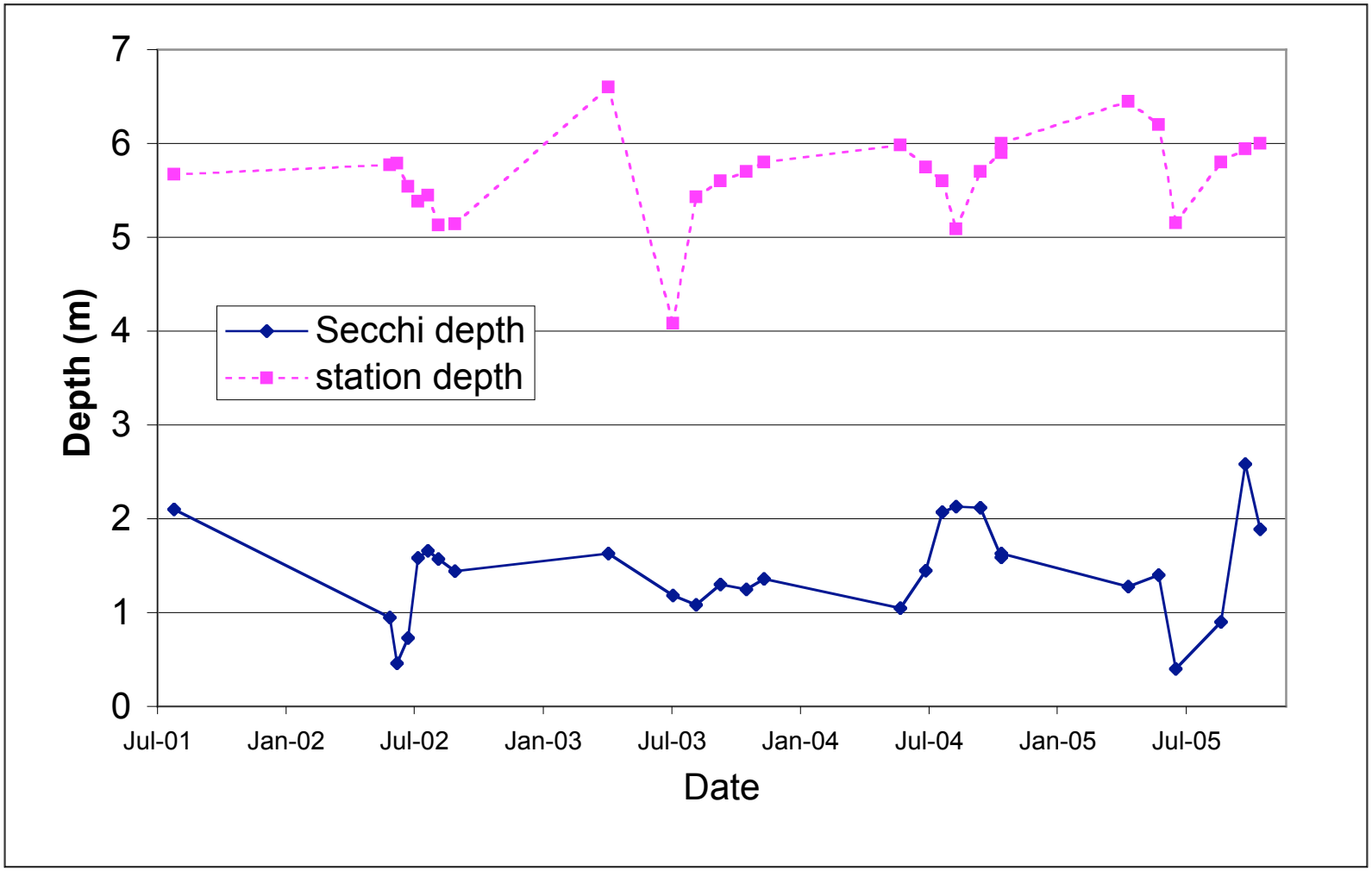


Figure VI-16. Secchi transparency readings in Boland Pond 2001-2005
Blue data points are Secchi depth readings, while station total depth is shown in pink. All readings were collected by Orleans volunteers. Both station depth and Secchi depth readings have slight upward trends, which are thought to reflect regional groundwater increases during the same time.

Average total phosphorus concentration at the upper station in Boland Pond is 30 ppb (n=17), which is three times the Cape Cod 10 ppb "healthy" threshold. As would be expected, the consistent anoxia deeper in the pond is freeing phosphorus bound in the sediments and releasing it to the overlying waters; the average TP concentration at the deep station (3.5 to 5 m) is 195 ppb (n=16). These results show that sufficient phosphorus is readily available to prompt extensive algal or rooted plant growth, as well as algal blooms and rapid changes the ecological conditions in the lake.

Based on monitoring data, the total mass of phosphorus in the pond averages 3.7 kg with 68% of the load contained in waters deeper than 2 m (35% of the pond volume). It is clear from the TP averages that the deepest station is significantly impacted by the sediment regeneration, but is not clear how much of the upper station mass is from watershed loads and how much is due to internal loading from the sediments. The average TP mass in the upper station is 0.8 kg and 2.8 kg at the deep station. Total phosphorus to total nitrogen ratios average 71 at the upper station and 51 at the 3 m station. Since the upper ratio is 4.4 times the Redfield ratio of 16, on average the pond is phosphorus limited, but the excessive sediment load is reducing the ratio into a range where co-limitation with nitrogen might be considered.

Developing a phosphorus-loading estimate for Boland Pond is somewhat different than the other ponds because the predominant potential loading sources are located on the watershed boundary. Two properties (a residence and a inn/motel) have leachfields in the 300 ft buffer, but they are located along the northern edge of the watershed boundary. Since the inn/motel has a Title 5 design flow of 3,520 gpd, it has the potential to be a major source. Based on best professional judgment, staff determined that the residence's leachfield is likely to be outside of the watershed.

Project staff obtained a sewage design layout for the inn/motel from town volunteers. This layout indicates that 3,080 gpd of wastewater leaching capacity on the site is within the watershed and 1,980 gpd is within 300 ft. Phosphorus loading estimates were then developed by using the factors in Table V-3 and reviewing the portion of the inn/motel's leachfields that are within the watershed and within 300 ft of the pond (see Figure V-3). Based on these factors, Boland Pond has a steady state annual load of 5.2 kg with 40% coming from wastewater and 35% from road runoff. This load is from the lawn of one single-family residence and the portion of loads from the inn/motel, school ballfields, and stormwater runoff from surrounding roads. This load is also the buildout load since there are no parcels classified as developable within 300 ft of the pond. If this mass is adjusted to account for the pond's 0.35 yr residence time, the mass from the watershed within an average residence time is 1.8 kg. Since this mass is less than the average measured mass of 3.7 kg, this suggests that the sediments are adding an average of 1.9 kg phosphorus.

In order to refine this estimate, delays in phosphorus discharge into the pond due to groundwater travel time were also evaluated. Town volunteers reviewed Board of Health records to determine the distance from the lake shoreline to the inn/motel septic system leachfields and cesspools within 300 ft. On average, these structures and the phosphorus they are adding to the groundwater are 253 ft from the pond edge and the estimated average age of

these systems, including multiple installations at the inn/motel, is 36 years with a 20 to 44 year range.

Since phosphorus from residential-sized septic systems takes approximately 91 years to travel 300 ft (*e.g.*, Robertson, *et al.*, 1998), the wastewater load to Boland Pond can be adjusted by both the average distance from the pond shoreline and the age of the wastewater systems at the inn/motel. Given an average of 253 ft to the pond shore, it will take approximately 77 years for the wastewater load to reach the pond. Given that the average age of the wastewater systems is 36 years, this analysis suggests that only 47% or 1.0 kg of the steady-state wastewater phosphorus load would have reached the pond. Adjusting this load for the pond residence time results in watershed load of 1.4 kg/residence time. The adjusted load is the same if age of the residences is considered because the residences and wastewater systems have the same average age. If an alternative approach is taken and only the wastewater systems old enough to have phosphorus loads reach the pond are counted, none of the systems are close enough to have added phosphorus to the pond and the revised overall annual steady-state load of 3.1 kg only includes runoff and fertilizer. Adjusting this estimate for the residence time, the watershed load is 1.1 kg/residence time. Using these estimates and the average mass of phosphorus in the pond, the average sediment phosphorus load is 2.2 kg and 2.6 kg, respectively. Overall, sediment regeneration is estimated to account for 49 to 69% of the total mass of phosphorus measured in the pond.

Although further review of travel times and loading factors should be considered to refine existing conditions, the comparison between the projected loads and the observed concentrations suggest that there are significant loads that are in transit toward the pond. These loads may take decades to arrive, but once they arrive the likely potential impact is an additional cause for concern. Projected steady state loads added to the pond will add approximately 14 ppb to existing surface TP concentrations. Projected TP concentrations could then reach 44 ppb, roughly four times the 10 ppb "healthy" threshold, and bring maximum surface concentrations to approximately 75 ppb. All the additional organic matter added to the sediments could also create conditions to favor greater release of internal phosphorus, which could shift concentrations even higher. It is also possible that given the relatively large volume of potential wastewater discharge from the inn/motel that additional loads from beyond 300 ft might reach the pond faster than the estimated travel times and further increase the loads. Attaining steady-state watershed loads would likely shift Boland Pond toward the upper range of Carlson's eutrophic category with occasional to regular occurrences of hypereutrophy (see Figure IV-1).

The temperature stratification in Boland Pond appears to be relatively stable, which likely keeps a portion of the regenerated sediment phosphorus from reaching the upper waters and promoting plant growth. However, consideration of the average phosphorus concentrations and the watershed phosphorus loading analysis suggest that a significant portion of the shallow phosphorus concentrations is due to regeneration from the sediments. If the estimates of sediment regeneration are removed from Boland Pond and steady-state watershed loading is the only source of phosphorus, project TP concentrations in the pond would be reduced to between 9 and 12 ppb. This range would be roughly equivalent to the 10 ppb "healthy" Cape Cod threshold.

The overall assessment of Boland Pond shows an impaired ecosystem with average anoxic conditions and a novel temperature regime. The anoxia supports internal regenerated phosphorus from pond sediments and sustains average total phosphorus concentrations that are three time higher than the 10 ppb "healthy" Cape Cod threshold. Regenerated phosphorus from pond sediments accounts for 49 to 69% of the phosphorus in the pond. Projections of watershed nutrient loads suggest that the eutrophication will accelerate and worsen as phosphorus that is already in transit reaches the pond. It is recommended that management/remedial strategies be developed to address the internal sources of nutrients, existing watershed loads and future potential watershed loads that will eventually reach the pond. Existing data are sufficient to develop management/remedial strategies.

Long term monitoring of Boland Pond should continue, but at a reduced rate until management strategies are implemented. Monitoring recommendations are discussed greater detail in a subsequent section.

VI.5 Cedar Pond

Cedar Pond is the second smallest of the ponds selected for more detailed review. It is 15.1 acres and, at 15 ft (4.6 m) at its deepest point, is the shallowest of the selected ponds. Cedar is located to the south of Route 6 and west of the Orleans Rotary (see Figure V-3). It is somewhat salty; available salinity readings range from 6 to 18 ppt. Prior to the construction of Route 6 nearly 50 years ago, Cedar Pond was connected to Rock Harbor through two culverts/streams that had "unhindered" tidal flow in and out of the pond (Town of Orleans, 2003). The salinity readings show that Cedar Pond is still influenced by tidal inputs and suggest that evaluation of this pond would more properly fit into a Massachusetts Estuaries Project review of Rock Harbor. Although an analysis of data provided by the town is included in this report, the analysis of the conditions in this pond cannot be completed without understanding its relationship to Rock Harbor.

Since Cedar is relatively shallow, it does not thermally stratify, but the deepest station (3 m) has a slightly lower temperature than the upper three stations (Figure VI-17). Given its shallow depth, it would be expected that the pond would be well mixed and well oxygenated, but average DO concentrations below the upper two stations (0.5 and 1 m) are significantly depressed with average anoxic (<1 ppm) conditions at the 2 and 3 m depths between June and September. Near anoxic conditions have been recorded up to the 1 m depth (Figure VI-18). A significant fish kill was observed in August 2001 (J. Scanlon, personal communication).

Dissolved oxygen concentrations in Cedar Pond are somewhat complicated by the lack of consistent salinity readings. Salinity reduces the solubility of oxygen in water, so readings need to be adjusted in order to be accurate. Since available salinity readings in Cedar Pond show that salinity generally increases with depth and also varies from sampling to sampling, accurate measurement of dissolved oxygen would require salinity readings at each depth DO measurements are made.

Although this procedure occurred on a number of occasions, the dataset does not have consistent salinity readings. In order to use the whole DO dataset, staff decided to rely on the

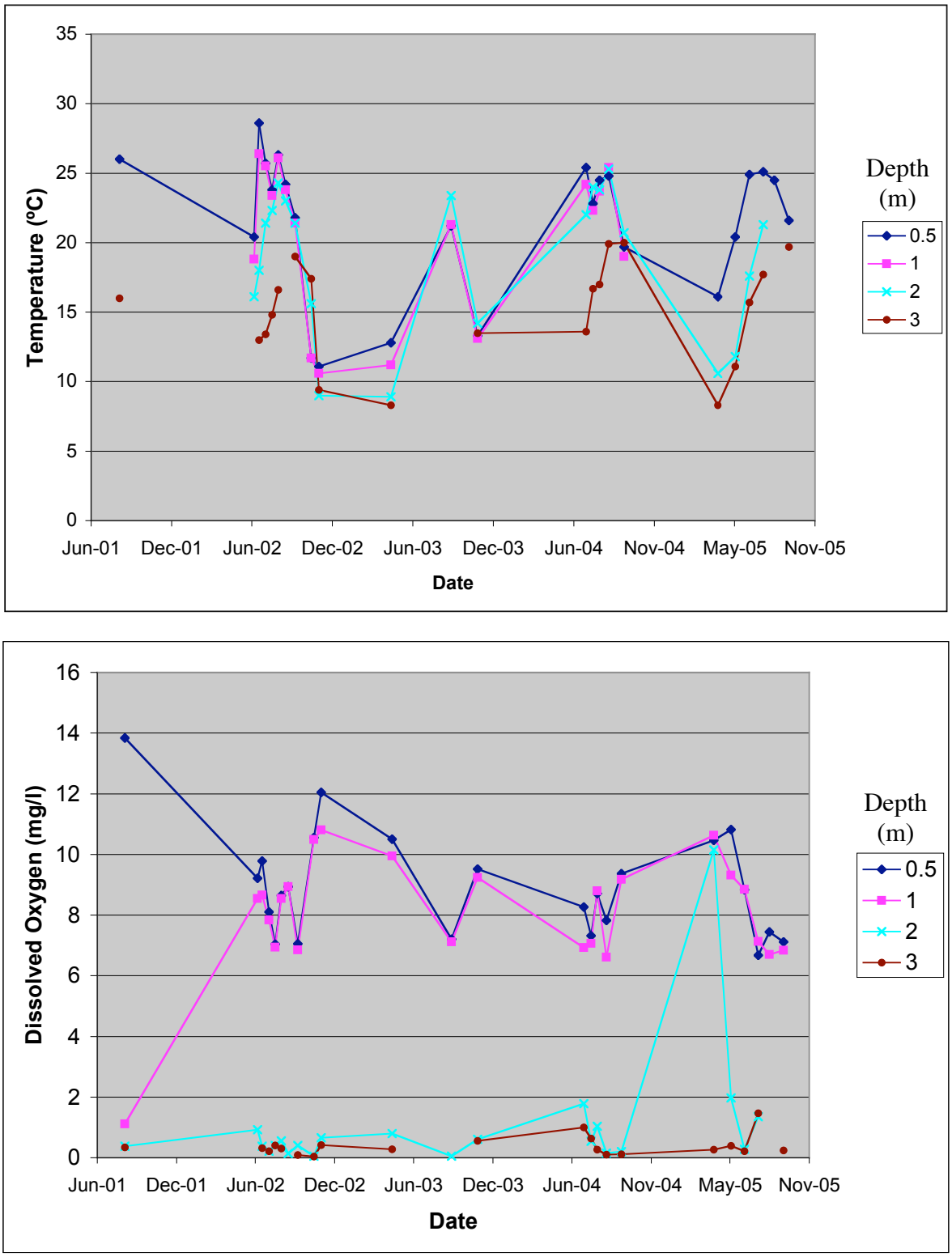


Figure VI-17. Cedar Pond Temperature and Dissolved Oxygen Measurements 2001-2005
Data collected by Orleans volunteers. These graphs include data from PALS Snapshots from 2001 to 2005. DO concentrations have not been corrected for salinity, which was measured only intermittently.

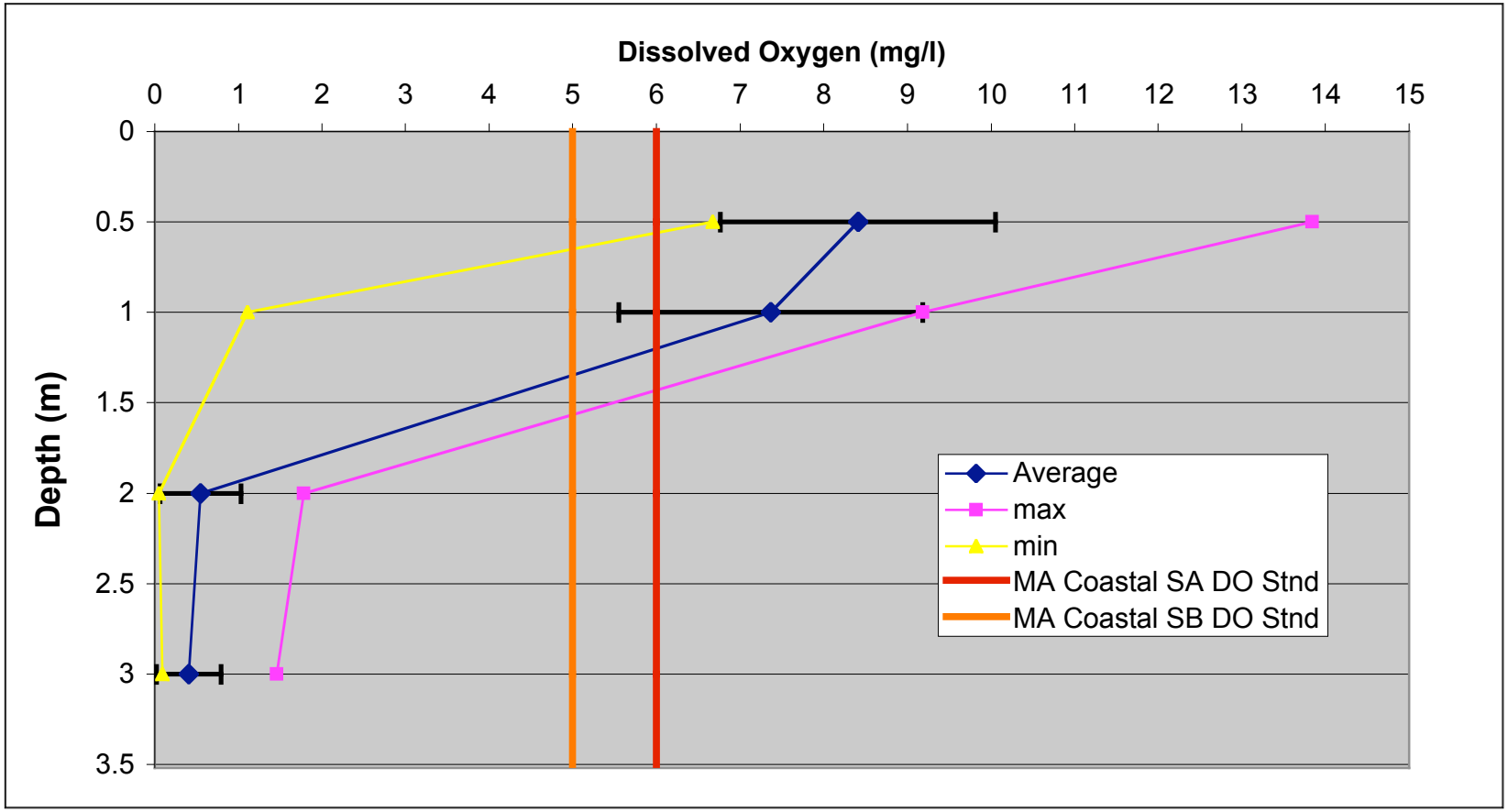


Figure VI-18. Average dissolved oxygen conditions in Cedar Pond June through September 2001-2005
Graph shows average DO profile with error bars (±1 standard deviation) plus maximum and minimum readings for each depth. Also shown are the state surface water 6-ppm DO standard for Class SA coastal waters and the state surface water 5-ppm DO standard for Class SB coastal waters. Depths have 14 to 18 readings. Concentrations have not been corrected for salinity, which was measured only intermittently.

raw concentrations. This assumption means that the DO analysis is somewhat more qualitative than the analysis on the other ponds selected for detailed review.

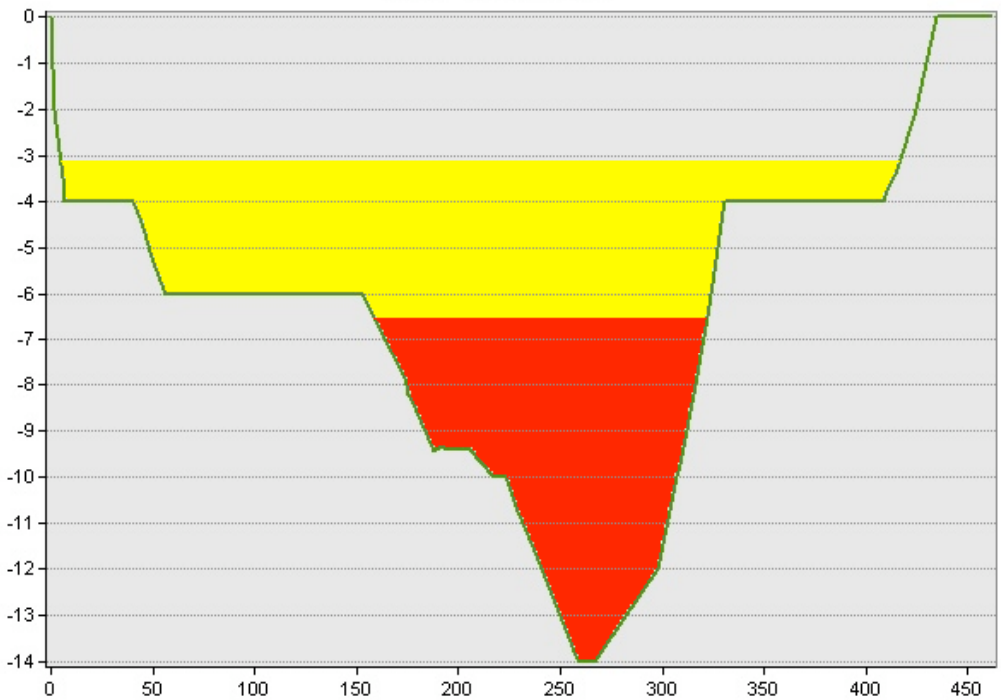
Because Cedar Pond has regularly measured salinity, state regulations for dissolved oxygen standards are located in a different section than the ones for fresh water ponds; all standards are in 314 CMR 4. The dissolved oxygen threshold for Class SA waters is 6 ppm, while the threshold for Class SB waters is 5 ppm. Class SA waters are described in the regulations as: "These waters are designated as an excellent habitat for fish, other aquatic life and wildlife and for primary and secondary contact recreation. In approved areas they shall be suitable for shellfish harvesting without depuration (Open Shellfish Areas). These waters shall have excellent aesthetic value" (310 CMR 4.05(4)(a)). Class SB waters are described in the regulations as: "These waters are designated as a habitat for fish, other aquatic life and wildlife and for primary and secondary contact recreation. In approved areas they shall be suitable for shellfish harvesting with depuration (Restricted Shellfish Areas). These waters shall have consistently good aesthetic value" (310 CMR 4.05(4)(b)).

On average, there is a distinct dividing line between the 1 and 2 m depths in DO concentrations in Cedar Pond between June and September; at 1 m and above, pond water exceeds a 6-ppm threshold, while at 2 m and below it never attains 6 ppm (see Figure VI-15). Salinity-corrected DO saturation percentages show that the shallowest waters on average are supersaturated, which is usually indicative of extensive algal photosynthesis. On average, approximately 17% of the pond volume fails to meet the 6-ppm DO standard (Figure VI-18).

Secchi readings average 1.02 m between June and September (n=17) during the 2001-2005 dataset. Based on an average station depth of 3.52 m, an average reading of 30% of the water column is clear enough to see a Secchi disk. Secchi readings have an overall range from 0.7 to 1.4 m. The average reading is less than the state visibility limit of 4 ft for swimming. Station depths have a slight upward trend, as would be expected due to increasing groundwater levels (Cape Cod Commission files); the slope of the increase is similar to the data from Crystal, Pilgrim, and Boland. Even though Cedar is partially tidal, increasing water levels will tend to increase watershed discharge and, thus, water levels in the pond. Secchi readings have no trend, indicating that transparency factors have been relatively constant over the past six years.

Because Cedar Pond is not a freshwater pond, its limiting nutrient is not likely to be phosphorus. Total phosphorus to total nitrogen ratios average 23 at the upper station and 12.5 at the deep (2-3.3 m) station. Since the upper ratio is just above the Redfield ratio of 16 and the deep ratio is just below, on average the pond is likely to be nitrogen limited or co-limited in the upper waters with phosphorus and nitrogen. Given this, staff completed the phosphorus loading analysis, but comparison to the Cape Cod phosphorus thresholds is not appropriate. It also reinforces the need to understand this pond in the context of the whole Rock Harbor system.

As would be expected in a system with low TP to TN ratios and the potential additions of phosphorus from tidal water from Rock Harbor, phosphorus concentrations are extremely high. The average surface total phosphorus concentration in Cedar Pond is 77 ppb at the shallow station with a range of 12 to 149 ppb. The consistent anoxia deeper in the pond is freeing phosphorus bound in the sediments and releasing it to the overlying waters; the average TP



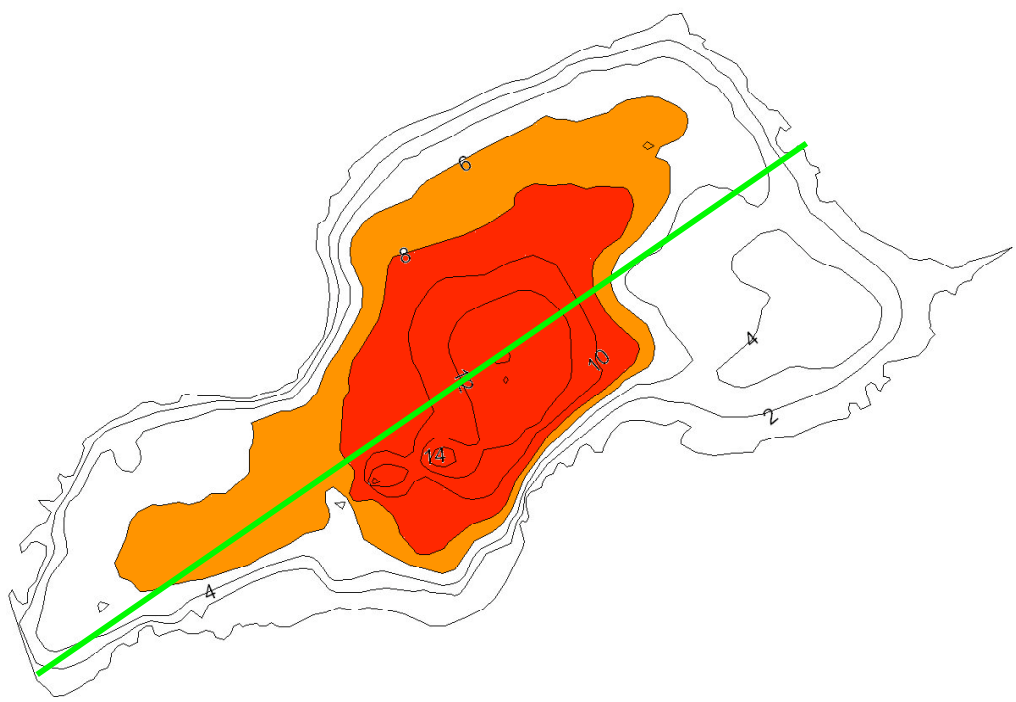


Figure VI-19. Cedar Pond Average Dissolved Oxygen and State Surface Water Standard
Depth profile shows portion of Cedar Pond that averages less than the state surface water 5-ppm standard for class SA warm water fisheries (shaded yellow) between June and September; areas shaded red have average anoxic concentrations (<1 ppm). Area on map is shaded orange since anoxic area only extents to 6.5 ft contour and only whole contours are shown. Green line on map shows depth profile track through the pond.

concentration at the deep station (2 to 3.4 m) is 459 ppb with a range of 122 to 1,291 ppb. These results show that on average sufficient phosphorus is readily available to prompt algal growth provided sufficient nitrogen is also available. They also indicate that there is the potential for rapid changes the ecological conditions in the lake.

Based on monitoring data, the total mass of phosphorus in the pond averages 19.9 kg with 54% of the load contained in waters deeper than 2 m (17% of the pond volume). It is clear from the TP averages that the deepest station is significantly impacted by the sediment regeneration, but is not clear how much of the mass is from watershed loads, internal loading from the sediments, and coastal water inputs. The observed average TP mass in the upper station is 7.7 kg, while 12.2 kg is the average mass at the deep station.

Phosphorus loading estimates can be developed by using the factors in Table V-3 and considering properties that are within 300 ft of the pond and are located on the upgradient side (see Figure V-3). As mentioned previously, all road areas within 300 ft are included in the phosphorus loading estimates. Applying the loading factors to the land uses in its watershed, Cedar Pond has a steady state annual load of 12.9 kg. This load is from 12 upgradient single-family residences, town land, road areas, and four residential properties classified as undevelopable by the town assessing department. Wastewater is 42% of this load and road runoff is 35%. This load will not increase at buildout since there are no additional parcels classified as developable within 300 ft of the pond. If this mass is adjusted to account for the pond's 0.18 yr residence time, the mass from the watershed within an average residence time is 2.4 kg.

In order to refine the phosphorus loads to get closer to actual loading and account for phosphorus lag time, project staff requested assistance from town volunteers. Volunteers reviewed of Board of Health records in order to determine the distance from the lake shoreline to septic system leachfields, leaching pits, and cesspools on adjacent and nearby developed properties within the watershed. On average, these structures and the phosphorus they are adding to the groundwater are 266 ft from the pond edge and the average age of these systems is 59 years. Properties with residences have been developed for an average of 81 years with a range of 36 to 228 years.

Since phosphorus from residential-sized septic systems takes approximately 91 years to travel 300 ft (*e.g.*, Robertson, *et al.*, 1998), the wastewater load from the Cedar Pond properties can be adjusted by both the average distance from the pond shoreline and the age of the wastewater systems and/or the age of the houses. Given an average of 266 ft to the pond shore, it will take approximately 81 years from the average load from all the existing watershed development to reach the pond. Given that the average age of the wastewater systems is 59 years, this analysis suggests that 74% or 11.5 kg of the existing annual phosphorus load would have reached the pond or 2.1 kg/residence time. If a similar analysis is completed based on the age of the residences, all 12.9 kg of the load (or 2.4 kg/residence time) would have reached the pond since it takes 81 years on average to reach the pond and the average of the houses is 81 years. Based on this analysis, the watershed is currently contributing 2.1 to 2.4 kg/residence time.

As mentioned above, the tidal connection of Cedar Pond to Rock Harbor sustains a salinity concentration in the pond. Limited salinity measurements within the pond range between 8 and 16 parts per thousand (ppt). Salinity measurements by Massachusetts Estuaries Project Technical Team members at the head of the Rock Harbor marsh generally are 7 ppt, while TP concentrations range between 172 and 195 ppb (Brian Howes, UMASS-D/MEP, personal communication). Using a range of 7 to 16 ppt and TP range from Dr. Howes, the estimated mass of phosphorus in Cedar Pond from tidal inputs ranges between 4.3 and 11.1 kg.

By combining the watershed and tidal phosphorus loading estimates and subtracting the total from the average mass of phosphorus in the pond, an estimate of the sediment phosphorus load can be developed. Using all the ranges, the estimated range for sediment regeneration is 6.4 to 13.5 kg per residence time. Based on this range, sediment regeneration is estimated to account for 32 to 68% of the total mass of phosphorus measured in the pond.

Although further data collection could be used to refine the analysis of existing conditions, consideration of Secchi measurements and the phosphorus loading analysis suggests that the system is close to steady state. If the maximum estimate of reasonable phosphorus loads is used, the annual watershed load will increase by only 11% or only 1% of the overall average phosphorus mass. It is also worth noting again that nitrogen, not phosphorus, is the key nutrient for controlling ecological conditions in Cedar Pond.

The overall assessment of Cedar Pond shows a highly impaired ecosystem with anoxic conditions, internal regenerated phosphorus, and extremely high phosphorus concentrations. Regenerated phosphorus from pond sediments accounts for 81 to 89% of the phosphorus in the pond. Cedar Pond is also not a freshwater pond and, as such, the above information should be evaluated within the context of nitrogen loads and a better understanding of the pond's ecological connections to the Rock Harbor estuary system. It is recommended that this analysis be part of the planned Massachusetts Estuaries Project technical review that is planned for Rock Harbor.

Long term monitoring of Cedar Pond should continue, but at a reduced rate until management strategies are implemented. Monitoring recommendations are discussed greater detail in a subsequent section.

VII. Recommendations

VII.1. Monitoring Recommendations

Project staff prepared an April 6, 2007 memo providing monitoring recommendations to the town for summer 2007. The memo is included in Appendix B. These recommendations are reinforced and expanded on in the following discussion.

Orleans volunteers under the guidance of the Marine and Fresh Water Quality Task Force (WQTF) have regularly collected data from 20 ponds. The majority of laboratory water quality datasets for most ponds generally consist of monthly to biweekly water quality samples collected during two summers (June-October 2002 and 2003). This data is supplemented with additional once-a-year PALS snapshot data from 2001-2006. Secchi transparency readings have generally been collected in the field on a monthly to biweekly basis between May and November from

2002 through 2006. Dissolved oxygen and temperature profiles throughout the water column have also generally been collected in the field on a monthly to biweekly basis between May and November for 2002 and 2006 with additional measurements for Crystal, Bakers, and Pilgrim during 2000.

In general, most of the ponds have between 15-20 total phosphorus (TP) readings and more dissolved oxygen and Secchi readings. Since Secchi and DO readings can be collected in the field and do not require laboratory analysis costs, their collection is relatively less expensive and generally depends on the access to field equipment and volunteer time. Since the upper portions of the water columns in most of the ponds are well mixed by normal Cape Cod winds, the upper DO readings tend to be stable. Deeper in these ponds, closer to the sediments where DO can be impacted by excessive oxygen consumption in the sediments, readings are consistently unstable. Total phosphorus, total nitrogen and chlorophyll all follow a similar pattern. The review of the data and the detailed analysis of selected ponds indicate that this variability is due to the impairment and lack of stability in these ecosystems. This finding also suggests that sufficient monitoring data has generally been gathered for the current list of parameters in order to begin development and evaluation of remedial and protection strategies for the following ponds: Bakers, Boland, Crystal, Deep, Gould, Icehouse, Kettle, Meadow Bog, Pilgrim, Reubens, Sarahs, Shoal, Twinings, Uncle Harvey's, Uncle Israel, Uncle Seth, and Wash. Cedar is not included in this list because it presents a number of additional issues since it is slightly salty and part of the Rock Harbor estuary system.

This conclusion then leads to the question of whether additional monitoring will be beneficial or useful. Additional monitoring would be useful if the monitoring program is refocused into a tiered effort to address additional data needs for ponds in the Town. It is suggested that this effort focus on 1) sampling and assessment of ponds that have not been monitored, 2), collection of targeted data from the well-monitored ponds that will help to better define remedial and protection strategies, 3) long-term monitoring and review to assess whether negative water quality trends are impacting these ponds, and 4) provisions to monitor and review the benefits of any remedial or protection strategies that are implemented. Each of these recommendations is briefly discussed below.

Even though the current dataset is sufficient to begin to define remedial and protection strategies for the approximately 18 ponds that have been the primary focus of volunteer monitoring efforts, these systems should continue to be regularly monitored, but with reduced frequency, in order to assess whether the systems are changing significantly. It is recommended that the town consider changing the monitoring program for these ponds to a twice-annual sampling strategy. Water samples and field readings would be collected in April and August/September using the PALS sampling protocols and parameters. The August/September sampling for long-term trend analysis could continue to be funded through the PALS Snapshot as long as it continues to be supported by UMASS Dartmouth, School of Marine Science and Technology and the Cape Cod Commission. A brief review at the end of each sampling season should be conducted to identify training needs for the next season and identify any other potential concerns. Every five years, gathered data should be reviewed for trend analysis and long term monitoring concerns. In addition, at the time any remedial activities are initiated either in a watershed or within a pond, it is recommended that monitoring frequency would then

be increased to at least once a month between April and November for at least one year or longer depending on projected groundwater flow times and/or pond residence times to assess whether projected benefits are realized. Details regarding the parameters to be measured could be worked out at the time the increased frequency and remedial activities are planned.

The reduced frequency of sampling recommended for the other ponds that have been monitored would allow volunteers to focus efforts on the approximately 40 other ponds in Orleans that have not been monitored. It is recommended that the WQTF consider adding additional ponds to the sampling program. The Commission's Cape Cod Pond and Lake Atlas lists Orleans as having 63 ponds, while approximately 20 are currently sampled. It would be useful to determine what is known about the ponds that are not sampled and assess whether monitoring and/or physical characterization (*e.g.*, bathymetry) is desired. It is recommended that the WQTF initiate a process to evaluate the interest and desirability of sampling or other information gathering for the ponds that have not been monitored.

Targeted additional data from the ponds that have been monitored will be necessary prior to the final development of remedial or protective strategies, but it is likely that this monitoring should be completed during the review of these strategies. Additional data to be collected would be evaluation of sediment nutrient (and potentially metals) concentrations, measurement of stormwater nutrient loads, and better measurement of stream inputs and outputs from selected ponds. Lake management consultants developing management strategies traditionally conduct these types of activities, but with proper training and guidance, volunteers could collect the samples to reduce costs to obtain this information. Further discussion of this issue should be addressed on a pond-by-pond basis and is discussed below for the ponds that were selected for detailed review.

The above recommendations are dependent on adequate funding. Volunteers provide savings for labor costs and the town has made investments in equipment costs, but implementation of the above refocusing will require additional funding for laboratory analysis and, potentially, equipment costs. Commission staff are available to help the town evaluate potential costs for monitoring options.

In summary, data for the regular monitoring parameters is sufficient to begin the development of remedial/protective strategies for the following ponds: Bakers, Boland, Crystal, Deep, Gould, Icehouse, Kettle, Meadow Bog, Pilgrim, Reubens, Sarahs, Shoal, Twinings, Uncle Harvey's, Uncle Israel, Uncle Seth, and Wash. Cedar will require additional consideration because of its salinity. Plans should be considered to develop strategies for the other 13 ponds that have not been reviewed in detail. It is further recommended that existing volunteer monitoring be refocused into a reduced frequency, longer-term schedule for the 17 ponds listed until management activities are implemented and consideration be given to extending monitoring to other ponds in Orleans that have not been monitored.

VII.2. Recommendations for Next Steps for Bakers, Crystal, Pilgrim, Cedar, and Boland

The review of data contained in this report indicates that sufficient basic data has been gathered from Bakers, Crystal, Pilgrim, Cedar, and Boland ponds in order to proceed toward the development of remedial/management activities to address their impairments and/or preserve

their water quality. Each of these ponds has unique characteristics that suggest that the next steps will require pond-specific tailoring of these activities.

VII.2.1. Bakers Pond Recommendations

Bakers Pond is relatively healthy and only one of Orleans' monitored ponds that is solidly oligotrophic, approximating a classic Cape Cod kettle pond. Bakers has adequate deep dissolved oxygen to support a cold-water fishery and meets state DO standards for most of its volume. There are signs for concern, however, that warrant long-term monitoring: deep anoxia has risen higher in the water column over the past 60 years and phosphorus loading analysis suggests that the potential load reaching the pond will triple before reaching steady state. It is recommended that long term monitoring use the existing data as a baseline and develop management strategies based on whether results worsen significantly beyond current results.

It is recommended above that Bakers Pond monitoring be transitioned to a schedule of early spring and late summer. This monitoring would then be compared to pertinent available data. For example, total phosphorus concentrations in the upper 9 m of Bakers Pond between June and September average 4.8 ppb (n=52) after correcting for outliers. Dissolved oxygen concentrations at a depth of 9 m have never dropped below 6 ppm, while one DO reading at 10 m and 14 (of 46 readings) at 11 m have been less than 6 ppm. Anoxic concentrations (<1 ppm) have never been recorded at 11 m depth and have been recorded 7 (of 46 readings) at 12 m. It is recommended that these results be used to develop a series of thresholds that, if exceeded, lead to development of management strategies. It is further recommended that the Town of Orleans work through the development of these thresholds and management activities that are triggered by their exceedance through a consensus building process perhaps facilitated through the WQTF. Commission staff are available to assist in this process.

VII.2.2. Crystal Lake, Pilgrim Lake, and Boland Pond Recommendations

Recommendations for Crystal Lake, Pilgrim Lake, and Boland Pond are grouped together because all of these systems are clearly ecologically impaired and fail to meet state surface water standards for dissolved oxygen. Within each pond, the sediment oxygen demand is causing low dissolved oxygen concentrations and these concentrations are, in turn, causing the release of phosphorus from the sediments that is prompting algal growth and reducing Secchi transparency. Remedial solutions for these ponds will have to be individually tailored, but the potential solutions will come from the same list of options.

Sediment oxygen demand in freshwater ponds is traditionally addressed by either aeration, alum treatment or dredging of the sediments. Within each of these categories are a variety of approaches and technologies. Recent efforts on the Cape to evaluate potential options have included the Management Plan for Long Pond in Brewster and Harwich (ENSR, 2001). In addition, the state has recently released a General Environmental Impact Report that reviews the use of lake management and remedial approaches in Massachusetts (Mattson, *et al.*, 2004). It is recommended that the Town of Orleans use these reports as a starting point for a process to review potential options and costs for implementing a strategy to address the sediments within each of these ponds. Commission staff are available to assist in this process.

As the town moves through this process, it should also be kept in mind that the ultimate source of the sediments that are causing the impairments in these ponds is the phosphorus reaching ponds from their watersheds. Whatever options are considered should also include options to address phosphorus loads coming from the watersheds. Commission staff are also available to assist in this process.

VII.2.3. Cedar Pond Recommendations

Cedar Pond is also an impaired system, but unlike Crystal Lake, Pilgrim Lake and Boland Pond, it is not a freshwater pond. It is part of the estuary system that interacts with Rock Harbor. Data presented above shows that nitrogen is likely its controlling nutrient, not phosphorus. However, it is clear that sediment oxygen demand is creating the impairments in the pond and remedial solutions will have to address these sediments. Developing strategies to address the impairments in Cedar Pond will have to account for these nutrient differences and the impact of tidal flows, but the list of potential management options for the sediments will likely be similar to those for the impaired freshwater ponds.

The Rock Harbor estuary system is currently under review by the Massachusetts Estuaries Project. MEP results will review the nitrogen loads coming from the Harbor watershed, how tides move in and out of the system, and an overall assessment of the ecological health of the system. Once the MEP analysis of Rock Harbor is available, it is recommended that the Town of Orleans combine the information available in this report with the MEP results and begin a process to review potential options and costs for implementing a strategy to address the ecosystem impairments in Cedar Pond. As with the freshwater ponds, these strategies will have to address both in-lake conditions and watershed nutrient loads. Commission staff are available to assist in this process.

VII.3. Recommendations for Town-wide Management Activities

All five of the ponds reviewed in detail have water quality concerns related to the land uses within their watershed. Four of the five have impaired water quality that impacts the ecosystem of these ponds to varying degrees, some in highly significant ways. It is clear from the town-wide overview of the ponds that every pond reviewed has excessive nutrients and average dissolved oxygen conditions in almost all fail to meet state surface water standards. What is not clear is how significant these impairments are in the other ponds.

In order to systematically address these findings, it is recommended that the Town of Orleans consider development of a pond remediation program to individually address the existing impairments and develop ways to ensure the long-term health of these ecosystems. This program would begin by completing watershed loading, water and nutrient budget development and water quality review for the 13 ponds with adequate data that were not selected for detailed review. This program would also incorporate the development and review of remedial and management options discussed above for the five ponds that have detailed review in this report. This program would also likely require funding for remedial in-lake activities such as alum treatments and aeration, as well as implementation of best management practices, such as removing or minimizing stormwater discharge into the ponds. As part of this program, the town could also consider review of existing town regulations (*i.e.,*, subdivision rules, conservation commission regulations, board of health regulations) as part of the watershed management

activities to better protect pond water quality when land is developed and when existing properties are sold. The town may also want to consider combining all of these activities with monitoring programs, so all pond-related activities are coordinated and mutually supportive. Commission staff are available to assist the town in discussion of these types of activities.

VIII. Conclusions

As part of Barnstable County's Growth Management Initiative and the Pond and Lake Stewardship (PALS) program, the Cape Cod Commission has completed an initial review of pond monitoring data collected by Town of Orleans monitoring volunteers from 18 ponds between 2000 and 2005. Results from an initial review of the data were presented before the Orleans Marine and Fresh Water Quality Task Force (WQTF) in May 2006 and the town was asked to select five ponds for more detailed evaluation. Through the WQTF, the town selected Bakers, Boland, Cedar, Crystal, and Pilgrim for detailed review.

The initial review found that 16 of the 18 ponds in Orleans has average dissolved oxygen concentrations during June through September that are worse than the state surface water standards. Review of phosphorus data show that every pond has average concentrations that exceed the "healthy" pond threshold developed by the Cape Cod Commission (Eichner, *et al.*, 2003).

The detailed review completed for the five selected ponds more thoroughly defined and quantified the extent of the impairments found in the initial review. Detailed review included delineation of watersheds and review of phosphorus loading, as well as more refined reviews of dissolved oxygen and temperature profiles, Secchi transparency readings, and phosphorus concentrations. Development of the watersheds allowed Commission staff to review current and future sources of phosphorus loads. Because phosphorus becomes bound to sand as it travels through the aquifer, phosphorus does not reach a pond until all binding sites are between its source and the pond are used. Therefore, it can take decades for loads from a nearby septic system, for example, to reach a pond shoreline.

The detailed review of the five individual ponds shows that these ponds span a continuum of ecological conditions. Bakers Pond is relatively pristine, although it has some deep-water conditions that warrant additional monitoring. Crystal Lake is relatively impaired, but most of the impairment is deeper in the pond and only occasionally are the impairments seen at the surface. Pilgrim Lake and Boland Pond are impaired with regular mixing of internal sediment-regenerated phosphorus prompting algal growth and near eutrophic conditions. Cedar Pond is significantly impaired, but it has ecological conditions more typical of an estuary and should be considered once the Massachusetts Estuaries Project review of Rock Harbor is completed. All ponds, except Bakers, have dissolved oxygen concentrations that are worse than state surface water minimums. In addition, existing conditions in the four freshwater ponds represent only a fraction of the nutrient loads coming from watershed development; water quality will worsen in time as systems move closer to steady state.

Since the results from the detailed and town-wide data reviews consistently show impairments in almost all of Orleans' ponds, it is recommended that the Town of Orleans consider development of an integrated pond remediation and monitoring program. This program

would be tasked with addressing the existing impairments and prevent future impairments of each pond, develop ways to ensure the long term health of these ecosystems, and integrate on-going monitoring to assess long term water quality trends and efficacy of remedial projects. The suggested details of such a program are described in a series of recommendations. Cape Cod Commission staff are available to assist the town in discussion of these types of activities, the pond analysis results, and recommendations contained in this report.

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