Review and Interpretation of Harwich Ponds Volunteer Monitoring Data

FINAL REPORT

December 2006

for the
Town of Harwich Water Quality Task Force
and Barnstable County

Prepared by:

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Cover photo: Olivers, Hawksnest, Black, and Walkers Ponds, Harwich (Tom Cambareri, 2003)

Executive Summary

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The Town of Harwich pond monitoring volunteers have provided sufficient data to allow a prioritization of the water quality problems in the 13 ponds that have been monitored: Andrews, Aunt Edies, Bucks, Cornelius, Flax, Hawksnest, Hinckley, John Joseph, Robbins, Sand, Skinequit, Walker, and White. Monitoring data show that all the ponds have water quality concerns, although some have clear water quality impairments. The worst among these, by increasing level of impairment, are Sand, Cornelius, Hinckley, John Joseph, and Skinequit.

Although existing data is sufficient for prioritization of future efforts, more refined data collection will be necessary to assess any of the individual ponds. The available data is inadequate to determine whether the variability in the individual ponds is due to natural variability in the ecosystems or is due to the limited number of samples. The water quality portion of refined data collection can be accomplished through enhancement of the existing monitoring program, including more careful adherence to the PALS sampling protocol and more frequent data sampling runs. Water quality data would then need to be brought into additional context through the delineation of watersheds, evaluation of nutrient sources within the watersheds, development of water and nutrient budgets, and potential sampling of pond sediments. One example of this type of individual pond analysis was recently completed by the Cape Cod Commission for the Indian Ponds in Barnstable (Eichner, *et al.*, 2006).

Short of more refined individual pond sampling, it is recommended that the Town, at a minimum, continue to sample the current list of ponds on an annual basis. This annual sampling should closely mirror the current sampling and laboratory procedures completed through the annual Pond and Lake Stewards (PALS) Snapshot sampling. The Snapshot has been coordinated every August and September since 2001 by the Cape Cod Commission and UMASS-Dartmouth, School of Marine Science and Technology (SMAST). Results from town annual monitoring should be reviewed and interpreted every five years to determine whether any notable water quality trends are occurring.

Any future sampling should work to maximize the effort and value of having volunteers collect the data and the Town pay for laboratory services. The existing dataset for Harwich ponds has some limitations because of inconsistent sampling procedures. Although the PALS protocol is the stated basis for sampling, a number of ponds have samples collected at non-standard depths, as well as dissolved oxygen recordings at depths intervals less than every meter. More consistent use of the PALS protocol will allow the town to have better confidence in interpretation of water quality results, provide a better basis for any future individual pond assessments that may be planned, and maximize the efforts of volunteers. It is recommended that training of monitoring volunteers be reviewed to ensure that the protocol is clearly understood.

Table of Contents

Review and Interpretation of Harwich Ponds Volunteer Monitoring Data
Final Report
December 2006

		Page
Executive Summary		E1
I.	Introduction	1
II.	Pond Data Sources	1
III.	Town-wide Water Quality Data	4
	A. Field Collected Water Quality Data	4
	1. Dissolved Oxygen and Temperature	4
	2. Secchi Depth	8
	B. Laboratory Water Quality Data	8
	1. Total Phosphorus (TP)	8
	2. Total Nitrogen (TN)	10
	3. Alkalinity and pH	13
	4. Chlorophyll *a* (CHL-a)	18
IV.	Water Quality Overview	18
	A. Trophic Status	18
	B. Monitoring Recommendations	24
	1. Town-wide Dataset/Monitoring	24
	2. Individual Ponds/Sampling Procedures	24
V.	Recommendations for Future Activities	27
VI.	Conclusions	28
VII.	References	30

List of Figures

Review and Interpretation of Harwich Ponds Volunteer Monitoring Data

Final Report
December 2006

	Page
Figure 1. Ponds monitored by Harwich volunteers…….…….	2
Figure 2. Average Dissolved Oxygen Concentrations in Harwich Ponds 2001-2005……..……..…	6, 7
Figure 3. Average Secchi Depth in Harwich Ponds 2001-2005…...	9
Figure 4. Average Total Phosphorus Concentrations in Harwich Ponds 2001-2005……..…….	11, 12
Figure 5. Average Total Nitrogen Concentrations in Harwich Ponds 2001-2005……..…….	14, 15
Figure 6. Average pH in Harwich Ponds 2001-2005……..……...	16, 17
Figure 7. Average Chlorophyll-*a* Concentrations in Harwich Ponds 2001-2005……..……..……	19, 20
Figure 8. Average Trophic Status Index (TSI) in Harwich Ponds 2001-2005……..…….	22
Figure 9. Standard Deviation and Certainty of Mean……..……	23

List of Tables

Review and Interpretation of Harwich Ponds Volunteer Monitoring Data

Final Report
December 2006

	Page
Table 1. Field and laboratory reporting units and detection limits for data collected for the Harwich Ponds……..……	3
Table 2. Carlson Trophic State Index (TSI) ……..……	21
Table 3. Review of Data Variability in Harwich Ponds……..…….	25
Table 4. Review of Sampling Depths for Harwich Ponds…..……..	26
Table 5. Water Quality Prioritization……..…….……	28

I. Introduction

The Town of Harwich has 63 ponds that collectively occupy 220 acres (Eichner, *et al*., 2003). Of these ponds, about half of them are greater than one acre and 20 of them are greater than ten acres. 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, including Harwich, took the opportunities presented by the annual PALS Snapshots, which have continued through 2005, to create volunteer pond monitoring programs. In Harwich's case, the monitoring program has included funding for laboratory analysis of water samples, training of volunteers, and coordination through the Water Quality Task Force. The Harwich program uses the PALS sampling protocol as guidance and the collection of samples from 13 of the town's 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 scope for a project to review this data; this project was funded using both GMI and Town funding. The agreement between the Town and Commission required the Commission to review of Harwich's data and provide trophic classifications and monitoring recommendations.

With the assistance of the Harwich Water Quality Task Force, 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 June 22, 2006. The information presented below details the review of the volunteer monitoring data, including recommendations for future monitoring.

II. Pond Data Sources

The initial PALS Snapshot in 2001 is the first volunteer data collected from the 13 ponds reviewed in this report. Data for all the ponds has been generally been collected twice a year since the initial 2001 PALS sampling with one of the samplings each year being the annual PALS Snapshot. Field sampling procedures followed the PALS Snapshot protocol, including

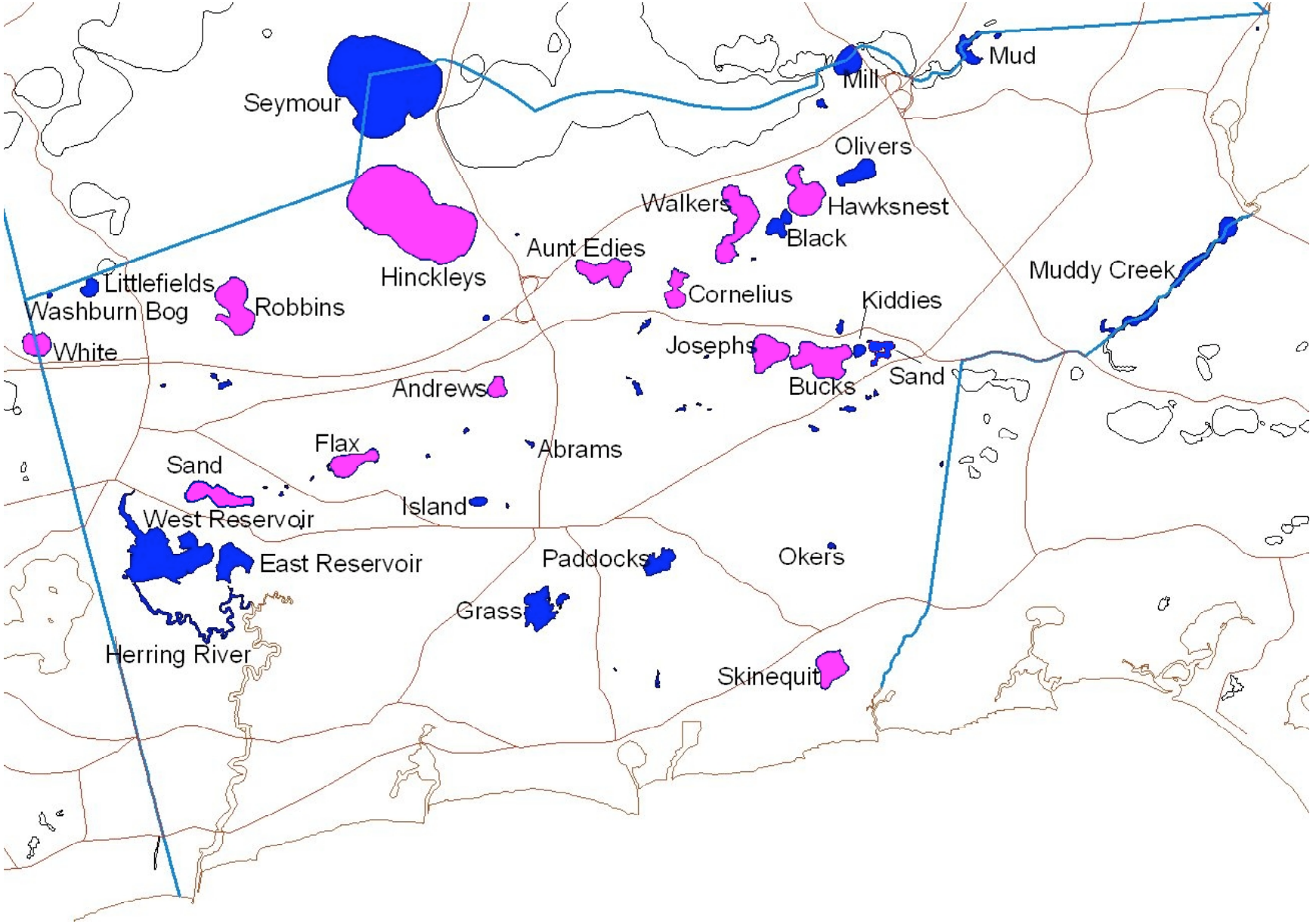

Figure 1. Ponds monitored by Harwich volunteers (ponds shown in pink are reviewed in this report)

water column profile measurements of dissolved oxygen and temperature, and Secchi disk transparency. All laboratory analysis has been completed by the SMAST lab; laboratory procedures are described in the SMAST Coastal Systems Analytical Facility Laboratory Quality Assurance Plan (2003). Laboratory analysis has included 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 1.

Table 1. Field and laboratory reporting units and detection limits for data collected for the Harwich Ponds

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 ppm	± 0.3 mg/l or ± 2% of reading, whichever is greater	0 – 20 mg/l
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 order to complete the data review, Commission staff organized the data by sampling station according to the PALS sampling protocol that was used for the data collection. Thus, a pond like Andrews Pond that is ~8 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.

Data was reviewed on both a town-wide basis and an individual pond basis. Town-wide analysis allows comparison between the ponds, while the individual pond analysis allows for the review of sampling procedures and development of recommendations for future activities. The analysis generally focuses on averages concentrations between June through September; this is the primary period of ecosystem activity in Cape Cod ponds.

III. Town-wide Water Quality Data

A. Field Collected Water Quality Data

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 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 Harwich 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 Harwich Ponds, only John Joseph is deep enough to have strong stratification of temperature and dissolved oxygen.

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. John Joseph tends to have low oxygen or anoxic conditions only in its deepest waters.

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 John Joseph) and not less than 5.0 mg/l in warm water fisheries (*e.g.*, the rest of Harwich's monitored ponds). 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 Harwich ponds. Readings were generally collected at an initial depth of 0.5 meter and then 2 m increments below that (*e.g.*, 0.5 m, 2 m, 4 m, etc.); the PALS protocol, which is the stated basis for the Harwich sampling requires readings at every meter (*e.g.*, 0.5 m, 1 m, 2 m, 3 m, 4 m, etc.). Among the 13 ponds in Harwich with collected volunteer data, there are 56 stations or depths where dissolved oxygen concentrations were measured between 2001 and 2005. These stations generally have between 8 and 22 readings. Among the 13 ponds, only John Joseph would meet the criteria for a cold-water fishery; the remainder of the ponds would be considered warm water fisheries.

Of the 47 stations in the 12 warm water fishery ponds, six had average concentrations between June and September less than the state 5 ppm standard for warm water fisheries (Figure 2). These six stations are located in the following five ponds: Cornelius (1.5 m depth), Hinckley (5 and 7 m), Sand (6 m), Skinequit (4 and 6 m), and Walker (8 m). John Joseph had two stations (14 and 15 m) that had average concentrations less than the state 6-ppm cold water fisheries standard.

Although Massachusetts has adopted regulatory limits for dissolved oxygen, the occurrence of physiologically significant concentrations 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. In addition to all nine of stations identified above that averaged less than the state regulatory concentrations, two additional stations in two additional ponds had dissolved oxygen minima of 1 ppm or less: Andrews (8 m) and Bucks (8 m) (see Figure 2).

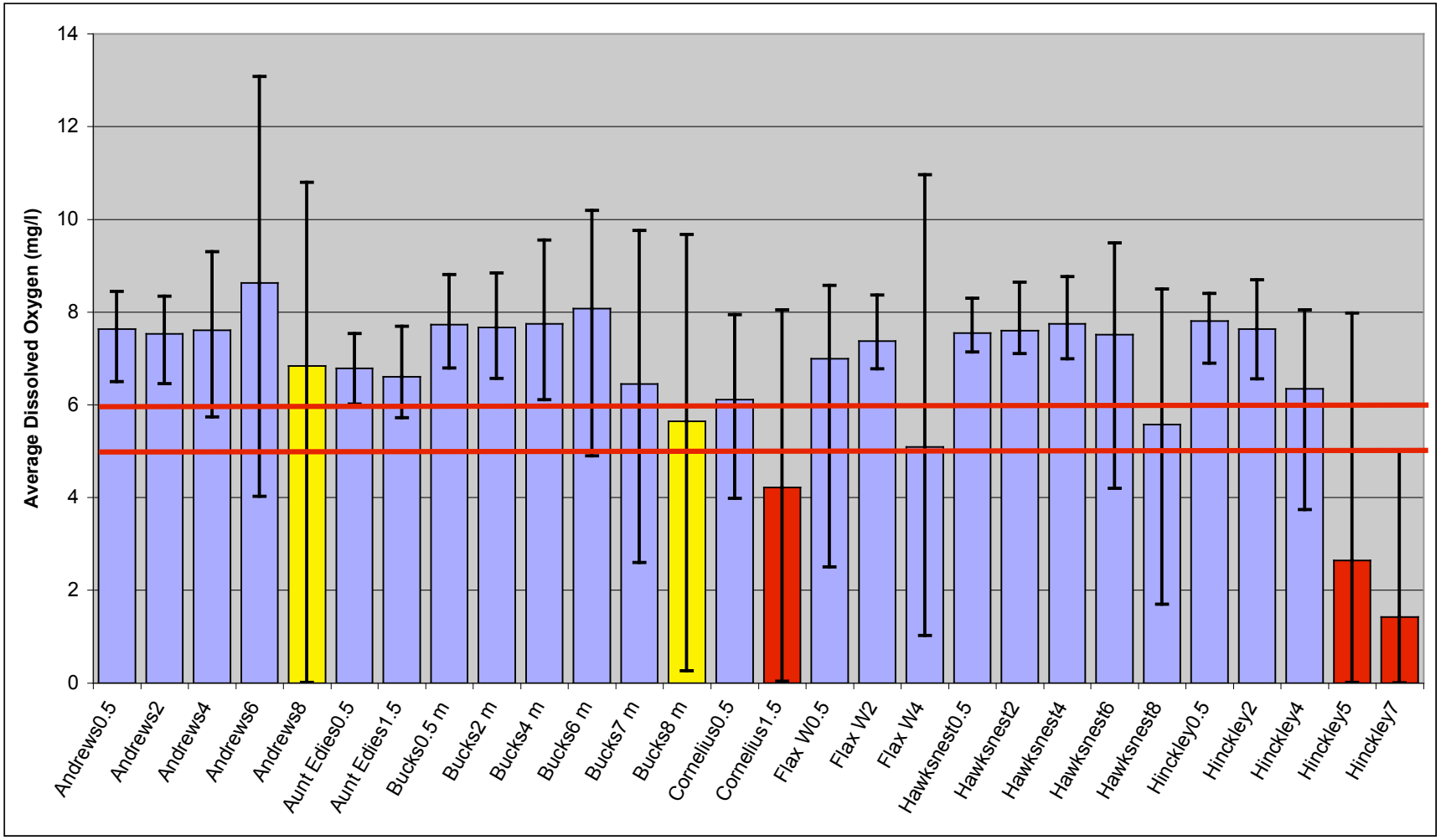

Figure 2a. Average Dissolved Oxygen Concentrations in Harwich Ponds 2001-2005 (Andrews – Hinckley)

Data collected by Harwich volunteers, ponds and station depths (in meters) are identified. Red bars identify stations with average concentrations less than the Massachusetts surface water standards (5 ppm for warm water fisheries; 6 ppm for cold water fisheries), while stations with yellow bars have minimum concentrations of less than 1 mg/l. Maximum and minimum concentrations are also identified for each station.

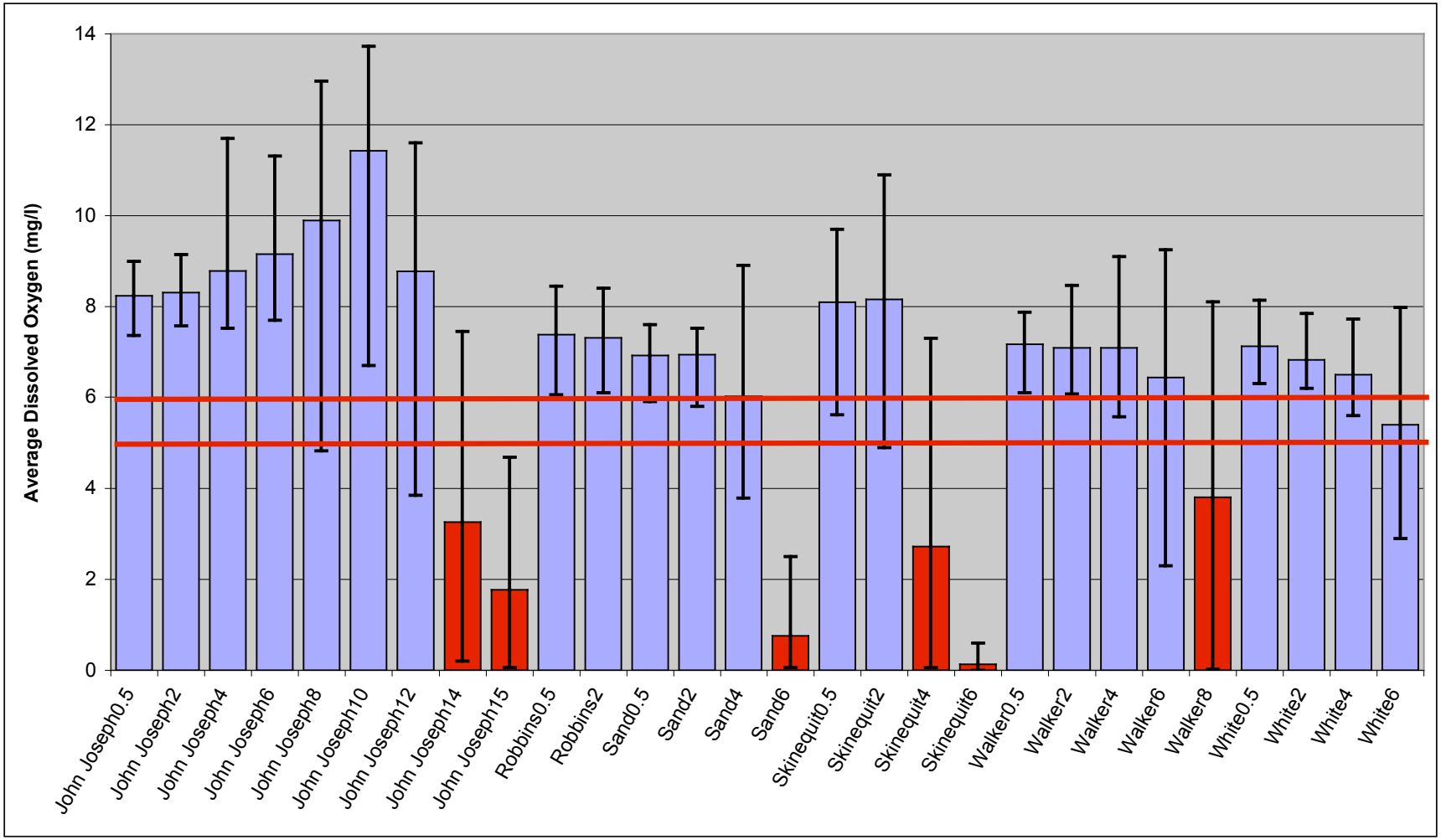

Figure 2b. Average Dissolved Oxygen in Harwich Ponds 2001-2005 (John Joseph – White)

Data collected by Harwich volunteers, ponds and station depths (in meters) are identified. Red bars identify stations with average concentrations less than the Massachusetts surface water standards (5 ppm for warm water fisheries; 6 ppm for cold water fisheries), while stations with yellow bars have minimum concentrations of less than 1 mg/l. Maximum and minimum concentrations are also identified for each station.

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 compared 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 Harwich volunteers each time dissolved oxygen and temperature readings were collected; the number of readings ranged between 8 (Flax W) and 23 (Skinequit and Walker). Absolute average readings generally met the state safe swimming clarity limit of 4 feet except for Cornelius, which averaged 3.7 ft (Figure 3). Relative average readings varied between 23 (Skinequit) and 98% (Robbins).

B. Laboratory Water Quality Data

As mentioned above, unfiltered 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 analyzed at the SMAST Coastal Systems Analytical Facility Laboratory at UMASS, Dartmouth for the following constituents: pH, total nitrogen (TN), total phosphorus (TP), alkalinity, and chlorophyll *a*.

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.

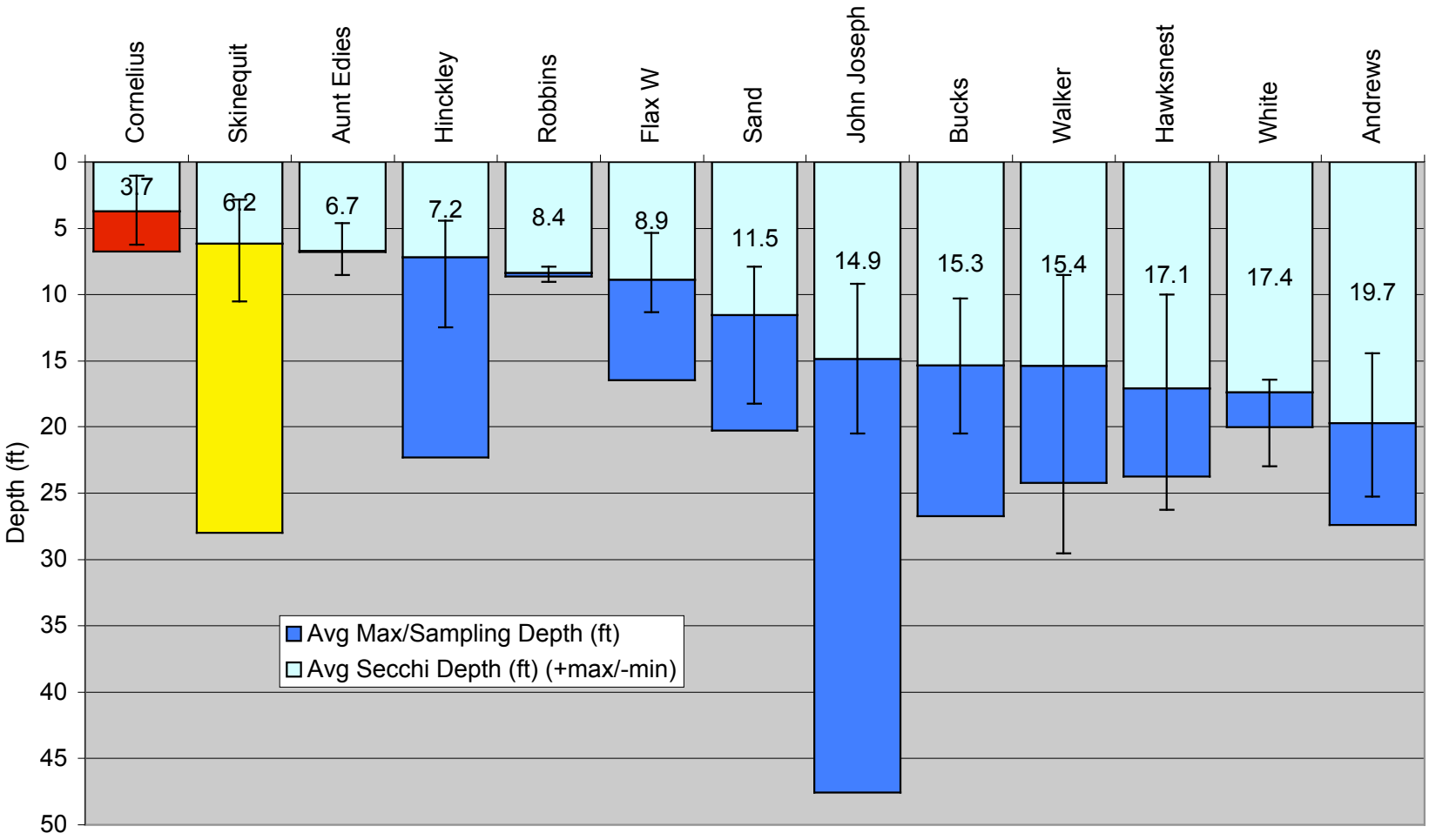

Figure 3. Average Secchi Depth in Harwich Ponds 2001-2005
Data collected by Harwich volunteers. Total bar length indicates average station depth in each pond, while light blue bar indicates average Secchi depth in feet. Maximum and minimum Secchi depths are also identified for each pond.

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 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.

The laboratory dataset for the Harwich ponds is much more limited than the field data; number of surface TP samples among the ponds range from 4 (White) to 12 (Hawksnest). The generally limited number of samples creates less certainty in conclusions based on the average readings; standard deviations are on average 67% of average concentrations. This uncertainty is compounded by the larger than expected variety of deeper sampling depths; some samples were not included in this analysis because of inconsistency in sampling depths and uncertainty about grouping the variety of depths. This issue is discussed further in the sampling review in Section IV.

Average TP concentrations at the 29 Harwich pond sampling stations range between 2.8 and 280.6 ppb (Figure 4). Average surface concentrations in 6 of the 13 ponds exceed the 10 ppb TP regional limit; these ponds are: Cornelius, Flax, Hinckley, Robbins, Sand, and Skinequit. Another 12 deeper stations have averages exceeding the 10 ppb limit; additional ponds with deep stations exceeding the limit are: Bucks, John Joseph, and Walker. These deeper exceedances are likely tied to low oxygen conditions releasing TP from the sediments. Overall, 18 of the 29 sampling stations have average TP concentrations exceeding 10 ppb.

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.

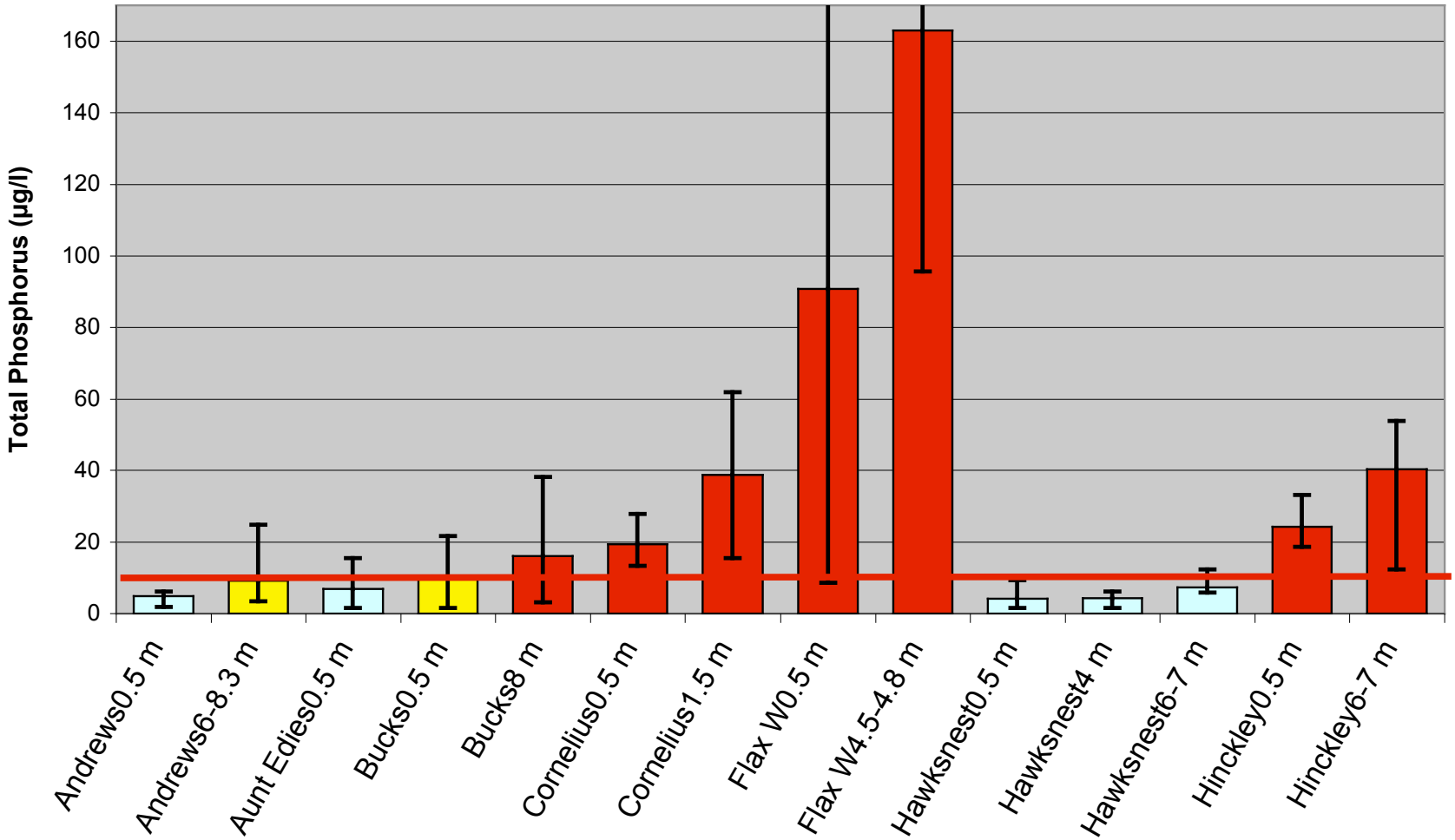

Figure 4a. Average Total Phosphorus Concentrations in Harwich Ponds 2001-2005 (Andrews – Hinckley)
Data collected by Harwich volunteers. Averages are corrected for outliers (±2 std dev). Red bars are stations with average concentration greater than 10-μg/l regional TP limit, while yellow bars exceed the 7.5 μg/l regional "clean" limit; red line also indicates the 10-μg/l limit. Limits were developed by the Cape Cod Commission (Eichner, *et al.*, 2003). Maximum and minimum are also identified for each pond; Flax W 0.5 m and deep maxima are 299 and 230 μg/l, respectively.

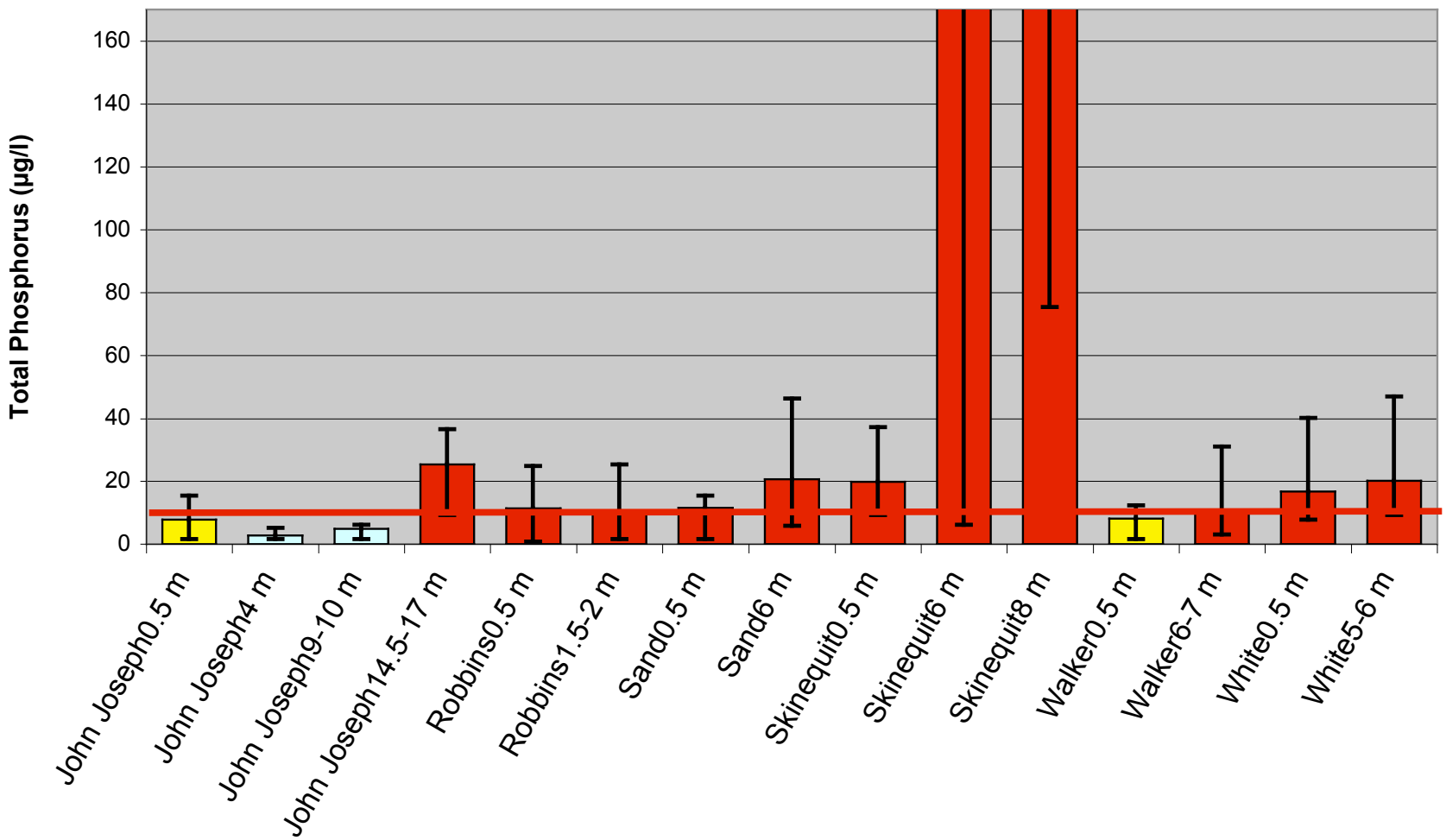

Figure 4b. Average Total Phosphorus Concentrations in Harwich Ponds 2001-2005 (John Joseph – White)
Data collected by Harwich volunteers. Averages are corrected for outliers (±2 std dev). Red bars are stations with average concentration greater than 10-μg/l regional TP limit, while yellow bars exceed the 7.5 μg/l regional "clean" limit; red line also indicates the 10-μg/l limit. Limits were developed by the Cape Cod Commission (Eichner, *et al.*, 2003). Maximum and minimum are also identified for each pond; Skinequit 6 and 8 m maxima are 904 and 630 μg/l, respectively.

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 28 Harwich pond sampling stations range between 0.14 and 2.07 ppm (Figure 5). The number of surface TN samples among the ponds range from 4 (White) to 11 (Hawksnest); standard deviations are on average 43% of average concentrations. Average surface concentrations in 11 of the 13 ponds exceed 0.31 ppm, while only Hawksnest is less than the 0.16 ppm "clean" limit. Overall 21 of the 28 stations exceed the "healthy" 0.31 ppm TN limit and all but the Hawksnest surface station exceed 0.16 ppm TN impacted limit.

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 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 28 Harwich pond sampling stations range between 4.93 and 7.45 (Figure 6). The number of surface TN samples among the ponds range from 4 (White) to 9 (Aunt Edies). Average surface readings in 9 of the 13 ponds exceed 5.62 ppm; average surface pH readings below 5.62 are in: Aunt Edies, Cornelius, Hawksnest, and Walker. Overall 19 of the 28 stations have pH averages exceeding 5.62. Standard deviations for pH readings are relatively compact, likely since pH is a log-based value; standard deviations are on average 3% of average concentrations.

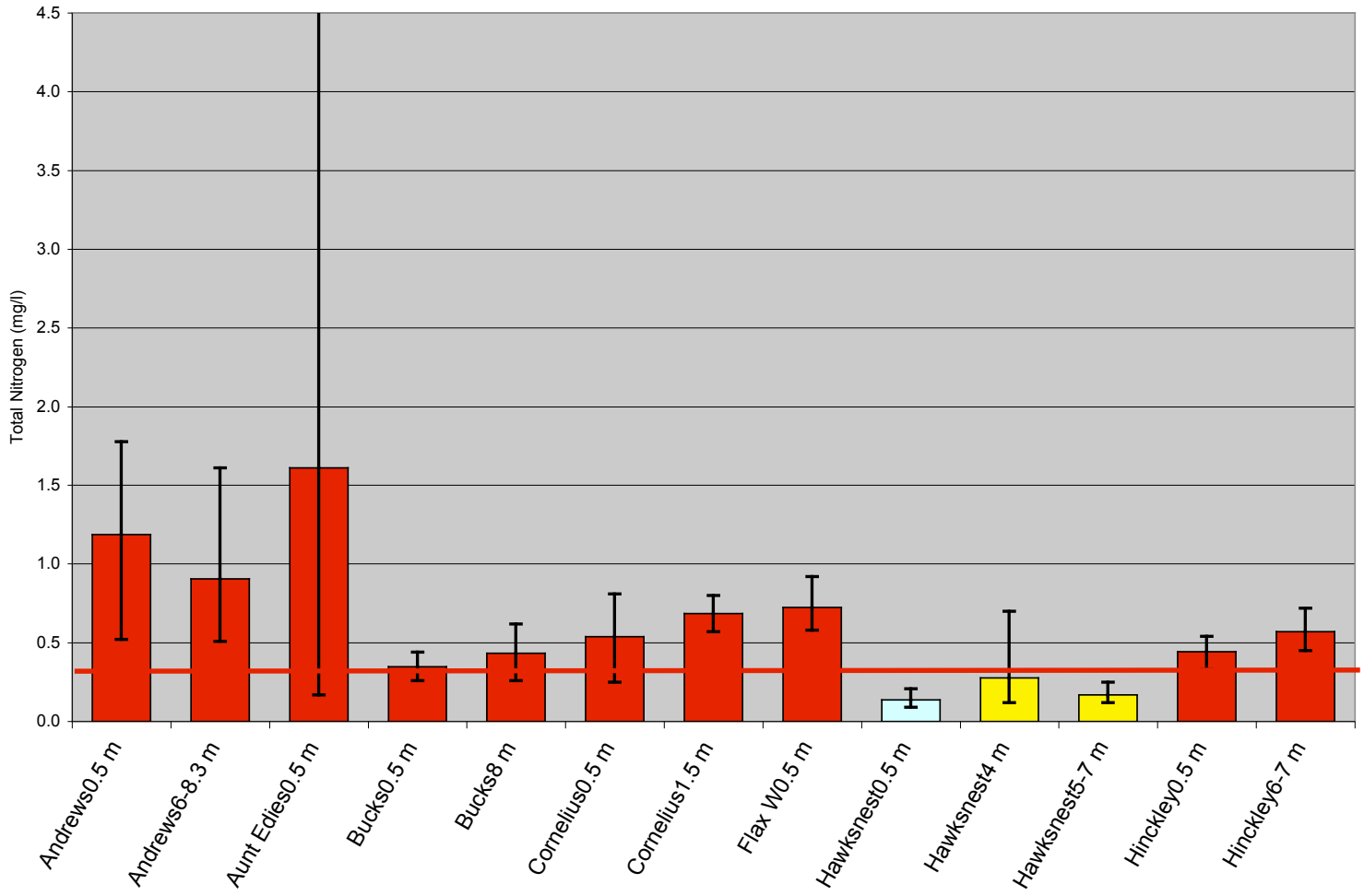

Figure 5a. Average Total Nitrogen Concentrations in Harwich Ponds 2001-2005 (Andrews – Hinckley)
Data collected by Harwich volunteers. Averages are corrected for outliers (±2 std dev). Red bars are stations with average concentration greater than 0.31 mg/l regional TN limit, while yellow bars exceed the 0.16 mg/l regional "clean" limit; red line also indicates the 0.31 mg/l limit. Limits were developed by the Cape Cod Commission (Eichner, *et al*., 2003). Maximum and minimum are also identified for each pond. Aunt Edies has a maximum of 12.76 ppm TN that is not shown.

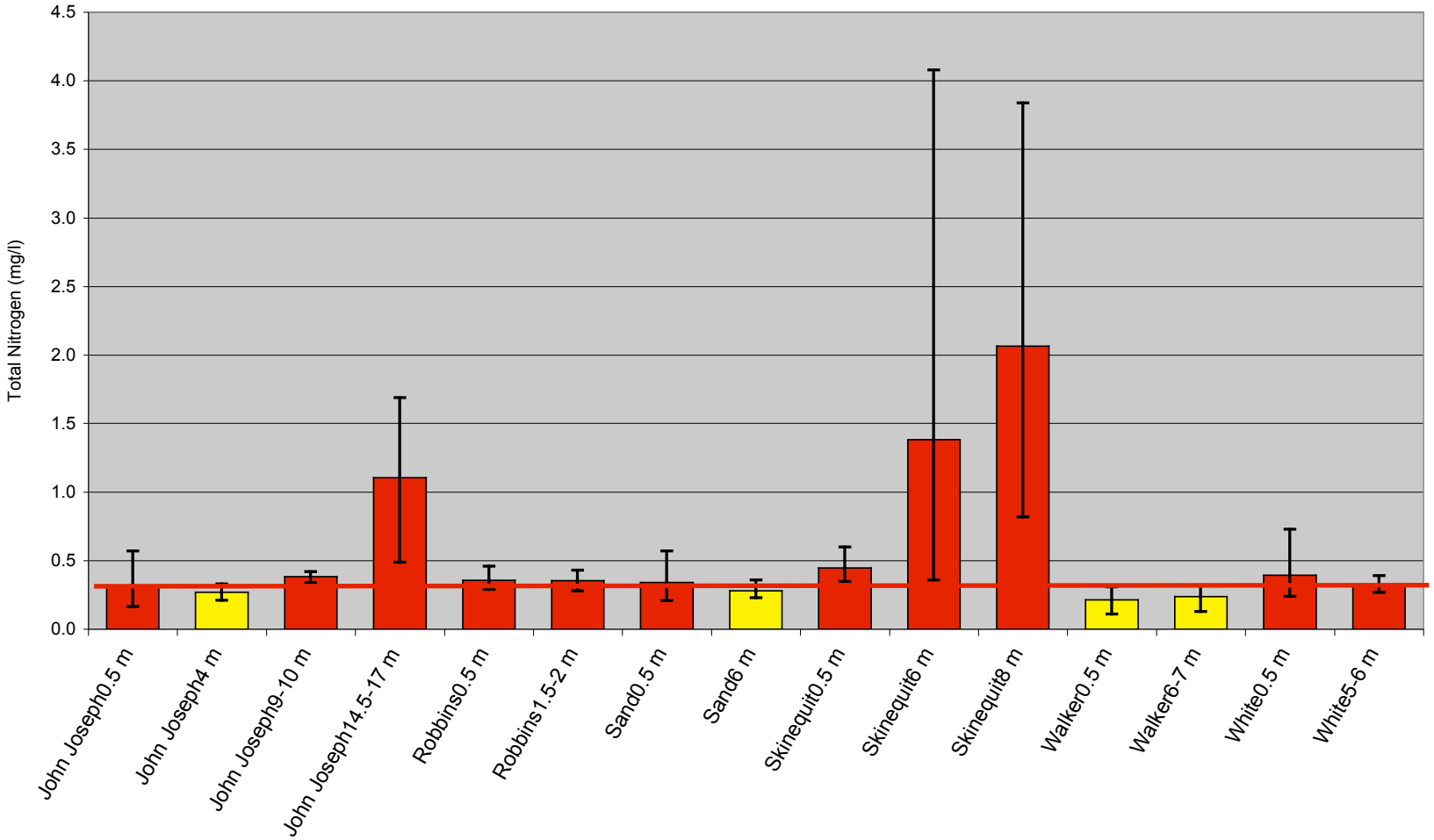

Figure 5b. Average Total Nitrogen Concentrations in Harwich Ponds 2001-2005 (John Joseph – White)
Data collected by Harwich volunteers. Averages are corrected for outliers (±2 std dev). Red bars are stations with average concentration greater than 0.31 mg/l regional TN limit, while yellow bars exceed the 0.16 mg/l regional "clean" limit; red line also indicates the 0.31 mg/l limit. Limits were developed by the Cape Cod Commission (Eichner, *et al.*, 2003). Maximum and minimum are also identified for each pond.

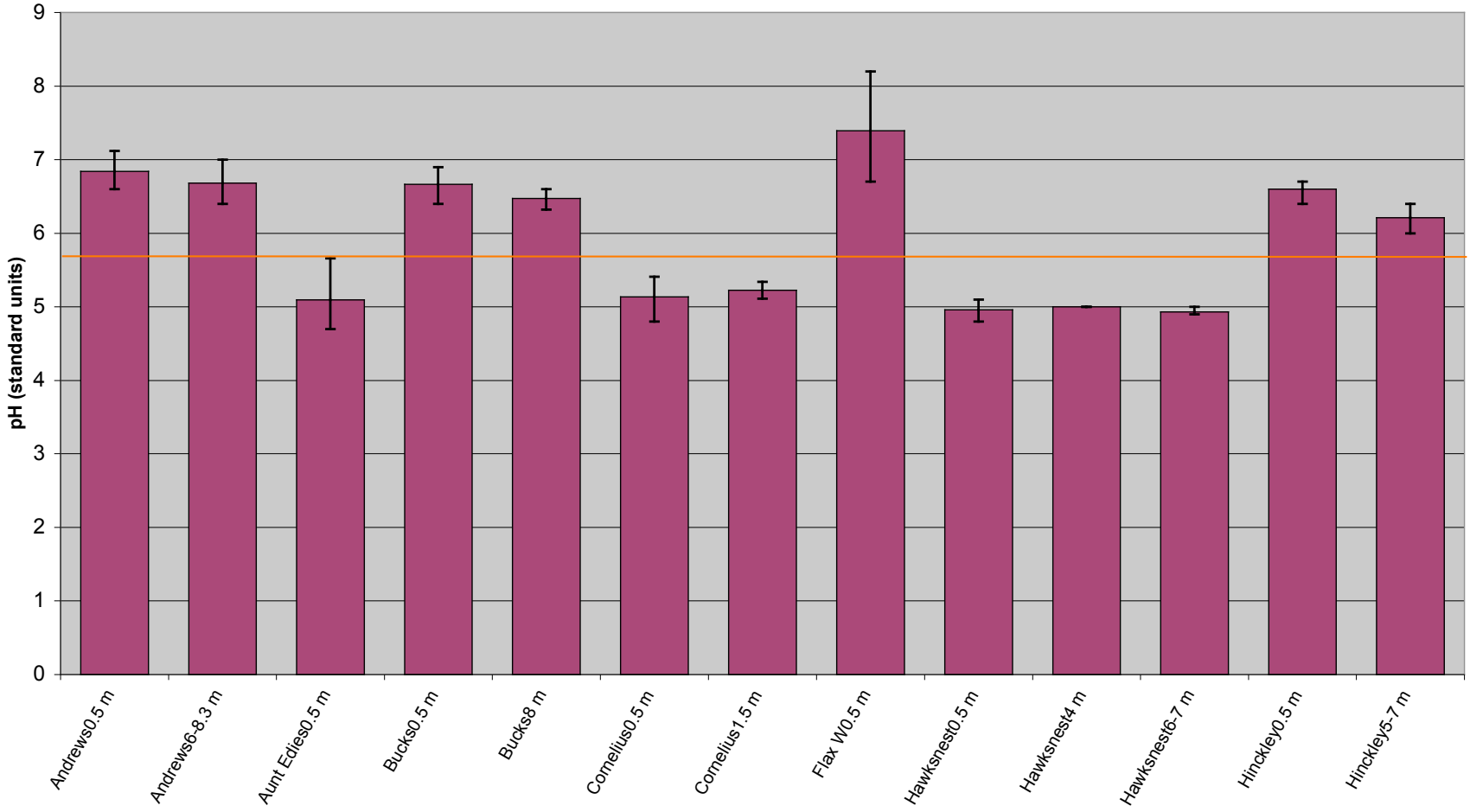

Figure 6a. Average pH in Harwich Ponds 2001-2005 (Andrews – Hinckley)
Data collected by Harwich volunteers. Averages are corrected for outliers (±2 std dev). Maximum and minimum are also identified for each pond. Orange line identifies pH of rainwater in balance with carbon dioxide in the atmosphere (5.65).

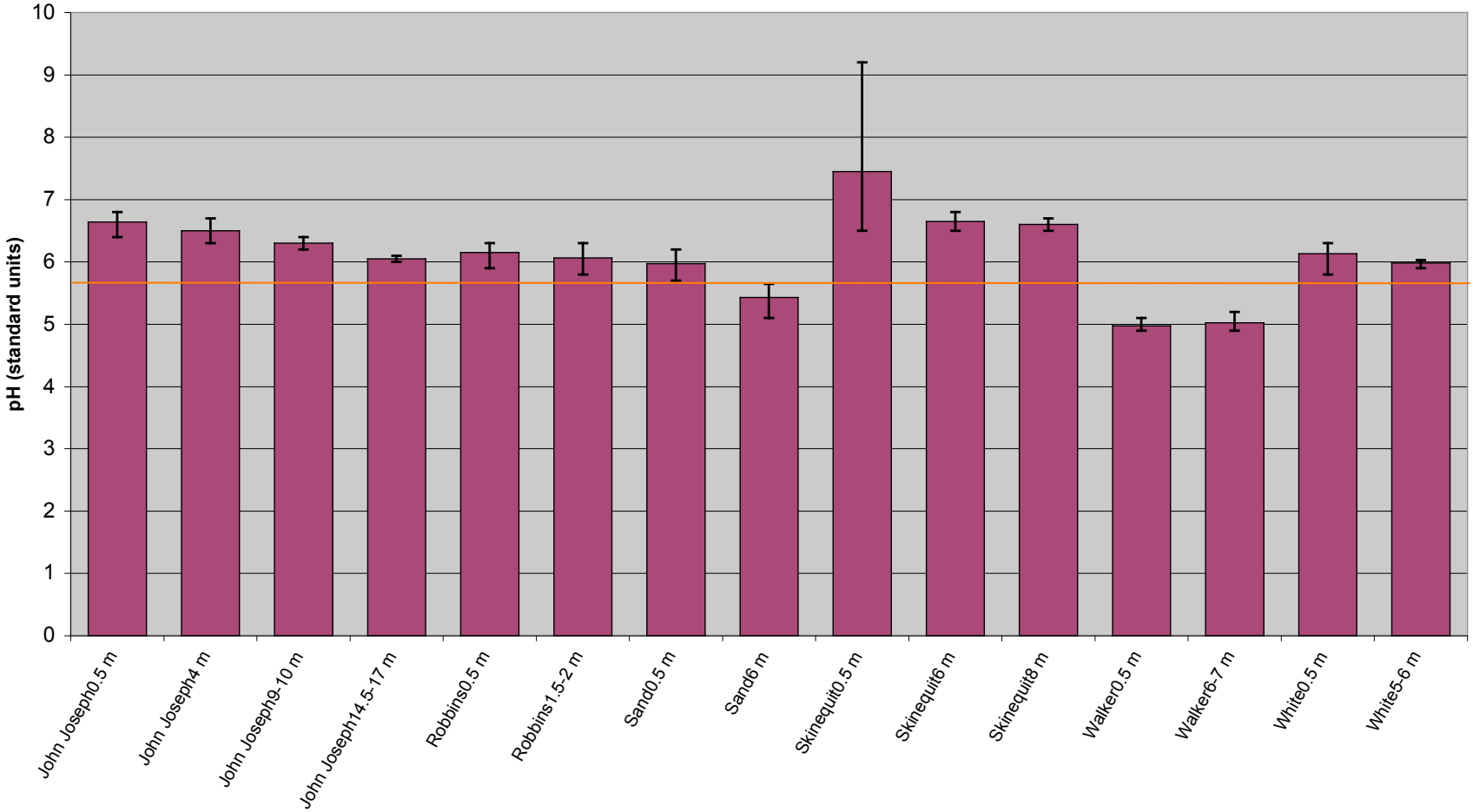

Figure 6b. Average pH in Harwich Ponds 2001-2005 (John Joseph – White)
Data collected by Harwich volunteers. Averages are corrected for outliers (±2 std dev). Maximum and minimum are also identified for each pond. Orange line identifies pH of rainwater in balance with carbon dioxide in the atmosphere (5.65).

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 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 28 Harwich pond sampling stations range between 1.1 (Walker 6-7 m) and 170.8 ppb (Skinequit 8 m) (Figure 7). The number of surface CHL-a samples among the ponds range from 4 (White) to 10 (Bucks, Hawksnest, and Hinckley); standard deviations are on average 75% of average concentrations. Average surface concentrations in 11 of the 13 ponds exceed the 1.7 ppb "healthy" threshold; none of the concentrations are less than the 1 ppb "clean" limit. Overall 25 of the 28 stations have average concentrations that exceed 1.7 ppb CHL-a and all concentrations exceed 1 ppb.

IV. Water Quality Overview

A. 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(s) of the biomass. One of the better known 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 2.

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 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."

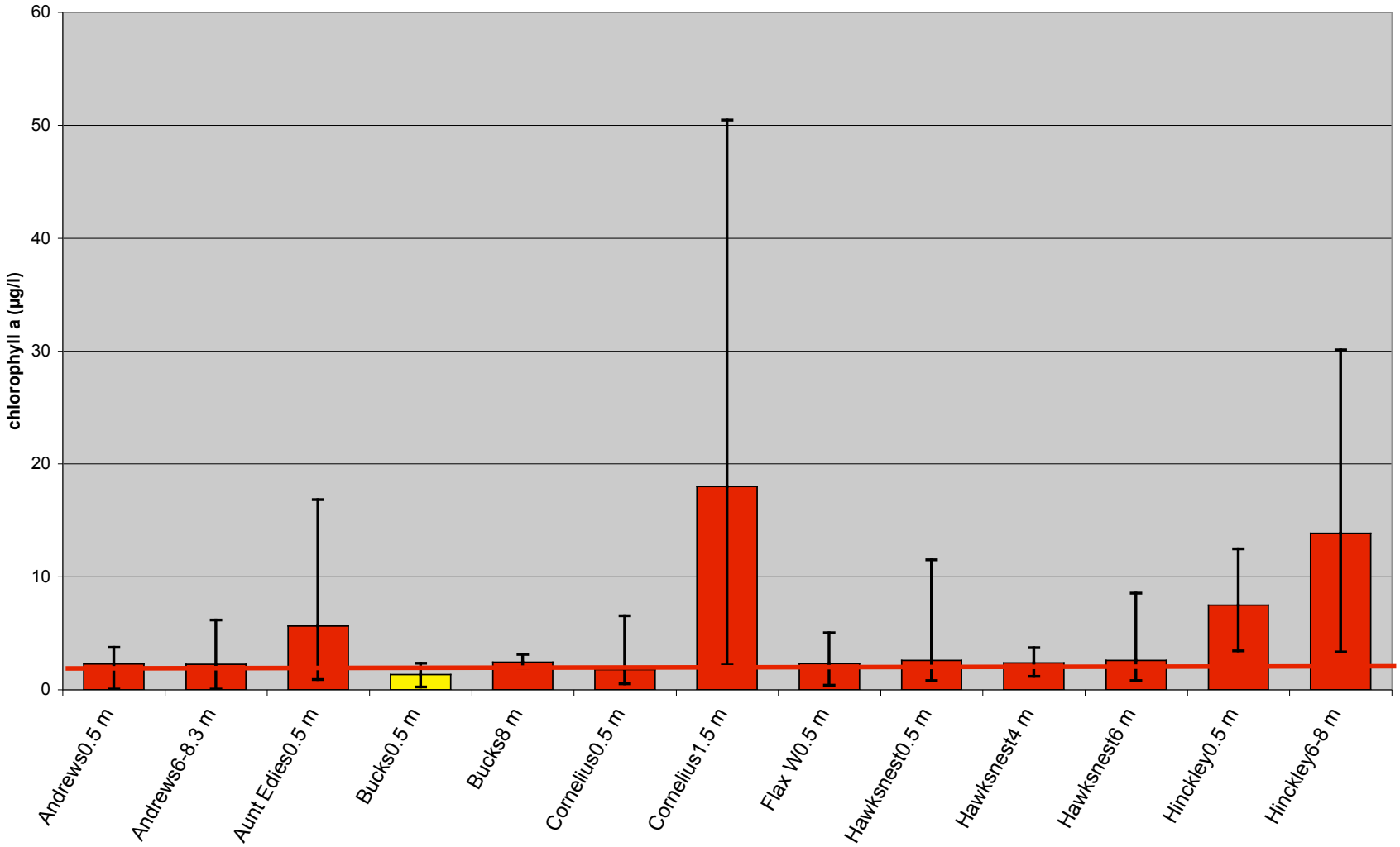

Figure 7a. Average Chlorophyll-*a* Concentrations in Harwich Ponds 2001-2005 (Andrews – Hinckley)
Data collected by Harwich volunteers. Averages are corrected for outliers (±2 std dev). Averages are corrected for outliers (±2 std dev). Red bars are stations with average concentration greater than 1.7 μg/l regional Chlorophyll a limit, while yellow bars exceed the 1.0 μg/l regional "clean" limit; red line also indicates the 1.7 μg/l limit. Limits were developed by the Cape Cod Commission (Eichner, *et al*., 2003). Maximum and minimum are also identified for each pond.

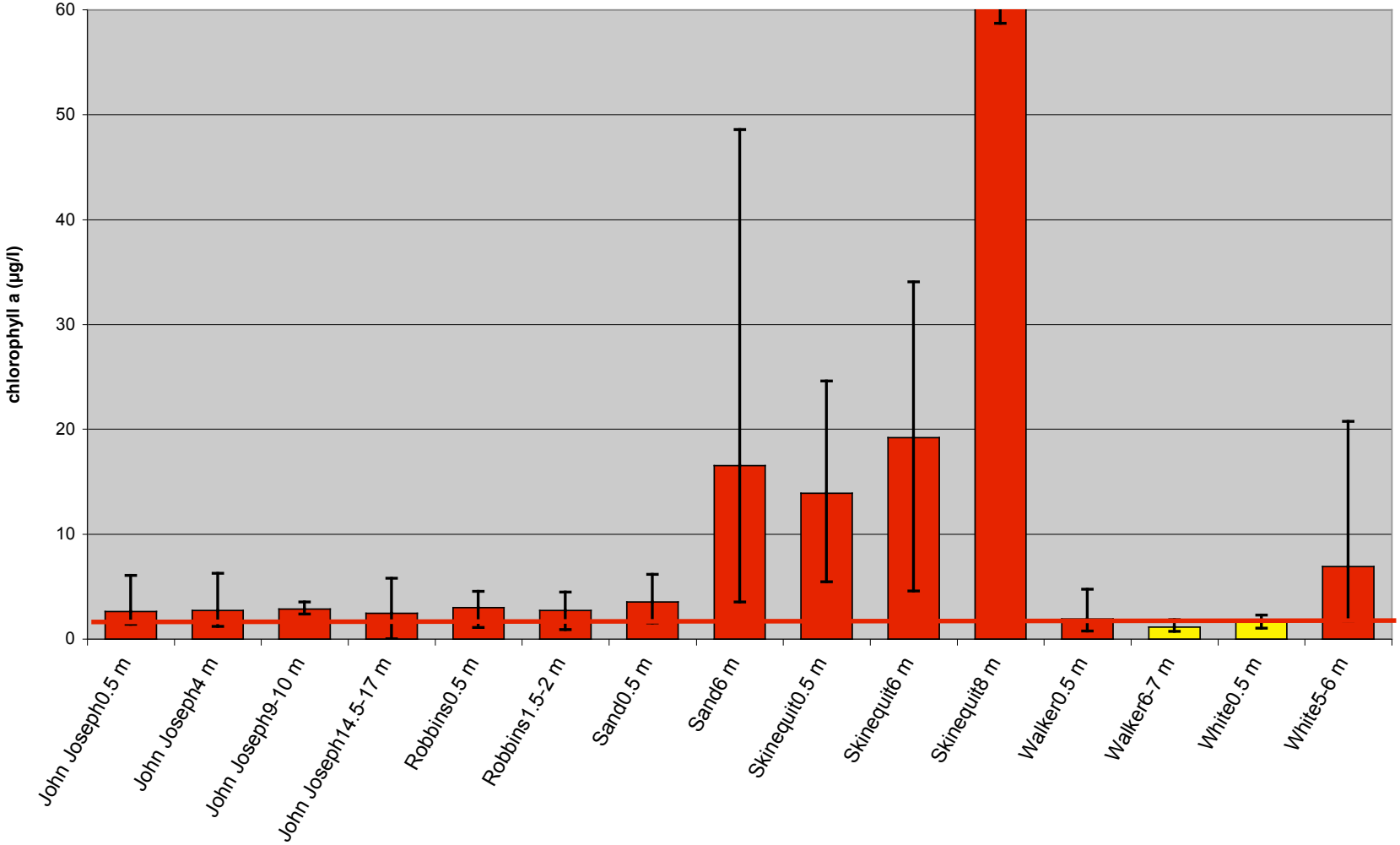

Figure 7b. Average Chlorophyll-*a* Concentrations in Harwich Ponds 2001-2005 (John Joseph – White)
Data collected by Harwich volunteers. Averages are corrected for outliers (±2 std dev). Averages are corrected for outliers (±2 std dev). Red bars are stations with average concentration greater than 1.7 μg/l regional Chlorophyll a limit, while yellow bars exceed the 1.0 μg/l regional "clean" limit; red line also indicates the 1.7 μg/l limit. Limits were developed by the Cape Cod Commission (Eichner, *et al*., 2003). Maximum and minimum are also identified for each pond. Average and maximum for Skinequit 8 m station are not shown and are 171 and 483 μg/l, respectively.

Table 2. – 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					

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 8 shows the trophic categories based on the average chlorophyll a concentrations in the Harwich ponds. Also shown in Figure 8 are error bars based on one standard deviation.

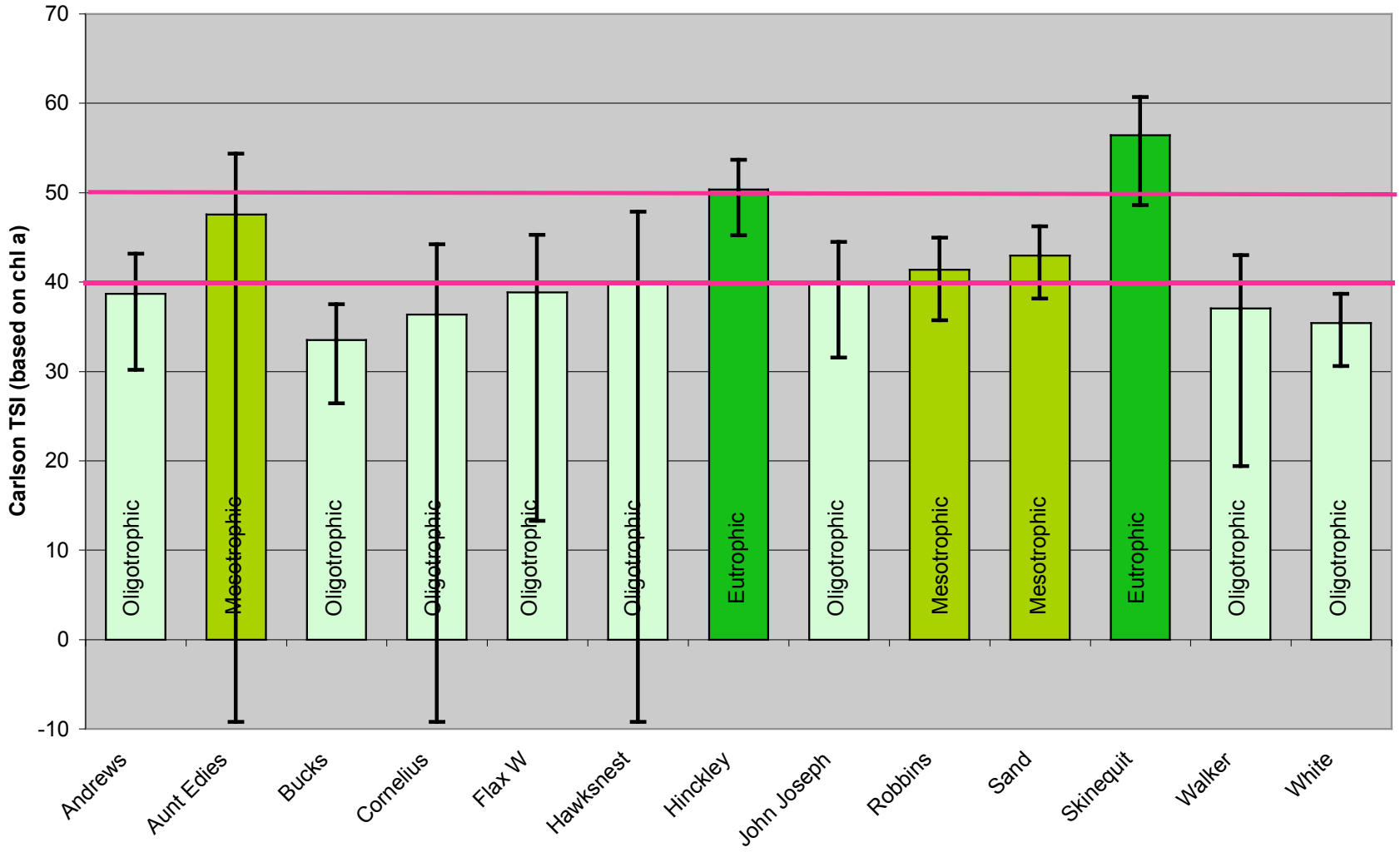

Figure 8. Average Trophic Status Index (TSI) in Harwich Ponds 2001-2005
Data collected by Harwich volunteers. TSI and classification labels based on Carlson and Simpson (1996) for chlorophyll a and average chlorophyll *a* concentrations. Pink lines show boundaries between classification values. Averages are corrected for outliers (±2 std dev). Error bars show one standard deviation.

Standard deviation is a statistical measure of how much variability there is among a group of individual measurements used to calculate an average. If data is normally distributed about the mean, the "actual" mean is 68% likely to be within one standard deviation. The smaller the amount of variability in the data, the sharper the standard curve is and the higher the confidence that the mean, and any conclusions based on the mean, is appropriate. Figure 9 shows the impact of increasing variability and higher standard deviations.

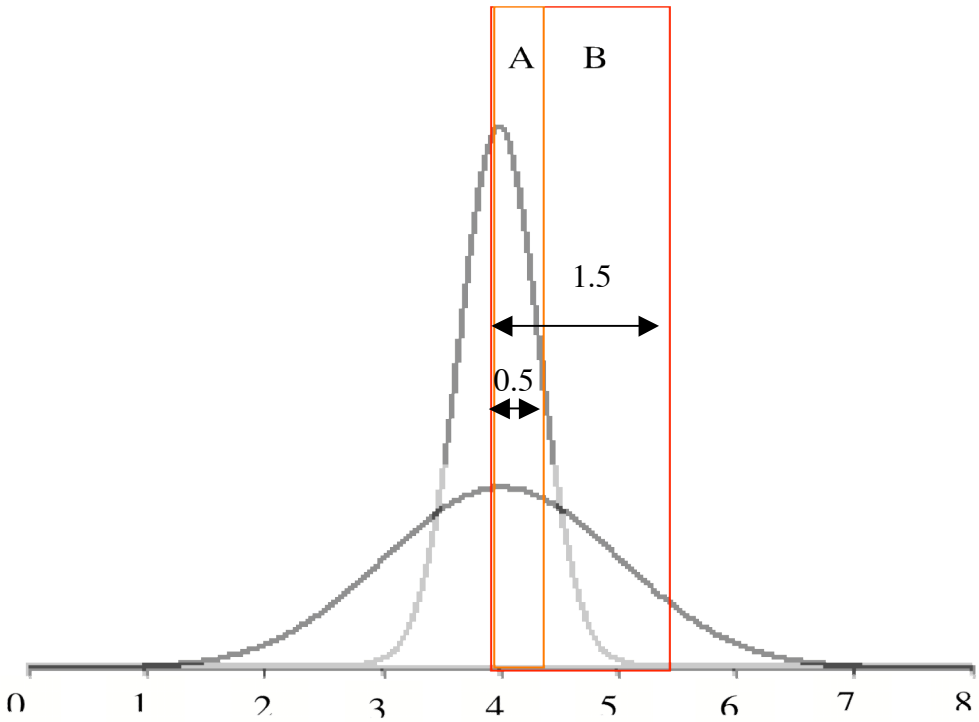

Figure 9. Standard Deviation and Certainty of Mean

The mean is 4 in both case A and B, but the standard deviation in case A is ~0.5, while in case B it is ~1.5. So in case A, the calculated mean is much better constrained and conclusions based on this mean have a higher degree of confidence than case B.

The variability of the Harwich pond data is readily apparent for selected ponds in shown in Figure 8. For example, Aunt Edies average TSI is classified as mesotrophic, but the range of variability in the data spans the oligotrophic and eutrophic categories, too. Other ponds with large TSI ranges are: Cornelius, Flax, Hawksnest, and Walkers. The other ponds have ranges that are fairly well constrained, although any pond with a classification above oligotrophic is impacted by excessive nutrients based on the average Cape Cod conditions. Data from the 2001 PALS Snapshot indicated that an appropriate Cape Cod target for chlorophyll *a* is 1.7 ppb, 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 analysis suggests that Aunt Edies, Hinckley, Robbins, Sand, and Skinequit have excessive algal concentrations.

B. Monitoring Recommendations

1. Town-wide Dataset/Monitoring

The extent and type of pond water quality data necessary depends on the question that is being asked. The review of the data discussed in this report suggests that sufficient data has been collected by Harwich volunteers to prioritize where future monitoring activities should be refined and where the Town may want to consider more detailed assessments. Individual lake assessments will require additional data collection.

In order to compare Harwich data between the ponds and among the data parameters, project staff divided the standard deviation by the average reading for Secchi, chlorophyll *a*, TP, and TN. This yields a percentage that can be compared across the ponds without adjusting for depths or magnitude of the numbers and gives some sense of the overall consistency of the data. Dissolved oxygen was not reviewed because certain depths should have high variability and each pond has a variety of station depths. Readings of pH were also not reviewed because the standard deviations are very small, which is likely because of the log transformation of the data. The analysis focused on surface concentrations, again to avoid multiple depth comparisons.

Table 3 shows that Secchi readings tend to have the most consistent datasets and least variability [*i.e.,* the lowest average percentage (23%)], while the variability increased to 47% for TN, 60% for TP, and finally to 70% for chlorophyll *a*. As part of other PALS activities, project staff are also reviewing more extensive volunteer pond monitoring datasets from the following towns: Brewster, Orleans, Eastham, and Dennis. As shown at the bottom of Table 3, the average percentages for the Harwich ponds within the various data categories are similar to those in other towns and the town-wide averages are constrained within a relatively small range among all of the towns. Since the data sets in the other towns are more extensive than in Harwich and yet the averages are similar, this analysis suggests that the available data in Harwich is appropriate for a town-wide overview, general comparison among ponds, and prioritization of future monitoring activities.

2. Individual Ponds/Sampling Procedures

In order to take the next step of assessing the conditions within individual ponds, sampling runs should be conducted more than twice a summer and steps should be taken to ensure that the PALS protocol is closely followed. The data collection steps in the PALS protocol are sufficient for characterizing the water quality although more frequent runs generally are required for individual pond assessments (*e.g.*, Eichner, *et al.*, 2006). The review of the averages and their variability in Table 3 shows that some of the individual pond datasets require additional sampling to better understand the large ranges in the current results. A comparison of the depths sampled in the ponds and the PALS protocol makes it is clear that better consistency in sampling procedures would help to resolve some of the variability in the data and provide a better basis for subsequent individual pond assessments.

Table 3. Review of Data Variability in Harwich Ponds

HARWICH POND ANALYSIS

POND	Secchi	TP	TN	chl a	AVG
Andrews	15%	33%	37%	58%	36%
Aunt Edies	18%	77%	244%	100%	110%
Bucks	17%	65%	17%	51%	38%
Cornelius	55%	30%	34%	123%	61%
Flax W	21%	127%	24%	93%	66%
Hawksnest	27%	70%	31%	125%	63%
Hinckley	33%	22%	20%	41%	29%
John Joseph	19%	62%	42%	58%	45%
Robbins	3%	68%	16%	44%	33%
Sand	23%	44%	37%	39%	36%
Skinequit	28%	48%	19%	55%	37%
Walker	29%	43%	35%	83%	47%
White	11%	94%	57%	39%	50%
AVG	23%	60%	47%	70%	50%
MAX	55%	127%	244%	125%	110%
MIN	3%	22%	16%	39%	29%

AVERAGE TOWN-WIDE ANALYSIS

TOWN	Secchi	TP	TN	chl a	AVG
HAR	23%	67%	43%	75%	52%
BRE	24%	57%	39%	76%	49%
ORL	28%	66%	39%	89%	56%
EAS	26%	59%	41%	69%	49%

note: all percentages are standard deviation divided by mean, Harwich percentages are for surface samples only, while town comparisons are all stations

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. All ponds in Harwich should have two samples, except for John Joseph, which should have the shallow and deep samples plus a 3 m and 9 m samples. Average sampling depth, expected sample depths according to the PALS protocol, and sample depths recorded between 2001 and 2005 in the Harwich ponds are shown in Table 4.

A sampling program following the PALS protocol would be expected to have some variability in the deepest sampling depth because pond levels fluctuate with the groundwater and groundwater levels in Harwich can fluctuate up to 5 feet (Frimpter and Belfit, 1992). Based on this range, station depths for the bottom sample in ponds should be constrained within approximately a 1.5 m range with perhaps up to another 1 meter to account for difficulties

locating a given pond's sampling station (*e.g.*, the deepest point, according to the PALS protocol).

Table 4. Review of Sampling Depths for Harwich Ponds

	Avg Max Depth	# of PALS Depths	PALS Depths				Deep 1.5 m range		Recorded Deep range		notes
POND	m		m	m	m	m	m	m	m	m	
Andrews	8.3	2	0.5			7.3	5.8	8.8	6	8.3	
Aunt Edies	2.1	2	0.5			1.1	0.0	2.6	2	5	
Bucks	8.1	2	0.5			7.1	5.6	8.6	3	9	3 m an additional sample (sampled 3 times)
Cornelius	2.1	2	0.5			1.1	0.0	2.6	1.5	1.5	
Flax W	5.0	2	0.5			4.0	2.5	5.5	4.5	4.8	
Hawksnest	7.2	2	0.5			6.2	4.7	7.7	1	7	4 m usually in lieu of deeper point (sampled 5 of 12 runs)
Hinckley	6.8	2	0.5			5.8	4.3	7.3	4	7	4 m additionally recorded once
John Joseph	14.5	4	0.5	3	9	13.5	12.0	15.0	15	17	2 (1 of 7), 4 (4 of 7 runs), 6 (2 of 7), 8 (1 of 7), 10 m (2 of 7) samples collected
Robbins	2.6	2	0.5			1.6	0.1	3.1	1.5	2	
Sand	6.2	2	0.5			5.2	3.7	6.7	1	6	2, 4 m samples collected in lieu of deeper point (2 of 8 runs)
Skinequit	8.5	2	0.5			7.5	6.0	9.0	4	9	4 m (1 of 8 runs) & 6 m (sampled 4 of 8 runs) usually in lieu of deeper point
Walker	7.4	2	0.5			6.4	4.9	7.9	4	7.4	4 m additionally recorded once
White	6.1	2	0.5			5.1	3.6	6.6	4.5	6.2	

The sampling depths for Harwich ponds from 2001-2005 show that volunteers followed the PALS protocol for 6 of the 13 ponds, collected additional samples beyond those required in the PALS protocol for 3 additional ponds, and had significant deviations from the protocol for the remaining four ponds (see Table 4). Collection depths were appropriate for the PALS protocol, including some reasonable variability, for the following ponds: Andrews, Aunt Edies, Cornelius, Flax, Robbins, and White. Bucks, Hinckley, and Walker also had depths appropriate for the PALS protocol, but also had some additional samples collected at extra, non-protocol depths. The remaining ponds with deviations from the PALS protocol generally had a deep sample collected at too shallow a depth based on the ponds average sampling station depth; in the majority of these situations it appears that the sampling station was not over the deepest portion of the pond.

Among the ponds with deviations from the PALS protocols is John Joseph, which is the only pond deep enough to have more than two depths sampled. According to the PALS protocol, sampling stations in John Joseph should be at the surface/0.5 m, 3 m, 9 m, and one meter above the bottom (generally 14 to 16 m). Yet, John Joseph has four samples from the seven sample

runs between 2001 and 2005 collected at 4 m, 2 of 7 collected at 6 m, and 1 of 7 collected at 10 m. It also has a number of occasions where the deepest sample was collected 4, 8 or 9 m.

Overall, most of the samples that were not collected according to the PALS protocol occurred because the sampling location was not over the deepest point in the pond. The remainder of the non-protocol samples appears to be based on some confusion about the appropriate depths in the protocol. Collectively, these results suggest that the majority of the sampling consistency issues can be addressed by: 1) ensuring that samplers are clear about what depths samples should be collected from and 2) ensuring that samples are consistently collected over the deepest point in each pond.

In the course of reviewing sample collection procedures according to the PALS protocol, it is also recommended that town coordinators adapt their field data collection procedures to collect dissolved oxygen and temperature readings every whole meter following a 0.5 m reading (*e.g.*, 0.5 m, 1 m, 2 m, 3 m, etc.). This procedure is also as specified in the PALS protocol and will allow more refined assessment of pond water quality, including better characterization of changes in dissolved oxygen and temperature with depth and analysis of any sediment oxygen demand.

V. Recommendations for Future Activities

As mentioned above, the available data can be combined together to help guide where the town will direct future pond efforts. Project staff used the Cape Cod pond water quality thresholds described above for total phosphorus, total nitrogen, chlorophyll *a*, and dissolved oxygen and assigned values, 1 or 2, if the average concentration at a given sampling station exceeded the unimpacted or the "healthy" threshold, respectively. These values were then summed and the ponds were then ranked (Table 5).

Based on this ranking, John Joseph and Skinequit are the ponds that are most impacted, followed by Hinckley, Cornelius, and Sand. As mentioned above, Table 5 shows that almost all of the ponds exceed the nutrient derived standards (TP, TN, and chlorophyll *a*). Those that have numbers in the dissolved oxygen column are those that clearly are impaired to one degree or another: Andrews, Walker, Bucks, Sand, Cornelius, Hinckley, John Joseph, and Skinequit. It is also clear from this ranking activity that this process has some limitations that should be considered when using it as the sole basis for deciding future activities.

The results of this ranking reinforce some of the difficulties in the available dataset that are mentioned above. For example, Flax Pond has been identified by this method as being one of the least impacted ponds, but previous analysis of other data has shown that Flax Pond has some significant water quality concerns (Eichner, 2004). It is not ranked higher because inconsistencies in the sampling depths left Flax with only one consistent sampling station. This result reinforces the need to consider a number of factors when prioritizing efforts.

Even without the results in Table 5, other factors should also be considered in prioritizing future pond activities. Among these factors are: use of the pond, sensitive or unique ecosystem features of concern (*e.g.*, herring run or endangered species), and presence of a pond association. The method used in developing the results in Table 5 already includes a feature that favors

deeper ponds with water quality issues over shallower ponds; deeper ponds have more stations, so the potential total can be higher.

Table 5. Water Quality Prioritization

POND	Total P	Total N	Chl a	Dissolved Oxygen	TOTAL
Aunt Edies		2	2		4
Flax W	4	2	2		8
Hawksnest		2	6		8
Andrews	1	4	4	1	10
Walker	3	2	3	2	10
Bucks	3	4	3	1	11
White	4	4	3		11
Robbins	4	4	4		12
Sand	4	3	4	2	13
Cornelius	4	4	4	2	14
Hinckley	4	4	4	4	16
John Joseph	3	7	8	4	22
Skinequit	6	6	6	4	22

note: each sampling station depth for TP, TN, and chl a are assigned a 1 if the average concentration exceeds the unimpacted threshold or a 2 if the average concentration exceeds the "healthy" threshold. Dissolved oxygen (DO) assignments are based on station depths that on average less than state limits, 5 or 6 ppm (assigned a 2), or having an anoxic reading (<1 ppm) in the dataset (assigned a 1).

VI. Conclusions

The Town of Harwich pond monitoring volunteers have provided sufficient data to allow a prioritization of the water quality problems in the 13 ponds that have been monitored: Andrews, Aunt Edies, Bucks, Cornelius, Flax, Hawksnest, Hinckley, John Joseph, Robbins, Sand, Skinequit, Walker, and White. Monitoring data show that all the ponds have water quality concerns, although some have clear water quality impairments. The worst among these, by increasing level of impairment, are Sand, Cornelius, Hinckley, John Joseph, and Skinequit.

Although existing data is sufficient for prioritization of future efforts, more refined data collection will be necessary to assess any of the individual ponds. The available data is inadequate to determine whether the variability in the individual ponds is due to natural variability in the ecosystems or is due to the limited number of samples. The water quality portion of refined data collection can be accomplished through enhancement of the existing monitoring program, including more careful adherence to the PALS sampling protocol and more frequent data sampling runs. Water quality data would then need to be brought into additional context through the delineation of watersheds, evaluation of nutrient sources within the watersheds, development of water and nutrient budgets, and potential sampling of pond

sediments. One example of this type of individual pond analysis was recently completed by the Cape Cod Commission for the Indian Ponds in Barnstable (Eichner, *et al.*, 2006).

Short of more refined individual pond sampling, it is recommended that the Town at a minimum, continue to sample the current list of ponds on an annual basis. This annual sampling should closely mirror the current sampling and laboratory procedures completed through the annual Pond and Lake Stewards (PALS) Snapshot sampling. The Snapshot has been coordinated every August and September since 2001 by the Cape Cod Commission and UMASS-Dartmouth, School of Marine Science and Technology (SMAST). Results from town annual monitoring should be reviewed and interpreted every five years to determine whether any notable water quality trends are occurring.

Any future sampling should work to maximize the effort and value of having volunteers collect the data and the Town pay for laboratory services. The existing dataset for Harwich ponds has some limitations because of inconsistent sampling procedures. Although the PALS protocol is the stated basis for sampling, a number of ponds have samples collected at non-standard depths, as well as dissolved oxygen recordings at depths intervals less than every meter. More consistent use of the PALS protocol will allow the town to have better confidence in interpretation of water quality results, provide a better basis for any future individual pond assessments that may be planned, and maximize the efforts of volunteers. It is recommended that training of monitoring volunteers be reviewed to ensure that the protocol is clearly understood.

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