EcoLogic Memorandum

TO: Frank Sampson and Nate Weeks
FROM: Liz Moran
RE: Harwich Ponds
DATE: October 9, 2009 *revised November 17, 2009*

EcoLogic was authorized to continue to support Stearns & Wheler GHD and the Town of Harwich on limnological issues related to the municipality's fresh water ponds. Mr. Frank Sampson has requested support on three issues, as noted below.

1. Review 2008 water quality data from the annual Harwich ponds monitoring program, with an emphasis on Bucks and John Joseph in light of the 2008 fall cyanobacterial blooms in these ponds.

2. Review historical data for all the Harwich ponds and provide a temporal analysis/discussion of those data. This task expands Task 1 by importing the historical data for each lake into a custom database to facilitate data summaries. The Access database has been transmitted separately. This task included data quality screening to identify potential outliers or errors.

3. Review water quality data for Hinckley Pond to investigate a perceived recent decline in water clarity. After reviewing the data, recommend the next steps.

1. 2008 Data Evaluation and Historical Comparisons

This section presents the results of the 2008 Harwich Ponds monitoring program. Where possible, the 2008 results are discussed in context of recent conditions to evaluate trends.

1.1 Phosphorus

Summer average concentrations of total phosphorus (TP) measured in the Harwich ponds in 2008 varied from a low of 6 ug/l in Andrews Pond to a high of 25 ug/l in Skinequit. These TP concentrations indicate that the ponds' levels of productivity range from oligotrophic (unproductive) to eutrophic (highly productive).

For the majority of the Harwich ponds, 2008 TP concentrations were comparable to concentrations measured from 2001 to 2007 (Figure 1). Annual variability in water quality conditions is normal, depending on weather conditions and the timing of the sample collections. Consequently, minor deviations do not necessarily indicate improving or worsening conditions.

Two ponds, Sand and Aunt Edies, exhibit 2008 TP concentrations notably different from the 2001- 2007 averages; 2008 concentrations were substantially lower in Sand Pond and substantially higher in Aunt Edies Pond. In both cases, this comparison is affected by a single TP result; in Sand Pond, 215 ug/L TP on 8/21/02 and in Aunt Edies Pond, 76 ug/L on 7/9/08. If these outliers are removed, the 2008 results compare well with the 2001-

2007 average conditions. The isolated elevated samples may have been collected during an algal bloom, or they may reflect analytical or data entry errors.

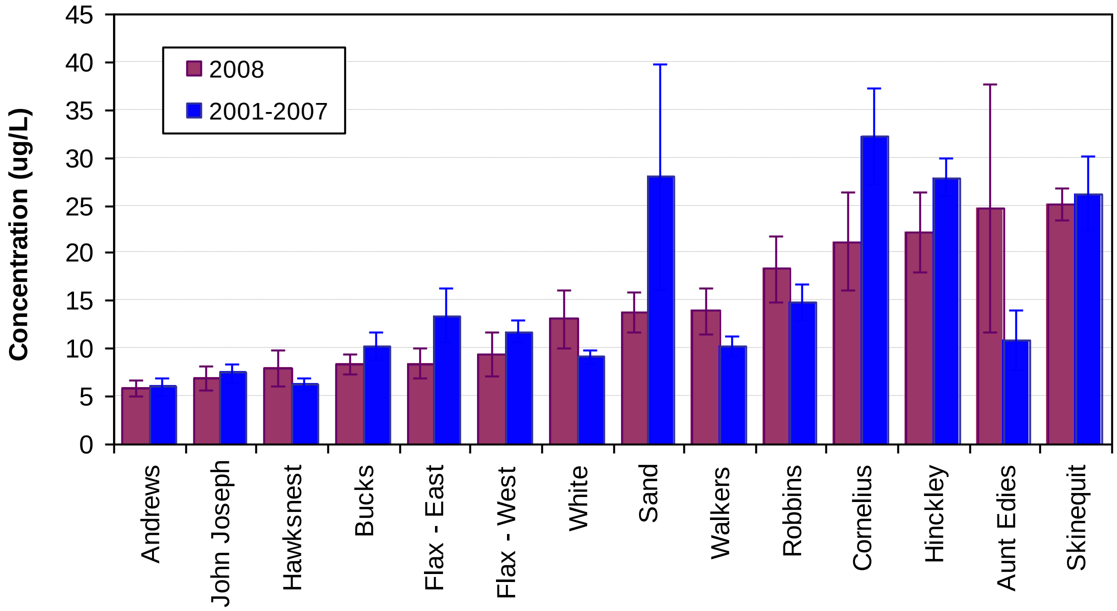

Figure 1. Comparison of 2008 average total phosphorus concentration in upper waters (≤4m) for thirteen ponds in Harwich, with long-term average 2000-2007.
Note: Average shown with standard error.

1.2 Internal Phosphorus Cycling

Internal recycling of phosphorus can occur when phosphorus held in the sediments is released due to chemical changes resulting from anoxia (no oxygen) conditions in the overlying water. This typically occurs in deep productive lakes exhibiting thermal stratification. In general, ponds the size of those in Harwich that are deeper than about 35 feet will be resistant to mixing because of the relatively deep water compared to their surface areas. This means that it is unlikely that significant quantities of phosphorus will be mobilized from lower water to the surface waters during the summer period of stable thermal stratification. However, phosphorus released from the sediments to the overlying waters may still eventually become available for algal growth in the kettle ponds, given the typically long water residence time and the lack of surface outlets. In shallower lakes with more transient stratification, mixing between the upper and lower waters may bring phosphorus released from sediments into the upper, sunlit waters where it is immediately available for algal growth.

The ratio of phosphorus in deep water compared to shallow water for eleven of the deeper ponds is displayed in Figure 2, this figure shows the 2008 results compared to average values from the last eight years. Higher values of the ratio indicate probable release from the sediments.

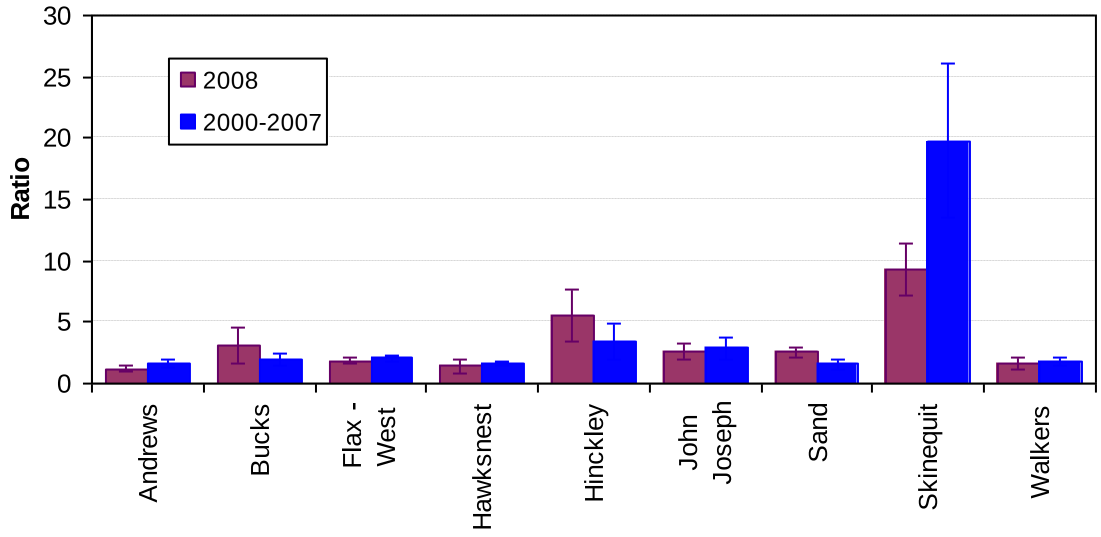

Figure 2. Ratio of deep water (>5m) phosphorus to surface water (≤4m) phosphorus in nine ponds in Harwich, 2008 and long-term 2000-2007. Higher numbers indicate increased P release from sediments.

Note: Ratios calculated for each sample date, then averaged for each year. Annual averages used to calculate average for period 2001-2007. Shown with standard error.

With few exceptions, the level of internal phosphorus release is consistent with past years. Phosphorus in the lower waters of Hinckley's Pond was somewhat elevated compared with previous results. TP profiles of this pond are recommended. In contrast, the TP concentration in the deep waters of Skinequit Pond was significantly lower than measured in previous years. This result may be related to the action of the solar-powered mixing device (SolarBee) installed on Skinequit Pond; the SolarBee enhances mixing within the pond and may be limiting the duration of the stratified period and/or mixing oxygenated water deeper into the water column.

However, there is a great deal of variability in this dataset and additional data collection and analysis is needed before firm conclusions can be drawn. Results are strongly influenced by the date of sample collection, because phosphorus accumulates in the lower waters increases over the period of stratification. Continued monitoring is recommended to determine whether 2008 results indicate a trend toward improvement.

1.3 Chlorophyll-a

Chlorophyll-*a* concentration is an indicator of algal abundance. The amount of algal production in a waterbody is largely a function of the concentration of the limiting nutrient (usually phosphorus), light and water temperature. Because algal blooms vary in frequency, intensity and duration, the annual measurements of peak and average chlorophyll-*a* concentrations will vary as well. Total P and chlorophyll- *a* concentrations in the Harwich ponds are correlated (Figure 3).

In 2008, average chlorophyll-*a* concentrations were generally low in most ponds (Figure 4). Elevated chlorophyll-*a* concentrations impart a greenish tinge to the water, making the waters less attractive for recreational use. In 2008, Cornelius, Hinckley's and Skinequit Ponds exhibited chlorophyll-*a* concentrations associated with diminished suitability for recreational use.

Most of the ponds in 2008 had average chlorophyll-*a* concentrations comparable to those measured in previous years, with the exception of Sand and Robbins Ponds. Sand Pond exhibited substantially lower chlorophyll-*a* and TP concentrations in 2008; levels in Robbins Pond, in contrast, were substantially higher.

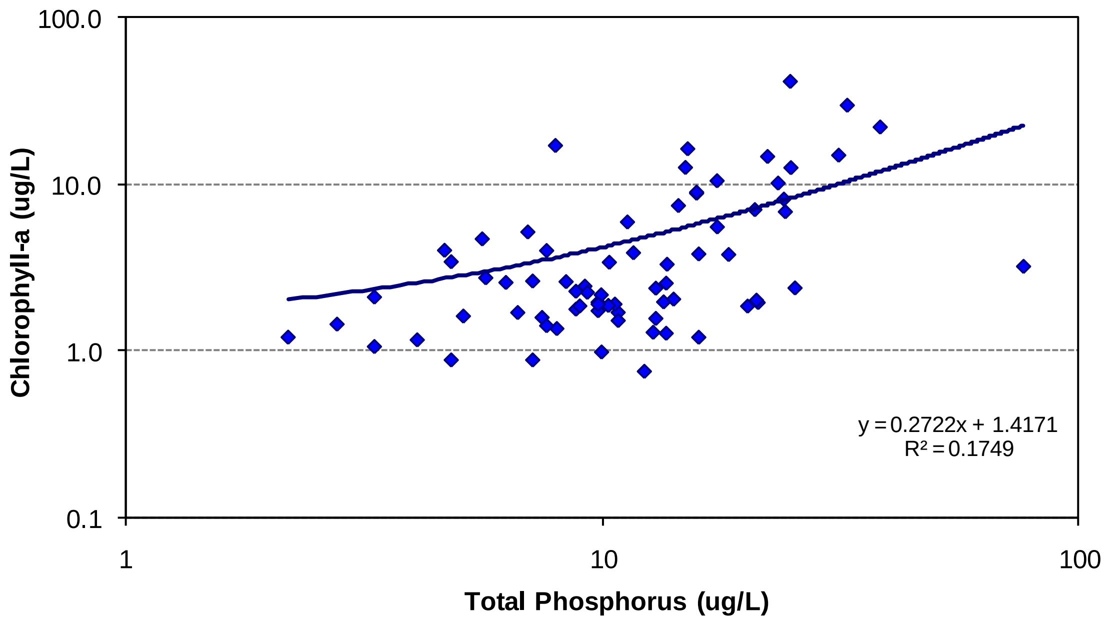

Figure 3. Correlation of paired chlorophyll-a and total phosphorus samples, collected in upper waters (≤4m) in thirteen Harwich ponds, 2008.
Note: axis on Log scale.

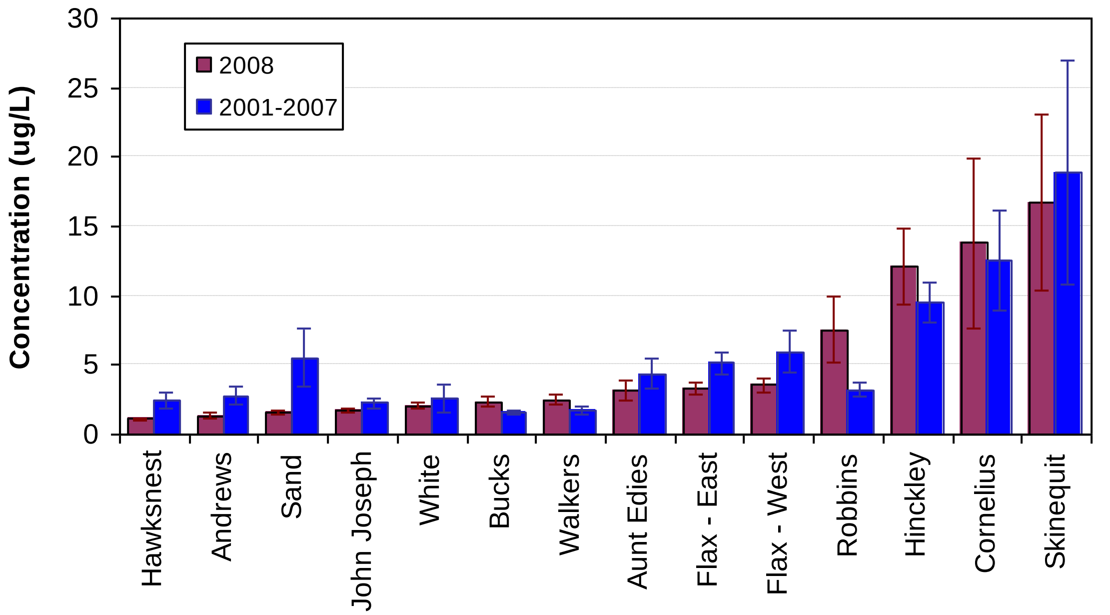

Figure 4. Average chlorophyll-a concentration, 2008 and 2001-2007, in upper waters (≤4m) for thirteen ponds in Harwich.
Note: Average shown with standard error.

1.4 Water Clarity

Water clarity, as measured by Secchi disk transparency over the June-September period, is another important indicator of water quality conditions and trophic state. In ponds where algal cells are the primary class of particulate material suspended in the water column, chlorophyll-*a* and Secchi disk transparency are correlated. This is the case for the Harwich ponds.

The average Secchi disk transparency in Cornelius, Skinequit, Flax (east) and Hinkleys Ponds was low in 2008, and was at or below the Massachusetts Health Department swimming standard for bathing beaches, which is 1.75 m (Figure 5). In general, the ponds with the lowest TP and chlorophyll-*a* concentrations exhibit the highest Secchi disk transparency. Secchi disk transparency measurements in Walkers, Bucks, White, Hawksnest, John Josephs, and Andrews Ponds were greater than 4 m, indicating exceptionally clear water.

The water clarity in the ponds for 2008 appears generally comparable to conditions measured in previous years.

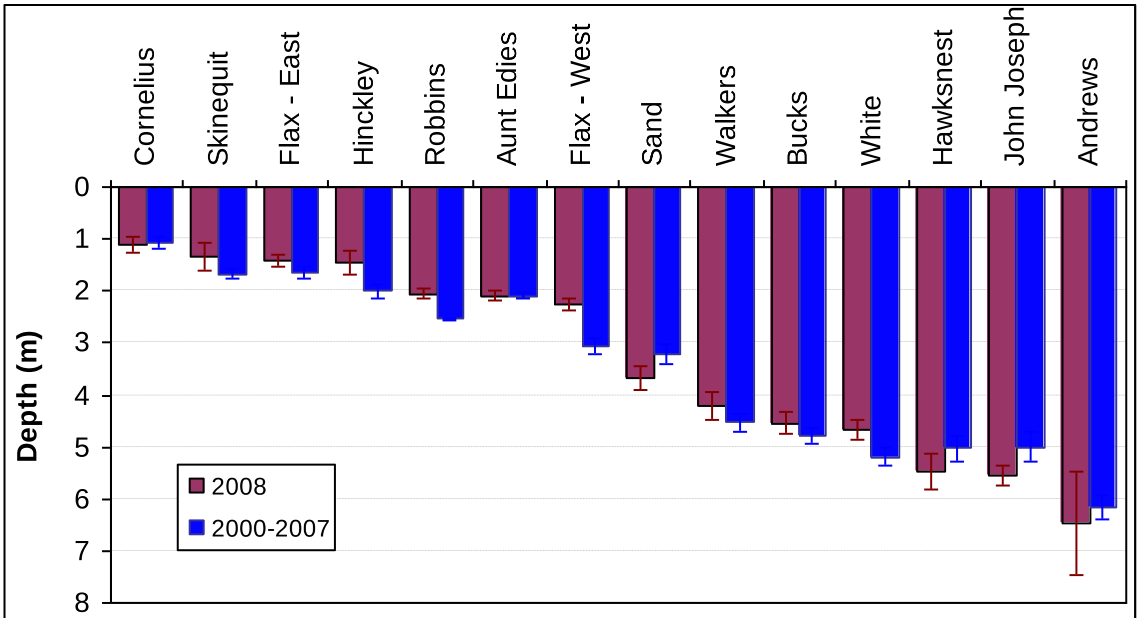

Figure 5. Secchi disk measurements for thirteen ponds in Harwich, comparison of 2008 average and long-term average 2000-2007.

Note: Shown with standard error. Flax is sampled twice as East and West.

1.5 Trophic State Indicators – Ecoregional Criteria

The USEPA is taking an ecoregional approach to developing nutrient criteria for surface waters, considering the large variation in geology, soil conditions, climate, land cover, development, and recreational use across the nation. Eastern Massachusetts is an ecoregion, and criteria for nutrients (total N, and total P) and chlorophyll-*a* were calculated from results of a 2001 synoptic survey of 191 ponds; the vast majority were Cape Cod kettle ponds. EPA calculated the ecoregional criteria using the lowest 25th percentile of nutrient and chlorophyll-a measurements from the synoptic survey. The Cape Cod Commission calculated two ecoregional criteria for Cape Cod ponds. The more stringent (CC-Least) is based on nutrient and chlorophyll-*a* conditions measured in the eight most pristine ponds in the sample, with undeveloped watersheds. The second (CC-All) is calculated using water quality conditions of all Cape Cod ponds sampled.

Results of 2008 measurements in each of the Harwich ponds are compared with the EPA and Cape Cod Commission's ecoregional criteria (Table 1). Measurements exceeding the Cape Cod reference condition (CC-All) are highlighted. This analysis indicates the Harwich ponds exhibiting the highest ambient concentrations of nutrients and chlorophyll-a. Only Hawksnest Pond exhibited TN, TP, and chlorophyll-*a* concentrations below the Cape Cod ecoregional criteria, while water quality conditions in five ponds (Aunt Edies, Cornelius, Hinckleys, Robbins and Skinequit Ponds) exceeded the criteria for all three indicator parameters.

Table 1. 2008 Harwich Ponds data compared with Cape Cod ecoregional criteria. Shaded cells exceed Cape Cod reference condition (CC-All).

Pond (upper waters)	Chlorophyll-a (µg/L)	Total Nitrogen (mg/L)	Total Phosphorus (µg/L)	Secchi Disk (m)
EcoRegion14	6	0.41	9	<2
CC-Least	1	0.16	7.5	--
CC-All	1.7	0.31	10	--
Andrews	1.3	0.81	6	6.5
Aunt Edies	3.2	0.42	25	2.1
Bucks	2.4	0.31	8	4.5
Cornelius	13.8	0.61	21	1.1
Flax - East	3.3	0.43	8	1.4
Flax - West	3.6	0.44	9	2.3
Hawksnest	1.1	0.14	8	5.5
Hinckley	12.1	0.44	22	1.4
John Joseph	1.7	0.35	7	5.6
Robbins	7.5	0.42	18	2.1
Sand	1.6	0.30	14	3.7
Skinequit	16.7	0.59	25	1.3
Walkers	2.5	0.27	14	4.2
White	2.1	0.27	13	4.7

Shaded cells indicate where pond data exceed the CCC-All ecoregional criteria.
Upper waters defined as samples collected from 4.0 meters or less.

1.6 Carlson Trophic State Index

The Carlson trophic state index (TSI) uses the chlorophyll-*a*, total phosphorus, and Secchi disk transparency measurements to classify a lake's trophic state. The TSI is useful for comparing lakes within a region, and assessing changes in trophic status over time. Trophic state is a continuum, and demarcations are not always clear. Oligotrophic lakes are low in productivity and generally have clear, well- oxygenated water. Many of these lakes are suitable for coldwater fish species such as trout, but often do not support a highly productive fish community. Eutrophic lakes are very productive and have high standing crops of phytoplankton that decrease water clarity. Eutrophic lakes may also have extensive beds of rooted aquatic vegetation. These lakes often have high standing crops of warmwater fish such as bass. Mesotrophic lakes are in an intermediate stage of productivity.

Of the 15 Harwich ponds sampled in 2008, most are considered mesotrophic indicating moderate levels of productivity. Three ponds, Cornelius, Hinckley, and Skinequit, exhibit TP, chlorophyll-*a* and Secchi disk transparency measurements consistent with eutrophic conditions (Table 2).

Table 2. 2008 Results of Trophic State Index (TSI) Calculations

Pond	Chlorophyll-a TSI	Total Phosphorus TSI	Secchi Disk TSI	Designated Trophic State
Cornelius	52	46	59	Eutrophic
Hinckley	54	48	56	Eutrophic
Skinequit	56	50	57	Eutrophic
Andrews	33	29	34	Mesotrophic
Aunt Edies	41	45	49	Mesotrophic
Bucks	39	34	38	Mesotrophic
Flax - East	42	33	55	Mesotrophic
Flax - West	43	35	48	Mesotrophic
Hawksnest	31	32	35	Mesotrophic
John Joseph	36	30	35	Mesotrophic
Robbins	48	44	50	Mesotrophic
Sand	35	41	41	Mesotrophic
Walkers	39	40	39	Mesotrophic
White	38	41	38	Mesotrophic

Note: The 2008 memorandum indicated "oligotrophic" were values in the 30's, mesotrophic were values in the 40's and Eutrophic were values in the 50's. According to new information from http://dipin.kent.edu/tsi.htm , divisions should be oligotrophic <30, mesotrophic 30-50, eutrophic 50-70.

TSI calculated for each sample date, then TSI values are averaged for each pond.

1.7 Focus: Cyanobacterial Blooms

John Joseph and BucksPonds

In early November 2008, cyanobacterial blooms were noted on John Joseph and Bucks Ponds. Also known as blue-green algae, cyanobacteria can be problematic when present in abundance; certain species exude a toxin that may be harmful to animals when present at elevated concentrations.

Cyanobacteria tend to be most abundant in warm, quiescent waters enriched in phosphorus. Some species of cyanobacteria are able to fix atmospheric nitrogen, thus gaining a competitive advantage as the ambient ratio of nitrogen to phosphorus declines. As a general rule, lakes and ponds are phosphorus limited when the N:P ratio is greater than about 16. Values below this benchmark are considered favorable for proliferation of cyanobacteria. The N:P ratio calculated from monitoring data collected in the Harwich ponds since 2001 is plotted in Figure 6.

It is important to note that routine water quality monitoring takes place during the summer months and generally ends in September. The cyanobacterial blooms in Bucks and John Josephs Ponds documented in 2008 occurred later in the fall. It is likely that the N:P ratios in the affected ponds become more favorable to cyanobacteria in the fall, as the water cools and winds can mix deep-phosphorus rich water throughout the pond.

Bucks Ponds is weakly stratified due to its shallow depth; periods of anoxia and sediment phosphorus release are interspersed with periods of complete mixing. Consequently, TP concentrations in Bucks Pond tend to be higher than John Josephs during summer. John Josephs Pond is deep enough to exhibit stable thermal stratification during the summer. In this pond, phosphorus released from sediments does not affect the upper waters until the water column cools and mixes in the fall. This influx of phosphorus could cause the N:P ratio to decrease sufficiently to provide a competitive advantage to the cyanobacteria.

A similar phenomenon may occur in Bucks Pond during years where stratification is stable into the fall. To evaluate this hypothesis, we recommend extending the water quality sampling for the deeper and most productive ponds through fall mixing, which typically occurs in October. Biweekly sampling and analysis of TP, total N, chlorophyll-*a*, Secchi disk transparency and phycocyanin (a pigment associated with cyanobacteria) are recommended. If available resources are not sufficient to sample at this frequency, we recommend adding one sampling event in October. Candidate ponds for the late fall sampling include Hinkley, Skinequit, John Joseph, Bucks, Sand and Walker Ponds. In addition to discrete samples of the upper and lower waters for nutrients and the upper waters for algal pigments, profile samples of dissolved oxygen and temperature should be collected at the deepest part of the pond.

Hinckley and Skinequit Ponds

Cyanobacterial blooms have also been observed on the two eutrophic ponds, Hinckley and Skinequit. Nitrogen and phosphorus ratios measured in 2007 and 2008 are plotted in Figure 7. These recent data indicate that the N:P ratio is lower and approaching a level where cyanobacteria could hold a selective advantage. In fact, a cyanobacterial bloom in July 2009 led the Department of Health to close Hinckley Pond for contact recreation for a two week period.

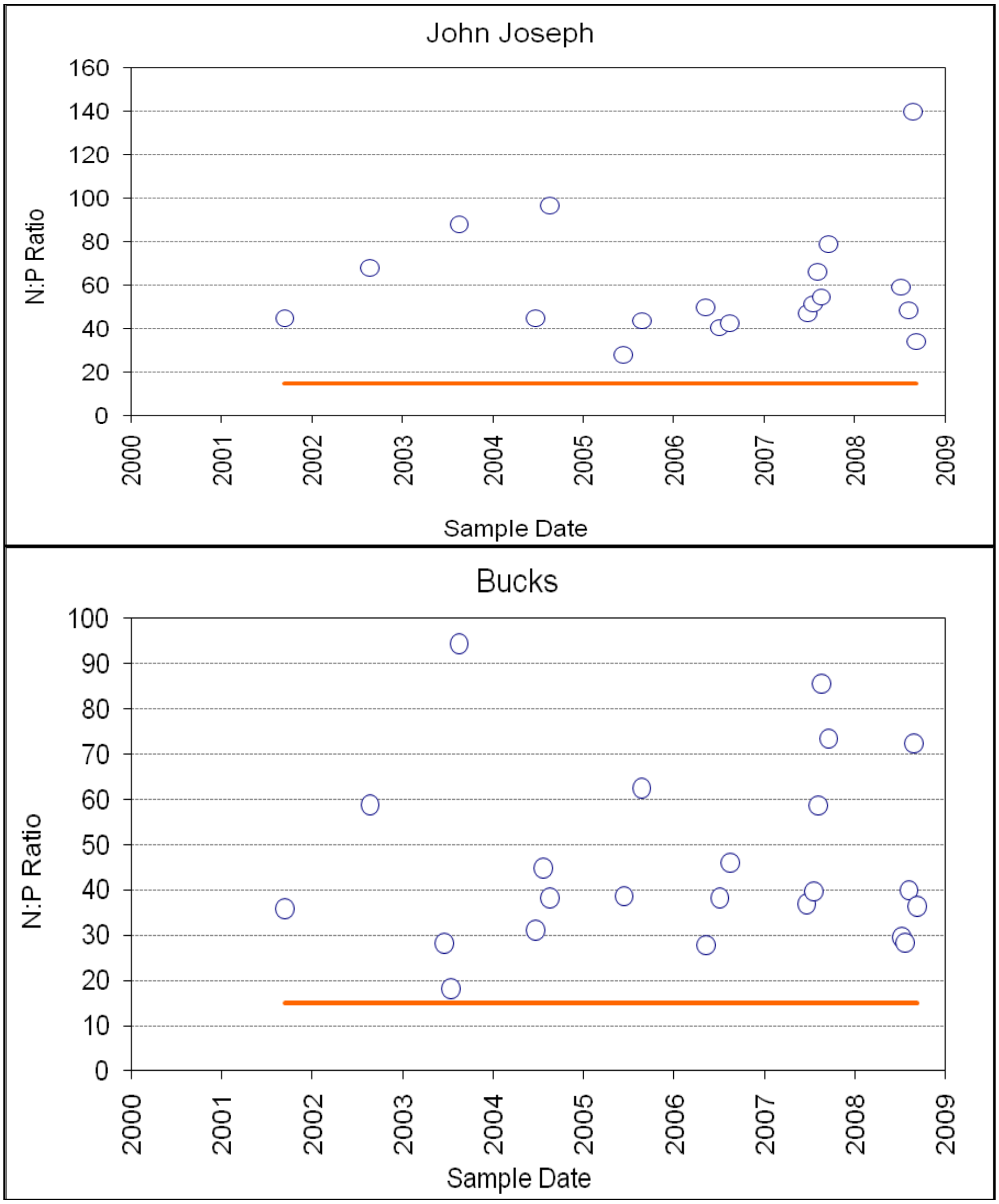

Figure 6. N:P ratio shown for each sample date, 0m to 4m sample depths in John Joseph and Bucks Pond. Where there is more than one depth sampled on a given date, the results for the depths are averaged into a single result. The algal community is considered to be phosphorus limited when the N:P ratio is greater than approximately 16; values below 16 may indicate nitrogen limitation.

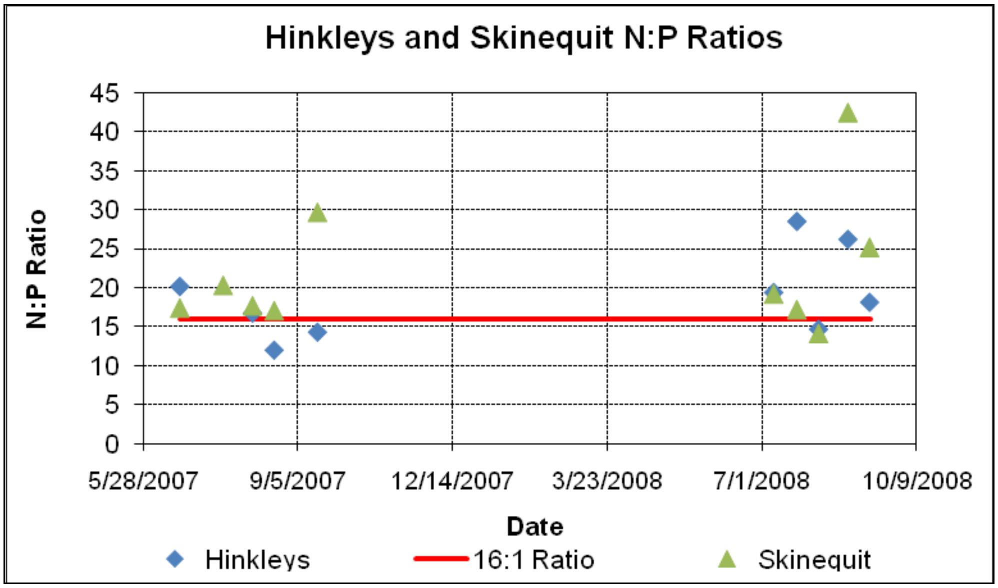

Figure 7. N:P ratio shown for each sample date, 0m to 4m sample depths in Hinckley and Skinequit Ponds. Where there is more than one depth sampled on a given date, the results for the depths are averaged into a single result. The algal community is considered to be phosphorus limited when the N:P ratio is greater than approximately 16; values below 16 may indicate nitrogen limitation.

2. Temporal Trends in Harwich Ponds Water Quality Conditions

This section discusses the long term trends in water quality in those ponds with a long-term monitoring program. The datasets were used to create regression figures of individual samples for TP, total N, chlorophyll-*a*, and Secchi disk depth (Figures 8 and 9). Two related variables are shown on each graph. Individual samples were used in this analysis instead of annual averages in order to incorporate the inherent variability within each year. A statistical test of the regression line (the best fit through the data) was completed (Tables 3 and 4). Trends with a p value less than 0.10 (indicating a 90% probability that the trend is real) are highlighted. If the p value is equal to or greater than 0.10, the variability in the data set is too large to evaluate whether an apparent trend is real or due to chance.

2.1 Phosphorus and Nitrogen

The trends in TP and nitrogen are closely related in most ponds, with the exception of White Pond and John Joseph Ponds (Figure 8). In White Pond, there is a trend of increasing TP, with a decreasing trend in nitrogen; in John Joseph pond the trends are reversed with TP decreasing and nitrogen increasing. For both ponds, neither trend is statistically significant.

Five ponds have decreasing trends (improving conditions) in TP and nitrogen; seven ponds are exhibiting increasing trends in both nutrients (deteriorating conditions). Sand Pond had a significant decreasing trend in both phosphorus and nitrogen, although these trends appear largely influenced by elevated sample results from a single sample event in 2002. Three ponds – Hawknest, Robbins and Walkers – exhibited statistically significant increases in both nutrients. Three other ponds – Flax-East, Flax-West, and Sand – exhibited statistically significant decreases in both nutrients. There is no town-wide trend toward water quality degradation; nor is there a town-wide trend toward improvement.

	TP		**Nitrogen**	
	Not Statistically Significant	***Statistically Significant***	***Not Statistically Significant***	***Statistically Significant***
Increasing Trend (more nutrients)	Aunt Edies Cornelius Hinckley Skinequit White	Hawknest Robbins Walkers	Hinckley John Joseph Skinequit	Aunt Edies Cornelius Hawknest Robbins Walkers
Decreasing Trend (less nutrients)	Andrews John Joseph	Bucks Flax – East Flax – West Sand	Andrews Bucks White	Flax – East Flax – West Sand

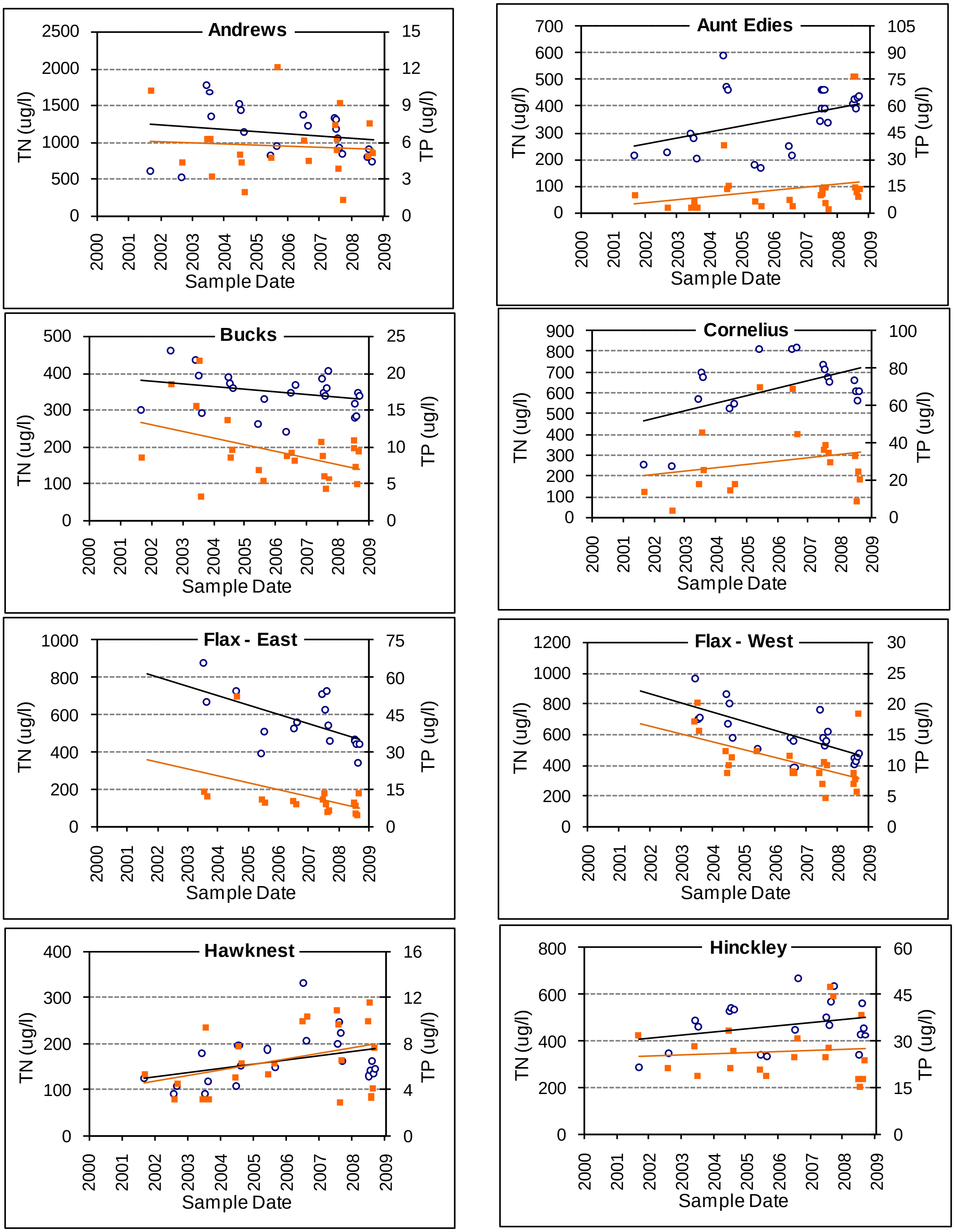

Figure 8. Total phosphorus and total nitrogen temporal trends in Harwich ponds. Orange squares are total phosphorus and open circles are total nitrogen. See Table 3 for statistical significance of the trend lines.

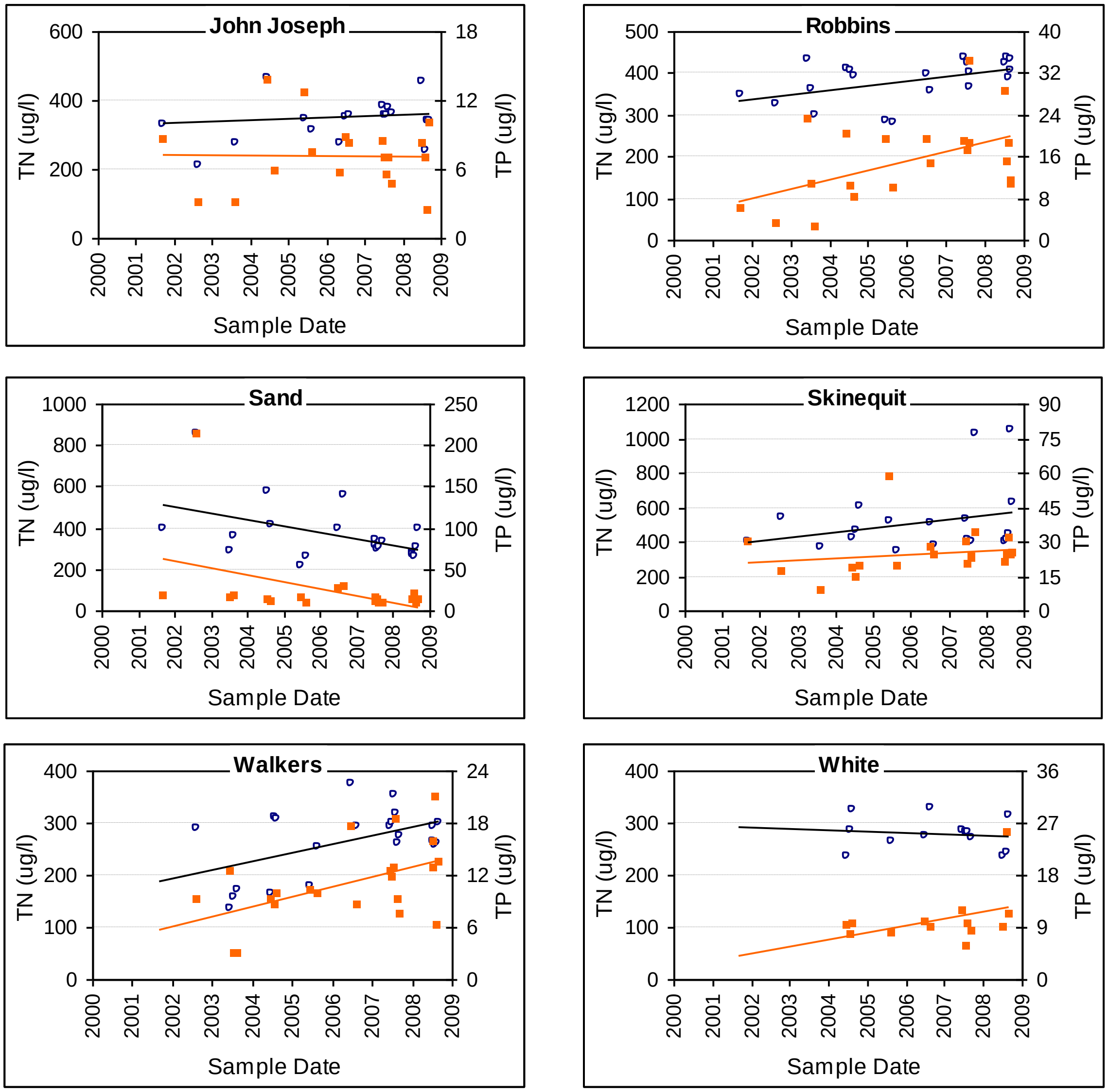

Figure 8 cont'd. Total phosphorus and total nitrogen temporal trends in Harwich ponds. Orange squares are total phosphorus and open circles are total nitrogen. See Table 3 for statistical significance of the trend lines.

Table 3. Long-term trend (positive or negative) and significance of trends for TP and TN in Harwich Ponds. Statistically significant trends (p<0.10) are highlighted.

	Total Phosphorus		**Total Nitrogen**	
	Trend	***Significance***	***Trend***	***Significance***
Andrews	-	0.78	-	0.42
Aunt Edies	+	0.28	+	0.046
Bucks	-	0.033	-	0.17
Cornelius	+	0.39	+	0.023
Flax - East	-	0.070	-	0.010
Flax - West	-	0.007	-	0.0002
Hawknest	+	0.070	+	0.090
Hinckley	+	0.75	+	0.22
John Joseph	-	0.95	+	0.64
Robbins	+	0.020	+	0.028
Sand Pond	-	0.072	-	0.034
Skinequit	+	0.45	+	0.25
Walkers	+	0.014	+	0.017
White	+	0.19	-	0.64

2.2 Chlorophyll-a and Secchi disk transparency

To the extent that most of the particulate material suspended in the pond waters is algal cells, water clarity (as measured by Secchi disk transparency) and chlorophyll-*a* are correlated. Decreasing water clarity correlates with increasing chlorophyll-a concentrations where algal cells dominate the particulate material suspended in the water column. The relationship between these two indicators of trophic state for the Harwich ponds is displayed in Figure 8. Other factors, in addition to algal abundance, also affect water clarity.

Statistically significant trends of declining Secchi disk transparency were detected in Cornelius, Flax-East, Robbins, Skinequit, and Walkers Ponds (Table 4). Robbins and Hinckley Ponds exhibited statistically significant increasing trends in chlorophyll-a. These statistically significant trends for Robbins Pond indicate that algal abundance is the cause of the decline in water clarity.

In contrast, improving trends in water quality are indicated by a statistically significant decrease in chlorophyll-a paired with a statistically significant increase in water clarity where algal cells dominate the particulate material in the water column. None of the ponds exhibited this pairing to indicate improving water quality conditions. Statistically significant decreasing trends in chlorophyll-a occurred in Andrews, Flax-West, and Hawknest, whereas statistically significant trend in improved water clarity was observed for Aunt Edies Pond. Statistical significance aside, four ponds - Andrews, Aunt Edies, Hawknest and John Joseph - exhibit increasing water clarity while at the same time exhibiting decreasing trends in chlorophyll-a concentrations.

Robbins Pond is the only pond to exhibit statistically significant increasing trends in nutrients and chlorophyll-a, with statistically significant decreasing trend in water clarity.

	Secchi disk transparency			**Chlorophyll-a**	
	Not Statistically Significant	***Statistically Significant***		***Not Statistically Significant***	***Statistically Significant***
Increasing Trend (more clarity)	Andrews Hawknest John Joseph	Aunt Edies	**Decreasing Trend (less algae)**	Aunt Edies Flax – East John Joseph Sand	Andrews Flax – West Hawknest
Decreasing Trend (less clarity)	Bucks Flax – West Hinckley Sand White	Cornelius Flax – East Robbins Skinequit Walkers	**Increasing Trend (more algae)**	Bucks Cornelius Skinequit Walkers White	Hinckley Robbins

Table 4. Long-term trend (positive or negative) and significance of trends for chlorophyll-a and Secchi disk transparency of Harwich Ponds. Statistically significant trends ($p<0.10$) are highlighted.

	Secchi Transparency		**Chlorophyll-a**	
	Trend	***Significance***	***Trend***	***Significance***
Andrews	+	0.16	-	0.027
Aunt Edies	+	0.0045	-	0.45
Bucks	-	0.21	+	0.84
Cornelius	-	0.056	+	0.54
Flax - East	-	0.00008	-	0.28
Flax - West	-	0.31	-	0.073
Hawknest	+	0.22	-	0.0030
Hinckley	-	0.20	+	0.053
John Joseph	+	0.39	-	0.58
Robbins	-	0.00050	+	0.038
Sand Pond	-	0.307	-	0.66
Skinequit	-	0.00019	+	0.49
Walkers	-	0.016	+	0.50
White	-	0.33	+	0.51

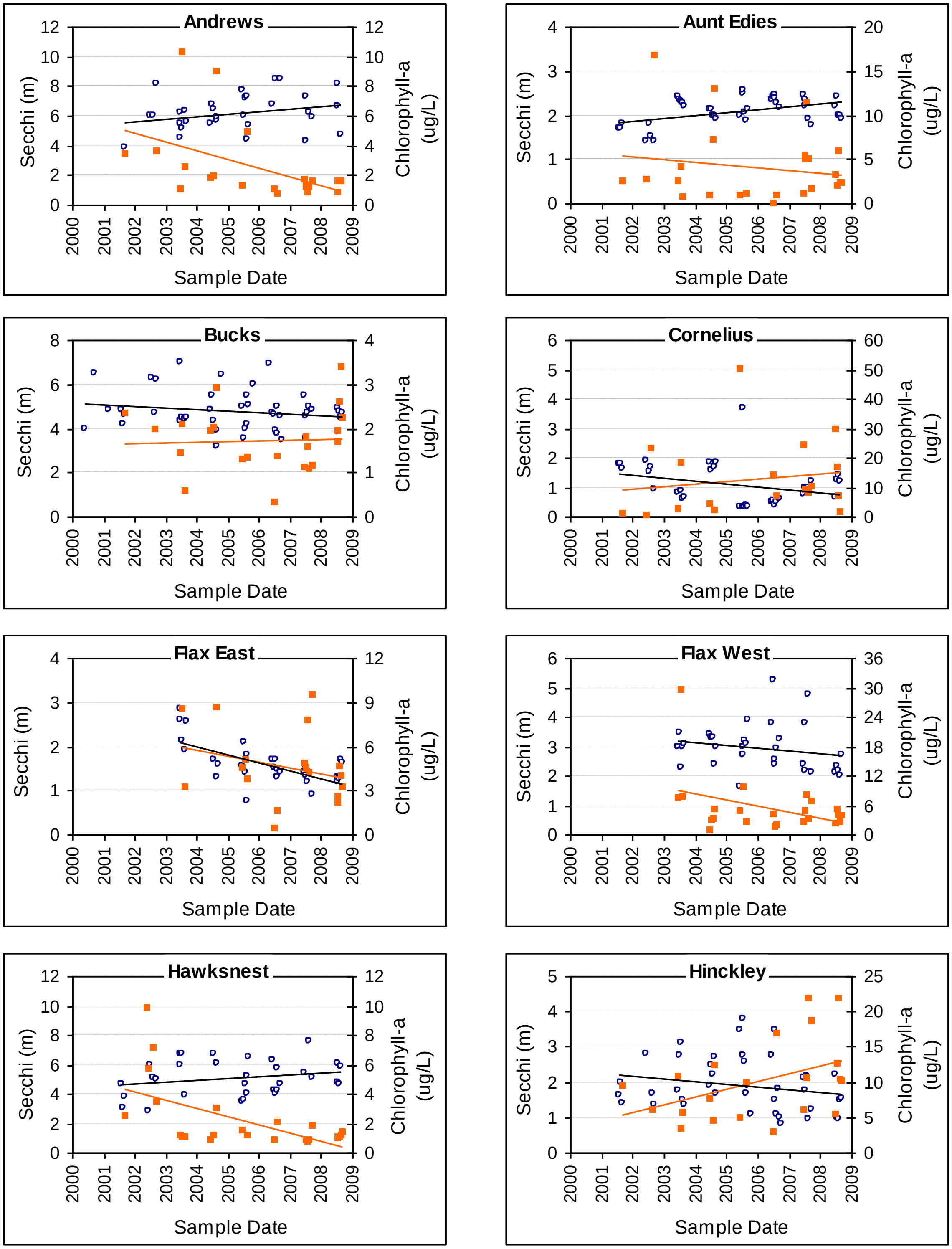

Figure 9. Chlorophyll-a and Secchi disk transparency temporal trends in Harwich ponds. Orange squares are chlorophyll-a and open circles are Secchi disk transparency. See Table 4 for statistical significance of the trend lines.

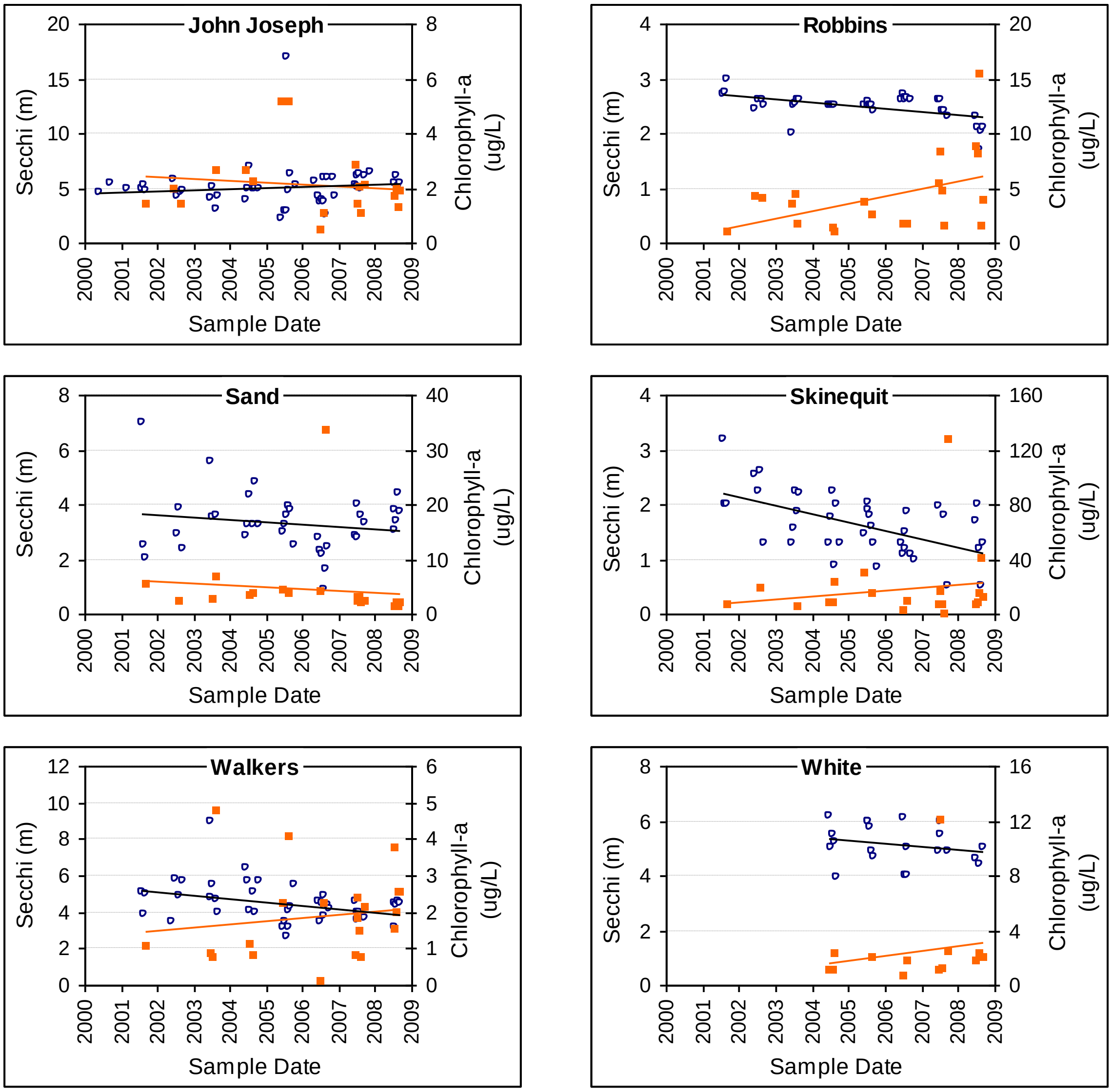

Figure 9 cont'd. Chlorophyll-a and Secchi disk transparency temporal trends in Harwich ponds. Orange squares are chlorophyll-a and open circles are Secchi disk transparency. See Table 4 for statistical significance of the trend lines.

3. Has the Water Quality of Hinckley Pond Declined?

Hinckley Pond is eutrophic based on its nutrient concentrations, algal abundance, and Secchi disk transparency. Water quality in Hinckley Pond may be influenced by adjacent cranberry bogs and the inflow from Long Pond; these sources can have both periodic impacts, as pulses of nutrients added from adjacent water bodies support transient blooms, and cumulative impacts. The long-term datasets provide a means to determine if the data support a hypothesis of deteriorating water quality.

Overall, nutrient levels in Hinckley Pond have not changed substantially in recent years (Figure 8). The slightly increasing trends in TP and total nitrogen (TN) are not statistically significant. However, several of the highest TP and TN results (as well as several of the lowest) were reported in 2007 and 2008. This may indicate a recent increase in nutrient loading. Moreover, the 2009 algal blooms and residents' concerns are consistent with a deterioration of water quality condition. Hinckley Pond should continue to be a priority for monitoring.

The chlorophyll-*a* and Secchi disk transparency data measured in Hinckley Pond are highly variable (Figure 9). There is a decreasing trend, which is not statistically significant, in Secchi disk transparency. In contrast, chlorophyll-*a* exhibited a statistically significant increasing trend, with several high concentrations measured in 2007 and 2008, indicating an increase in algal abundance. A closer examination of the Secchi disk transparency data reveals that there were no measurements deeper than approximately 2.2 m in both 2007 and 2008; in the years since 2001, the deepest Secchi disk measurements ranged from 2.7 m to 3.8 m. The reduced water clarity in 2008 is consistent with the observed increase in chlorophyll-*a* concentrations. These findings confirm that water quality in Hinckley Pond has declined.

Phosphorus release from the sediments is one possible contributing factor to the decline in water quality. As noted in Section 1.2, Hinckley Pond had an increase in the ratio of deep to surface water TP in 2008 compared with historical data. The TP contribution from upstream Long Pond and adjacent cranberry bogs is unknown, but could also be contributing factors.

In order to define potential solutions to the deteriorating water quality, it is first necessary to understand the relative magnitude and importance of the nutrient sources. Hinckley Pond is part of an interconnected waterway; water and nutrients flow into the lake from Seymour and Long Ponds, and include outflow from managed cranberry production bogs. A program to estimate the annual mass loading of phosphorus from these sources (i.e., an estimate of hydrologic inflow and TP concentrations) is recommended.

4. Conclusions

In general, ponds in the Town of Harwich exhibit good water quality conditions and support the designated use. Compared with the Cape Cod ecoregional criteria for TP, total N and chlorophyll-*a*, most of the ponds are classified as somewhat impacted; however, the impact is generally slight. The trophic state for most ponds is considered to be mesotrophic, or moderately productive. These ponds maintain good water quality conditions most of the year. Three of the Harwich ponds are eutrophic and experience periodic algal blooms that impair water clarity.

Water quality conditions in 2008 were largely comparable to average conditions documented over the previous years of this decade. Some slight variations from average TP, TN, chlorophyll-*a* and Secchi disk transparency measurements were noted, but year-to-year variability is expected. There were no results in the 2008 dataset suggesting the need for immediate action.

Long-term trends indicate that several ponds have water quality that has steadily deteriorated over time. Water quality conditions in several other ponds appear to have improved. Because of the factors affecting water quality conditions in a given year, most notably weather, it can be difficult to distinguish true change from natural year-to-year variability. Even slight modifications to the timing of sampling can also affect the long term data set, as discussed earlier. Inclusion of anomalous high or low values can skew the results, making it more difficult to detect trends. However, the last two years of measurements on Hinckley Pond indicate deteriorating conditions. Additional investigations are recommended to determine the underlying cause of the deteriorating water quality.

The pond monitoring program provides data and information regarding water quality conditions, and enables managers to evaluate current status and trends. Given the natural variability in water quality due to weather and other factors, it can be challenging to differentiate real changes from year-to-year variability. As such, the monitoring program should continue, and be extended with an additional sampling event in October, if possible, to characterize conditions during fall mixing in the deeper and more productive ponds.

5. Summary of Monitoring Recommendations

- Continue routine monitoring of trophic state indicator parameters during the summer to track water quality status and trends

- Extend sampling for Hinkley, Skinequit, John Joseph, Bucks, Sand and Walker Ponds into October. Discrete samples of the upper and lower waters for TP and TN is recommended, and of the upper waters for algal pigments (chlorophyll-a and phycocyanin). In addition, profile sampling through the water column at 1 m intervals is recommended for dissolved oxygen and temperature.

- Construct a hydrologic and TP budget for Hinckley Pond. This effort involves estimating inflows from upstream ponds and sampling TP concentration at inflow points over an annual cycle. Sampling should encompass a range of hydrologic conditions, e.g., wet weather and dry weather, and encompass the agricultural production cycle of the cranberry growers. Estimates of the external water and TP budget can be compared to estimates of TP accumulation in the deep waters to assess the relative magnitude of external and internal loading.