Flax Pond Water Quality Review

Final Report to Town of Harwich

October, 2004

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1. Introduction

Flax Pond is a 17.25 acre pond located in the western portion of the Town of Harwich, Massachusetts (Figure 1). Adjacent to the pond, along its northeast edge, is the Town of Harwich Transfer Station. This site is also the location of a capped municipal landfill and former septage disposal lagoons. Groundwater flowing from the landfill and the lagoons has created impacts on the pond. At the request of the Town, the Cape Cod Commission Water Resources staff have prepared the following review of water quality data collected from Flax Pond, including recommendations for future activities.

2. Flax Pond History

Previous projects and water table maps in the area have indicated that Flax Pond receives groundwater flow along its north side and discharges surface water back to groundwater along its southern side. The Town of Harwich utilized a site directly upgradient of the pond as a landfill, including septage lagoons, since 1966 (HWH, 1992). In 1989, an experimental solar aquatics septage treatment facility was constructed on the site by Ecological Engineering Associates. The landfill and the septage lagoons were capped with an impervious cover in 1999. Other land uses around the pond include cranberry bogs and single family residences (see Figure 1).

During the early 1990's, concerns about the water quality of Flax Pond led to the Town to hire Ocean Arks International, Incorporated (OAI). Over a number of years, OAI undertook a number of activities to attempt to improve the pond's water quality, including the installation of a floating raft (known as "Lake Restorer 1), which pumped lake water through a number wetland plant cells before returning it to the pond. Table 1 provides a chronology of activities on the pond. OAI provided the Town with an annual report on activities on the pond each year between 1993 and 2002. These annual reports are the primary source of water quality data reviewed in this report.

3. Review of Available Data

OAI collected various samples over the nearly ten years worth of activities on Flax Pond. Samples were collected from the water and sediments within the pond. These samples were analyzed mostly by OAI's in-house laboratory for a variety of constituents with a more limited number of samples analyzed by outside laboratories. Description of OAI laboratory methods and method detection limits are not included in any of the available annual reports and clarification requests to OAI's Flax Pond Project Director have not provided this information. Lack of this information makes it difficult to confidently compare other laboratory monitoring data or to rely extensively on these monitoring results. Water quality data with associated methods and detection limits from outside laboratories is limited to less than 10 sampling dates.

Data collected in the field by OAI (*e.g.*, pH, dissolved oxygen, and temperature readings) generally were collected using meters, so there is less uncertainty with these results. Because of the limitations on the use of the laboratory analyses, the water quality analysis presented below is largely confined to the field measurements except for the discussion of phosphorus. Because of the central role phosphorus plays in determining the ecological characteristics of freshwater ponds, it was thought that the OAI data should be reviewed. The concerns associated with data used in this analysis are discussed below for each of the chemical constituents reviewed in this section.

a. Phosphorus

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 (Vollenweider, 1968). Laboratory analysis of total phosphorus (TP) includes ortho-phosphorus and all phosphorus bound in organic matter, including algae.

Most Cape Cod lakes have 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 µg/l (0.016 mg/l)(Eichner, *et al*., 2003). A more limited sampling of 60 Cape Cod lakes in 1997 and 1998 found a mean TP concentration in surface waters of 0.014 ppm (14 µg/l)(Aherns and Siver, 2000). Using the US Environmental Protection Agency (USEPA) method for determining a nutrient criteria and the 2001 PALS Snapshot data, Commission staff determined that unimpacted ponds on Cape Cod should have a surface TP concentration no higher than 10 µg/l (Eichner, *et al*., 2003).

i. Flax Pond Data

OAI collected over 800 total phosphorus and ortho-phosphorus surface-water samples between 1991 and 1998 (OAI, 1998). As mentioned previously, laboratory methods and detection limits are not available for the analysis of the majority of these samples, so review of this data must be tempered and comparison of these data to data collected during the PALS Snapshots, by the Town Water Quality Task Force, or by OAI in previous years (*e.g*., OAI, 2002) cannot be done confidently.

A common problem with some past lake studies on Cape Cod is the reliance on drinking water laboratory methods for phosphorus analysis, rather than requiring labs to run ortho-P methods with a lake-appropriate 5 µg/l or less detection limit. In OAI's case, ortho-phosphate was not detected in about 50% of the samples collected in the 1991-1998 dataset. Since the method detection limits are not known, it is unclear whether these non-detections are due to the detection limit being too high or whether the detection limit is appropriate and the concentrations are extremely low. Because of these difficulties, Commission staff focused on TP concentrations in this review and generally focused on comparison among the samples rather than relying on absolute concentrations.

Beginning in April 1992, OAI collected surface water TP samples at seven stations in Flax Pond (Figure 2). The Restorer was located at Station 2, while Stations 6 and 7 were located near the deepest point in the pond.

Review of the TP concentrations at the individual stations shows that Stations 2 and 6 recorded the maximum concentration on the most sampling dates, while Stations 2 and 7 had the highest median concentrations (Table 2). Comparison of the TP data collected at the various stations does not show any statistically significant relationships (*e.g.*, the highest R^2 is 0.375

between samples from Stations 2 and 3). Average concentrations at the individual stations range between 85 µg/l and 184 µg/l, while median concentrations range between 30 and 60 µg/l.

TP data collected early in OAI's sampling generally show low concentrations with minimal differences between the stations (Figure 3a). Beginning in March 1993, significant variations between the station TP concentrations began to be observed. These variations have an upward trend over the entire dataset (Figure 3b) and appear to have a seasonal component with higher ranges observed in latter summer than spring or winter.

There are four sediment collection dates (10/26/93, 8/24/94, 8/8/96 and 6/26/02) with confirmed analysis methods. The irregular sampling and the variability of the results do not support definitive trend analysis (see Table 2).

In order to provide another perspective on the general ecological conditions of the pond, project staff reviewed the OAI TP data using the Carlson Trophic Status Index (TSI) (Carlson and Simpson, 1996). The Carlson TSI was developed to classify lakes into various trophic categories based on the amount of nutrients available. The TSI calculation converts either TP, chlorophyll *a*, or Secchi disk depth information into a single number, which is then related to a trophic classification (*e.g,* oligotrophic, mesotrophic, eutrophic). In order to review Flax Pond over the years, the average TP concentration for each sampling event was converted into a Carlson TSI value (Figure 4).

Figure 4 shows that average trophic conditions in Flax Pond in 1992 and 1993 generally fluctuated between the mesotrophic and eutrophic categories. In 1994, higher average TP concentrations caused the pond to fluctuate between the eutrophic and hypereutrophic categories, while in 1995 and 1996, the pond was generally in the hypereutrophic category. More limited sampling in subsequent years generally show a decline in trophic level culminating with an average TP concentration in 2002 that places the pond in the oligotrophic category.

ii. Phosphorus discussion

TP concentrations in water fluctuated extensively during the time the Restorer was operating. Overall TP concentrations were highest at stations over the deepest portions of the pond and near the Restorer; deeper portions of ponds that have or approach anoxia in waters near the sediments generally have higher TP at that point. As to the higher concentrations observed near the Restorer, the TSI analysis seems to indicate that the Restorer was functioning to transfer phosphorus that was otherwise located in the sediments into the water column, making it available for plant growth. The decline in the TSI after the cessation of Restorer operation also supports this hypothesis. More extensive sediment sampling than is available would be necessary to more definitively assess the impact on the sediments.

An alternative way to look at the impact of the Restorer, is to estimate the expected concentration in the pond if the landfill and septage lagoons were the only factors determining pond TP concentrations. By combining the volume of the pond, the highest upgradient groundwater TP concentrations, and annual recharge, a crude estimate of the expected concentration (50 µg/l) in the pond can be developed. Since the average concentrations at the various OAI sampling stations range between 90 µg/l and 180 µg/l, it appears that the sediments in the pond are contributing between two and three times the amount of phosphorus coming from the watershed. Additional sampling and analysis of both the sediments and water would be necessary to see how the removal of the Restorer has changed the TP balance between these two sources.

Although there are concerns about the laboratory methods, the average TP concentrations observed in Flax Pond over the entire dataset are among the highest observed in ponds on Cape

Cod (Eichner, *et al*, 2003). The lowest average TP concentration among the stations (Station 1, 85 µg/l) is in the upper 95th percentile among all the ponds sampled in the 2001 PALS Snapshot. However, TP concentrations measured in 2002 and 2003 are much lower, with concentrations approaching the lower 25th percentile (10 µg/l) of all Cape Cod ponds.

b. pH and alkalinity

pH is a measure of acidity; pH values less than 7 are considered acidic, while pH values greater than 7 are considered basic. pH is the negative log of the hydrogen ion concentration in water (*e.g.*, water with a H^+ concentration = $10^{-6.5}$ has a pH of 6.5). pH is determined by the interaction of all of the ions with carbon species, like carbon dioxide, carbonate, and bicarbonate, having the most direct effect (Stumm and Morgan, 1981). The 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. 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. 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. However, landfills can add alkalinity to the groundwater system; concentrations within 500 ft of the Brewster Landfill ranged between 126 and 150 mg/L as $CaCO_3$ (Cambareri and Eichner, 1993).

i. Flax Pond Data

Over 480 pH readings have been collected from surface water on Flax Pond (OAI, 1998). The majority of these were collected by OAI utilizing a Hanna pH meter (model# HI 9025). Average readings from all sampling sites are greater than 7 (see Table 2). During the period in which OAI was conducting regular sampling (June 1990 to October 1995), pH fluctuated mostly between 7 and 8 (Figure 5). Waters in the two basins (eastern/shallower basin (sampling stations 1, 2, 3) and western/deeper basin (stations 4, 5, 6, 7)) have little statistical probability of pH differences among them, while comparisons of pH between the two basins are statistically significant (*e.g.*, stations 3 and 4 have a probability of less than 0.00005% of having no significant difference). Readings in the deeper basin are higher than in the shallower basin. This difference between the two basins appears to be most pronounced beginning in April 1993, which is the first sampling following the installation of the Restorer. Average pH readings in both basins are both greater than the upper 90th percentile among all ponds sampled during the 2001 PALS Snapshot (Eichner, *et al.*, 2003).

Alkalinity data generally mirrors the pH results, although only nine readings were analyzed by outside labs and have methods and detection limits available. Average concentrations generally are approximately 66 mg/l as $CaCO_3$ and 53 mg/l as $CaCO_3$ in the shallow basin and deep basin, respectively. These concentrations are both greater than the upper 98th percentile among all ponds sampled during the 2001 PALS Snapshot (Eichner, *et al.*, 2003).

ii. pH/alkalinity discussion

Impacted groundwater flowing into the pond from the landfill is generally in the 6.2 to 6.8 pH range, with alkalinity ranging from 70 to over 400 mg/l as $CaCO_3$ (Weston & Sampson, 1995). The impact of in-pond interactions is causing the rise in pH observed in the pond, but more refined pond/landfill analysis would be necessary to evaluate alkalinity readings.

Since higher levels of photosynthesis increase pH, pH is generally higher in ponds with more productive ecosystems. But pH is also impacted by other factors, such as alkalinity, and this can lead to a range of photosynthesis-influenced measures at the same pH. In this way, a measure of pH combines the impact of many factors. Accounting for all the factors determining pH in Flax Pond requires a more refined dataset than is available,

This accounting might also include an analysis of the addition of a total of 16 tons in four applications of "bluestone" between 1994 and 1995 (see Table 1). These applications were apparently completed in order to boost the pH of the pond, but information about the material added, its source, and chemical makeup is not found in the available reports from OAI.

Lower pH readings observed in the shallower basin where the Restorer was installed suggest that the deeper basin had more photosynthesis than the shallower basin even though TP data does not suggest significant differences between the basins. This difference might be related to the impact of iron associated with the landfill/septage lagoon impacts. Dissolved iron in well oxygenated waters precipitates into a solid form, often bound with phosphorus creating a solid called strengite ($FePO_4.2H_2O$) or iron hydroxide ($Fe(OH)_3$) (Stumm and Morgan, 1981). Iron entering the shallower basin from the landfill might be in competition with algae for the phosphorus in the water thereby decreasing opportunities for photosynthesis; more coordinated sampling of groundwater and pond water might help to clarify this issue.

c. Dissolved oxygen and temperature

Pond and lake ecosystems are controlled by interactions among the physical, chemical and biological factors within the lake. The availability of oxygen determines distributions of various species living within a lake; some require higher concentrations, while others are more tolerant of occasional low oxygen concentrations. Oxygen concentrations also determine the solubility of many inorganic elements; 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 negatively 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 bacteria 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.

Shallow 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 constant from surface to bottom.

i. Flax Pond Data

Flax Pond is relatively shallow (less than 9 meters deep) with two basins (see Figure 2). OAI collected dissolved oxygen (DO) and temperature measurements first with a YSI 51B meter and then with a YSI 95 meter. Most of these measurements have limitations that make conclusions and comparisons difficult. These limitations include measurements only made at the surface, depth of collection is unclear, and/or lack of corresponding temperature measurements. Lack of corresponding temperature readings does not allow one to compare various dates because of the relationship between temperature and DO concentrations. During the summer of 1996, OAI (1997) collected both temperature and DO measurements at five stations and collected measurements throughout the water column (Figure 6). Town Water Quality Task Force (WQTF) volunteers collected similar readings at the deepest point in the pond during the summers of 2002 and 2003 (see Figure 6f).

The 1996 readings reveal a number of differences between the stations. DO readings at Station 1 show well oxygenated conditions at the surface and declining DO saturation with depth; August and September measurements show waters near the sediments have DO concentrations only 10% of what would be expected based on temperature alone (see Figure 6a). Similar, but slightly better conditions were measured at Station 2 (see Figure 6b). At somewhat shallower Station 3, waters are uniformly well oxygenated with progressively higher supersaturation levels as the summer progressed (see Figure 6c). Station 4 conditions are somewhat worse than Station 3, but waters are well mixed down to approximately 8 ft depth (see Figure 6d). Conditions at Station 5, over the deepest portion of the pond, also show relatively well-mixed conditions down to an 8 ft depth throughout the summer and declining DO saturation with increasing depth below 8 ft (see Figure 6e). Data collected by the town WQTF in 2002 and 2003 at approximately OAI's Station 5 is not as detailed as OAI's but generally shows the same sort of pattern as observed in 1996 (see Figure 6f). During the summer of 1996, the OAI's Restorer was operating at Station 1 (OAI, 1998)(see Figure 2 for station location).

ii. DO and temperature discussion

These DO and temperature readings seem to indicate that the two basins in Flax Pond operate somewhat differently. The deeper basin (with Stations 3, 4, and 5) has well mixed conditions down to about 8 ft (2.4 m) and these conditions extend out to at least Station 3, which is located on the eastern edge of the deeper basin. The shallower basin (with Stations 1 and 2), where the most obvious impacts of the landfill plume are observed (HWH, 1992) and the Restorer was located, appears to be significantly impacted by the sediments located in this basin.

A statistical comparison of the basin readings at representative stations (Station 5 for the deep and Station 1 for the shallow) shows the differences between the basins appear to be related to conditions in the shallower waters. Overall DO saturation measurements at the two stations are significantly different (α<1.5%). However, the DO conditions in the deepest waters of Station 1 and Station 5 are not significantly different; a t-test shows that there is an 86% probability that there is no significant difference between the percent saturation measurements in deepest waters of the two basins. This suggests that the waters over the sediments in the two basins are impacted by similar conditions, but the smaller volume of the shallow basin is allowing these conditions to have a greater impact on surface waters. In addition, since the landfill and septage lagoons are primary source of nutrients leading to the oxygen demand, it is clear that these sources have impacted the whole pond and that current organic loads (*e.g.*, algal

biomass) throughout the pond are greater than the capacity of the pond sediment bacteria to degrade them.

The trends toward DO supersaturation observed in surface waters during summer 1996 also support the apparent positive seasonal trend observed in the TP concentrations. As the summer progressed and DO concentrations dropped toward or into anoxic conditions near the pond sediments, more TP would be released from the sediments and become mixed into the surface waters. This release of additional TP would allow additional phytoplankton growth, greater photosynthesis, and higher DO concentrations. More refined TP sampling and chlorophyll *a* monitoring along with appropriate DO and temperature readings would be needed to confirm this hypothesis.

d. other chemical and biological measures

A number of other datasets have been collected over the years of OAI involvement on Flax Pond. These datasets have included chemical constituents in water (*e.g.*, ammonia-nitrogen, nitrate-nitrogen, and total iron), Secchi disk depths, sediment constituents (*e.g.*, volatile solids, total solids, total Kjeldahl nitrogen, copper, lead, and mercury), and biological measures (sediment macroinvertebrate and phytoplankton monitoring). As with much of the chemical data available for Flax Pond, most of this data does not have accompanying analysis methods or detection limits. In addition, some constituents that would have helped to clarify the overall status of the pond were analyzed in only a handful of samples (*e.g.*, total nitrogen or chlorophyll *a* in water samples) and some of the available data does not appear to be consistent with other measures collected at the same time. More inclusive sampling would be necessary to present a more comprehensive understanding of pond function and interactions.

As an example of an additional chemical constituent that would be helpful for understanding the pond, total nitrogen should have been collected at the same time as ammonia and nitrate. By comparing TP and TN concentrations, one may determine a limiting nutrient; some ponds on the Cape with large nutrient loads appear to be nitrogen limited during certain times of the year. If this occurs in Flax Pond, the nitrogen loads from the landfill and septage lagoons may be more of a concern for the pond and it would be helpful to ascertain whether this might be the case during the prime growing season (May to September). In order to fully assess this, measurements of total nitrogen (nitrate-nitrogen and total Kjeldahl nitrogen) would be needed in both the sediments and the water. The water quality dataset for Flax Pond does not contain complete nitrogen series data.

As an example of the lack of agreement between different measures, one might look at pH readings, ammonia-nitrogen and dissolved oxygen concentrations in Flax Pond. Ammonia is a reduced form of nitrogen, which when fully oxidized is converted to nitrate. At a pH above 7 and fully saturated dissolved oxygen concentrations (*i.e.*, surface waters on Flax Pond), ammonia concentrations should be minimal (at or less than 0.01 ppm) even with the septage lagoons impacts. Yet Flax Pond ammonia concentrations measured by OAI in surface waters throughout the pond routinely exceed 1 ppm and in some cases exceed 4 ppm.

Additional analysis and monitoring would be needed to resolve some of these apparent inconsistencies. Additional analysis steps to be considered would include: review of groundwater monitoring at the landfill, a more refined characterization of the pond's recharge area, more thorough characterization of internal pond processes, additional measures of pond biota (including sediment macroinvertebrates, plankton, and rooted aquatic plants), complete mapping of sediment depths, and modeling of the lake and sediment interactions. Some of this

analysis might be able to proceed without additional data collection if OAI in-house lab methods and detection limits for past monitoring can be recovered.

The town has taken some steps toward more refined monitoring during the past three summers; available laboratory data is in included in Table 3. Laboratory analyses have been limited to pH, alkalinity, total phosphorus, total nitrogen, and chlorophyll-*a*, but 2003 included samples collected from both the east and west basins of the pond. Citizen volunteers also recorded field readings of dissolved oxygen, temperature, and Secchi disk depth. More frequent sampling and an accompanying analysis of the watershed to the pond would be necessary to develop active management options to control the ecosystem fluctuations that are likely to continue in the pond.

4. Water Quality and Cranberry Bog Operation

As part of this project, staff, the town health director, and chairman of the Board of Health tried to arrange a meeting to discuss any concerns that cranberry bog owners who utilize pond water might have. On May 25, 2004, Mr. Leo Cakounas, owner of the cranberry bog at the western end of Flax Pond graciously shared some information about his operation and his observations around the pond. Mr. Cakounas is generally pleased with the pond water quality and remarked that it seems to be "a lot cleaner than 3 years ago." He noted that there did not seem to be too many people swimming or fishing in the pond, although there appeared to be a lot of fish. Mr. Cakounas also noted that an extensive mass of "reeds" generally drifts into his end of the pond in the spring.

Mr. Cakounas also provided some information about his bog operations. He operates the bog as an organic bog and uses Flax Pond water for irrigation, pest control, and flooding. He has a state water withdrawal permit to withdraw 11 million gallons per year from the pond; during most of his activities, he attempts to return the majority of the water removed from the pond back into the pond. In January/February, he floods the bog and returns 75-80% of the water to the pond via gravity flow. In early April, he again floods the bog, returns approximately 70%, and the rest of the water flows through Thatcher Bog to the Herring River. Throughout the summer, he uses pond water to irrigate the bog. In the fall, he floods the bog for harvesting and returns approximately 80% back to the pond. Mr. Cakounas noted that he uses a tractor pump pumping at 8,000 gallons per minute (gpm) from along the shoreline for the floods and uses a 1,200 gpm pump for irrigation with a 30 foot long intake hose secured to a float that rests approximately 2 feet below the pond surface.

Subsequent to this meeting, Mr. John Sarkes, owner of the cranberry bog at the eastern end of Flax Pond graciously spoke with staff on July 8 about his bog operations and observations of his bog since 1979. Mr. Sarkes noted that water quality in the pond was generally good and that the clarity of the pond is "a lot better than it used to be." He expressed concerns about his measurements of pH in the pond being higher than cranberry plants prefer and whether capping of landfill would cause the leachate into the pond to become a more chronic problem than if the cap was not installed.

Mr. Sarkes also noted that over the past 25 years, he has withdrawn water throughout the year for flood and irrigation purposes. He stated he has an annual state water withdrawl registration for 10 acre-ft (3.259 million gallons). While this year he has only irrigated one or two times, there have been years when he has irrigated every other day. Similarly, he has flooded the bog between zero and seven times in a given year. Mr. Sarkes uses a 750 gpm irrigation pump, that he pumps at an estimated 440 gpm, and a homemade flood pump. Flood

waters are discharged to the bog to the south. Over the last four years, he has managed the bog less intensively than in the past.

Mr. Sarkes stated that he is pursuing Integrated Pest Management of the bog with occasional use of herbicides and pesticides. He had two insecticide applications last year and seven the year before. He applied the herbicide Roundup last August, but has not applied insecticide or herbicides this year.

As a result of these discussions, it was generally agreed that the town would benefit from better understanding of all the bog owner concerns and uses of Flax Pond and that bog owners would benefit from an annual briefing on the pond water quality data collected by the town. Bog owner observations would also be helpful to the town for planning future management activities. The following information should be updated on a regular basis:

a) When was water pumped from the bog? How much was pumped?
b) What happened to water after bog was flooded?
c) Approximately how long to flood bog?
d) Where in the pond was the water withdrawn from? What depth?
e) Any herbicide or pesticide applications? Amounts?
f) Any water quality testing done?
g) Any observations of the pond or its water quality?
h) Any overall concerns?

It was suggested that the town and the bog owners could meet on an annual basis to share information.

5. Overall Discussion and Recommendations for Future Activities

Review of the available data suggests that Flax Pond can attain a number of trophic categories depending on treatment or condition of its sediments. The recent trophic characterization of the pond as oligotrophic suggests that external phosphorus loads to the pond from its watershed are relatively minimal; fairly well oxygenated conditions near the sediments at the time appear to have caused phosphorus to remain bound in the sediments. However, progressively higher trophic levels observed during the operation of the OAI Restorer, which disturbed the sediments in the pond, suggest that these sediments are a significant source of nutrients and have the ability to alter the productivity, water quality, and trophic category of the pond.

The anoxic conditions observed in deeper water in the pond throughout the available monitoring can allow nutrients back into the water column and prompt plant (algal) growth. This addition of nutrients creates an unstable ecosystem; one that will fluctuate between a variety of trophic levels depending on how much oxygen remains in the bottom waters. These fluctuations may occur across weekly, monthly, and yearly timeframes, often depending on weather conditions. The data suggests that the Restorer accentuated these fluctuations. Figure 7 presents conceptual water quality conditions within the pond and the factors likely to influence the creation of the conditions.

Additional data would be necessary to understand how often and at what intensity these fluctuations are likely to occur. Listed below are a series of ecological monitoring steps of increasing intensity that would allow the town to understand the impact of these fluctuations:

a. Maintenance Monitoring

Sample up to once a month in May, July, and September in the deep (western) and shallow (eastern) basins. Samples should be collected at the surface and 1 m off the bottom in the shallow basin and at the surface, 3 m, and 1 m off the bottom in the deep basin. Samples should be analyzed for the following constituents, at a minimum (with minimum listed detection limits): total nitrogen (5 ppb), total phosphorus (5 ppb), pH (na), chlorophyll a (1 ppb), and alkalinity (0.5 ppm). Additional sampling of ammonia-nitrogen, nitrate-nitrogen, and ortho-phosphorus could also be considered. Dissolved oxygen and temperature profiles with readings every 2 ft should be collected at the same time as water quality samples are collected, as should Secchi disk depth readings. An additional sampling round through the annual Pond and Lake Stewardship (PALS) Program Snapshot could be included in August as long as the Snapshot sampling program is continued. Monitoring results should be reviewed on a yearly basis and after five years, a review of monitoring procedures and results should occur to discuss whether monitoring could be reduced to once a year.

b. Monthly Variability Monitoring

Sample monitoring procedures as completed under Maintenance Monitoring with the addition of June, August, and October sampling dates and twice a month/every other week sampling during June, July, August, and September. This monitoring will allow a more refined understanding of the variability in constituent readings and better definition of constituent budgets. It is anticipated that this would be a one time sampling project accompanied by a review of results during the subsequent winter/spring. Additional sampling could occur on an annual cycle to establish year-to-year variability.

c. Diagnostic Monitoring

Sample monitoring procedures as completed under Monthly Variability Monitoring with the addition of sediment sample testing in May and August at five locations along a transect between the deepest portions of the two basins and corresponding water sampling of orthophosphate, ammonium-N, nitrate-N, magnesium, calcium, manganese, bicarbonate, dissolved inorganic carbon, dissolved organic carbon, total carbon, sulfate, total sulfur, and total and dissolved iron at depths listed above in both basins. Sediments will be analyzed for total phosphorus, total nitrogen, total carbon, total sulfur, total iron, and total mercury in subsamples taken from the upper 10 cm and the 10-20 cm increments. Sediment depth will be established at each testing site prior to sampling. A sediment depth mapping task will occur prior to the sampling. Additional tasks to consider would be placement of seepage meters along the north and south sides to establish groundwater flow into and out of the pond and along a north/south transect to establish flows at various depths and the establishment of a water level recorder station to record day-to-day fluctuations in the pond level. It would also be recommended that the town consider tasks to better characterize the watershed area to the pond and another to characterize mercury in fish tissue. The watershed task would include installing additional monitoring wells to the west of the

landfill and utilization of a groundwater model. The fish tissue task would involve sampling and testing of fish using USEPA and MADPH protocols.

6. Conclusions

Flax Pond appears to have an unstable ecosystem. The pond will fluctuate between trophic levels depending on the amount of nutrients released from the pond sediments, which in turn depends on oxygen conditions in the waters above the sediments. These sediments contain an undetermined number of years worth of nutrients from the Town of Harwich landfill and septage lagoons, which are directly upgradient of the pond. Prior to the installation of the Ocean Arks International's (OAI's) Pond Restorer, the pond fluctuated between oligotrophic, mesotrophic, and eutrophic trophic levels. The Restorer disturbed the sediments and moved otherwise sediment-bound nutrients into the water column. These additional nutrients pushed the pond into the highest trophic category (hypereutrophic). Removal of the Restorer has allowed much of the nutrients disturbed by the Restorer to return to the sediments and, as a result, recent water quality measurements appear to show a return to oligotrophic/mesotrophic levels. More frequent monitoring of the pond would likely show that its trophic condition fluctuates between trophic categories in much the same way as it did before the installation of the Restorer. As long as the nutrient-rich sediments remain in place, Flax Pond will continue to fluctuate between trophic levels.

More refined characterization of the interactions within the pond and between the pond and its watershed would help to clarify whether the trophic level fluctuations are likely to increase with time or whether they are somewhat stable. In order to complete this characterization, the town would need to collect additional water quality data, sediment data, and better understand the watershed interactions. Simple maintenance monitoring could provide a better understanding, but data would need to be collected for a minimum of five years. More intensive sampling over a year could accomplish much the same thing, but additional tasks would be necessary to provide the basis for remedial activities in the pond or sediments. The details of these monitoring tasks are provided. In addition, it is recommended that the town facilitate a regular meeting with all stakeholders around Flax Pond, including the cranberry owners to review monitoring data, solicit observations, and discuss concerns.

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Table 1 - History of Flax Pond Activities

Year	Event	Source
1966	Landfill and septage lagoon operations begun	HWH, 1993
1990 (spring)	Ocean Arks International installs upwelling windmills ("three small floating windmills with underwater blades that produced upwellings during windy periods")	OAI, 1997
1992	Septage lagoons closed	OAI, 1997
1992 (Oct)	Restorer installed on Flax Pond	OAI, 1995
1994	Spring, 4 tons of bluestone added to pond	OAI, 1997
1994 (Jul)	Blue green algal bloom	OAI, 1994
1994 (Aug)	Solar backup systems added to Restorer	OAI, 1995
1994	Fall, 4 tons of bluestone added to pond	OAI, 1997
1995	Spring, 4 tons of bluestone added to pond	OAI, 1997
1995	Fall, 4 tons of bluestone added to pond	OAI, 1997
1996 (May)	Restorer II installed on Flax Pond	OAI, 1996
1997	More solar panels added to Restorer	OAI, 1998
1997	Shore Restorer tested on pond	OAI, 1998
prior to 1998	Manual harvesting of bladderwort	OAI, 1998
1998	Shore Restorer dismantled	OAI, 1998
1999	Restorer dismantled and removed	Harwich BOH, 2004

Table 2. Flax Pond Water Quality Data Review - TP and pH

Total Phosphorus Data Summary

WATER

	units	Station Number 1	2	3	4	5	6	7
Average	µg/l	85	135	184	143	115	162	126
Median	µg/l	30	55	30	30	30	30	40
Maximum	µg/l	760	810	1200	1150	1800	1200	1230
Minimum	µg/l	0	0	0	0	0	0	0
n		53	62	61	57	56	58	61
earliest reading		4/14/92	4/14/92	4/14/92	4/14/92	4/14/92	4/14/92	4/14/92
last reading		5/28/98	8/20/03	5/28/98	5/28/98	9/18/02	5/28/98	8/20/03

SEDIMENTS

Method: SM-4500-P E1 Persulfate & Ascorbic acid					Method: EPA 365.4 Mod				
Detection Limit		0.01	mg/Kg		Detection Limit		200	mg/Kg	
Lab	Collector	Collection Date	Field ID	mg/Kg	Lab	Collector	Collection Date	Field ID	mg/Kg
Aqua Test	OAI	8/8/96	1L	275	GW Analytical	OAI	6/26/02	1	1100
Aqua Test	OAI	8/8/96	2L	119	GW Analytical	OAI	6/26/02	2	1100
Aqua Test	OAI	8/8/96	3L	78	GW Analytical	OAI	6/26/02	3	1200
Aqua Test	OAI	8/8/96	4L	295	GW Analytical	OAI	6/26/02	4	360
Aqua Test	OAI	8/8/96	5L	315	GW Analytical	OAI	6/26/02	5	760
Aqua Test	OAI	8/24/94	station 1	40	GW Analytical	OAI	6/26/02	6	BRL
Aqua Test	OAI	8/24/94	station 2	43	GW Analytical	OAI	6/26/02	7	1900
Aqua Test	OAI	8/24/94	station 3	126					
Aqua Test	OAI	8/24/94	station 4	40					
Aqua Test	OAI	8/24/94	station 5	30					
Aqua Test	OAI	8/24/94	station 6	254					
Aqua Test	OAI	8/24/94	station 7	686					
Aqua Test	OAI	10/26/93	station 1	1100					
Aqua Test	OAI	10/26/93	station 2	1180					
Aqua Test	OAI	10/26/93	station 3	1410					
Aqua Test	OAI	10/26/93	station 4	612					
Aqua Test	OAI	10/26/93	station 5	263					
Aqua Test	OAI	10/26/93	station 6	2070					
Aqua Test	OAI	10/26/93	station 7	2040					

pH Data Summary

WATER

	units	Station Number 1	2	3	4	5	6	7
Average	pH	7.2	7.2	7.2	7.8	7.8	7.8	7.7
Median	pH	7.2	7.2	7.2	7.8	7.8	7.8	7.7
Maximum	pH	8.3	8.1	9.0	8.7	9.1	9.1	8.7
Minimum	pH	5.8	5.6	6.3	6.2	6.9	6.4	6.4
n		63	75	68	67	71	75	77
earliest reading		6/14/90	6/14/90	6/14/90	6/14/90	6/14/90	6/14/90	6/14/90
last reading		6/26/02	8/20/03	6/26/02	6/26/02	9/18/02	6/26/02	8/20/03

Source data: OAI, 1998; OAI, 2002; Cape Cod PALS Database (2001); Harwich WQTF data

Table 3. Flax Pond Lab Data from Harwich Water Quality Task Force							
Date	Basin	Sample Depth	pH	Alk	TP	TN	Chl-a
		m		mg/l as CaCO3	µg/l	mg/l	µg/l
6/19/02	WEST	0.5	8.40	ND	ND	1.00	2.34
		4		ND	ND	0.96	3.08
9/18/02	WEST	0.5	8.04	63.8	28.2	0.58	2.31
		3.85	8.04	64.6	<3.1	0.64	1.86
6/18/03	WEST	0.5	7.26	34.1	15.5	0.85	7.20
		8	6.69	40.1	18.6	1.07	7.63
7/17/03	WEST	0.5	6.81	35.4	12.4	0.59	5.24
		8	6.57	37.1	27.9	0.79	53.77
7/17/03	EAST	0.5	6.75	35.8	12.4	0.66	6.79
		2	6.72	37.5	15.5	1.16	10.22
8/19/03	WEST	0.5	7.17	3.7	6.2	0.50	4.69
		8	6.80	4.2	24.8	0.91	10.78
8/19/03	EAST	0.5	6.99	3.9	9.3	0.64	2.66
		2	6.89	4.0	15.5	0.69	3.86
All laboratory analyses completed by SMAST, UMASS-Dartmouth							

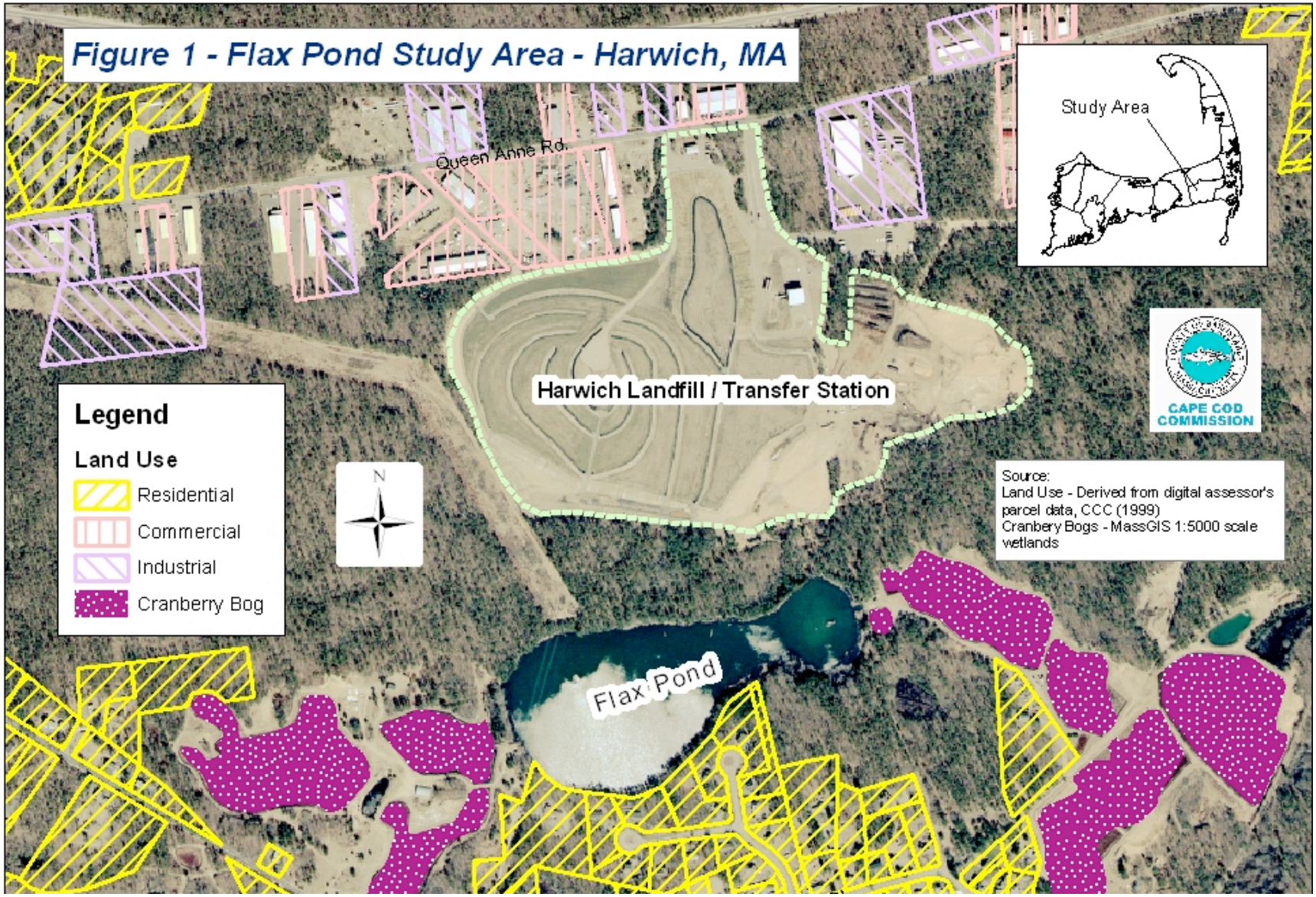
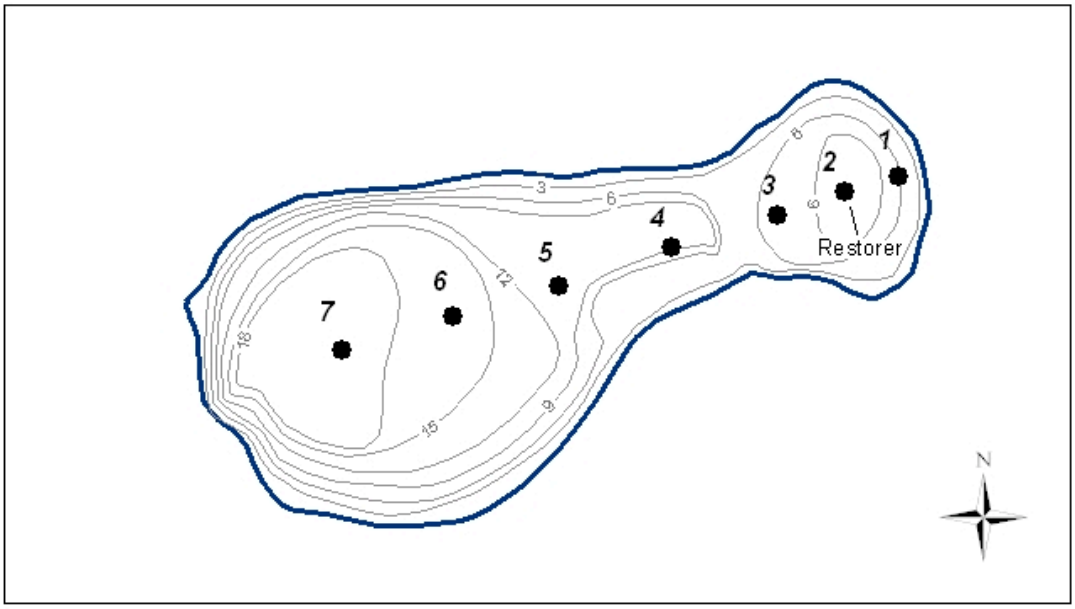


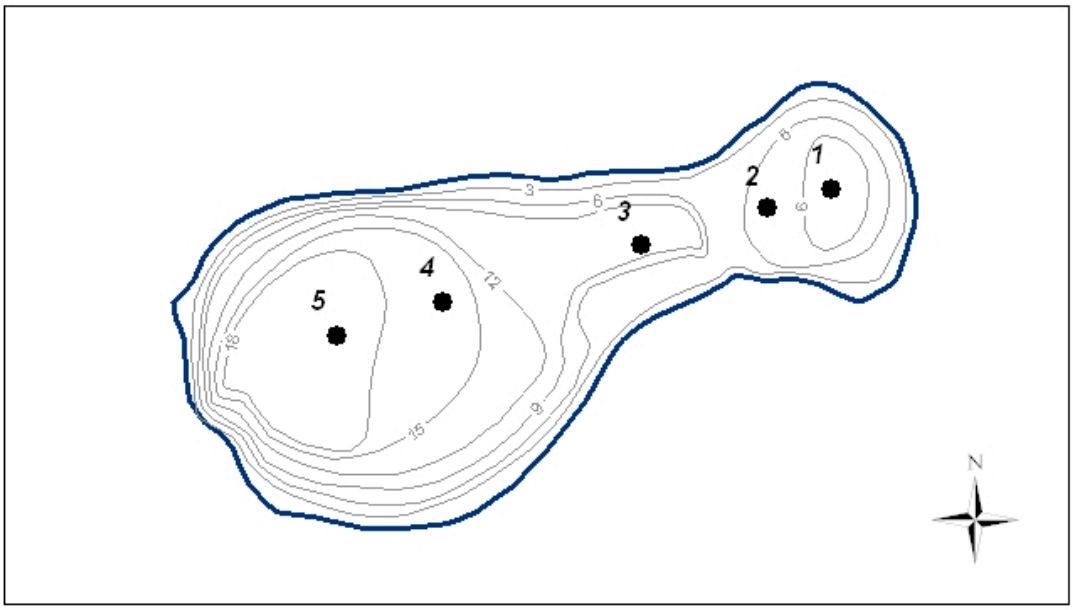
Figure 1 - Flax Pond Study Area - Harwich, MA
Queen Anne Rd.
Study Area
Harwich Landfill / Transfer Station
CAPE COD COMMISSION
Legend
Land Use
Residential
Commercial
Industrial
Cranberry Bog
N
Source:
Land Use - Derived from digital assessor's parcel data, CCC (1999)
Cranbery Bogs - MassGIS 1:5000 scale wetlands
Flax Pond

Figure 2 - Flax Pond Sampling Stations and Bathymetry (feet)

Source: OAI, 1997

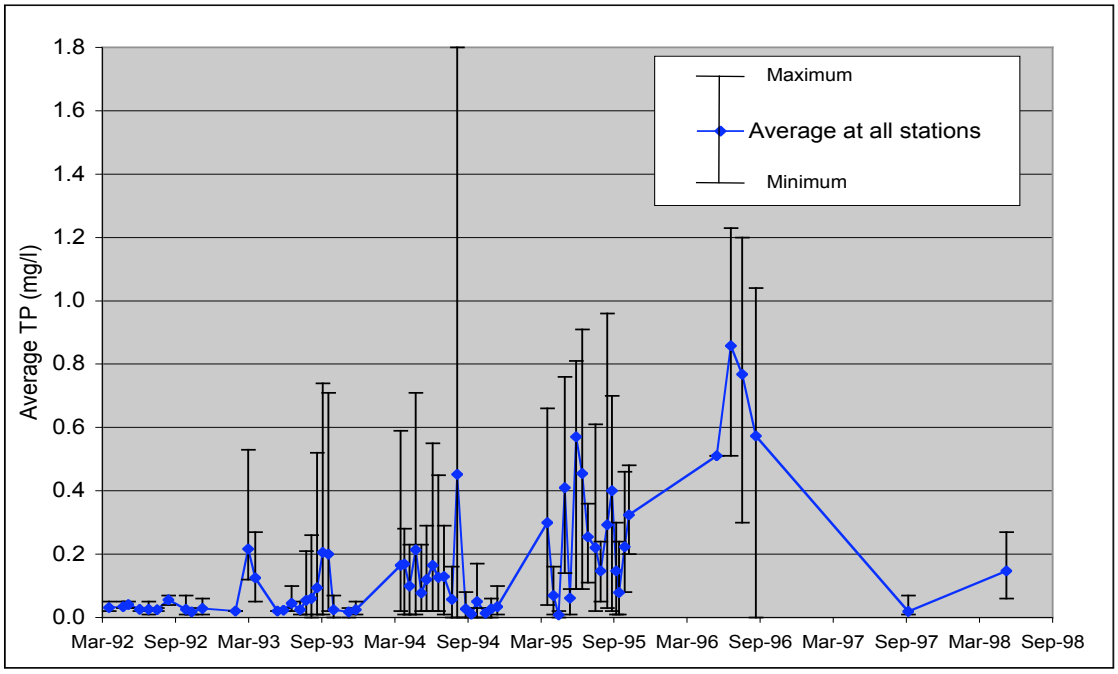


A. 1991-1995

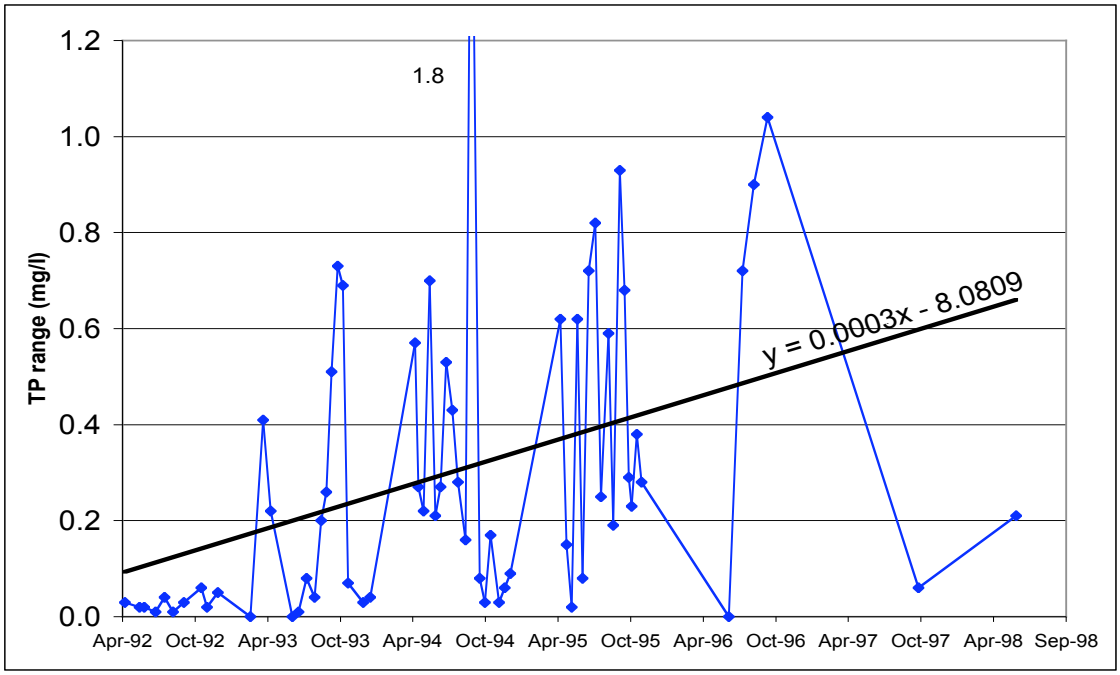


B. 1996

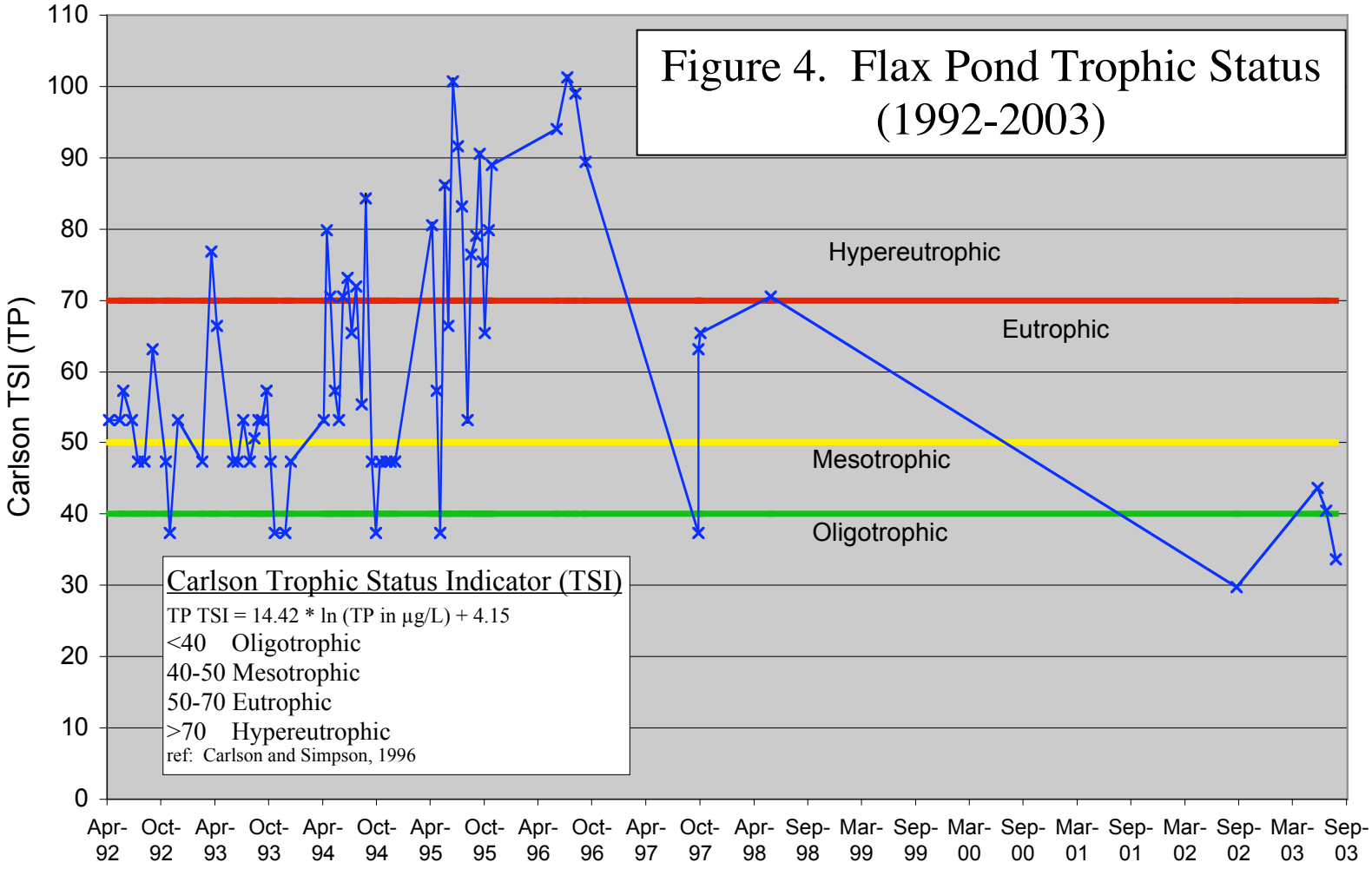
Figure 3. - Total Phosphorus in Surface Waters at Flax Pond



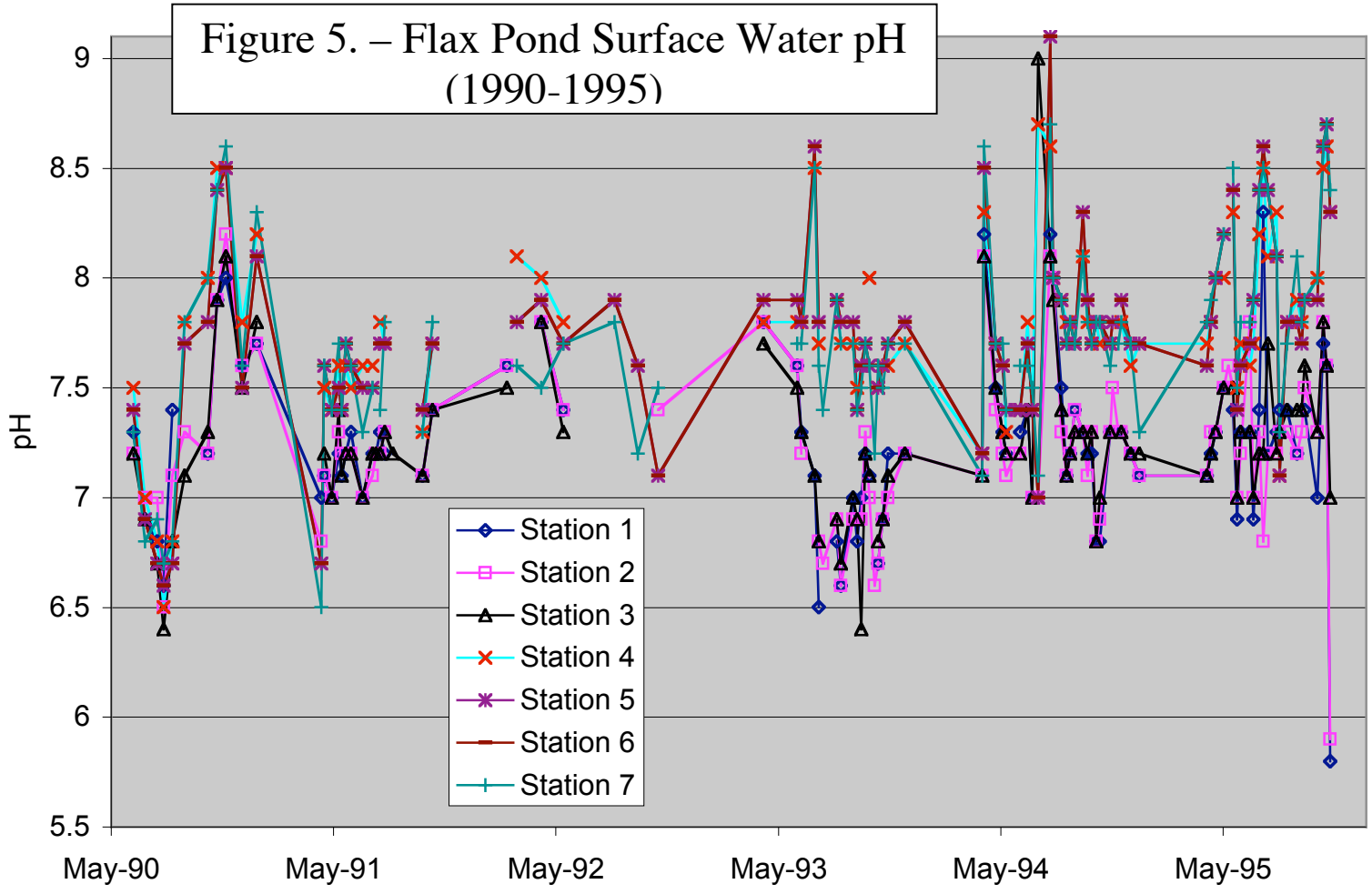
a. Average Total Phosphorus concentrations at Flax Pond (1992-1998): Average of each sampling date with maximum and minimum (Source data: OAI, 1998)



b. Range of Total Phosphorus concentrations in Flax Pond surface waters (1992-1998) by sampling date (Source data: OAI, 1998)



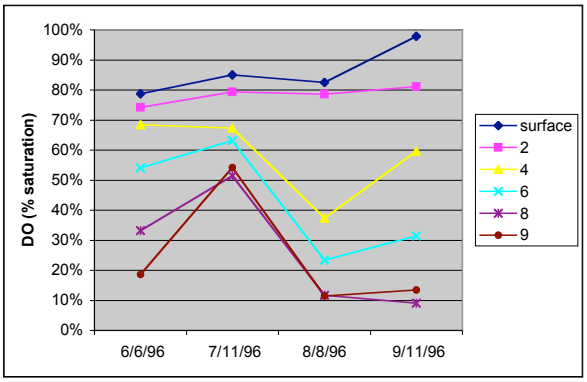
Source data: OAI, 1998; OAI, 2002; Cape Cod PALS database (2002); Harwich WQTF



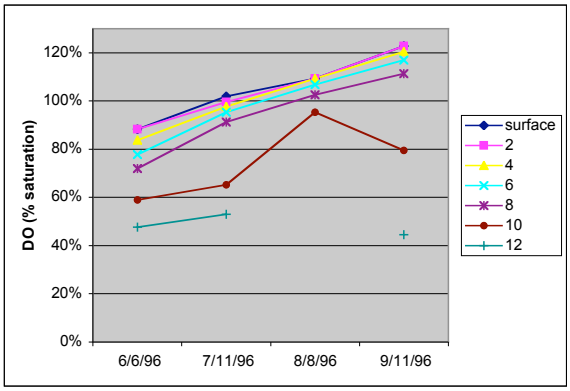
source data: OAI, 1998

Figure 6. - Dissolved Oxygen in Flax Pond

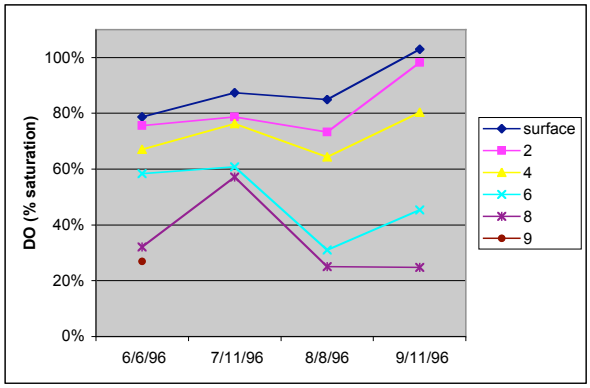
a. Station 1 (1996)



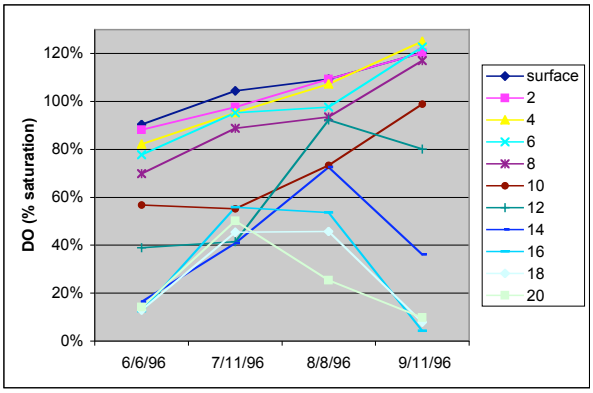
d. Station 4 (1996)



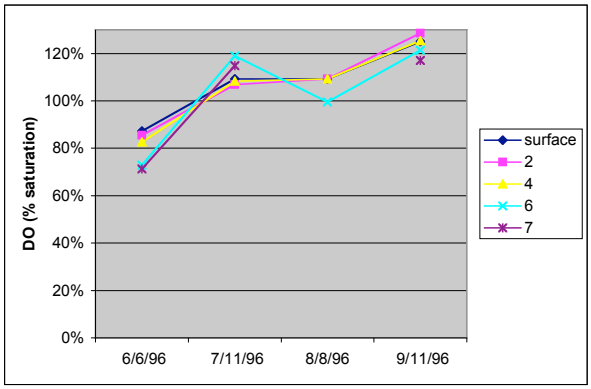
b. Station 2 (1996)



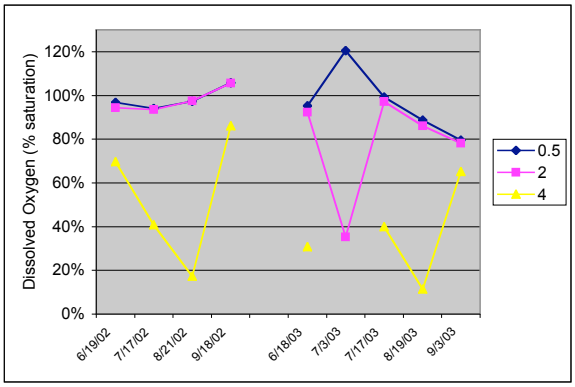
e. Station 5 (1996)



c. Station 3 (1996)



f. West Station (2002 & 2003)



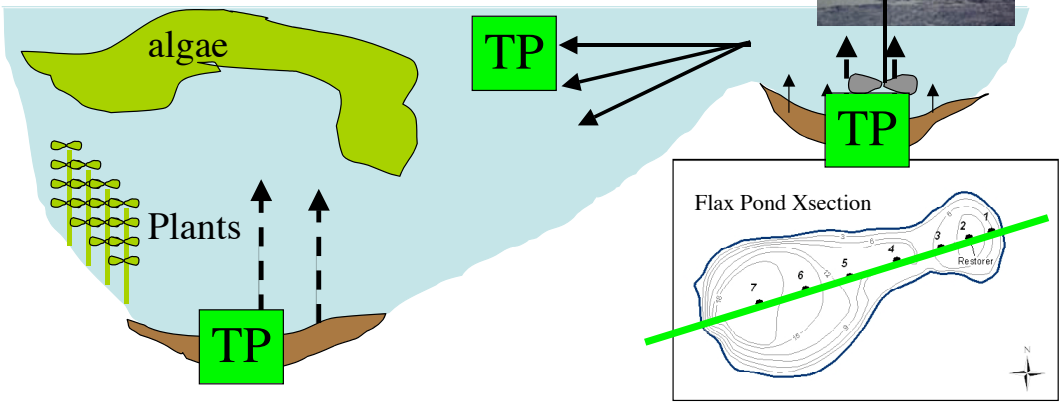
Data sources:
1996 data recreated from OAI, 1997
2002 & 2003 data from Harwich Water Quality Task Force citizen volunteer data

Figure 7. Flax Pond Conceptual Water Quality Conditons

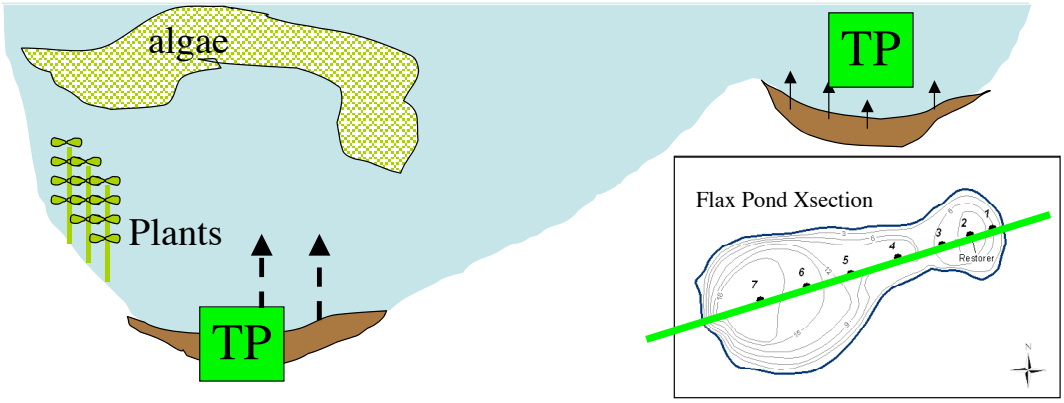
a. Conceptual Restorer Conditions

Key factors:

- Mixing of waters by Restorer during regular low oxygen conditions over sediments appears to increase transfer of TP from sedinents to watercolumn
- Higher TP availability leads to increased plant growth and higher trophic level; upward trend during Restorer operation
- Most TP remains in pond (increasing percentage in water)



b. Conceptual No Restorer Conditions

Key factors:

- Sediments and deeper waters still experience low oxygen; TP transfer to water reduced without facilitated mixing of Restorer
- Extended periods of quiescent, cloudy days will exacerbate low oxygen conditions and TP transfer from sediments
- Most TP remains in pond (higher percentage remains in sediments)