WHITE POND PRELIMINARY DIAGNOSTIC STUDY

prepared for

White Pond Advisory Committee
Concord, Massachusetts

by

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TABLE OF CONTENTS

1.0 Introduction

This report describes results of water quality studies conducted on White Pond during 1987. The impetus for the studies is the occurrence of algal blooms during August and October of 1986. Primary objectives are as follows:

(1) to assess existing water quality in the pond with respect to algae and related factors;

(2) to describe cause-effect relationships which may control pond conditions; and

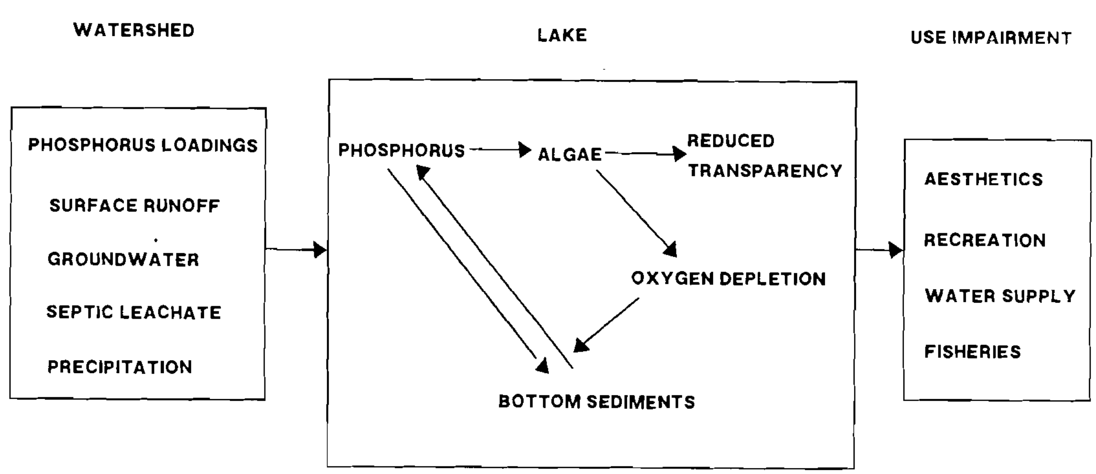
(3) to recommend additional diagnostic, protection, and/or restoration measures.

Preliminary studies of this type usually raise more questions than they answer. This study is no exception. The primary intent is to begin a systematic diagnosis of pond and watershed conditions which can lead to basic understanding and appropriate management decisions. Results are described below, following a brief discussion of basic concepts pertaining to pond algal problems.

2.0 Basic Concepts

Algal blooms are symptomatic of **eutrophication**, a process involving enrichment of water bodies with nutrients (e.g., nitrates and phosphates), which originate from various natural and cultural sources. As illustrated in Figure 1, this process has several direct and indirect influences on pond water quality conditions and uses.

Figure 1
Lake Eutrophication Process



In White Pond, as in most lakes and ponds, algal growth is limited by the supply of phosphorus. Nitrogen is usually present in excess relative to algal requirements (roughly 7 to 1 by weight). While algae come and go in response to season, weather patterns, and other random factors, many studies have shown that average algal concentrations and bloom frequencies are related to phosphorus concentration (Dillon and Rigler,1974; Carlson,1977; Heiskary and Walker, 1987). General sources of phosphorus include precipitation, dustfall, runoff from forested, agricultural, and urban watersheds, erosion of shoreline areas, groundwater inflows, municipal or industrial discharges, onsite sewage disposal systems, migrant water fowl, and leaching from pond bottom sediments. Phosphorus is not a "contaminant" or "poison", but an essential nutrient which only causes problems when it is present in excessive quantities.

Ponds undergo fundamental changes in response to increased nutrient loadings. At low loadings, algal growth supplies the food chain without reaching objectionable levels, the ecosystem remains in balance, and water quality is not noticeably impaired. Excessive nutrient loadings can lead to ecological imbalances. High densities of algae may develop and, in turn, cause reduced transparency, surface scums, objectionable odors, depletion of oxygen from bottom waters, loss of fish habitat, and other negative impacts on water quality, aesthetics, and water uses.

To facilitate classification of lakes and ponds with respect to nutrient enrichment, limnologists have invented the rather vague concept of "**trophic state**". Categories can be roughly defined as follows:

> **oligotrophic**: nutrient-poor; extremely clear (transparency greater than 15 feet); cold-water fishery supported; desirable for water contact recreation.
>
> **mesotrophic**: intermediate nutrient and productivity level; transparency 7 to 15 feet; cold-water fishery may be impaired by loss of oxygen from bottom waters; suitable for water contact recreation.
>
> **eutrophic**: nutrient-rich; transparency less than 7 feet; warm-water fishery only; occasional algal blooms; aesthetics impaired; undesirable for water contact recreation.
>
> **hyper-eutrophic**: extremely nutrient-rich; transparency less than 4 feet; algal blooms frequent; algal scums, floating mats, noxious odors, fish kills possible; water contact recreation infeasible.

The definitions and uses of these terms are rather subjective. The primary uses of White Pond for recreation and cold-water fishery suggest, however, that a eutrophic classification should be avoided to protect those uses.

Pond phosphorus sources can be influenced dramatically by land uses and human activity. For example, regional watershed studies have shown that conversion of forested land into urban land without special controls typically increases phosphorus export by five- to twenty-fold (Reckhow et al.,1980, Meta Systems,1982). These increases partially reflect increased surface runoff, which has a much higher potential for transporting phosphorus, as compared with water which percolates through the soil column before reaching a pond or tributary stream. Phosphorus concentration in stormwater runoff from residential areas typically averages from 250 to 600 ppb (Athayede et al.,1983). In the absence of specific point-source contributions, groundwater phosphorus levels in this region are usually less than 15 ppb. In pond environments, phosphorus concentrations exceeding 25 ppb are usually accompanied by eutrophic conditions. These comparisons reveal the importance of minimizing direct runoff and promoting infiltration as a means of protecting ponds from nutrient enrichment and resulting algae problems.

Aside from runoff, domestic sewage represents another potentially significant phosphorus source in urban watersheds. Phosphorus in domestic sewage from a typical household (2.2 lbs/capita-year) usually exceeds phosphorus loading in urban runoff by more than a factor of ten (Meta Systems,1982). For this reason, it is desirable to avoid discharge of untreated (or treated) domestic sewage to lakes or to their tributaries.

In many watersheds, such as White Pond's, onsite soil treatment systems are employed for sewage disposal. Because of filtration, chemical precipitation, and adsorption mechanisms, soil systems usually have high capacities for removing phosphorus in domestic wastewaters and preventing it from reaching lakes in significant quantities. Phosphorus removal efficiency depends upon many factors, including leach field size, depth to groundwater, hydraulic loading rate, loading patterns (seasonal vs. year-round), soil texture and chemical composition, permeability, groundwater movement, soil moisture and oxygen content, distance from lake or tributary, slope, vegetation, maintenance practices, and system age (Reckhow et al.,1980; Sawney and Starr,1977; Meta Systems,1982). For the purposes of estimating lake phosphorus budgets, removal efficiencies of 90% or more are typically assumed for onsite systems in proper working order. Detailed inventories and groundwater studies are needed to develop more accurate estimates of phosphorus loadings from onsite disposal systems in situations where such loadings may be significant in relation to other phosphorus sources (tributaries, direct runoff, etc.).

The amount of phosphorus loading which a pond can tolerate without causing eutrophic conditions depends upon a number of pond-specific factors, including volume, surface area, depth, and water budget. For these reasons, diagnosis of eutrophication problems requires a fundamental understanding of pond hydrology and watershed characteristics, in addition to water quality monitoring data from the pond itself. To a limited extent, mathematical models can be used to predict pond water quality conditions, based upon morphometric, hydrologic, and watershed characteristics. These models provide a frame of reference for interpreting monitoring data and a means for predicting changes in water quality likely to result from changes in watershed land uses or other controlling factors.

3.0 Setting

White Pond is located in the Sudbury River Basin near the Concord/Sudbury Town Line, as shown in Figure 2. Approximate watershed boundaries and depth contours are indicated in Figures 3 and 4, respectively. The surface water drainage divide, estimated from a USGS topographic map, includes an area of approximately 150 acres (Davis, 1972). The watershed is bounded by tributaries of the Sudbury/Assabet Rivers (Second Division Brook to the Northwest, Cold Brook to the South, and Dugan Brook to the North). Various morphometric, watershed, and hydrologic features are summarized in Table 1.

A detailed description of watershed geologic and topographic features is contained in a report by Davis (1972). Soils are well-drained loamy sands. The immediate shoreline is relatively steep (>30% grade) and susceptible to erosion. Bank erosion, apparently aggravated by loss of vegetation, trampling, and surface runoff, is evident at several locations, particularly on town conservation land along the southern shore.

Approximately two thirds of the shoreline is developed with a mixture of seasonal and year-round residences. The percentage of year-round residences (approx. 70%) has increased in recent years. Onsite sewage disposal systems are employed throughout the watershed. Based upon information provided by the White Pond Advisory Committee, onsite disposal systems in 30 shoreline houses and cottages receive wastewaters from approximately 76 people on an annual average basis. Some of these systems are within 100 feet of the shoreline and some are antiquated (cess pools without septic tanks). Because of sandy soils, slopes, and setbacks, leach fields are generally unsaturated and well above pond and groundwater elevations. High iron concentrations are characteristic of private wells in the watershed. Although sandy soils are generally considered to be conducive to phosphorus transport, this transport may be impeded by elevated iron levels in the soil/water system and by depth to groundwater.

White Pond is used intensively for swimming, boating, and fishing. A private beach, town conservation land, and public boat ramp provide legal access for non-residents. Gasoline-powered motor boats are banned. A routine trout stocking program is conducted by the Massachusetts Division of Fisheries and Game.

White Pond has no surface outlet and would be classified as a "kettle" or "seepage" pond. Elevation gradients suggest that groundwater discharge towards the southeast (Cold Brook and town water supply well) is most likely (E. Walker et al.,1980). Inflows include groundwater, precipitation on the lake surface, and surface drainage from the surrounding watershed. Surface inflows include direct runoff from shoreline areas and intermittent "streams" formed by drainage from roadways and other impervious surfaces in the watershed.

An approximate water budget for White Pond is summarized in Table 1. This budget assumes that the surface watershed boundary (Figure 3)

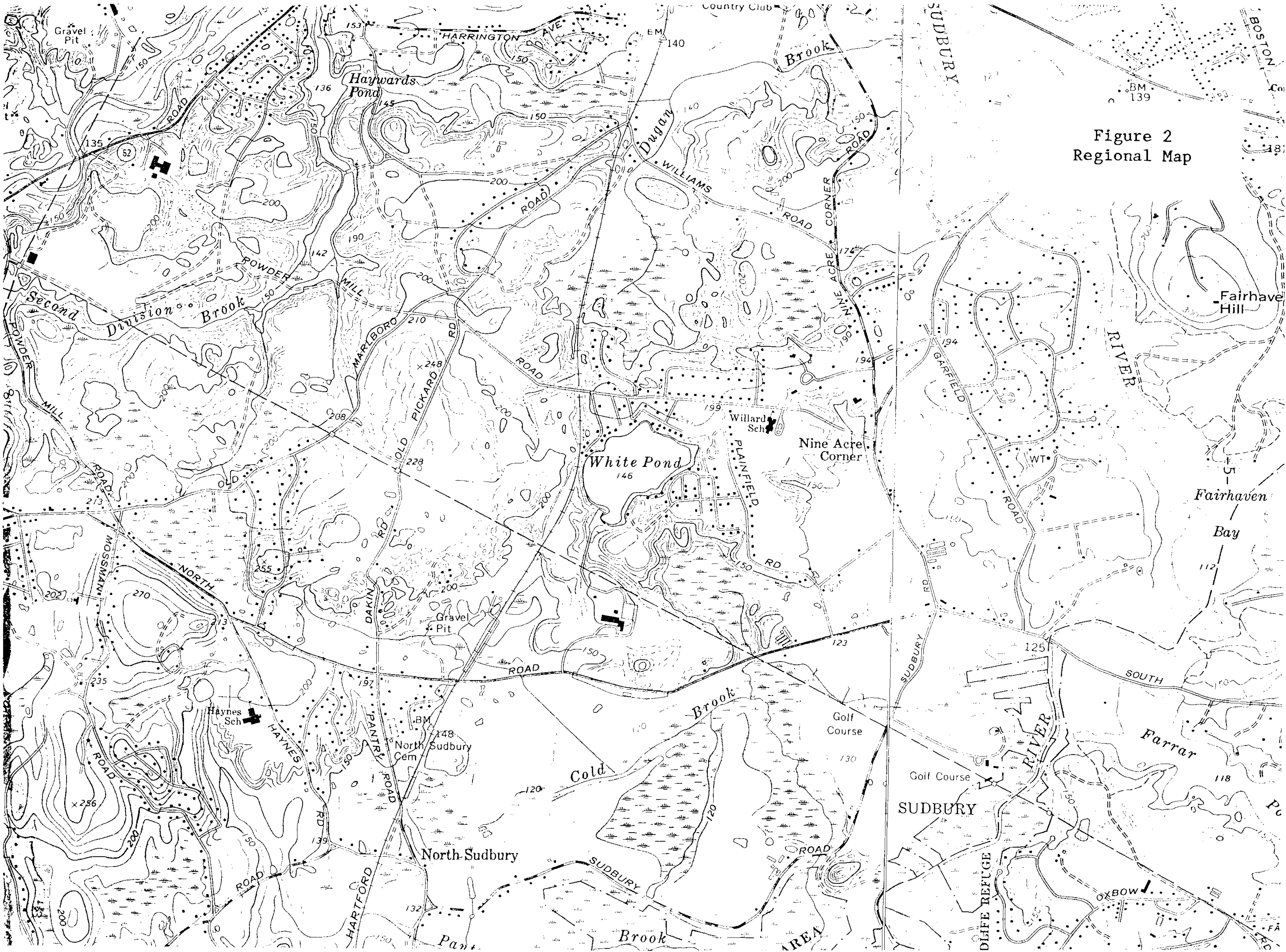
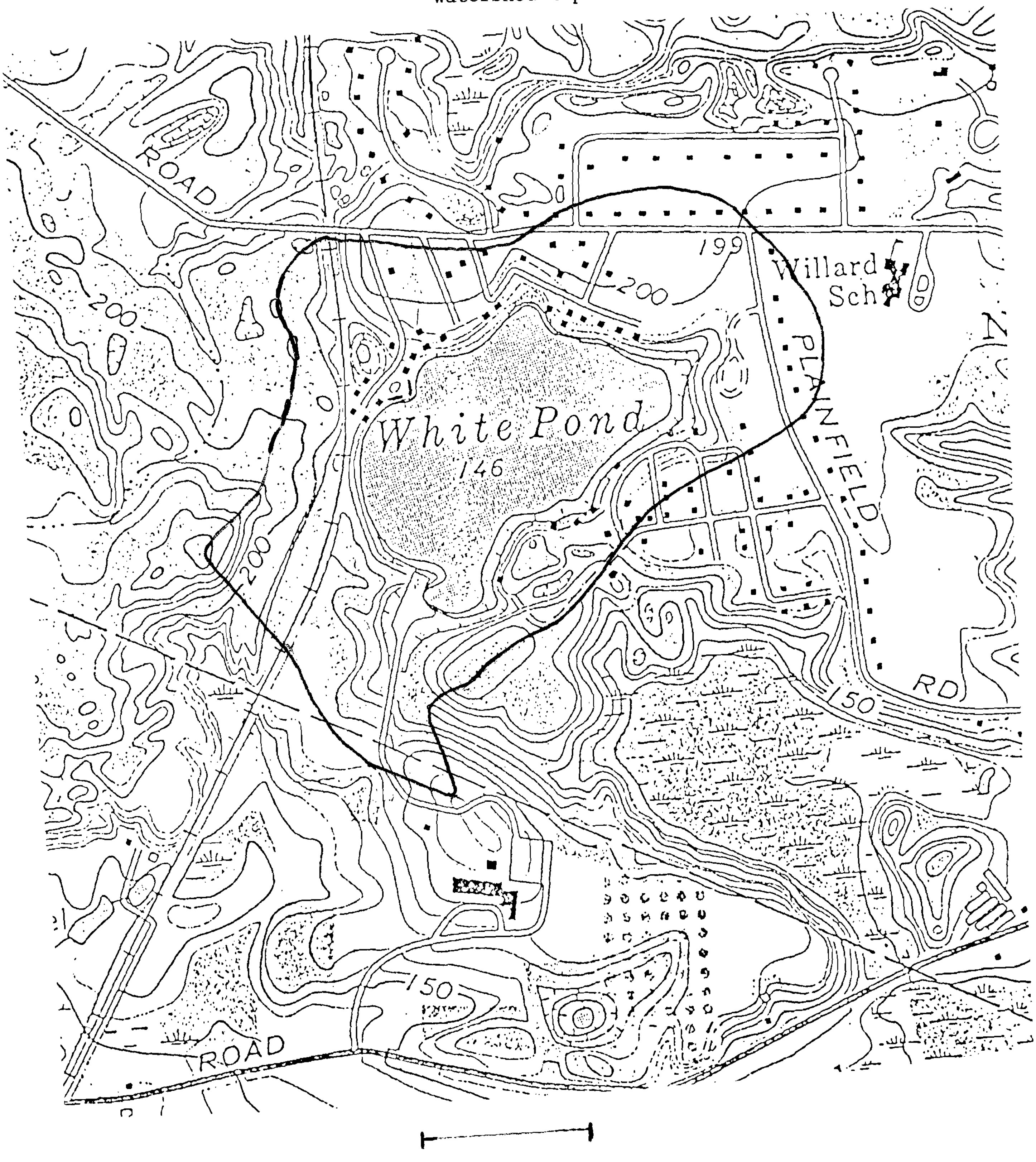


Figure 2
Regional Map

Figure 3
Watershed Map



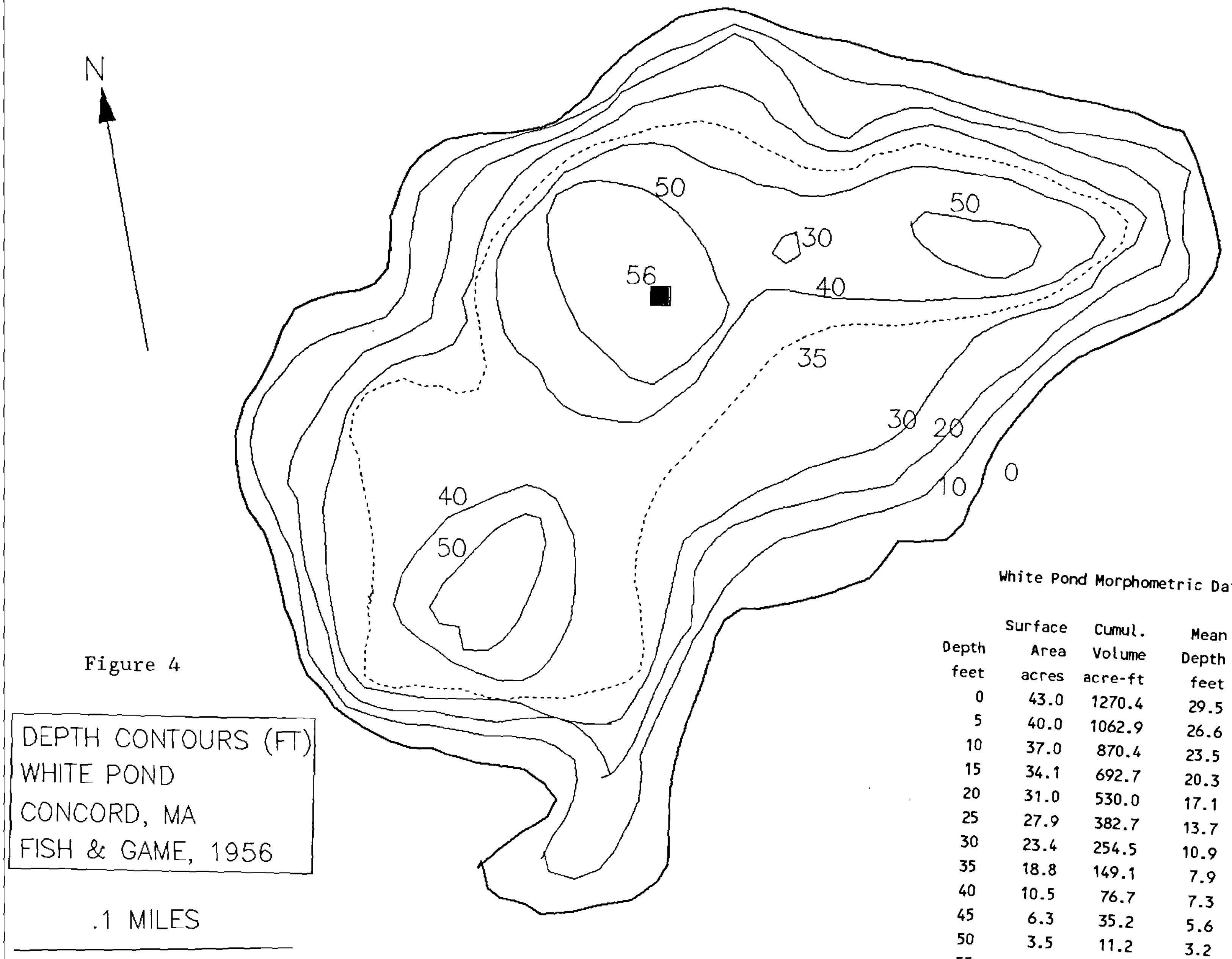


Figure 4

White Pond Morphometric Data

Depth feet	Surface Area acres	Cumul. Volume acre-ft	Mean Depth feet	Sediment Contact acres
0	43.0	1270.4	29.5	3.0
5	40.0	1062.9	26.6	3.0
10	37.0	870.4	23.5	2.9
15	34.1	692.7	20.3	3.1
20	31.0	530.0	17.1	3.1
25	27.9	382.7	13.7	4.5
30	23.4	254.5	10.9	4.5
35	18.8	149.1	7.9	8.3
40	10.5	76.7	7.3	4.2
45	6.3	35.2	5.6	2.8
50	3.5	11.2	3.2	2.4
55	1.1	0.4	0.3	1.1
56	0.0	0.0	0.0	0.0

Table 1

White Pond Watershed, Morphometry, and Water Balance Data

Variable	Value	Reference
Mean Surface Elevation	146 feet	a
Maximum Watershed Elevation	261 feet	a
Watershed Area	150 acres	a
Pond Surface Area	43 acres	b
Maximum Depth	56 feet	b
Mean Depth	30 feet	b

Estimated Water Budget	Area acres	Flow acre-ft/yr	Yield inches/yr
Watershed Inflows	107	196	22 c
Direct Precipitation	43 b	154	43 c
Total Inflows	150 a	350	
Evaporation	43	89	25 c
Groundwater Discharge		261 d	

a Davis (1972)

b derived from depth contour map (Figure 4)

c Water budget calculations are based upon typical regional values for watershed yield, precipitation, and evaporation, assuming that ground watershed divide equals surface watershed divide.

d estimated by difference.

also defines the area contributing groundwater to the pond. Detailed hydrologeologic studies would be required to justify alternative assumptions.

E. Walker et al.(1980) concluded that the town well, located in the wetland area southeast of the pond (Figure 3), is fed partially by pond outflow. The well's cone of influence has a radius of 1070 feet and intersects White Pond's surface watershed boundary. Town records indicate annual pumping rates ranging from 85 to 100 million gallons/yr over the 1984-1987 period. These values are comparable to the estimated mean annual outflow from the pond (261 acre-ft/yr or 85 million gallons/yr, Table 1). As shown in Figure 5, well pumping has generally occurred between May and December of each year. Since it has a large recharge area which is remote from the pond, the town well is not fed exclusively by pond outflow. There is a possibility, however, that pond surface levels and rates of groundwater flow through the pond are influenced by pumping rates from the town well and from other wells in the region, including those associated with the Sperry Rand aquifer cleanup operation.

Detailed hydrogeologic studies would be required to evaluate relationships between pond levels, pond discharge, and regional well pumping activity. These relationships may be relevant to pond eutrophication problems. Increased discharge from the pond would lower the average water residence time, reduce the opportunity for phosphorus sedimentation, and thereby increase average phosphorus concentrations in the pond water column. Higher rates of groundwater flow through the region may impede removal of phosphorus contributed by onsite wastewater disposal systems. Finally, lowering of pond surface elevations late in the summer season may promote algal blooms by lowering the thermocline and bringing nutrient-rich bottom waters to the surface.

Because of topographic variations, portions of the watershed within the boundaries shown in Figure 3 do not contribute surface runoff directly to the pond. For example, watershed areas west of the railroad tracks appear to be isolated by the railroad bed. Other apparently isolated areas include residential properties north of Powder Mill Road and east of Plainfield Road. While they may contribute flow to the pond via subsurface drainage, there is no pathway for surface drainage to reach the pond from these areas.

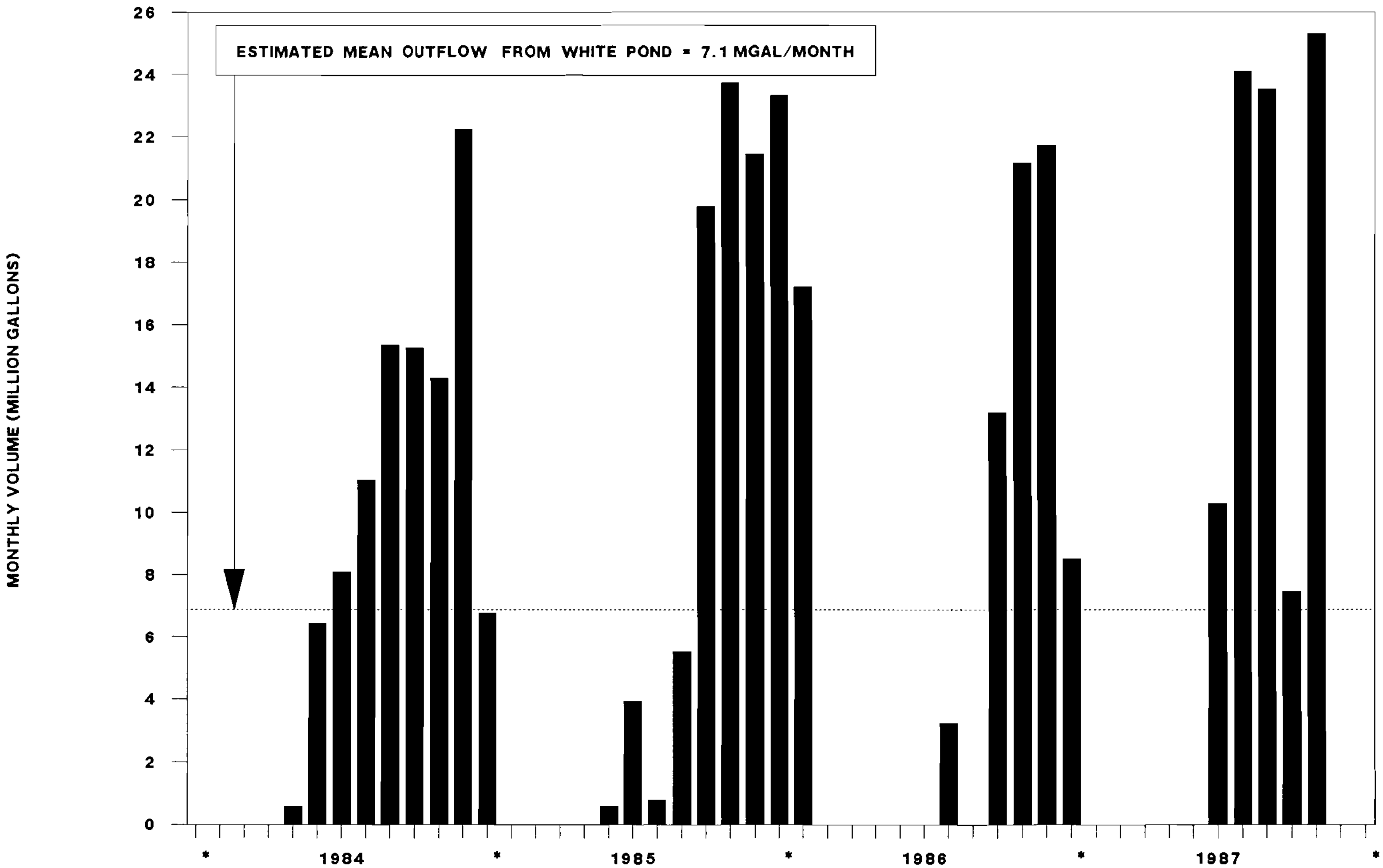
Direct surface runoff contributions are evident from the steep shoreline areas, the state boat ramp and private beach parking lot (east), former Sperry Rand beach access road (southwest) and other roadway drainage systems along the north, northwest, and south perimeters of the pond. These are the areas which have the highest potential for contributing phosphorus to White Pond in the form of surface runoff.

4.0 Monitoring Program Design

The monitoring program was designed to accommodate study objectives, budget, and time constraints. The pond was sampled at its deepest location (Figure 4) on seven occasions between June and October

Figure 5

PUMPING RATES - WHITE POND WELL



of 1987. Normally, pond studies of this type are initiated in early spring because conditions just after ice out (especially, phosphorus concentration) contain important diagnostic information. Future studies of the pond should include the critical early spring period. Variables monitored during 1987 include:

Oxygen and Temperature	(2-foot intervals)
Secchi Disk Transparency	(surface)
Total Phosphorus	(3 depths)
Chlorophyll-a (algal pigment)	(1-3 depths)
Nutrients and Inorganic Chemistry (Ortho P, Nitrate N, Nitrite N, Ammonia N, Kjeldahl N, Turbidity, Alkalinity, Conductivity, Sulfate, pH, Total Iron, Total Manganese)	(3 depths, 1 date)

Oxygen and temperature measurements were conducted in the field using a Yellow Springs Model 57 dissolved oxygen meter calibrated to saturation. Chemical analyses were conducted by a commercial laboratory using EPA approved methods. Samples were preserved by refrigeration and, where appropriate, acidification, prior to chemical analysis. Chlorophyll-a analyses were conducted spectrophotometrically using the method of Parsons and Strickland (1963); samples were filtered within a few hours of collection and preserved via freezing prior to extraction and analysis.

The Appendix contains listings of the data collected under the above program. Measurements taken in Walden Pond on June 14 for purposes of comparison are also listed in the Appendix, along with historical White Pond data compiled from Davis (1972) and Mass. Division of Fisheries and Wildlife files. Results are discussed below.

5.0 Temperature Profiles

Vertical temperature profiles were taken at 2-foot intervals on seven dates, as shown in Figure 6. The profiles are typical of deep ponds and lakes in this region. The vertical structure is usually described as consisting of three distinct zones during the summer:

epilimnion: relatively warm, well-mixed, surface layer of the pond, where temperature is fairly uniform with depth;

metalimnion or **thermocline**: intermediate layer, where temperature declines sharply with depth;

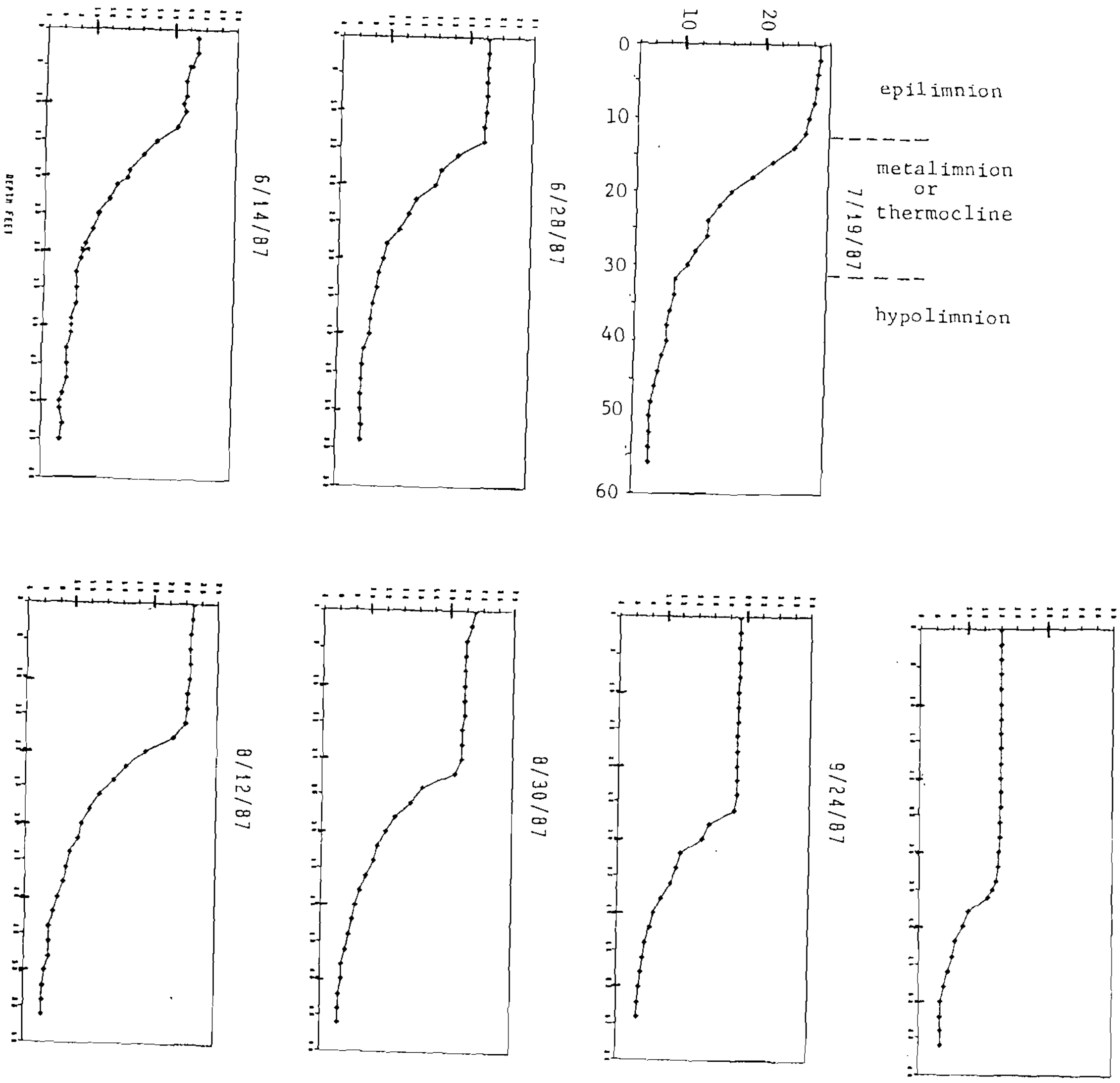
hypolimnion: relatively cool, bottom layer, which is essentially isolated from the surface waters and the atmosphere during the summer season.

Because water density varies with temperature, the thermocline acts as a barrier to vertical mixing. As shown in Figure 6, the thermocline moved downward from a range of 12-25 feet on June 14 to a range of 35-40 feet

Figure 6

WHITE POND - 1987

TEMPERATURE PROFILES - (DEG C)



on October 25. This downward movement reflects wind-induced mixing and gradual cooling which occurs in late summer and fall. A more complete profile of the pond would include turnover periods in early spring and late fall, when temperature is uniform with depth and the water column is well-mixed from top to bottom.

7.0 Oxygen Profiles

Oxygen profiles (Figure 7) contain important information on pond condition with respect to algal productivity and metabolism of organic materials. Settling of algae growing in the pond and other organic particles contributed by the watershed causes organic materials to accumulate in the bottom waters or hypolimnion. As these organic materials decompose, oxygen is consumed and the oxygen concentration in the hypolimnion (isolated from oxygen sources) decreases. Because of these relationships, the rate of oxygen depletion from the hypolimnion (typically reported in milligrams per square meter per day) is an important symptom of eutrophication. As depicted in Figure 1, the loss of oxygen from the hypolimnion is also important because it can trigger the release of phosphorus from the bottom sediments which, in turn, can trigger additional algal growth, especially as the thermocline moves downward in the fall and causes mixing of bottom and surface waters.

Figure 7 shows that oxygen was depleted at the deepest point in White Pond (56 feet) on the first sampling date (June 14). As the season progressed, the thickness of the anaerobic layer gradually increased. On September 24, oxygen was less than 1 ppm between 36 and 56 feet. The thermocline imposes an upper limit on the extent of anaerobic water in White Pond. Replenishment by diffusion and photosynthesis prevents loss of oxygen in the thermocline and surface layer.

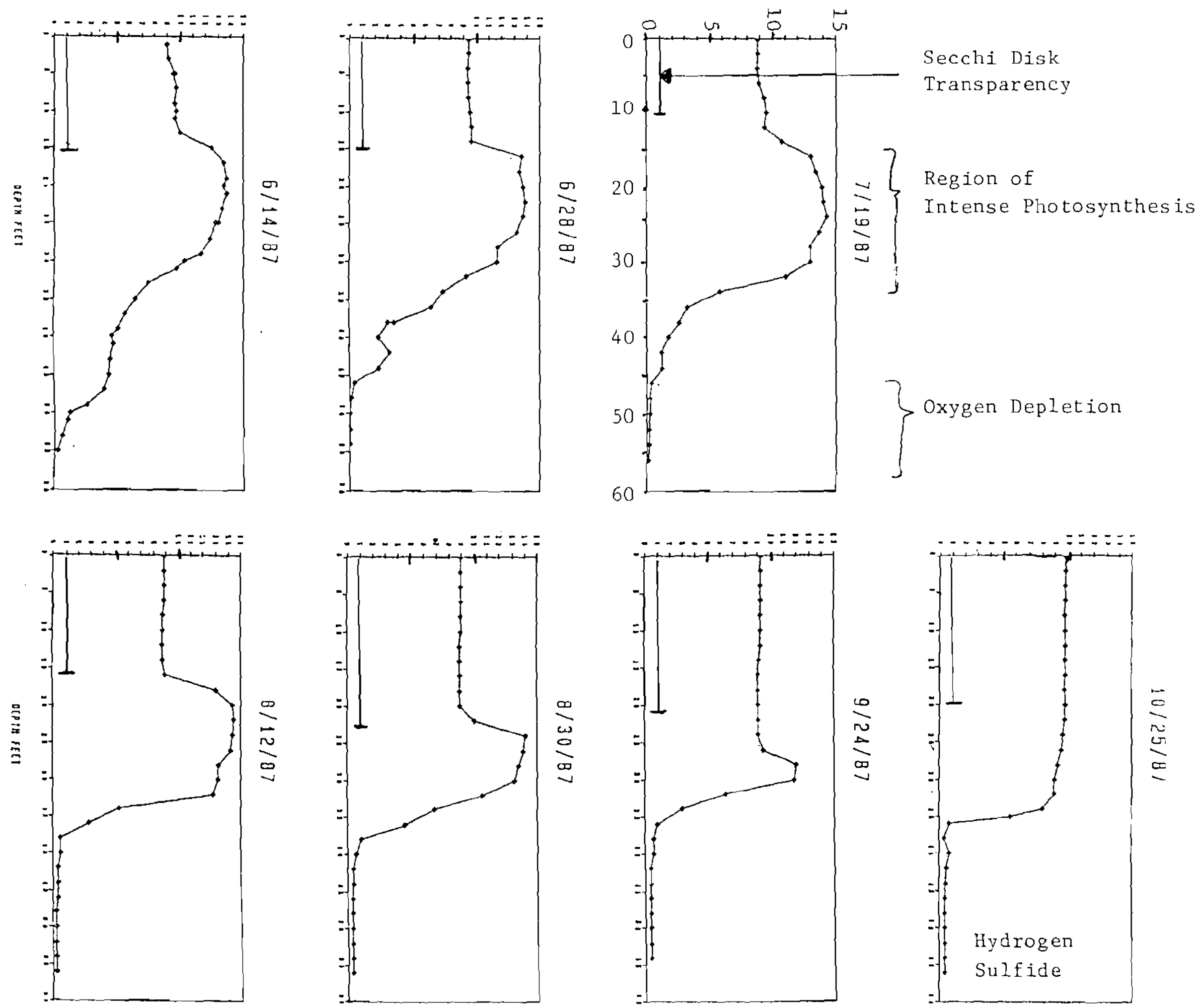
Another important feature of the oxygen profiles is the relatively high concentrations which were measured in the thermocline region (15-30 feet). The oxygen "bulge" approached 150% of saturation. Although trapping of oxygen-rich water in the thermocline in early spring can contribute to this behavior, it is usually indicative of algal growth in the thermocline. Although algal growth is usually focused in the epilimnion, peak algal densities and resulting oxygen maxima have often been observed in the thermoclines of relatively transparent lakes with stable thermal stratification (Wetzel, 1972). Settling of algae through the thermocline can be slowed by sharp temperature and density gradients. Algae growing in this region are usually adapted to relatively low light intensities. As shown in Figure 7, the oxygen bulge gradually diminished on successive sampling dates, as the thermocline moved downward and as the growing season waned. It was totally absent from the October 25 profile.

Intensive diurnal (day-night) sampling would provide a better basis for evaluating effects of algal photosynthesis and respiration on metalimnetic oxygen levels in White Pond. All of the profiles shown in Figure 7 are derived from mid-afternoon sampling. Metalimnetic oxygen concentrations may be considerably lower in the early morning hours,

Figure 7

WHITE POND - 1987

DISSOLVED OXYGEN PROFILES (PPM)



following a period of algal respiration (oxygen consumption) without photosynthesis (oxygen production).

The rate of oxygen depletion below the thermocline in late spring and early summer can be used as an index of eutrophication (Hutchinson, 1957; Walker,1979). Lack of spring sampling data for 1987 precludes direct calculation of this rate for White Pond. Oxygen concentrations of 12 ppm are typical of lakes in this region at spring turnover (roughly April 15). If this value is assumed for White Pond, the average rate of depletion below 35 feet between spring turnover and June 14 (first sampling date) is estimated at .15 ppm/day. Applying this rate to the mean depth of the pond below 35 feet (Figure 4), an areal depletion rate of 362 mg/m^2-day is estimated.

Temperature profile data indicate, however, that the depth range between 25 and 35 feet could also be considered part of the hypolimnion in late spring. Oxygen measurements from this range cannot be used for computing depletion rates because of apparent photosynthetic introduction of oxygen. Because of this fact and because oxygen was already depleted at the bottom of the pond on the first sampling date, the actual depletion rate exceeded 362 mg/m^2-day. Applying the .15 ppm/day volumetric depletion rate to the mean depth below 25 and 30 feet yields depletion rate estimates of 495 and 626 mg/m^2-day, respectively. These values suggest that the oxygen depletion rate in White Pond is close to the 549 mg/m^2-day value suggested by Hutchinson (1957) as a criterion for eutrophic lakes. Spring oxygen profiles are needed to more accurately determine this rate for White Pond, however.

7.0 Walden Pond Comparison

Figure 8 compares oxygen and temperature profiles taken in White Pond on June 14 with profiles taken in Walden Pond on June 15. These ponds are similar with respect to location, shape, size, and hydrologic type (kettle ponds lacking surface inflows and outflows). Walden is considerably deeper (Walden maximum depth 97 feet vs. White 56 feet) and has a less developed watershed. Water transparencies on these dates were similar (16 and 15 feet, respectively). Metalimnetic oxygen maxima were observed in both ponds, although the maximum was somewhat more distinct in White Pond when expressed on a percent of saturation basis (120% in Walden vs. 140% in White). The major difference in the profiles is that oxygen was less than 1 ppm on bottom of White Pond vs. 4 ppm on the bottom of Walden. Differences in depth and algal productivity may contribute to differences in the oxygen profiles.

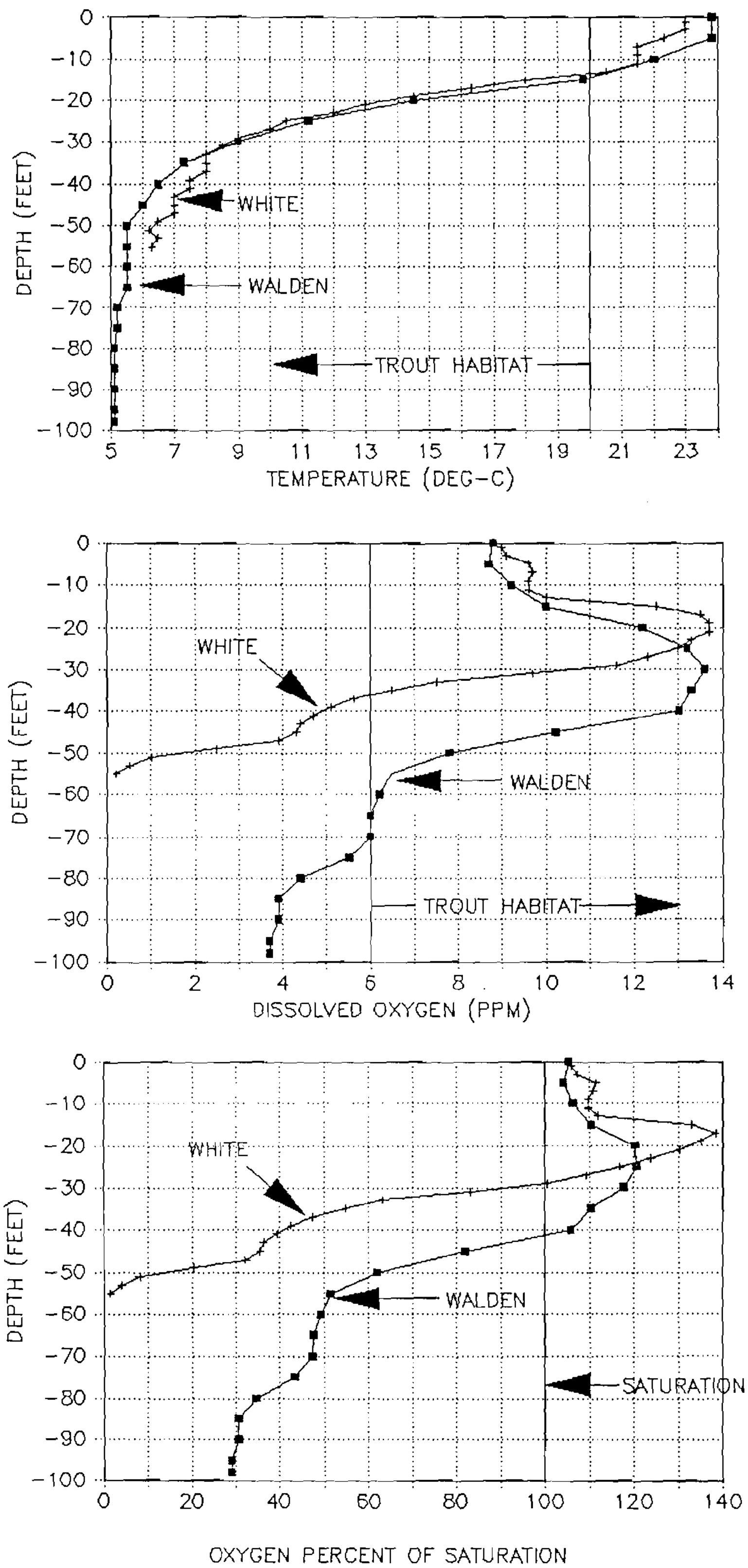
Recent monitoring conducted for the Mass. Department of Environmental Management indicates that oxygen is also depleted on the bottom of Walden Pond later in the season (JMC & Assoc.,1987). A more complete comparison of the two ponds would consider full seasonal profiles of temperature, oxygen, nutrients, algae, and water chemistry.

8.0 Phosphorus, Chlorophyll-a, and Transparency

Surface-layer measurements of phosphorus, chlorophyll-a, and transparency are often used to characterize lake trophic state

Figure 8

JUNE 14-15, 1987



(Carlson,1977). Phosphorus is the nutrient which generally limits or controls algal growth. Chlorophyll-a, a photosynthetic pigment, is used as a relative indicator of algal density. Transparency, determined in the field with a Secchi Disk, measures the absorption and scattering of light by algal cells and other substances. In the absence of high color or inorganic turbidity levels (true of White Pond), transparency is also a good relative indicator of algal density. Statistical summaries of these measurements are given in Table 2.

Table 2
Trophic State Classifications for White Pond Based upon Phosphorus, Chlorophyll-a, and Transparency Measurements *

	Phosphorus	Chlorophyll-a	Transparency
Units	ppb	ppb	feet
N	20	12	7
Mean	21	2.0	17
Minimum	10	1.2	10
Maximum	30	3.9	23
Classification	Mesotrophic	Oligotrophic	Oligotrophic

* data summaries for samples between 0 and 35 feet

Average surface chlorophyll-a (2 ppb) and transparency (17 feet) values for White Pond are characteristic of oligotrophic (nutrient-poor) lakes. The average phosphorus concentration (21 ppb) is in the mesotrophic (intermediate) range, but close to the 25 ppb level indicative of eutrophic (nutrient-rich) conditions. The discrepancy in classifications is attributed to the tendency for algal populations to concentrate in the thermocline of White Pond. Thermocline algal populations are not reflected in the oligotrophic classification based upon surface chlorophyll-a and transparency measurements. Phosphorus and oxygen depletion measurements are more reliable indicators of productivity and trophic state in this case.

Vertical chlorophyll-a measurements are shown in Figure 9. Chlorophyll-a samples were taken on four dates, only one of which included a complete depth profile. This profile indicated an algal peak at 40 feet on June 14, which is consistent with observed oxygen maxima in the thermocline (Figure 7). Complete sampling with depth over the entire growing season would be required to fully define algal abundance and distribution.

Phosphorus increased somewhat with depth on most sampling dates (Figure 10). These increases reflect accumulation of settled algal cells and phosphorus releases from pond bottom sediments. The highest phosphorus concentration (70 ppb) was measured at 50 feet on the last sampling date (October 25). Phosphorus accumulations in the bottom waters were generally low in relation levels found in the bottom waters of eutrophic lakes, which often exceed 1000 ppb. Phosphorus uptake and/or oxygen input by algae growing in the lower regions of the thermocline may limit these accumulations.

Figure 9

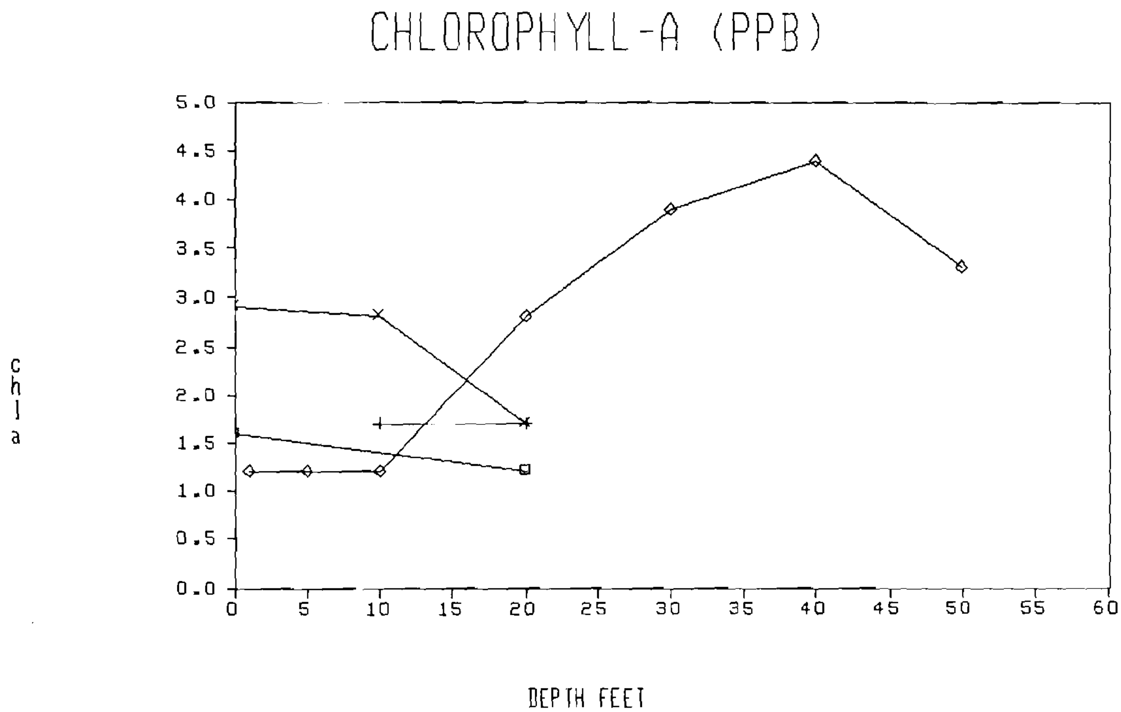
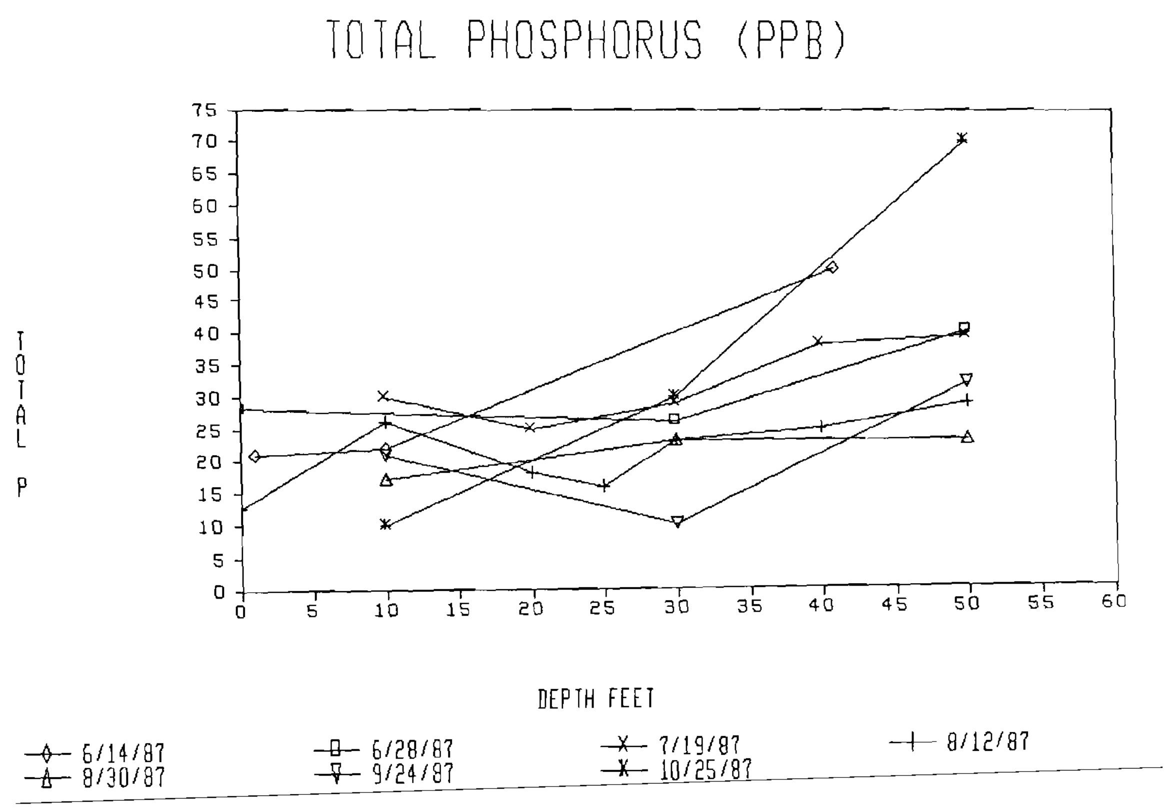


Figure 10



Water transparency averaged 17 feet and ranged from 10 to 40 feet on seven sampling rounds. Figure 11 shows that transparency was high relative to other Massachusetts lakes. Out of 373 lakes in a computer data base maintained by the Massachusetts Division of Water Pollution Control (Godfrey, et al., 1979), only 23 had mean transparencies exceeding 17 feet. Recent studies in Minnesota (Heiskary and Walker,1987) indicate that the Secchi Disk measurement is highly correlated with subjective evaluations of visual appearance and suitability for recreation. Transparencies less than 13 feet (4 meters) were associated with "minor aesthetic problems" and transparencies less than 6.6 feet (2 meters) were associated with "swimming impairment". For safety purposes, the Massachusetts Department of Public Health (MDPH,1969) requires a Secchi disk transparency of at least 4 feet at bathing beaches. These criteria can be compared with the minimum transparency of 10 feet observed in White Pond on July 19.

The relatively high transparency of White Pond can be attributed to the following factors:

(1) apparent tendency for algal growth to concentrate in the thermocline (out of sight and below the Secchi depth);

(2) presence of flake-forming algae (observed macroscopically during July and August sampling); these types have less impact on transparency per unit of chlorophyll-a than algae which remain dispersed;

(3) lack of tributary streams, which would otherwise contribute turbidity, color, and nutrients;

(4) sandy watershed soils; sand particles have higher settling velocities than silts and clays and are less susceptible to resuspension from the pond bottom during and following strong winds; and

(5) pond depth and relatively steep shoreline contours, which also reduce the potential for wind-induced resuspension of bottom sediments.

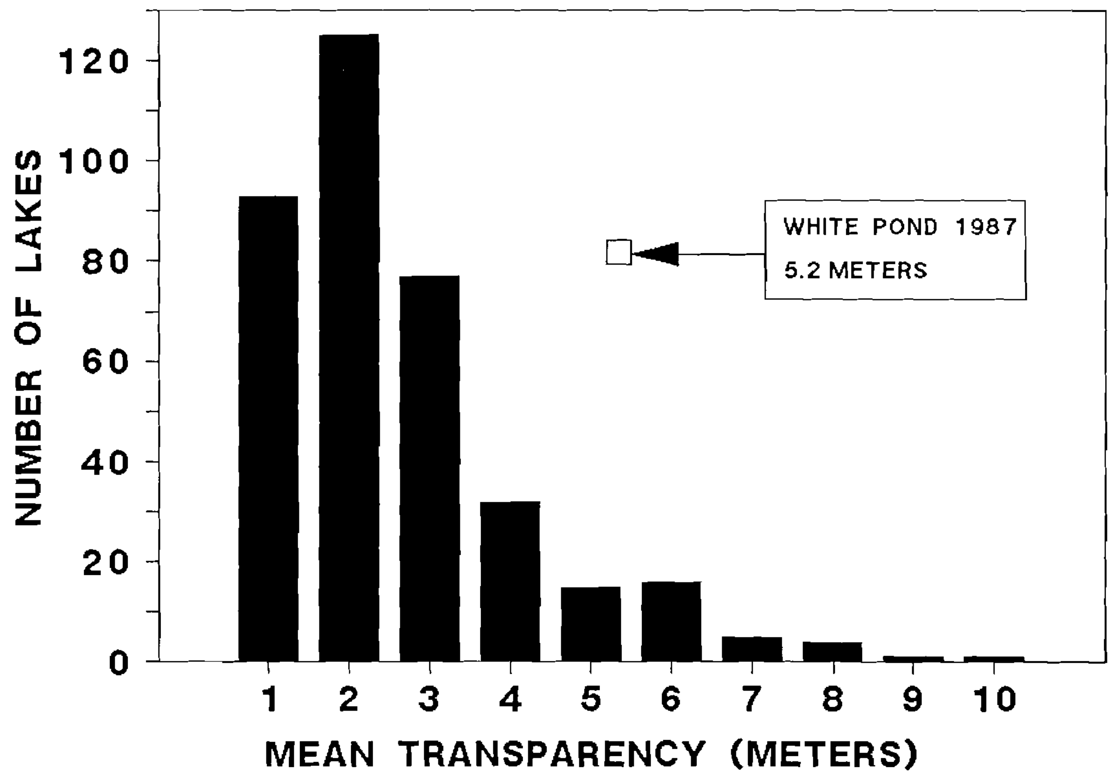
Because of its relatively high transparency, White Pond has good aesthetic qualities and recreational potential. This transparency would be jeopardized, however, by further increases in nutrient loadings. A shift in algal habitat from the thermocline to the surface layer (largely unpredictable) would also cause significant reductions in water clarity.

9.0 Algal Identification

As noted above, flake-forming algae were observed during July and August sampling rounds. Based upon conversations with local residents, a brief algal bloom occurred near the end of July (between the July 19 and August 12 sampling dates). This bloom was accompanied by accumulation of algal flakes around the shoreline. It is possible that

Figure 11

TRANSPARENCY DISTRIBUTION
MASSACHUSETTS LAKES



water transparency dipped below the minimum observed value (10 feet) during this period.

On August 30, a small patch of algal flakes was observed along the shore near the state boat ramp. The predominant algae were identified as Nostoc linkia, a bluegreen alga which is usually found in nutrient-rich water bodies, but is not particularly common in the Northeast. Other algal types included Oscillatoria, Cryptomonas, and Pandorina species. Oscillatoria, another bluegreen, is often found to concentrate in the thermoclines of relatively transparent lakes and ponds (Wetzel,1972). Flakes accumulating around the shoreline most likely reflect die-off or wind-induced mixing of algal cells growing in the thermocline.

Other algal types were identified during the bloom which occurred in August of 1986. These included Anabaena (bluegreen), Chroococuss (bluegreen), Fragilaria (diatom), Stauroneis (diatom), and Coelastrum (green). Anacystis and Anabaena (both bluegreens) were identified during the October 1986 bloom (Morrell Assoc.,1986). The presence of bluegreen algae, particularly at bloom levels reported in 1986, is generally indicative of eutrophic conditions.

10.0 Other Chemical Data

More complete nutrient and inorganic chemistry analyses were conducted on samples collected at 0, 25, and 50 feet on August 12. Early August is an important time for sampling lakes in this region because it generally represents the period of maximum surface water temperatures and maximum vertical stratification.

Dissolved nutrients (ortho phosphorus, nitrite nitrogen, and ammonia nitrogen) were below detection limits in all samples. Nitrate nitrogen was detected at relatively low levels ranging from 40 ppb on the bottom to 250 ppb at the surface. The presence of soluble nitrate during the period of maximum water temperature indicates that algal populations in White Pond were more likely to be limited by phosphorus than by nitrogen.

Low alkalinities in the range of 4.2 to 7.1 ppm are typical of seepage lakes in the region. Sandy soils have low buffering capacity and provide limited protection from the effects of acid rain. The pH profile was very interesting: 7.0 at 0 feet, 8.8 at 25 feet, and 6.0 at 50 feet. The surface and bottom pH's are in normal ranges for waters of this alkalinity. The elevated pH at 25 feet (8.8) is another important symptom of algal growth in the thermocline. Algal photosynthesis removes carbon dioxide (an acid) from the water. This, in turn, can cause to pH to increase, if the carbon dioxide is not replaced by exchange with the atmosphere or some other source.

Elevated iron (550 ppb) and manganese (150 ppb) levels were detected at 50 feet. These substances are normally present in lake sediments as insoluble oxides. Soluble, reduced forms are generated under anaerobic conditions. High iron concentrations are typical of private wells in the White Pond watershed. From a eutrophication standpoint, iron is important because it increases the phosphorus binding capacity of watershed soils and pond bottom sediments.

Lack of oxygen in bottom waters for prolonged periods can lead to production of hydrogen sulfide, which is formed by microbial reduction of sulfate under anaerobic conditions. Hydrogen sulfide odors were detected in bottom samples from White Pond only on the last sampling date (October 25). Sulfide formation is undesirable because it can promote the release of soluble phosphorus from pond bottom sediments (Stauffer, 1981). Formation of insoluble iron sulfides prevents control of phosphorus via iron phosphate precipitation. These processes are probably important in White Pond, based upon three additional observations. First, the October 25 bottom sample also had the highest phosphorus concentration (70 ppb) of all samples analyzed. Second, while a visible iron floc formed in previous bottom samples after aeration, floc did not form in the October 25 sample. Third, the August 12 chemical profile revealed lower sulfate concentrations on the bottom (8 ppm) than at other sampled depths (10-12 ppm). Phosphorus released from bottom sediments may contribute to algal growth in the thermocline and stimulate blooms when mixed into the surface waters in late summer and fall.

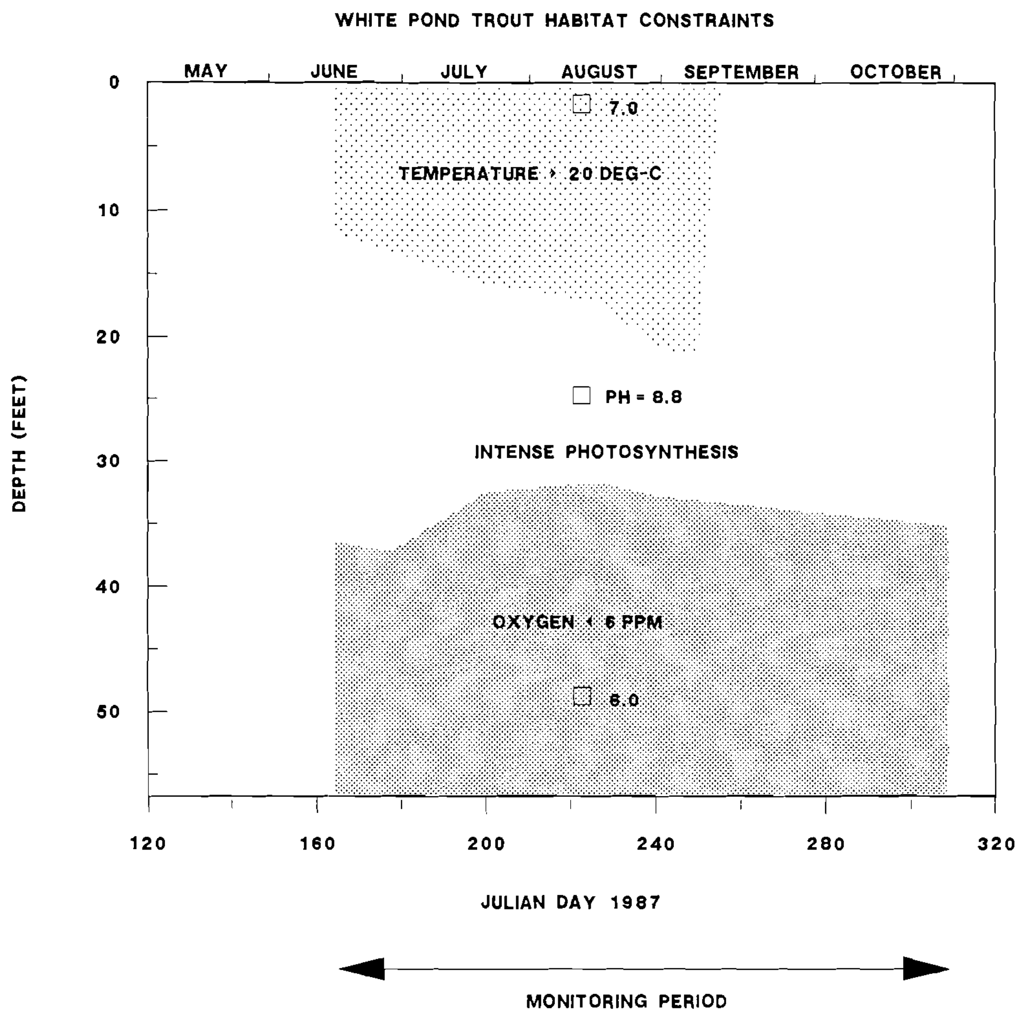
11.0 Trout Habitat

White Pond is a popular fishing spot and is stocked seasonally with trout. Trout and other cold-water fish have rather demanding water quality requirements which are jeopardized in eutrophic lakes. Water quality criteria for protection of cold-water fisheries include a maximum temperature of 20 degrees C and minimum dissolved oxygen concentration of 6 ppm (USEPA, 1976). Because of seasonal warming, the temperature criterion is commonly violated in the surface waters of lakes and ponds. In mesotrophic or eutrophic lakes, oxygen depletion from bottom waters can further restrict habitat.

Trout habitat constraints for White Pond are illustrated in Figure 12. Based upon the above temperature and oxygen criteria, trout habitat would be restricted to mid-depths (20-35 feet) during August (Julian Days 212 to 243). During this period, surface waters are too warm (> 20 Degrees C) and bottom waters lack sufficient dissolved oxygen (< 6 ppm). Although it helps to provide a food supply, intense photosynthesis in the thermocline during this period imposes another water quality constraint. The high pH level (8.8) measured on August 12 exceeds Massachusetts water quality standards for Class B waters, which are designed for protection of aquatic life (pH range 6.5 - 8.0).

On August 12, there was no location in the water column which did not violate either temperature, dissolved oxygen, or pH standards applicable to cold-water fisheries in Massachusetts. While this does not mean that a major fishkill is imminent, it suggests less-than-ideal conditions for a cold-water fishery, particularly a self-sustaining (vs. put-and-take) fishery. Nutrient enrichment contributes to these conditions by promoting oxygen depletion from bottom waters and algal growth in the thermocline. Ample habitat for warm-water fish (e.g., bass) exists in the pond.

Figure 12


WHITE POND TROUT HABITAT CONSTRAINTS
MAY
JUNE
JULY
AUGUST
SEPTEMBER
OCTOBER
7.0
TEMPERATURE > 20 DEG-C
PH = 8.8
INTENSE PHOTOSYNTHESIS
OXYGEN < 6 PPM
6.0
DEPTH (FEET)
0
10
20
30
40
50
120
160
200
240
280
320
JULIAN DAY 1987
MONITORING PERIOD

12.0 Historical Comparisons

Historical water quality monitoring data from White Pond are extremely limited. Data compiled from miscellaneous sources are plotted in Figure 13. Although the historical data are insufficient for statistical comparisons, increases in nitrate and total phosphorus levels since the early 1970's are suggested. Based upon limited measurements from as early as 1949, little change in average transparency has occurred; these measurements do not reflect changes which may occurred in the thermocline, however. Possible decreases in alkalinity and pH are also indicated.

Figure 14 compares temperature and oxygen profiles taken in late summer during 1975 and 1987. The 1975 profiles were measured by the Massachusetts Division of Fisheries and Game. No significant change in the thermal structure is indicated. Both sets of data indicate oxygen depletion below 38-40 feet. The 1975 measurements, however, lack the oxygen bulge detected between 25 and 32 feet in 1987. This suggests that more algae were present in thermocline region during 1987.

Lack of a routine monitoring program precludes definitive evaluation of recent water quality trends. The general indication of increasing nutrient levels, combined with the other water quality observations described above, suggests that eutrophication should be a major concern. Given the resource value of White Pond, a routine monitoring program should be established to permit tracking of pond conditions in the future.

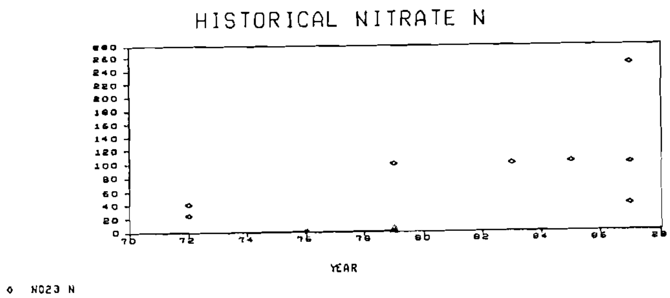
13.0 Modeling Results

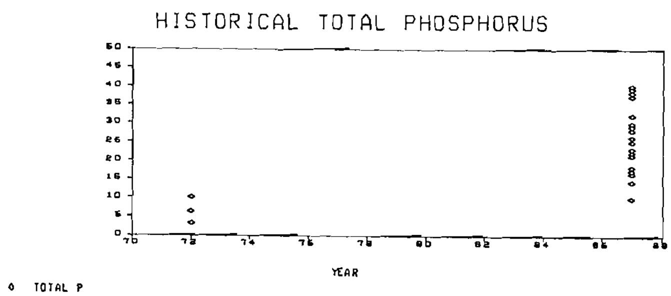
Quantitative perspectives on pond conditions and controlling factors can be derived from application of mathematical models which relate pond trophic state to various morphometric, hydrologic, and watershed characteristics. These models employed below have been developed in studies of other lakes and watersheds in the Northeast (Meta Systems, 1982; Walker,1982a,1982b,1988). Model output is listed in Table 3 and displayed in Figures 15 and 16.

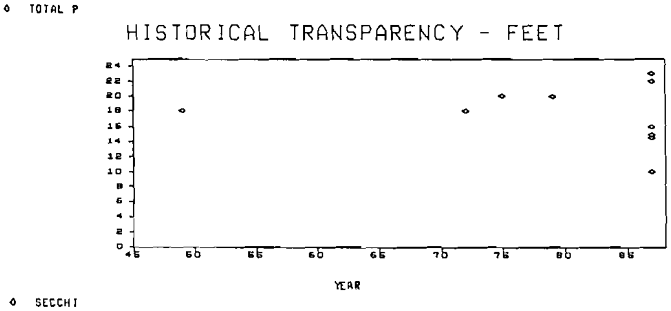
Model predictions are driven largely by the phosphorus budget of the pond, which is an accounting of phosphorus sources and sinks. Estimated phosphorus contributions in runoff from undeveloped and residential watersheds are based upon contributing watershed areas and regional export factors. The contributing residential area (38 acres) equals the 48 acre value estimated by Davis(1972) minus 10 acres of residential watershed east of Plainfield Road and north of Powder Mill Road which probably do not contribute direct runoff to the pond.

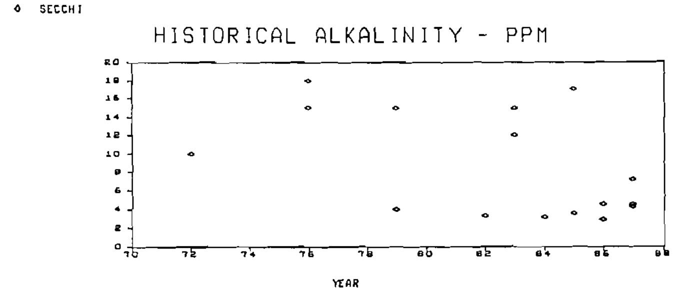
Phosphorus loading from shoreline sewage disposal systems (8.4 lbs/yr) is calculated from use intensity (76 capita/yr), an average phosphorus contribution of 2.2 lbs/capita-yr, and assumed phosphorus removal efficiency of 95%. These estimates are approximate and based upon values determined in other lake and watershed studies. While actual values for White Pond may deviate from the assumed values, the

Figure 13
Historical Water Quality Data









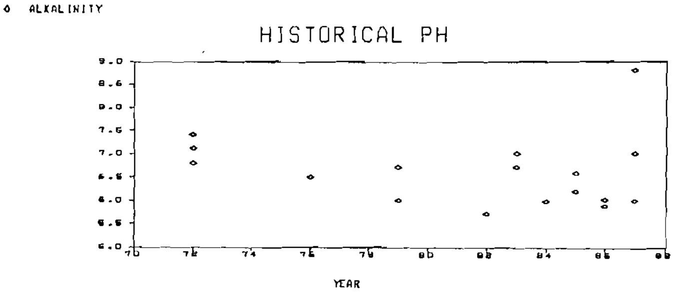
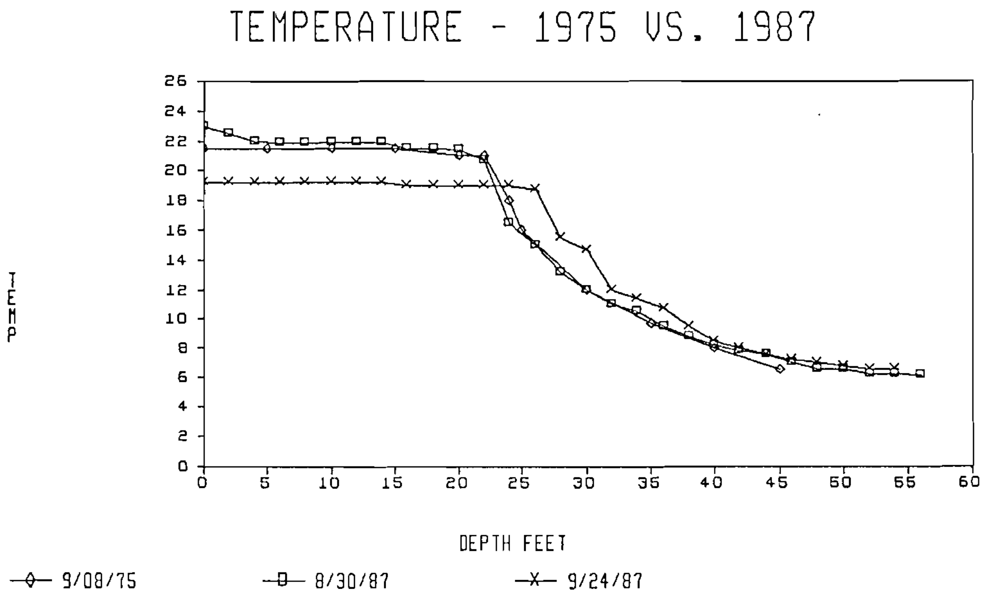


Figure 14
Temperature and Oxygen Profiles - 1975 vs. 1987



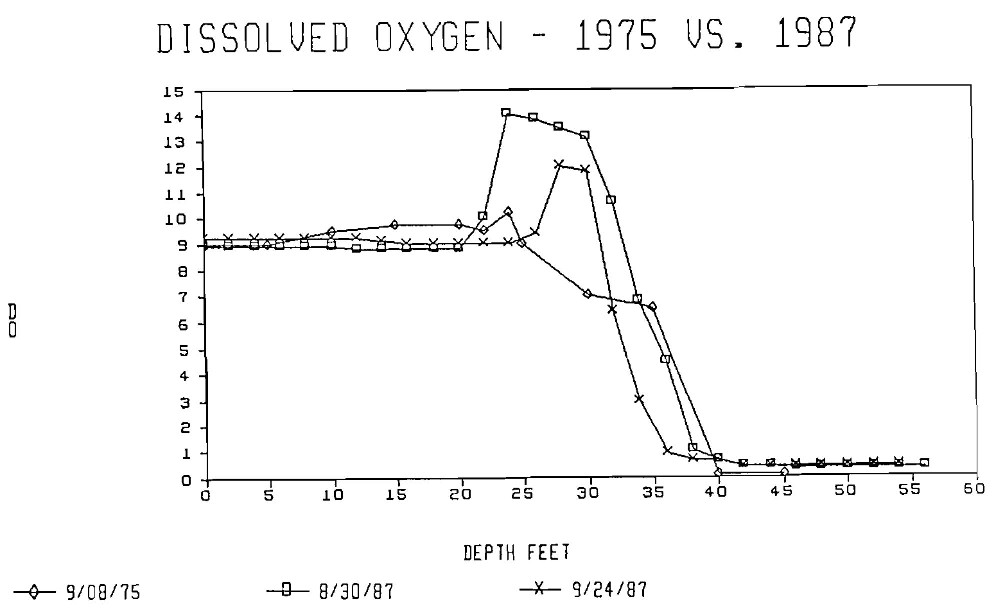


Table 3
Eutrophication Model Predictions for White Pond

LAKE EUTROPHICATION ANALYSIS PROCEDURE REPORT ON: WHITE POND, CONCORD, MA

LAKE CONDITION...		Observed	PREDICTED LAKE CONDITIONS Existing	Pristine	Full Dev
Total Phosphorus	ppb	21.0	21.0	6.9	39.8
Chlorophyll-a	ppb	2.0	6.9	1.4	17.5
Transparency	feet	17.1	13.0	28.7	6.3
Hypol. Oxygen Depletion	mg/m2-day	498	522	252	795

ALGAL NUISANCE FREQUENCIES...		Existing	Pristine	Full Dev
No Problems	Chl-a < 10 ppb	81.9%	100.0%	0.0%
Algae Visible	Chl-a 10-20 ppb	18.1%	0.0%	72.5%
Nuisance Conditions	Chl-a 20-30 ppb	2.1%	0.0%	30.1%
Severe Nuisance	Chl-a > 30 ppb	0.4%	0.0%	12.0%

EXISTING WATER AND PHOSPHORUS BUDGETS...				Water	Total Phosphorus		
	Area	Flow	Flow	Yield	Load	Load	Export
Item	acres	ac-ft/yr	%	in/yr	lbs/yr	%	lbs/ac-yr
undeveloped area	69.0	126.5	36.1%	22.0	5.2	10.8%	0.075
urban area	38.0	69.7	19.9%	22.0	26.4	55.4%	0.694
shoreline sewage disposal			0.0%		8.4	17.5%	
precipitation	43.0	154.1	44.0%	43.0	7.7	16.2%	0.180
total inflow	150.0	350.3	100.0%	28.0	47.6	100.0%	0.318
evaporation	43.0	89.6	25.6%	25.0			
sedimentation					32.8	68.8%	
outflow	150.0	260.7	74.4%	20.9	14.9	31.2%	0.099

PHOSPHORUS EQUIVALENTS...	Impact on Lake Phosphorus P Load	Conc.	Conc.
	lbs/yr	ppb	%
one acre undeveloped land	0.07	0.03	0.2%
one acre urban land	0.69	0.31	1.5%
one acre impervious surface	1.78	0.78	3.7%
one "typical" urban lot	0.55	0.24	1.2%
onsite disposal - input /capita	2.20	0.97	4.6%
onsite disposal - treated/capita	0.11	0.05	0.2%
one 5-lb box tide /year	0.49	0.22	1.0%
one 50-lb bag fertilizer /year	0.65	0.29	1.4%
one cubic yard top soil /year	1.11	0.49	2.3%

LAKE MORPHOMETRIC AND HYDROLOGIC VARIABLES...			
lake surface area	43.0 acres	hydraulic residence time	4.87 years
mean depth	29.5 feet	surface overflow rate	6.06 ft/yr
maximum depth	56.0 feet	phosphorus residence time	1.52 years
mean hypolimnetic depth	10.9 feet	hypolimnetic oxygen supply	76.4 days

Figure 15
Estimated Water and Total Phosphorus Budgets

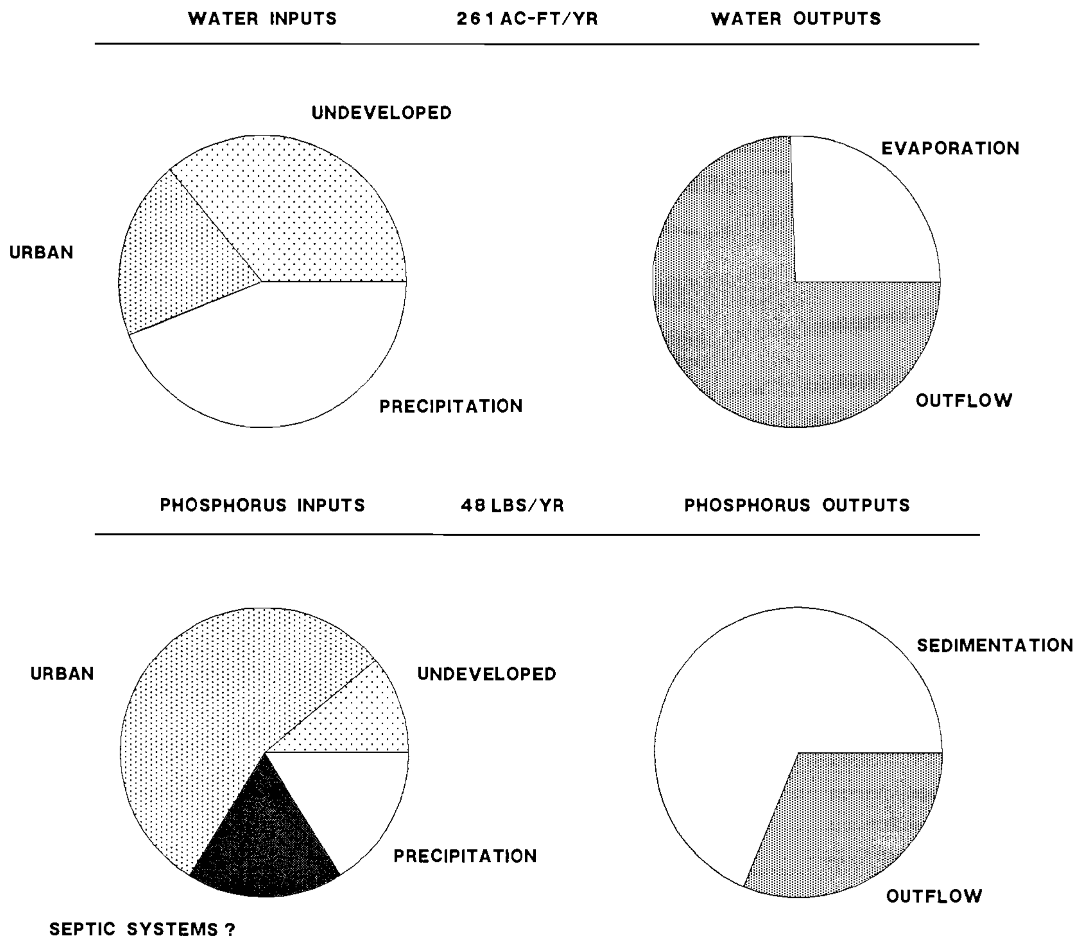
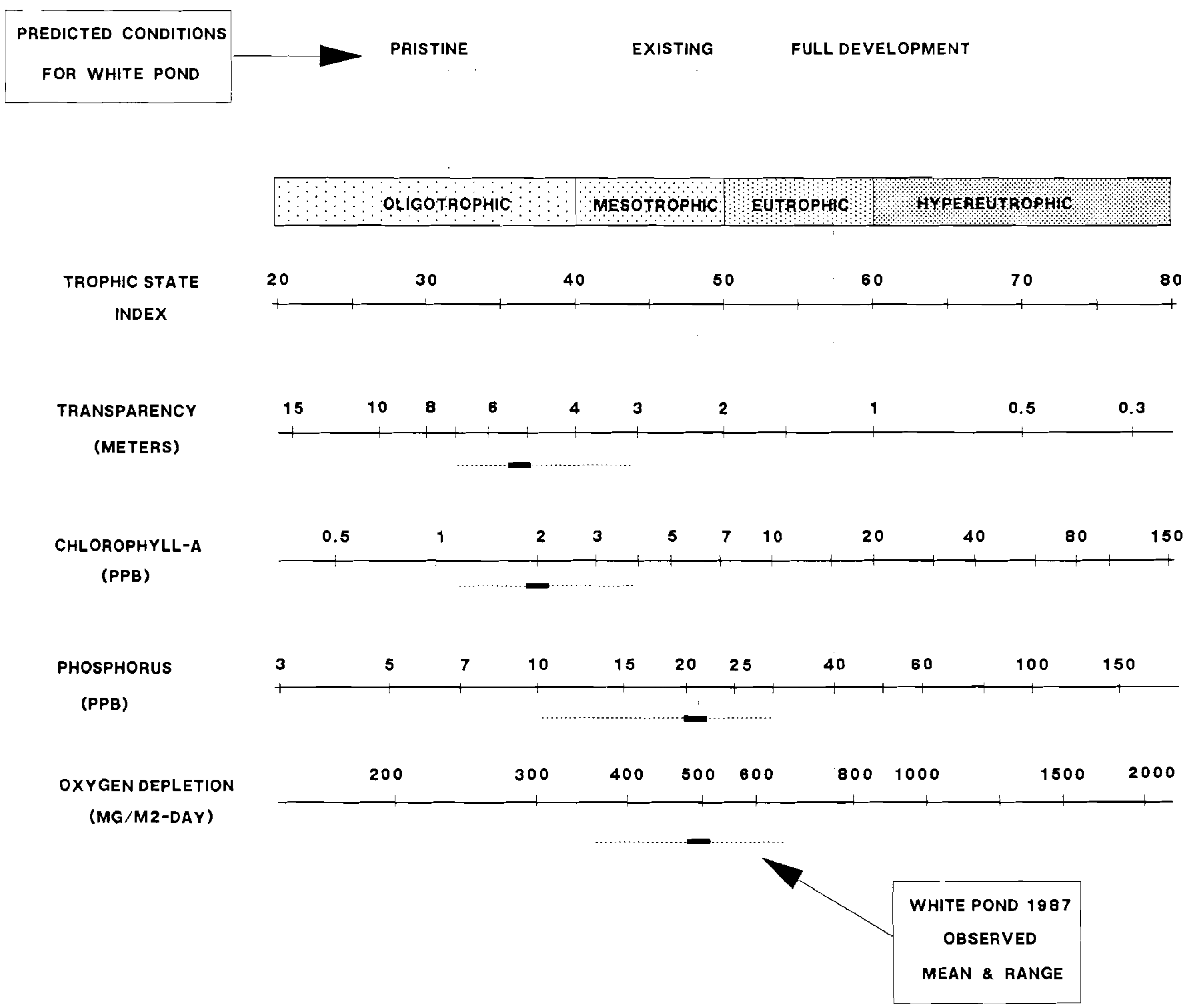


Figure 16
Trophic State Index Calculations



calculations provide an approximate frame of reference which may be refined by obtaining additional site-specific data.

Phosphorus and water budget results are displayed in Figure 15. The estimated total phosphorus loading (48 lbs/yr) is comprised of runoff from undeveloped areas (10.8%), runoff from residential areas (55.4%), shoreline sewage disposal (17.5%), and precipitation/dustfall directly on the pond surface (16.2%). Based upon pond volume and water residence time, the model estimates that 68.8% of the phosphorus loading is deposited to pond bottom sediments and the remaining 31.2% leaves in the subsurface outflow. The predicted average phosphorus concentration (21 ppb) equals the average observed value.

The relative contributions of various sources may deviate from those estimated by the model. For example, shoreline sewage disposal may account for more than 17.5% of the total loading and residential runoff, less than 55.4%. Because of the agreement between the observed and predicted pond concentrations, however, the total loading estimate (48 lbs/yr) is reasonably reliable (within 25%), assuming that the groundwater divide for the pond equals the surface watershed divide.

The "Phosphorus Equivalents" section of Table 3 lists changes in phosphorus loading and concentration likely to result various additional sources. For example, addition of one acre of urban watershed area (without special runoff control measures) would increase the phosphorus loading by .69 lbs/yr or 1.5%. Because of the relatively small watershed area, the pond phosphorus budget is particularly sensitive to shoreline land uses and sewage disposal. Input to shoreline sewage disposal systems is estimated to be 2.2 lbs/capita-yr or 4.6% of the annual total phosphorus input to the pond. Actual discharge to the pond, assuming 95% removal in the onsite treatment system, would be .11 lbs or .2% of the existing load. A single shoreline residence with 4 inhabitants and a failing sewage disposal system (0% phosphorus removal) would increase the annual phosphorus budget by 8.8 lbs or 18.5%! Because of this sensitivity, additional field investigations of shoreline disposal systems and related groundwater conditions are suggested. Sampling of private wells around the shoreline would provide general indications of phosphorus concentrations in the groundwater.

Model predictions of pond conditions have been made for three scenarios (Table 3, Figure 16):

Existing: 1987 land uses and shoreline sewage disposal

Pristine: undeveloped watershed without shoreline sewage disposal

Full Development: full residential development with 1987 shoreline sewage disposal

Water and phosphorus budgets are used to predict pond phosphorus concentrations under each scenario. Chlorophyll-a, transparency, and oxygen depletion rates are, in turn, predicted from phosphorus concentrations using empirical models which have been developed in studies of other lakes (Carlson,1977; Walker,1982a,1982b,1985).

As shown in Figure 16, observed and predicted phosphorus and oxygen depletion rates indicate a late mesotrophic status for White Pond under existing conditions. Observed transparency and chlorophyll-a levels indicate oligotrophic conditions. As discussed above, this deviation reflects the tendency for algae to concentrate in the thermocline. Predicted pond phosphorus concentrations for the pristine, existing, and full development scenarios are 7 ppb (oligotrophic), 22 ppb (mesotrophic), and 40 ppb (eutrophic), respectively. The difference between the 7 and 22 ppb values reflects existing cultural influences on pond phosphorus concentrations and trophic state.

The Maine Department of Environmental Protection employs the concept of the **Lake Vulnerability Index** to protect lakes and ponds from the cumulative impacts of watershed development (Dennis and Dennis, 1987). According to this scheme, the cumulative increase in lake phosphorus concentration is limited to 1 ppb. This increase is calculated using models of the type employed above. As indicated in Table 3, addition of one "typical" urban lot to the White Pond watershed would increase the pond phosphorus concentration by .24 ppb. Thus, if White Pond were managed as recommended in Maine, the watershed would have a capacity to support only four urban lots. This capacity would increase if special measures were taken to reduce runoff and phosphorus export (e.g., infiltration, detention ponds). Pond sensitivity and existing cultural impacts are revealed by comparing the four-lot capacity with the existing watershed, which contains approximately 30 houses and cottages around the immediate shoreline alone.

14.0 Conclusions and Recommendations

(1) Temperature profiles indicate that White Pond has a typical vertical structure consisting of a warm surface layer, thermocline, and cold bottom layer from late spring through late October.

(2) Dissolved oxygen concentrations were depleted at the bottom of the pond by mid June and remained depleted through October. This depletion is caused primarily by decay of settled algae and associated organic materials. Oxygen levels exceeding 120% of saturation suggest high rates of photosynthesis in the thermocline (15-30 feet) between early June and late September.

(3) Monitored surface algal densities were below nuisance levels (<4 ppb chlorophyll-a) and transparencies were high (10-24 feet) throughout the period. These measurements do not reflect the intense algal growth in the thermocline, however. Dieoff of subsurface algal blooms likely resulted in shoreline accumulations of algal cells in late July and early September.

(4) Phosphorus concentrations (15-30 ppb, average 21 ppb) were at levels where lakes generally begin to experience problems related to algal blooms, as reflected by noticeable impairment in aesthetic qualities and recreation potential.

(5) Midsummer trout habitat was limited by low dissolved oxygen in the bottom layer (<6 ppm), warm temperatures in the surface layer (>20 deg C), and elevated pH in the thermocline (pH 8.8). These limitations are partially related to nutrient enrichment and resulting algal growth.

(6) Limited historical data suggest that nutrient and algal levels have increased since the early 1970's. Further increases should be avoided to protect existing pond quality and uses.

(7) Because of its relatively small watershed, lack of surface inflows, and depth, White Pond has high water quality potential. It is relatively susceptible to impacts associated with shoreline development and uses (erosion, surface runoff, leachate from onsite sewage disposal systems).

(8) Watershed protection measures should be implemented to reduce phosphorus loadings to the pond. These measures should be designed to promote infiltration (vs. surface runoff) and to stabilize eroding shoreline areas.

(9) A few malfunctioning onsite sewage disposal systems along the shoreline could have major impacts on the pond's phosphorus budget. A detailed inventory of these systems should be developed. Measurements of groundwater flow and quality are recommended to provide an improved basis for evaluating impacts of onsite sewage disposal systems.

(10) Pond phosphorus loadings resulting from onsite disposal systems can reduced by avoiding use of high-phosphate detergents (typically one third of the total domestic contribution to onsite systems) and garbage disposals. Routine pumping of septic tanks and conservative water usage is recommended to avoid failures and resulting pond impacts.

(11) Investigations of regional geohydrology are required to develop an adequate understanding of factors controlling White Pond inflows, surface elevation, and discharge. A permanent staff gauge should be installed to permit monitoring of pond elevations on a weekly basis. Possible interactions between pond surface level and pumping rates from nearby wells should be investigated.

(12) Continuation of the current monitoring program is recommended through 1988. This will provide important data on year-to-year variability and on winter and spring conditions, which were not sampled in 1987. A less intensive, long-term monitoring effort should also be initiated in order to permit evaluation of water quality trends.

(13) The Town should seriously consider participation in the state Clean Lakes program, as a vehicle for obtaining funds to support a more detailed diagnosis of pond and watershed conditions and to support design and implementation of specific protection measures.

15.0 References

Athayede, D.N., P.E. SHelley, E.D. Driscoll, D. Gabuoury, and G. Boyd, "Results of the Nationwide Urban Runoff Program, Volume I - Final Report", Office of Water Program Operations, Water Planning Division, U.S. Environmental Protection Agency, Washington, December 1983.

Carlson, R.E, "A Trophic State Index for Lakes", Limnology and Oceanography, Vol. 22, No. 2, pp. 361-369, March 1977.

Davis, S.C., "Ecological Analysis of the White Pond Watershed, Concord, Massachusetts", prepared for Town of Concord, by Ecosystems, Inc., October 1972.

Dennis, J. and M.E. Dennis, "A Statewide Model for Assessing Relative Vulnerability of Lakes to Development", presented at 7th International Symposium on Applied Lake and Reservoir Management, North American Lake Management Society, Orlando, Florida, November 1987.

Dillon P.J. and F.H. Rigler, "The Phosphorus-Chlorophyll Relationship in Lakes", Limnology and Oceanography, Vol. 19, No. 4, pp. 767-773, 1974.

Godfrey, P.J., S.A. Joyner, E.L. Goldstein, L. Ross, "The Development of Palis: A Ponds and Lakes Information System for Massachusetts", Water Resources Research Center, University of Massachusetts, Amherst, Publication No. 108, December 1979.

Heiskary, S. and W.W. Walker, "Developing Phosphorus Criteria for Minnesota Lakes", presented at 7th International Symposium on Applied Lake and Reservoir Management, North American Lake Management Society, Orlando, Florida, November 1987.

Hutchinson, G.E., A Treatise on Limnology, Volume I, Geography, Physics and Chemistry of Lakes, Part 2, Chemistry of Lakes, John Wiley and Sons, New York, 1957.

Jason M. Cortell and Associates, Inc., Letter to Gilbert Bliss, Director, Massachusetts Division of Forests and Parks, February 1987.

Massachusetts Department of Public Health, State Sanitary Code, Article 7, Regulation 10.2B, Boston, 1969.

Meta Systems, Inc., "Land Use/Water Quality Relationships in the West River System, Connecticut", prepared for New Haven Water Company, April 1982.

Morrell Associates, Microscopic Examination of White Pond Samples, conducted for White Pond Beach Association, Inc., 1986.

Parsons, T.R. and J.D.H. Strickland, "Discussion of Spectrophotometric Determination of Marine Plant Pigments, with Revised Equations for Ascertaining Chlorophylls and Carotenoids, J. Mar. Res., Vol. 21, pp. 55-163, 1963.

Reckhow, K.H. and S.C. Chapra, Engineering Approaches for Lake Management, Volume 1: Data Analysis and Empirical Modeling, Butterworth Publishers, Boston, 1983.

Sawney, B.L. and J.L Starr, "Movement of Phosphorus from a Septic System Drainfield", Journal of the Water Pollution Control Federation, Volume 49, No. 11, pp. 2238-2242, November 1977.

Stauffer, R.E., "Sampling Strategies for Identifying the Magnitude and Importance of Internal Phosphorus Supplies in Lakes", prepared for Office of Water Regulations and Standards, Criteria and Standards Division, U.S. Environmental Protection Agency, EPA-600/3-81-015, April 1981.

U.S. Environmental Protection Agency, "Quality Criteria for Water", Office of Water Planning and Standards, Washington, July 1976.

Walker, E., P. Gabriel, and A. O'Donnell, "The Water Budget for the Town of Concord", First Report as Part of the Groundwater Protection Program, October 1980.

Walker, W.W., "Use of Hypolimnetic Oxygen Depletion as a Trophic State Index for Lakes", Water Resources Research, Vol. 15, No. 6, pp. 1463-1470, December 1979.

Walker, W.W., "Calibration and Testing of a Eutrophication Analysis Procedure for Vermont Lakes", prepared for Vermont Agency of Environmental Conservation, Water Quality Division, Montpelier, Vermont, January 1982a.

Walker, W.W., "A Sensitivity and Error Analysis Framework for Lake Eutrophication Modeling", Water Resources Bulletin, Vol. 18, No. 1, pp. 53-61, February 1982b.

Walker, W.W., "Empirical Methods for Predicting Eutrophication in Impoundments, Report 2: Model Refinements", prepared for Office, Chief of Engineers, U.S. Army, Technical Report E-81-9, Environmental Laboratory, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi, March 1985.

Walker, W.W., "A Eutrophication Analysis Procedure for Massachusetts Lakes", Computer Software Under Development for Mass. Division of Water Pollution Control, 1988.

Wetzel, R. G., Limnology, W. B. Saunders Company, Philadelphia, 1975.

APPENDIX

White Pond Profiles - 1987

White Pond Chemical Analyses - August 12, 1987

White Pond Profiles - Historical

Walden Pond Profile - 1987

WHITE POND PROFILES - 1987

DATE	DEPTH FEET	TEMP DEG-C	DISSOLVED OXYGEN PPM	TOTAL PHOSPHORUS PPB	CHLORO-PHYLL-A PPB	SECCHI DEPTH FEET
6/14/87	1	23.0	9.0	21	1.2	15
6/14/87	3	23.0	9.1			
6/14/87	5	22.2	9.6		1.2	
6/14/87	7	21.5	9.7			
6/14/87	9	21.5	9.6			
6/14/87	10	21.2	9.7	22	1.2	
6/14/87	11	21.5	9.6			
6/14/87	13	20.5	10.0			
6/14/87	15	18.0	12.5			
6/14/87	17	16.3	13.5			
6/14/87	19	14.5	13.7			
6/14/87	20	14.2	13.5		2.8	
6/14/87	21	13.0	13.7			
6/14/87	23	12.0	13.3			
6/14/87	25	10.6	12.9			
6/14/87	27	10.0	12.3			
6/14/87	29	9.0	11.6			
6/14/87	30	8.7	10.3		3.9	
6/14/87	31	8.5	9.7			
6/14/87	33	8.0	7.5			
6/14/87	35	8.0	6.5			
6/14/87	37	8.0	5.6			
6/14/87	39	7.5	5.1			
6/14/87	40	7.5	4.6	50	4.4	
6/14/87	41	7.5	4.7			
6/14/87	43	7.0	4.4			
6/14/87	45	7.0	4.3			
6/14/87	47	7.0	3.9			
6/14/87	49	6.5	2.5			
6/14/87	50	6.2	1.2		3.3	
6/14/87	51	6.2	1.0			
6/14/87	53	6.5	0.5			
6/14/87	55	6.3	0.2			
6/28/87	0	22.2	9.4	28	1.6	15
6/28/87	2	22.2	9.4			
6/28/87	4	22.2	9.3			
6/28/87	6	22.1	9.3			
6/28/87	8	22.1	9.4			
6/28/87	10	22.1	9.5			
6/28/87	12	21.9	9.6			
6/28/87	14	21.9	9.6			
6/28/87	16	18.7	13.6			
6/28/87	18	16.5	13.4			
6/28/87	20	15.9	13.7		1.2	
6/28/87	22	13.5	13.9			
6/28/87	24	12.5	13.7			

WHITE POND PROFILES - 1987

DATE	DEPTH FEET	TEMP DEG-C	DISSOLVED OXYGEN PPM	TOTAL PHOSPHORUS PPB	CHLORO-PHYLL-A PPB	SECCHI DEPTH FEET
6/28/87	26	11.5	13.2			
6/28/87	28	10.0	11.7			
6/28/87	30	9.5	11.6	26		
6/28/87	32	9.0	9.2			
6/28/87	34	8.8	7.3			
6/28/87	36	8.2	6.4			
6/28/87	38	8.0	3.3			
6/28/87	40	7.8	2.2			
6/28/87	42	7.2	3.1			
6/28/87	44	7.0	2.2			
6/28/87	46	6.9	0.3			
6/28/87	48	6.9	0.1			
6/28/87	50	6.9	0.0	40		
6/28/87	52	7.0	0.0			
6/28/87	54	7.0	0.0			
7/19/87	0	26.7	8.8		2.9	10
7/19/87	2	26.7	8.8			
7/19/87	4	26.5	8.8			
7/19/87	6	26.3	8.9			
7/19/87	8	26.0	9.3			
7/19/87	10	25.5	9.5	30	2.8	
7/19/87	12	25.0	9.3			
7/19/87	14	23.7	10.7			
7/19/87	16	21.0	13.0			
7/19/87	18	18.5	13.4			
7/19/87	20	16.0	13.9	25	1.7	
7/19/87	22	14.5	14.0			
7/19/87	24	13.0	14.3			
7/19/87	26	13.0	13.7			
7/19/87	28	11.5	13.0			
7/19/87	30	10.5	13.0	29		
7/19/87	32	9.0	11.0			
7/19/87	34	8.9	5.8			
7/19/87	36	8.3	3.2			
7/19/87	38	8.0	2.5			
7/19/87	40	8.0	1.7	38		
7/19/87	42	7.5	1.1			
7/19/87	44	7.0	1.2			
7/19/87	46	6.5	0.3			
7/19/87	48	6.2	0.2			
7/19/87	50	6.0	0.2	39		
7/19/87	52	6.0	0.2			
7/19/87	54	6.0	0.2			
7/19/87	56	6.0	0.1			
8/12/87	0	25.0	8.8	13		16
8/12/87	2	24.8	8.8			

WHITE POND PROFILES - 1987

DATE	DEPTH FEET	TEMP DEG-C	DISSOLVED OXYGEN PPM	TOTAL PHOSPHORUS PPB	CHLORO-PHYLL-A PPB	SECCHI DEPTH FEET
8/12/87	4	24.6	8.8			
8/12/87	6	24.5	8.8			
8/12/87	8	24.5	8.7			
8/12/87	10	24.5	8.7	26	1.7	
8/12/87	12	24.3	8.7			
8/12/87	14	24.2	8.7			
8/12/87	16	24.1	8.9			
8/12/87	18	22.5	13.0			
8/12/87	20	19.0	14.3	18	1.7	
8/12/87	22	16.5	14.4			
8/12/87	24	15.0	14.3			
8/12/87	25			16		
8/12/87	26	13.2	14.1			
8/12/87	28	12.0	13.2			
8/12/87	30	11.0	13.1	23		
8/12/87	32	10.5	12.8			
8/12/87	34	9.5	5.2			
8/12/87	36	9.0	2.8			
8/12/87	38	8.7	0.5			
8/12/87	40	8.0	0.5	25		
8/12/87	42	7.5	0.3			
8/12/87	44	7.0	0.3			
8/12/87	46	7.0	0.3			
8/12/87	48	7.0	0.2			
8/12/87	50	6.5	0.2	29		
8/12/87	52	6.3	0.2			
8/12/87	54	6.2	0.2			
8/12/87	56	6.2	0.2			
8/30/87	0	23.0	8.9			23
8/30/87	2	22.5	8.9			
8/30/87	4	22.0	8.9			
8/30/87	6	21.9	8.9			
8/30/87	8	21.8	8.9			
8/30/87	10	21.8	8.9	17		
8/30/87	12	21.8	8.8			
8/30/87	14	21.8	8.8			
8/30/87	16	21.5	8.8			
8/30/87	18	21.5	8.8			
8/30/87	20	21.4	8.8			
8/30/87	22	20.7	10.0			
8/30/87	24	16.5	14.0			
8/30/87	26	15.0	13.8			
8/30/87	28	13.2	13.5			
8/30/87	30	12.0	13.1	23		
8/30/87	32	11.0	10.6			
8/30/87	34	10.5	6.8			
8/30/87	36	9.5	4.5			

WHITE POND PROFILES - 1987

DATE	DEPTH FEET	TEMP DEG-C	DISSOLVED OXYGEN PPM	TOTAL PHOSPHORUS PPB	CHLORO-PHYLL-A PPB	SECCHI DEPTH FEET
8/30/87	38	8.8	1.0			
8/30/87	40	8.2	0.6			
8/30/87	42	7.8	0.4			
8/30/87	44	7.5	0.4			
8/30/87	46	7.0	0.3			
8/30/87	48	6.5	0.3			
8/30/87	50	6.5	0.3	23		
8/30/87	52	6.2	0.3			
8/30/87	54	6.2	0.3			
8/30/87	56	6.1	0.3			
9/24/87	0	19.2	9.2			22
9/24/87	2	19.2	9.2			
9/24/87	4	19.2	9.2			
9/24/87	6	19.2	9.2			
9/24/87	8	19.2	9.2			
9/24/87	10	19.1	9.2	21		
9/24/87	12	19.1	9.2			
9/24/87	14	19.1	9.1			
9/24/87	16	19.0	9.0			
9/24/87	18	19.0	9.0			
9/24/87	20	19.0	9.0			
9/24/87	22	19.0	9.0			
9/24/87	24	19.0	9.0			
9/24/87	26	18.7	9.4			
9/24/87	28	15.5	12.0			
9/24/87	30	14.7	11.8	10		
9/24/87	32	12.0	6.4			
9/24/87	34	11.4	2.9			
9/24/87	36	10.7	0.9			
9/24/87	38	9.5	0.6			
9/24/87	40	8.5	0.6			
9/24/87	42	8.0	0.4			
9/24/87	44	7.5	0.4			
9/24/87	46	7.2	0.4			
9/24/87	48	7.0	0.4			
9/24/87	50	6.7	0.4	32		
9/24/87	52	6.5	0.4			
9/24/87	54	6.5	0.4			
10/25/87	0	14.0	9.8			19
10/25/87	2	14.0	9.8			
10/25/87	4	14.0	9.8			
10/25/87	6	14.0	9.8			
10/25/87	8	14.0	9.7			
10/25/87	10	14.0	9.8	10		
10/25/87	12	14.0	9.8			
10/25/87	14	14.0	9.8			

WHITE POND PROFILES - 1987

DATE	DEPTH FEET	TEMP DEG-C	DISSOLVED OXYGEN PPM	TOTAL PHOSPHORUS PPB	CHLORO-PHYLL-A PPB	SECCHI DEPTH FEET
10/25/87	16	14.0	9.8			
10/25/87	18	14.0	9.7			
10/25/87	20	14.0	9.8			
10/25/87	22	14.0	9.7			
10/25/87	24	14.0	9.6			
10/25/87	26	13.9	9.5			
10/25/87	28	13.9	9.2			
10/25/87	30	13.8	9.0	30		
10/25/87	32	13.7	8.9			
10/25/87	34	13.5	8.0			
10/25/87	35	13.0	5.5			
10/25/87	36	12.5	0.7			
10/25/87	38	10.0	0.3			
10/25/87	40	9.3	0.7			
10/25/87	42	8.4	0.5			
10/25/87	44	8.0	0.5			
10/25/87	46	7.5	0.4			
10/25/87	48	7.0	0.4			
10/25/87	50	6.5	0.4	70		
10/25/87	52	6.5	0.4			
10/25/87	54	6.5	0.4			
10/25/87	56	6.5	0.4			

WHITE POND CHEMICAL ANALYSES - AUGUST 12, 1987

Arnold Greene
Testing Laboratories

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Telex 948459 GREENELAB NTIK

CONAM INSPECTION

Nondestructive • Chemical • Pollution • Metallurgical
Inspection • Evaluation • Analysis
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(413) 734-6548

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CONAM INSPECTION A UNIT OF QUALCORP
California, Texas, Illinois, Pennsylvania, Ohio

To: WILLIAM WALKER
1127 LOWELL ROAD
CONCORD, MA 01742

Date 8/14/87
Job No. P2642-1
Lab No. 6662
AUJ.WCJ-PI
Order No. NONE

Material: WATER
Book No. 204-18-LE
Specifications: NONE

Sample ID: Water Samples @ WHITE POND
Date received: 8/12/87

Depth (Feet)	0	25	50	0	50
	#1	#2	#3	#4	#5
Total Alkalinity (mg/l)	4.4	4.2	[illegible]	--	--
Specific Conductance (umhos/cm)	46.6	47.8	48	--	--
Turbidity (NTU S)	<2	<2	<2	--	--
Ammonia (mg/l) as N	<0.1	<0.1	<0.1	--	--
Nitrate (mg/l) as N	0.25	0.10	0.04	--	--
Nitrite (mg/l)	<0.01	<0.01	<0.01	--	--
Sulfate (mg/l)	10	12	8	--	--
Ortho-Phosphate (mg/l)	<0.01	<0.01	<0.01	--	--
Phosphate, Total (mg/l) as P	<0.01	0.016	0.027	0.014	0.022
Total Kjeldahl-Nitrogen (mg/l) as N	0.37	0.37	0.86	--	--
pH	7.0	6.8	6.0	--	--
Total Metals: (mg/l)					
Iron	--	--	0.55	--	--
Manganese	--	--	0.15	--	--

IN WITNESS WHEREOF, I HAVE HEREUNTO SET MY HAND THIS
14TH DAY OF AUGUST 1987
ARNOLD GREENE TESTING LABORATORIES
DIVISION OF CONAM INSPECTION

Geoffrey A. Coelho, Manager

WHITE POND PROFILES - HISTORICAL

DATE	DEPTH FEET	TEMP DEG-C	DISSOLVED OXYGEN PPM	TOTAL PHOSPHORUS PPB	CHLORO-PHYLL-A PPB	SECCHI DEPTH FEET
8/25/49	0	23.8				18
8/25/49	47	12.8				
9/13/68	0	17.5				
9/13/68	5	17.5				
9/13/68	10	17.5				
9/13/68	15	17.5				
9/13/68	20	17.5				
9/13/68	25	17.5				
9/13/68	30	17.5				
9/13/68	31	13.9				
9/13/68	33	12.8				
9/13/68	34	11.7				
9/13/68	35	11.1				
9/13/68	38	10.0				
9/13/68	40	8.6				
9/13/68	43	7.2				
9/13/68	45	6.4				
9/13/68	48	5.6				
9/13/68	50	5.0				
9/13/68	53	4.4				
9/13/68	56	4.4				
9/25/72	0	18.5	9.8	7		18
9/25/72	46	11.0	1.0	6		
9/08/75	0	21.5	9.0			20
9/08/75	5	21.5	9.0			
9/08/75	10	21.5	9.5			
9/08/75	15	21.5	9.7			
9/08/75	20	21.0	9.7			
9/08/75	22	21.0	9.5			
9/08/75	24	18.0	10.2			
9/08/75	25	16.0	9.0			
9/08/75	30	12.0	7.0			
9/08/75	35	9.7	6.5			
9/08/75	40	8.0	0.1			
9/08/75	45	6.5	0.1			

WALDEN POND PROFILE - 1987

DATE	DEPTH FEET	TEMP DEG-C	DISSOLVED OXYGEN PPM	TOTAL PHOSPHORUS PPB	CHLORO-PHYLL-A PPB	SECCHI DEPTH FEET
6/15/87	0	23.8	8.8			16
6/15/87	5	23.8	8.7			
6/15/87	10	22.0	9.2			
6/15/87	15	19.8	10.0			
6/15/87	20	14.5	12.2			
6/15/87	25	11.2	13.2			
6/15/87	30	9.0	13.6			
6/15/87	35	7.3	13.3			
6/15/87	40	6.5	13.0			
6/15/87	45	6.0	10.2			
6/15/87	50	5.5	7.8			
6/15/87	55	5.5	6.5			
6/15/87	60	5.5	6.2			
6/15/87	65	5.5	6.0			
6/15/87	70	5.2	6.0			
6/15/87	75	5.2	5.5			
6/15/87	80	5.1	4.4			
6/15/87	85	5.1	3.9			
6/15/87	90	5.1	3.9			
6/15/87	95	5.1	3.7			
6/15/87	98	5.1	3.7			