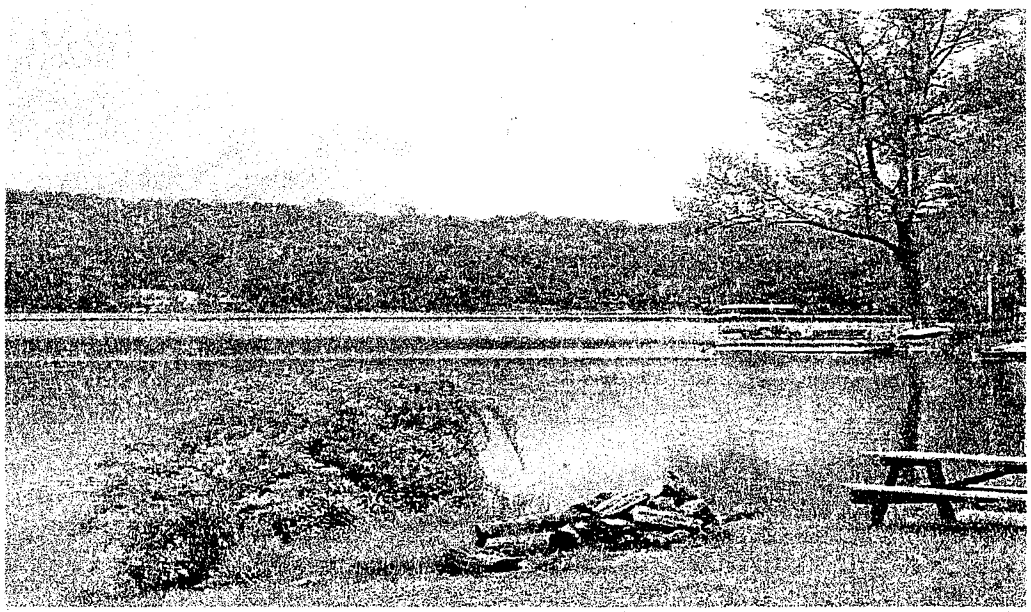
Prepared For:

Property Owners Association of Lake Hayward

Diagnostic/Feasibility Study of Lake Hayward East Haddam, Connecticut



May 2003

Prepared By:

Northeast Aquatic Research, LLC

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George W. Knoecklein

74 Higgins Highway

Mansfield Center, CT 06250

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EXECUTIVE SUMMARY

Lake Hayward was studied for two years, 2000 and 2001 to assess the existing lake and drainage basin trophic condition. The lake was found to have low levels of phosphorus but higher levels of nitrogen. Water clarity was good in the spring and fall but declined during the summer. The poorer summer clarity was blamed on increased water color and proliferation of larger cell sized blue green and golden algae. The lake developed several meters of anoxic water during the summer but internal loading of phosphorus was found to be low and insignificant during the study period. The lake could be ranked as oligotrophic with regard to phosphorus but would be oligo-mesotrophic to mesotrophic with regard to nitrogen and Secchi disk depth, respectively.

The lake has a significant infestation of the invasive aquatic plant species fanwort (*Cabomba caroliniana*) that has apparently spread from the boat ramp south into the lake to cover about 60 acres. It is assumed that boats using the state boat ramp probably transport fanwort out of the lake. The southern end of the lake where the dam and lake's outlet is located was also completely infested with fanwort. It is likely that fanwort is exported out of the lake via the outlet. The herbicide SONAR™ is recommended to control the fanwort in the lake.

The drainage basin has about 161 acres of high density residential land-use on the west side and about 132 acres of low density residential land-use on the east side. These values include the new developments on the east side, and to the north of the lake. Storm event sampling revealed that nutrient loading to lake during storm runoff can become higher than base flows which was generally low. Storm water runoff may account for as much as 59 percent of the total runoff on the west side of the lake. A review of existing storm water routing should be considered with the goal of eventually retrofitting the existing conveyance in order to minimize storm water pollutant loads.

Additional development of the watershed will increase the percentage of impervious surfaces into a critical range. A comprehensive review of existing zoning regulations within the drainage basin is recommended with the goal of insuring that any additional developments including upgrades of existing structures include all available best management techniques.

INTRODUCTION

General Introduction

This report presents the results of two years of data collection at Lake Hayward, in the town of East Haddam, Connecticut. The study was funded jointly by the Bureau of Water Management of the Connecticut Department of Environmental Protection through their Lake Management Program, and the Property Owners Association of Lake Hayward. The study included both lake and drainage basin inlet sampling. The goal of the study was to provide a detailed description on the state of the lake from which a list of management needs could be developed.

Report Organization

The first year of field data collection was started in April 2000 and progressed through to October of 2000. The second year of field collection started in March 2001 and ended in October 2001. The lake was visited once each month to collected water samples and record measurements from as many as three in-lake stations, the outlet, and as many as 14 tributary inlets. During the summer, aquatic plant beds were surveyed to determine the species present and measure the surface coverage of fanwort, an invasive species infesting the lake.

The report begins with an overview of the documents containing historical Lake Hayward data that were reviewed during this study. This is followed by an assessment of the lake basin and the watershed and drainage basin of the lake. The results of the different measurements and test results in the following order. The Secchi data collected during this study are reported first followed by the historical Secchi disk depth collected from difference sources. The Secchi disk depth and light extinction are used to define the transparency of the lake which can be used to classify the trophic status of the lake. The temperature and oxygen data are discussed next. Here the data is presented to define the location and strength of the thermocline, a temperature boundary, and the location of the anoxic boundary, the depth in the lake where oxygen is depleted. At this point, the three types of data are presented together, Secchi, thermocline, and anoxic boundary as a way of defining the physical structure of the lake.

The chemical test results are presented beginning with phosphorus and nitrogen, the two important nutrients in lakes, then in turn each of the other chemical parameters that have been analyzed with iron and sulfide completing the chemical results section. The last section of the in-lake results are the phytoplankton, zooplankton, fisheries and aquatic plant data.

The drainage basin tributary sampling results are presented next including subbasin areas and boundaries and discharge flow measurements. The water chemistry results follow with a consideration of historical data collected from different inlet sites. The section on the drainage basin concludes with mass loading estimates for phosphorus and nitrogen.

The estimated nutrient loading to the lake is considered next. The report concludes with an outline of the lake problems identified in this report. A set of restoration alternatives is given for each of problem areas. Each list is critiqued for feasibility limitations with alternatives removed leaving a short list of likely alternatives which serve as the recommendations for future actions.

Historical Reports

There is a long history of water testing at Lake Hayward (**Table 1**). The earliest record of limnological information for Lake Hayward is from Edward Deevey's survey of Connecticut lakes conducted between 1937 and 1939 (Deevey 1940). He collected chlorophyll, nutrients, transparency, and alkalinity from 48 Connecticut lakes including Lake Hayward, listed among other eastern highland lakes. The Connecticut State Board of Fisheries and Game published a bathymetric map of Lake Hayward and briefly discussed the fisheries in the lake but didn't include any water quality data (CT State Board of Fisheries and Game 1959). The next set of data on the lake was collected by Frink and Norvell (1984) during a statewide survey of 70 lakes conducted between 1973 and 1974. Lake Hayward was included with sampling dates of November 20, 1973, April 25, 1974, and July 29, 1974. Data collected included temperature oxygen, Secchi depth, nutrients, chlorophyll, alkalinity, cations and anions.

In 1977 Larry Battoe, then a University of Connecticut Master of Science degree candidate, conducted a study of the three large East Haddam Lakes, Moodus, Bashan, and Hayward (Battoe 1977, 1978). His study focused on the bacterial and respiration aspects of the three lakes, with the only data collected being Secchi disk depth, temperature, oxygen, carbon dioxide, and bacterial indicator organisms. This work was an important contribution to the limnology of Lake Hayward because he sampled the lake approximately every two weeks between May and October 1976 providing a comprehensive picture of one full growing season (April to October).

The Connecticut Department of Environmental Protection listed Lake Hayward in two published trophic classifications of Connecticut lakes. The first, The Trophic Classifications of Seventy Connecticut Lakes, 1982, listed the water chemistry results from the

Frink and Norvell (1984) survey of 1974. The second, The Trophic Classifications of Forty-Nine Connecticut Lakes, 1991, presented water chemistry results from a survey conducted in 1989 by United States Geological Survey, the data was also given in their (USGS) publication Water-Quality Characteristics of Selected Public Recreational Lakes and Ponds In Connecticut (Healy and Kulp 1995). Sampling during that survey was conducted on April 14, 1989, and August 29, 1989, and included temperature, oxygen, Secchi disk depth, nutrients, chlorophyll, alkalinity, and conductivity but not cations and anions. The CT DEP listed the lake as having a mesotrophic classification in 1982 but changed that to late-mesotrophic in 1991 primarily due to aquatic weed beds.

A summary of the existing lake and watershed data was performed by Marine and Freshwater Research Service in 1992 (Baillie 1992). The report pooled together all of the scattered survey results up to that time and provided an overview of the limnology of Lake Hayward.

Water quality data for Lake Hayward was also collected as part of a statewide survey of Connecticut lakes published in Canavan and Siver's Connecticut Lakes, A Study of the Chemical and Physical Properties of Fifty-six Connecticut Lakes (1995). The survey collected water quality samples from Lake Hayward on four dates between June 1990 and September 1993 and made comparisons between Lake Hayward results and statewide averages.

The Property Owners Association of Lake Hayward (POALH) established a lake monitoring program in 1991 to obtain water quality data from the lake. The POALH, through the Lake Hayward Water Quality Committee, conducted annual lake sampling in the years of 1992, 1993, 1998, and 1999 (POALH 1993, 1994, 1999, 2000). The sampling consisted of surface water samples collected between May and August and indicator bacteria samples from the three beaches on the west side of the lake (First Beach, Second Beach, and Third Beach).

Table 1. Summary of Sources of Lake Data For Lake Hayward.

Author	Title	Dates of Data Collection
Deevey (1940)	A Contribution to Regional Limnology	1937-1939
Frink & Norvell (1984)	Chemical and Physical Properties of CT Lakes	1973-1974
Battoe (1978)	A Bacteriological and Limnological Study of Three Lakes in East Haddam, CT	1976-1977
CT DEP (1982)	Trophic Classifications of Seventy Connecticut Lakes	1974
BEC, Inc. (1990)	Calculations and Tables Relating to Lake Hayward	1990
CT DEP (1991)	Trophic Classifications of Forty-nine Connecticut Lakes	1989
Healy & Kulp, USGS (1995)	Water-Quality Characteristics of Selected Public Recreational Lakes and Ponds In Connecticut	1989 (same as CT DEP 1991)
CT DEC (1991)	Lake Hayward Inflow Stream Water Quality Survey Data	1991
Canavan & Siver (1995)	Connecticut Lakes, A Study of the Chemical and Physical Properties of Fifty-six Connecticut Lakes	1991 - 1993
POALH (various)	Water Quality Monitoring Reports	1992,1993,1994,1998,1999

LAKE AND DRAINAGE BASIN CHARACTERISTICS

Lake Basin

Lake Hayward (previously known as Shaw Lake) is located in the northeast corner of the town of East Haddam, in Middlesex County, Connecticut. The drainage basin extends to the east into the towns of Salem and Colchester in New London County, Connecticut. The lake basin has a north-south orientation narrowing at both the north and south ends. The size was previously given as 199 acres (Frink and Norvell 1984) but the development of wetlands has reduced the open water surface area to approximately 170 acres

The surface area of the lake was given as 192.98 acres (78.1 hectares) by Deevey (1940), and 198.9 acres in the CT Fisheries Survey of 1959 (CT Board of Fisheries and Game Lake and Pond Survey Unit 1959). The bathymetric contours of the lake were published in that volume and then re-published in Chemical and Physical Properties of Connecticut Lakes (Frink and Norvell, 1984). Battoe (1978) presented a bathymetric map that appeared to be prepared from soundings made by that author and gave the surface area as 79 hectares (195.2 acres). Canavan and Siver (1995) reported the surface area of the lake at 80 hectares (197.68 acres). A new publication of Connecticut Lakes (Jacobs and O'Donnell 2002) gives the surface area of Lake Hayward as 173 acres but appears to include the large oval wetland on the east side as open water but not the wetlands to the north of Lake Hayward Road. **Table 2** summarizes the surface areas reported by different authors.

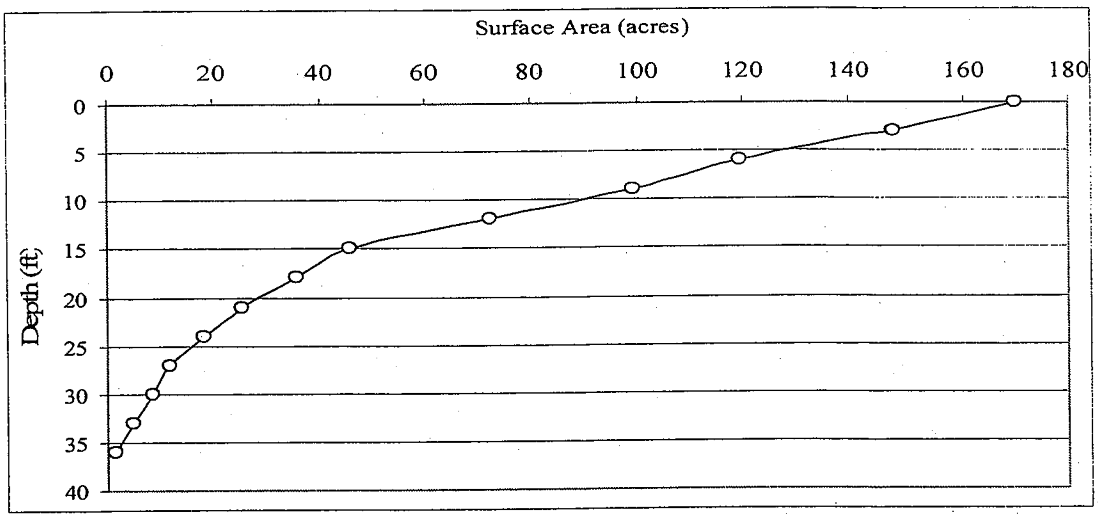
Table 2. Lake Hayward Surface Areas.

Author/Report	Surface Area (acres)
Deevey (1940)	192.98
CT Fisheries (1957)	198.98
Battoe (1978)	195.20
Frink and Norvell (1984)	198.98
CT DEP 1984, 1991	198.90
Healy and Kulp 1995	199.00
Canavan and Siver (1995)	197.68
Jacobs and O'Donnell (2002)	173.00

The oval wetland to the east was approximately 12.1 acres and the wetlands both north and south of Lake Hayward Road total 16.5 acres (following the 350 foot elevation contour). Together these two areas account for 28.6 acres that may have been included as open water by earlier authors, adding 173 acres and 28.6 acres yields 201.6 acres, very close to earlier estimates of the surface area of the lake.

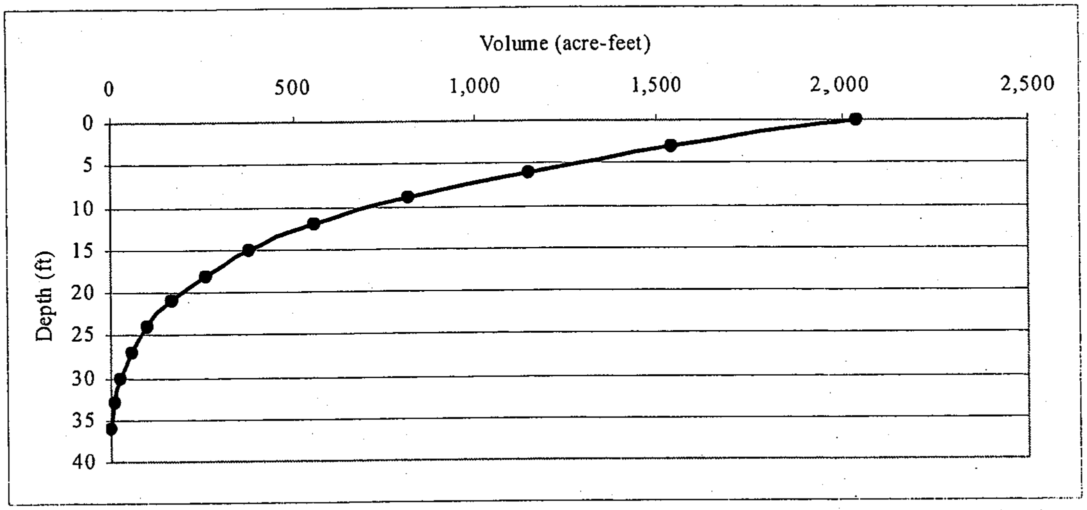
The hypsographic curve for Lake Hayward is shown in **Figure 1**. This is a graphic representation of the surface area at each depth and shows the general proportion of bottom area and depth. For instance, the curve starts at the top of graph at 173 acres or the total open water surface area of the lake, and then progresses downward in increments of 3 feet such that the 10 ft depth the surface area is closer to 90 acres. From this relationship, it is possible to determine the approximate surface area at each interval of water depth.

Figure 1. Hypsographic (Depth-Area) Curve for Lake Hayward.



The total water volume of the lake is approximately 2,035 acre-feet or about 2.5 million cubic meters (m^3), or in English units about 670 million gallons. The water volume below each depth is shown in **Figure 2**. The graph shows a curve that begins at the top right and progresses toward the bottom left. At each point along the graph the curve reads the volume of water contained in the lake below that depth. For example reading across from 15 feet the mark on the curve occurs at about 400 acre-feet (1 acre-foot = 325,900 gallons) meaning that there is about 400 acre-feet of water below 15 feet. The graph is useful because it shows the quantity of water contained in different layers such as between 0 and 15 feet, contains the largest volume, or about 1,600 acre-feet of water (80%), while the deep-water layer between 15 feet and bottom contains only 400 acre-feet (20%).

Figure 2. Depth - Volume Curve for Lake Hayward.



The maximum depth of the lake occurred south of the middle of the basin and toward the west side, off shore from Second Beach. The deepest water found during the study was 11.3 meters (37 feet). The mean depth of Lake Hayward is 3.44 meters (11.3 feet). The mean depth is determined by dividing the volume of the lake by the surface area, and represents the water depth if the total basin was smoothed to one uniform depth. The estimated flushing rate of Lake Hayward is 1.8 times per year. The flushing rate is calculated by dividing the lake volume by the total annual water inflow. The inverse of the flushing rate is the residence time or the hypothetical time that water remains in the lake, Lake Hayward has an estimated residence time of 208 days.

Drainage Basin

The drainage basin of a lake is the land area that provides runoff to the lake. A watershed boundary is the dividing line that circles a lake and defines the direction that water will flow. On one side of the boundary runoff will flow toward the lake on the other side it flows away from the lake. The drainage area is all the land inside the watershed boundary minus the surface area of the lake. The watershed boundary includes both the drainage basin and the lake. Watershed maps are including in **Appendix 2**

The drainage basin of Lake Hayward is 1,489 acres and is partially in the town of East Haddam but also extends to the southeast into the town of Salem and to the north and northeast into the town of Colchester. The largest fraction or about 719 acres is in Colchester. The smallest or about 98 acres was in Salem, with the remaining area, 672 acres, in East Haddam.

There was a large variation in the size of watershed area reported in prior reports. The size of the drainage basin was first given by Battoe (1978) as 645 hectares or 1,593.8 acres, later Frink and Norvell (1984) reported 1,592 acres. Frink and Norvell state that the watershed area included the surface area of the lake. The CT DEP (1984) listed the size of the drainage basin as 4.55 square miles or 2,912 acres. In a letter of transmittal from Baystate Environmental Consultants, Inc., (BEC 1990) to the CT DEP, BEC requested, that the watershed area be corrected from 2,912 acres to 1,846.2 acres. A review of the delineation of the watershed boundary BEC submitted to DEP revealed that some area they included around the south end of the lake actually flows away from the lake and should be excluded. The next CT DEP (1991) published watershed area gave the basin size as 1,657.1 acres but did not publish a map showing the location of the boundary. The DEP (1991) cite the Gazetteer of Natural Drainage Areas of Streams and Water Bodies Within the State of Connecticut (DEP 1972) as the source of the new watershed area. Healy and Kulp (1995) also gave the watershed size at 1,657 acres.

Canavan and Siver (1995) although not stating the watershed size, reported the watershed to lake surface area ratio was 8 meaning that the watershed area used for the calculation was 1,581 acres. CT DEP (1991) reported the watershed/surface area ratio at 8.3 (no value was given in 1984), while BEC calculated the ratio by dividing 1,846.2 by 198.9 yielding 9.28. Jacob and O'Donnell (2002) gave the total area of the watershed as 1,663 acres and a drainage basin area of 1,489 acres, these are the values used in this report.

It is clear from the above that there is significant variation between the different estimates of the watershed size for Lake Hayward. It is not always stated if the watershed size includes the lake surface area. The areas reported by the various authors are summarized in **Table 3.**

Table 3. Lake Hayward Total Watershed Surface Areas.

Author/Report	Surface Area (acres)
Battoe (1978)	1,594
Frink and Norvell (1984)	1,592
CT DEP (1984)	2,912
BEC (1990)	1,846
CT DEP (1991)	1,657
Healy and Kulp 1995	1,657
Canavan and Siver (1995)	1,581
Jacobs and O'Donnell (2002)	1,663
Lake Surface Area	*173 acres*

This report will make use of a watershed size of 1,663 acres given by Jacobs and O'Donnell (2002), with the lake surface area of 173 acres the effective drainage basin area to the lake is of 1,489 acres. The important lake and drainage basin statistics used in this report are summarized in **Table 4**.

Table 4. Lake and Watershed Statistics Used in This Report.

Watershed Size	1,663 acres
Drainage Basin	1,489 acres
Lake Surface Area	173 acres
Maximum Depth	37 ft (11.3 meters)
Mean Depth	11.3 ft (3.4 meters)
Lake Volume	2,020 acre feet
Residence Time	208 days
Flushing Rate	1.7 times / year

IN-LAKE WATER QUALITY RESULTS

Methods

During each of the two years of sampling, 2000 and 2001, the lake was visited once each month beginning in April and ending in October. The sampling dates are given in **Table 5**.

Table 5. Lake Sampling Dates At Lake Hayward, 2000, and 2001.

2000	4-28	5-23	6-29	7-29	8-21	9-29	10-26
Lake Stations	St. 1	St. 1	St. 1-3	St. 1-3	St. 1-3	St. 1	St. 1

2001	4-16	5-17	6-26	7-20	8-29	9-17	10-12
Lake Stations	St. 1	St. 1	St. 1-3	St. 1-3	St. 1-3	St. 1	St. 1

The in-lake testing included water clarity, percent light transmission, (Licor Model 185A light meter), and temperature and oxygen measurements made at each one-meter depth from top to bottom using a YSI Model 58 oxygen meter. These data were tabulated on profile sheets that show the vertically arranged measurements and plot the data graphically. The profile sheets are included in **Appendix 3.** Water samples were collected from 1, 3, 5, 7, and 9 meter depths at Station 1 and from mid depth at both Station 2 and Station 3. The maximum water depth at Station 2 was 3 meters (10 feet), so the sample was collected from approximately 1.5 meters (5 feet) feet. The maximum water depth at Station 3 was 6 meters (20 feet) so the water sample was collected at about 3 meters (10 feet). Stations 2 and 3 were visited during June, July, and August.

Water samples were collected using a non-metallic foot pump fitted with intake and outlet tubes of 1/2" ID Tygon tubing. The inlet tube had an attached brass orifice opening horizontally (Stauffer 1981). The volume of water in the tube was flushed twice before depth-discrete samples were collected. Each sample bottle was then flushed 3 times before stoppering. No samples were collected unless the sampling tube/calibrated line assembly hung vertically in the water column.

Water samples were analyzed for the following parameters: total phosphorus, ammonia, nitrate and organic nitrogen, turbidity, conductivity, alkalinity, total iron, pH, color, and redox potential. Each quarter, April, July, and October, the lake water samples from Station 1 were also analyzed for chloride, sodium, calcium, and potassium. All water analysis was performed by Columbia Environmental Laboratory, Columbia, Connecticut.

Once each month a sample of water for phytoplankton and one for zooplankton was collected from Station 1. The phytoplankton sample was collected using a 5-meter ½ inch ID latex tube that was lowered vertically in the water column, closed, brought to the surface and emptied into a 500 mL bottle. A 15 mL aliquot was removed and preserved with Gluteraldyhe and or Lugols Solution. The phytoplankton analysis was performed by PhycoTech of St. Joseph, Michigan. The zooplankton sample was collected with a 153 micron mesh net (1 micron = 1000 mm) that was lowered to 0.5 meters from the bottom than raised back up through the water column. Captured organisms were rinsed into a 15 mL vial and preserved with Lugols Solution.

Secchi Disk Depth

The Secchi disk depth was measured on 7 dates from Station 1, and three dates from Station 3 during both 2000 and 2001 seasons with data given in **Table 6.** The Secchi depth was also measured at Station 2 but the disk was always visible on the bottom.

Table 6. Secchi Disk Depths (meters) At Lake Hayward during 2000 and 2001.

2000	April	May	June	July	August	Sept.	Oct.
St. 1	5.8	7.0	5.1	4.0	4.8	4.1	7.0
St. 3	~	~	4.8	3.5	4.5	~	~

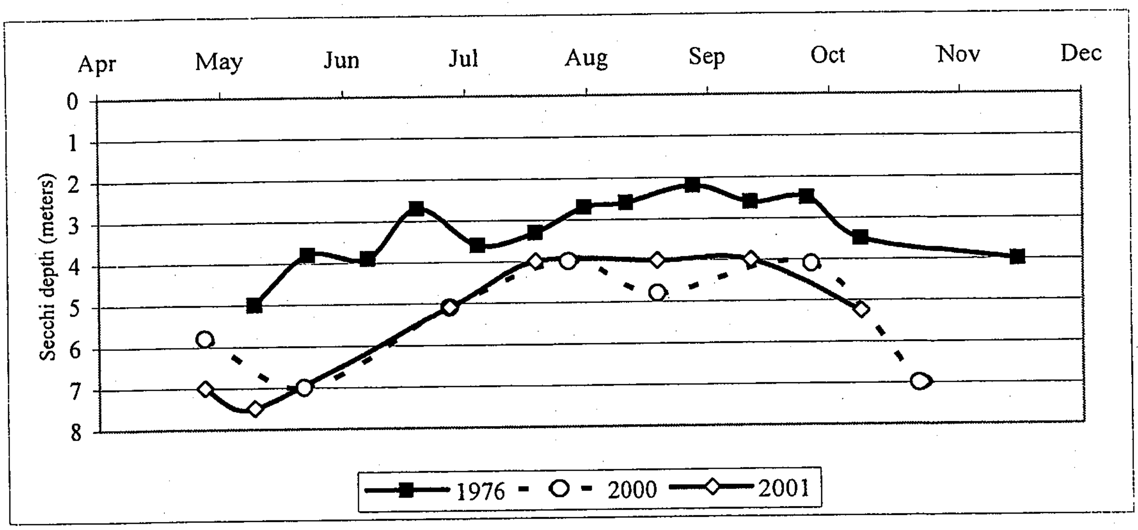
2001	April	May	June	July	August	Sept.	Oct.
St. 1	7.0	7.5	5.1	4.0	4.0	4.0	5.3
St. 3	~	~	4.2	4.0	3.9	~	~

The Secchi disk depths from 1976, 2000, and 2001 are shown graphically in **Figure 3.** The data from both 2000 and 2001 were very similar with almost identical readings during some of the months. The water clarity during the spring months of April and May was very good, with a range between 5.8 and 7.5 meters. In June during both years the water clarity was 5.1 meters representing an intermediate condition between the clear water in the spring and the cloudy water of summer. During the summer months of July, August, and September, the clarity remained at a constant 4 meters, with the exception of August in 2000 when clarity had increased to 4.8 meters. The water clarity in October was better than the summer conditions during both years with between 5 and 7 meter transparency.

The water clarity data showed that a trend existed in which the lake went thought three general periods, a clear water spring period during April and May, followed by a cloudy summer period during July, August and September, and an improved condition in October.

The data from 1976 shows that clarity was not as good during that year as it was during the 2000 and 2001 seasons. Although the same general seasonal trend in clarity was apparent, the clarity was at least 1 meter poorer suggesting that the lake had more algae and probably higher levels of phosphorus at that time as opposed to now.

Figure 3. Secchi Disk Depth At Lake Hayward During 1976, 2000, and 2001.



A light meter was used to measure the actual penetration of light into the water column. The depth in the lake where light is diminished to only 1% of that impinging the surface is considered to be the point where the two processes of photosynthesis and respiration are balanced. In other words at that depth the light has been diminished to the point where algae cannot make more food than they consume so no growth occurs. When light is sufficiently high photosynthesis can take place and oxygen is produced in excess of that required by respiration. Below this depth any oxygen produced by the plant is consumed by the plant during respiration.

The compensation depth or depth of 1% light at Lake Hayward is given in **Table 7**. The value of 1% is calculated from the best-fit logarithmic curve from the recorded values of percentage extinction through the water column. In the case of April, the estimated depth of 1% is at the sediment surface.

Table 7. Depth of 1% Light (meters) At Lake Hayward during 2000 and 2001.

2000

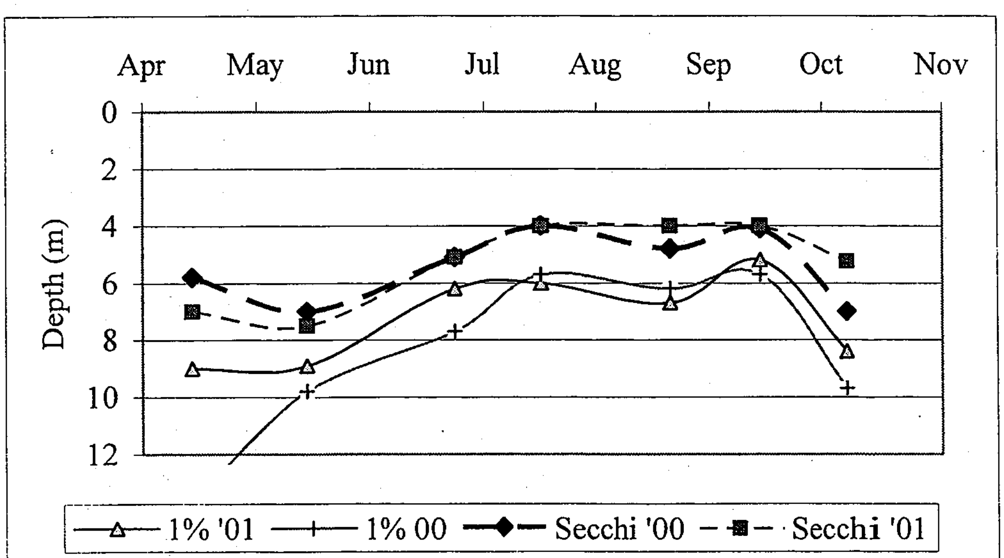
	April	May	June	July	August	Sept.	Oct.
St. 1	Bottom	9.8	7.7	5.7	6.2	5.7	9.7

2001

	April	May	June	July	August	Sept.	Oct.
St. 1	9.0	8.9	6.2	6.0	6.7	5.2	8.4

When the Secchi disk data and depth of 1% light are plotted together as shown in **Figure 4** the similarity between them can be seen. With the exception of the April data, the depth of 1% light was roughly 2 meters deeper than the Secchi disk depth. The April data is unusual in that although the Secchi was not as good as the May value the light penetration was considerably better.

Figure 4. Lake Hayward Secchi Disk Depth and Depth of 1% Light At Station 1, 2000 and 2001



The graph shows that light reached the sediment surface at all depths in April, to the 10 meter depth in May and again in October but was diminished at shallower depths between June and September. There appeared to be a similarity with the depth of the penetration of light during the summer months of July, August, and September. On the sampling dates in each of those three months, the depth held to about 4 meters for the Secchi and 6 meters for the 1% light limit.

Temperature and Oxygen

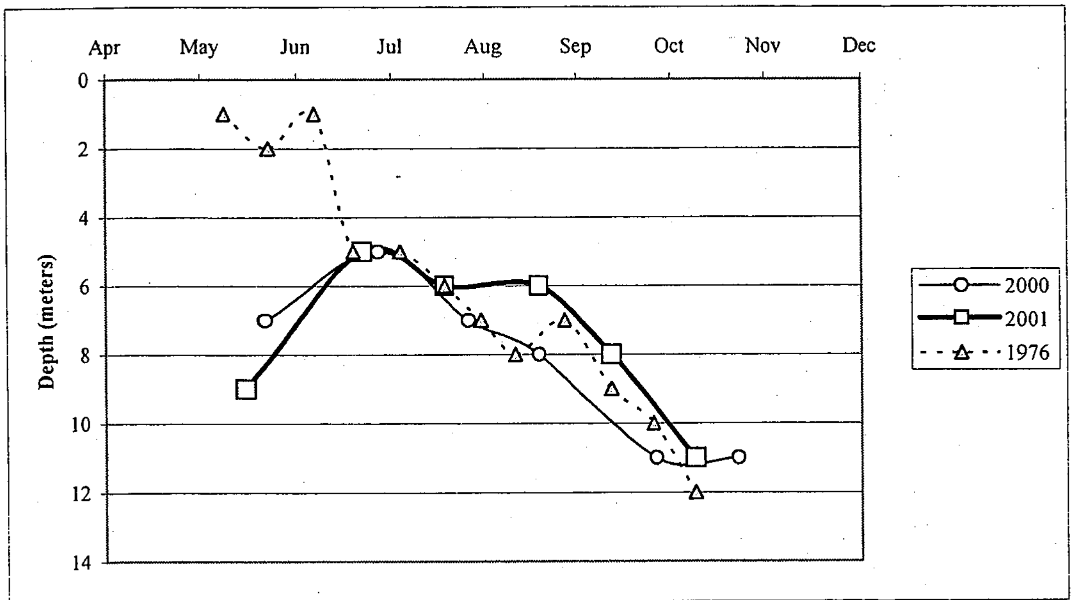
Temperature

The water temperature of Lake Hayward was measured at each one meter depth from top to bottom at the deep-water station. The resulting temperature profiles, one for each monthly visit, were used to determine the depth at which thermal stratification occurred. Thermal stratification is the boundary that is caused when water on the top of the lake warms faster than the water at the bottom of the lake. Generally, somewhere in the middle depth the temperature changes quickly with depth. When warm water sits on top of cooler water, the two layers will not mix without being forced to by wind blowing across the surface. The upper layer will be mixed by wind action on the lake surface and the bottom layer will remain isolated and stagnant. The degree or strength of the stratification can be calculated by the change in temperature between each meter of water depth. Stronger stratification means greater stagnation of the water below but also means that there will be less diffusion of materials across the boundary such as phosphorus from deep water.

The temperature measurements at Lake Hayward showed that the lake stratified during the summers of 2000, and 2001. The depth in the lake where the layer of stratification occurred is shown in **Figure 5**. This point is called the thermocline as it refers to the depths with the greatest water temperature change. The stratification of the lake started in June and persisted until September although there were some weak boundaries formed in May. The thermocline was not static at one depth during the year but rather moved downward as the water above it warmed and winds continued to mix this warm water deeper into the lake. The data in **Figure 5** shows that the thermocline moved steadily downward between July and September eventually reaching the bottom in October. The depth of the thermocline was about 2 meters higher in the water column during the summer of 2001 than the summer of 2000, but the migration downward after the end of August followed the same general deepening trend. The location of the thermocline in 2001 was stable at 6 meters during most of August because the lake was warmer at the surface during that time.

The thermocline is a function of warming of the upper water layers, between it and the surface. The location in the water column where the thermocline will be located is due to wind distributing this upper warmed water. The strength of the wind will determine the depth in the lake were the thermocline will be stable. If the wind was stronger it would push it deeper or likewise if the water was either clearer so that it was warmer deeper the thermocline would be deeper. As the temperature of the water increases at deeper depths during the late summer the action of the wind causes the thermocline to descend deeper. This process is different than the expansion of the anoxic boundary that is discussed in the oxygen section next.

Figure 5. Lake Hayward Thermocline Depth at Station 1, 2000, and 2001.



These data show that Lake Hayward develops three temperature layers regularly each season. An epilimnion, or upper mixed layer, forms between the water surface and the top of the thermocline. A metalimnion, or middle layer, forms between the epilimnion above and hypolimnion below. And a hypolimnion, or deep stagnant water, exists below the metalimnion to the bottom. The thermocline forms at the beginning of June and persists until October. Prior to June the location of the thermocline varied but in each case it was weak and didn't represent much of a boundary. After it strengthens, which takes place during June; it slowly migrates downward as the water in the epilimnion (water above the thermocline) warms. This migration continues during the summer until it reaches the bottom in late September. The hypolimnion is formed as soon as the thermocline is strengthened in June because by definition it is the stagnant water below the thermal boundary. As the thermocline progresses downward during the summer the hypolimnion is gradually compressed into a narrower layer. In June the hypolimnion was a few meters thick from about 8 meters to the bottom but by August it was only a meter thick. By the end of the September it had disappeared altogether because the lake had mixed down to the bottom.

Oxygen

The dissolved oxygen in Lake Hayward was measured at the same time and location as was temperature. The two important aspects of the oxygen data are the depths of the lake where the concentration of oxygen exceeds 100 % and where it is less than 1 mg/L. The former is super saturated while the latter is anoxic. Super saturation occurs when algae are very abundant and photosynthesizing at a high rate. This typically happens in the top couple of meters of water during the summer or fall. Anoxic water occurs during the summer below the thermocline.

The 2001 data showed the lake to have super saturated oxygen levels during all months except September, while in 2000 super-saturation occurred only in April, and May (**Table 8**).

Table 8. Average % Oxygen Saturation in Top 3 Meters of Lake Hayward, 2000, and 2001.

2001

April	May	June	July	August	September	October
108	101	103	103	109	94	103

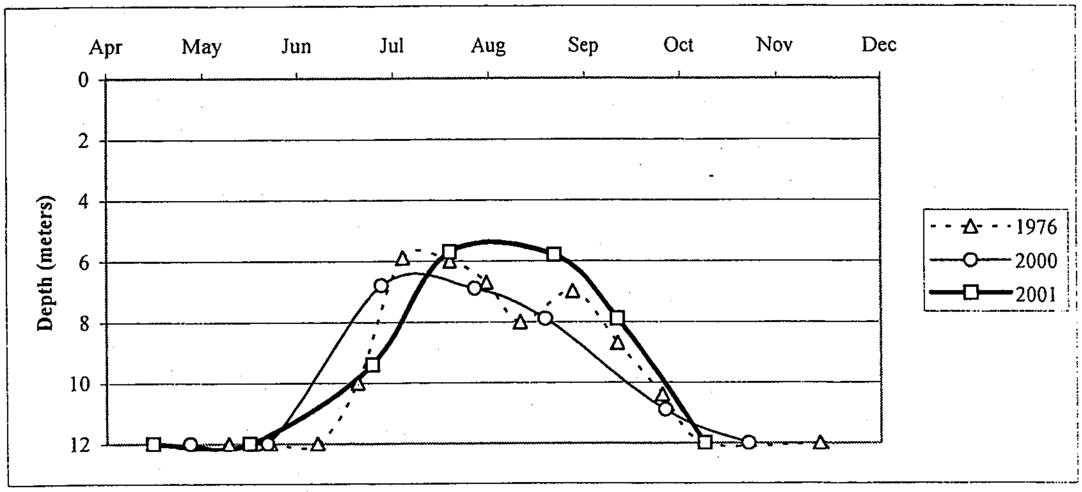
2000

April	May	June	July	August	September	October
102	104	97	75	98	80	90

Water that is anoxic has been depleted of dissolved oxygen. The sources of dissolved oxygen in water are 1) the atmosphere, where oxygen is mixed into the lake from the air, and 2) photosynthesis from plants and algae, both produce oxygen during the day which is dissolved into the water column. In water deeper than the compensation point (where photosynthesis and respiration are balanced because of low light availability), oxygen will be consumed by respiration faster than it is produced by photosynthesis. When the lake stratifies oxygen from the atmosphere will be distributed into the water down to the depth of the thermocline and not below meaning that below the thermocline oxygen is depleted during the summer. This depletion starts in the sediments and progresses upward into the water column. When water is devoid of oxygen it is referred to as being anoxic or without oxygen. The point or depth in the water column where the oxygen is only 1 mg/L is called the anoxic boundary because below that point the water is anoxic but above it oxygen is present.

The location of the anoxic boundary was tracked during both years of this study and during 1976 (**Figure 6**). In 1976 the boundary appeared at the sediment surface in early June whereas during both 2000 and 2001 the boundary appeared at the sediment surface in mid May or about 2 weeks earlier than in 1976. However, the rate of anoxia development during June appeared to follow the same trend, with data points falling on the same line during each of the three years. In each of the three years the rate at which it ascended up into the water column was similar such that by late June or early July the boundary reached its maximum height (measured from the bottom up). The exact depth of maximum extent was somewhat different for the three years, 1976 was 6 meters, 2000 was 6.8 meters, and in 2001 it was 5.7 meters. In each case the anoxic boundary descended back to the sediment surface gradually during August and September, reaching the bottom in late September or early October.

Figure 6. Anoxic Boundaries In Lake Hayward, 1976, 2000, and 2001.



The anoxic boundary stayed up higher in the water column during 2001 because the thermocline was higher due to the warmer water in the top couple of meters of the lake. After August the anoxic boundary began to descend toward the bottom almost identically to the trend observed in 2000. In fact, each of the three years that the anoxic boundary has been tracked has shown the same trend in the descent during September. This deepening of the anoxic boundary is caused by the gradual deepening of the thermocline as will be shown in the following figures. The thermocline is the site where oxygen is transferred from the upper epilimnion where oxygen is plentiful to the hypolimnion where oxygen has been depleted. This pattern should be tracked in future monitoring programs to verify that it still follows the same general trend shown here.

In order to see the interaction of the thermocline and the anoxic boundary the three boundaries can be combined together onto one graph (light penetration, temperature stratification, and oxygen loss). The boundaries from 2001 are shown in **Figure 7,** the 2000 data is shown in **Figure 8,** and 1976 is shown in **Figure 9**. The three boundaries are 1) the penetration of light as measured by the Secchi disk and the depth of 1% light, 2) the depth of stratification as shown by the thermocline, and 3) the depth where oxygen is depleted as shown by the anoxic boundary.

Figure 7. Physical Boundaries for Lake Hayward, 2001.

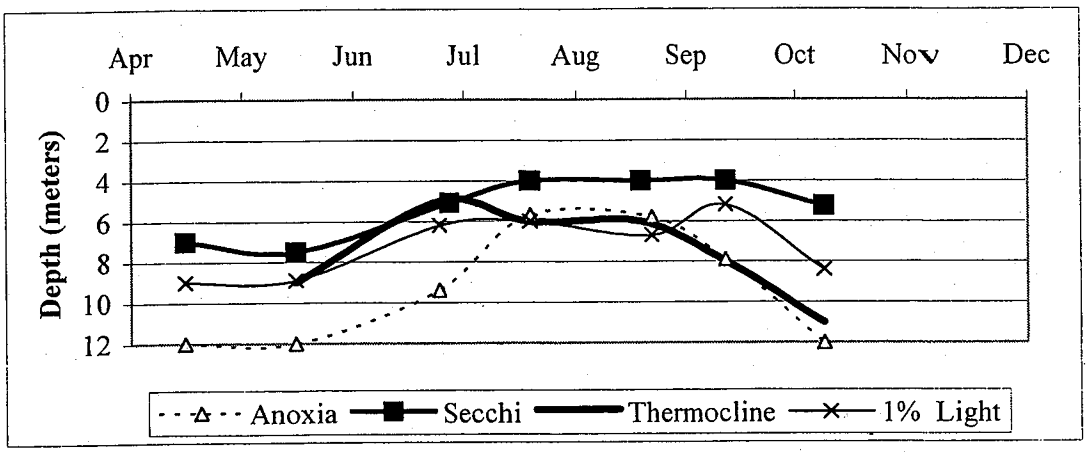


Figure 8. Physical Boundaries at Lake Hayward, 2000.

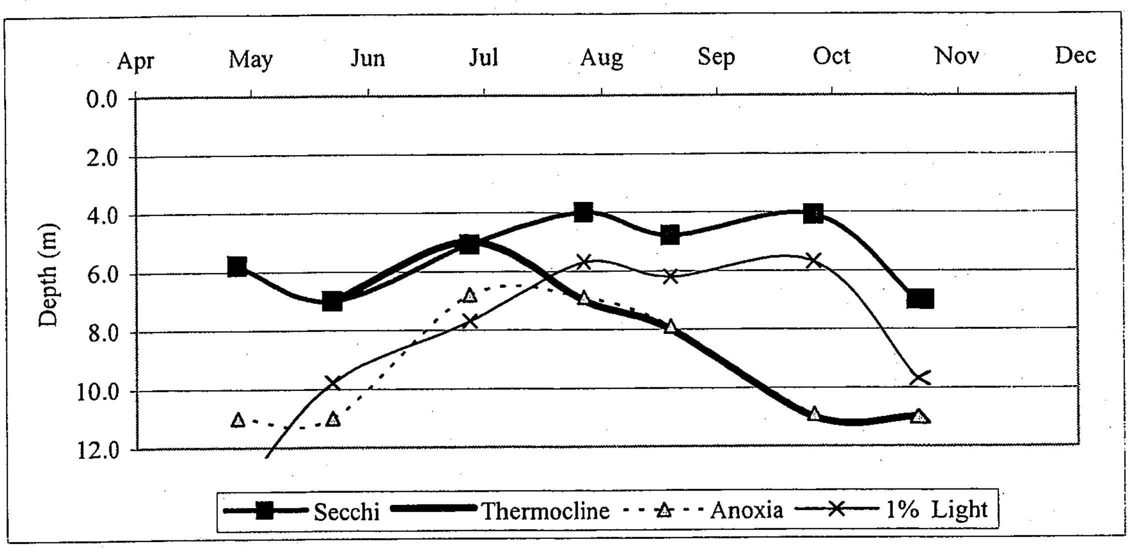
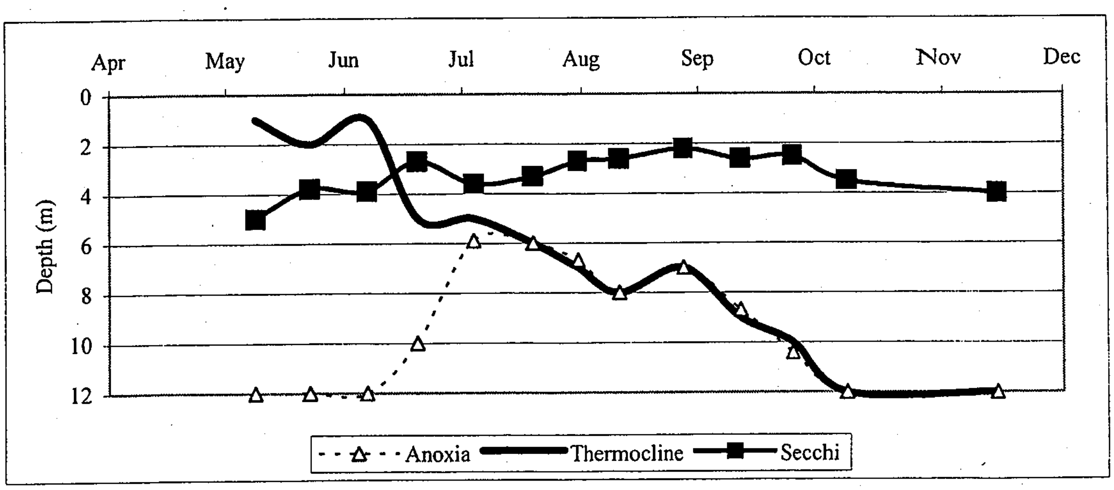


Figure 9. Physical Boundaries at Lake Hayward, 1976.



These graphs tell us that during each of the three years the thermocline descended and met the ascending anoxic boundary in mid-July after which the two boundaries track together to the bottom of the lake. This indicates that lake mixing and the migrating thermocline controlled the position of anoxia in the lake after about the middle of July. As mentioned earlier the epilimnion of the lake has uniformly warm water and plenty of oxygen, while the hypolimnion is cold and devoid of oxygen. The thermocline divides the two and prevents oxygen from crossing into the hypolimnion. As the summer progresses the depth of warm water increases extending deeper into the lake moving the thermocline downward. This brings oxygen deeper into the lake relieving the oxygen depletion as it moves downward.

In Lake Hayward the thermocline meets the anoxic boundary in mid July effectively preventing any further upward movement of the anoxia, and proving a source of oxygen that begins to dissipate the anoxia during the remaining part of the summer. These two forces, up ward moving anoxia, and downward moving thermocline appear to be balanced having shown very similar patterns in each of the three years presented here, representing a period of 25 years. The force that drives the ascent of the anoxia is derived from the bottom sediments and organic material that accumulates at the bottom due to settling. The consumption of oxygen at the bottom and in the mud eventually uses up dissolved oxygen in the water causing the anoxia but decomposition continues after oxygen is gone producing instead reduced materials like ferrous iron. These reduced metals can diffuse upward to consume more oxygen essentially moving the anoxic boundary upward. With increased material at the bottom to be decomposed the level in the lake that anoxic can be pushed higher toward the surface. When the anoxic boundary reaches the thermocline oxygen that is diffused in the upper layer is consumed. But this oxygen is being continually re-supplied by the atmosphere and the algae and plants. So in most cases the upward movement of the anoxic boundary stops when it reaches the bottom of the thermocline. But given enough oxygen demand at the bottom it can continue up through the thermocline and actually cross over into the upper layers. When this happens materials that are dissolved in the anoxic water can be mixed into the upper layers where most of the algae are located. If phosphorus has been accumulating in the anoxic water this leakage across the thermocline can trigger a serious algae bloom.

Total Phosphorus

Total phosphorus was measured at 1, 3, 5, 7, and 9 meter depths at Station 1 with the results shown in **Table 9**. In general, the phosphorus concentrations in the lake were representative of oligotrophic waters (i.e. below 10 ppb, see **Appendix 4**). The values that were above 10 ppb were consistently from deeper water samples taken from the anoxic hypolimnion. The water above the thermocline, typically were the algae grow, had phosphorus values that ranged between 3 and 9 ppb. The spring phosphorus concentration, the mean lake value averaged from all depths in April, was 4 ppb in 2000, and 5 ppb in 2001 and was also the lowest concentration from either season. This suggests that the lake is flushed of nutrients during the winter such that by the beginning of spring a similar low phosphorus condition existed each year. The low spring phosphorus concentration also indicates that overall the watershed is not contributing excessive levels of phosphorus to the lake.

Table 9. Lake Hayward Total Phosphorus Concentrations (ppb), 2000, and 2001.

2001

Depth	April	May	June	July	August	September	October
1	4	5	3	7	5	9	3
3	3	7	5	8	5	5	4
5	3	5	7	8	6	11	5
7	6	4	7	12	16	7	5
9	9	7	7	23	8	12	6
Mean	*5*	*6*	*6*	*12*	*8*	*9*	*5*

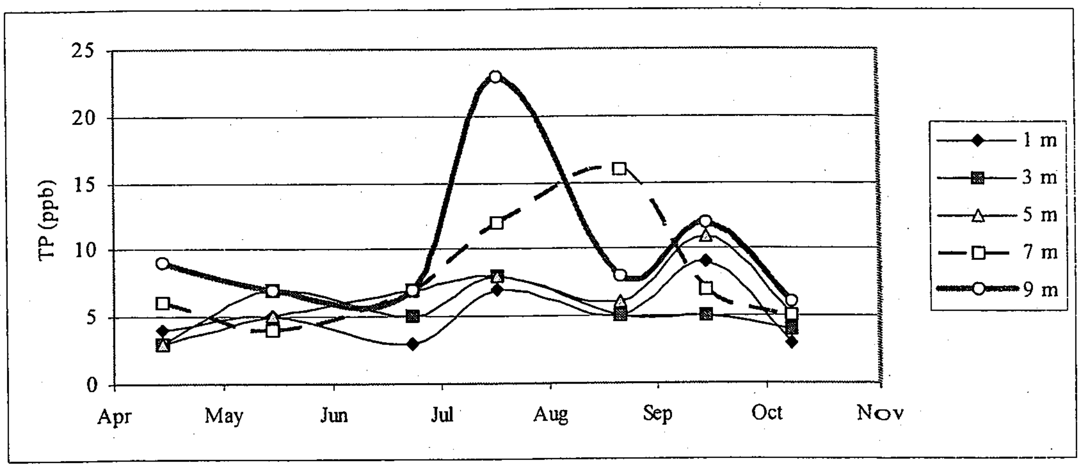
2000

Depth	April	May	June	July	August	September	October
1	4	6	4	7	5	9	7
3	4	5	4	8	8	9	7
5	4	5	5	6	10	6	6
7	4	5	6	6	9	6	7
9	6	6	9	12	20	7	6
Mean	*4*	*5*	*7*	*8*	*10*	*7*	*7*

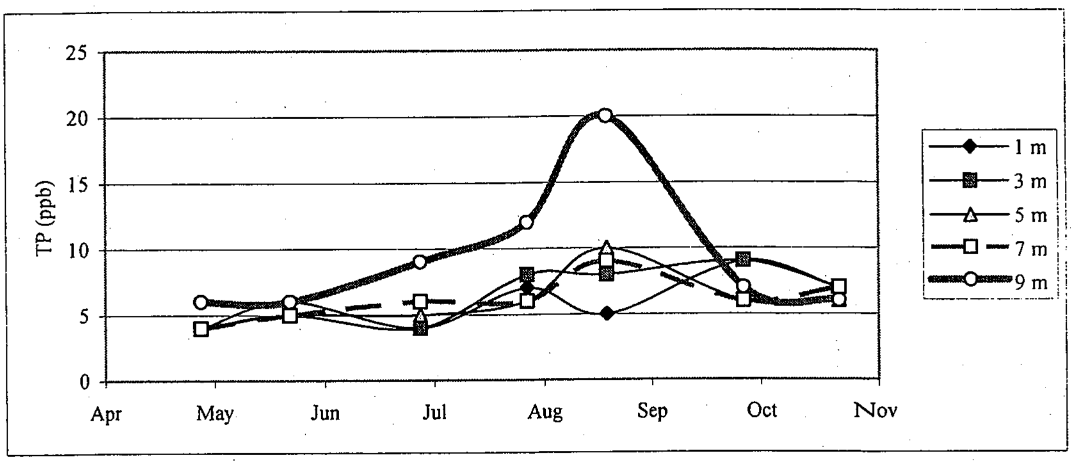
The total phosphorus concentrations observed in Lake Hayward during the 2000 and 2001 seasons are also presented graphically in **Figure 10**. The graphs show the difference between phosphorus concentrations at the 1 – 5 meter sampling depths and the 7 and 9 meter water. The upper 5 meters had a relatively constant level of phosphorus during each year while 7 and 9 meter water showed fluctuations characterized by 9 meters gradually increasing between May and August and 7 meters trailing behind or oscillating with 9 meters in the case of 2001.

Figure 10. Trends of Total Phosphorus in Lake Hayward, 2001 and 2000.

2001



2000



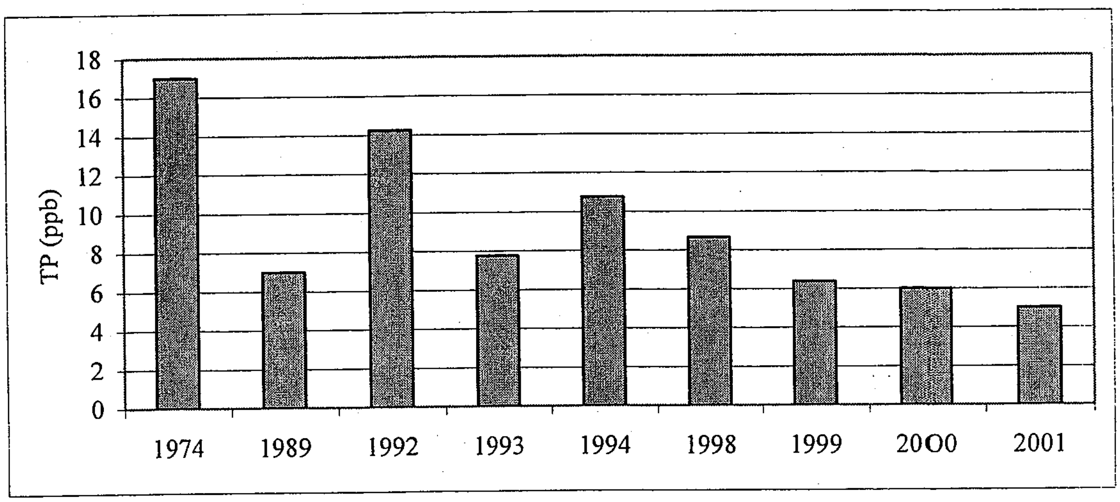
The 9 meter phosphorus concentration represents accumulated phosphorus below the thermocline in the anoxic water. Since phosphorus is soluble in anoxic water any phosphorus that either comes out of the sediments or is precipitated from the water column above will generally remain in solution. Some of that phosphorus may originate from the sediments as internal loading. Internal loading is the process whereby phosphorus leaks out of anoxic sediments into the overlaying anoxic water. As that is happening algae and zooplankton that die in the upper water settle to the bottom where they are decomposed, releasing phosphorus in the process. Together these two processes account for the accumulation of phosphorus at 9 meters.

The two years were similar in that both years showed phosphorus concentrations that trended along similar tracks i.e. lowest levels in April with a gradual increase over the course of the summer such that by September the 1, 3, and 5 meter depths exhibited maximum levels. The

October values show that once the lake begins to mix again in the fall, phosphorus levels return to low levels, very similar to those observed in the spring.

The historical record for phosphorus at Lake Hayward contains mostly data from the surface water of the lake. The average phosphorus value from each of the years that surface water data was available is given in **Figure 11**.

Figure 11. Average Surface Water Total Phosphorus Concentrations at Lake Hayward.



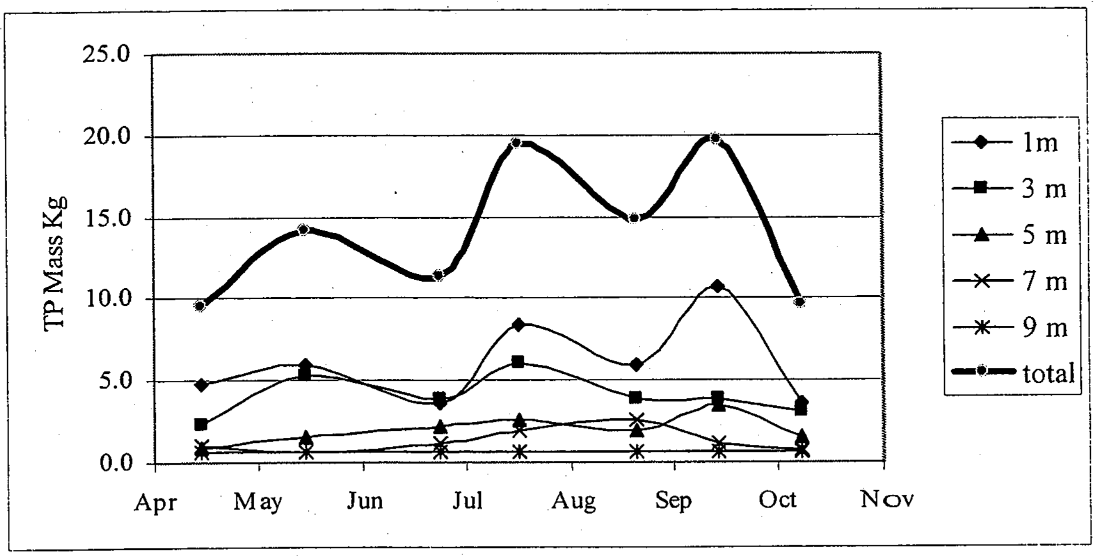
The results show that surface phosphorus concentrations observed in 2001 were the lowest on record. Prior years had similar average surface water values with most years showing concentrations between 6 and 10 ppb. Two years, 1974 and 1992, had higher values, 17 and 14 ppb respectively, suggesting that some variability in the seasonal phosphorus concentration is inevitable but that overall the phosphorus has remained below about 15 ppb with typically observed averages of between 6 and 10 ppb. The data from 1974 may represent pre-phosphorus ban from detergents.

Another way to present the phosphorus data from the lake is by looking at the change in the mass of phosphorus or the total quantity of phosphorus in the lake over the season. This number is obtained by multiplying the concentration from the sample times the volume of water in a layer bounding that sample. For example, the 1 meter sample represents water between the surface, (0 meters), and 2 meters deep, so the concentration at 1 meter is multiplied times the volume of water between 0 and 2 meters. In this way each of the samples is apportioned to a different layer of water in the lake. Because the volumes get progressively smaller going deeper in the lake the resulting mass values get smaller.

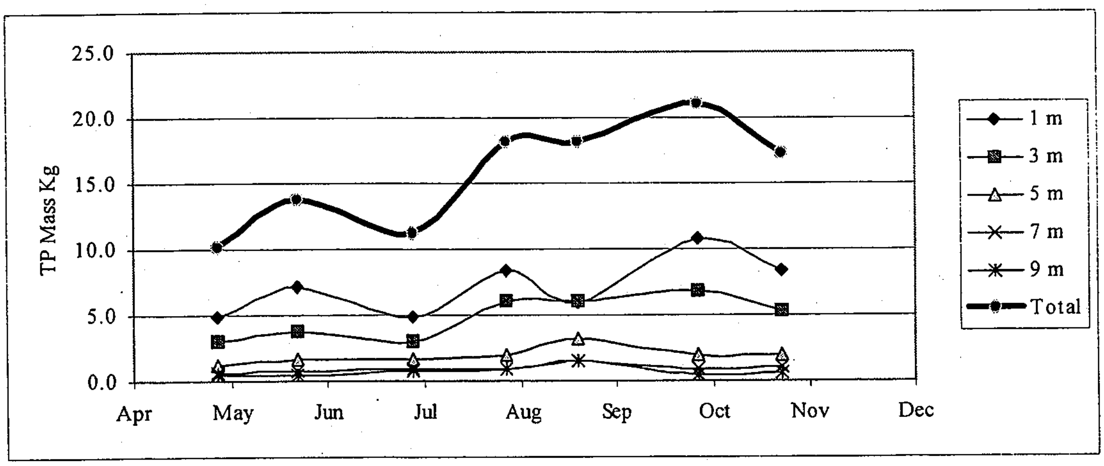
The trends in phosphorus mass in the lake are shown in **Figure 12**. The largest mass of phosphorus is contained in the top layer represented by the 1 meter sample, followed closely by the sample represented by the 3 meter sample, because a majority of the water occurs in the top 10 feet of the lake.

Figure 12. Total Phosphorus Mass in Lake Hayward, 2000 and 2001.

2001



2000



The lake had a total mass of between 10 and 20 kg phosphorus during both 2000 and 2001. Each April the lake began the season with about 10 kg of phosphorus and ended in October with 10 kg of phosphorus in 2001, and about 16 kg in 2000. During each summer the lake accumulated phosphorus such that it reached a peak in mass between July and September. The year 2000 was characterized by a slow steady rise in mass until reaching a peak in September, while 2001 showed more of a fluctuation between 15 and 20 kg. The overall gain in phosphorus between spring and summer was about 7 kg of phosphorus. The largest increases occurred at the 1 meter and 3 meter depths between July and September.

Total Nitrogen

Nitrogen in lake water occurs in two basic forms, inorganic and organic. The inorganic form is commonly represented by nitrate and ammonia and to a lesser extent by nitrite. Organic nitrogen is a combination of several different types of organic material that is collectively considered organic nitrogen because of the association of carbon molecules. The organic forms and ammonia are reported together as Total Kjeldahl Nitrogen (TKN), which has significance because these two forms will both consume oxygen. All three forms were tested for in Lake Hayward lake samples.

Nitrate

In both 2000 and 2001 nitrate was detected only the spring months of April, May, and June. The concentrations in the range of detection, 20 ppb and above, were between 38 ppb and 119 ppb. This was a relatively low level of nitrate for lake water and appeared to disappear quickly. Nitrate was not detectable at all depths during those months. The June nitrate was found only in 2001 and only from deeper water samples. The concentration was always highest in April and showed decreasing trends during subsequent months in each year. The nitrate was probably quickly used by algae in the lake at that time. The nitrate during the spring months may have influenced the dominance of small green algae during those months. The rapid depletion of nitrate in the lake suggests that it may accumulate in the lake over the winter but is rapidly consumed by algae production that begins at ice-out

Ammonia

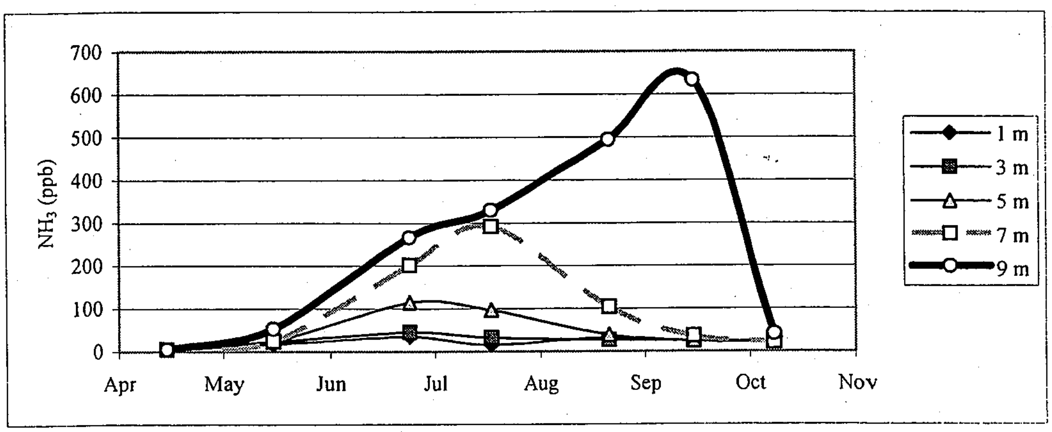
Ammonia is a by-product of the decomposition process and is liberated from sediments during anoxic conditions. It is quickly oxidized to nitrate in the presence of oxygen so is typically not found in the presence of oxygen. Ammonia will accumulate in water without oxygen so typically concentrations increase in the anoxic hypolimnion of lakes during the summer and under the ice in the winter. Ammonia is also toxic to fish and other organisms so when the concentration increases in the hypolimnion fish will not tolerate the environment there.

In 2000 the concentration of ammonia at both 7 and 9 meters in Lake Hayward increased to a first peak of between 200 and 300 ppb in June (**Figure 13**). The concentration of ammonia at 7 meters decreased during July to return to a level similar to the upper water depths, while the 9 meter concentration first remained constant through July then increased to 600 ppb in August. By September the ammonia at 9 meters had decreased to levels consistent with the upper water depths. The ammonia concentration at the other depths remained constant during the rest of the season.

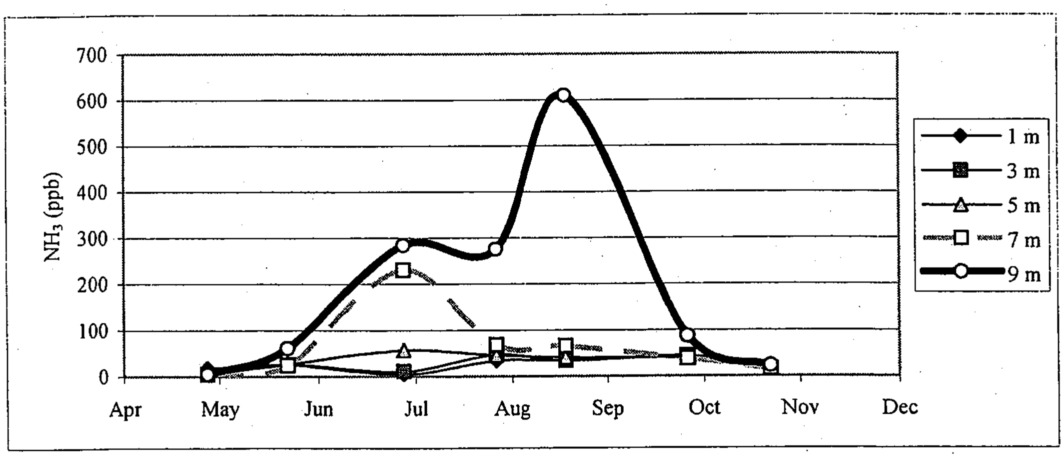
In 2001 the concentration of ammonia increased at roughly the same rate at both 7 and 9 meters until July. After that time, ammonia began decreasing at the 7 meter depth while continuing to increase at 9 meters, until reaching a peak in September of 600 ppb. The 7 meter ammonia concentration returned to surface water levels in September, while 9 meter ammonia returned to surface water levels in October.

Figure 13. Ammonia Nitrogen Concentrations in Lake Hayward, 2000, 2001.

2001



2000



In each of the two years ammonia accumulated at both the 7 and 9 meter depths early in the summer as the anoxic boundary began to ascend up into the water column. The concentration of ammonia at 7 meters reached a peak concentration in late June. After that time, the concentration of ammonia at 7 meters declined presumably as oxygen began reaching that depth. At 9 meters ammonia continued increasing unit September.

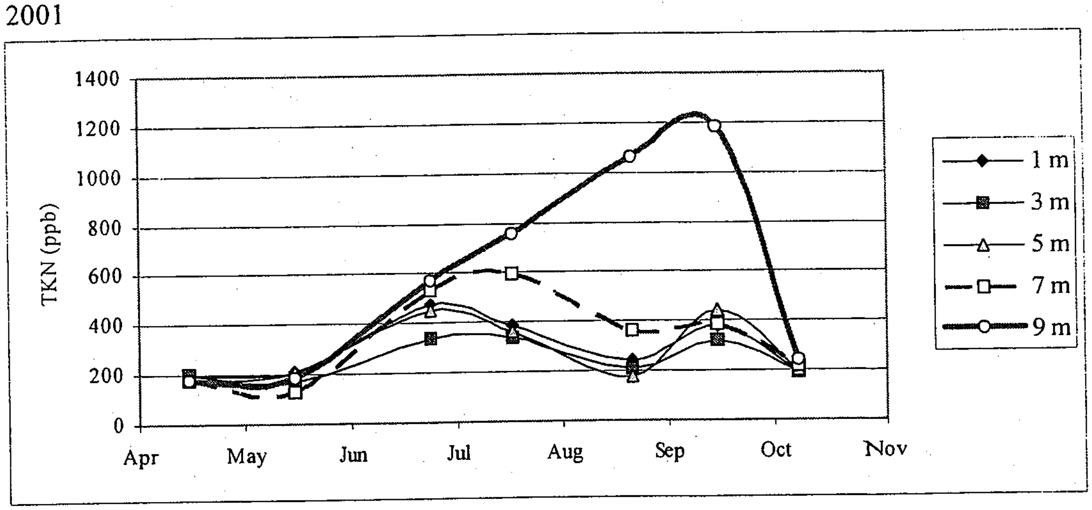
Organic Nitrogen

The organic nitrogen (TKN) followed a similar trend as observed for ammonia, except that the concentrations about equal to ammonia **(Figure 14)**. The concentration of TKN increased between May and June at 7 and 9 meters as did ammonia, but TKN also increased at all other depths indicating a lake wide increase in organic nitrogen occurred. This was followed, in July, by a lake wide decrease in TKN occurring at all depths. The TKN at the 9 meter depth reached a peak in August of about 1,200 ppb but decreased in September to about 200 ppb, a level similar to the other depths.

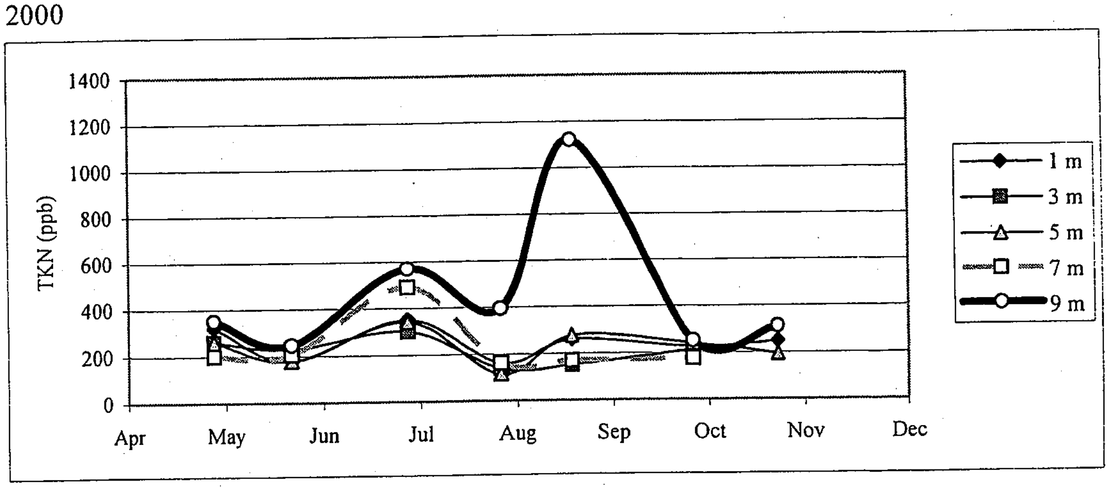
The TKN levels in Lake Hayward represent the total quantity of oxygen consuming nitrogen in the lake water. The total nitrogen value is obtained by summing the TKN and nitrate concentrations and is used to infer trophic status of the lake. The average value of total nitrogen in the upper 1 meter of the lake was about 300 ppb during 2001 and 250 ppb during the 2000. Lake Hayward total nitrogen was between 200 and 300 ppb within the Oligo-mesotrophic category.

Figure 14. Total Kjeldahl Nitrogen Concentrations in Lake Hayward, 2000 and 2001.

2001

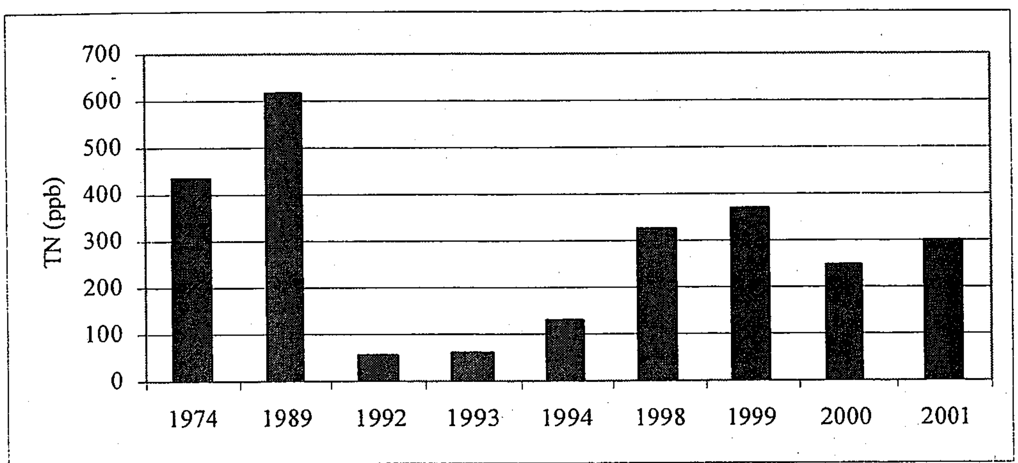


2000



The historical data record for average total nitrogen from surface samples is shown in **Figure 15**. Data from 1974 and 1989 showed high total nitrogen levels in Lake Hayward, with 600 ppb in 1989, about twice that observed in either 2000 or 2001. However total nitrogen was very low in 1992 and 1993, with average levels of 57 and 61 ppb. There was an apparent increase in total nitrogen between 1994 and 1999 with 1999 having an average total nitrogen concentration of about 370 ppb. These data suggests that the range of potential total nitrogen in the lake is large, at least between 50 and 620 ppb.

Figure 15. Average Surface TKN Concentrations from Lake Hayward.



Conductivity

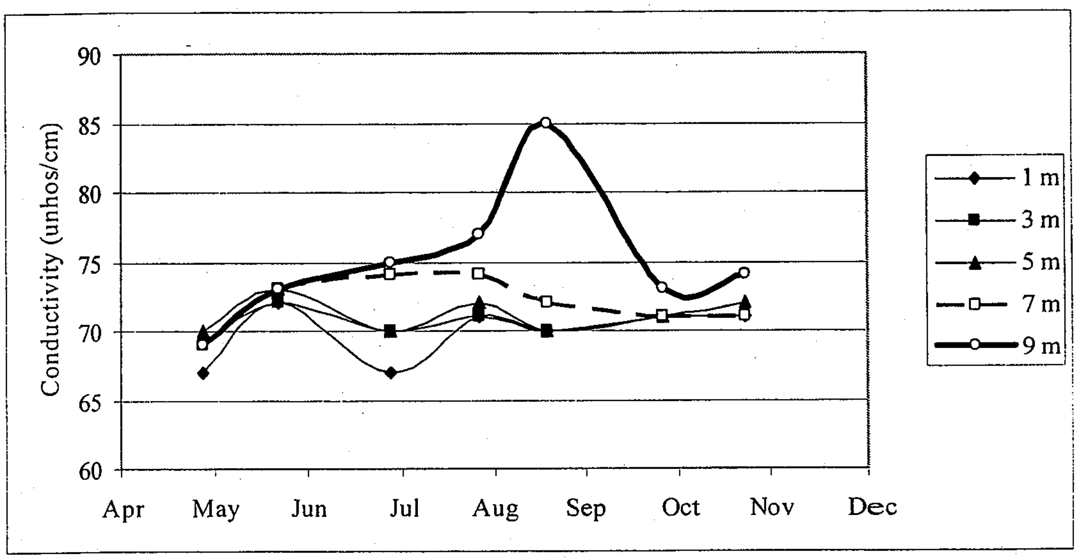
Conductivity- The specific conductance of water is the capacity to carry an electrical current by the salts dissolved in the water. The salts, like sodium chloride, become separate ions when dissolved in water and each has a charge associated with it such that the sodium ion is positive and the chloride ion is negative. These charged ions are what carry the electrical current through the water. So the conductivity test measures the amount of salts that are dissolved in the water. The units of conductance are micro mhos which is the reverse of ohms the unit of electrical resistance. Conductivities below 100 µmhos/cm are common in Connecticut Lakes, while hard water lakes typically have conductivities between 100 µmhos/cm and 200 µmhos/cm. Conductivities over 300 µmhos/cm indicate high mineral content.

There are a number of common elements that are dissolved in water as ions. The most common of these is calcium, an ion that also governs the alkalinity and pH of the water. Road salts used for winter deicing can increase conductivity because of the sodium, potassium and chloride ions used as salts. The other common positive ions are potassium, sodium, and magnesium, while the most common negative ions are chloride, sulfate, bicarbonate, and carbonate. Typically, these salts are found in very low quantities hence many lakes in the state are have soft water.

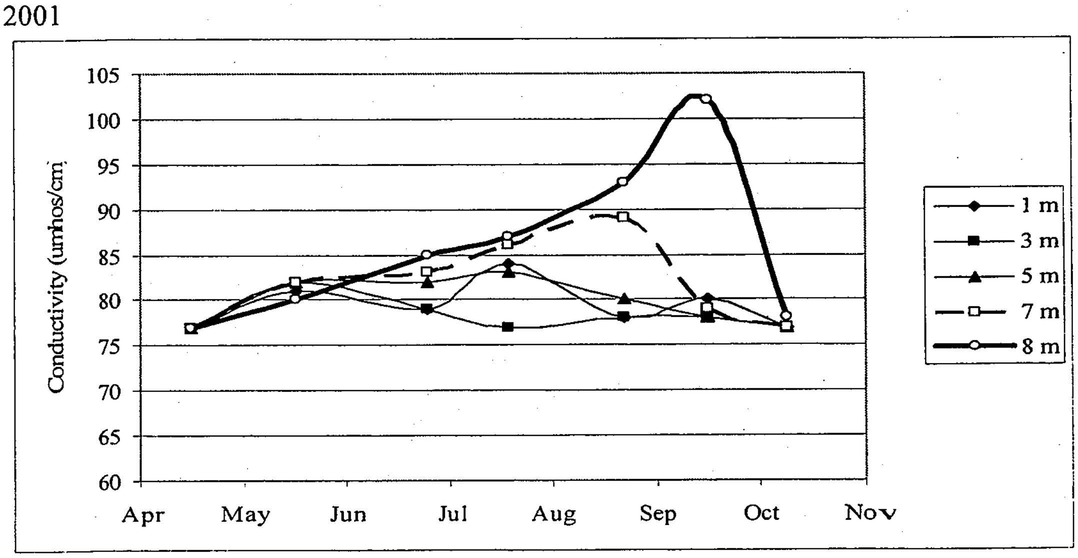
The conductivity of the Lake Hayward waters during the 2000 and 2001 seasons is shown graphically in **Figure 16**. Generally, conductance ranged between 65 and 75 µmhos/cm in 2000 and 75 and 90 µmhos/cm in 2001. The 9 meters conductivity increased to a peak of 85 µmhos/cm in August while in 2001 it peaked at 102 µmhos/cm in September. These peaks reflect the generation of dissolved ions in the anoxic water.

Figure 16. Conductivity Values From Lake Hayward, 2000, and 2001.

2000



2001



Other ions

Lake samples were analyzed for the cations (postive ions), potassium, calcium, and sodium, and the chloride anion (negative ion) quarterly in April, July, and October, during both seasons. The sodium concentration averaged 6.9 mg/L in 2000 and 7.9 mg/L in 2001. The potassium concentration averaged 1.2 mg/L in both years. The calcium concentration averaged 2.6 mg/L in 2000 and 2.9 mg/L in 2001. The chloride concentration averaged 18.5 mg/L in 2000 and 14.1 mg/L 2001.

Canavan and Siver (1995) reported ion concentrations from 1992 and 1993. Their reported sodium levels were between 4.4 mg/L and 6.0 mg/L, lower than the data obtained during this study. The potassium levels were reported between 0.4 and 1.6 mg/L, bracketing the values from this study. The reported calcium levels were comparable to those observed during this study, between 3.0 mg/L and 3.2 mg/L. Chloride was not included in their survey analysis. Frink and Norvell (1984) listed values for calcium, and potassium from 1973 and 1974. There values for those ions were identical to the values reported by both Canavan and Siver (1995) and this study. Sodium was reported at a concentration of 4.4 mg/L, and chloride was reported at 2 mg/L. The Frink and Norvell data suggests that sodium increased from 4.4 mg/L to 7.4 mg/L and that chloride has increased from 2 mg/L to 16.3 mg/L.

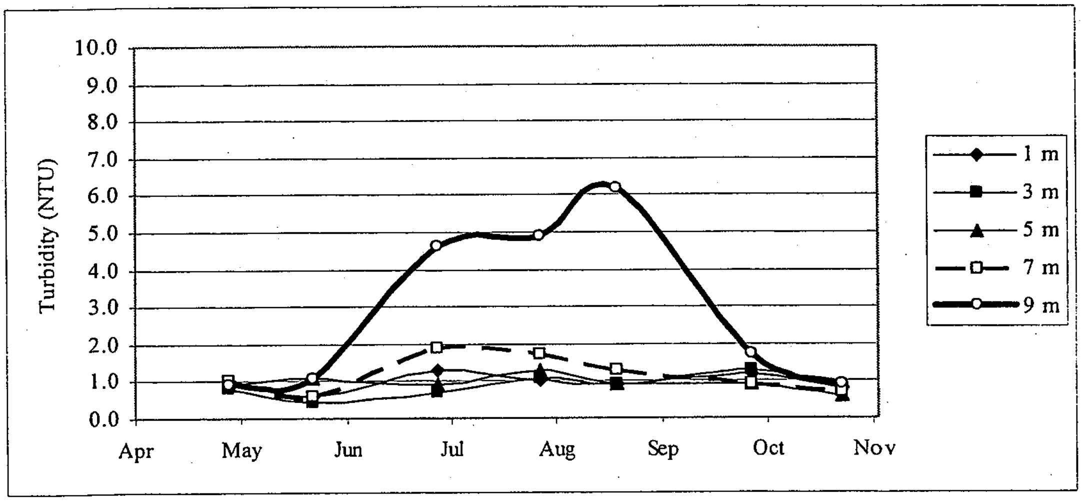
Turbidity

The turbidity of the water is a measure of how cloudy the water is. The measurement is taken by passing a beam of light through the sample with a sensor the measures how much of the light gets through. Turbidity is given arbitrary units related to the cloudiness of the reference samples called Nephelometric Turbidity Units or NTU. Drinking water has turbidities that are less than 1 NTU and class AA waters should have a turbidity maximum of 5 NTU.

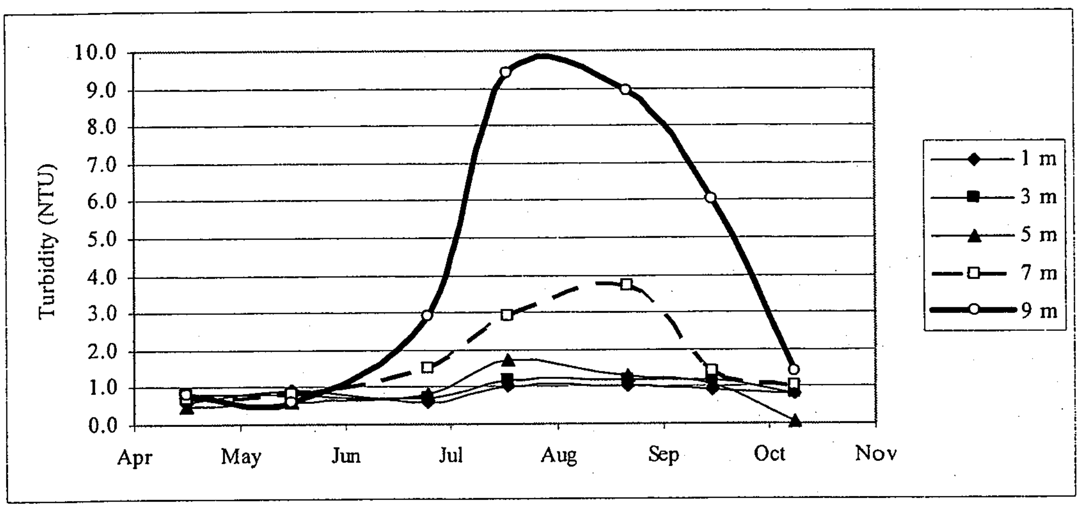
The turbidity of Lake Hayward water during each of the two seasons behaved similarly to the conductivity trends in that each of 1, 3, and 5 m depths showed very little change during the season while the 7 and 9 m depths showed increases during the summer **(Figure 17)**. The top 5 meters had turbidity readings that remained consistently around 1 NTU during both years. In 2000 the turbidity at 9 meters increased to a maximum of 6 NTU during August, while in 2001 the peak turbidity was 9.4 NTU occurring in July. The 9 meter turbidity remained high through August and September.

Figure 17. Turbidity in Lake Hayward, 2000, and 2001.

2000



2001



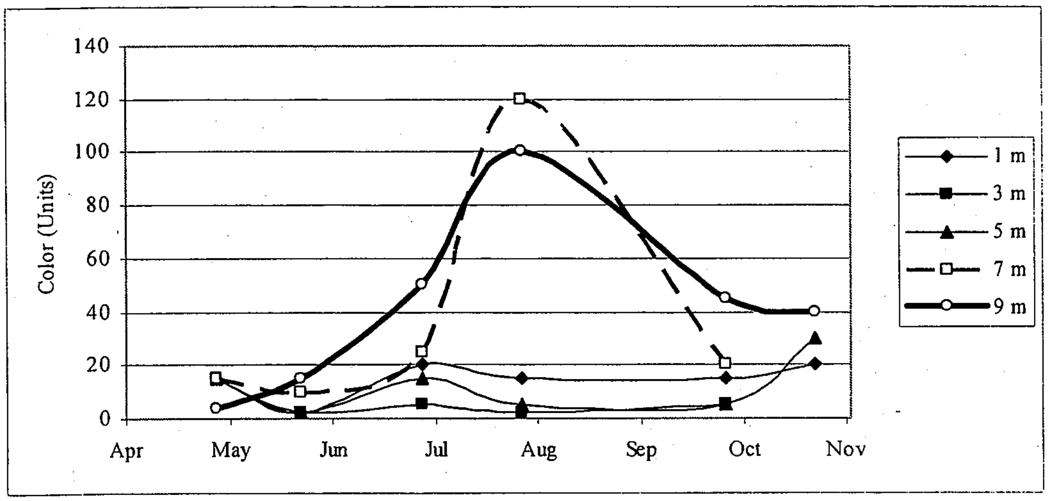
Color

The color of lake water refers to the degree of reddish or brownish staining that has been imparted to the water from tannic and humic acids. As the concentration of these materials gets higher the water looks more like weak tea.

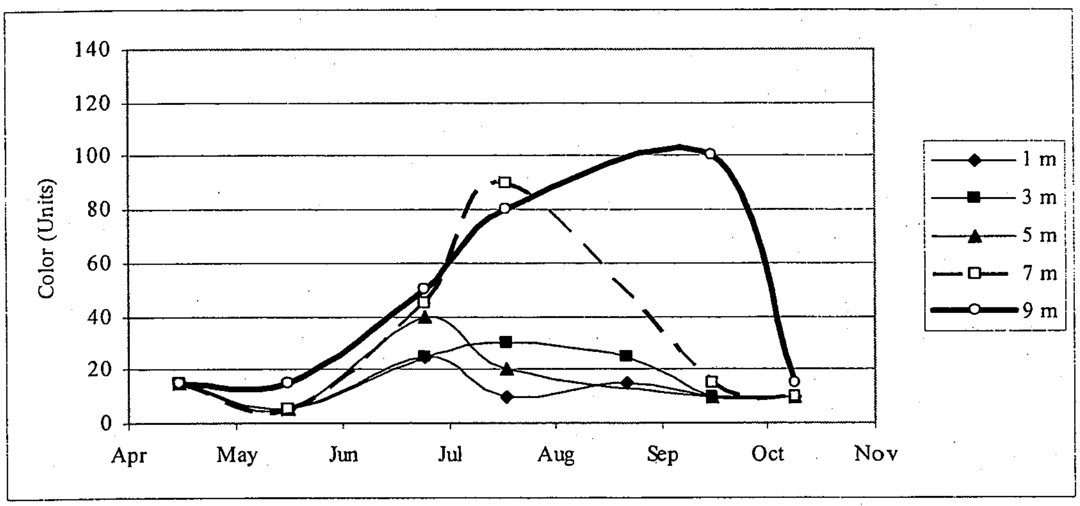
The water color during each of the two years for Lake Hayward is shown in **Figure 18.** The data show that water color at 1 – 5 meters remained somewhat constant during both years, while the 7 and 9 meter depths experienced large increases during the summer anoxic period as organic matter from aquatic plants and wetlands decomposes.

Figure 18. Water Color Trends in Lake Hayward, 2000, and 2001.

2000



2001



Alkalinity and pH.

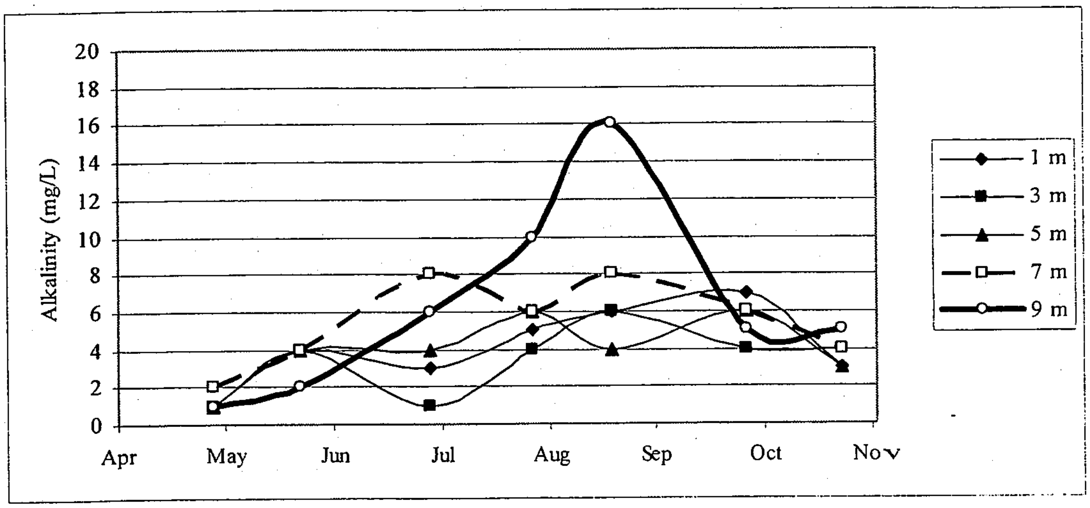
Alkalinity

The alkalinity of the water is a measure of the acid buffering capacity or its neutralizing ability in units of milligrams of calcium carbonate. The higher the alkalinity the more acid can be neutralized without any change in pH. The pH of the water is the log of the hydrogen ion concentration. The hydrogen ions are responsible for a liquid having an acidity characteristic such a citrus juice or vinegar.

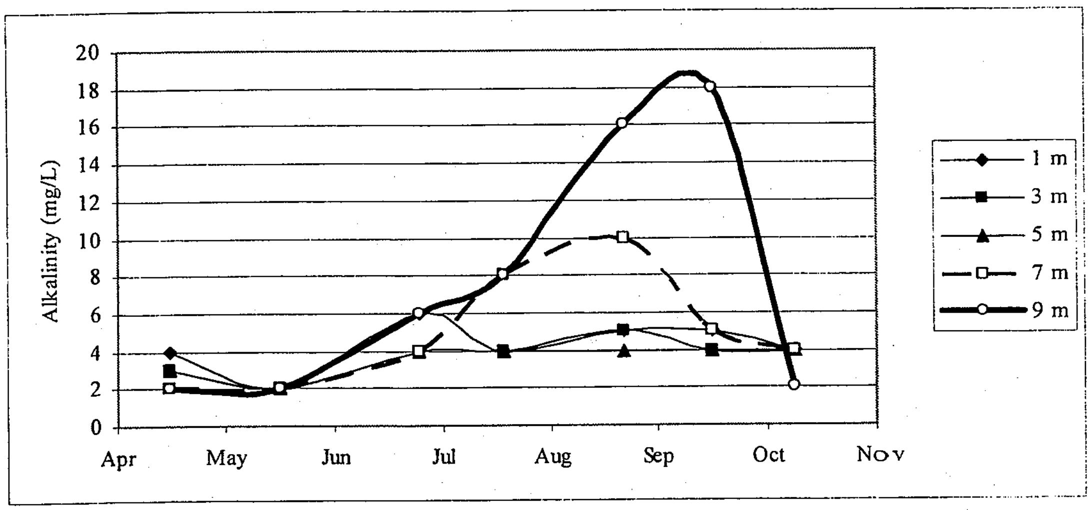
The alkalinity of Lake Hayward was found to be very low, generally surface water alkalinity ranged between 0 and 7 mg/L (**Figure 19**).

Figure 19. Alkalinity Trends at Lake Hayward, 2000 and 2001.

2000



2001



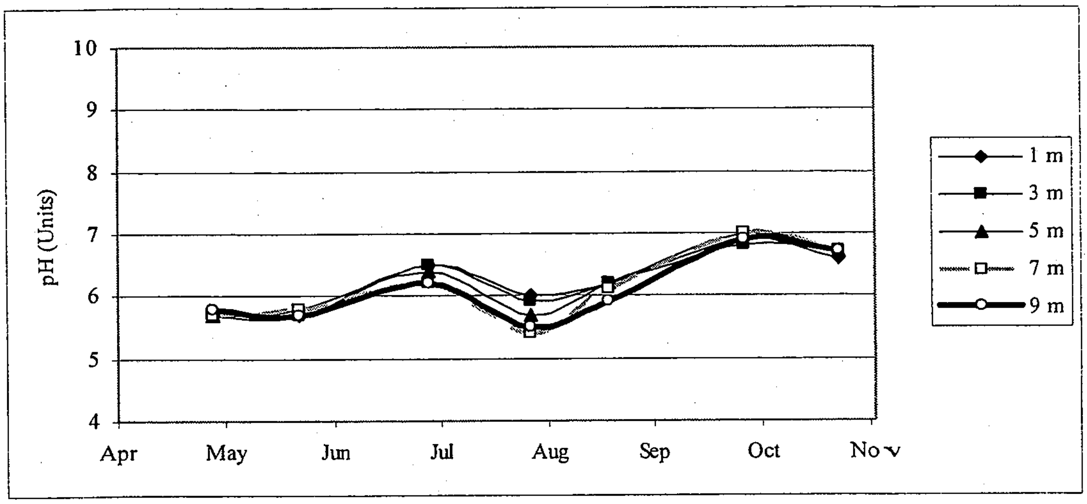
Spring alkalinity was lowest with values all below 4 mg/L. There were lake-wide increases in alkalinity during both years during the summer but the maximum alkalinity of upper waters (1 – 5 meters) never got over 7 mg/L. Alkalinity increased at 7 and 9 meters during both summers as did conductivity with peaks at 9 meters in August and September for 2000 and 2001 respectively. The CT DEP (1991) lists lakes with alkalinity in the range of 0 – 5 mg/L as being acid threatened. This may be the case for Lake Hayward because at some times of the year the lake appears to have no buffering capacity.

pH

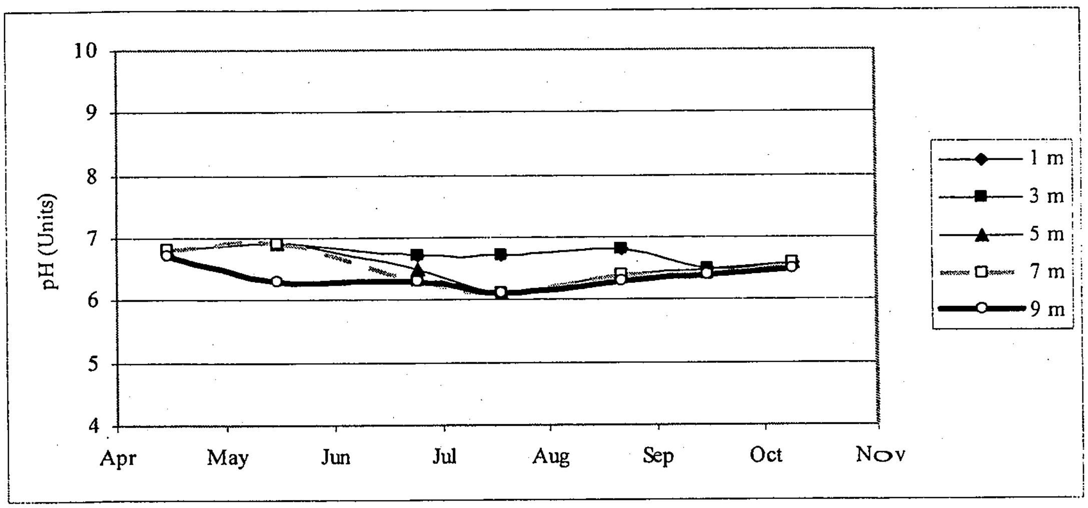
The lake water pH is presented in **Figure 20**. The lake had a uniformly low pH during both years. During 2000, the pH ranged from a low of pH 5.7 in April, to a high of pH 7 in September. In 2001 the pH remained between pH 6 and pH 7 for the season.

Figure 20. pH Trends at Lake Hayward, 2000, and 2001.

2000



2001



Iron and Sulfide

The iron and sulfide parameters are both constituents that are released from sediments during anoxic conditions. Both are common ions in surface waters with iron being abundant in Connecticut lakes.

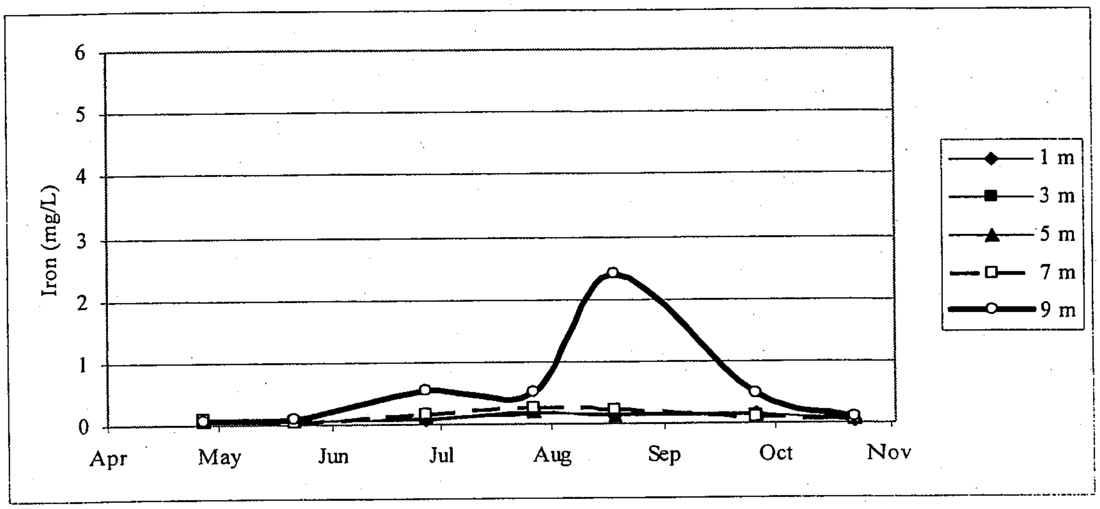
Iron

The levels of iron observed in Lake Hayward during the seasons are shown in **Figure 21**. Iron was uniformly at low concentrations at all depths except 9 meters. In 2000 the 9 meter iron concentration reached a peak in August of only 2.4 mg/L, while in 2001 it reached a peak in

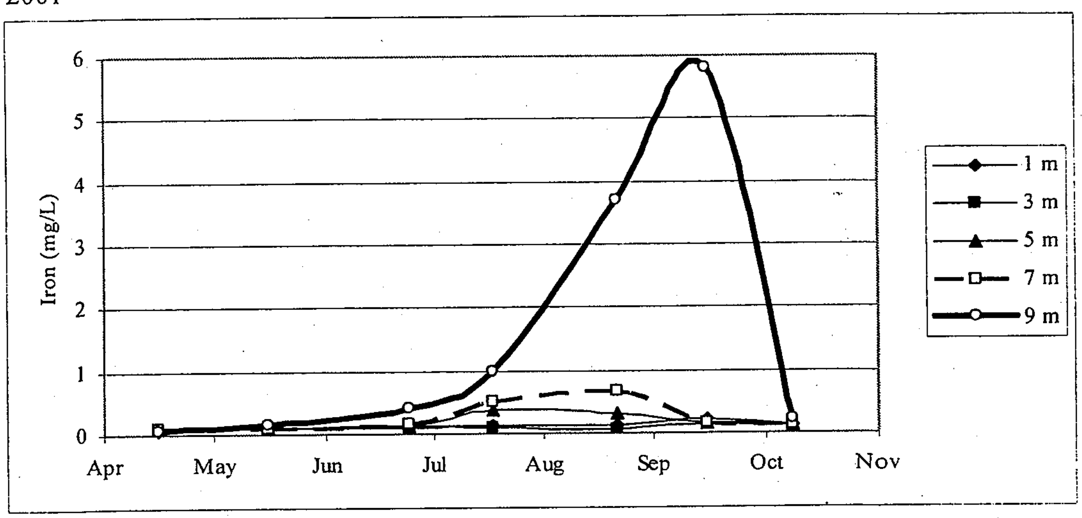
September of 5.8 mg/L. Higher levels at the bottom reflect anoxic reduction of insoluble iron to soluble forms.

Figure 21. Total Iron Concentration in Lake Hayward, 2000.

2000



2001



Sulfide

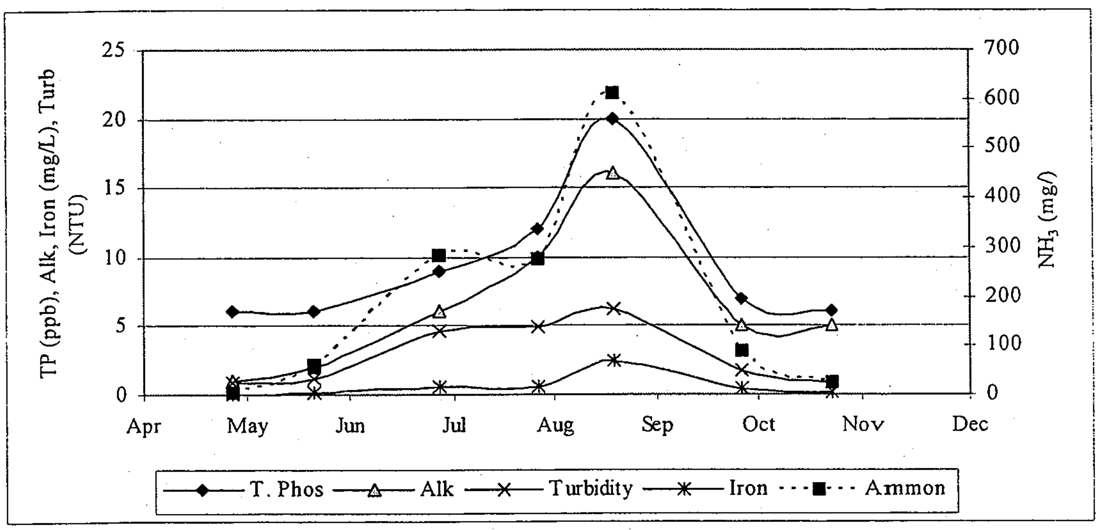
Sulfide is a by product of anaerobic bacterial respiration and only occurs in water that is anoxic and typically only at the sediment surface. Sulfide in Lake Hayward was detected only once during each the 2000 and 2001 seasons. In 2000 sulfide was found in August while in 2001 it was found in September. In both years sulfide was found at only 9 meters, at a concentration in 2000 of 0.009 mg/L and in 2001 at a concentration of 0.04 mg/L.

The redox potential, or the measure of how reducing the environment in the anoxic water becomes, was measured during the season but no values were observed less than an eH of 200 mV. This indicates that although the lake lost oxygen in deep water during the mid summer the anoxic water did not become very reducing.

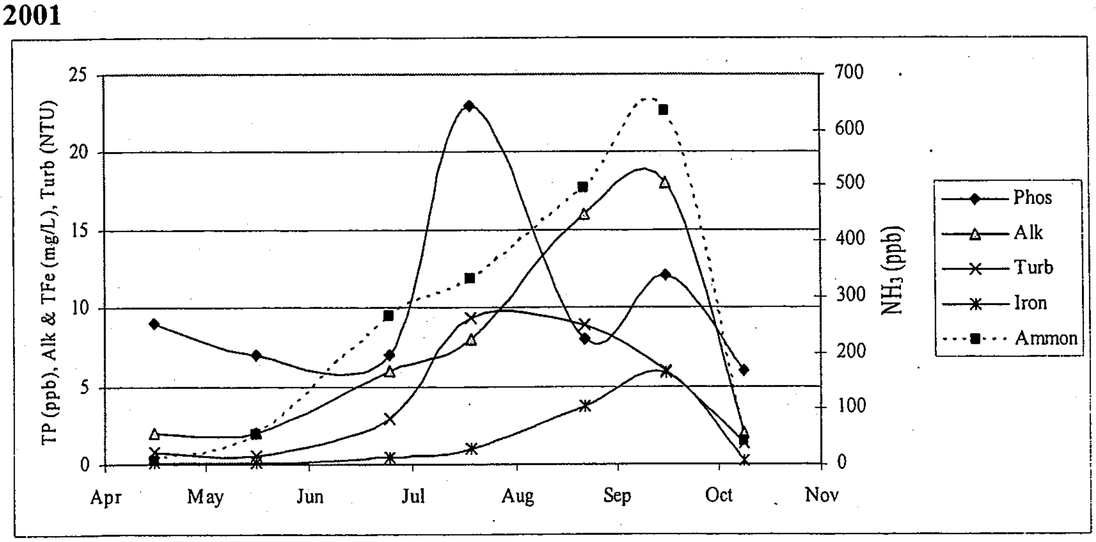
The concentrations of several constituents at the 9 meter depth are presented in **Figure 22.** This graph shows the simultaneous peaks of these parameters during August in 2000 and September in 2001. The peak concentrations represent the maximum development of anoxic water at the bottom. By July in each of the two years the thermocline reached the same depth as the anoxic boundary and began forcing the anoxic boundary down into deeper water, after that time oxygen diffusion into deep water began to cause decreases in each of the parameters.

Figure 22. Phosphorus, Alkalinity, Turbidity, Iron, and Ammonia Concentrations at 9 Meters in Lake Hayward, 2000 and 2001.

2000



2001



The anoxic boundary had been forced to the sediment surface by September after the lake mixed during strong winds in September. The values of the parameters shown in **Figure 22** all decreased dramatically from peak values in August to low background levels in September or October because of the improved oxygen conditions at all depths.

Algae and Zooplankton Results

The open water part of the lake contains single celled algae that are microscopic and free-floating. These types of algae can become very numerous in lakes with high phosphorus concentrations causing decreases in water clarity. The loss of Secchi depth is usually directly attributable to the increase in the number of algae cells in the water.

The zooplankton in a lake are free swimming crustaceans that range in size between 0.4 and 2.0 mm. They graze on populations of algae and other small organisms in the lake. They, in turn, are prey items for juvenile and adult fish species.

Both of these kinds of organisms were sampled for in Lake Hayward during each of the 14 months of lake visits. In September 2001 the fresh water jellyfish, *Craspedacusta sowerbii,* was observed in the surface waters of the lake.

Phytoplankton

The phytoplankton lakes range in size from a few microns to hundreds of microns (there are 1,000 microns in a millimeter). Some types form colonies of from a few to many hundreds. Lake Hayward phytoplankton was characterized by many very small celled types. The trends of cell numbers for each of the 5 major groups of algae are shown in **Figure 23**. These groups are diatoms, greens, bluegreens, golden, and cryptophytes. The diatoms are algae that utilize silica from the water to form glass cell walls; they are typically present in the spring and fall while the lake is experiencing overturn. Green algae are generally the most common, with many being very small single cells. This group usually appears in late spring and sometimes in early fall after the diatoms have depleted all the silica in the water and have diminished in numbers. The bluegreens are a large group that has a bad reputation for causing severe surface blooms that result in scums and slicks. Golden algae are a small group of algae with a distinctive golden-brown coloration. They can also act something like animals in that they can ingest bacteria. Golden algae can have very low phosphorus and light requirements, and some of them have swimming flagella. The cryptophytes are usually always present in lakes but generally in low numbers. There is relatively little know about this group, they swim using flagella.

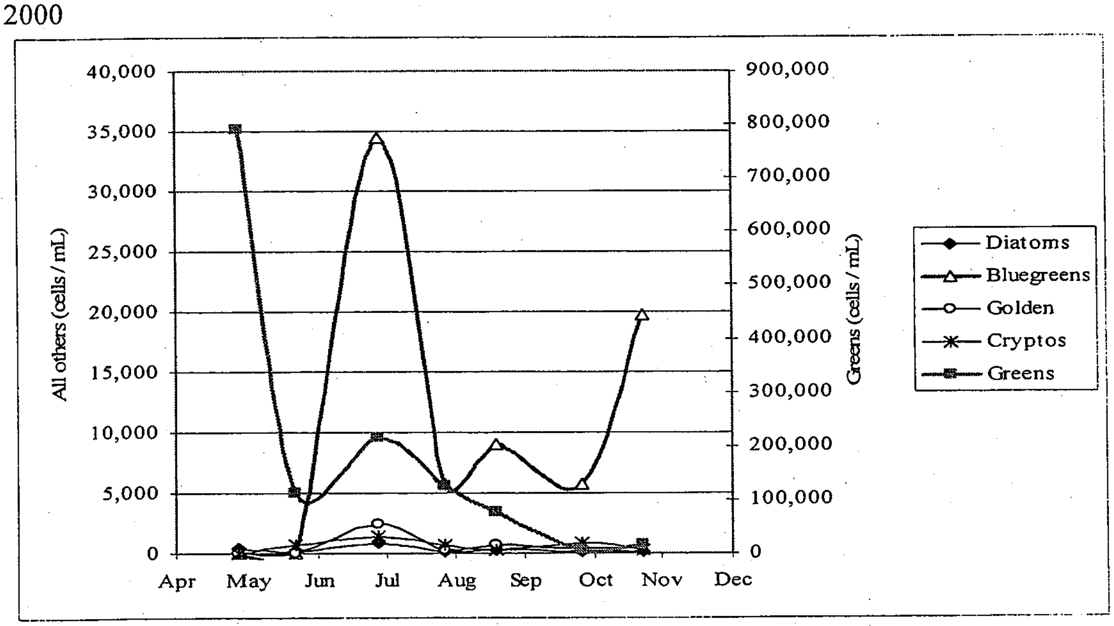
The algae counts, with cells identified to genera, for each of the two years appear in **Appendix 5.**

In 2000 there were very high numbers of a small green algae in April, although its numbers declined as the season progressed it still occurred in higher numbers than the other types. The high numbers of this alga in April apparently had little affect on the water clarity as the lake had 6 meter transparency on that date. The bluegreens reached peak numbers in June but were represented by very small organisms. There did not seem to be any group or genera that increased during the period of July to September that could have solely been responsible for the decrease in water clarity.

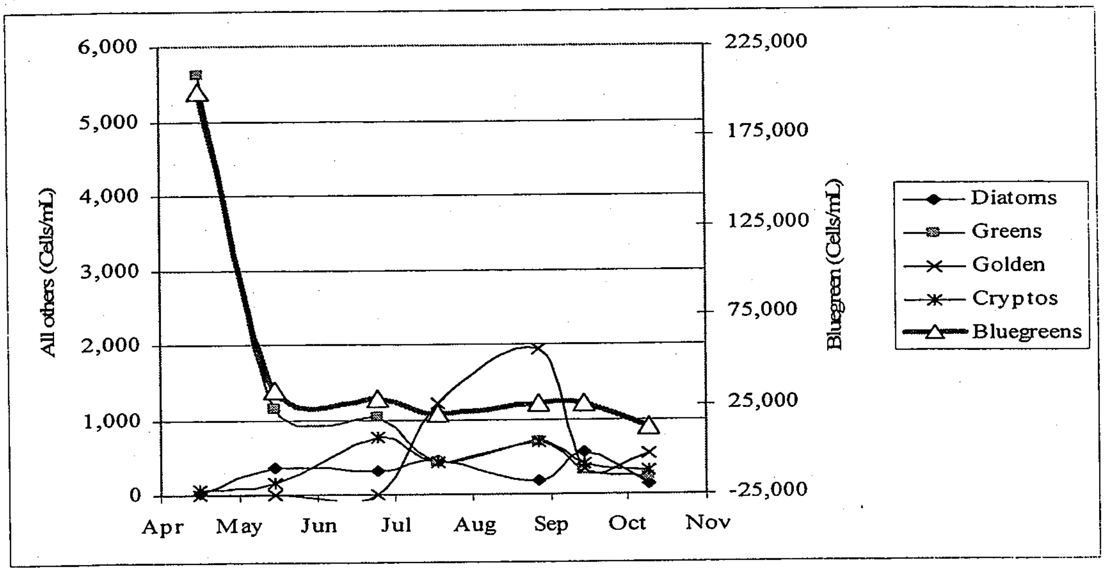
In 2001 the phytoplankton community was again represented by high numbers of small sized organisms in the lake in April. However the Secchi disk depth was very good in April so these cells did not represent an appreciable limiting agent to transparency. The only group that showed an increase during July to September was the golden algae. This group had relatively higher numbers during July and August but decreased by September and October. The bluegreens that were very plentiful in April tapered off in numbers by the summer to be replaced by a set of other bluegreens that had relatively higher numbers during the summer. A list of alga genera and cells per ml that were observed in Lake Hayward during this study are given in **Appendix 5.**

Figure 23. Planktonic Algae in Lake Hayward, 2000 & 2001.

2000



2001

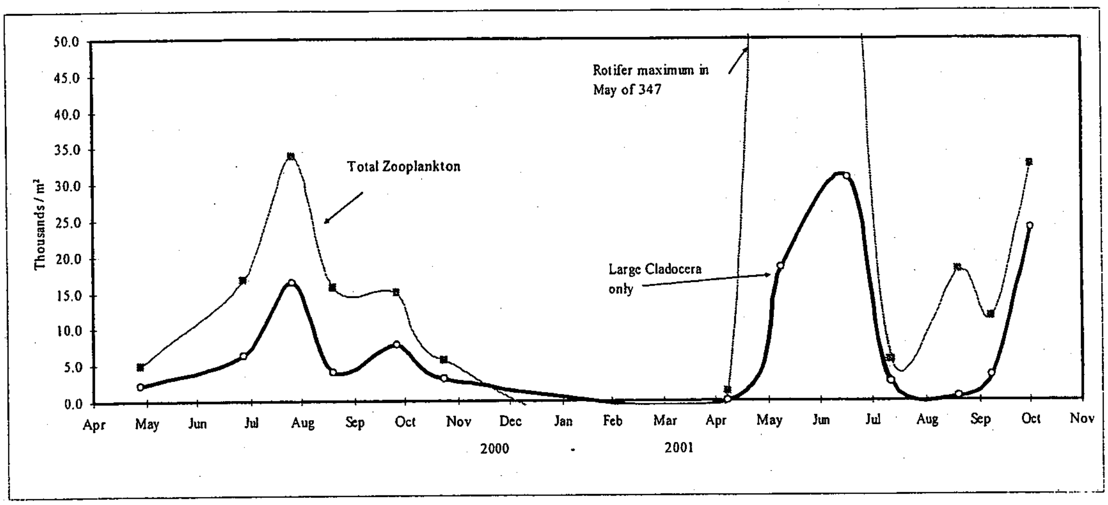


Zooplankton

The zooplankton in Lake Hayward were sampled using a vertically towed plankton net with a mesh size of 153 microns (0.153 mm). The net is lowered to the bottom then brought back to the surface. Organisms were preserved for later counting.

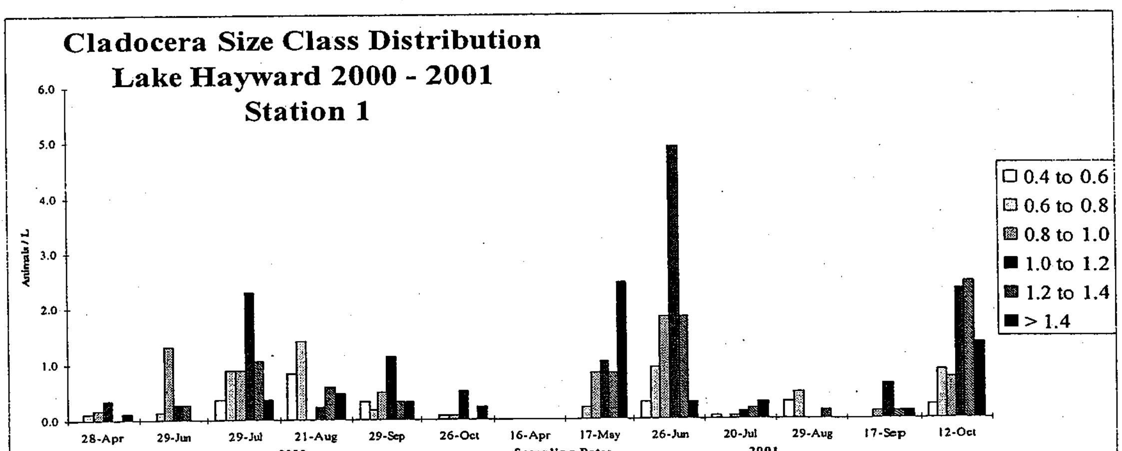
The zooplankton in a fresh water lake typically ranges in size between 0.2 and 1.6 mm and consist of several groups of animals. The cladocera are considered the most important group because they are very efficient phytoplankton grazers. The cladocera feed by filtering algae cells out of the water. The zooplankton in Lake Hayward were found to be of very large size, almost all individuals counted were over 1.2 mm and roughly half were over 1.5 mm in length. In addition, cladocera were the dominant organism, making up 80% of the population. High numbers of cladocera were collected on each of the sampling dates. The density of cladocera in Lake Hayward during both the 2000 and 2001 seasons is shown in **Figure 24.** The graph shows the numbers of cladocera, in this case mostly all daphnia and the total number of zooplankton. The values are normalized to the surface area of the lake such that the units are in numbers of organism per square meter of lake surface. The graph also shows increases of rotifers during eh mid summer. These small organisms, between 0.2 and 0.4 mm feed on the small algae and protoza in the open water and may have increased in association with the peak numbers of tiny green algae in the spring. The daphnia probably contributed to the decrease of diatoms that occurred in the spring.

Figure 24. Large Cladocerian Zooplankton Density in Lake Hayward, 2000 and 2001.



There were two peaks in zooplankton population density during the 2000 season, the first in July, and second in September. During 2001 there was one large peak in July with roughly twice the population density as was observed in 2000. The size class distribution of cladocera zooplankton is shown in **Figure 25.** This graph gives the numbers of organisms that were found in each 0.2 mm size class beginning at 0.4 to 0.6 mm and ending with those organisms over 1.4 mm in size. The abundance of large bodied cladocera indicates that the zooplankton are not being grazed by fish in excess of recruitment.

Figure 25. Cladocerian Size Class Distribution 2000 – 2001.



Summary of Lake Data

The lake had low total phosphorus levels during both seasons of sampling. The concentrations in upper waters (1-3 meters) were always below 10 ppb while deeper water had slightly higher concentrations, with the bottom water having a maximum of only 23 and 20 ppb on one occasion in 2000 and 2001 respectively. This level of phosphorus would put Lake Hayward in the oligotrophic category. The concentration of phosphorus at the time of ice-out in the spring was 4 ppb in 2000 and 5 ppb in 2001 indicating that the drainage basin contributes low levels of phosphorus during the winter. The total mass of phosphorus in the lake increased from 10 kg in April to 20 kg during the summer but declined again to 10 kg in October.

The lake had very little detectable nitrate during the two year study, however, low levels were observed during the spring of each year. Ammonia was generally at low levels or below detection in upper water but showed high accumulation rates at the bottom. Highest ammonia levels observed at 9 meters were about 600 ppb during mid summer. Organic nitrogen was higher beginning in April at 200 ppb and increased in surface waters to as much as 400 ppb and in bottom waters to a maximum of 1,200 ppb. The lake had nitrogen levels that were representative of meso-oligotrophic or mesotrophic lakes.

The lake had very soft water with alkalinities of between 1 and 10 mg/L, and both low conductivity and low pH. The lowest levels of these parameters were seen during the early spring months. The lake was poor buffered during April and May but showed some modest buffering capacity during the summer.

The water clarity was very good in the spring and fall months but poorer during the summer. Typical spring clarity was between 5 and 7 meters while summer clarity was 4 meters. The lake lost oxygen in deep water in May and developed an anoxic zone that reached up to a depth of 6 meters by the summer. A strong thermocline developed in June at around 5 meters and descended continuously deeper into the water column after that date to reach the bottom in late September. As the thermocline descended it met the anoxic boundary after which the two boundaries tracked together.

The phytoplankton were composed of mostly very small sized cells with both years showing some different dominant genera. Greens were very plentiful in the lake during 2000 while bluegreens were very plentiful during 2001. Larger sized bluegreens and golden algae tended to increase in numbers during the summer. The zooplankton population was found to composed of high numbers of large sized daphnia. Peak numbers of rotifers occurring during late spring.

AQUATIC PLANT SURVEY RESULTS

The aquatic plants in Lake Hayward were surveyed during the summers of 2000 and 2001. The species of plants observed in the lake during the survey are presented in **Table 10.** The only invasive non-native species seen was Fanwort. The distribution of the fanwort in Lake Hayward is shown in **Figure 26.**

Table 10. Aquatic Plant Species List for Lake Hayward.

Common Name	Scientific Name
Fanwort *	*Cabomba caroliniana*
Pondweed	*Potamogeton amplifolius*
Pondweed	*Potamogeton robbinsii*
Pondweed	*Potamogeton epihydrus*
Pondweed	*Potamogeton pulcher (DEP)*
Pondweed	*Potamogeton pusillus (DEP)*
Mermaid weed	*Proserpinaca palustris*
Water weed	*Elodea Canadensis*
Tape Grass	*Vallisneria Americana*
Coontail	*Ceratophyllum demersum*
Muskgrass	*Nitella* sp.
Stonewort	*Chara.* sp.
Water naiad	*Najas flexilis*
Pipewort	*Eriocaulon aquaticum.*
Bladderwort	*Utricularia minor*
Bladderwort	*Utricularia purpurea*
Bladderwort	*Utricularia vulgaris (DEP)*
White Waterlily	*Nymphaea odorata*
Floating Heart	*Nymphoides cordata (DEP)*
Yellow Waterlily	*Nuphar variegatum*
Water-shield	*Brasenia schreberi*

* = Non native invasive species
DEP = species observed by CT DEP EGIC and not seen during this study

The open water of the lake has a significant infestation of the invasive plant fanwort, *Cabomba caroliniana*. The fanwort has apparently spread south from the boat ramp out into the lake. There is a 1-2 acre patch of very dense fanwort that grows to the surface and produces flowers, beginning at the southern end of the lily beds at the north end of the lake. The fanwort bed continued southward for an additional 2,500 feet into water depths of between 15 and 18 feet deep. The plant did not reach the surface in those areas. The deeper beds had bladderwort species mixed with it. There was a second dense bed of deep growing fanwort on the east side of the long shallow bar that extends into the lake from the east. A third bed of deep growing fanwort existed in the southern narrows, south of second beach and north of third beach. Fanwort was also dense in the extreme southern end where it fills the southern most 1,000 feet of the lake. This last bed grows to the surface and produces flowers in 8 feet of water. Together there was about 60 acres of fanwort in Lake Hayward.

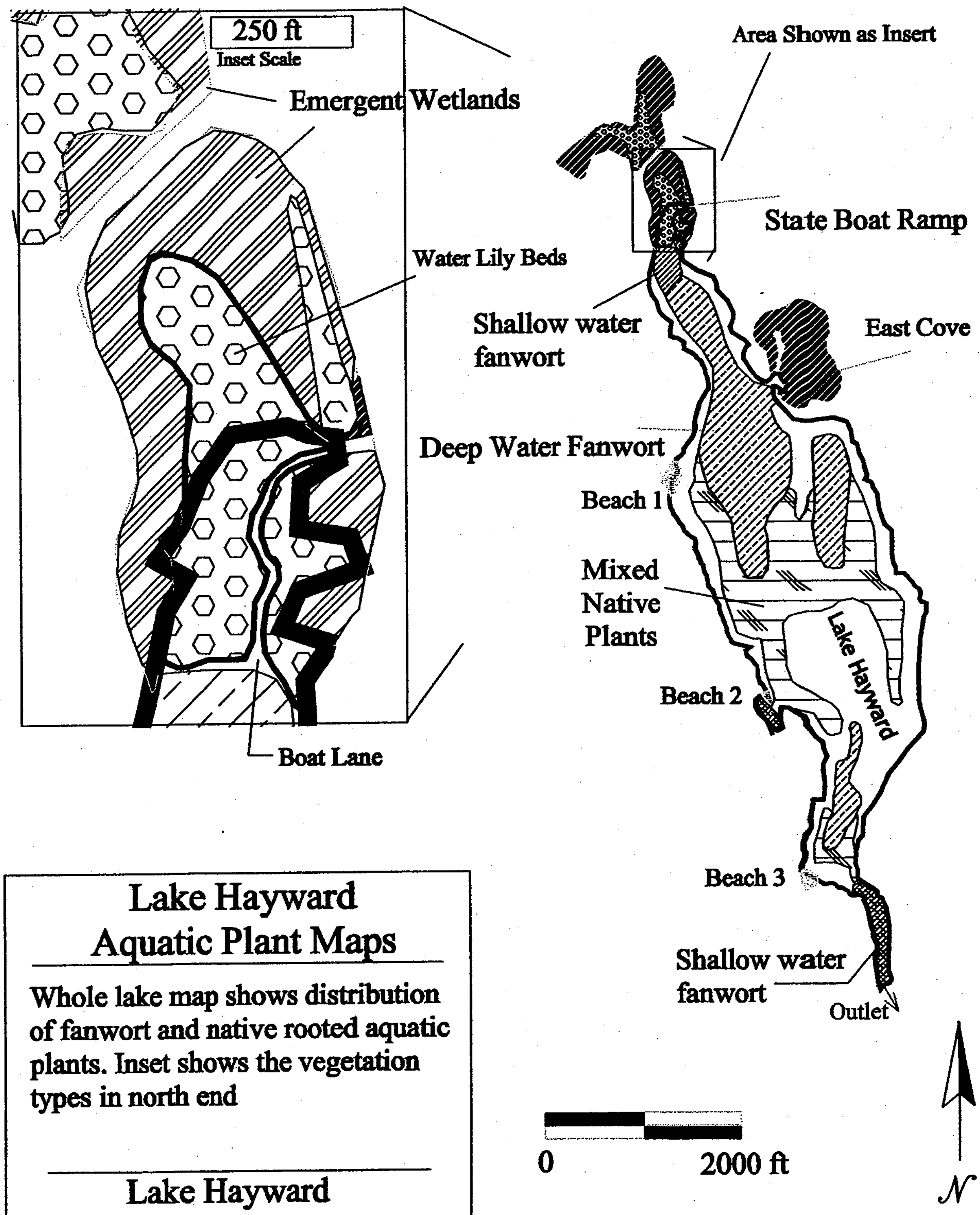
The DEP 1982 Trophic Classification of Seventy Lakes doesn't contain information about aquatic plants in Lake Hayward. The DEP 1991 Trophic Classification of Forty-nine Lakes gives a list of prominent aquatic plants in the lake but does not include fanwort. The field survey for that publication was conducted in 1989 so it is probably safe to assume that fanwort was not in the lake at that time.

The lake has emergent wetlands on the north end and inside the circular cove on the east side. The emergent wetlands consist of the shrubs; buttonbush, sweet pepperbush, alder, and the herbs; jewelweed, spirea, and steeplebush. The emergents line the banks and form small islands and inclusions into the open water parts of the coves. Within the coves the water is covered with floating leaved aquatic plants with white and yellow water lily dominant. Within these areas the lilies have formed numerous floating islands that have a diameter of 3 – 10 feet. These islands consist of buoyant rhizomes that have enough organic matter associated with them that smaller plants can germinate on the floating surface.

Over time the water lily mats become stable floating islands that can support small sedges that have maximum height of only a few inches. However over several seasons these smaller plants give way to annuals and perennial wetland herbs that are 12 to 15 inches in height. Eventually small shrubs such as red maple saplings can be supported. At first the maximum height of these saplings is only a couple of feet but can continue to increase over several seasons to heights of 6 to 8 feet. This process has caused the view of the lake from Lake Hayward Road to disappear due to growths of saplings and wetland shrubs such as alder and pepper bush. This area was open water in the 1930s. The gradual expansion of the wetlands into the lake appears to be continuing in the area of the boat ramp. During the period of the study a channel existed from the boat ramp, through an extensive cover of lily beds, to the open water. This channel may become more difficult to keep open over the next 5 to 10 years.

A request was made to the Connecticut Department of Environmental Protection, Environmental and Geographic Information Center (EGIC) for any records of populations of Federal or State listed Endangered, Threatened, or Special Concern species in Lake Hayward. The resulting response from that office included a species list of aquatic plants observed in the lake during a survey conducted by personnel from EGIC on September 30, 1998. No state listed plants have been recorded from Lake Hayward. However, the review of the Natural Diversity Data Base did indicate that three invertebrate species of special concern have been collected from the north end wetland areas. These are: 1) *Lycaena epixanthe* (Bog Copper), 2) *Tabanus fulvicallus* (Horse Fly), and 3) *Merycomyia whitneyi* (Tabanid Fly). A copy of the response letter from EGIC is included in **Appendix 10**

Figure 26



Lake Hayward Aquatic Plant Maps

Whole lake map shows distribution of fanwort and native rooted aquatic plants. Inset shows the vegetation types in north end

Lake Hayward
East Haddam, CT

DRAINAGE BASIN SAMPLING RESULTS

Sampling Stations and Discharge

In 2000 there were 6 stream sites on the east side of the lake, 4 on the west side, and one at the north end that were sampled. In 2001 the number of inlets that were visited was increased from 11 to 14 (**Table 11**). A map showing the sampling stations and subbasin boundaries of the sampled inlet tributaries is shown in **Appendix 2.** Of these new streams two were on the west and one was on the east. Two of these, one on each side, were small tributaries that only had flowing water during the wet months of March and April. The third stream added to the 2001 monitoring was W2, a stream identified in the first year sampling as important but not sampled because the culvert was found to discharge under the lake level adjacent to First Beach. During the 2001 monitoring, this stream was sampled upland from the lake at a site above the tennis courts (labeled W2u); a sample was also collected from inside the culvert at the outlet to the lake (W2l). This sample was collected knowing that it would not be representative of the stream water but instead a blending of the two, stream and lake water

Table 11. Tributary Stream Sampling Dates.

Date 2000	**4-27**	**5-19**	**6-28**	**7-25**	**8-28**	**9-29**	**10-27**
# of Inlets sampled	11	11	11	3	4	5	3

Date 2001	**3-23**	**4-17**	**5-17**	**6-17**	**6-26**	**7-18**	**8-17**
# of Inlets sampled	14	13	7	6	11	6	2
Date 2001	**9-17**	**10-11**					
# of Inlets sampled	1	3					

In 2000 all eleven streams were flowing in April, May, and June, but beginning in July several of the streams dried with only the north and two east streams flowing for the remaining months. In 2001 sampling was initiated in March by sampling storm water flows. During that sampling all 14 inlets were sampled. In April the drainage basin was still wet with 13 of the inlets flowing. After that date the tributaries began to dry with only 7 flowing in May. On June 17th a severe storm passed through the region dropping several inches of rain. During that storm, 6 of the largest inlets to the lake were sampled while they discharged high storm water flows. The streams were again sampled on June 26th and 11 of the inlets had flowing water. There was very little rain for the remaining months of the season so streams dried, only 2 were sampled in August, 1 in September and 3 in October.

The total number of stream samples collected from each of the inlets is given in **Table 12**. In 2000, 46 stream samples were collected, in 2001, 69 samples were collected. Of all the streams, the ones that flowed continuously, i.e. there was collectable flow during each of the 7 monthly field visits, were N1 and E5, the two largest drainage subbasins. All other streams dried during the summer and fall. The monitored streams accounted for 1,152, of the 1,489 acres of drainage basin area or about 77%. The remaining 337 acres was mostly direct drainage land near the lake shore.

Table 12. Lake Hayward Tributary Subbasin Areas.

Basin Identifier	Samples in 2000	Samples in 2001	Area (acres)
N1	7	8	405.79
E1	3	3	131.95
E2	2	3	10.2
E3	6	6	131.2
E4	2	3	9.6
E5	7	9	232.8
E6	3	3	43.8
E7	0	1	20.39
W1	4	5	58.4
W2	0	5	22.2
W3	6	5	38.0
W4	3	5	12.0
W5	3	4	10.8
W6	0	2	24.6
Total	**46**	**69**	**1,152**

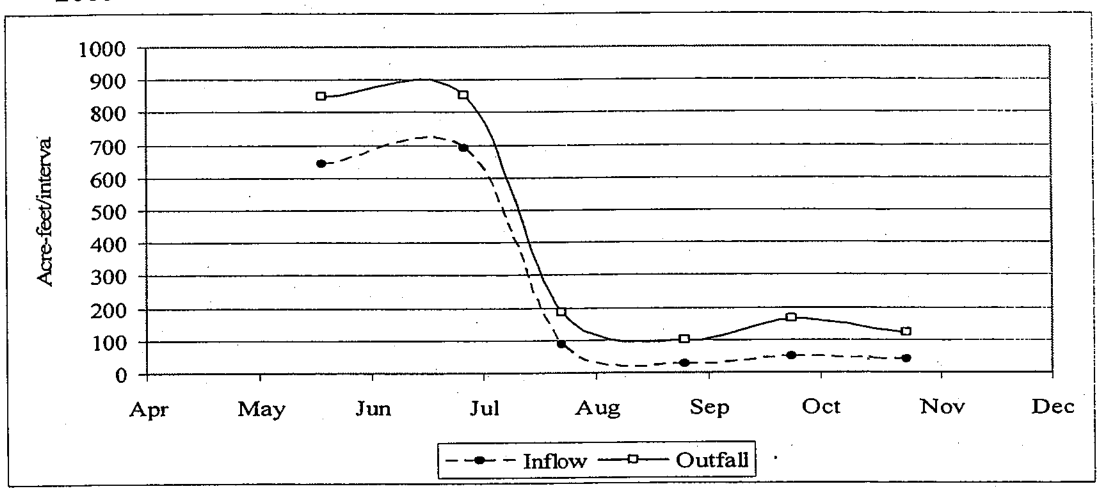
The inlet streams were monitored for discharge velocity and flow during each sampling visit. The flow values measured at each of the streams sites during the two years appear in **Appendix 9**. The discharge in cubic feet per second was converted to acre-feet during the interval of sampling. This is only a rough estimate because it assumes that the average of the two flows represents the average flow during the interval. For example, flow for inlet N1 was measured on May 19, 2000 at 5.96 cfs and on June 28, 2000 at 1.8 cfs. The average of the two was 3.88 cfs. This value was then applied to the time period between the two dates, 40 days, to estimate the total volume of water discharged at inlet N1 during that period. The method has a serious drawback in that it ignores any change in flow that may have occurred between those two dates such as storm flows, but it does provide a way of estimating baseline flows over a season. The results of this exercise are shown in the two graphs given as **Figure 27**.

During both years flows were highest in the spring tapering off quickly to low summer and fall discharge levels. In 2001 the flows out of the lake were significantly higher than 2000. The lake was experiencing ice-out during the first visit in March so a large volume of water that was stored in the lake as ice was melting and discharging. There was also high groundwater inflow and overland flow to the lake that was not measured. For example the wetland at the north end of the lake was full and discharging directly over the road to the lake suggesting that the total inflow for that date was underestimated.

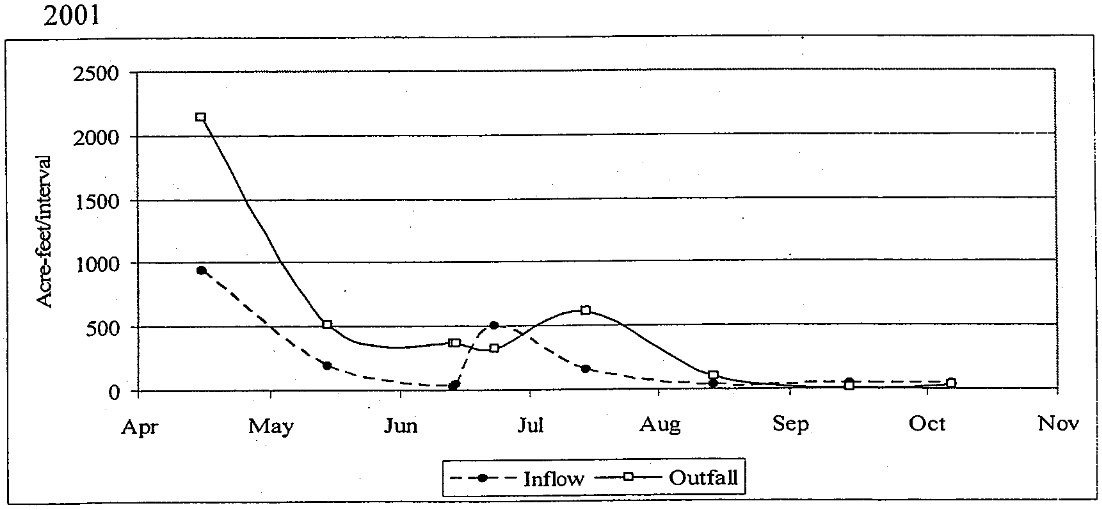
The graph of the 2001 flows shows the effect of the storm on June 17, 2001. That storm produced significant quantities of rain causing very high flows at all the inlets. The result is a small peak in the inlet discharge volume followed by a peak in the lake outlet discharge at the time of the next visit.

Figure 27. Total of Measured Flows Into (dashed line) and Out of (solid) Lake Hayward, 2000 and 2001.

2000



2001



The total estimated inflow volume for the 2000 season, April to October, was 1,527 acre-feet, while the flow for 2001 March to October was 2,102 acre-feet. The estimated discharge from the lake in 2000 was 2,267 acre-feet and 4,491 acre-feet for 2001. The difference between inlet and outlet for the two years was 740 acre feet in 2000, and 2,224 acre-feet in 2001. The lake has approximately 475 acre-feet stored in the top three feet and in each of the two years the lake lost water depth during April. In 2000 the lake lost 0.3 feet or approximately 48 acre-feet of water volume and in 2001 the lake decreased by 0.65 feet or 96 acre-feet between the March and May visits. During the March visit in 2001 the lake was also losing ice cover and had a high discharge flow out of the lake. Roughly half of the total estimated discharge for the 2001 season occurred between March 27 and April 17. The difference between inflow and discharge volumes would have come from the direct drainage areas i.e. areas of the drainage basin not represented by the sampling stations, direct precipitation on the lake surface, or groundwater inflow.

This suggests that Lake Hayward receives significant flows of groundwater during the spring but by summer these flows are diminished. These ground water flows probably help flush the lake during the spring. The loss of the groundwater inflow may have been partly responsible for the change in water color as the flows diminish in June and July.

Drainage Basin Water Quality Results

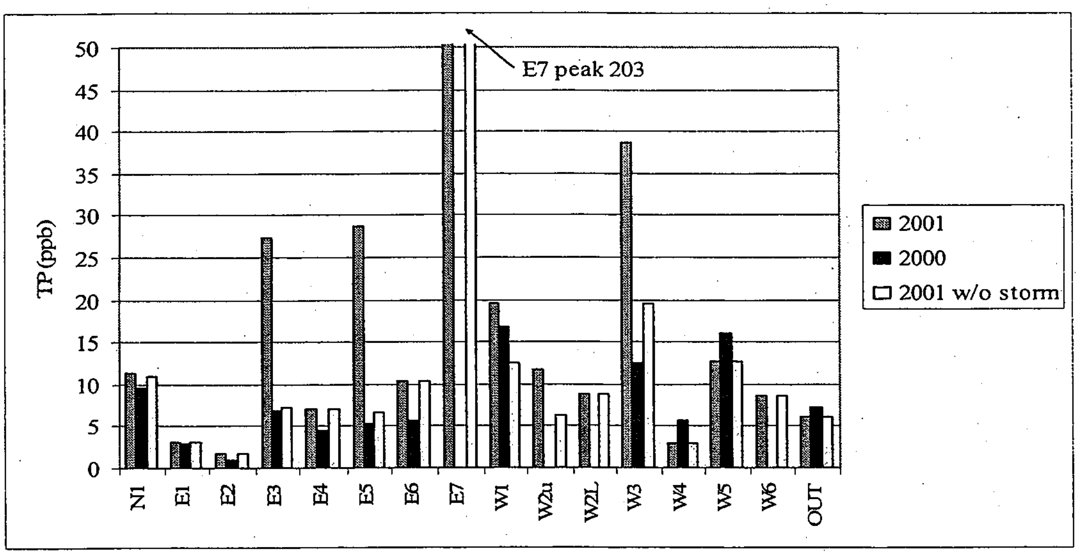
The inlet streams were sampled for several water quality parameters including total phosphorus, ammonia nitrogen, nitrate nitrogen, TKN or organic nitrogen, conductivity, alkalinity, turbidity, pH, and temperature and oxygen.

Phosphorus

The phosphorus concentration in the tributary streams varied between a low of below the detection limit of 2 ppb to a high of 31 ppb during 2000, and between a low of below the detection limit of 2 ppb to a high of 205 ppb in 2001. Most of the higher levels were due to the storm of June 17^{th} 2001. The average stream phosphorus concentrations from each of the two years are shown in (**Figure 28**). Streams E3 and E5 had inflated averages in 2001 due to concentrations observed during the storm of 128 ppb and 205 ppb, respectively. The value shown for E7 consists of a single sample collected during March and represents phosphorus in the storm water runoff. If the concentrations recorded during the storm are removed (see **Figure 28**) all eastern streams had average levels of about 10 ppb or less while western streams had average levels of between 3 and 20 ppb with three western side streams, W1, W3, and W5, having values between 10 and 20 ppb phosphorus.

The eastern streams E1, and E2, represent flows from mostly undeveloped wood land with relatively low flow discharge and non erosive banks. These streams show background or baseline phosphorus levels. Stream E3 had high flows as it drained areas of high elevation and steeper slopes suggesting that during storm flows there was probably some bank erosion causing higher phosphorus levels observed in storm event samples (June 17, 2001). Stream E5 flowed past a new development with storm water retention basins located adjacent to the stream channel. The storm on June 17th caused significant quantities of eroded material to wash into the brook and into the lake. The E7 stream drained a dirt section of East Shore Drive; the only sample from that stream was collected in March 2001 when storm water runoff was washing sediments from the road into the channel.

Figure 28. Average Stream Phosphorus Concentrations For Lake Hayward Inlets, 2000, 2001.

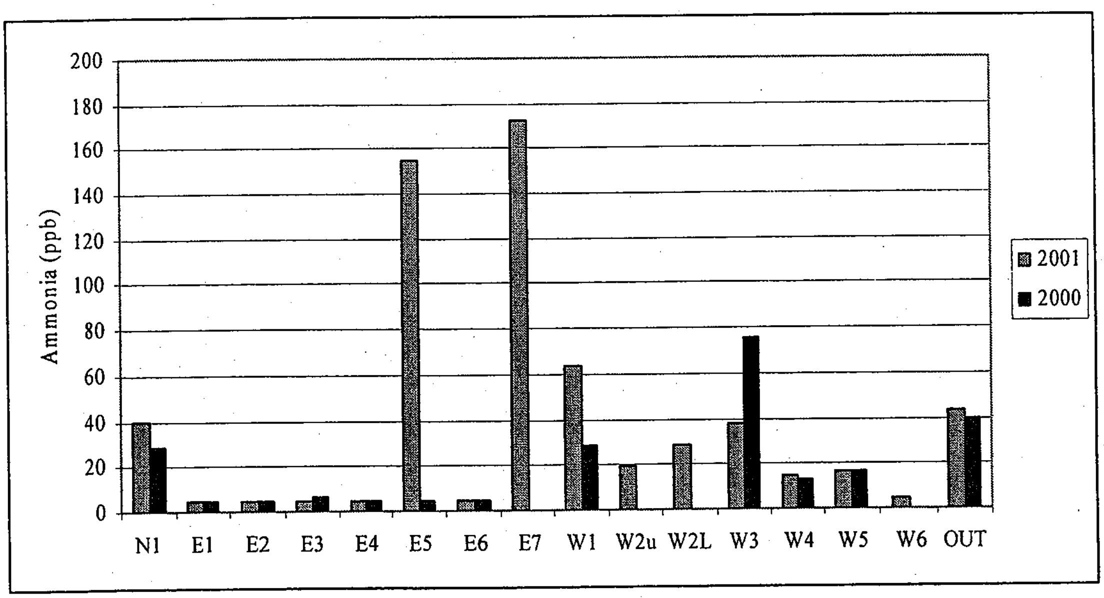


The west shore streams generally all flowed from smaller sized subbasins with dense residential land use. Each of the sampled culverts received runoff from catch basins and culverts that drained several roads. Most of the culverts had sand deltas at the discharge point to the lake. Suspended sediments from storm water have accumulated at the larger drains. The high levels of phosphorus in some samples collected during the storm in March 2001 and in June 2001 show that storm water runoff is a concern to the long term health of Lake Hayward. The average concentration of phosphorus at the outlet of the lake was about 6 ppb for both years. The difference between the outlet concentration and the higher levels observed in the inlet streams suggests that the lake retains a significant quantity of the phosphorus that it receives from the drainage basin.

Ammonia Nitrogen

Ammonia nitrogen concentrations in the streams were mostly below detection (**Figure 29**). All samples from streams E1, E2, E4, E5, and E6 had ammonia nitrogen concentrations below the detection limit of 10 ppb. The one sample from E7 showed high ammonia levels. At stream E3, W4, and W5 only one sample had ammonia levels that exceeded the detection limit. The streams N1 and W1 had most samples with detectable ammonia concentrations. The stream N1 had an average ammonia concentration of 34 ppb while stream W1 had an average concentration of 45 ppb. The average ammonia concentration for the eastern streams was 10 ppb, while the average concentration for the western streams was 29 ppb (the one sample from E7 was ignored).

Figure 29. Average Stream Ammonia Nitrogen Concentrations.



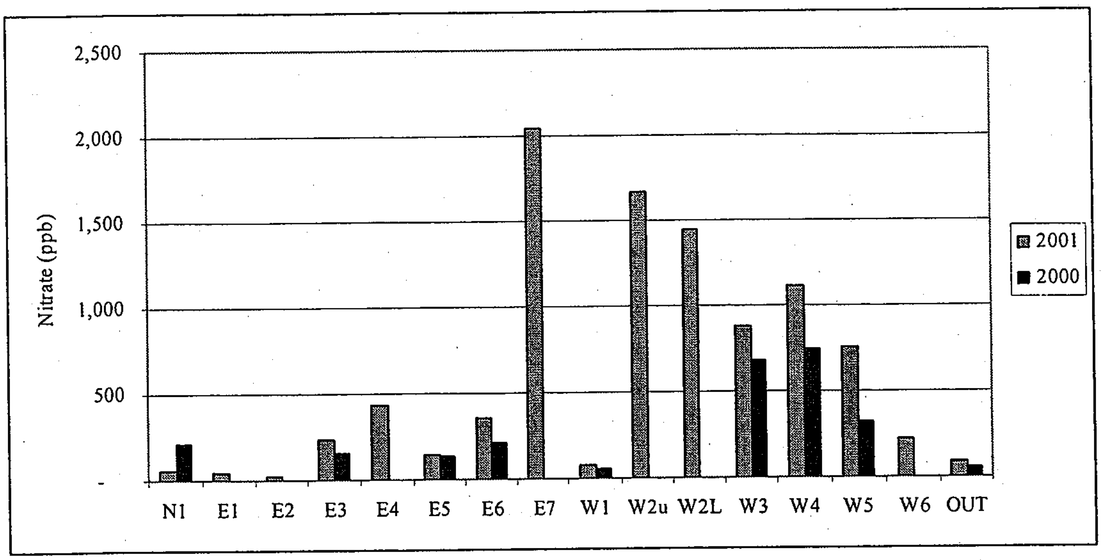
There was a clear difference in the concentration of ammonia between the eastern and western side streams. The eastern side streams, with the exception of one sample, had little to no ammonia, while the western side streams had between 10 and 80 ppb ammonia. The higher levels of ammonia in the west side streams is of interest and probably represents contribution from the residential land-use, i.e. septic systems, lawn fertilizers, and decomposition of organic matter in the streams.

The outlet had average ammonia levels of about 40 ppb which was about twice the concentration observed in the 1 meter sample at Station 1. This suggests that ammonia concentration increased between Station 1 and the outlet of the lake. One possible explanation for this increase is that the dense fanwort beds at southern end of the lake contribute organic nitrogen to the lake water which is broken down to ammonia and discharged out of the lake.

Nitrate Nitrogen

The nitrate concentrations in the inlet streams were significantly different between the east and west sides of the lake (**Figure 30**). All eastern streams, with the exception of the one sample collected from E7 had low nitrate concentrations. The two lowest were E1 and E2 where nitrate was undetectable. The western streams of W2, W3, W4, and W5 all had average nitrate concentrations that ranged between 700 and 1,600 ppb in 2001. Although the 2000 samples had somewhat less nitrate the average values for W3 and W4 both exceeded 500 ppb.

Figure 30. Average Stream Nitrate Nitrogen Concentrations.



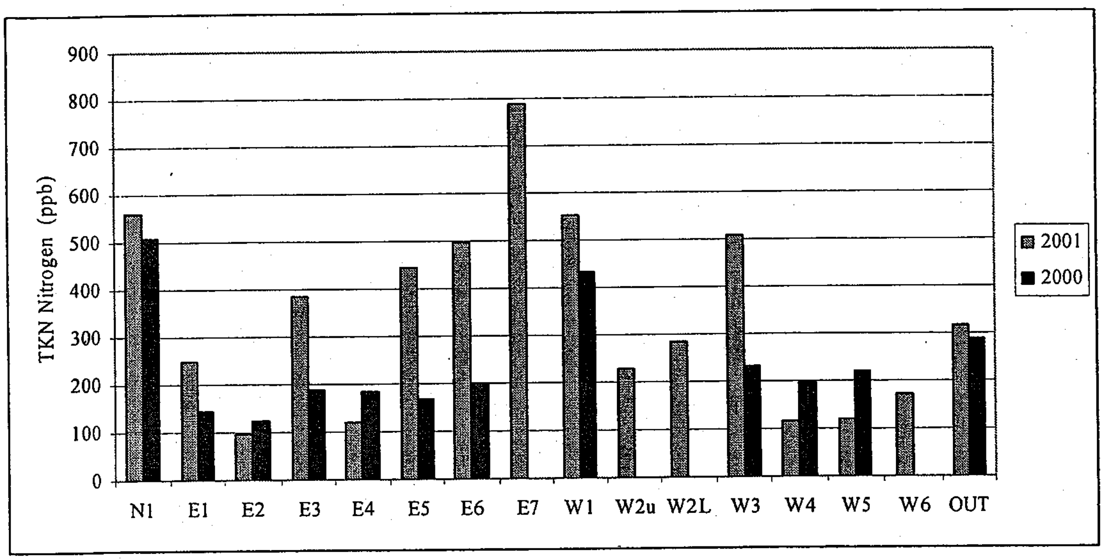
These nitrate values suggest that there is contamination of both the ground water and surface streams with nitrate from fertilizers and septic system leach fields. These waste waters have been mostly renovated of harmful contaminates but the nitrogen has been converted into nitrate during that renovation process. This nitrate becomes very mobile in the groundwater and in culvert and stream channel flows. The highest concentrations were detected in the W2 stream where the average for the 2001 season was over 1.5 mg/L. High nitrate can become a drinking water health hazard if the concentration exceeds 10 mg/L. This is possible where several tiers of houses exist on slopes allowing upstream leach field plumes to overlap down slope sources. It is also possible that the groundwater levels of nitrate exceed the levels observed in the surface streams.

TKN Organic Nitrogen

The organic nitrogen is a combination of ammonia and additional nitrogen compounds like protein and organic matter like small pieces of plant and animal matter. It represents both a source of nitrogen that can be converted to other forms and oxygen demand as it is a substrate for bacterial decomposition. There are several results of high organic nitrogen loading. Organic nitrogen almost always leads to biological ammonia accumulation as bacteria break down the complex molecules during respiration. This process called ammonification can take place in either aerobic or anaerobic conditions. After bacteria have exhausted the available energy out of the organic nitrogen molecules the remaining material is more resistant to decomposition so it accumulates as sediments with a fraction of the residue consisting of highly refractory carbon compounds, of which humic and tannic acids typically remain dissolved in the water imparting a reddish brown coloration to the water.

There is always some organic nitrogen in lake systems so levels below 200 ppb are considered low and oligotrophic. Lake Hayward streams had levels between 100 ppb and 800 ppb with most streams having between 200 and 500 ppb of organic nitrogen (**Figure 31**).

Figure 31. Average Stream TKN Organic Nitrogen Concentrations.



The stream N1 had the highest constant level with an average of 500 ppb during both years. Streams W1 and W3 also showed high average levels. Many of the 2001 averages were inflated by the storm values obtained during the June 17th, 2001 storm.

Conductivity, Alkalinity, Turbidity, pH.

Conductivity represents both the weathering of the landscape, reflecting the composition of the parent rocks and soil characteristics and the degree of both impervious surface and domestic waste water. Most rocks and soils in the eastern portion of Connecticut are low in calcium so generally lake and stream waters are soft, as was shown for the Lake Hayward. There was a very clear difference in conductivity of stream water on the east and west sides of the lake (**Figure 32**). All average conductivities on the east side were below 100 µmhos/cm while most on the west side were above 100 µmhos/cm. The values observed in W2, both at the upper site and down at the lake were the highest of all the streams. Streams W3, W4, W5, and W6 were also high suggesting that impervious surface runoff and septics are influencing stream water quality on the west side of the lake.

The alkalinity of the inlet streams is governed by calcium concentrations which in turn are determined by the presence of calcium rich rocks and soils in the drainage basin. Most of eastern Connecticut has little limestone so alkalinity levels are low. The Lake Hayward alkalinity has been shown to be lowest in the spring increasing slightly over the course of the summer. Most all stream alkalinities were below 4 mg/L (**Figure 33**), with a few of the streams showing higher levels but none exceeded 11 mg/L. Alkalinity was lowest in the spring and showed progressively higher levels over the summer to reach maximum levels in late summer and early fall. The average alkalinity values from all streams on each of the sampling months from both years are presented in **Figure 34** to show the gradual increase in alkalinity in the inlet stream water. This increase may be due to a combination of factors. The winter and spring rains may be acidic enough to lower the pH of the stream water causing the alkalinity of the water to be depressed. Once leaf out occurs acidity in the rain may have less impact on the alkalinity of the streams allowing for a rebound during the summer. Another possibility is that the streams have increased organic carbon concentrations during the summer as biological activity in the drainage basin increases. This increased carbon level elevates the alkalinity of the water. In any event the alkalinity values show that overall the streams have soft water with low buffering capacity.

Figure 32. Average Conductivity of Streams Entering Lake Hayward, 2000, 2001.

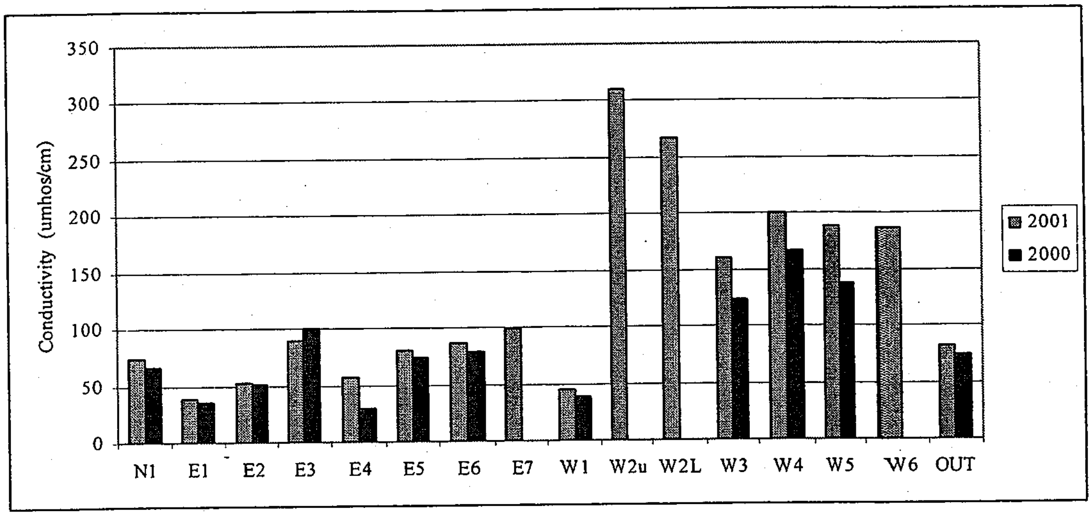


Figure 33. Average Alkalinity of Tributary Streams to Lake Hayward, 2000, 2001.

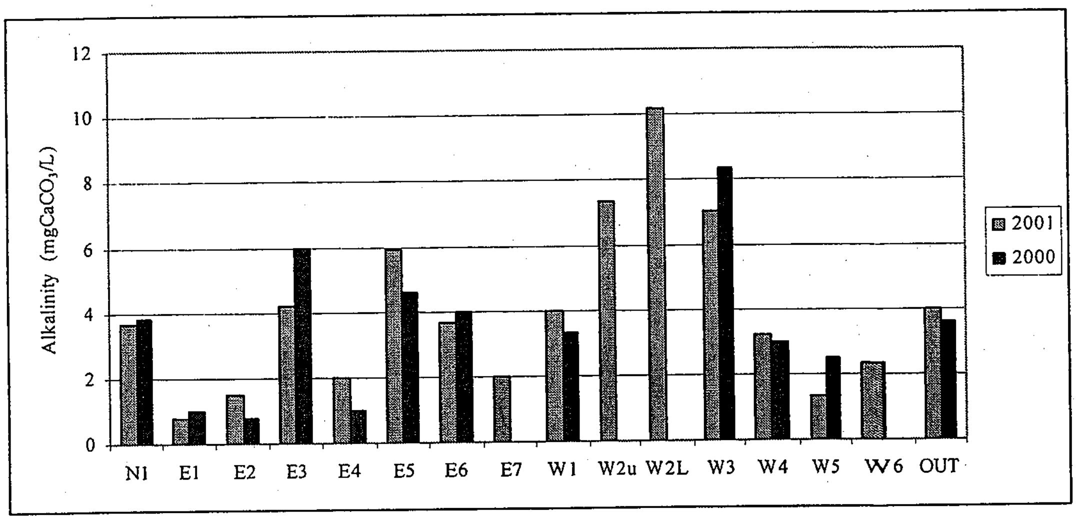
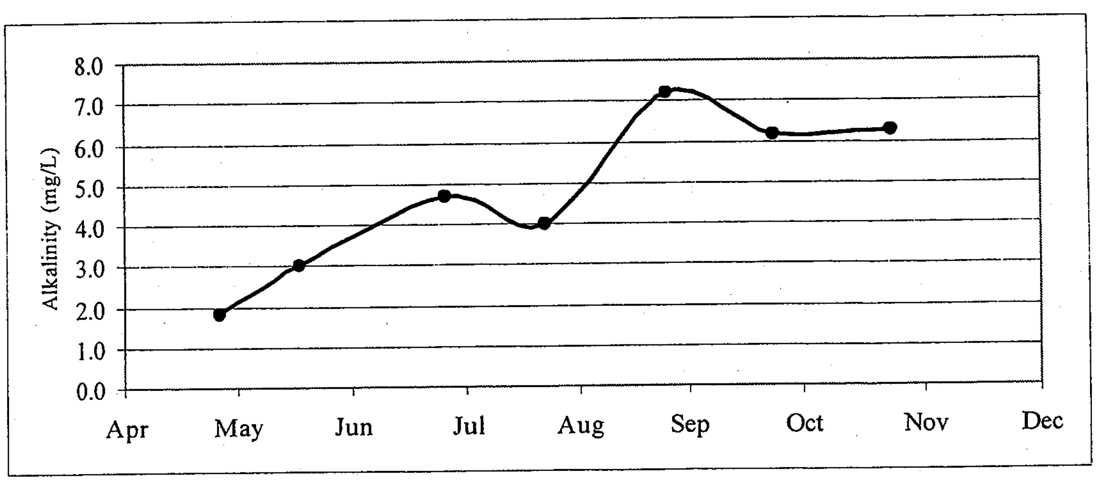
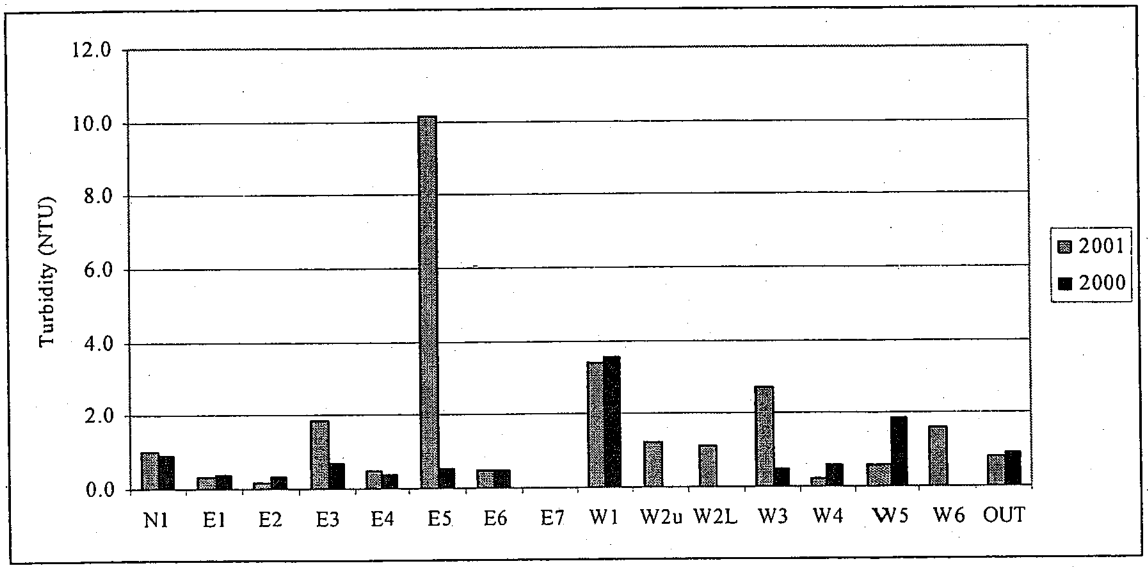


Figure 34. Alkalinity Trend For Inlets to Lake Hayward.



The turbidity levels in the streams were generally low with east side streams having values consistently below 2 NTU, except for E5 which had the average inflated due to the storm of June 17, 2001 (**Figure 35**)

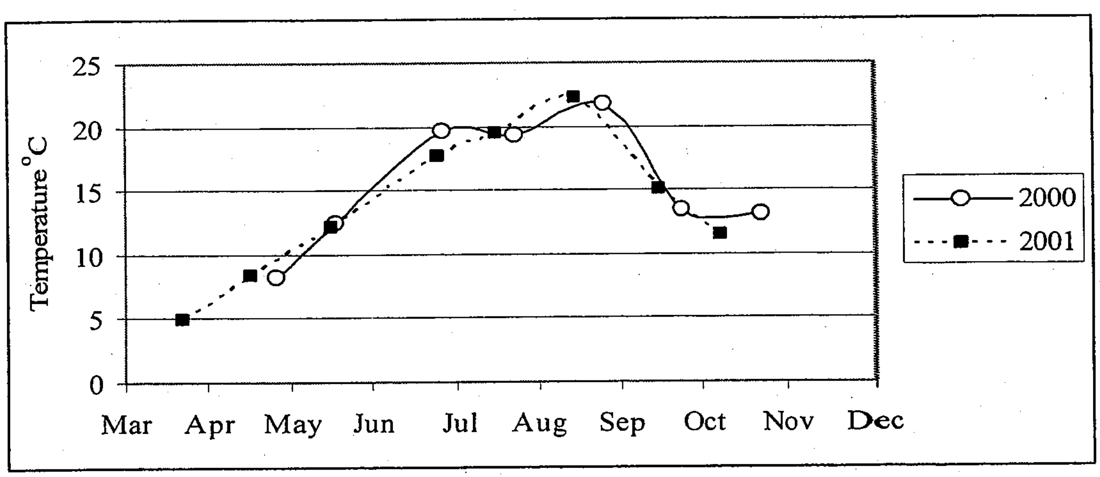
Figure 35. Average Turbidity of Streams Entering Lake Hayward.



Temperature And Oxygen

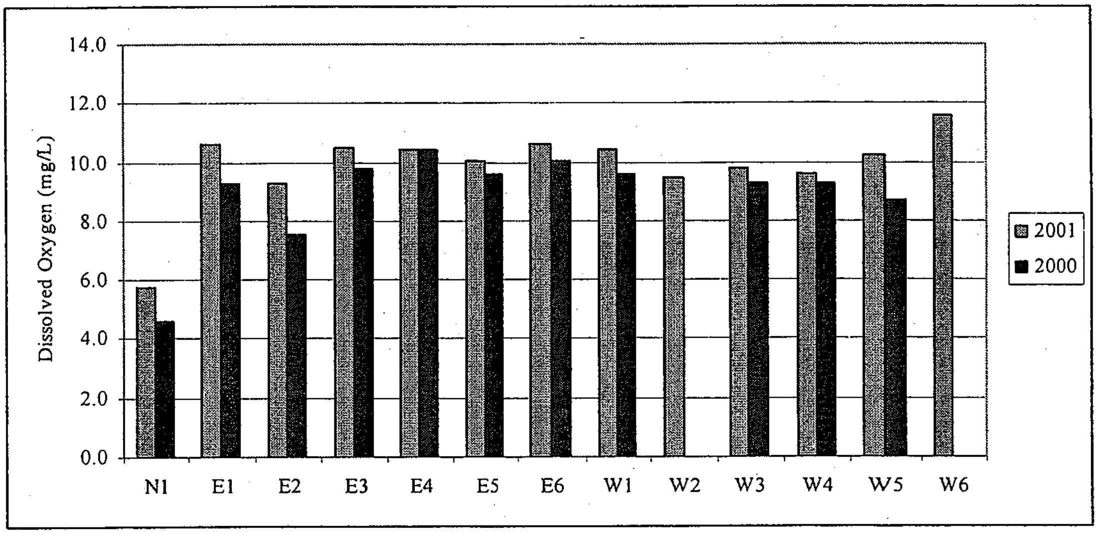
The water temperatures of the various inlets to Lake Hayward were all very similar to each other. The trend in seasonal variation is shown in **Figure 36**. The two years had trends that were similar. Stream water temperature warms steadily between March and August. Temperature declines quickly after August. Maximum water temperatures appeared to be between 20 and 23 °C.

Figure 36. Average Stream Temperature Of Inlets To Lake Hayward, 2000, and 2001.



The dissolved oxygen concentration of the inlet streams was similar between each of the inlets. **Figure 37** shows the average dissolved oxygen concentration from each of the sampled inlets. Inlet dissolved oxygen was consistently between 8 and 11 mg/L for most all sites. Stream N1 had lower oxygen in both years and on all sampling visits. That water discharged from a large wetland and represents the results of oxygen consumption in the stagnant water of the swamp.

Figure 37. Average Dissolved Oxygen Concentration of Inlets to Lake Hayward, 2000 and 2001.



Nutrient Loading

The concept of estimating nutrient loading to a lake is based on the premise that phosphorus is the nutrient in shortest supply, limiting algae growth, and that the principal source of phosphorus is from the drainage basin. The primary ways that phosphorus is transported to lakes is through the hydrology of the basin as direct runoff that occurs in streams and culverts. The amount of phosphorus that is carried by the inlet tributaries can be estimated by the existing land-use in the drainage basin, by the spring phosphorus concentration in the lake, or by directly measuring the concentration of phosphorus in the stream water.

In this report, the phosphorus loading to the lake is reviewed using three different methods. The first is the land-use method where the existing land-use is evaluated and phosphorus export coefficients are applied to those uses to estimate an annual phosphorus budget. The second way that phosphorus loading to the lake is estimated is using the spring phosphorus concentration in the lake. This method utilizes the empirical lake relationships derived from studying many different lakes over several regions. Finally, the actual phosphorus runoff data was used to estimate the total annual load to the lake.

Land Use

The CT DEP (1982) gives a break down of the Lake Hayward drainage basin area into 7 different land use categories. However, that publication incorrectly identified the total area of the basin as 2,912 acres. Frink and Norvell (1984) gave the percentages of the total drainage basin in only three categories; 6.7 urban, 5.5 agricultural, and 87.8 wooded or wet which were numerically the same percentages as given in CT DEP (1982). Frink and Norvell (1984) gave the total area of the drainage basin as 1,592 acres including the lake. As stated earlier in this report (page 15 Table 13) the area of the drainage basin is 1,489 acres and the entire basin is 1,663 acres. The land use fractions were reviewed using the 1995 CT DEP aerial photograph of the Lake Hayward drainage basin and visual surveys of the drainage basin conducted during 2001 (**Table 13**). The areas of the three types of land-use are shown in **Appendix 11.**

Table 13. Areas for Different Land Use Categories In Lake Hayward Drainage Basin.

Categories	Area (acres)	%	Area (acres)	%
	DEP 1982		This Study 1995 – 2002	
Low Density Residential (east and north)	23	0.8	132	7.9
Moderate Density Residential (west)	172	5.9	161	9.7
Other Impervious including roads			57	3.4
Urban Total	**195**	**6.7**	**350.0**	**21.0**
Crop Land (apparently all hay or pasture)	161	5.5	58.5	3.5
Agricultural Total	**161**	**5.5**	**58.5**	**3.5**
Open land	126	4.3	21.2	1.3
Wetland	40	1.4	76	4.6
Water	185	6.4	173	10.4
Woodland	2205	75.7	457.8	27.5
Wooded/Open Total	**2,556**	**87.8**	**728**	**43.8**

The percentages of the total drainage basin in the three categories are 21.0% urban, 3.5% agricultural, and 43.8% wooded. Using the phosphorus runoff coefficients given in Frink and Norvell (1984) for these three land use categories the total watershed loading of phosphorus to the lake can be estimated. The phosphorus export coefficient from urban/residential land was given as 1.52 lb/acre, for agricultural land 0.48 lb/acre, and for wooded land 0.09 lb/acre. Multiplying, coefficient times the number of acres of that land use, through gives 351.5 lbs from urban, 28 lbs from agricultural, and 65.5 lbs from the wooded/open/wet land. Together these sum to 445 lbs per year, or about 201 kg / year.

Empirical Phosphorus Models

Empirical modeling uses the relationships derived from studying a large group of similar lakes over several seasons. The phosphorus supplied to the lake during the winter and spring typically comprises a large percentage of the total annual input. That phosphorus is then mixed uniformly in the whole lake by the time of ice out. That supply of phosphorus is considered the initial growing condition, because once leaf-out occurs in the drainage basin the input of phosphorus decreases as water flows decline. Empirical studies of lakes have shown that the concentration of phosphorus in the lake at ice-out, or shortly after, is related to the annual input of phosphorus and the summer chlorophyll level or the summer Secchi depth.

Four empirical models were used to estimate the annual phosphorus loading to the lake. These models were: 1) Kirchner and Dillon (1975), 2) Vollenweider (1975), 3) Jones and Bachmann (1976), and 4) Chapra (1975) (See **Appendix 6**). Each model uses the mean depth, the flushing rate, and a retention coefficient for the phosphorus that stays in the lake and settles to the bottom. The spring phosphorus concentrations used in the models were 4 ppb for 2000, and 5 ppb for 2001. The results of the models are given in **Table14.**

Table 14. Results of Empirical Phosphorus Loading Models For Lake Hayward.

Model	Kg Phosphorus / year	
	2000 (4 ppb)	2001 (5 ppb)
Kirchner and Dillon	56	67
Vollenweider	46	56
Jones and Bachmann	24	30
Chapra	64	77
Mean	**47**	**58**

The results of the empirical modeling suggest that much less phosphorus is entering the lake than was predicted by the land use estimate. The land use method provided an estimate of 201.8 kg P/yr while the empirical modeling from the two years yielded and average estimate of 52.5 kg P/yr or about ¼ the land-use predicted load.

Direct Loading Estimates

The inlet phosphorus data collected during this study was also used to estimate the total annual load of phosphorus to the lake. The flow estimates for the period of study were used to calculate the potential load of phosphorus over the same intervals assuming that the average of the two data points represents the average phosphorus and flow during that interval. The values were estimated by averaging the phosphorus values between two simultaneous dates, i.e. April and the following May, then averaging the flow between the same two dates. This provided an average flow and average concentration for the interval between one sampling date and the next. Using these averages an estimate of the total phosphorus load for that interval was calculated. This was done for each interval and then summed for the study period. The total estimated phosphorus runoff during the period of study for each stream is shown in **Figure 38,** and the total nitrogen runoff is shown in **Figure 39**.

Figure 38. Estimated Total Phosphorus Loading from Tributary Streams During Period of Study, April – October, 2000 and March – October 2001.

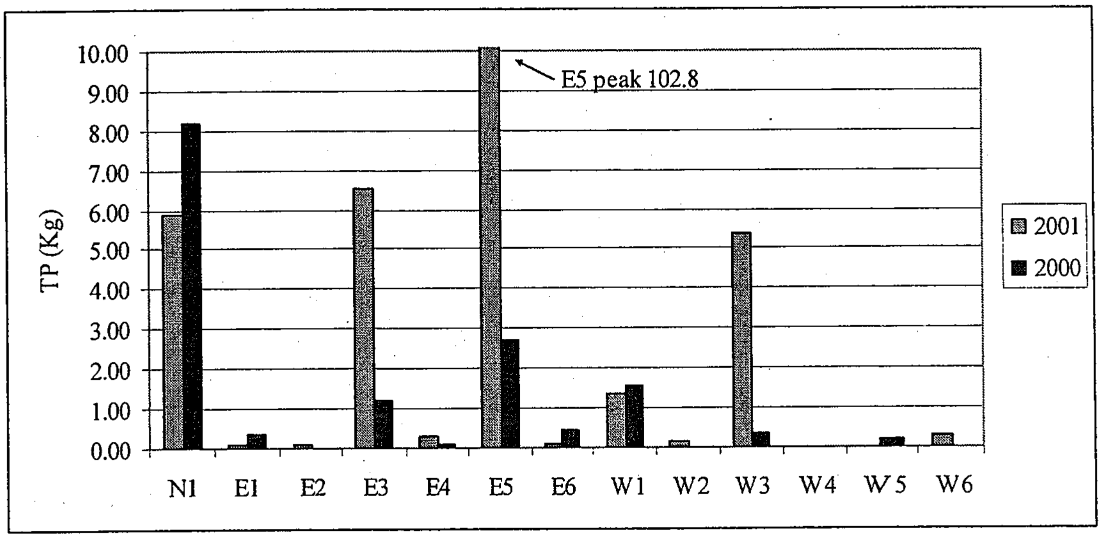
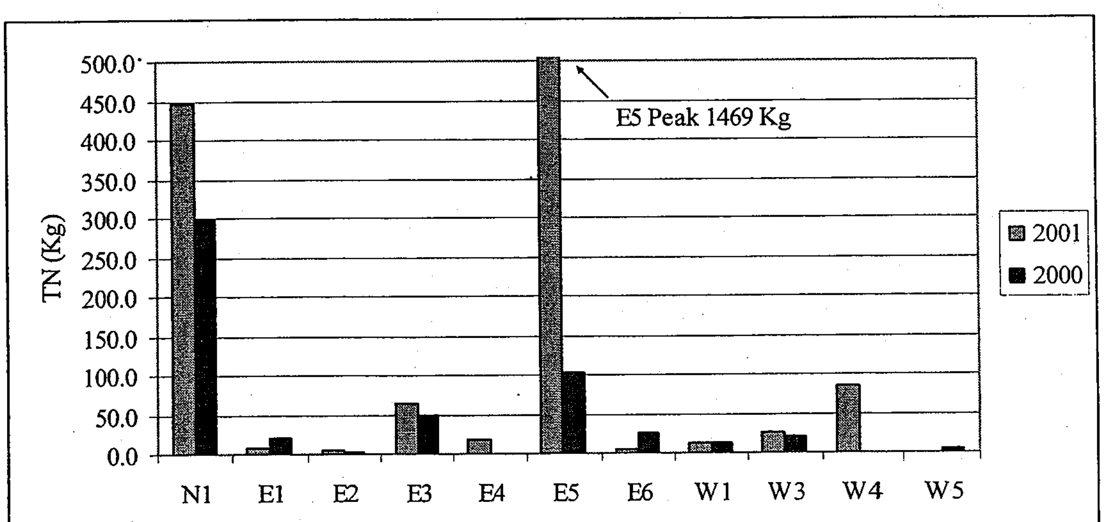


Figure 39. Estimated Total Nitrogen Loading from Tributary Streams During Period of Study, April – October, 2000 and March – October 2001



The time interval represented by the data collected during this study was 6 months or ½ of each of the two years. The total phosphorus input during that time was 15 Kg in 2000 and 123

Kg in 2001. These values are presented in **Table 15** for both phosphorus and nitrogen. It is interesting to note the high loading value for phosphorus for the May June interval due to the storm on June 17, 2001. If this value was subtracted from the total, the 2001 load would be very similar to the 2000 estimate.

Table 15. Total Phosphorus and Total Nitrogen Loads per month to Lake Hayward from Inlet Streams, 2000 and 2001.

	Total Phosphorus		Total Nitrogen	
	2000	**2001**	**2000**	**2001**
March – April		7.7		398.3
April – May	4.7	1.1	163.6	111.3
May – June	8.1	110.6	253.5	1437.3
June – July	0.9	2.12	61.0	106.1
July – August	0.4	0.6	19.7	23.3
August – September	0.6	0.5	25.2	12.7
September - October	0.4	0.5	17.1	18.8
Total	***15.1***	***123.0***	***540***	***2,138***

These data were collected beginning at the end of the rainy season and during the driest period of the year. The total water flow into the lake over the 6 months was 1,510 acre-feet in 2000 and 2,102 in 2001. The total annual hydrologic load to the lake is about 3,550 acre-feet based on the size of the watershed and an average annual precipitation level of 47 inches, and also assuming that about 23.6 inches of that rain is converted into runoff. The measured runoff was about 42% of the total annual flow in 2000 and 59% in 2001. Given an estimated phosphorus concentration of 5 ppb (mean of April and October) the phosphorus load for the remaining period of the year can be estimated and added to the measured portion to yield total phosphorus inputs to the lake for the two years of 27 Kg in 2000 and 135 Kg in 2001.

The three different loading estimates each yield different results of the total annual TP loading to Lake Hayward. The land use export coefficient method predicted 187 Kg/yr.; the empirical loading method predicted 52.5 Kg/yr., while the direct loading estimate suggested that the actual phosphorus load to the lake is between 27 and 135 Kg/year.

The export of phosphorus and nitrogen from the different subbasins is shown in **Figures 40 and 41**. The highest phosphorus per basin area was from E5 during 2001 due to the storm in June of that year, and from W3 in 2001. Export of phosphorus was generally low for 2000 and for other streams in 2001. Nitrogen export was highest at N1 for both years, E4, E5, and W4 in 2001, probably due to the storm.

Figure 40. Estimated Phosphorus Export Rates From Each Subbasin.

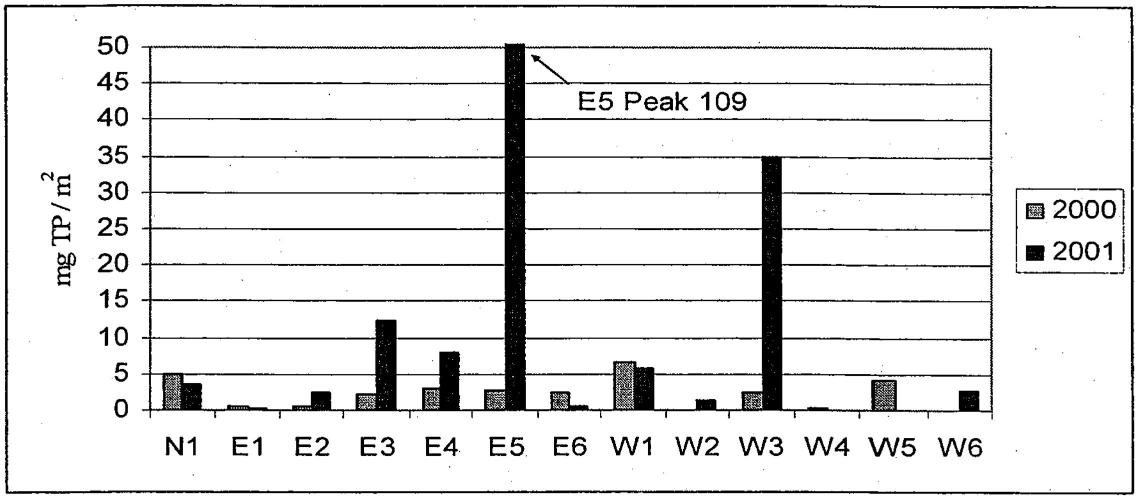
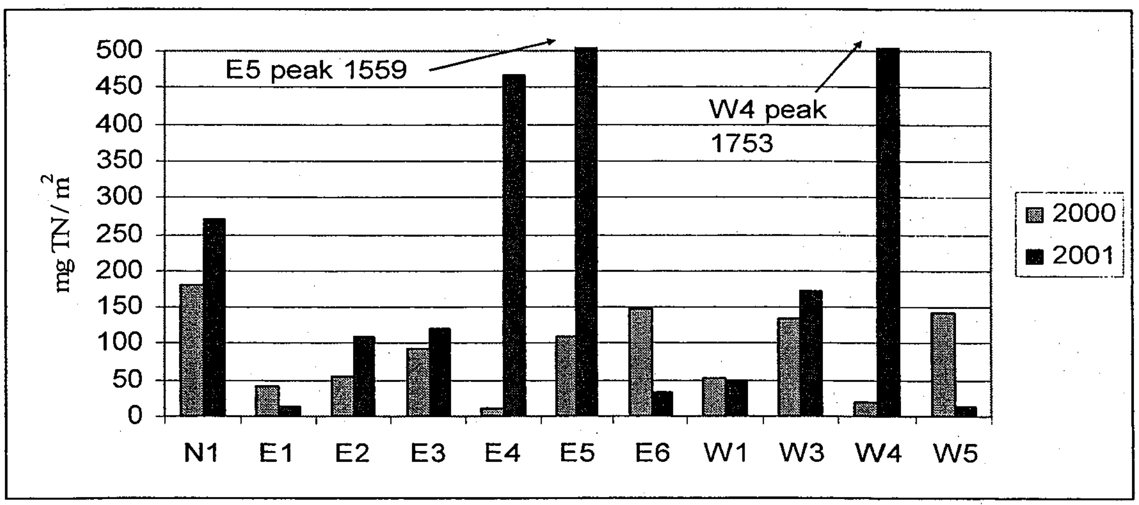


Figure 41. Estimated Total Nitrogen Export Rates From Each Subbasin.



Indicator Bacteria

In this section two aspects of pathogenic bacteria indication at Lake Hayward are presented. The first are the results of a study into the occurrence of toxin producing Escherichia coli at 1st Beach in 1999. The second are the results of routine testing for indicator bacteria at the three beaches and at several of the tributaries.

1999 Bacteria Outbreak

Three cases of hemolytic-uremic syndrome were identified in children that had been swimming at 1st Beach between July 17 and July 19, 1999. An extensive investigation was performed by the State Department of Health, local Health Departments and other state and local agencies, of environmental factors such as well water, municipal water company water and lake water. The entire shoreline of the lake was examined, but the focus of the examination was the properties within two house lots of the lakefront in the area where the infected patients resided. There was also a telephone survey of all the people that had stayed or visited homes in the area of lake during July 16–25, 1999. Out of the identified population, 436 people provided interview data. The report concluded that the most likely source of contamination was a toddler in diapers with onset of severe diarrhea on July 16, 1999. People that were in the water during the period of July 16-18, 1999 were exposed to contaminated lake water. Children younger than 10 years old were at greater risk along with people who drank lake water.

The environmental survey did not identify any environmental problems that could account for the outbreak at 1st beach. No E. coli was detected from the lake water or the municipal water, however E. coli indicative of fecal contamination was isolated from sediment samples and water samples collected from inlet W2.

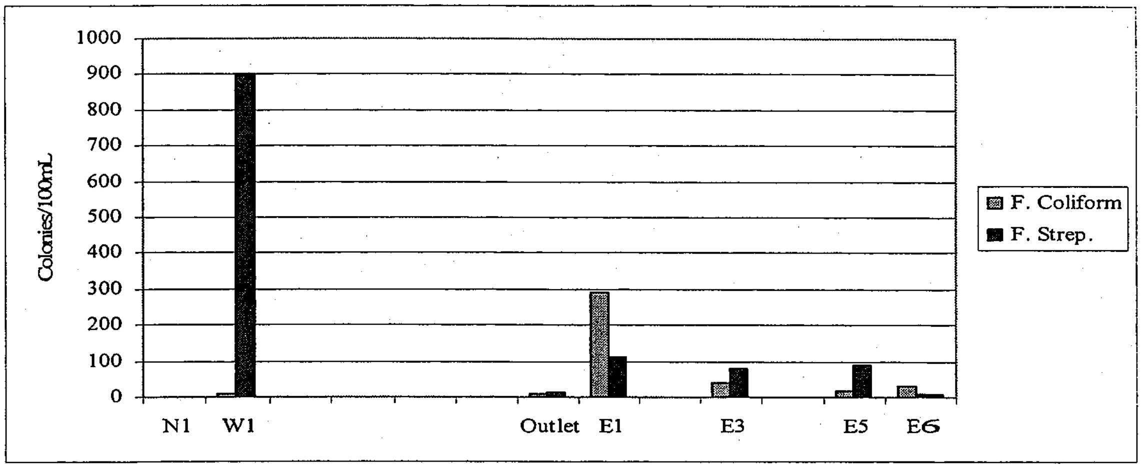
The report, published in Pediatrics October 2001 (Vol. 108, No. 4), and several newspaper clippings have been attached to the end of this report as **Appendix 7**.

Routine Testing

No bacteria samples were collected as part of this study. However, indicator bacteria have been collected from inlets during both the 1989 and 1991 stream surveys and from the beaches in 1985, 1988, 1989, 1990, 1992, 1993, 1994, 1998, and 1999. The stream survey of 1989 was conducted in October with testing for fecal coliform and fecal streptococcus only. Six streams were sampled, W1, E1, E3, E5, E6 and the outlet. The 1991 survey, conducted in December, included total coliform, fecal coliform, fecal streptococcus, and total enterococcus. That survey tested inlets; N1, W1-W5, E1, E3, E5, and the outlet. The beach surveys tested for total coliform beginning in 1985, following with fecal coliform, fecal streptococcus, and total enterococcus beginning in 1992.

The results of the 1989 survey are shown in **Figure 42**. The highest bacteria were found at inlet W1 where there were 900 colonies/100 mL of fecal streptococcus, with no fecal coliform bacteria present. Inlet E1 had 290 col./100mL fecal coliforms and 110 fecal streptococcus col./100 mL. Other inlets had levels of bacteria that were below 100 col./100mL.

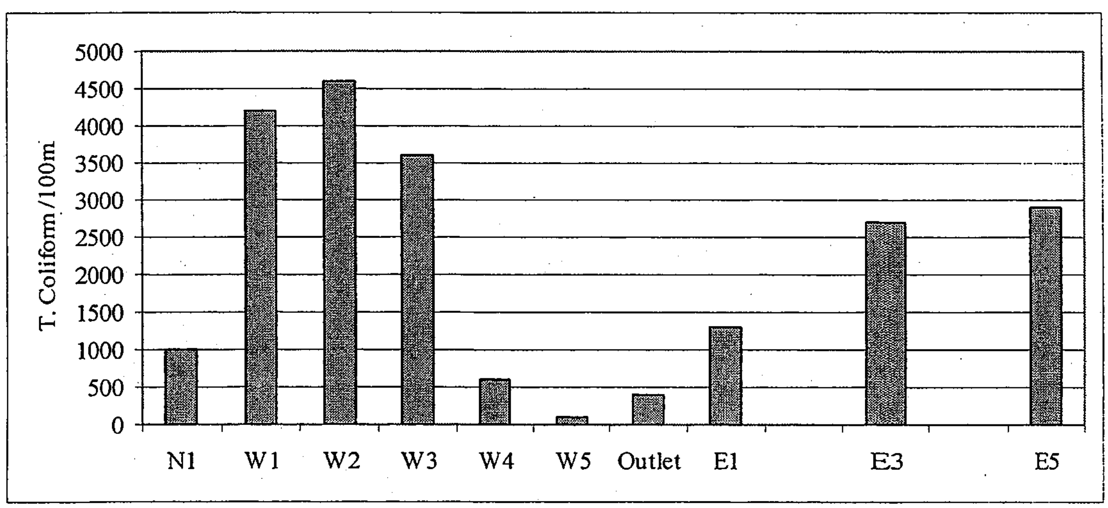
Figure 42. Fecal Coliform and Fecal Streptococcus Bacteria Results From 1989 Survey.



These results indicate that some level of bacteria was present at the two inlets, W1 and E1; with W1 presenting a level that warranted concern. The interesting aspect of the results was that fecal coliform was undetectable while streptococcus was high at W1. The streptococcus bacteria are more tolerant of conditions outside their original host and so have a longer survival period perhaps up to 9 days, while the coliforms usually die off rapidly within a day or so.

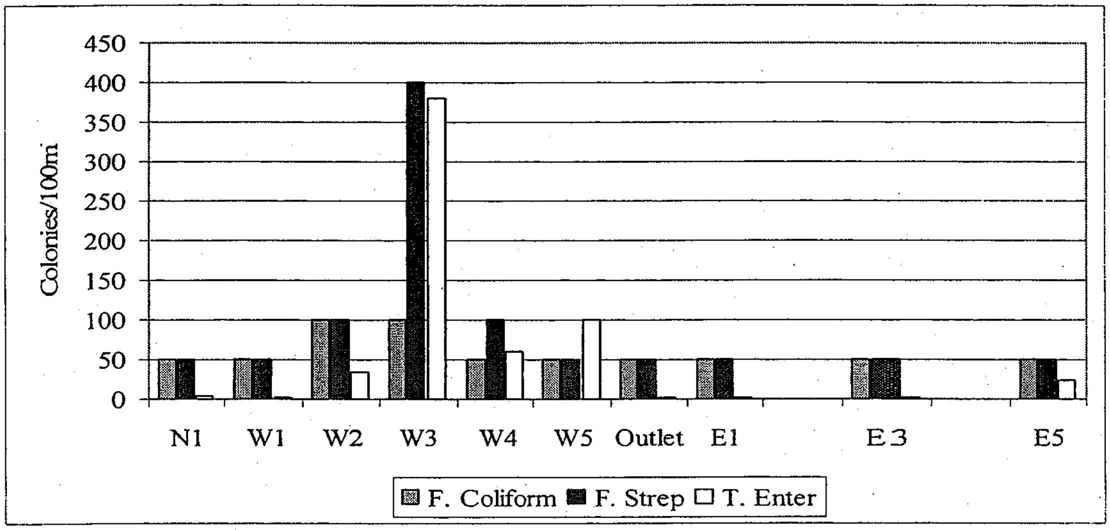
The 1991 results are presented in two graphs. **Figure 43** shows the total coliform data, while **Figure 44** shows the remaining three indicator organisms. The total coliform data show that streams W1, W2, and W3 had levels between 3,500 and 4,500 col./100 mL, while other western inlets W4, and W5 had low levels. The eastern inlets E3 and E5 had between 2,500 and 3,000 col./100mL, while E1 had 1,500 col./100mL.

Figure 43. Total Coliform Bacteria Collected From Inlet Streams Dec. 1991.



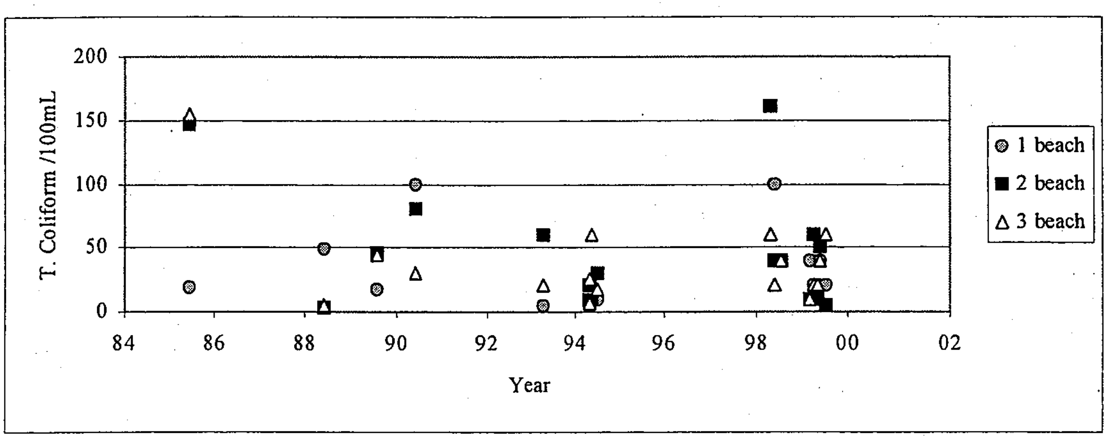
The other indicator groups were high only at inlet W3. Other inlets were below either 100 or 50 col./100 mL. The inlet W3 had high levels of both fecal streptococcus and total enterococcus, both exceeding safe bathing levels. The inlets that were high in 1989 survey, W1 and E1, did not have significant levels measured in 1991.

Figure 44. Fecal Coliform, Fecal Streptococcus, and Total Enterococcus Bacteria Collected From Inlet Streams Dec. 1991.



The data from the beaches has been presented in four graphs, one each for the four different indicator organisms total coliform, **Figure 45**; fecal coliform, **Figure 46**; fecal streptococcus, **Figure 47**; and total enterococcus, **Figure 48**. The samples were collected from near shore water at the three bathing beaches on the west side of Lake Hayward; Beach 1, Beach 2 and Beach 3 (see Aquatic Plant Map **Figure 26** for the beach locations).

Figure 45. Total Coliform Bacteria Results From Three Lake Hayward Beaches, 1985 – 1999.

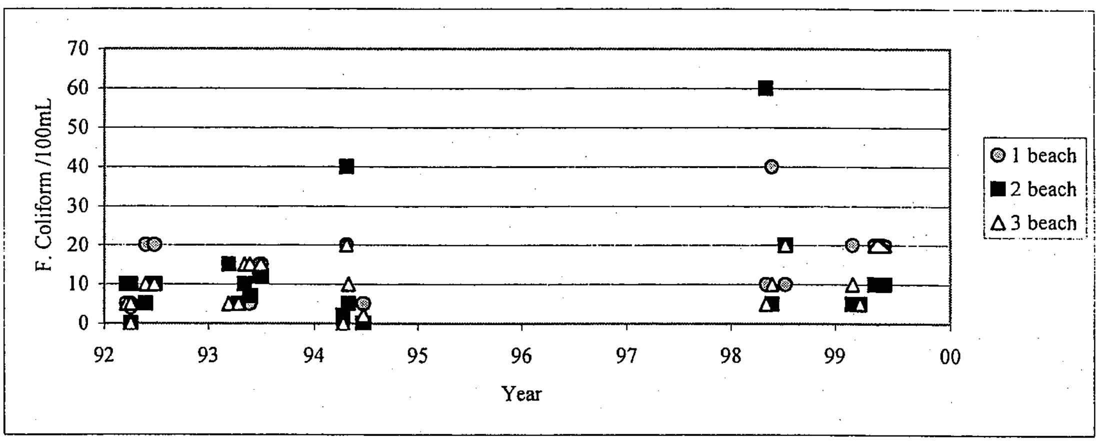


The first graph showing the total coliform results spans the period between 1985 and

1999. The level of total coliform at the beaches was consistently below 200 col./100mL. There does not appear to be any clear indication that any one beach had consistently higher or lower bacteria levels than the others. Beach 2 and Beach 3 both had maximum values greater than 100 col./100 mL while Beach 1 had maximum values equaling 100 col./100mL.

The fecal coliform bacteria levels measured at the three beaches are shown in **Figure 46.** Fecal coliform monitoring was initiated in 1992. Fecal coliform is a subset of the total coliform so will occur in lesser numbers. Data from 1992, 1993, and 1999 showed that Fecal Coliform levels were consistently below 20 col./100mL. During the years of 1994 and 1998 isolated episodes of higher fecal coliforms occurred at Beach 1 and Beach 2. The 1998 data reflects higher values of total coliform also observed at those beaches.

Figure 46. Fecal Coliform Bacteria Results From Three Lake Hayward Beaches, 1992 – 1999.



The fecal streptococcus values for the three beaches are shown in **Figure 47**. The fecal streptococcus measurements were initiated in 1992. The data indicate that during 1993 and again in 1994 at least one date had high levels of fecal streptococcus at all three beaches. The 1994 data showed maximum values of between 200 and 300 col./100mL for each of the three beaches. The 1998 and 1999 data were mostly all low with only one data point above 50 col./100mL.

The total enterococcus results for the three beaches are shown in **Figure 48**. Monitoring for total enterococcus began in 1992. A concentration equal to or less than 61 per 100mL is considered satisfactory for a single sample from a bathing area. A running geometric mean is used when evaluating the long-term microbiological suitability of recreational water quality. However, at least 5 samples are required that span a 30 day period. The single sample data collected at the three beaches shows that values were high in the first three years of testing, 1992, 1993, and 1994, with several measurements over the threshold level of 61 col./100 mL, while samples collected during 1998 and 1999 were all below that threshold. The high values in 1994 samples occurred in September when high values for fecal streptococcus were also observed.

Figure 47. Fecal Streptococcus Bacteria Results From Three Lake Hayward Beaches, 1992 – 1999.

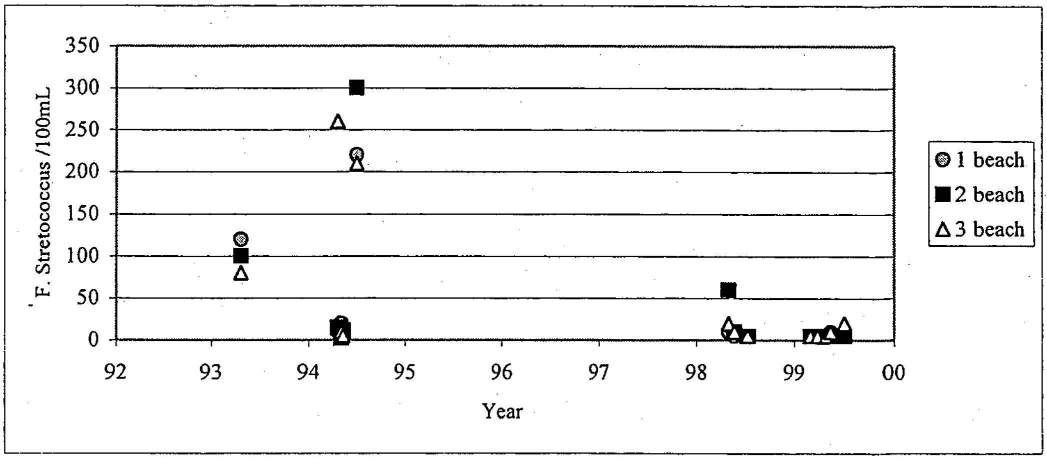
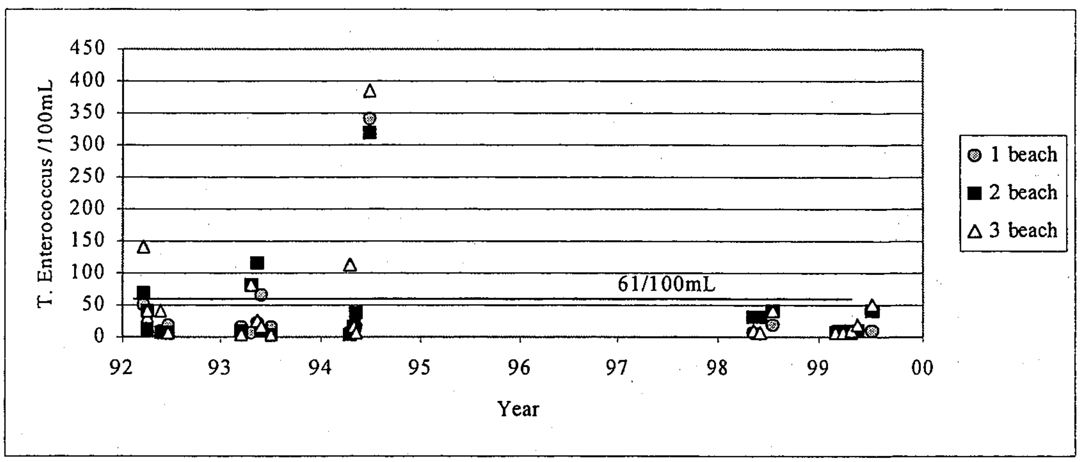


Figure 48. Total Enterococcus Bacteria Results From Three Lake Hayward Beaches, 1992 – 1999.



The indicator bacteria data collected at the inlets and the beaches indicate that on certain occasions the levels can exceed safe bathing conditions, but that over the long-term the levels are low. The inlet sampling conducted in 1991 suggested that inlet W3 had significantly high levels of total enterococcus, however no follow-up samples were collected to determine if the results were related to storm water flows or septic systems. The beach data do not point to any one beach having a significant, long-term high bacteria condition. When bacteria levels are high they are high at all the beaches simultaneously, suggesting that occasional storm water flows are responsible.

The indication from these data is that storm drains and public beaches should not be in close proximity to each other. At each of the three beaches storm drains discharge at one or both ends of the beach. The storm drain system on the west side of the lake is extensive, draining several streets and probably intercepting groundwater along the routes.

Fisheries Survey Summary

The CT Fisheries Division has performed 5 electroshocking surveys of fisheries in Lake Hayward in recent years, 1989, 1991, 1997, 1998, and 1999. The catch per unit effort is a way of normalizing the number of fish caught during a shocking survey. The unit of effort is time measured in hours. The data shown below (**Table 16**) are the number of fish caught per hour for each of the surveys. Largemouth bass was the principal gamefish found in the lake with chain pickerel next most abundant. Smallmouth bass and brown trout were found on only one occasion. The yellow perch was the most abundant of the larger panfish with black crappie and bullhead present at lower densities. Of the sunfish, bluegill was the most numerous. Other fish observed in the lake include tessellated darter, golden shiner, bridled shiner, killifish and American eel.

Table 16. Fisheries Data for Lake Hayward. Numbers Refer To Catch Per Unit Effort For Stock Size Fish And All Sizes In Parenthesis.

Species and Stock Size (cm)	1989	1991	1997	1998	1999
Largemouth Bass (20)	41.1 (61)	95.4 (138)	54.7 (103)	27.7 (43)	40.8 (53)
Chain Pickerel (25)	13.0 (19)	35 (51)	23.9 (32)	26.9 (30)	18.7 (21)
Smallmouth Bass (18)	~	~	~	~	(0.8)
Brown Trout (20)	~	~	0.8 (0.8)	~	~
Yellow Perch (13)	280 (296)	131 (145)	160 (230)	171 (231)	90.4 (167)
Black Crappie (13)	0.7 (0.7)	7.1 (7.1)	2.6 (8.5)	8.4 (22.7)	6.8 (49)
Brown bullhead (15)	4.3 (4.3)	~	1.7 (1.7)	10 (10)	2.5 (2.5)
Bluegill (8)	284 (298)	356 (380)	448 (661)	624 (851)	382 (618)
Pumpkinseed (8)	50 (52)	29 (31)	48 (53)	0.34 (25)	18.8 (22)
Bluegill/pumpkinseed cross	(2.3)	(1.6)	~	~	~
Sunfish (0)	(2.3)	(31)	~	~	~
American Eel (0)	(16.6)	(23.4)	(28.2)	(26.9)	(8.5)
Killifish (0)	~	(23)	(5.1)	(5)	(8.5)
Golden shiner (0)	(13)	(4)	~	(3.4)	(7.6)
Bridled Shiner (0)	~	~	(1.7)	(6.7)	(0.85)
Tessellated Darter (0)	~	(0.6)	~	~	~

The abundance of largemouth bass has varied over the five surveys from a high of 95.4 C/E to a low of 27.7 C/E. The largemouth bass state mean C/E for exploited lakes, those that are fished, was 44.5 for stock size fish (>20 cm). Stock size is Lake Hayward exceeded the state mean in 1991 and 1997, was under but close to the state mean in 1989 and 1999, and was about half the state mean in 1998. Lake Hayward has exceeded the state mean of 10 C/E for chain pickerel in each of the five surveys. The number of chain pickerel larger than the stock length of 25 cm appears to make up a significant fraction of the population in the lake.

The population of yellow perch in the lake exceeded the state mean (101.5 C/E) during four of the five surveys while black crappie have been either below the state mean or slightly above the state mean of 7.6 C/E. Brown bullhead was below the state mean on all but one survey date, with one survey resulting in no observed brown bullhead.

The bluegill population in the lake was high with observed numbers exceeding the state mean of 204.7 C/E during each of the surveys. Bluegill numbers during some of the surveys were considerably higher than the state mean with the highest occurring in 1998 when stock length bluegills were caught at a rate 624 C/E. Other sunfish were not as abundant.

The lake is stocked each spring with 1,000 catchable sized brown and rainbow trout by the CT DEP Fisheries Division. These trout do not hold over well during the summer due to limited deep water habitat with well oxygenated cold temperatures as can be noted by the lack of fish observed in the shocking surveys. The bass are at moderate abundance although large sized fish are not as common. The pickerel and perch densities are at state average although black crappie and brown bullhead are less abundant. I observed many schools of yellow perch during the weed surveys when using the underwater video camera. The state record brown bullhead was caught in Lake Hayward (3 lbs) in 1969.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

The two years of monitoring have indicated that the lake has very low inputs of phosphorus from drainage basin during base flows from inlet tributaries and from the bottom sediments during summer anoxia. However, storm water flows have been shown to contain high levels of phosphorus. Total phosphorus annual load to the lake has been estimated at between 27 kg and 187 kg per year depending on the method of estimation. Nitrate and organic nitrogen inputs to the lake from the drainage basin were high with west side streams having generally higher levels than the east side streams. Total nitrogen annual load to the lake has been estimated at between 600 and 2,500 kg per year. There were moderate levels of organic nitrogen in the lake during the summer with high levels at the bottom.

The lake had very good water clarity in the spring and fall but transparency decreased during the summer. Despite very high algae cell counts the Secchi disk depth was in the oligotrophic range during the spring and fall and oligo-mesotrophic during the summer. The level of phosphorus in the water was generally within the range given for oligotrophic lakes, while nitrogen ranged between oligo and mesotrophic levels.

The lake also was found to have low pH and very low alkalinity. The low buffering capacity of the water leaves the lake vulnerable to acid rain that could result in sudden shifts in pH.

The hydrology data suggests that the lake has large inputs of groundwater during the spring that may be partially responsible for the clarity of the water at that time. Both surface and ground water inputs are low during the summer and fall such that most of the surface streams become dry and the lake stops discharging over the dam.

The lake has an extensive bed of fanwort at the north end and a less extensive area but considerably dense bed at the south end of the lake. The north end bed extends from the area dominated by water lilies south into about 18 feet of water depth. There were large reaches along both the eastern and western shorelines that had no aquatic vegetation of any type suggesting that fanwort could continue to expand its area of coverage. It is very likely that fanwort is also being taken out of the lake by boats and trailers at the public launch. It is also probable that fanwort is discharged from the lake at the outlet. No other invasive species were observed during the survey.

There was about 8 acres of fanwort in shallow water where it reached the surface. There was an additional 51 acres of fanwort in deep water at moderate to high density. In these areas the plant did not reach the surface. Together these estimates total about 60 acres of fanwort in Lake Hayward during the study period.

The bacteria data from the inlets and the beaches show that on occasion all three beaches had elevated indicator bacteria. The total enterococcus values have been below 61 col/100mL the last few years.

The fisheries data show that the lake has a large and viable largemouth bass population but other game fish were less abundant. The yellow perch population was also high usually exceeding the state mean. Black crappie was present in fair numbers but brown bullhead usually had low numbers.

East Shore Drive along the southeast side of the lake experiences erosion during rain events. The dirt is washed from the road to a back yard adjacent to the lake and ultimately to the lake. That area needs to be investigated to determine the method needed to control water flow and reduce the erosion.

The fanwort in the lake is likely to continue to spread south into the open water area of the lake and along the east and west sides of the lake. The control of this plant as soon as possible is necessary. Because the east shore was found to have very few aquatic plants that area is a prime area for colonization by fanwort.

Recommendations

There are two primary causes of concern at Lake Hayward. The first is the infestation of the non-native invasive aquatic plant Fanwort, the second is the development of the drainage basin and the overall condition of the storm water runoff especially the location of storm water outfalls adjacent to public bathing beaches. Any future management efforts at Lake Hayward should include a comprehensive plan of development of the drainage basin that addresses two things, first the inclusion of best management practices for any new development and second a careful review of the existing storm water routing on the west side of the lake that includes implementation of source controls and eventual retrofitting of structural components.

FEASIBILITY

Management Options for Weed Control

There are several different types of weed control techniques available to control aquatic plant nuisances. Each has a different approach varying from large-scale methods that affect the entire lake to small-localized methods. Each of the methods is listed here with a brief description of how it works.

Benthic Barriers

The term benthic refers to the sediment surface so a benthic barrier is a bottom cover or liner that is placed over the plants on the lake bottom. The goal of the barrier is to cut off the light to the plant as well as provide a barrier through which the plant cannot grow. In theory, these barriers work very well, but in practice, a number of shortcomings have limited their use to specific situations. The materials tended to trap gases under them causing them to billow up, or the material did not hold up to long-term exposure to light. Accumulated sediments on top of the barriers allow for rooting of plants essentially burying the barrier. New porous materials have solved the billowing problem by allowing gases to pass through the barrier but accumulated sediment must still be removed annually.

Benthic barriers are effective in small areas such as dock spaces and swimming beaches to completely terminate plant growth. They are also useful in creating access lanes through areas of dense plant growth. Large areas are not often treated, however, because the cost of the material and installation is high, and maintenance can be problematic. Treating large areas also impacts native or non-target species and can significantly limit habitat for aquatic organisms.

Benthic barriers may provide some limited use at Lake Hayward where boating lanes are required through either water lily beds or pondweed. A benthic barrier may also be useful around the outside edge of beaches where fanwort or tape grass may interfere with swimming lanes.

Dredging

Dredging works as a plant control technique when either light limitation on growth is imposed through increased water depth or when enough soft sediment is removed to expose less hospitable substrates such as gravel or coarse sand.

In order to make the lake deep enough to limit the amount of light reaching the plants sediments have to be removed such that the new depth is greater than the associated light penetration. This limits the use of dredging to areas away from shore because some slope is still necessary at the lake edge. In addition, if water clarity is already very good, then the depth required to induce light limitation may be too excessive to be practical.

If the soft sediments that are supporting the nuisance plants are not especially thick it may be possible to create a substrate limitation instead. In this situation the organic mucks are removed leaving coarser material that don't support plant growth. It is usually impossible to remove all the muck so some re-growth occurs.

There are several different ways that sediments can be removed:

- Dry excavation, in which the lake is drained to some extant and sediments are dewatered by gravity and or pumping, and removed by conventional excavating equipment such as backhoes, bulldozers, or draglines.
- Wet excavation, in which the lake is not drained, but may be partially drawn down to minimize downstream flows. The sediments are removed by various bucket dredges mounted on cranes or amphibious excavators.
- Hydraulic dredging, requires a substantial amount of water in the lake to float the dredge and provide a transport medium for the sediment. These dredges are typically equipped with a cutter head that loosens sediments that are then mixed with water and transported as a pumped slurry of 80 to 90 % water and 10 to 20% solids through a pipeline that traverses the lake from the dredge to a disposal area.
- Pneumatic dredging is when air pressure is used to pump sediments out of a lake at a higher solids content than hydraulic dredging. This is not widely used in the US and I don't know of any operations of this type in CT.

There are a number of disadvantages to dredging that limit its use. In each case, a site is necessary to contain the sediments that are to be removed. If no local site is available next to the lake, than sediments need to be trucked to an off-site disposal area, usually at great expense. Local sediment containment basins need some type of capability to allow dewatering flows to get back to the lake. Since these flows are turbid and contain nutrients the flows need to either pass through a settling basin or have a flocculent added to remove the turbidity. In the latter case, a NPDES permit would probably be required, as the discharge would be considered a pollutant. Those flows would have to be monitored and may need to be treated so as not to impact the lake. Dredging itself causes turbidity in the lake and may impact invertebrate populations, non-target species of plants and fish habitats.

Dredging is probably the only real long term solution for lakes with sedimentation problems and accumulated organic rich sediments. Dry excavation tends to be very thorough because the operator can visually observe the results of the work as it happens, and can work in one specific target area. Hydraulic dredging allows for sediment removal without lowering the lake level, and can work in deeper areas that may be inaccessible to land based machines even if the lake was dewatered.

Some limited dredging may have applicability at Lake Hayward where sediments have accumulated at the outfalls of street drains, and to remove water lily beds.

Light Limitation Dyes

Blue dyes are used to limit the light transmission into water and therefore restrict the depth at which rooted plants can grow. These dyes tend to reduce the maximum depth that plants will grow but usually have limit affect in shallow water (< 4 ft deep). The dye has to be replenished based on the flushing rate of the water body to retain its effectiveness. The low light tolerant plants, and those that can reach the surface, are favored. Because the dyes limit light penetration there may be some decreases in algae photosynthesis in deeper water causing a subsequent decrease in deep water oxygen. These types of plant controls are not suitable for controlling weeds at Lake Hayward because they will have no effect on floating leaved species and in order to have any effect on fanwort the entire lake would have to be treated with unknown consequences due to the reduction of light penetration to deep water and the discharge of dyed water from the lake to downstream habitats. Additionally, any decrease in light level that would affect the fanwort would almost certainly affect the native plant population resulting in negative lake effects. Dyes are not recommended at Lake Hayward.

Mechanical Removal

There are several methods of mechanical removal. These are, hand pulling, cutting without collection, harvesting with collection, rototilling, and hydroraking. Harvesting techniques are similar to mowing your lawn in that they remove the tops of plants down to a certain depth, hand pulling is like weeding your garden, and rototilling or hydroraking are like tilling the soil.

Hand pulling is done by a diver who pulls out the target plants individually. This can be very time consuming but because it is highly selective and is done using a visual operator it can be very effective at controlling target plants in a specific location. Although hand pulling leaves little doubt about whether an individual plant has been removed once the operation is underway it is difficult to keep the area from becoming too turbid to see more plants. Hand pullers have to move to an alternate site until the sediments settle out and the plants can be seen again. Often the site has to be revisited several years in a row in order to insure that all the plants have been removed.

Both cutting and harvesting involve a specialized barge that is fitted with a cutter bar or a cutter bar and a conveyor assembly that retrieves the cut plant material and loads it on the barge. A cutter boat only cuts the plants and leaves the fragments in the lake to be removed by another means or not at all. A harvester collects the cut fragments and transports the material to an off loading site on the shore. In either case, the plant root system and lower shoots are left intact so re-growth is possible and in some case can be so rapid that the area needs re-cutting in a week or two. Cutting or harvesting aggressive colonialist plants such as fanwort is a particularly bad idea because it greatly promotes the spread of these plants into other areas of the lake.

Hydroraking involves the equivalent of a floating backhoe outfitted with a York rake, which looks like a large pitchfork. The tines of the rake are moved through the sediment to rip out thick root masses and associated sediment and debris. A hydrorake can be very effective at removing submerged stumps, water lily root masses, and floating islands. The raking process is not a clean process causing considerable turbidity of the water as well as releasing plant fragments and other debris.

Hydroraking is a method that may provide good control of floating leaved weed beds that would be cheaper than dredging and would not involve the use of chemical herbicides. Harvesting, on the other hand may provide some control over fanwort that reaches the surface but at the cost of spreading the plant or increasing the density of the existing beds.

Eventually hydroraking may be required to keep open the boat lane from the public boat ramp since it is an effective control of water lily beds.

Water Level Control

Lake drawdown has been used in Connecticut for many years as a standard cure-all. It is cheap, all you have to do is open the dam, simple, removing boards (or opening a valve) at the dam in the fall and closing it in the spring. The lower water in the winter allows for access to shoreline structures for maintenance, a side benefit that has value on its own. The ability of this method to control rooted aquatic plants is dependent on several factors. Only those plants that grow in the exposed area will be impacted by the lower water level. Plants that live below the water level will not be impacted and may instead increase in range by expanding into the now shallower areas or into the cleared areas after refill. Plants that are exposed by the drawdown are subject to both drying and freezing if down during the winter. However, freezing is not always guaranteed, heavy snowfall can insulate the sediments, while areas with steady groundwater input can remain unfrozen. Drawdown is non-selective as it will affect all the plants growing within the exposed areas, good and bad. There is also the problem of refilling the lake during the spring. A deep drawdown will require more water for refilling once the dam is closed. Timing the closing of the valve is important because, generally, runoff of the drainage basin decreases dramatically after leaf-out in May. The ability of the drainage basin to provide enough water during a refill window needs to be estimated prior to a deep drawdown. Once started drawdown needs to be done each year or every other year.

Drawdowns may also impact the other organisms living in the exposed area. Sometimes this may cause significant harm to the food webs by eliminating invertebrates, reptiles, and amphibians. The littoral zone is a very productive part of a lake ecosystem that would take several years to recover from one winter of freezing and drying. If the sediments are organic or mucky a drawdown that eliminates rooted plants on those substrates may cause the proliferation of filamentous algae the following spring due to the abundant nutrients in the muds. Drawdown also exposes sediments to rain causing erosion during the drawdown period that can wash minerals into the lake causing nutrient increases.

Some plants are just plain tolerant of drawdown, while others can actually increase as a result of water level drawdown.

Drawdown is probably not feasible at Lake Hayward because of the limitation of the dam to lower the lake. Although there is a significant elevation difference below the dam, there does not appear to be any deep release piping what could be used to drain water out of the lake. Water could be either pumped or siphoned but these methods would require large diameter pipes in order to stay ahead of the inflows during the fall and winter.

Herbicides

Chemicals to control weeds and algae have been used for many years, and other than drawdown are probably the most widely used of all weed control methods. It has only been recently that the other techniques have gained acceptance.

There are only seven active ingredients currently approved for use in aquatic herbicides in USA today, with the seventh being new in 2002.

- Copper products are not usually used for control of rooted plants, instead being used as a herbicide against algae both filamentous and planktonic. Copper can be used in conjunction with other herbicides to render them more effective if the plants have a dense growth of attached algae on their surfaces. The copper kills the attached algae so the herbicide can be affective against the plants.

- Endothall is a contact herbicide, attacking plants at the point of contact. Only the part of the plant that it contacts with will be affected. The roots will not be impacted so re-growth and recovery can be expected. The herbicide acts quickly against the leaves and shoots causing accumulation of large amounts of dead plant material on the sediment surface, which in turn can cause oxygen loss. There are use restrictions on the label against using it in drinking water supply reservoirs, although there shouldn't be toxicity impacts to other lake fauna.
- Diquat is another fast acting contact herbicide. Again, there is a domestic water use restriction and it is not used in water supplies. This herbicide can be toxic to invertebrates, fish, and other animals. Because contact herbicides do not affect the roots and buried seeds re-growth is probably certain.
- Glyphosate is another contact herbicide. It is typically used against emergents and floating leaved plants but not against submersed species.
- 2,4-D is a systemic herbicide meaning that it is absorbed by the roots and incorporated into the whole plant. This herbicide has been in use for over 30 years, and has shown to be very effective against Eurasian Milfoil. The herbicide can be used in either liquid or solid form so the area of treatment can be very well controlled. 2,4-D has variable toxicity to fish, and the label restricts its use in water used for drinking water supply or other domestic uses, or for irrigation or watering of livestock.
- Fluridone is another systemic herbicide introduced in 1979, becoming widespread since the mid 1980's. Fluridone has proven to be very affective against milfoil and some of the other invasive aquatic plants. The herbicide comes in both a liquid and a slow release pellet allowing for both spot treatments and whole lake treatments. The herbicide has low toxicity to other organisms. The use of the liquid fluridone does require a 40 day contact period during which lake outflow should be minimized. Sometimes the level of fluridone has to be bumped up because of dilution and flushing out of the lake.
- Triclopyr is a new systemic herbicide similar to 2,4-D in that it is absorbed into the plant and causes metabolic changes in growth process. It is not as yet approved for use in CT. It targets dicots such as milfoil.

Biological Introductions

The biological controls most often used today are herbivorous fish such as grass carp and the aquatic weevil. The goal of using these organisms is that they will graze on the desired target plant and affect some control without using herbicides. Grass carp has been used since the 1960's because of its high grazing rates on aquatic plants. It has a very high growth rate so it can consume large quantities of plant material in a season, although they tend to eat less as they age. The fish usually avoid the floating leaved species like lilies and go after the submersed plants like pondweed, elodea, and coontail. Although it is impossible to predict which plant the carp will feed on, overstocking grass carp can eradicate all the plants in a lake. There is also a possibility that grass carp can increase the nutrient cycling in a lake by passing digested plant material out as excrement faster than the natural decay of the senescing plants in the fall. Grass carp are approved for use in Connecticut under special conditions. The lake outlet must be fitted with a grate structure to insure that the fish will not leave the lake, and only sterile fish can be stocked.

The weevil feeds exclusively on Eurasian milfoil. The presence of the weevils is often difficult to determine but there is documentation of the existence of native populations of these organisms. Natural crashes of milfoil due to the grazing of these insects have been reported from a few lakes but the evidence is still preliminary that it will become a widespread control method. Some lakes with dense milfoil beds have stocked weevils in an attempt to establish a population at a dollar per weevil but again there is little information that these introductions are working on the long term.

Table 17. Methods Considered For Control of Fanwort in Lake Hayward.

Treatment Method	Effective Time	Application Cost / Annual Cost	Water Quality	Toxic/Carcionogenic	Effect on Fish	Swimming	Permitting	Other Comments	Recommendation
Mechanical Harvesting -	1 1/2 months in summer	$350 per acre per cutting/ $2,800	no effect	none	some killed	Restricted to recently harvested areas.	not required	Contracted Harvester, would greatly increase the spread of fanwort.	Not recommended
Herbicide Fluridone - Sonar(TM)-	2-3 years	$200 to $300 per acre/ $30,000 to $55,000	meets drinking water standard	Non-toxic, non-carcinogenic per EPA, lake dosage will be 95% below maximum allowable	none	30 day restriction	CT DEP Permit required	Application in April or Early May	Tentative Recommend to Treat lake in 2003 or 2004
Bottom Barrier -	1-3 years	$20,000 to 40,000 per acre/ not applicable	no effect	none	destroys habitat	none		Dangerous to boats or swimmers if dislodged	Tentative Shore owner option
Scuba, suction dredging	1 year	$5,000 to 30,000 per acre/ not applicable	Stirs up sediments	none	destroys habitat	none	unknown		Not recommended
Biological Controls	None known								
Grass Carp -	long term	Unknown / not applicable	excrement and stirred up sediments	none	destroys habitat and drives out other species,	muddy water	DEP not likely to permit	Grass Carp eat ALL weeds; must have positive containment	Not recommended, and not feasible for Lake Hayward.

Note: Lake Hayward surface area is 170 acres; 60 acres are infested with fanwort about 8 acres is at the surface.

Management Options for Storm Water and Non Point Source Control

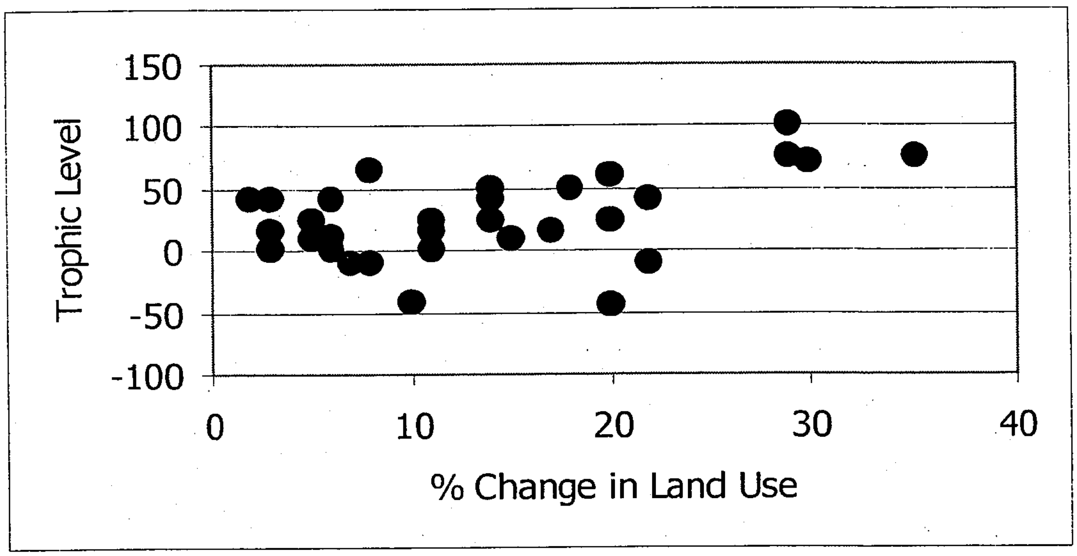
In general, urbanization increases the amount of impervious land surface area, which in turn leads to increases in storm water runoff. The western side of the lake has about 161 acres of densely developed residential land-use that drain directly to the lake. The eastern side of the lake side has one tier of residential home along the lake shoreline and two large lot size developments that are away from the lake, the northern end also has a large lot size development that are set away from the lake. Together these developments and the shoreline east side homes and east shore road total about 132 acres. The east shore does not have an extensive street drain system to convey storm water and that one road is mostly unpaved. The watershed has an additional 57 acres of road surface that is not accounted for in either east, north or west residential area estimates. The total drainage basin size was given to be 1,489 acres meaning that about 23.5% of the drainage basin area is currently developed impervious surface. The areas of residential and road coverage land use are shown in **Appendix 11**. These values are probably overestimates of the actual area because not all of the lots are impervious such as grassed lawns and other sections of lots that remain wooded, but they do provide a rough estimate. The values are summarized in **Table 18**.

Table 18. Summary of Impervious Surfaces Estimates For Lake Hayward Drainage Basin.

	Acres	Percent of Total
West Side	161	10.8
East Side	132	8.9
Roads	57	3.8
Total	**352**	**23.5**

The change from undeveloped wood land to urban impervious surfaces in a lake drainage basin has been linked to increase in the trophic tendency of the water (Siver *et al.* 1999). The data in **Figure 49** shows the trophic measures representing either increasing conductivity, decreasing water clarity or increasing nutrient content related against the percent of the drainage basin from wooded to impervious. The results of changing trophic level are uncertain in the 0 to 20% range but once a watershed reaches 20% impervious surface are there was a tendency to show trophic level increases. If trophic level used in the graph can be equated to progressing up the categories listed in **Appendix 4** this indicates that Lake Hayward may be at a critical point where more development in the drainage basin could lead to decreases in the lake water quality. The existing condition of the Lake Hayward drainage basin is that about 23.5% is developed and impervious. However the west side of the lake has a large fraction of the total that is concentrated in a small area of the drainage near the lake with steep slopes and direct culverting system to convey storm water quickly to the lake. The 161 acres of developed land occurs in an area of about 275 acres of the drainage basin comprising about 59% of the land on the west side of the lake. This implies that over half of the water draining from the west side is storm water runoff.

Figure 49. Trophic Index Changes Due To Increasing Impervious Surface.



The implication here is two fold, first storm water runoff is already a problem on the west side of the lake and is likely responsible for pollutants entering the lake, and second any additional development of the drainage basin is likely to result in increased trophic levels of the lake.

Non point source and urban stormwater controls fall into three basic categories

- Regulatory Controls
- Source Controls
- Structural Controls

A table of the possible activities and estimates of possible costs is included in **Table 19**.

Regulatory Controls

Land-use Regulations

A comprehensive review of zoning regulations within the drainage basin should be conducted to determine 1) where future development is possible given current regulations, 2) the potential build out capacity, 3) the kinds of development that are permitted, 4) the level of upgrade to existing houses such as seasonal to year round, and 5) the controls that are currently required for new developments such as erosion control features.

Effecting changes in the existing land-use regulations will be difficult for the Lake Hayward drainage basin because it involves three towns, East Haddam, Colchester and Salem. However, there are at least three goals of changes in zoning, 1) preservation of open space, 2) control of future new developments and 3) control of changes made to existing development. The east and north sections of the drainage basin have large areas of undeveloped land that may at some time in the future become developed. Increases in the percentage of impervious surface over the existing level may result in further degradation of the lake water quality if development is not strictly regulated. It is important that future new developments be performed in way that reduces their load of pollutants to the storm water. Changes in existing homes on the west side where the density of development is already high can also lead to increased pollutant loads. And where ever possible important natural features should be purchased so that they remain in an undeveloped condition.

Protection of Natural Resources

Protection of water quality can also be accomplished by restricting development in land that serves important water quality enhancement and restorative functions. These areas include floodplains, wetlands, stream buffers, steep slopes, groundwater recharge areas, and undeveloped lake frontage. A land-use review of the basin shows that several significant wetlands and water corridors exist in the drainage basin of the lake. Contained in the review of zoning regulations in the drainage basin should be an overlay of the important natural features that are critical to the protection of water quality. The listing of these features should not be limited to those that are in a natural condition now but also include stream corridors that could be targeted for improvement with a goal of returning them to a more natural condition. Streams on the west side of the lake are examples where stream bed restoration could be initiated so that the water course can perform water quality regeneration functions. The stream on the west side, W1- through W6 could be walked to determine the percentage of natural bed that remains. Places were debris and trash could be noted and designated for removal. Natural stream beds should be returned to natural conditions.

Land Acquisition

The municipalities can purchase land or seek conservation easements so that important water features are preserved.

Source Controls

The methods identified in this section are nonstructural practices that can reduce the load of pollutants that get into either storm water flows or into streams. In all cases the use of these practices requires diligence and a long term commitment or change in behavior. It is not enough to perform one or more of these actions once and than forget or lapse back to negligence. Instead a plan or program needs to be installed such that a schedule of activities is set in place and adhered to each year. It may be that in order to follow through with these methods a person or committee would need to be given responsibility of overseeing the completion each year. A paid position of Lake Manager or Watershed Protection Committee is an example.

Street Sweeping

Street sweeping is the cleaning of road surfaces of accumulated sand, debris, dirt, and their associated pollutants. By regularly sweeping streets these materials don't get washed into storm drain systems and into the lake. Street sweeping can be effective only if conducted at regular intervals and if done consistently. In most cases sand and salts that are applied in the winter are washed into catch basins and culverts during the first rain events in the spring. Only a progressive program of early year street sweeping would remove these sediments prior to the first spring rain storms. Streets should be cleaned at least twice per year, once in the spring to remove the sands from winter and once in late summer or early fall to remove dry fall and accumulated dirt and silts.

Catch Basin Cleaning

The catch basins around the lake should be cleaned periodically such that the sump does not reach two thirds full. Often these sumps are the only interception between the impervious surface and the lake. It is the only site where sediments and solids can be trapped. Any cleaning program should also include an annual inspection to insure that sumps have been cleaned. Of course this assumes that all the catch basins have sumps. This is not always a safe assumption as many of the basins don't have sumps meaning that materials carried by the storm water flows are passed directly through the basin and into the lake.

Fertilizer Controls

The use of fertilizers on residential lawns and gardens can result in over saturation of phosphorus and nitrogen in soils. Once these levels have been reached excess nutrients are either washed off or carried by groundwater flows. Public education is probably the only way that limitations can effectively be reached. There is probably no need to apply phosphorus fertilizers to residential lawns. Individual home owners can have soils test to determine the phosphorus content.

Animal Waste Removal

Domestic animal waste represents a source of both bacteria and nutrients that can be washed directly into storm drains. Pet clean up ordinances is one way but general education about the effects of these kinds of practices is probably better because it will really depend on a voluntary action and commitment by private citizens.

Solid Waste Management

A municipal program should be set up to collect solid waste like yard trash, leaves, and brush to help prevent these materials from getting into the storm water system and clogging pipes and catch basins. When these systems back up storm water will travel directly down street surfaces seeking its way to the lake in other ways. A program to collect this type of material helps discourage dumping into lake shore areas where it can cause deterioration of the lake.

Reduced Sanding and Salting

The use of sands and salts in the winter on snow and ice covered roads is not likely to be stopped. Also there may not be any feasible ways to reduce the use of these materials given the steepness of many of the roads on the west side of the lake. However it should be realized that without controls the sand will be transported directly into the lake. If the streets are not cleaned soon after spring in April or May most of the sands will be moved into catch basins, and discharged to the lake.

Because it is much easier to apply the sand than it is to retrieve it in most cases sand collection is performed much later in the season when it becomes convenient. Because of this sand deltas have formed at most of the culvert outfalls to the lake.

Septic System Maintenance

The on-site septic system represents a significant source of bacteria and nutrients to lakes. The density of homes on the west side almost definitely means that plumes of nutrients, especially nitrate, exist in the ground water. There are several ways that this impact can be minimized. Regular pump-outs should be performed to insure that the leach field does not become clogged. Also routine inspections should also be done to locate and identify failed systems.

Structural Controls

When existing storm water conveyance systems are inadequate to remove pollutants from the water these systems have to be retrofitted to improve their effectiveness. In places where there is already significant development this process is often very complicated due to the limitation of space to install new features, existing structures such roads, bridges, bulkhead, and the lack of easements over private property.

The function of new structural control devices seeks to remove pollutants from runoff through the actions of settling, filtration, microbial decay, and vegetation uptake. Often the use of all types is necessary in areas where existing systems are inadequate and retrofitting is complicated by extensive existing development.

Detention Basins

These systems are features that seek to detain the water in a constructed pond or wetland. Once collected the water is retained long enough to allow settling of sands and silts and their associated nutrients and metals. The water is released in a controlled way after sufficient time. There are three general types of detention basins: dry ponds, wet ponds and constructed wetlands.

Dry ponds are used to collect and detain peak runoff such that velocity and volumes are reduced prior to discharge to receiving bodies. Dry ponds are constructed to allow all of the contained water to eventually drain out of the basin such that it becomes dry. Dry ponds are effective at removing heavy sediments and some fraction of nutrient load especially if the basin of the pond contains vegetation. They are not very good at removing dissolved nutrients and bacteria.

Wet ponds are designed to retain permanent pools of water. Storm water enters the pool and once it fills to spillway level water is discharged to receiving streams of the lake. The concept behind a wet pond is to have a flushing rate of the correct period to accommodate the intended water pollutant settling. Essentially it becomes a mitigation lake that absorbs the nutrients and sediment so that the resource lake doesn't have to.

Created wetlands are basins that contain established wetland plant communities. These systems filter and trap constituents in the storm water. They are effective at removing a wide range of different pollutants. However, as in wet ponds they need to be designed to fit the intended flushing rate of the water load, water volumes in excess of its capacity will simply channelize the wetland and pass through.

Infiltration Structures

The concept behind infiltration is to provide a means for storm water to be discharged to the groundwater. This allows the soils to act as a filter and remove sediments and other solid and solid adsorbed nutrients from the storm water. Infiltration does not remove dissolved nutrients like nitrate. Infiltration requires the correct soils for proper functioning for example clays soils are not suitable. The installation of infiltration structures can be of any size and located in most any area where water is piped or culverted. Parking lots, road side ditches, house lots can all have infiltration trenches or dry wells. These systems can only accommodate a limited amount of water but if enough are placed in series they become very effective in reducing the quantity of storm water and the pollutant load.

Vegetative Practices

The use of vegetation to remove nutrients can be used in conjunction with other systems as pretreatment in absorption of dissolved nutrients. Promote infiltration, capture solids and decreases velocity. There is a growing body of literature on the use of vegetated buffer strips and vegetation shorefronts in reducing nutrients entering a lake.

Filtration Practices

Filtration is the use of some filtration medium, such as sand, to remove constituents from the water. Water is passed through a bed of filtration medium then passed back to a stream or culvert.

Water Quality Inlets

These are specific devices that separate oil and grease or gross particles from the storm water. They usually are installed in conjunction with other removal systems and can reduce the maintenance required to keep them free of sediments, debris and trash.

Table 19. Estimates Of Probable Costs of Storm Water Corrective Measures.

Management Option	Total Costs	Notes
Studies		
Zoning Study and Overlay	$ 20,000	Review existing zoning regulations and develop land-use overlays
Drainage Study	$ 30,000	Engineering study of existing storm water conveyance
Zoning	$ 25,000	Cost of outside professional consultant
Ongoing Programs		
Public Education	$ 25,000	Brochure and other documents and production costs
Lake Manager Position	$ 15,000	Retired or part time position to oversee various activities
Street Sweeping	$ 200,000	10 year program, 2 sweeps per year @ $10,000/sweep
Catch Basin Cleaning	$ 100,000	10 year program, 200 basins/yr, @ $50/basin
Construction Projects		
Infiltration	$ 150,000	Sites to be determined by drainage study above, 3 infiltration systems @ $50,000 each
Detention	$ 150,000	Sites to be determined by drainage study above 3 detention systems @ $50,000 each
Vegetation	$ 100,000	Sites to be determined by drainage study above 2 created wetland systems and 5 year maintenance
Separators	$ 100,000	10 chambers set in catch basins on west side, @ 10,000 each
Stream Restoration	$ 90,000	Remove trash, debris and accumulated silt, 3 west side streams

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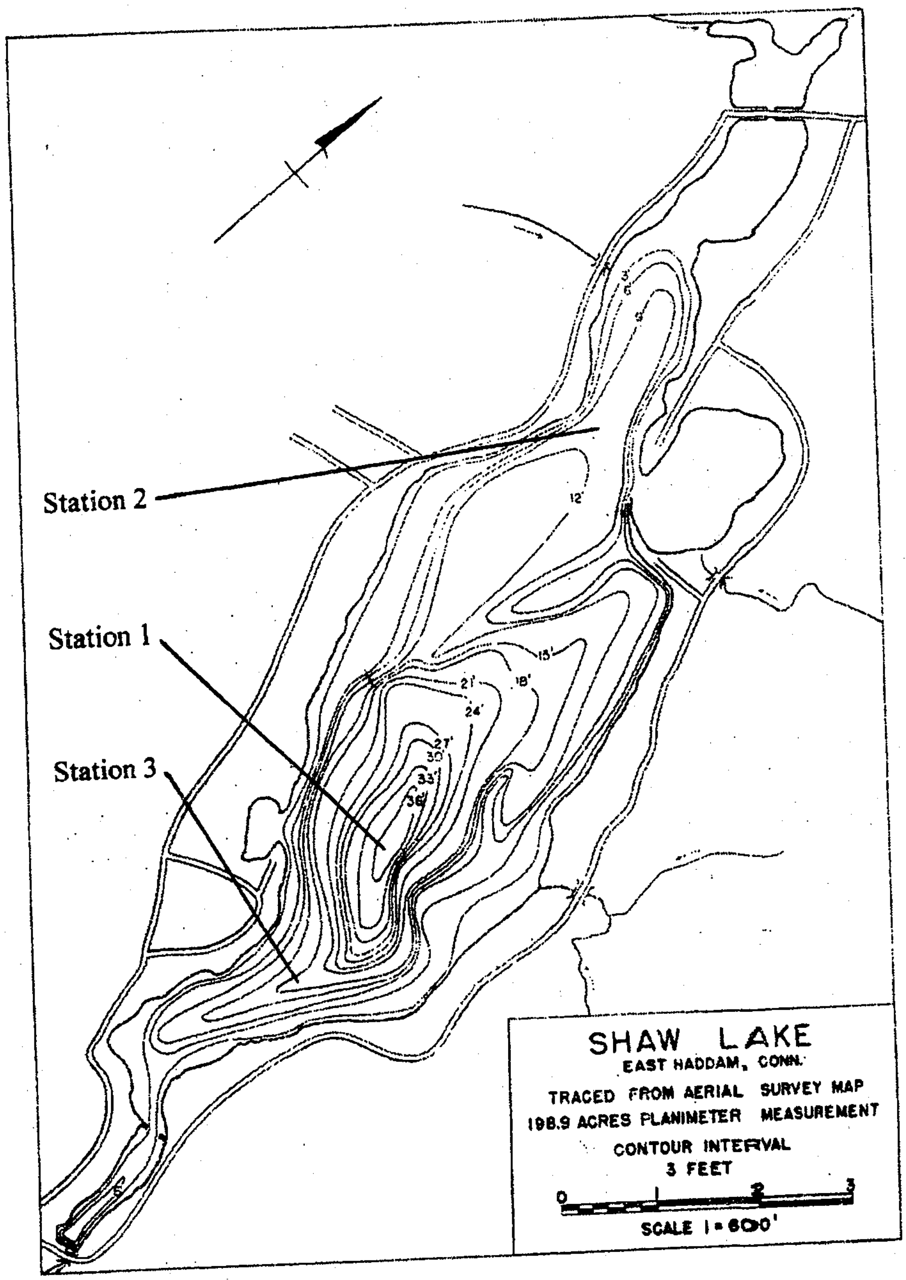
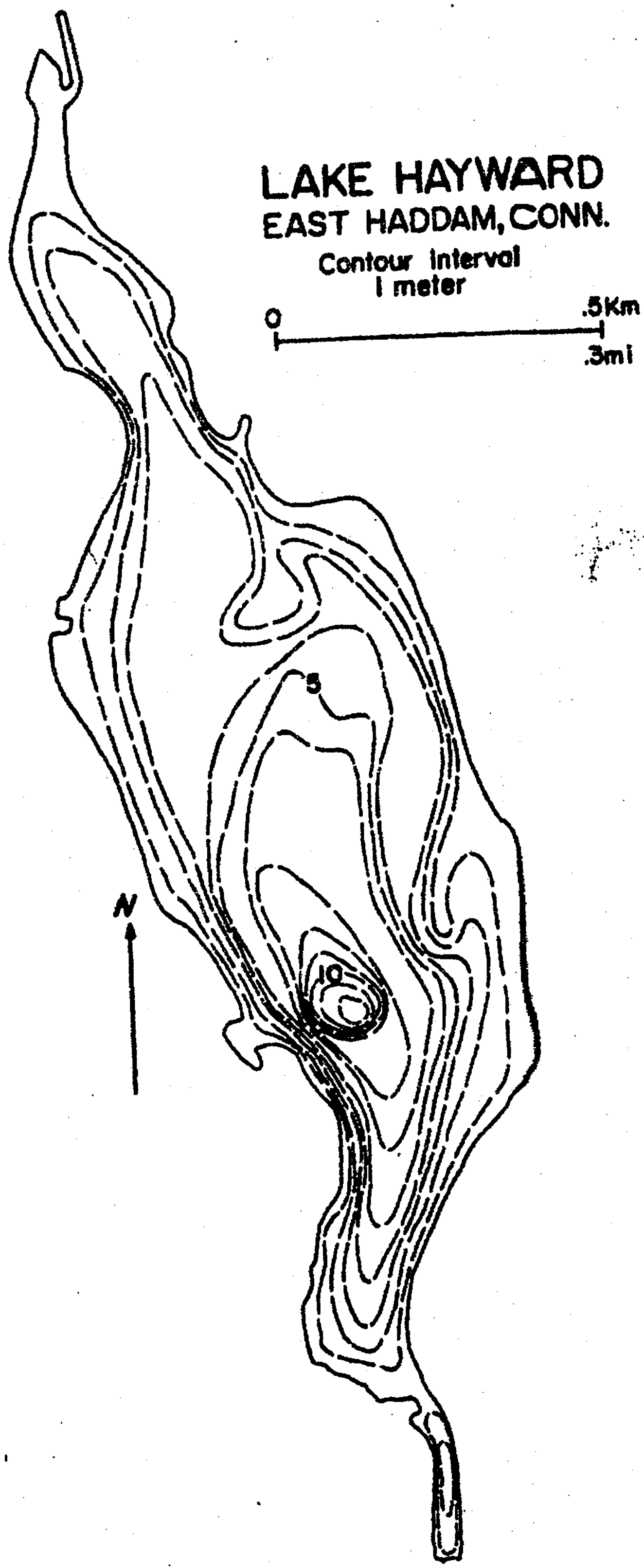
Appendix 1

Bathymetric Maps of Lake Hayward

1. Map From CT. Fisheries Board, 1958, and later by Frink and Norvell, 1984.



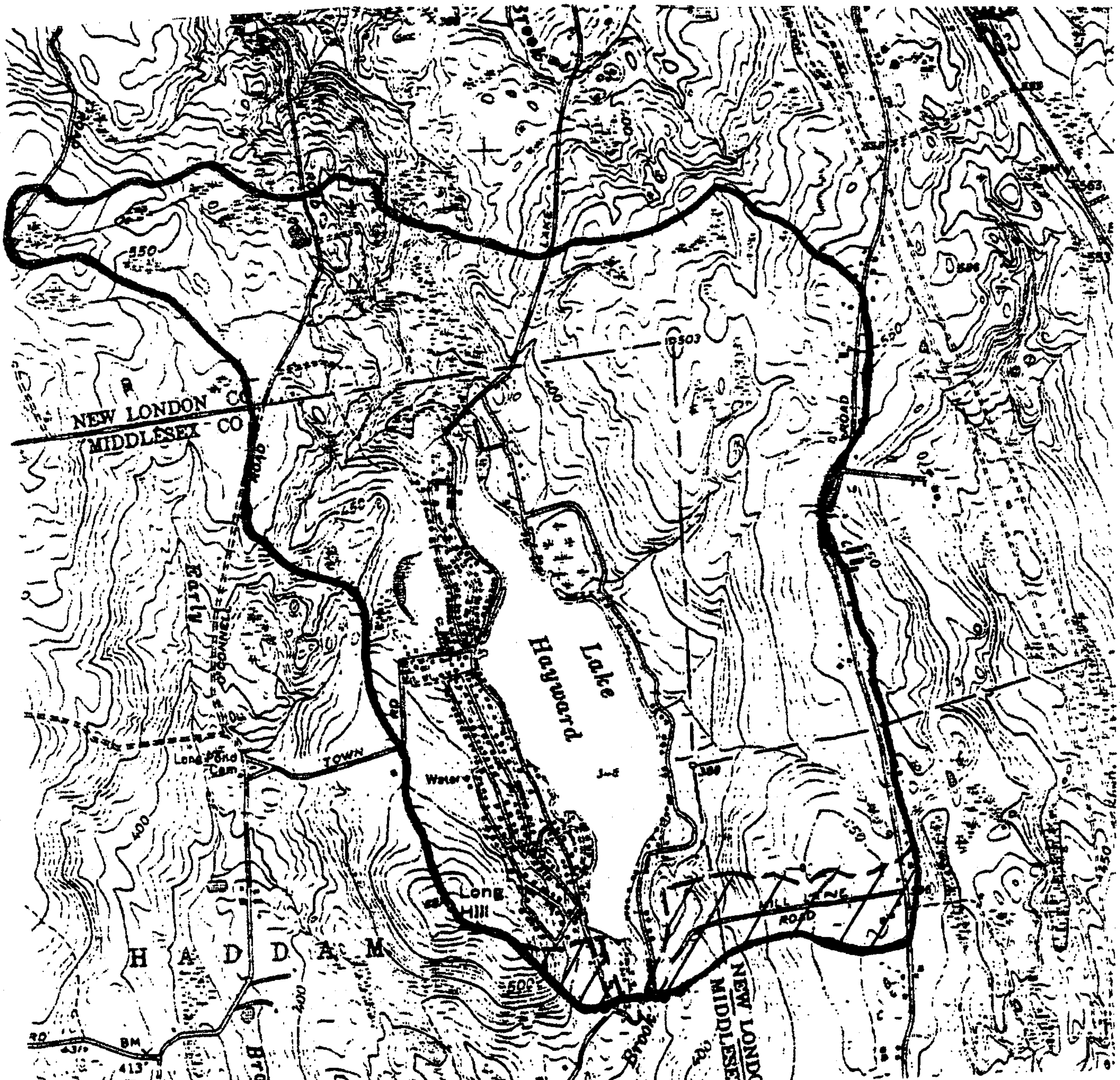
2. Map From Battoe 1979.



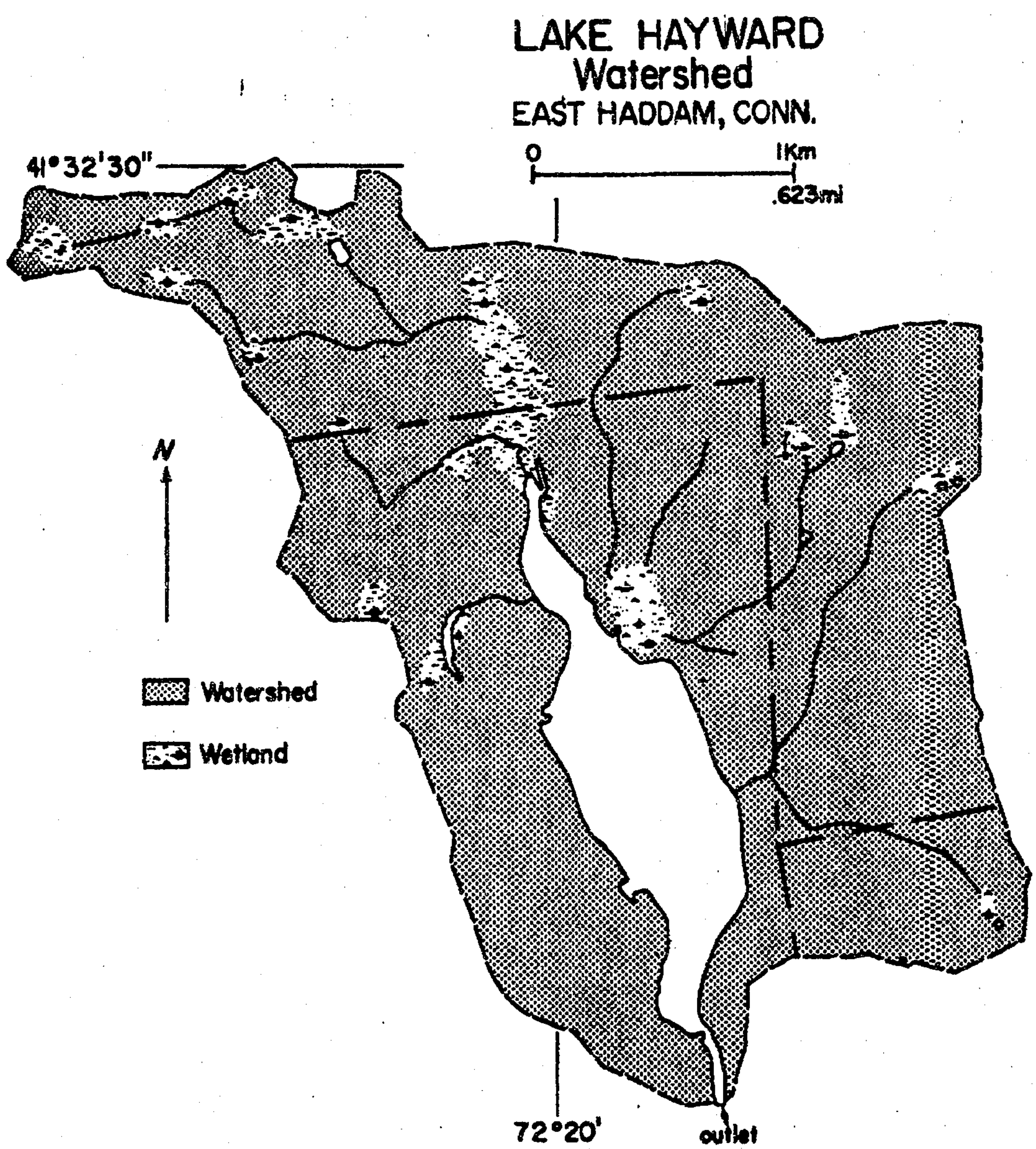
Appendix 2

Watershed Maps For Lake Hayward.

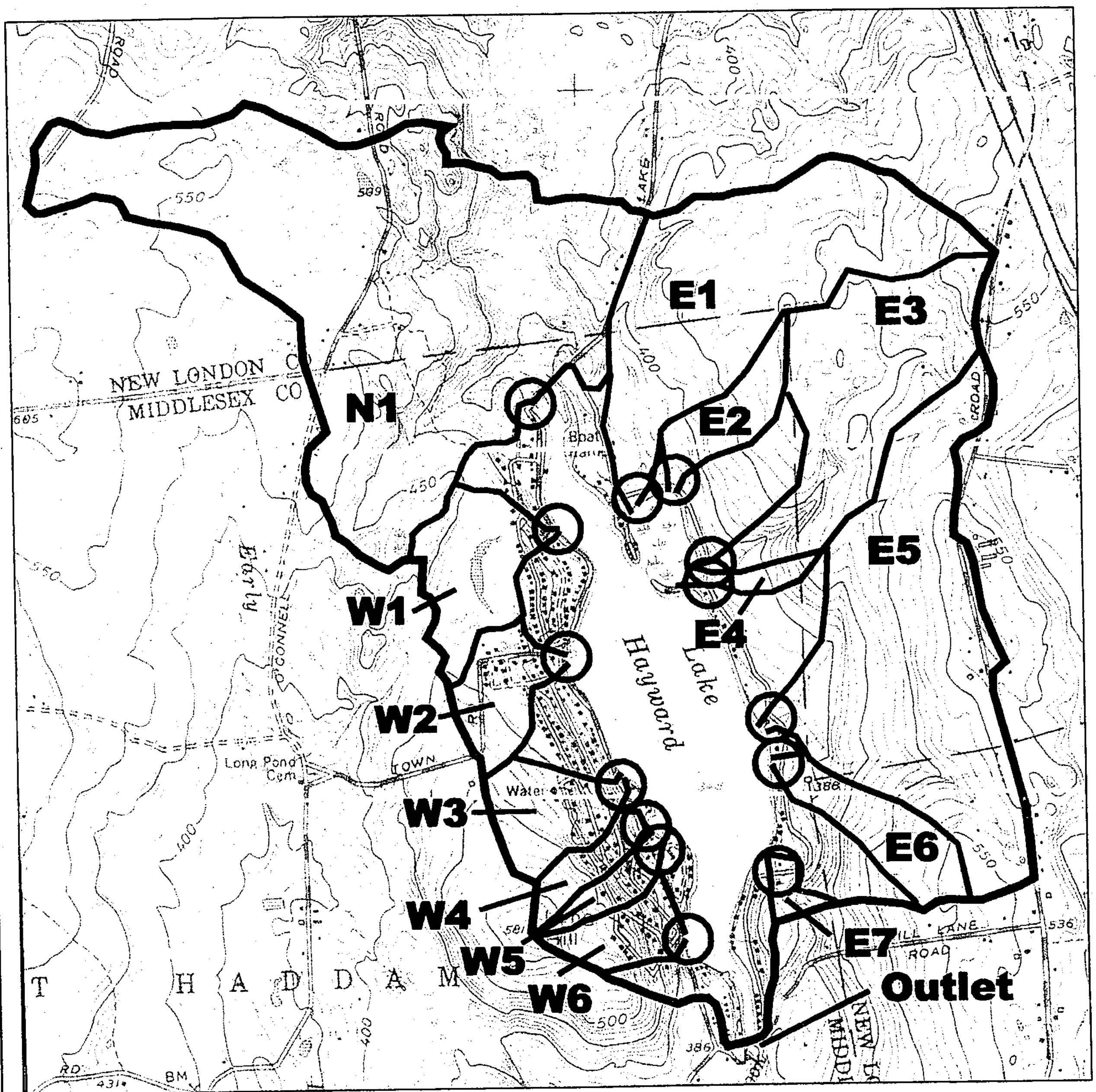
1) Watershed Boundary Map Produced By Baystate Environmental Consultants, and amended for this report.



2) Watershed Map from Battoe 1979.



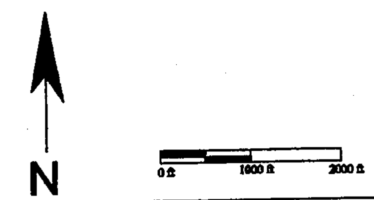
3. Watershed Map Showing Subbasin Boundaries and Sampling Stations.



Lake Hayward
Drainage Basin and
Individual Subbasins

Circles Show locations of
Stream Sampling Stations

Lake Hayward
East Haddam, CT



Appendix 3

Temperature and Oxygen Profile Sheets

Each of the sheets shows the temperature and oxygen values recorded at each one-meter depth beginning at the surface, 0 meters, and ending at the bottom. The third column gives the calculated percent oxygen saturation value, based on the measured temperature and oxygen values at that depth. The fourth column shows the difference in the water density between each meter as calculated in Relative Thermal Resistance to Mixing a unit less number. The RTRM value is calculated using the following formula:

Water density at depth X – water density at depth X-1 (with depth in meters)/(1-0.9999919). Theses final values are the density of water at 4°C and 5°C respectively.

WATER COLUMN PROFILE DATA

Lake Hayward — *April 28, 2000*

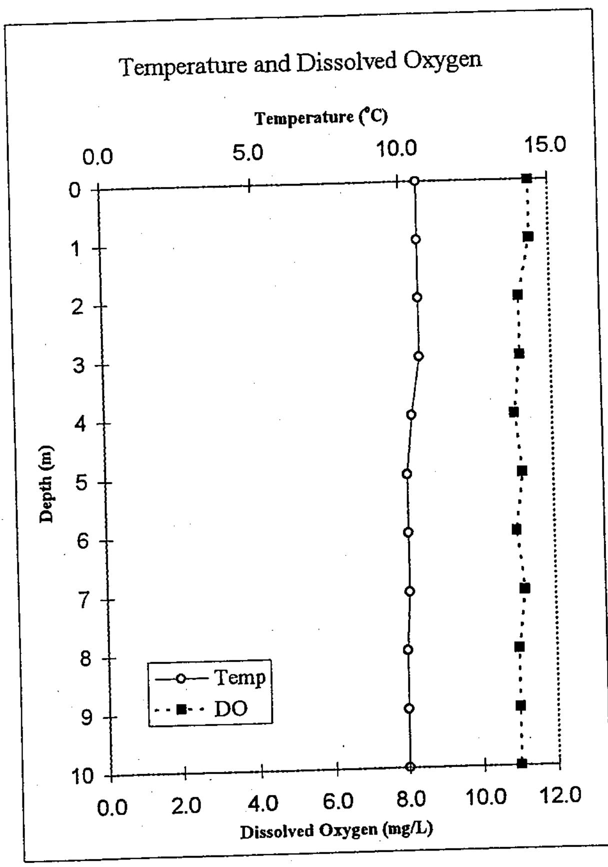
Station #
1

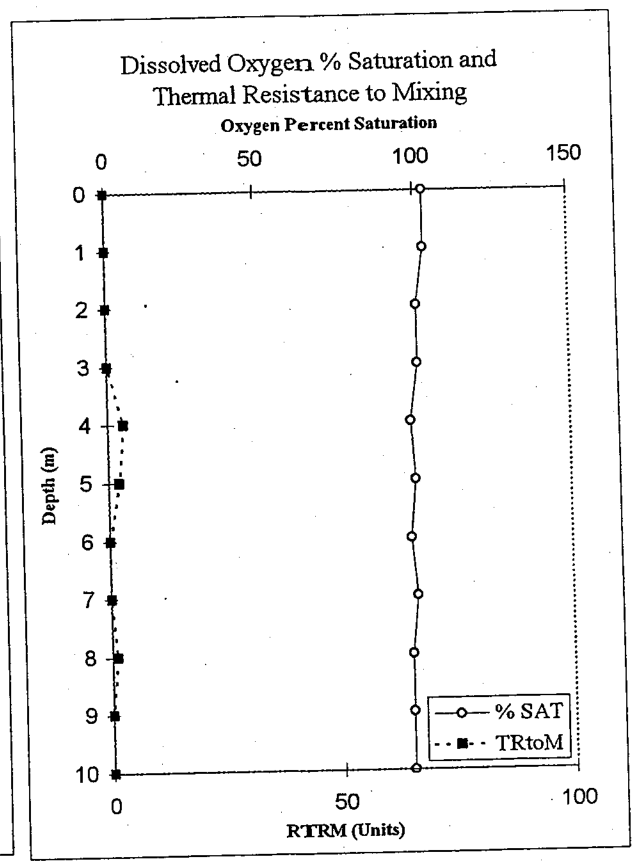
Anoxic Boundary Location
none

Secchi Disk Depth (m)
5.8

Total Mixing Resistance
7

Water Depth (m)	Temperature (°C)	Dissolved Oxygen (mg/L)	% Oxygen Saturation	Mixing Resistance
0	10.6	11.5	103	0
1	10.6	11.5	103	0
2	10.6	11.2	101	0
3	10.6	11.2	101	0
4	10.3	11.0	98	4
5	10.1	11.2	99	2
6	10.1	11.0	98	0
7	10.1	11.2	99	0
8	10.0	11.0	97	1
9	10.0	11.0	97	0
10	10.0	11.0	97	0





WATER COLUMN PROFILE DATA

Lake Hayward — *July 29, 2000*

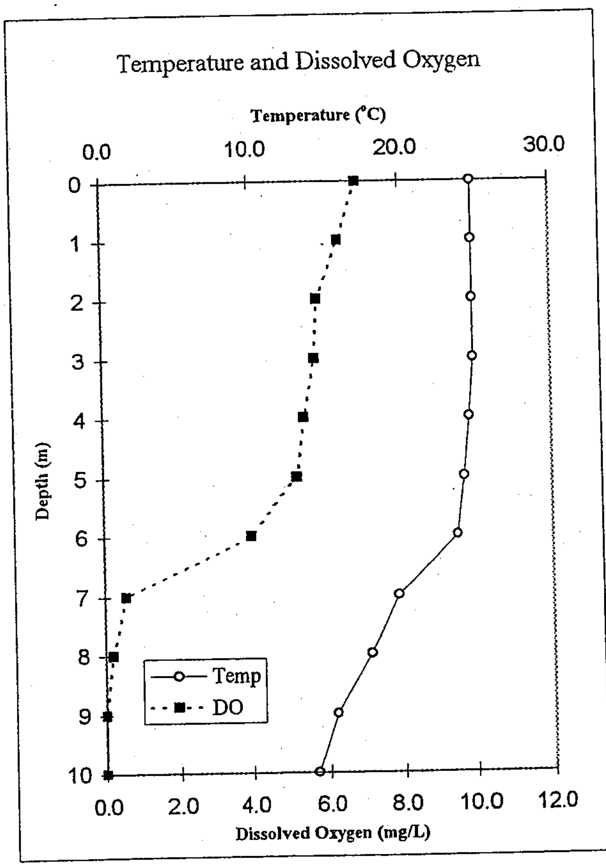
Station #
1

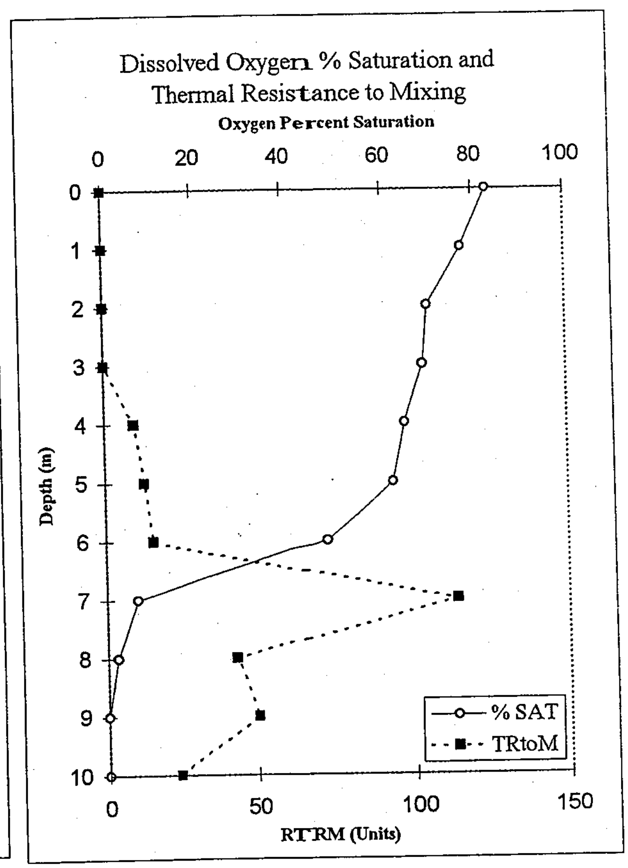
Anoxic Boundary Location
6.9 m

Secchi Disk Depth (m)
4.0

Total Mixing Resistance
268

Water Depth (m)	Temperature (°C)	Dissolved Oxygen (mg/L)	% Oxygen Saturation	Mixing Resistance
0	25.0	6.9	84	0
1	25.0	6.4	77	0
2	25.0	5.8	70	0
3	25.0	5.7	69	0
4	24.7	5.4	65	9
5	24.3	5.2	62	12
6	23.8	4.0	47	15
7	19.7	0.6	7	113
8	17.9	0.2	2	43
9	15.5	0.0	0	50
10	14.2	0.0	0	24





WATER COLUMN PROFILE DATA

Lake Hayward — *August 21, 2000*

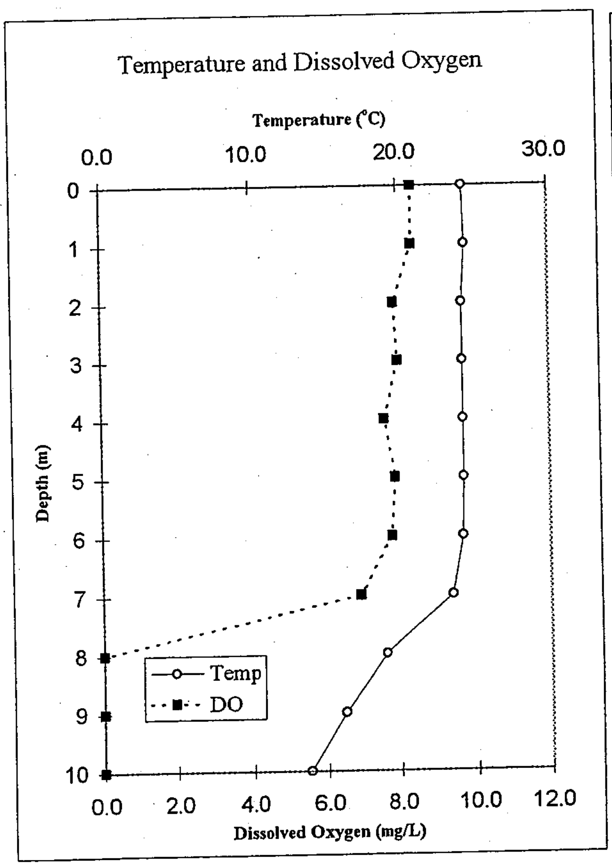
Station #
1

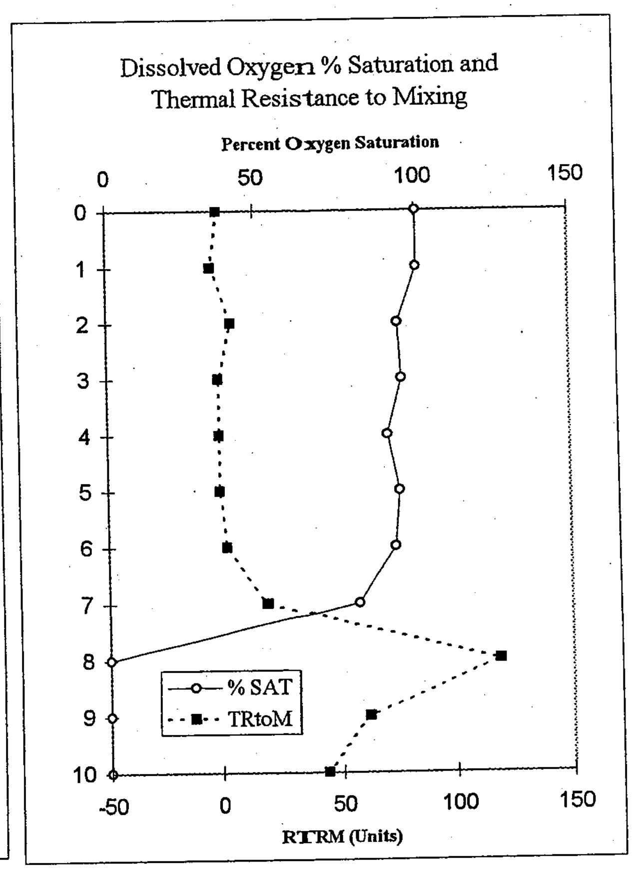
Anoxic Boundary Location
7.9 m

Secchi Disk Depth (m)
4.8

Total Mixing Resistance
251

Water Depth (m)	Temperature (°C)	Dissolved Oxygen (mg/L)	% Oxygen Saturation	Mixing Resistance
0	24.3	8.4	100	0
1	24.4	8.4	101	-3
2	24.2	7.9	94	6
3	24.2	8.0	95	0
4	24.2	7.6	91	0
5	24.2	7.9	94	0
6	24.1	7.8	93	3
7	23.4	6.9	81	21
8	19.0	0.0	0	119
9	16.2	0.0	0	62
10	13.9	0.0	0	43





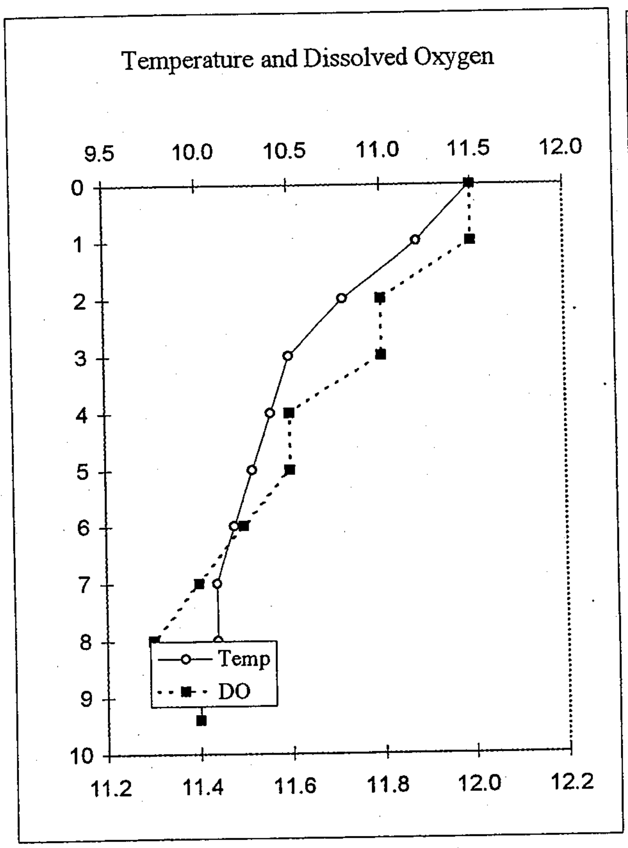
WATER COLUMN PROFILE DATA

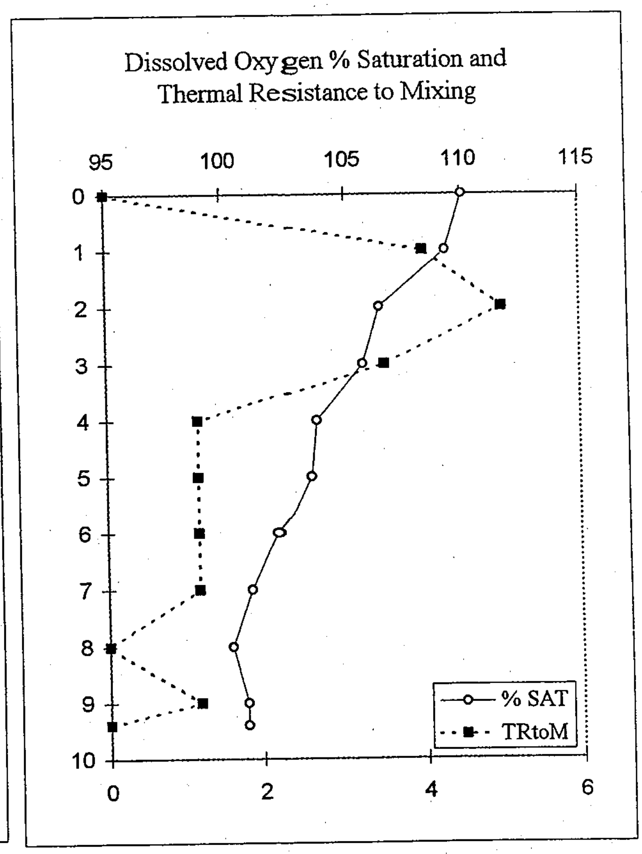
Lake Hayward — *April 16, 2001*

Station #	Anoxic Boundary Location
1	none

Secchi Disk Depth (m)	Total Mixing Resistance
7.0	18

Water Depth (m)	Temperature (°C)	Dissolved Oxygen (mg/L)	% Oxygen Saturation	Mixing Resistance
0	11.5	12.0	110	0
1	11.2	12.0	109	4
2	10.8	11.8	107	5
3	10.5	11.8	106	4
4	10.4	11.6	104	1
5	10.3	11.6	103	1
6	10.2	11.5	102	1
7	10.1	11.4	101	1
8	10.1	11.3	100	0
9	10.0	11.4	101	1
9.4	10.0	11.4	101	0





WATER COLUMN PROFILE DATA

Lake Hayward — *May 17, 2001*

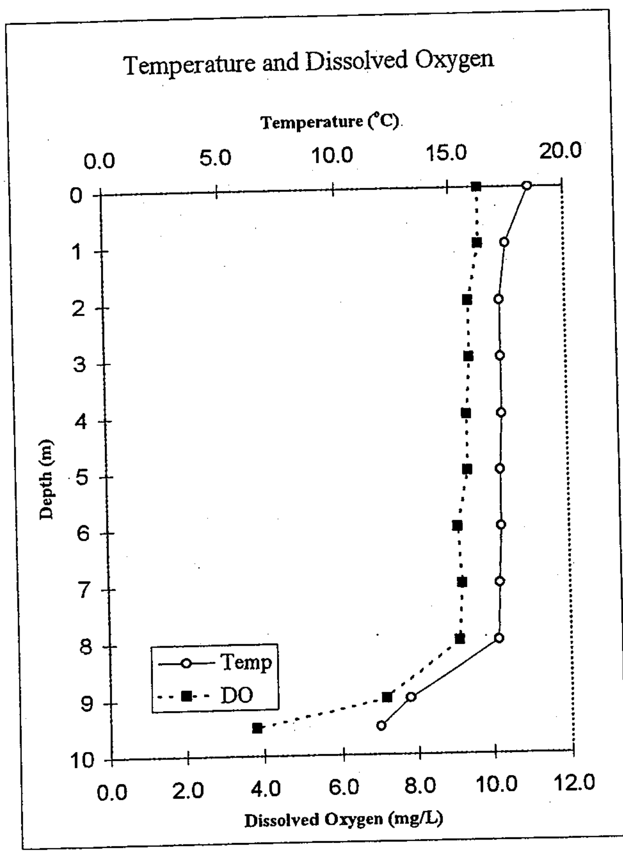
Station #
1

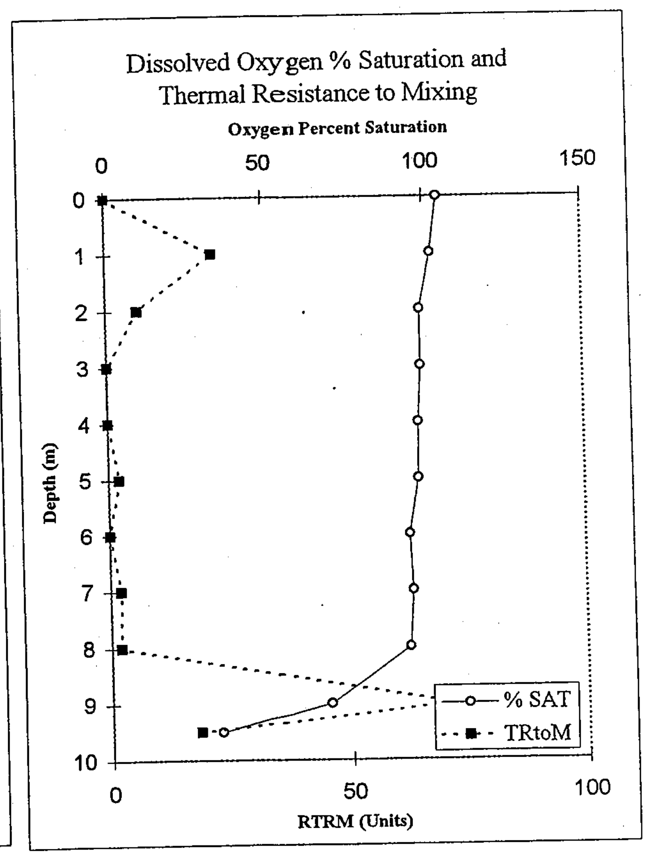
Anoxic Boundary Location
none

Secchi Disk Depth (m)
7.5

Total Mixing Resistance
127

Water Depth (m)	Temperature (°C)	Dissolved Oxygen (mg/L)	% Oxygen Saturation	Mixing Resistance
0	18.5	9.8	105	0
1	17.5	9.8	102	23
2	17.2	9.5	99	7
3	17.2	9.5	99	0
4	17.2	9.4	98	0
5	17.1	9.4	97	2
6	17.1	9.1	94	0
7	17.0	9.2	95	2
8	16.9	9.1	94	2
9	13.0	7.2	68	72
9.5	11.7	3.8	35	19





WATER COLUMN PROFILE DATA

Lake Hayward — *June 26, 2001*

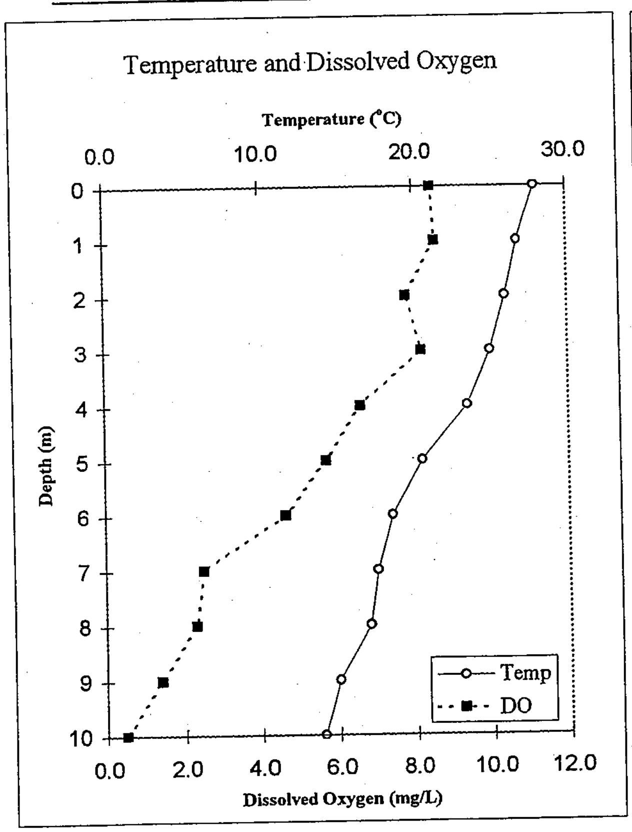
Station #
1

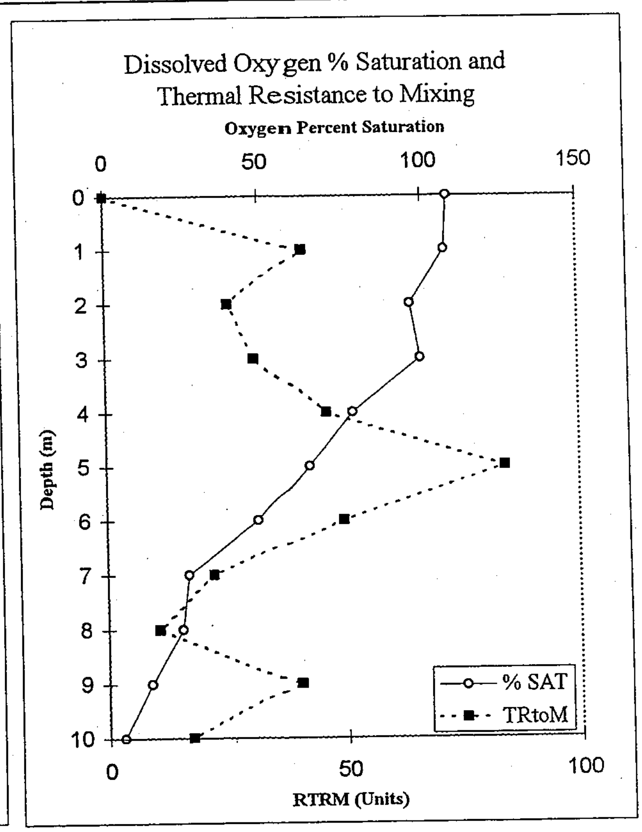
Anoxic Boundary Location
9.4 m

Secchi Disk Depth (m)
3.5

Total Mixing Resistance
371

Water Depth (m)	Temperature (°C)	Dissolved Oxygen (mg/L)	% Oxygen Saturation	Mixing Resistance
0	28.0	8.5	109	0
1	26.8	8.6	108	41
2	26.0	7.8	96	27
3	25.0	8.2	99	32
4	23.5	6.6	78	46
5	20.5	5.7	63	84
6	18.5	4.6	49	50
7	17.5	2.5	26	23
8	17.0	2.3	24	11
9	15.0	1.4	14	40
10	14.0	0.5	5	18
11	14.0	0.0	0	0





WATER COLUMN PROFILE DATA

Lake Hayward *July 20, 2001*

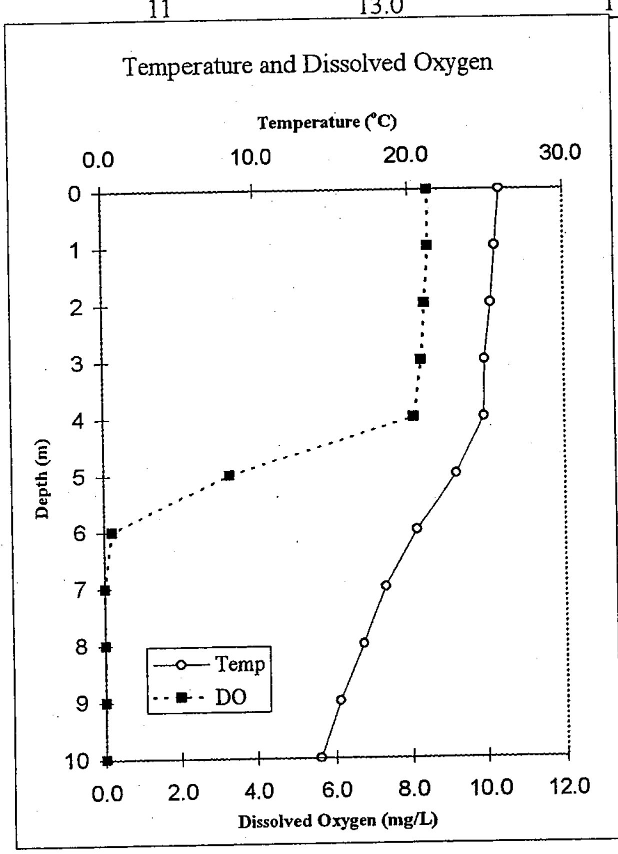
Station #
1

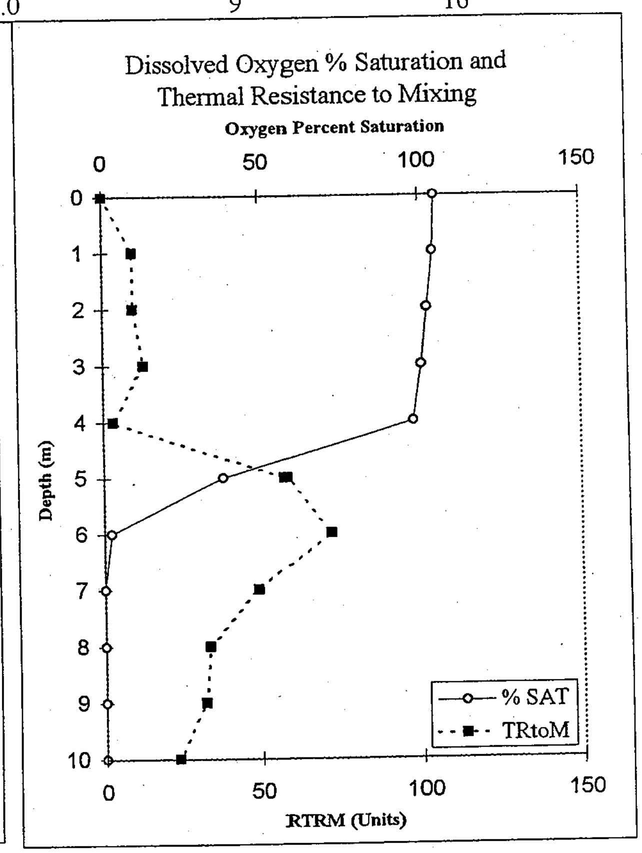
Anoxic Boundary Location
5.7 m

Secchi Disk Depth (m)
4.0

Total Mixing Resistance
320

Water Depth (m)	Temperature (°C)	Dissolved Oxygen (mg/L)	% Oxygen Saturation	Mixing Resistance
0	26.0	8.5	105	0
1	25.7	8.5	104	10
2	25.4	8.4	102	10
3	25.0	8.3	100	13
4	24.9	8.1	98	3
5	23.0	3.3	38	58
6	20.4	0.2	2	72
7	18.4	0.0	0	49
8	16.9	0.0	0	34
9	15.3	0.0	0	32
10	14.0	0.0	0	24
11	13.0	1.0	9	16





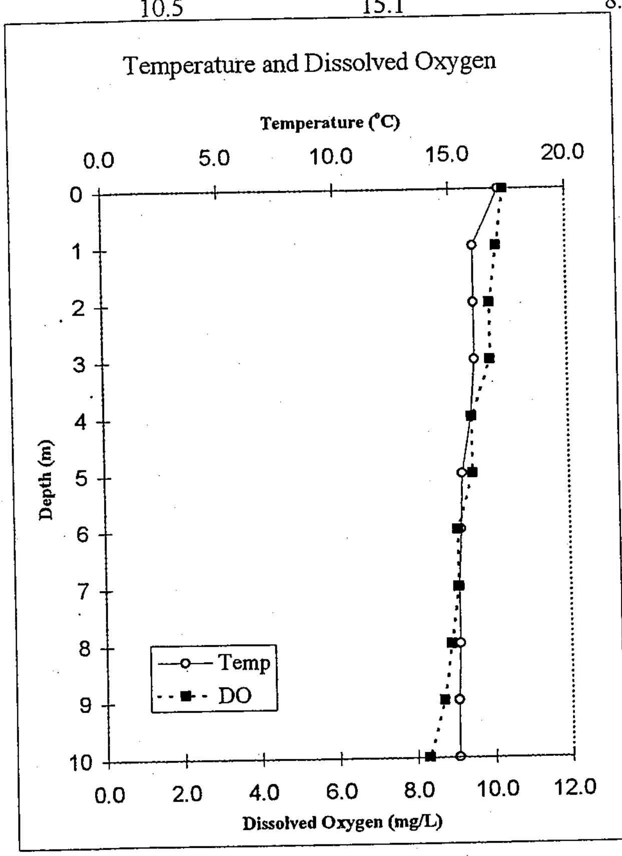
WATER COLUMN PROFILE DATA

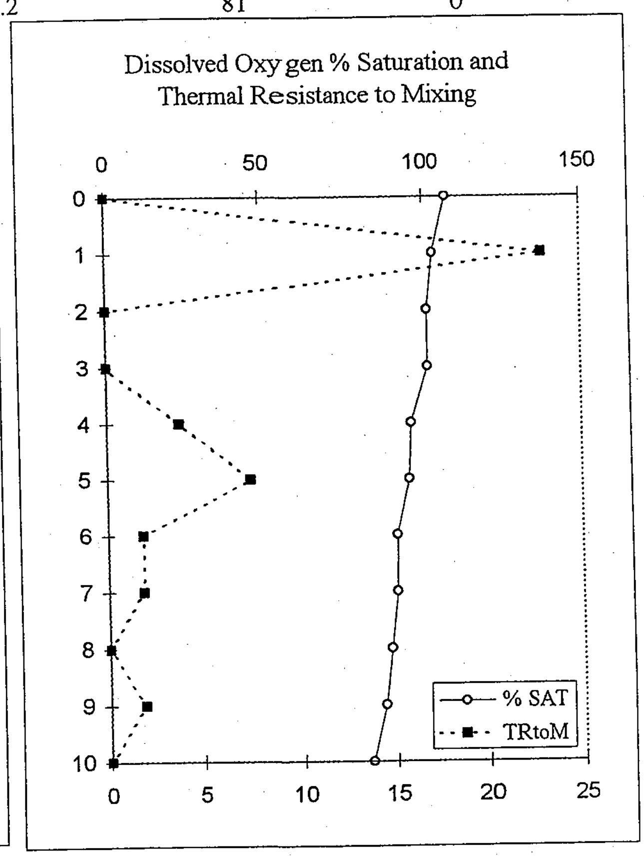
Lake Hayward — *October 12, 2001*

Station #	Anoxic Boundary Location
1	1.3 m

Secchi Disk Depth (m)	Total Mixing Resistance
5.3	40

Water Depth (m)	Temperature (°C)	Dissolved Oxygen (mg/L)	% Oxygen Saturation	Mixing Resistance
0	17.1	10.4	108	0
1	16.0	10.2	103	23
2	16.0	10.0	101	0
3	16.0	10.0	101	0
4	15.8	9.5	96	4
5	15.4	9.5	95	8
6	15.3	9.1	91	2
7	15.2	9.1	91	2
8	15.2	8.9	89	0
9	15.1	8.7	86	2
10	15.1	8.3	82	0
10.5	15.1	8.2	81	0





Appendix 4

CT DEP Lake Trophic Categories.

Category	T.P. (ppb)	T. Nitrogen (ppb)	Chlorophyll (ppb)	Secchi Depth (m)
Oligotrophic	0 - 10	0 – 200	0 - 2	6+
Oligo-mesotrophic	10 - 15	200- 300	2 - 5	4 - 6
Mesotrophic	15 - 25	300 – 500	5 - 10	3 - 4
Meso-eutrophic	25 - 30	500 – 600	10 - 15	2 - 3
Eutrophic	30 - 50	600 – 1000	15 - 30	1 - 2
Highly Eutrophic	50+	1000+	30+	0 - 1

Appendix 5

Phytoplankton Counts in Cells per mL.

Lake Hayward	Algal Cells/ml	2000						
Division	**Genus**	**April**	**May**	**June**	**July**	**August**	**Septem**	**October**
Bacillariophyta	Cymbella	347			174			
	Synedra	88						
	Asterionella		88					
	Cyclotella			694		44	65	29
	Synedra			88				22
	Anomoeomeis			88				
	Navicula					174		
	Gomphonema						22	
	Fragilaria							58
Chlorophyta	Chlorococcal	1,389			1,215		195	
	Stichococcus	788,900	113,700	215,300	123,600	75,526	4,297	16,263
	Protoderma		44					
	Quadrigula			88				
	Monomastix			347	347		22	
	Monoraphidium			347				29
	Apodochloris				174			
	Chlamydomonas				44			
	Crucigenia						175	
	Oocystris						195	
	Scenedesmus						44	
	Sphaerocystis						174	
	Lobomonas						22	
	Sryptomonas						109	
Chrysophyta	Mallomonas		44			174		
	Erkenia			2,431	347		87	29
	Stichogloea					347		116
	Uroglena					174	326	434
	Ochromonas						22	29
Cryptophyta	Cryptomonas		347	88	88		781	22
	Rhodomonas		347	1,389	694	347	434	318
Cyanophyta	Merismopedia					5,556	651	579
	Aphanocapsa					694	3,907	3,704
	Aphanothece			31,947	2,778		694	1,447
	Oscillatoria			1,389	1,736			
	non-motile BG				174			
	Coelosphaerium							4,384
Pyrrhophyta	Gomphosphaeria						22	
Misc	Misc			1,042	1,042	2,778	2,735	9,636
Total =		**790,724**	**114,570**	**255,237**	**132,413**	**85,814**	**14,977**	**37,098**

Lake Hayward	Algal Cells/ml	2001						
Division	**Genus**	**April**	**May**	**June**	**July**	**August**	**Septeml**	**October**
Bacillariophyta	Tabellaria	22						
	Achnanthes		163		87	26	13	
	Cyclotella		163	203	174	104	117	52
	Eunotia		22					
	Nitzschia		22					
	Fragilaria			66	78		432	78
	Synedra			41	104	26		13
	Navicula				17	26		
Chlorophyta	Chlorococcaceae	22	407	203	174	52	156	78
	Monoraphidium	5,599	732	122	17	52	26	
	Ankistrodesmus			41		26	13	
	Oocystis			41		52	13	114
	Pediastrum			326				
	Quadrigula			41	78			
	Sphaerocystis			175		351		
	Tetraedron			81				13
	Chlamydomonas				35		39	
	Crucigenia				88		52	
	Monomastix				35		13	
	Psephonema					52		
	Scenedesmus					104		
	Micractinium							13
Chrysophyta	Chrysophyceae				17	26		65
	Mallomonas				17	78	13	26
	Stichogloea				69			
	Uroglena				1,111	1,834	313	417
	Erkenia							26
Cryptophyta	Cryptomonas	66	163	163	104	130	39	104
	Rhodomonas			610	417	573	365	208
Cyanophyta	Chroococcaceae	1,042	244		1,953	1,823		78
	Synechococcus	198,581	31,171	13,347	2,800	2,344	1,823	13
	Aphanocapsa		651	14,649	5,521	1,563	1,511	417
	Oscillatoria		610				208	
	Aphanothece				3,056	13,334	9,784	8,855
	Chroococcus				104	52		
	Coelosphaerium				3,472			
	Gomphosphaeria				4,514		1,042	
	Merismopedia				208		2,917	2,083
	Microcystis					6,823	8,243	1,432
Miscellaneous		1,823	3,125	4,651	191	5,209	4,427	2,083
Pyrrhophyta	Gymnodinium	22	17	44	13	13		
	Peridinium		22	26				
Xanthophyta	Centratractus						13	

Totals =		207,177	37,512	34,830	24,456	34,674	31,571	16,170

Appendix 6

Lake Eutrophication Modeling Results for Lake Hayward.

PHOSPHORUS LOADING INFORMATION

LAKE HAYWARD

Existing Conditions

PARAMETER	English Units		Metric Units	
Lake Surface Area	170	acres	687,966	m^2
Littoral Area	70	acres	283,280	m^2
Profundal Area *(Too deep for weeds < 10 ft)*	100	acres	404,686	m^2
Lake Volume	2,020	acre-ft	2,492,680	m^3
Mean Depth	11.9	feet	3.62	m
Maximum Depth	37.0	feet	11.3	m
Watershed Area *(Total)*	1,805	acres	7,304,582	m^2
Depth of Epilimnion	15	feet	4.5	m
Surface Area at Bottom of Epiliminon	46	acres		
Epilimnion Sediment Area (A_e)	124.0	acres	501,811	m^2
Epilimnion Volume (V_e)	1,772	acre-ft	2,185,727	
Mean Depth of Epilimnion (Z_e)	14.3	feet	4.4	m
$1-A_t/A_o$ Probability of sedimenting particle fall in epilimnion	0.74			
$(A_e) / (V_e)$ = $(1-A_t/A_o) / Z_e$	0.171			
Grams Carbon m^3/yr	5.751			
Chlorophyll ppb	3.784			
Predicted Secchi Depth	10.763	Feet	**3.280**	m
Watershed Area/Lake Area	11			
Lake/Watershed Area	8.6	%		
Mean Depth/Maximum Depth	0.32	Ratio		
Residence Time	0.569	years	208	
Depth / Residence Time	6	m/yr		
Flushing Rate	1.76	times / year	208	Days
Areal Water Load	21	feet / year	6	m / year
Daily Flushing Rate	0.005	days		
Diluition Rate	0.0016	days		
Inflow Rate	3,550	acre-ft / year	4,378,648	m^3 / year
Total Precipitation =	47.2	inches		
Effective Precipitation =	23.6	inches		
Spring Total Phosphorus Concentration (STP)			4.0	ppb
Predicted Load from Observed STP			0.17	$g\ P\ m^{-2} yr^{-1}$
Areal Water Load			6.4	m / yr
Morphometry Data From: Frink and Norvell				

EUTROPHICATION MODELS

LAKE HAYWARD — Existing Conditions

Variables and Constants	Value	Symbol	Units
Spring Total Phosphorus Concentration	**10.0**	**TP**	**mgP/m^{-3}**
Mean Depth	3.62	-z-	m
Flushing Rate	1.76	F	times/year
Areal Water Load (-z- * F)	6.37	qs	m/year
Retention Coefficient (Kirchner Dillon)	0.67	Rp	
Retention Coefficient (Vollenweider)	2.76	S	
Retention Coefficient (Chapra)	0.72	R	

MODEL 1 Kirchner and Dillon 1975 (Water Resources Res. 2(1): 182-183)

Prediction of annual phosphorus load from; Spring Total Phosphorus Concentration (TP), Mean Depth (-z-), Flushing Rate (F), and Retention Coefficient (Rp)

L = TP (-z-) (F) / (1-Rp) ... where TP is Obs(- **10** mg P / m^3

Predicted L = **0.20** g P / square meter / year

Predicted TP Load 135 kg/year

MODEL 2 Vollenweider 1975 (Sch. Zeit. Hydrol. 37: 53-84)

Prediction of annual phosphorus load from; Spring Total Phosphorus Concentration (TP), Mean Depth (-z-), Flushing Rate (F), and Retention Coefficient (S)

L= TP * (-z-(S+F))

Predicted L= **0.16** g P / square meter / year

Predicted TP Load= 113 kg/year

MODEL 3 Jones and Bachmann 1976 (Jour WPCF 48(9): 2176 - 2182)

Prediction of L from TP, -z-, F, and S:

L= TP * (-z-(S+F)) S=0.65

Predicted L= **0.09** mg P/square meter / year

Predicted TP Load= 60 kg/year

MODEL 4 Chapra 1975 (Water Resources Res. 2(6): 1033-1034)

Retention Coefficent (R), Mean Depth (-z-) and Retention Coefficent (S)

L = (TP)(-z-)(F) / (1-R)

Observed TP= 10 mg P / m^3

Predicted L= **0.22** mg P/square meter/year

Predicted TP Load= 154 kg/year

MODEL 5 Dillon & Rigler 1974 (Limno. Oceanogr 19(5) 767-773)

0.313

2.06 = ppb chlorophyll a — Prediction of summer Chlorophyll a using sprimg TP

4.1 = Summer Secchi meters — Prediction of summer Secchi Disk Depth using Chlorophyll a from model

SUMMARY OF EMPIRICAL MODEL RESULTS

	Load from Observed Spring TP		
	gp/m^{2}yr^{-1}	kg/year	kgP/year
Model 1	0.196	135	135
Model 2	0.164	113	113
Model 3	0.087	60	60
Model 4	0.22	154	154
MEAN	**0.168**	**115**	**115**

Appendix 7

1999 Bacteria Outbreak Documents.

State

Three children suffer kidney failure after swimming in lake

Associated Press

EAST HADDAM — State health officials on Friday were trying to determine what caused 10 children to become sick, including three who suffered kidney failure, after swimming in Lake Hayward.

The children were expected to recover, but town officials posted warning signs not to use the small private lake in the town's northeast corner until further notice. State health officials suspect the children were exposed to a dangerous strain of E. coli bacteria.

"We don't know what pathogen we're dealing [illegible]," said East Haddam Health [illegible]tor Baker Salsbury. "The signs point to E. coli. It's suspicious. The one thing they had in com[illegible] the lake. [illegible] Everybody's [illegible]

Hospitalized at the Connecticut Children's Medical Center in Hartford were a 6-year-old boy from Windsor and two unrelated girls from Wethersfield, ages 3 and 9. The 9-year-old girl was in serious condition, and the other two in fair condition Friday afternoon, said hospital spokesman Tom Hanley.

Both of the girls were in intensive care and on dialysis, but Hanley described their prognosis as good. The seven other children who became sick experienced symptoms of severe diarrhea.

Results of tests taken on water from the lake to determine whether it is contaminated with E. coli are expected to come back on Saturday, said Health Department spokesman William Gerrish. The tests also will ascertain whether Lake Hayward is tainted with fecal matter.

Stool samples of the sickened children, which will help identify the bacteria, are not expected for [illegible] have also been sent to the state lab.

Dr. Matthew Cartter, coordinator of the health department's epidemiology program, said the three youngsters with the most serious illness have been diagnosed with hemolytic uremic syndrome (HUS), a rare and serious disease affecting the kidneys and the blood clotting system. After exposure, the incubation period ranges from three to eight days.

"The most common bacteria that causes this is E. coli exposure," he said. "We suspect (exposure) occurred in the second or third week of July."

The state is also investigating the neighborhood association's recent "Halloween in July" cookout as a possible source, Cartter said.

Town officials posted an advisory W[illegible]day night, warning people against swimming at Lake [illegible] private beaches until [illegible] and source of the illnesses. The state boat launch on the lake has also been closed.

Frank H.
Frank S.
Bill S.
Jerry
Ray

FYI
Tom

B.11 FYI

8/17 Hartford Courant

Lake Gets Presidential Bum Rap

Officials Say Swimming Hole Clean Enough For Everyone — Including Clinton

By GARY LIBOW
Courant Staff Writer

EAST HADDAM —The first selectwoman plans to invite President Clinton to swim in a clean Lake Hayward.

First Selectwoman Susan Merrow is among residents surprised that Clinton, in his nationwide weekend radio address, cited the lake as an example of why the federal government needs to get tougher on water quality.

Clinton said he was shocked to learn that at least 10 children became ill after swimming in a private Connecticut lake that might have been contaminated with E. coli bacteria

But Lake Hayward had been exonerated as a source of the contamination by the time Clinton spoke. Merrow said Monday.

Clinton also said it's unacceptable that 40 percent of the nation's waterways are too polluted for fishing and swimming. The Environmental Protection Agency, he said, will work with states to assess and identify the most polluted waters so that plans are enacted to restore their health.

While applauding Clinton's interest in healthy waterways, Merrow said the president was misinformed about Lake Hayward.

"The unfortunate thing was that the president was apparently not possessed with all information," Merrow said Monday. "Unfortunately, in the electronic media, the lake was not innocent until proven guilty. I'll probably write the president a letter, inviting him to take a swim."

She credited the town's lake association for methodically testing the lake and drinking water.

Alice Miles, treasurer of the lake association, was also shocked East Haddam's trials and tribulations reached Pennsylvania Avenue.

"Oh, good grief. The health department has about ruled out the lake," she said. "To have the president say something, yes, I am amazed. It's surprising that the president would mention it."

Miles, who considers the waterway safe, reported the lake was bustling over the weekend with swimmers and boaters.

"The only thing we're telling the children is that if they take water into their mouths, spit it out rather than swallow it," she said. "As a precaution."

Town Health Director Baker Salsbury was also not pleased with Clinton's weekend address.

"I'm a little unhappy," he said, noting that water tests found no signs of E. coli in the private lake, while stool tests of youngsters suffering from diarrhea so far have tested negative for the bacteria.

Because blood tests of two recuperating youths hospitalized for kidney failure indicated E. coli contamination, Salsbury said, town and state health officials want the remainder of youths who had been sickened to take blood tests. Health officials are now looking at drinking water and possible septic system failure as possible causes, he said.

Despite the health scare, Salsbury said he considers Lake Hayward a "pristine body of water," perfectly suitable for swimming by people of all ages — that includes President Clinton.

Man Charged With Attacking Estranged Wife

By TRACY GORDON FOX
Courant Staff Writer

[illegible] beat [illegible] the [illegible] and [illegible]

High Court Upholds Award For Sewage Plant Stench

Associated Press

The state Supreme Court on Monday upheld a $675,000 award to two Stonington couples who endured horrible odors for years after the town built a sewage treatment [illegible] along the Pawcatuck River since the 1960s. The plant was built in 1980 and the lawsuit was filed in 1991.

The town appealed. In arguments before the high court in June, a lawyer for the town said Stonington needed the plant, and [illegible] site [illegible] was [illegible]nab[illegible]

1 Dies, Several Injured In Van Rollover

By DWIGHT F. BLINT and JANICE D'ARCY
Courant Staff Writers

MIDDLETOWN — A van [illegible] ing a mother, her father, h[illegible] band and 12 of their c[illegible] went out of control and c[illegible] Monday afternoon, killi[illegible] and seriously injuring oth[illegible]

The large, close-knit Ro[illegible] ily was returning home [illegible] Rockaway, Queens, after [illegible] ing a son's wedding in [illegible] over the weekend. Invest[illegible] think a tire blowout ma[illegible] sent the family's van tumb[illegible] olently across I-91.

The accident left Al[illegible] Freund, who turned 78 S[illegible] dead at the scene, and som[illegible] other family members se[illegible] injured, police said.

Fraidy Ross, daugh[illegible]

Please see ONE, [illegible]

EAST HADDAM

Lake Hayward Back In Business

Test Results Deem Water Safe For Use

By GARY LIBOW
Courant Staff Writer

EAST HADDAM — Swimmers young and old frolicked in Lake Hayward Monday, assured by health officials the lake water has tested safe.

About 50 people enjoyed a sunny but cool day on Lake Hayward's three private beaches, two days after the town health director posted a revised health advisory stating that bacterial levels were slightly elevated but well within ranges considered permissible for swimming and boating.

"This lake is 'open,'" an updated health advisory stated.

Dated Saturday, the advisory recommended that ingesting lake water should be avoided, and that anyone who has an illness, especially diarrhea, should stay out of the lake. The advisory also asked that children in diapers be kept out of the water and that no wildlife — especially geese — should be encouraged to enjoy the lakefront.

Meanwhile [illegible] officials are awaiting results of stool tests that should identify the organism that caused kidney failure in three children — who were hospitalized — and sickened at least seven others.

Sue Dupuis of Meriden, on the first day of vacation with her family, ventured into the water confidently. Prior to the water's current clean bill of health from E. coli and other dangerous bacteria, she was "very concerned."

"We're just making sure we don't swallow any, spit water at each other," she said. "Before the day is finished, we'll be in there. All the time we're in the lake, especially this summer with all the heat."

Trish Lane, a Lake Shore Drive resident, said she's enjoyed the lake for 40 years without incident. Her four children played "in and out" of the water, she said.

"I was never nervous about the lake water," Lane said. "The water has always been clean." She said she thinks a contaminated food [illegible] for the illnesses.

Belle Barlow, who had four youngsters in tow, has been a year-round lake resident for two years. She said she understands health officials had to methodically proceed with testing to ensure the water wasn't tainted.

"It was a precaution that had to be taken, to eliminate the possibility of it being the lake or not," Barlow said. "The results I trust. I am letting the children go under water."

Town Health Director Baker Salsbury, noting that the water testing results cannot discern whether the lake water was tainted in mid-to-late July, is still targeting Lake Hayward.

On Monday, Salsbury and the town sanitarian walked the lake perimeter, looking for possible points of waste discharge, animal carcasses or any other possible source of pollution.

Salsbury expects to have definitive results of stool tests from diarrhea sufferers between Wednesday and Friday. The tests, he hopes, will pinpoint the pathogen-containing organism that sickened the young-[illegible]

Teacher

By MARK SPENCER
Courant Staff Writer

WILLINGTON — Kathy Ge[illegible] who lost her job as a teacher fabricating evidence against [illegible] mer student who had stalked h[illegible] suing the school board for dar[illegible] and to get her job back.

The school board last year Gerardi, who wanted to retu[illegible] her fifth-grade classroom at Memorial School after a twc[illegible] medical leave during which dealt with the mental illnes[illegible] said precipitated her behavior.

Although the board said sh[illegible] mentally fit to resume her dut[illegible] was concerned that her re[illegible] would exacerbate the split i[illegible] community caused by her case.

Gerardi's lawsuit accuses board of discriminating agains[illegible] because of a history of menta[illegible] order and a "perception" of a tal disorder.

Board member Michael I[illegible] dredge, who is listed as a defer[illegible] declined Monday to commer[illegible] the suit.

Gerardi and her lawyer, Wi[illegible] J. Dolan, could not be reache[illegible]

DURHAM

Commission Unmoved In Lot Dispute

By MARLENE CL[illegible]
Courant Staff Writer

DURHAM — The participants were smiling, but no one was budging.

"We do not want a car in that front area," planning and zoning commission Chairman George Eames said. "That's why I'm here," attorney Bruno Morasutti replied. "To convince you otherwise."

Morasutti's client is Peter Grippo, who claims he is caught between an imaginary sidewalk, a state right-of-way and a lawsuit filed by the town.

But when the lawyer met with the planning and zoning commission last week, land-use officials were unmoved. Call the front area [illegible]rd for pedestrians who must proceed through the paved area as they walk along sidewalks to the north and south, members said. The town had once suggested Grippo build a sidewalk to connect the two existing walkways, but Grippo declined.

Since there was no sidewalk, the Grippos figured that parking for sale vehicles behind the grassy island was allowed.

"He thought he was complying by keeping off the island," said Morasutti, referring to the concept of an "imaginary" sidewalk. "He needs something to let people know he's selling cars."

Grippo is seeking what he calls a compromise: He'd like to park one automobile in an area abutting the [illegible] grassy island [illegible] this is now.

Morasutti asked whether the town can tell people what to do on a state right-of-way, on property that he doesn't own. He'll get his answer.

The commission voted to write a letter to the state Department of Transportation to examine he situation on behalf of the town.

ESSEX

Factory

Continued from Page B1

that would need approval from the state Department of Health and the Department of Environmental Protection.

Project architect William Grover

To: Matt Cartter, MD, MPH
Coordinator, Epidemiology Program

From: Tara McCarthy, MD, MPH
EIS Officer

Subject: HUS and diarrheal illness at Lake Hayward, CT, Summer 1999

Date: September 23,1999

Preliminary Report

SUMMARY

Between July 30, 1999 and August 5, 1999 there were 3 cases of hemolytic uremic syndrome (HUS) reported to the Connecticut Department of Public Health in residents who had spent time at Lake Hayward. There were no cases of HUS reported to the state for the previous year, 1998. A cohort study was conducted which targeted 211 homes in a defined area at Lake Hayward. One hundred and sixty-five homes were reached and interviews were conducted for any individual who had spent any time at the house from July 16, 1999 to July 25, 1999. Four hundred thirty-six interviews were conducted. A total of 11 cases (2.5%) of severe diarrheal illness (including the 3 HUS cases) occurred in persons who were at the lake during this time. The attack rate in those less than 10 years old who swam on July 17 or July 18 was 12.1% (7/58). Among these, the three HUS cases required hospitalization and two of these required dialysis. There were no deaths. A total of 3 cases had bloody diarrhea. Eight cases had cramping associated with their diarrhea. No organisms were isolated from the stool of any case. Four of the cases had antibodies to E. Coli isolated from the blood that indicated recent illness. Swimming in the lake on the July 17 or July 18 was strongly associated with developing illness (RR 4.7, p = .02 and 5.7, p = .01 respectively). Swallowing water July 17 or July 18 was significantly associated with illness among swimmers (RR 7, p = .0003). Persons who swam at beach 1 were [illegible] likely to get sick than those who swam at other beaches (p = .049). Of those who swam only [illegible] 18, no one got ill. No food item, drinking water source or association sponsored activity was suggestive of a common source of infection.

[illegible]

Hemolytic Uremic Syndrome (HUS) is a reportable disease in Connecticut. On July 30, 1999, the Connecticut Department of Public Health was notified of a case of HUS in a nine year old girl from Wethersfield. A second HUS case was reported to the state health department on August 2, 1999 in a three year old girl from Wethersfield.

These cases were contacted as a part of routine follow-up. Both cases resided in Wethersfield. Their onset of illness was July 26, 1999. The cases did not know each other. They both shopped at the Stop and Shop and Food Mart. Neither had bought or consumed any beef the week prior to their illness. They swam at two different town pools in Wethersfield. They both had been to Lake Hayward in mid-July and swam at the lake, had exposure to the municipal drinking water and shopped at the Stop and Shop in Colchester. They resided on the same street at the lake. We contacted area residents in Lake Hayward and found that there were other children with diarrheal illness in the community.

Lake Hayward is a small lake community with an association on the west side of the lake that includes approximately [illegible] homes. There [illegible] three beaches and a [illegible] water pump at beach 1. There are 2 different water systems within the community. Permanent residents have their own well..Seasonal residents have water piped in through the Eastern Connecticut Regional Water Company.

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PEDIATRICS Vol. 108 No. 4 October 2001, p. e59

ELECTRONIC ARTICLE:

Hemolytic-Uremic Syndrome and *Escherichia coli* O121 at a Lake in Connecticut, 1999

Tara A. McCarthy, MD, MPH*, Nancy L. Barrett, MS, MPH‡, James L. Hadler, MD, MPH‡, Baker Salsbury, MPH, MHSA, MSW§, Robert T. Howard, MS||, Douglas W. Dingman, PhD¶, Cynthia D. Brinkman, MA||, William F. Bibb, PhD#, and Matthew L. Cartter, MD, MPH‡

From the * Epidemic Intelligence Service, assigned to the Connecticut Department of Public Health, Epidemiology Program Office, Centers for Disease Control and Prevention, Atlanta, Georgia; ‡ Connecticut Department of Public Health, Epidemiology Program, Hartford, Connecticut; § East Haddam Health Department, East Haddam, Connecticut; || Connecticut Department of Public Health, Laboratory Division, Hartford, Connecticut; ¶ Connecticut Agricultural Experiment Station, New Haven, Connecticut; and # National Center for Infectious Disease, Centers for Disease Control and Prevention, Atlanta, Georgia.

▸ ABSTRACT

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Objective. Non-O157 Shiga toxin-producing *Escherichia coli* (STEC) have emerged as an important public health problem. Outbreaks attributed to non-O157 STEC rarely are reported. In 1999, follow-up of routine surveillance reports of children with hemolytic- uremic syndrome (HUS) identified a small cluster of 3 cases of HUS, all of whom had spent overlapping time in a Connecticut lake community in the week before onset of symptoms. We conducted an investigation to determine the magnitude and source of the outbreak and to determine risk factors associated with the transmission of illness.

Methods. We conducted a cohort study and an environmental investigation. The study population included all people who were at the lake in a defined geographic area during July 16-25, 1999. This time and area were chosen on the basis of interviews with the 3 HUS case-patients. A case was defined as diarrhea (≥3 loose stools/d for ≥3 days) in a person who was at the lake during July 16-25, 1999. Stool samples were requested from any lake resident with diarrheal illness. Stools were cultured for *Salmonella*, *Shigella*, *Campylobacter*, and *E coli* O157. Broth cultures of stools were tested for Shiga toxin. Case-patients were asked to submit a serum specimen for antibody testing to lipopolysaccharides of selected STEC. Environmental samples from sediment, drinking water, lake water, and ice were obtained and cultured for *E coli* and tested for Shiga toxin. An environmental evaluation of the lake was conducted to identify any septic, water supply system, or other environmental condition that could be related to the outbreak.

Results. Information was obtained for 436 people from 165 (78%) households. Eleven (2.5%) people had illnesses that met the case definition, including the 3 children with HUS. The attack rate was highest among those who were younger than 10 years and who swam in the lake on July 17 or 18 (12%; relative risk [RR]: 7.3). Illness was associated with swimming (RR = 8.3) and with swallowing water while swimming (RR = 7.0) on these days. No person who swam only after July 18 developed illness. Clinical characteristics of case-patients included fever (27%), bloody diarrhea (27%), and severe abdominal cramping (73%). Only the 3 children with HUS required hospitalization. No bacterial pathogen was isolated from the stool of any case-patient. Among lake residents outside the study area, *E coli* O121:H19 was obtained from a Shiga toxin-producing isolate from a toddler who swam in the lake. Serum was obtained from 7 of 11 case-patients. Six of 7 case-patients had *E coli* O121 antibody titers that ranged from 1:320 to >1:20 480. *E coli* indicative of fecal contamination was identified from sediment and water samples taken from a storm drain that emptied into the beach area and from a stream bed located between 2 houses, but no Shiga toxin-producing strain was identified.

Conclusions. Our findings are consistent with a transient local beach contamination in mid-July, probably with *E coli* O121:H19, which seems to be able to cause severe illness. Without HUS surveillance, this outbreak may have gone undetected by public health officials. This outbreak might have been detected sooner if Shiga toxin screening had been conducted routinely in HUS cases. Laboratory testing that relies solely on the inability of an isolate to ferment sorbitol will miss non-O157 STEC, such as *E coli* O121. Serologic testing can be used as an adjunct in the diagnosis of STEC infections. Lake-specific recommendations included education, frequent water sampling, and alternative means for toddlers to use lake facilities. *Key words: Shiga toxin-producing E coli, enterohemorrhagic E coli, hemolytic uremic syndrome, gastroenteritis.*

Infections with Shiga toxin-producing bacteria are an important public health problem. *Escherichia coli* O157:H7 is the most common Shiga toxin-producing *E coli* (STEC) in the United States. *E coli* O157:H7 initially was recognized as a human pathogen in 1982 during outbreaks of diarrhea associated with the consumption of contaminated ground beef at fast-food restaurants in Oregon and Michigan.[1] Since then, *E coli* O157 has been associated with other foods, water, and person-to-person transmission. In the United States, *E coli* O157 is responsible for an estimated 73 000 illnesses annually.[2] The number of *E coli* O157 outbreaks reported to the Centers for Disease Control and Prevention (CDC) has increased from <5 in 1983 to >35 in 1999.[3,4]

E coli O157:H7 is the most common pathogen associated with postdiarrheal hemolytic-uremic syndrome (HUS) in the United States. HUS is characterized by microangiopathic hemolytic anemia, thrombocytopenia, and azotemia and is the most frequent cause of acute renal failure in children. The annual incidence of HUS in the Untied States is approximately 3 cases per 100 000 population among children who are younger than 5 years. Approximately 5% to 10% of people with diarrhea caused by *E coli* O157:H7 develop HUS. The mortality rate among children with HUS is 3% to 5%.[5,6]

Although researchers have learned much regarding the clinical spectrum of disease, modes of transmission, and long-term sequelae of *E coli* O157:H7, little is known about non-O157 STEC infection. Non-O157 STEC usually are recognized only when specialized testing is performed in the setting of investigations of HUS or diarrheal outbreaks.[7-10] Historically, standard laboratory testing for *E coli* O157 has not detected non-O157 STEC. Most *E coli* O157 do not ferment sorbitol within 24 hours, allowing for easy screening if specimens are collected within a week of onset of diarrhea. Most non-O157 STEC are sorbitol fermenters, leaving them without an easily discernible biochemical marker. Screening for Shiga toxin production in broth cultures is an important way to identify non-O157 STEC and does not require the presence of viable organisms.

HUS has been a reportable disease in Connecticut since 1994. On July 30, 1999, a pediatric nephrologist notified the Connecticut Department of Public Health (DPH) of a case of HUS in a girl age 9 years. On August 2, DPH received a second report of HUS in a girl age 3 years from the same town. Interviews with the children's parents revealed that the children did not know each other but that both families shopped at the same chain grocery store in town and had vacationed at the same lake in mid-July. Anecdotal reports of diarrheal illness were reported to the state and local health department from others who reported vacationing at this lake in mid-July. On August 3, the local health director was contacted. A town meeting was held August 4, and residents were warned against swimming in the lake because of suspected transmission of infection through lake water. A third case of HUS in a boy age 6 years was reported to DPH on August 5. This child lived in a different town but had spent time at the same lake in mid-July. In all 3 cases, the children stayed in housing located on the same block at the lake and reported swimming at the same beach (hereafter called beach 1).

The lake is small (approximately 190 acres) and is located in mid-southern Connecticut. The western side of the lake has approximately 380 homes. Owners are members of a lake association, and there are 3 beaches on association property. The community has 2 different water systems. By state law, all permanent residents must have their own well. Water for seasonal residents is supplied by a regional water company.

METHODS

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Epidemiologic Investigation

A case was defined as diarrhea (≥3 loose stools/d for ≥3 days) in a person who was at the lake during July 16-25, 1999, in the defined geographic area. This time and area were chosen on the basis of interviews with the parents of the 3 HUS case-patients. People with chronic diarrhea were excluded as case-patients. An HUS case-patient was defined as a person who developed acute illness characterized by evidence of microangiopathic hemolytic anemia, thrombocytopenia, and renal impairment.

To determine the magnitude and source of the outbreak, we conducted a cohort study. The study population included all people who stayed at or visited homes in a defined geographic area at the lake during July 16-25, 1999. Addresses were obtained for both the seasonal and permanent residences from the town assessor records. Telephone numbers were obtained for recorded residences through telephone books, directory assistance, and neighbors. To obtain unlisted telephone numbers, we sent a newsletter to all association members. The local real estate agency was contacted, and addresses were obtained for people who had rented property at the lake during the specified time.

DPH staff contacted households by telephone from August 17 through September 10. DPH staff attempted to contact households ≥5 times, including once at night and once on weekends. Adults were interviewed by proxy for all children who were younger than 15 years. Demographic data, specific gastrointestinal symptoms, food exposures, restaurant or shopping exposures, drinking water source, participation in lake association-sponsored activities, and lake water exposures were collected using a standard questionnaire.

Statistical analyses were computed using Epi Info version 6 (CDC, Atlanta, GA). Contingency tables and Mantel-Haenszel stratified analyses were used to determine associations between various exposure activities, food and water consumption, and illness. Relative risks (RR) were calculated, and $P \leq .05$ was considered significant.

Laboratory Investigation

We requested a stool sample from any lake resident with diarrheal illness. Stool specimens from people who met the case definition were actively sought and sent to the DPH State Laboratory for testing. Stools were cultured for *Salmonella*, *Shigella*, and *Campylobacter* using standard methods and for *E coli* O157 on sorbitol-MacConkey agar (SMAC).[11,12] Broth cultures of stools were tested for Shiga toxin using the Premier enterohemorrhagic *E coli* (EHEC) enzyme-linked immunosorbent assay (ELISA), which detects Shiga toxin 1 and Shiga toxin 2. This test uses monoclonal anti-Shiga toxin capture antibody absorbed to microwells.[13,14] All Shiga toxin-producing isolates were sent to CDC for further testing and serotyping. Case-patients were asked to submit a serum specimen for antibody testing to lipopolysaccharides (LPS) of known STEC. ELISAs for antibodies to *E coli* O121 LPS were developed as described previously for *E coli* O157 LPS, with positive cutoff values similarly determined.[15] An immunoglobulin M (IgM) titer or immunoglobulin G (IgG) titer of ≥1:320 was considered positive.

Environmental samples from sediment, drinking water, lake water, and ice were obtained and cultured for *E coli*. Each 25-g (mL) sample was suspended in 225 mL of modified *E coli* broth containing vancomycin (20 µg/mL) and incubated overnight at 37°C with aeration.[16,17] Approximately 1 mL of the overnight growth was filtered through a 1000-µL micropipette tip containing a small piece of paper to remove particulate debris. Then 0.1 mL of the filtrate was plated directly onto SMAC containing cefixime (50 ng/mL) and potassium tellurite (2.5 µg/mL; SMAC-CT). A modified immunomagnetic separation procedure using anti-O157 immunomagnetic beads (Dynal, Lake Success, NY) was conducted on 1.0 mL of filtrate according to the manufacturer's recommendations and plated onto SMAC and SMAC-CT.[18] After overnight incubation at 37°C, presumptive *E coli* colonies were isolated. The original sample (0.1 mL) also was plated directly onto Levin eosin methylene blue agar and incubated overnight at 37°C, and potential *E coli* colonies were isolated. All isolated colonies were identified as *E coli* by API20E analysis (BioMerieux Vitek, Inc, Hazelwood, MO), screened for the O157 antigen using a latex agglutination test (Remel, Inc, Lenexa, KS), and tested for O157 pathogenicity gene markers using multiplex polymerase chain reaction.[19] *E coli* isolates also were tested for Shiga toxin using standard methods.[20,21]

Environmental Investigation

DPH staff tested the wells and distribution points of the municipal water company and the lake water. Previous results were obtained from routine lake water testing conducted in mid-July by the lake association. Samples were tested for total coliforms and enterococcus and fecal streptococcus. DPH and local health department staff conducted an environmental evaluation of the lake on August 9-10, 1999, to identify any septic, water supply system, or other environmental conditions that could be related to the HUS/diarrheal outbreak. The entire shoreline of the lake was examined, but the main focus was on the west side, where the 3 HUS case-patients resided. All properties within 2 house lots of the lakefront were examined. An additional street was inspected because all 2 HUS case-patients stayed at houses on this block. Investigators from the Connecticut Agricultural Experiment Station surveyed the lake area and collected lake, well-water, and sediment samples on the west side of the lake on 3 different occasions during August through October 1999.

RESULTS

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Epidemiologic Results

The 3 HUS case-patients were reported to the state as part of the HUS surveillance system. Twenty-five people who were not part of the cohort but who resided at the lake reported nonbloody diarrheal illnesses to the state or local health department. Stool samples were obtained from 11 of these residents.

The study cohort consisted of 211 eligible households. Of these, 165 households (78.2%) were reached, and interviews were conducted with any person who had spent time at the house during July 16-25. Forty-six households (21.8%) were not interviewed; 26 (12.3%) had unpublished or unlisted telephone numbers, and 20 (9.5%) were not reached after ≥5 attempts (including weekends and nights). Data were obtained for 436 people, 11 (2.5%) of whom had illnesses that met the case definition, including the 3 children with HUS. Seventeen people reported mild nonbloody diarrheal illness that did not meet the case definition and were included as non-ill.

Onset dates of diarrheal illness ranged from July 16 to August 4 (Fig 1). The earliest onset occurred in a toddler who was swimming with a diarrheal illness during July 16-21. Onset dates of diarrhea among the 3 HUS case-patients were July 25 and 26.

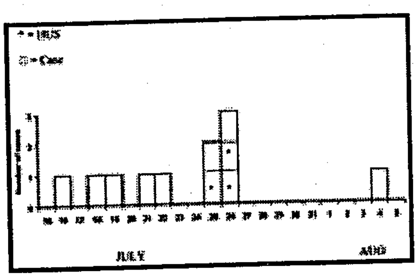

Fig. 1. Onset dates of diarrheal illness and/or hemolytic-uremic syndrome, lake cohort, Connecticut, July 16-25, 1999.

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Of the 11 people who had illnesses that met the case definition, 8 were children who were younger than 12 years and 3 were adults (Table 1). The median age was 6.5 years (range: 1-62 years). Clinical characteristics included fever (27%), bloody diarrhea (27%), and severe abdominal cramping (73%). Average duration of diarrhea was 4.9 days, with an average of 6.7 stools per day. Six case-patients sought medical care. No case-patient received antibiotics for his or her illness or during the month before the illness. Only the 3 children with HUS required hospitalization. Of these, 2 required dialysis, 3 required packed red blood cell transfusions, and 2 required platelet transfusions. Average duration of hospitalization was 12.7 days (range: 4-22 days). No case-patients died.

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TABLE 1
Demographic and Clinical Characteristics of 11 People With Severe Diarrheal Illness and/or HUS, Lake Cohort, Connecticut, July 16-25, 1999

Illness was associated with swimming on July 17 or 18 (Table 2). Those who swam on either day were 8 times more likely to develop illness. The attack rate was highest among people who were younger than 10 years and who swam on July 17 or July 18 (12%; 7 of 58). Those who swallowed water while swimming on these days were 7 times more likely to develop illness. Those who swam at beach 1 on July 17 or 18 and swallowed water were 8 times more likely to develop illness. There also was an increase in risk for those who swam longer on these days (RR = 4.8; $P = .08$). People who swam at beach 1 on any day were more likely to get sick than those who swam at other beaches. No illness occurred among people who swam only after July 18. Illness was not associated with any particular food item, restaurant, drinking water source, or association-sponsored activity. No one who drank only municipal water developed illness.

TABLE 2

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Risk Factors Associated With Severe Diarrheal Illness and/or HUS, Lake Cohort, Connecticut, July 16-25, 1999

Laboratory Results

Stool samples were obtained from 20 lake residents, including 11 people with reported diarrhea outside the cohort, 6 (54%) of the case-patients, and 3 people with mild diarrhea in the cohort. Initial stool samples from case-patients were received a mean of 13.7 days after the onset of symptoms (range: 1-36 days). No bacterial pathogens were isolated from the stool of any case-patient (Table 3). Among the other lake residents, *E coli* O121:H19 was obtained from a Shiga toxin-producing isolate from 1 toddler who swam at a beach on the eastern side of the lake. This was the only Shiga toxin-producing isolate confirmed in our study.

TABLE 3

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Serologic and Microbiologic Features Among People With Severe Diarrheal Illness and/or HUS, Lake Cohort, Connecticut, July 16-25, 1999*

Serum was obtained from 7 of 11 case-patients a mean of 25.7 days (range: 7-65 days) after onset of diarrheal illness. Antibody titers were positive for *E coli* O157 in 2 of 7 case-patients (Table 3). After the *E coli* O121 isolate was identified from 1 toddler, sera were retested for *E coli* O121. Six of 7 case-patients had positive antibody titers; all were at least 8 times higher to *E coli* O121 than to O157. Titers to *E coli* O121 ranged from 1:320 to >1:20 480. Serum from the patient who did not have elevated titers to *E coli* O121 or O157 was drawn 7 days after the onset of symptoms.

Environmental Results

Water samples that were collected from wells and distribution points of the municipal water system were in compliance with the standards mandated for public drinking water, except for elevated iron and manganese levels. There were no pressure drops noted in the records kept at the municipal water company. No survey to detect possible cross connections between the municipal water system and private wells was conducted.

No *E coli* was isolated from lake water or ice cubes made in mid-July from the municipal water. The environmental evaluation of the lake conducted on August 9-10 did not identify an environmental problem that could account for the outbreak. No cattle or other livestock grazed near the lake or run-off areas. *E coli* indicative of fecal contamination was isolated from sediment samples and water taken from a storm drain that emptied into the beach area and from a stream bed located between 2 houses, but no Shiga toxin-producing strain was identified.

DISCUSSION

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Our findings are most consistent with a transient local beach contamination in mid-July, probably with *E coli* O121:H19. Swimming in the lake or swallowing water on July 17 or 18 were strongly associated with the development of illness. No cases were reported among people who swam only after July 18. No food item, drinking water source, or association-sponsored activity was associated with illness.

The most likely source of contamination was a toddler in diapers with onset of severe diarrhea on July 16. The toddler spent >2 hours a day in the water during the time of illness, July 16-21. The infectious dose for *E coli* O157 is presumed to be low, and the incubation period is 1 to 8 days.[22] Although little is known about the pathogenicity of *E coli* O121, we expect the infectious dose and incubation period to be similar to *E coli* O157. People in our cohort were presumed to be exposed to contaminated lake water during July 16-18; therefore, the onset of symptoms should have occurred during July 17-26. Eighty-two percent of the cases occurred during this time. Although we cannot rule out the possibility of an environmental source of contamination, this seems less plausible given the extensive environmental survey and the failure to find any environmental isolates of STEC.

The attack rate was highest among children who were younger than 10 years. This is consistent with studies of *E coli* O157 that show that the attack rate is higher among children.[23-25] Clinical characteristics were similar to those described for outbreaks caused by *E coli* O157, although the proportion of cases with bloody diarrhea was somewhat lower (27%).[26] Fever is an infrequent finding in infections with *E coli* O157 and was documented in <30% of our cases.

This seems to be the first outbreak in the United States of STEC associated with swimming caused by an *E coli* serotype that was not O157. Most likely, this outbreak was caused by *E coli* O121 or a closely related STEC. Historically, stool testing for *E coli* O157 has relied on the inability of this pathogen to ferment sorbitol within 24 hours. Most non-O157 STEC ferment sorbitol and, thus, are not detected by this test. In the United States, most cases of non-O157 STEC are detected because of outbreak investigations or other unusual circumstances. The percentage of HUS and severe diarrheal illness in the United States caused by non-O157 STEC is unknown. Non-O157 STEC increasingly have become an important public health problem in other countries. In Italy, STEC O103 and O26 accounted for 44% of HUS cases reported in 1996, compared with 8.1% of HUS cases reported during 1988 to 1995.[27] Other studies in Argentina, Australia, and Europe also illustrated the importance of non-O157 STEC in causing human disease.[28-30] With increased international travel and importation of beef from areas such as Argentina that have a high incidence of HUS, the role of non-O157 STEC in causing human disease should be defined further.

Without HUS surveillance, this outbreak might have gone undetected by public health officials. Postdiarrheal HUS is believed to be related to the production of Shiga toxin. In previous studies of patients with HUS, *E coli* O157 was isolated more frequently in stool samples taken from a case-patient within 6 days of onset of symptoms,[31-33] yet by the time patients with HUS seek medical attention (typically 1 week after the onset of diarrhea), STEC might no longer exist in the stool.

The Connecticut outbreak might have been detected sooner if Shiga toxin screening had been conducted routinely. In our study, stool samples from 2 of the HUS case-patients were tested for *E coli* O157 within 1 day of onset of diarrhea, then again at day 4 or day 11 of illness. All stools were negative for *E coli* O157. If Shiga toxin testing had been conducted on these initial broth cultures of stools collected during the bloody diarrheal phase, then *E coli* O121 might have been identified. Laboratory testing that relies solely on the inability of an isolate to ferment sorbitol will miss non-O157 STEC. Laboratories should test for Shiga toxin in appropriate clinical scenarios, such as bloody diarrhea and HUS. This would lead to a better understanding of the role of non-O157 STEC in causing human disease.

Serologic testing can be used as an adjunct in the diagnosis of STEC infections. Patients often present with HUS when they are less likely to be shedding STEC in their stool. Bacterial LPS enters the bloodstream, and an antibody response typically is seen within 7 to 10 days after infection. Previous studies reported that IgG and IgM antibodies to *E coli* O157 are good indicators of recent infection.[15,34,35] In 1992, Caprioli et al[36] investigated an outbreak of HUS in Italy. They isolated *E coli* O111 from the stool of a case-patient and subsequently proved that 6 of 7 HUS case-patients had antibodies to O111 LPS using an ELISA-based test. There was no cross-reactivity with O157 LPS. None of 30 control subjects in this study had antibodies to O111. Other studies suggested that antibodies to some LPS are not specific and that cross-reactivity with other non-O157 STEC exists.[37,38]

In the CDC laboratory (W.F.B.), we examined the reaction of sera from culture-confirmed O157 cases and O121 LPS. Our data indicate that in most cases, the reaction with O121 LPS would be considered negative, but occasionally a serum would exhibit a titer close to the homologous antigen. It seems that there is a similar cross-reaction between sera from culture-confirmed O121 cases and O157 LPS. The reaction with O157 LPS is greatly reduced, being positive only when the titer of O121 was extremely high. Thus, it seems that there is some minimal cross-reaction between the 2 antigens, but the implicated serotype can be deduced by the ratio of the reactions. The source of these cross-reactions is not known but may result from reactions with a common core LPS or another shared antigen that is co-purified along with the LPS. The sera in this study also were examined against antigens prepared to other LPS (O111, O104, and O26), and no reactions were observed. These antigens were chosen because they are responsible for the majority of the non-O157 STEC outbreaks reported in the United States.

In our study, serum was obtained a mean of 25.7 days (range: 7-65 days) after the onset of symptoms. The finding of elevated antibody titers to *E coli* O121 LPS in 6 of the 7 case-patients tested, along with the epidemiologic data, strongly supports this as the cause of illness. Titers were at least 8 times higher to *E coli* O121 than to O157.

Serologic results were based on a single titer and showed only an IgG response to *E coli* O121 LPS. There are several reasons that could account for the lack of IgM response. One person whose serology was negative for both *E coli* O121 and O157 had her serum drawn 7 days after the onset of symptoms. This person might not have mounted an immune response to the LPS antigen yet. Three case-patients had serum obtained >21 days after the onset of symptoms (range: 21-65 days). These patients had significant IgG responses, and the timing of their serology could explain the lack of IgM response. Three people had IgG responses that were >1:2560 (range: 1:2560-1:20 480). The CDC laboratory (W.F.B.) found that when the IgG response is so significant, it often can block the binding of IgM to the well of the plate. We reproduced this experimentally by mixing a serum that has both an IgG and an IgM response with a second serum that has a high IgG titer. The serum is no longer positive for IgM.

This study demonstrates the usefulness of serology as an important adjunct in the identification of causative agents in STEC outbreaks. People who work in outbreak investigations should be aware of this important tool and understand its limitations. In most cases, the serologic diagnosis is very specific and cross-reactions for most serotypes of STEC are rare. However, antibody cross-reactions should be considered when interpreting serologic test results, particularly with sporadic cases of HUS. During outbreaks, determining serologic results in control subjects might help better address issues of cross-reactivity.

As demonstrated by this outbreak, non-O157 STEC are important causes of bloody diarrhea and HUS. Most non-O157 STEC would be overlooked by current laboratory practices. Without routine screening of appropriate stool specimens for Shiga toxin, valuable clinical and epidemiologic information would be missed.

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FOOTNOTES

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Reprint requests to (T.A.M.) Infectious Disease Division, Connecticut Department of Public Health, 410 Capitol Ave, MS #11 EPI, Hartford, CT 06134-0308. E-mail: tara.mccarthy@po.state.ct.us

ABBREVIATIONS

STEC, Shiga toxin-producing *Escherichia coli*; CDC, Centers for Disease Control and Prevention; HUS, hemolytic-uremic syndrome; DPH, Department of Public Health; RR, relative risk; SMAC, sorbitol-MacConkey agar; EHEC, enterohemorrhagic *Escherichia coli*; ELISA, enzyme-linked immunosorbent assay; LPS, lipopolysaccharides; IgM, immunoglobulin M; IgG, immunoglobulin G.

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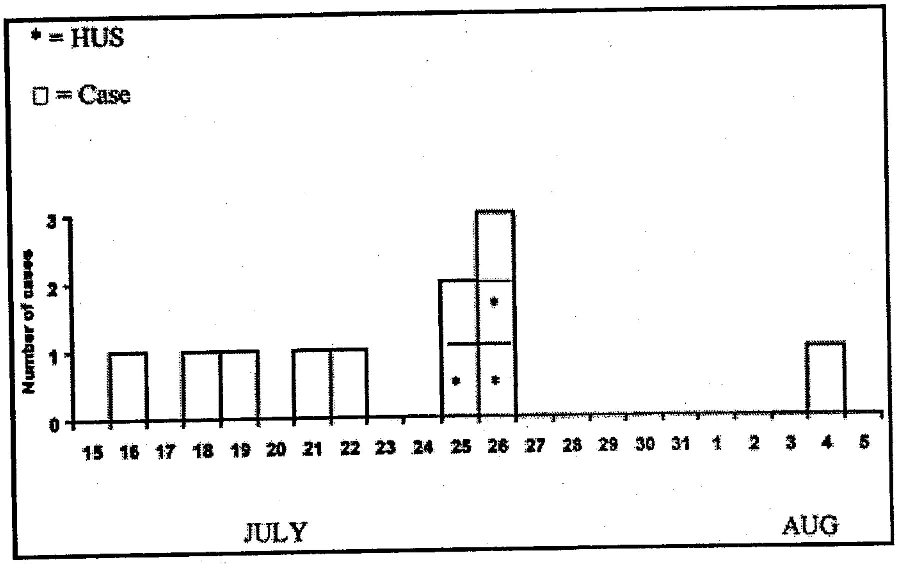

Fig. 1. Onset dates of diarrheal illness and/or hemolytic-uremic syndrome, lake cohort, Connecticut, July 16-25, 1999.

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TABLE 1

Demographic and Clinical Characteristics of 11 People With Severe Diarrheal Illness and/or HUS, Lake Cohort, Connecticut, July 16-25, 1999

Characteristics of case-patients	
Median age (y)	6.5 (range: 1-62)
Gender	
Female	6 (55%)
Male	5 (45%)
Characteristics of illnesses	
Diarrhea ≥3 d	11 case-patients (100%)*
Duration of diarrhea	4.9 d (range: 3-7 d)
Maximum number of stools/d	6.7 (range: 3-20)
Bloody diarrhea	3 case-patients (27%)
Abdominal cramping	8 case-patients (73%)
Fever	3 case-patients (27%)
Sought medical care	6 case-patients (55%)
Hospitalization	3 case-patients (27%)
Duration of hospitalization	12.7 d (range: 4-22 d)

* Required by case definition.

TABLE 2

Risk Factors Associated With Severe Diarrheal Illness and/or HUS, Lake Cohort, Connecticut, July 16-25, 1999

	Cases (n = 11)	Noncases (n = 425)	Attack Rate (%)	RR	P Value
Days swam					
Swam any day	10	289	3.3	4.6	.09
Swam July 16	3	115*	2.5	1.0	.61
Swam July 17	9	202*	4.3	4.8	.03
Swam July 18	9	183*	4.7	5.7	.01
Swam July 19	3	107*	2.7	1.1	.56
Swam July 17 or 18	10	229*	4.2	8.3	.01
Location: Beach 1	10/10	207/288	4.6		.04
Swam July 17 or 18	n = 10	n = 229			
Age <10 yr	7	51	12.1	7.3	.002
Age ≥10 yr	3	178			
Swallowed water	6	35/222	14.6	7.0	.003
Swam longer	9	147	5.8	4.8	.08
Beach 1	10	170	5.6		.06
Beach 1 and swallowed water	6	22/165	21.4	7.9	.001
Beach 1 and swam longer	9	104	8.0	5.3	.06
Drank	n = 10	n = 419			
Municipal water	4/10	82	4.6	2.7	.12
Well water	1/10	145	0.7	0.22	.09
Municipal water July 17 or 18	4/9	46/227	8.0	3.0	.10

* Excludes 1 non-case-patient with missing information.

TABLE 3

Serologic and Microbiologic Features Among People With Severe Diarrheal Illness and/or HUS, Lake Cohort, Connecticut, July 16-25, 1999*

Age (yr)	Date of Stool Collection	Stool Isolate	Stool Shiga Toxin	Date Sera Drawn	Anti-O157 LPS Antibody	Anti-O121 LPS Antibody
9[†]	7/27, 7/30	None	Negative	8/2	IgG 1:80 IgM 1:80	IgG 1:80 IgM 1:80
3[†]	8/12	None	Negative	8/3	IgG 1:40 IgM <1:40	IgG 1:320 IgM 1:80
6[†]	7/25, 8/5	None	Negative	8/5	IgG 1:320 IgM <1:40	IgG 1:5120 IgM 1:40
2	8/12	None	Negative	8/12	IgG 1:160 IgM <1:40	IgG 1:2560 IgM <1:40
11	8/27	None	Negative	8/12	IgG 1:160 IgM 1:80	IgG 1:1280 IgM 1:80
7	Not done			9/24	IgG 1:2560 IgM 1:40	IgG 1:20 480 IgM 1:80
1	8/4	None	Negative	Not done		
62	Not done			9/7	IgG 1:40 IgM <1:40	IgG 1:640 IgM 1:40

* A titer of ≥1:320 for IgM or IgG generally is considered positive for both O157 and O121 by ELISA testing.

† HUS cases.

Appendix 8

Raw Data Collected During This Study From Lake And Stream Sampling.

2000 Lake Water Quality Data

Total Phosphorus (ppb)							
Depth	28-Apr	23-May	29-Jun	29-Jul	21-Aug	29-Sep	26-Oct
1	4	6	4	7	5	9	7
3	4	5	4	8	8	9	7
5	4	5	5	6	10	6	6
7	4	5	6	6	9	6	7
9	6	6	9	12	20	7	6

Ammonia Nitrogen (ppb)							
Depth	28-Apr	23-May	29-Jun	29-Jul	21-Aug	29-Sep	26-Oct
1	18	26	5	34	34	43	14
3	5	26	11	47	34	44	15
5	5	27	57	46	41	39	24
7	5	24	230	68	65	38	16
9	5	61	283	275	610	87	23

Nitrate / Nitrite -Nitrogen (ppb)							
Depth	28-Apr	23-May	29-Jun	29-Jul	21-Aug	29-Sep	26-Oct
1	<20	53	< 10	< 10	< 10	< 20	< 20
3	<20	64	< 10	< 10	< 10	< 20	< 20
5	73	57	< 10	< 10	< 10	< 20	< 20
7	<20	38	< 10	< 10	< 10	< 20	< 20
9	73	53	< 10	21	< 10	< 20	< 20

TKN -Nitrogen (ppb)							
Depth	28-Apr	23-May	29-Jun	29-Jul	21-Aug	29-Sep	26-Oct
1	320	180	350	162	260	226	247
3	260	230	300	139	153	214	
5	260	180	340	116	276	240	195
7	200	205	490	162	170	176	
9	350	246	570	395	1120	252	312

Specific Conductance (umhos/cm)							
Depth	28-Apr	23-May	29-Jun	29-Jul	21-Aug	29-Sep	26-Oct
1	67	72	67	71	70	71	71
3	69	72	70	71	70	71	71
5	70	73	70	72	70	71	72
7	69	73	74	74	72	71	71
9	69	73	75	77	85	73	74

2000 Lake Water Quality Data

Alkalinity (mg/L)							
Depth	28-Apr	23-May	29-Jun	29-Jul	21-Aug	29-Sep	26-Oct
1	1	4	3	5	6	7	3
3	1	4	1	4	6	4	4
5	1	4	4	6	4	6	3
7	2	4	8	6	8	6	4
9	1	2	6	10	16	5	5

Turbidity (NTU)							
Depth	28-Apr	23-May	29-Jun	29-Jul	21-Aug	29-Sep	26-Oct
1	1.0	0.6	1.3	1.0	0.9	1.2	0.8
3	0.8	0.45	0.7	1.1	0.9	1.3	0.8
5	0.9	1.1	0.9	1.3	0.9	0.9	0.6
7	1.0	0.6	1.9	1.7	1.3	0.9	0.7
9	0.9	1.1	4.6	4.9	6.2	1.7	0.9

Total Iron (mg/L)							
Depth	28-Apr	23-May	29-Jun	29-Jul	21-Aug	29-Sep	26-Oct
1	0.07	0.07	0.08	0.19	0.14	0.16	0.04
3	0.08	0.07	0.08	0.17	0.15	0.12	0.05
5	0.06	0.07	0.1	0.18	0.13	0.14	0.05
7	0.09	0.042	0.15	0.27	0.22	0.11	0.05
9	0.07	0.1	0.54	0.5	2.4	0.48	0.1

pH							
Depth	28-Apr	23-May	29-Jun	29-Jul	21-Aug	29-Sep	26-Oct
1	5.7	5.7	6.5	6	6.2	6.9	6.6
3	5.7	5.7	6.5	5.9	6.2	6.8	6.7
5	5.7	5.8	6.4	5.7	6.2	7	6.7
7	5.7	5.8	6.2	5.4	6.1	7	6.7
9	5.8	5.7	6.2	5.5	5.9	6.9	6.7

Color (units)							
Depth	28-Apr	23-May	29-Jun	29-Jul	21-Aug	29-Sep	26-Oct
1	15	2.5	20	15		15	20
3	15	2.5	5	2.5		5	
5	15	2.5	15	5		5	30
7	15	10	25	120		20	
9	4	15	50	100		45	40.0

2000 Lake Water Quality Data

Chloride (mg/L)							
Depth	28-Apr	23-May	29-Jun	29-Jul	21-Aug	29-Sep	26-Oct
1	12			28			13
3	12			28			
5	13			28			13
7	12			28			
9	13			28			13

Potassium (mg/L)							
Depth	28-Apr	23-May	29-Jun	29-Jul	21-Aug	29-Sep	26-Oct
1	1.1			1.2			1.25
3	1.1			1.2			
5	1.1			1.2			1.25
7	1.1			1.2			
9	1.0			1.2			1.3

Sodium (mg/L)							
Depth	28-Apr	23-May	29-Jun	29-Jul	21-Aug	29-Sep	26-Oct
1	6.5			7.2			7.1
3	6.5			7.2			
5	6.5			7.3			7.0
7	6.5			7.0			
9	6.5			7.1			7.0

Calcium (mg/L)							
Depth	28-Apr	23-May	29-Jun	29-Jul	21-Aug	29-Sep	26-Oct
1	2.5			3.3			2.1
3	2.4			3.3			
5	2.4			3.3			2.2
7	2.4			3.5			
9	1.6			3.4			2.0

Total Sulfide (mg/L)							
Depth	28-Apr	23-May	29-Jun	29-Jul	21-Aug	29-Sep	26-Oct
7							
11	~	~	< .005	< .01	0.009	~	~

Redox mV							
Depth	28-Apr	23-May	29-Jun	29-Jul	21-Aug	29-Sep	26-Oct
1		300	430	167	220		
3		290	370	174	180		
5		300	330	176	217		
7		313	320	204	233		
9		300	280	220	230		

2001 Lake Water Quality Data

Total Phosphorus (ppb)

Depth	16-Apr	17-May	26-Jun	20-Jul	24-Aug	18-Sep	12-Oct
1	4	5	3	7	5	9	3
3	3	7	5	8	5	5	4
5	3	5	7	8	6	11	5
7	6	4	7	12	16	7	5
9	9	7	7	23	8	12	6

Ammonia Nitrogen (ppb)

Depth	16-Apr	17-May	26-Jun	20-Jul	24-Aug	18-Sep	12-Oct
1	5	17	34	16	33	24	22
3	5	23	45	32	27	25	23
5	5	25	114	96	39	25	23
7	5	25	201	291	104	36	22
9	5	53	266	330	494	633	41

Nitrate / Nitrite -Nitrogen (ppb)

Depth	16-Apr	17-May	26-Jun	20-Jul	24-Aug	18-Sep	12-Oct
1	104	61	< 10	< 10	< 10	< 20	< 20
3	109	61	< 10	< 10	< 10		< 20
5	119	67	23	< 10	< 10		< 20
7	100	56	41	< 10	< 10		< 20
9	109	101	54	< 10	< 10	< 20	< 20

TKN -Nitrogen (ppb)

Depth	16-Apr	17-May	26-Jun	20-Jul	24-Aug	18-Sep	12-Oct
1	204	208	475	390	240	380	190
3	204	170	340	340	212	325	190
5	180	208	450	360	173	440	205
7	180	130	530	595	360	390	218
9	180	182	570	760	1060	1180	245

Specific Conductance (umhos/cm)

Depth	16-Apr	17-May	26-Jun	20-Jul	24-Aug	18-Sep	12-Oct
1	77	81	79	84	78	80	77
3	77	82	79	77	78	78	77
5	77	82	82	83	80	78	77
7	77	82	83	86	89	79	77
9	77	80	85	87	93	102	78

Stream Water Quality Data

2000 Total Phosphorus (ppb)								
Stream	27-Apr	19-May	28-Jun	25-Jul	28-Aug	26-Sep	26-Oct	Mean
N1	3	12	10	8	13	11	10	10
E1	3	3	3	~	~	~	~	3
E2	< 2	<2	~	~	~	~	~	<2
E3	6	9	9	~	6	7	4	7
E4	3	6	~	~	~	~	~	5
E5	4	10	6	4	6	4	3	5
E6	2	8	7	~	~	~	~	6
W1	9	22	15	~	~	21	~	17
W3	3	14	7	14	18	19	~	13
W4	1	15	1	~	~	~	~	6
W5	2	15	31	~	~	~	~	16
OUT	6	11	8	7	6	6	7	7

2001 Total Phosphorus (ppb)										
Stream	3/23/2001	4/17/2001	5/17/2001	6/17/2001	6/26/2001	7/18/2001	8/17/2001	9/17/2001	10/11/2001	Mean
N1	4	3	13	13	11	15	24	~	7	11
E1	3	1.5	~	~	5	~	~	~	~	3
E2	3	1.5	~	~	1	~	~	~	~	2
E3	9	7	6	128	9	5	~	~	~	27
E4	10	4	~		~	~	~	~	~	7
E5	4	4	15	205	6	4	9	9	2	29
E6	5	3	~	~	23	~	~	~	~	10
E7	203	~	~	~	~	~	~	~	~	203
W1	6	7	~	48	16	21	~	~	~	20
W2u	8	5	2	44	4	10	~	~	9	12
W2L	11	4	7	~	5	17	~	~	~	9
W3	53	6	7	115	12		~	~	~	39
W4	4	<1	<1	~	<1	2	~	~	~	3
W5	5	<1	31	~	2	~	~	~	~	13
W6	12	5	~	~	~	~	~	~		9
OUT	5	5	9	~	4	8	7	~	4	6

2000 Nitrate/Nitrite (ppb)								
Stream	27-Apr	19-May	28-Jun	25-Jul	28-Aug	26-Sep	26-Oct	Mean
N1	< 10	< 10	< 20	< 10	210	< 20	< 20	210
E1	< 10	< 10	< 20	~	~	~	~	< 10
E2	< 10	< 10	~	~	~	~	~	< 10
E3	180	87	129	~	< 20	310	98	161
E4	< 10	< 10	~	~	~	~	~	< 10
E5	201	106	136	63	< 20	144	< 20	130
E6	370	133	122	~	~	~	~	208
W1	74	< 10	45	~	~	56	~	58
W3	670	360	510	500	1,070	975	~	681
W4	1,220	300	725	~	~	~	~	748
W5	465	176	320	~	~	~	~	320
OUT	63	45	< 10	< 10	63	< 20	< 20	57

2001 Nitrate/Nitrite (ppb)										
Stream	3/23/2001	4/17/2001	5/17/2001	6/17/2001	6/26/2001	7/18/2001	8/17/2001	9/17/2001	10/11/2001	Mean
N1	57	<20	< 20	< 10	<20	< 20	<20		< 20	57
E1	46	<20	~	~	<20	~	~	~	~	46
E2	26	< 10	~	~	<20	~	~	~	~	26
E3	265	229	385	92	143	260	~	~		229
E4	436	<20	~	~	~	~	~	~	~	436
E5	<20	299	145	300	186	108	65	58	32	149
E6	488	424	~	~	157	~	~	~	~	356
E7	2,050	~	~	~	~	~	~	~	~	2,050
W1	103	63	~	<20	90	56	~	~	~	78
W2u	3,180	2,050	1,673	740	1,260	1,160	~	~	1,565	1,661
W2L	2,000	1,673	1,580	~	1,040	940	~	~	~	1,447
W3	1,100	1,320	510	600	855		~	~	~	877
W4	1,515	1,495	1,320	~	372	830	~	~	~	1,106
W5	795	912	~	~	555	~	~	~	~	754
W6	187	258	~	~	~	~	~	~	~	223
OUT	138	97	37		<20	< 20	~	~	< 20	91

2000 Ammonia Nitrogen (ppb)								
Stream	27-Apr	19-May	28-Jun	25-Jul	28-Aug	26-Sep	26-Oct	Mean
N1	< 10	< 10	11	14	18	19	79	28
E1	< 10	< 10	< 10	~	~	~	~	< 10
E2	< 10	< 10	~	~	~	~	~	< 10
E3	5	12	5	~	5	5	5	6
E4	< 10	< 10	~	~	~	~	~	< 10
E5	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
E6	< 10	< 10	< 10	~	~	~	~	< 10
W1	< 10	17	50	~	~	18	~	28
W3	< 10	137	< 10	< 10	< 10	14	~	76
W4	< 10	< 10	13	~	~	~	~	13
W5	< 10	17	< 10	~	~	~	~	17
OUTLET	< 10	70	14	15	28	32	78	40

2001 Ammonia Nitrogen (ppb)										
Stream	3/23/2001	4/17/2001	5/17/2001	6/17/2001	6/26/2001	7/18/2001	8/17/2001	9/17/2001	10/11/2001	Mean
N1	19	< 10	92	39	20	19	19		71	40
E1	< 10	< 10		~	12	~			~	5
E2	< 10	< 10	~	~	<10	~			~	5
E3	< 10	< 10	< 10	< 10	< 10	< 10				5
E4	< 10	< 10	~	~	~	~			~	5
E5	<10	<10	<10	155	<10	<10	<10	<10	<10	22
E6	< 10	< 10		~	<10	~			~	5
E7	172									172
W1	< 10	< 10	50	38	102				~	63
W2U	20	13	<10	29	<10	< 10			16	20
W2L	19	26	24		29	46				29
W3	20	< 10		79	< 10	14			~	38
W4	< 10	< 10	<10	~	<10	15			~	15
W5	17	< 10	< 10	~	<10	~			~	17
W6	< 10	< 10								5
OUT	13	<10	72		47	43			<10	44

2000 TKN -Nitrogen (ppb)								
Stream	27-Apr	19-May	28-Jun	25-Jul	28-Aug	26-Sep	26-Oct	Mean
N1	210	264	690	760	540	535	560	508
E1	112	204	116	~	~	~	~	144
E2	126	120	~	~	~	~	~	123
E3	182	230	232	~	220	143	117	187
E4	126	240	~	~	~	~	~	183
E5	126	204	167	450	124	65	52	170
E6	126	278	193	~	~	~	~	199
W1	266	486	620	~	~	360	~	433
W3	98	125	130	355	< 50	460	~	234
W4	140	125	320	~	~	~	~	195
W5	112	250	300	~	~	~	~	221
OUTLET	240	278	90	725	248	221	220	289

2001 TKN -Nitrogen (ppb)										
Stream	3/23/2001	4/17/2001	5/17/2001	6/17/2001	6/26/2001	7/18/2001	8/17/2001	9/17/2001	10/11/2001	Mean
N1	246	240	590	610	650	565	830		760	561
E1	239	180		~	320					246
E2	100	77	~	~	116					98
E3	151	167	110	1,310	360	197				383
E4	176	64	~	~	~					120
E5	76	605	98	2,420	290	184	91	182	51	444
E6	100	103		~	1,290					498
E7	790									790
W1	200	63		930	1,010					551
W2u	86	200	98	620	290	144			150	227
W2L	114	200	148		655	302				284
W3	400	88		1,300	243					508
W4	43	63	61	~	297	118				116
W5	29	113		~	216					119
W6	128	213								171
OUT	172	180	332		700	355	286		190	316

Stream Water Quality Data

2000 Specific Conductance (umhos/cm)								
Stream	27-Apr	19-May	28-Jun	25-Jul	28-Aug	26-Sep	26-Oct	Mean
N1	54	56	69	72	68	63	84	67
E1	37	36	35	~	~	~	~	36
E2	50	51	~	~	~	~	~	51
E3	79	84	97	~	110	114	120	101
E4	30	29	~	~	~	~	~	30
E5	62	71	81	60	68	95	86	75
E6	78	79	81	~	~	~	~	79
W1	41	37	37	~	~	39	~	39
W3	108	101	108	129	149	143	~	123
W4	169	158	173	~	~	~	~	167
W5	126	91	193	~	~	~	~	137
OUTLET	72	77	73	72	70	76	75	74

2001 Specific Conductance (umhos/cm)										
Stream	3/23/2001	4/17/2001	5/17/2001	6/17/2001	6/26/2001	7/18/2001	8/17/2001	9/17/2001	10/11/2001	Mean
N1	42	69	80		73	80	90		82	74
E1	39	40			36					38
E2	54	53			51					53
E3	75	86	92		92	105				90
E4	83	31								57
E5	28	96	92		103	89	69	69	96	80
E6	82	87			91					87
E7	98									98
W1	39	50			43					44
W2u	267	455	262		276	278			319	310
W2L	224	367	261		235	243				266
W3	129	160			194					161
W4	197	190	193		199	226				201
W5	161	178			225					188
W6	165	207								186
OUT	78	82	87		80	80	82		78	81

2000 Alkalinity (mg/L)								
Stream	27-Apr	19-May	28-Jun	25-Jul	28-Aug	26-Sep	26-Oct	Mean
N1	1	< 1	4	2	4	6	6	4
E1	1	< 1	1	~	~	~	~	1
E2	0.5	1	~	~	~	~	~	1
E3	2	4	6	~	9	7	8	6
E4	< 0.5	1	~	~	~	~	~	1
E5	1	3	6	4	5	6	7	5
E6	2	4	6	~	~	~	~	4
W1	< 0.5	2	4	~	~	4	~	3
W3	4	8	8	8	14	8	~	8
W4	4	1	4	~	~	~	~	3
W5	1	< 1	4	~	~	~	~	3
OUTLET	2	3	4	2	4	6	4	4

2001 Alkalinity (mg/L)										
Stream	3/23/2001	4/17/2001	5/17/2001	6/17/2001	6/26/2001	7/18/2001	8/17/2001	9/17/2001	10/11/2001	Mean
N1	1	4	2			2	8		5	4
E1	0.5	<1			1					1
E2	1	<1			2					2
E3	2	4	4		6	5				4
E4	3	1								2
E5	0.5	5	6		8	6	8	8	6	6
E6	2	4			5					4
E7	2	~	~	~	~	~	~	~	~	2
W1	1	<1			7					4
W2u	9	7	5		9	6			8	7
W2L	17	10	6		10	8				10
W3	4	5			12					7
W4	6	1	2		4	3				3
W5	1	1			2					1
W6	3	1			3					2
OUT	2	3	3		6	4	6		4	4

Stream Water Quality Data

2000 Turbidity (NTU)								
Stream	27-Apr	19-May	28-Jun	25-Jul	28-Aug	26-Sep	26-Oct	Mean
N1	0.7	0.9	1	0.65	0.9	0.9	1.1	0.9
E1	0.18	0.6	0.35	~	~	~	~	0.4
E2	0.26	0.38	~	~	~	~	~	0.3
E3	0.45	1.5	0.7	~	0.8	0.3	0.24	0.7
E4	0.31	0.46	~	~	~	~	~	0.4
E5	0.6	1.2	0.7	0.27	0.15	0.45	0.31	0.5
E6	0.25	0.6	0.65	~	~	~	~	0.5
W1	1.8	0.9	5	~	~	6.5	~	3.6
W3	0.3	0.22	0.9	0.45	0.47	0.5	~	0.5
W4	0.17	1.1	0.55	~	~	~	~	0.6
W5	0.32	1	4.3	~	~	~	~	1.9
OUTLET	0.8	0.8	0.85	0.7	0.9	1.9	0.5	0.9

2001 Turbidity (NTU)										
Stream	3/23/2001	4/17/2001	5/17/2001	6/17/2001	6/26/2001	7/18/2001	8/17/2001	9/17/2001	10/11/2001	Mean
N1	0.6	0.25	0.7	1.5	1	1	2		1.2	1.0
E1	0.32	0.16			0.51					0.3
E2	0.27	0.05			0.16					0.2
E3	0.5	0.5	0.18	9.4	0.33	0.11				1.8
E4	0.7	0.25								0.5
E5	0.35	0.8	0.43	87	0.44	0.32	0.45	1.1	0.25	10.1
E6	0.35	0.21			0.9					0.5
E7	155	~	~	~	~	~	~	~	~	
W1	2	0.9		5	5.6					3.4
W2u	0.8	0.35	0.3	5.3	0.18	0.6			1.2	1.2
W2L	1.6	0.39	0.8		1.3	1.6				1.1
W3	4.5	0.28		5.6	0.38					2.7
W4	0.21	0.16	0.14		0.15	0.27				0.2
W5	1.2	0.28			0.27					0.6
W6	2.6	0.6								1.6
OUT	1.1	0.9	0.9		0.47	0.6	0.6		0.9	0.8

pH (Units)								
Stream	27-Apr	19-May	28-Jun	25-Jul	28-Aug	26-Sep	26-Oct	Median
N1	5.2	5.2	5.9	5.3	5.7	6.0	6.5	5.7
E1	5.0	5.1	5.9	~	~	~	~	5.1
E2	5.0	5.3	~	~	~	~	~	5.2
E3	5.5	5.4	6.1	~	6.2	7.0	7.0	6.2
E4	5.2	5.3	~	~	~	~	~	5.3
E5	5.4	5.6	6.2	5.6	6.3	6.9	7.0	6.2
E6	5.5	5.7	6.3	~	~	~	~	5.7
W1	5.6	5.7	6.1	~	~	6.9	~	5.9
W3	5.6	5.9	6.2	5.9	6.3	7.1	~	6.1
W4	5.2	5.1	5.7	~	~	~	~	5.2
W5	5.2	5.2	5.7	~	~	~	~	5.2
OUTLET	5.5	5.5	6.0	5.9	6.1	6.7	6.5	6.0

2001 pH (Units)										
Stream	3/23/2001	4/17/2001	5/17/2001	6/17/2001	6/26/2001	7/18/2001	8/17/2001	9/17/2001	10/11/2001	Median
N1	6	6.2	5.9	6	5.9	6	5.9		5.9	6.0
E1	5.8	6			6					6.0
E2	5.8	5.6			5.6					5.6
E3	6	6.6	0.68	6.4	6.5	6.6				6.5
E4	5.2	6								5.6
E5	6.2	6.6	0.68	6.1	7	6.7	7.2	6.8	6.6	6.6
E6	6.1	6.6			6.9					6.6
E7	6.2									6.2
W1	6.3	6.3		6.3	6.8					6.3
W2u	6.3	6.4	6.6	6.5	6.6	6.6			6.4	6.5
W2L	6.5	6.5	6.5		6.7	6.6				6.5
W3	6.7	6.8			7					6.8
W4	5.9	5.6	0.58		5.8	5.9				5.8
W5	6	5.8			5.8					5.8
W6	6.1	6								6.1
OUT	6.3	6.5	6.5		6.8	6.7	7.1		6.4	6.5

Stream Water Quality Data

2000 Temperature °C								
Stream	27-Apr	19-May	28-Jun	25-Jul	28-Aug	26-Sep	26-Oct	Mean
N1	9.2	16	29	23.5	26.3	14.5	13.5	18.9
E1	8	12	20.5	~	~	~	~	13.5
E2	8	12.1	~	~	~	~	~	10.1
E3	7.9	12.1	21	~	20.8	13	13	14.6
E4	8	12.1	~	~	~	~	~	10.1
E5	8	11.8	19.5	17.5	20	13	12.8	14.7
E6	6.5	11.8	19	~	~	~	~	12.4
W1	9	14.8	23.1	~	~	13	~	15.0
W3	8.2	10.2	16.7	17	20	13.2	~	14.2
W4	9	11.8	13.9	~	~	~	~	11.6
W5	8.1	11.5	14.5	~	~	~	~	11.4
OUTw	9.6	17	27.1	25	25.7	18	13.8	19.5
OUT_E	9.6	11.2	28.5	~	~	~	~	16.4

2001 Temperature °C										
Stream	3/23/2001	4/17/2001	5/17/2001		6/26/2001	7/18/2001	8/17/2001	9/17/2001	10/11/2001	Mean
N1	4	11.5	14.2		25.4	28.5	24.6		11	17.0
E1	5	9			19					11.0
E2	4.5	8			17					9.8
E3	6	9	11		18.6	19.2				12.8
E4	5.5	9								7.3
E5	5	9	11		18	18.6	20	15	11	13.5
E6	4.5	8.3			17.5					10.1
W1	5	9.8			20					11.6
W2		7.2			14.3	16.7			12.2	
W3	5	7			15.3	17.8				11.3
W4	5	7			13.9	16				10.5
W5	4	7			15					8.7
W6	5	7								6.0
	4.9	8.4	12.1		17.6	19.5	22.3		11.4	13.7
OUTw	2	11.2	16		26	26	25.5		12.1	17.0
OUT_E		11								11.0

2000 Dissolved Oxygen (mg/L)								
Stream	27-Apr	19-May	28-Jun	25-Jul	28-Aug	26-Sep	26-Oct	Mean
N1	8.6	8.9	3.0	2.8	2.0	2.5	3.3	4.4
E1	11.3	10.3	7.2	~	~	~	~	9.6
E2	10.1	9.2	~	~	~	~	~	9.7
E3	11.5	10.3	8.0	~	8.0	10	10.2	9.7
E4	10.2	8.9	~	~	~	~	~	9.6
E5	10.8	10.1	8.5	8	8.7	9.7	8.2	9.1
E6	10.2	10.0	7.5	~	~	~	~	9.2
W1	10.8	8.7	7.9	~	~	9.6	~	9.3
W3	11.8	10.5	8.5	7.8	8.4	8.6	~	9.3
W4	9.3	12.1	6.8	~	~	~	~	9.4
W5	10.4	12.2	8.2	~	~	~	~	10.3
OUTw	11.1	8.05	7.2	8.0	7.8	7.0	7.8	8.1
OUT_E	11.1	10.0	6.9	~	~	~	~	9.3

2001 Dissolved Oxygen (mg/L)										
Stream	3/23/2001	4/17/2001	5/17/2001		6/26/2001	7/18/2001	8/17/2001	9/17/2001	10/11/2001	Mean
N1	10	8.3	4.6		4	5.3	4.5		3.5	5.7
E1	11.8	12			8					10.6
E2	12	9	10.4		5.8					9.3
E3	12	11			9.3	9.6				10.5
E4	11	9.8								10.4
E5	11.5	10.9	10.5		9	8.7	9.5	9.8	10.6	10.1
E6	11.5	10.8			9.5					10.6
W1	12	10.5			8.8					10.4
W2		10.2			9.6	8.7			9.3	9.5
W3		11.3			9.8	8.3				9.8
W4	11.8	10			7.7	8.8				9.6
W5	11.6	10			9					10.2
W6	11.6	11.5								11.6
OUTw	11	10	7.4		7.7	8	8.5		8.8	8.8
OUT_E		10.3								10.3

Appendix 9

Water Flow Measurements Taken During This Study From Sampled Inlets.

Flow (cfs) 2000							
Depth	27-Apr	19-May	28-Jun	25-Jul	28-Aug	26-Sep	26-Oct
N1	5.80	5.96	1.80	0.23	0.51	0.37	0.06
E1	0.72	1.16	0.08	0.0	0.0	0.0	0.0
E2	0.26	0.14	0.0	0.0	0.0	0.0	0.0
E3	1.12	1.16	0.28	0.0	0.0004	0.07	0.04
E4	0.11	0.24	0.0	0.0	0.0	0.0	0.0
E5	5.85	4.05	0.54	0.02	0.04	0.49	0.05
E6	0.35	0.64	0.06	0.0	0.0	0.0	0.0
W1	0.45	0.66	0.05	0.0	0.0	0.19	0.0
W3	0.24	0.26	0.11	0.003	0.00004	0.01	0.0
W4	0.01	0.02	0.001	0.0	0.0	0.0	0.0
W5	0.09	0.14	0.01	0.0	0.0	0.0	0.0
Total In	**14.99**	**14.41**	**2.92**	**0.25**	**0.55**	**1.12**	**0.15**
OUTw	21.20	14.50	4.61	0.63	2.30	3.33	0.75
OUTE	2.34	0.78	1.63	0.00	0.00	0.00	0.00
Total Out	**23.54**	**15.28**	**6.24**	**0.63**	**2.30**	**3.33**	**0.75**

Flow (cfs) 2001									
Depth	23-Mar	17-Apr	17-May	17-Jun	26-Jun	18-Jul	17-Aug	18-Sep	11-Oct
N1	15.49	2.64	0.10	*3.30*	4.46	0.90	0	0	0.38
E1	0.30	0.34		*0.67*	0.13	0	0	0	0
E2	1.04	0.095		*0.22*	0.00	0	0	0	0
E3	2.79	0.45	0.03	*3.38*	0.67	0.09	0	0.0	0
E4	0.97	0.04	0.00	*1.06*		0	0	0.0	0
E5	7.20	1.50	0.32	*39.90*	0.06	0.26	0	1.40	0.16
E6	0.31	0.14		*0.00*		0	0	0	0
W1	1.29	0.51		*1.51*	0.002	0	0	0	0
W2		0.28			0.21	0	0	0	0
W3	1.51	0.12		*0.47*	0.57	0	0	0	0
W4		0.01			0.0002	0	0	0	0
W5		0.16			0.0004	0	0	0	0
W6	0.75				0	0	0	0	0
Total In	**31.7**	**6.3**	**0.4**	***50.5***	**6.1**	**1.3**	**0.0**	**1.4**	**0.5**
OUTw	40.50	14.50	0.48	*11.67*	23.75	3.03	0.29	0.00	1.55
OUTE	29.25	2.40	0	*0*	1.13	0	0	0	0
Total Out	**69.8**	**16.9**	**0.5**	***11.7***	**24.9**	**3.0**	**0.3**	**0.0**	**1.6**

Appendix 10

Response Letter from CT DEP Environmental and Geographic Information Center regarding the presence of federal and state listed threatened, endangered, and special concern species in Lake Hayward.

STATE OF CONNECTICUT

DEPARTMENT OF ENVIRONMENTAL PROTECTION

ENVIRONMENTAL AND GEOGRAPHIC INFORMATION CENTER
79 Elm Street, Store Level
Hartford, Connecticut 06106-5127
Natural Diversity Data Base

April 25, 2001

George Knoecklein
Northeast Aquatic Research
74 Higgins Highway
Mansfield Center, CT 06250

Re: Lake Hayward, East Haddam, CT

Dear Mr. Knoecklein:

I have reviewed Natural Diversity Data Base maps and files regarding the area delineated on the map you provided and listed above. According to our information, there are extant populations of Federal or State Endangered, Threatened or Special Concern Species that occur at the site in question.

The following list of aquatic plants from Hayward Lake were observed by Nancy Murray on 30 Sept 1998. This list is based upon a half day site visit to the lake. If you have any questions about this list of aquatic plants please contact Nancy Murray (860-424-3589 or nancy.murray@po.state.ct.us).

Nymphaea odorata
Brasenia scherebi
Potamogeton pulcher
Potamogeton epihydrus
Utricularia vulgaris
Scirpus sp.
Decodon verticillatus
Eleocharis sp.
Sparganium
Nitella sp.
Nuphar variegatum
Nymphoides cordata
Potamogeton pusillus
Utricularia purpurea
Cabomba caroliniana
Pontederia cordata
Vallisneria americana
Eriocaulon aquaticum
Sagittaria sp.
Fontinalis sp.

Our records indicate three Invertebrate Species of Special Concern were collected at the northern most end of Lake Hayward. These are: 1) *Lycaena epixanthe* (Bog copper), 2) *Tabanus fulvicallus* (Horse fly) and 3) *Merycomyia whitneyi* (Tabanid fly). Please contact Julie Victoria (DEP-Wildlife; 860-642-7239) for more information on these invertebrates.

Natural Diversity Data Base information includes all information regarding critical biologic resources available to us at the time of the request. This information is a compilation of data collected over the years by the Environmental & Geographic Information Center's Geological and Natural History Survey and cooperating units of DEP, private conservation groups and the scientific community. This information is not necessarily the result of comprehensive or site-specific field investigations. Consultations with the Data Base should not be substituted for on-site surveys required for environmental assessments. Current research projects and new contributors continue to identify additional populations of species and locations of habitats of concern, as well as, enhance existing data. Such new information is incorporated into the Data Base as it becomes available.

Please contact me if you have further questions (424-3592). Thank you for consulting the Natural Diversity Data Base.

Sincerely,

D McKay

Dawn McKay
Biologist/Environmental Analyst III

DMK/md

Appendix 11

Map Showing the General Land Use in The Lake Hayward Drainage Basin.