Pemaquid Ponds
Water Quality Monitoring: 1996
Summary and Recommendations
NH Lakes Lay Monitoring Program

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UNIVERSITY OF NEW HAMPSHIRE
COOPERATIVE EXTENSION

To obtain additional information on the NH Lakes Lay Monitoring Program (NH LLMP) contact the Coordinator (Jeff Schloss) at 603-862-3848 or Assistant Coordinator (Bob Craycraft) at 603-862-3546.
PARAMETERS SAMPLED
NH LAKES LAY MONITORING PROGRAM

LAY MONITORS

BASIC PROGRAM
- Secchi Disk Depth
- Temperature Profile
- Chlorophyll a
- Dissolved Color
- Total Alkalinity
- Total Phosphorus

ADVANCED OPTIONS
- pH
- Metalimnetic Chlorophyll a
- Specific Conductivity
- Hypolimnetic Total Phosphorus
- Dissolved Oxygen
- Bacteria
- Fish Condition
- Rainfall & pH
- Aquatic Vegetation Surveys
- Motorboat Effects
- Watershed NPS Surveys
- Road Salt Runoff

STREAM MONITORING
- Observational Surveys
- Temperature
- Specific Conductivity
- Total Alkalinity
- Total Phosphorus
- Stream Flow
- Macro-Invertebrates
- Storm Event Sampling
- Bacteria

Freshwater Biology Group (FBG) corroboration with the lay monitor data includes assessment of 1) physical parameters (water transparency, temperature profiles, light transmission profiles and water color); 2) chemical parameters (dissolved oxygen profiles, "free" carbon dioxide, total alkalinity, pH, total phosphorus and specific conductivity profiles); 3) biological parameters (chlorophyll a, phytoplankton community and zooplankton community). Note: in addition to the above parameters, other measurements are often collected at the discretion of the FBG or at the request of the lake association.
PREFACE

This report contains the findings of a water quality survey of the ponds in the Pemaquid Watershed Association (PWA), towns of Bremen, Bristol, Damariscotta, Nobleboro and Waldoboro, Maine, conducted in the summer of 1996 by the Freshwater Biology Group (FBG) of the University of New Hampshire and the Pemaquid Watershed Association.

The report is written with the concerned lake resident in mind and contains a brief, non-technical summary of 1996 results as well as more detailed "Introduction" and "Discussion" sections. Graphic display of data is included, in addition to listings of data in appendices, to aid visual perspective.
1996 was the ninth year of participation in the Lakes Lay Monitoring Program (LLMP) for the Pemaquid Watershed Association monitors. Peter Fischer again undertook the formidable task of coordinating the multi-lake study and acted as liaison to the Freshwater Biology Group (FBG).

The Freshwater Biology Group congratulates the Lay Monitors on the quality of their work, and the time and effort put forth. We encourage other interested members of the Pemaquid Watershed Association to continue the ongoing water quality monitoring effort in future years.

Financial support for the volunteer monitoring effort was provided by the towns of Bremen, Bristol, Damariscotta and Nobleboro. The Freshwater Biology Group is a not-for-profit research program co-supervised by Dr. Alan Baker and Dr. James Haney and coordinated by Jeffrey Schloss. Members of the FBG summer field team included, Robert Craycraft (laboratory and field coordinator), Laura Boddington, Steve Paulding, Steve Tobin and Alex Wong. Other FBG staff assisting in the fall included Shawna Durley and Michelle Hermon.

The FBG acknowledges the University of New Hampshire Cooperative Extension for funding and furnishing office, laboratory and storage space. The College of Life Sciences and Agriculture provided accounting support and the UNH Office of Computer Services provided computer time and data storage allocations.


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</thead>
<tbody>
<tr>
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<td>Biscay</td>
</tr>
<tr>
<td>Peter Fischer</td>
<td>Boyd</td>
</tr>
<tr>
<td>David Libby</td>
<td>Duckpuddle</td>
</tr>
<tr>
<td>Marcia Armstrong</td>
<td>McCurdy</td>
</tr>
<tr>
<td>Tim Kimpton</td>
<td>McCurdy</td>
</tr>
<tr>
<td>Albert &quot;Mac&quot; Rogers</td>
<td>McCurdy</td>
</tr>
<tr>
<td>Steve O'Bryan</td>
<td>Paradise</td>
</tr>
<tr>
<td>David McLeod</td>
<td>Pemaquid</td>
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INTRODUCTION

The New Hampshire Lakes Lay Monitoring Program

1996 marked the nineteenth year of operation for the NH Lakes Lay Monitoring Program (LLMP). The LLMP has grown from a university class project on Chocorua Lake and pilot study on the Squam Lakes to a comprehensive state-wide program with over 500 volunteer monitors and more than 100 lakes participating. Originally developed to establish a database for determining long-term trends of lake water quality for science and management, the program has expanded by taking advantage of the many resources that citizen monitors can provide (Figure 1).

The NH LLMP has an international reputation as a successful cooperative monitoring, education and research program. Current projects include: use of volunteer generated data for non-point pollution studies using high tech analysis system (Geographic Information Systems and Satellite Remote Sensing), intensive watershed monitoring for the development of lake nutrient budgets, and investigations of water quality and indicator organisms (food web analysis, fish condition, and stream invertebrates). The key ingredients responsible for the success of the program include innovative costshare funding and cost reduction, assurance of credible data, practical sampling protocols and, most importantly, the interest and motivation of our volunteer monitors.

The 1996 sampling season was another exciting year for the New Hampshire Lakes Lay Monitoring Program. National recognition for the high quality of
work by you, the volunteer monitors, continued with awards, requests for program information and invitations to speak at national conferences (Figure 2).

Our work with volunteer monitors, data analysis, use of Geographic Information System technology and our new watershed evaluation system for non-point source pollution ("Following the Flow") was presented at meetings and conferences across the country including the prestigious Watershed '96 Conference in Baltimore, Maryland, the Sixth National Citizen's Environmental Monitoring Conference in Wisconsin, the Gulf of Maine Monitoring Conference, the Merrimack River Monitoring Network Conference and the North American Lake Management Society's Annual International Symposium in Minnesota. We also hosted a group of coordinators of the Australian and Tasmanian StreamWatch Programs who were interested in our sampling methods and the "Following the Flow" site evaluation system. They toured Bow Lake with monitor Jim McCarthy and even saw some loons, an Aussie first! We expanded our monitoring on Lake Winnipesaukee as a result of our analysis completed last year for the Lakes Region Planning Commission and helped to train Americorp volunteers on how to assist local residents with watershed protection concerns.

On the local front, the NH Senate Agricultural and Environment committee and the NH House Resource, Recreation and Development Committee were again briefed on NH LLMP activities. We continue to be listed as a model citizen monitoring program on the Environmental Success Index of Renew America, the Environmental Network Clearinghouse and the National Awards Council for Environmental Sustainability. To date, the approach and methods of the NH LLMP have been adopted by new or existing programs in twenty four states and eleven countries (Figure 3)!

**Importance of Long-term Monitoring**

A major goal of our monitoring program is to identify any short or long-term changes in the water quality of the lake. Of major concern is the detection of cultural eutrophication: increases in the productivity of the lake, the amount of algae and plant growth, due to the addition of nutrients from human activities. Changes in the natural buffering capacity of the lakes in the program is also a topic of great concern, as New
Hampshire receives large amounts of acid precipitation, yet most of our lakes contain little mineral content to neutralize this type of pollution.

For almost two decades, weekly data collected from lakes participating in the New Hampshire Lakes Lay Monitoring Program have indicated there is quite a variation in water quality indicators through the open water season (April through November) on the majority of lakes. Short-term differences may be due to variations in weather, lake use, or other chance events. Monthly sampling of a lake during a single summer provides some useful information, but there is a greater chance that important short-term events such as algal blooms or the lake's response to storm run-off will be missed. These short-term fluctuations may be unrelated to the actual long-term trend of a lake or they may be indicative of the changing status or "health" of a lake.

Consider the hypothetical data depicted in Figure 4. Sampling only once a year during August from 1988 to 1992 produced a plot suggesting a decrease in eutrophication. However, the actual long-term trend of the lake, increasing eutrophy, can only be clearly discerned by frequent sampling over a ten year period (Figure 5). In this instance, the information necessary to distinguish between short-term fluctuations "noise" and long-term trends "signal" could only be
Figure 6. Location of the ponds falling within the Pemaquid Watershed.
Figure 7. Location of the Duckpuddle Pond, Site 1 Basin; and Pemaquid Pond, Sites 1 Basin and 2 Basin; in-lake sampling stations. The location of the Glendon Stream sampling station, which feeds Duckpuddle Pond, is also listed.
Figure 8. Location of the Biscay Pond, Site 1 North; McCurdy Pond, Site 1 Basin; and Pemaquid Pond, Site 1 Basin; in-lake sampling stations. The location of the Biscay Stream (Site 20 Biscay Road) is also included and functions as both the major outlet of Pemaquid Pond and the major inlet to Biscay Pond.
Figure 9. Location of the Biscay Pond, Site 1 North; McCurdy Pond, Site 1 Basin; and Paradise Pond, Site 2 North; deep in-lake sampling stations. The location of the Pemaquid River (10 Lessner Road) sampling station which functions as the major outlet of Biscay Pond is also included.
Figure 10. Location of the Boyd Pond deep sampling station, Site 1 Center.
accomplished through the frequent collection of water quality data over many years. To that end, the establishment of a long term database was essential to trend detection.

The number of seasons it takes to distinguish between the noise and the signal is not the same for each lake. Evaluation and interpretation of a long-term data base will indicate that the water quality of the lake has worsened, improved, or remained the same. In addition, different areas of a lake may show a different response. As more data are collected, prediction of current and future trends can be made. No matter what the outcome, this information is essential for the intelligent management of your lake.

There are also short-term uses for lay monitoring data. The examination of different stations in a lake can disclose the location of specific problems and corrective action can be initiated to handle the situation before it becomes more serious. On a lighter note, some associations post their weekly data for use in determining the best depths for finding fish!

It takes a considerable amount of effort as well as a deep concern for one’s lake to be a volunteer in the NH Lakes Lay Monitoring Program. Many times a monitor has to brave inclement weather or heavy boat traffic to collect samples. Sometimes it even may seem that one week’s data is just the same as the next week’s data. Yet every sampling provides important information on the variability of the lake.

We are pleased with the interest and commitment of our Lay Monitors and are proud that their work is what makes the NH LLMP the most extensive, and we believe, the best volunteer program of its kind.

**Purpose and Scope of This Study**

1996 was the eighth year that monitoring of Boyd Pond and the ninth year monitoring of Biscay, Duckpuddle, McCurdy, Paradise and Pemaquid Ponds was undertaken by the Freshwater Biology Group in conjunction with the Pemaquid Watershed Association (Refer to figures 6 through 10 for site locations). The monitoring program was designed to continue adding data to the long-term data base. Sampling emphasis was placed on one open water deep sampling station in each pond while additional tributary sampling locations have also been monitored historically.

The primary purpose of this report is to discuss results of the 1996 monitoring season with emphasis on the current condition of Biscay, Boyd, Duckpuddle, McCurdy, Paradise and Pemaquid Ponds including the extent of eutrophication. This information is part of a large data base of historical and more recent data compiled and entered onto computer files for Maine and New Hampshire lakes that include the Maine DEP surveys, New Hampshire Fish and Game surveys of the 1930’s, the surveys conducted by the New Hampshire Water Supply and Pollution Control Commission and the FBG surveys. However, care must be taken when comparing results among the various studies. Many complications arise due to methodological differences of the various analytical facilities and technological improvements in testing.
The General Scenario - 1996

1996 Climatic Summary

Precipitation

The winter months of 1995-1996 were characterized by above average precipitation in coastal Maine (Figure 11) and included wetter than normal conditions during the months of January and February, relative to data collected over the past 9 years during which volunteer water quality monitoring was undertaken in conjunction with the New Hampshire Lakes Lay Monitoring Program; NH LLMP (Figure 12). March was characterized by below average precipitation while the spring months of April and May were again characterized by above average precipitation that exceeded the historical average and translated into heavy runoff periods. June kicked off the summer with below average precipitation levels while July was an extremely wet month (over 3" above the historical, 9 year, average). August was by far the driest month of the year (0.51") and one of the drier readings on record over the past 100 years. Above average precipitation levels were again documented in September, October and December while November was a dry month, over 3" below the 9 year average.

The 1996 Coastal Maine seasonal average precipitation level (54.25") was the highest level documented over the past 9 years (1988-1996) and had a profound effect on water quality for many participating NH LLMP lakes (discussed later in this section). Note: climatological variations exist among sampling locations and thus should be considered when discussing local climatological conditions and their impacts upon specific water bodies.
Temperature

The 1996 temperature patterns were near normal for most of the year while deviations from the Coastal Maine monthly averages over the past 9 years were most evident during the months of December (above average temperatures), July and November (below average temperatures) as depicted in Figure 13. Unlike previous years when above average temperatures, conducive to aquatic plant and “algal” (microscopic plant) growth, resulted in “excessive” plant and algal growth, the average 1996 temperature conditions helped keep aquatic plant and “algal” growth in check.

1996 Water Quality Observations

Water Clarity

The precipitation patterns characteristic of 1996 favored reduced water clarieties, increased dissolved color concentrations, increased nutrient concentrations and increased algal concentrations in most participating New Hampshire Lakes Lay Monitoring Program lakes. A number of variables contribute to poorer water quality during periods of heavy rainfall. Watershed runoff often results in the flushing of sediments into the lake, particularly during periods of heavy runoff and when protective vegetative buffers are reduced or absent. Vegetative buffers are naturally reduced in the early spring before plants recolonize and before leaves grow out. Vegetative buffers can be more permanently reduced during periods of construction and logging throughout the year.
While precipitation levels generally favored poorer water quality (in terms of increased algal growth, increases in nutrient concentrations and water clarity decreases) in participating NH LLMP lakes, the temperatures characteristic of 1996 were not highly conducive to algal and macroscopic plant growth like they were in 1994 and 1995; when above average temperatures favored excessive vegetative growth around the periphery of our lakes and ponds. Thus, while the heavy precipitation levels often resulted in reduced water quality, the near average monthly temperatures through most of 1996 tended to keep microscopic plant “algal” and aquatic weed growth “in-check” (visual surveys suggest aquatic plant growth tends to increase as temperatures increase in New Hampshire lakes). Shallow Secchi Disk transparency readings, relative to 1995, were characteristic of Boyd Pond and McCurdy Pond while Duckpuddle Pond and Pemaquid Pond exhibited deeper water transparency readings. The Secchi Disk transparency remained unchanged in Biscay Pond while comparisons were not made for Paradise Pond due to the shallowness of the pond (e.g. the Secchi Disk reached the lakebottom before disappearing from view). Greater concentrations of dissolved colored compounds (dissolved organic matter resulting from the breakdown of vegetation and soils) characterized the participating Pemaquid Ponds with the exception of Paradise Pond, which remained unchanged, and Pemaquid Pond where the dissolved color concentration decreased. Dissolved water color is not indicative of water quality problems (although large increases in dissolved color sometimes follow large land clearing operations) but in some of our more pristine program lakes, it nevertheless has a large effect on water clarity changes.

Sediments were flushed into our lakes and ponds during periods of heavy watershed runoff, particularly early in the season and again during and following sporadic storm events during the summer and fall months. Many New Hampshire lakes experienced water clarity decreases following storm events such as those described above. Lakes, ponds and rivers are particularly susceptible to sediment loadings in the early spring months when vegetated shoreside buffers, often referred to as riparian buffers, are reduced. With limited vegetation to trap sediments and suspended materials, a high percentage of the watershed runoff gets into the lake. Other activities such as logging, agriculture, construction and other forms of soil disturbance can also increase sediment displacement during and following heavy storm events throughout the year and were the likely culprits of excessive sediment loading in many of our lakes and ponds. As these materials (sediments) are transported into a receiving water they can degrade water quality in a number of ways. When fine sediments (silt) enter a lake they tend to remain in the water column for relatively long periods of time. These suspended sediments can be abrasive to fish gills, ultimately leading to fish kills. Suspended sediments also reduce the available light necessary for plant growth which can result in plant die-offs and oxygen depletion under extreme conditions.

As sediments settle out of the water column they can smother bottom dwelling aquatic organisms and smother fish spawning habitat. As the dead materials begin to decay the result could be noxious odors as well as stimulation of nuisance plant growth (i.e. scums along the lakebottom, new macroscopic plant growth). Note: one should keep in mind that nuisance plants such as water milfoil, *Myriophyllum heterophyllum*, will generally regenerate more rapidly than more favorable plant forms and can result in more problematic weed beds than those present before the disturbance. Habitat changes associated with the accumulation of fine sediments and associated “muck”
might also favor increased nuisance plant growth in the future. Another un-favorable attribute of sediment loading is that the sediments tend to carry with them other sorts of contaminant such as pathogens, nutrients and other toxic chemicals (i.e. herbicides and pesticides).

Early symptoms of excessive sediment runoff include deposits of fine material along the lakebottom, particularly in close proximity to tributary inlets and disturbed regions previously discussed (i.e. construction sites, logging sites, etc.). Silt may be visible covering rocks or aquatic vegetation along the lakebottom. During periods of heavy overland runoff the water might appear brown and turbid which reflects the sediment load. As material collects along the lakebottom you might notice a change in the weed composition reflecting a change in the sub-straight type (note: aquatic plants will display natural changes in abundance and distribution, so be careful not to jump to hasty conclusions). If excessive sediment loading is suspected, take a closer look in these areas and assess whether or not the change is associated with sediment loading (look for the warning signs discussed above) or whether the changes might be attributable to some other factor.

**Nutrients**

Nutrient loading tended to be high in 1996, particularly during the periods of heavy watershed runoff. Elevated phosphorus (generally considered the limiting nutrient for excessive plant and algal growth in New Hampshire and Maine lakes) concentrations were most evident in tributary inlets (when stream sampling was undertaken). Much of the phosphorus entering our lakes was complexed with particulate matter (i.e. sediments, vegetative debris), but also included phosphorus associated with fertilizer applications and septic system discharge. While the amount of fertilizers and the integrity of septic systems might not have changed relative to 1995, when water quality was generally high in participating NH LLMP lakes, the high groundwater levels associated with the heavy watershed runoff collected and transported nutrients like phosphorus into our lakes and ponds.

**Algal Growth**

Most lakes experienced "algal blooms" during the 1996 sampling season. "Algal blooms" are often "green water events" associated with decreases in water clarity due to their ability to absorb and scatter light within the water column, but can also accumulate near the lake bottom in shallow areas as "mats" or on the water surface as "scums" and "clouds". The 1996 algal blooms were predominantly "green water events" composed of algae distributed within the water column. New Hampshire lakes were particularly susceptible to algal blooms in 1996 as a function of the heavy runoff associated with the atypically wet year. Wet years such as 1996 can be particularly hard on lakes where excessive fertilizer applications, agricultural practices, construction activities, etc. favor the displacement of nutrients into a receiving water. The occasional formation of certain "algal blooms" are naturally occurring phenomena and are not necessarily associated with changes in lake productivity. However, increases in the occurrence of "bloom" conditions can be a sign of eutrophication (the "greening" of a lake). Algal blooms occurred even in our most pristine lakes throughout the 1996 sampling season and in many instances included the presence of nuisance cyanobacterial forms such as *Anabaena, Lyngbya, Mermisomedia* and *Oscillatoria*.
If decreased water clarity was not the result of more dissolved color or more algal growth (measured as chlorophyll α) then, by default, it was likely due to suspended sediments. Note whether changes in water clarity (Secchi Disk transparency) correspond to chlorophyll α or dissolved color concentration changes or whether it is a combination of the two. If neither seem to exhibit a consistent effect, then suspended sediment likely plays an important role in your lake's clarity.

While the open water appeared greener than previous years, filamentous candelabra-like "clouds" of the nuisance green filamentous algae, Mougeotia, and related species were not well documented in 1996. These algal "clouds" often develop within nearshore weed beds where they can be seen along the lakebottom and tend to flourish during atypically warm periods which warm our surface waters. Unlike 1994 and 1995, when temperatures were well above normal in June and July and in-turn stimulated large growths of filamentous algae, 1996 was a mild summer and in-turn kept this type of algal growth in "check".

In other lakes, metalimnetic algae, algae which tend to grow in a thin layer along the thermocline gradient in a lake's middle depths, sometimes migrate up towards the lake surface causing a "bloom" event. If these algae are predominantly "nuisance" forms, like certain green or blue-green algae, they can be an early indication of nutrient loading. The LLMP will continue to monitor "bloom" phenomena in 1997 as they can be a sign of the changing land use practices and impacts within your lake's watershed that can result in a long-term increase in lake productivity (eutrophication). Future monitoring will continue to monitor the frequency of algal blooms in our Northern New England lakes and discern whether or not they are signs of short-term perturbations in water quality, the "noise" within the true long-term signal, induced by the weather conditions of this past summer. For a limited number of lakes, the 1996 weather patterns resulted in less algal problems and better water quality. Lakes which exhibited improved water quality were generally those lakes which experience what is known as internal nutrient loading (nutrients released from the bottom sediments due to low oxygen concentrations). Internal nutrient loading can be extremely hard on a lake during drier years when the waters stagnate, oxygen is depleted, and the nutrients are not flushed out of the waterbody. Since 1996 was wetter than normal, the flushing of these types of lakes caused higher oxygen levels and less nutrient accumulation in the spring and late fall which in turn reduced the occurrence and magnitude of algal blooms.
Figure 15. Comparison of the 1996 Biscay Pond, Boyd Pond, Duckpuddle Pond, McCurdy Pond and Pemaquid Pond lay monitor Secchi Disk Transparency data. The patterns of the bars display the minimum, mean and maximum values for the respective years sampled while the length of the bars represents the total range of values. The shaded regions on the graph denote the Maine DEP Secchi Disk standards for low, moderate and high water clarities. The higher the Secchi Disk value, the clearer the water. Secchi Disk readings are measured to the nearest tenth (0.1) of a meter. Note: Paradise Pond is not included in the intercomparison due to the shallowness of the pond (the Secchi Disk reached the lakebottom before disappearing from view).
LAY MONITOR SECCHI DISK DATA
PEMAQUID PONDS

The higher value = clearer water
Figure 16. Comparison of the 1996 Biscay Pond, Boyd Pond, McCurdy Pond, Paradise Pond and Pemaquid Pond lay monitor chlorophyll a data with previous yearly data. The patterns of the bars display the minimum, mean and maximum values for the respective years sampled while the length of the bars represents the total range of values. The shaded regions on the graph denote the Maine DEP standards for low, moderate and high chlorophyll a concentrations. The higher the chlorophyll a concentration, the greener the water. Note: Duckpuddle Pond is not included in the intercomparison due to the difference in scale (i.e. much higher chlorophyll a concentrations). Refer to figure 33 for a graphic depiction of the historical Duckpuddle Pond chlorophyll a data.
The higher value = more algal growth
Figure 17. Comparison of the 1996 Biscay Pond, Boyd Pond, McCurdy Pond, Paradise Pond and Pemaquid Pond lay monitor dissolved color data with previous yearly data. The patterns of the bars display the minimum, mean and maximum values for the respective years sampled while the length of the bars represents the total range of values. The shaded regions on the graph denote the ranges characteristic of low, moderately and highly colored waters. The higher the dissolved color concentration the more colored the water (i.e. more tea colored). Color data are expressed as chloroplatinate color units (ptu). *Note: the Duckpuddle Pond Dissolved Color data are depicted in Figure 18.*
The higher value = more "tea" colored water
Figure 18. Comparison of the 1996 Duckpuddle Pond lay monitor dissolved color data with previous yearly data. The patterns of the bars display the minimum, mean and maximum values for the respective years sampled while the length of the bars represents the total range of values. The shaded regions on the graph denote the ranges characteristic of low, moderately and highly colored waters. The higher the dissolved color concentration the more colored the water (i.e. more tea colored). Color data are expressed as chloroplatinate color units (ptu).
The higher value = more "tea" colored water
Table 2. Biscay Pond - Trophic Indicators, 1996

Lakes Lay Monitoring Program, U.N.H.  
[Lay Monitor Data]

Biscay Pond, Maine  
-- subset of trophic indicators, all sites, 1996

1996 SUMMARY
Average transparency: 4.8 (1996: 11 values; 4.0 - 6.3 range)  
Average chlorophyll: 4.3 (1996: 11 values; 2.9 - 7.1 range)  
Average Lake Phos.: 7.7 (1996: 4 values; 6.3 - 8.3 range)  
Average color, 440: 43.2 (1996: 10 values; 35.2 - 56.7 range)

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<th>Site</th>
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<th>Total Phos (ppb)</th>
<th>Alk. (gray)</th>
<th>Alk. (pink)</th>
<th>Color Pt-Co units</th>
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<< End of 1996 listing, 13 records >>
BISCAY POND

1996 NON-TECHNICAL SUMMARY

Bi-weekly water quality data were collected at the Biscay Pond deep sampling station, Site 1 North, between May 19, 1996 and October 19, 1996 (refer to Table 2 and Figures 19 through 21). The following section summarizes the 1996 Biscay Pond water quality data and when applicable, incorporates historical data into the interpretation. A more detailed discussion of the water quality parameters is included in the section of the report titled "Discussion of Lake Monitoring Measurements".

Table 3: Biscay Pond Water Quality Summary Table (1996) and Maine DEP Water Quality Classification Criteria.

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<td>Total Phosphorus (ppb)</td>
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<td>6.0-13.0</td>
<td>&gt;13.0</td>
<td>7.7 *</td>
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</table>

1) The 1996 Biscay Pond water clarity (Secchi Disk transparency) measurements were representative of a moderately productive lake based on the water quality criteria employed by the Maine Department of Environmental Protection (Table 3). The 1996 seasonal water transparency average of 4.8 meters (15.8 feet) matched the 1995 seasonal average water transparency (4.8 meters) and remained within the historical range of water transparency readings (range: 3.2 to 6.8 meters) collected between 1988 and 1995 (Figure 22).

2) The 1996 Biscay Pond microscopic plant “algal” concentrations (reported as chlorophyll a) measured in the surface waters were moderate to high. The seasonal average chlorophyll a concentration (4.3 milligrams per cubic meter; mg m⁻³) falls within the Maine Department of Environmental Protection (DEP) criteria for a moderately productive lake (Figure 23 and Table 3). The 1996 seasonal average Biscay Pond chlorophyll a concentration increased for the third consecutive year while the 1996 chlorophyll a concentrations remain well within the range of historical values: 1.7 to 11.9 mg m⁻³).

3) The 1996 Biscay Pond seasonal average dissolved lakewater color level (a measure of naturally occurring “background” color) was moderate (43.2 chloroplantinate color units; ptu) and higher than the 1995 Biscay Pond seasonal average dissolved color concentration (42.6 ptu).

4) The 1996 Biscay Pond total phosphorus (generally considered the limiting nutrient for plant growth in freshwater systems) concentrations, measured in the surface
waters, were moderate when collected by Scott Giguere on May 19 and August 24, 1996 (range: 6.3 to 8.3 parts per billion; ppb). The 1996 Biscay Pond total phosphorus concentrations are within the range of historical total phosphorus values recorded by the NH LLMP and the Maine DEP and fall within the range characteristic of a moderately productive lake (Table 3).

5) Biscay Pond temperature profiles collected by Scott Giguere indicate the upper mixed layer of water extended to about 6.0 meters (19.8 feet) during the period of summer thermal stratification, typical of a northern temperate lake. Historical dissolved oxygen data, collected by the Maine DEP (1974, 1976, 1981, 1982, 1988 and 1990), indicate reduced dissolved oxygen concentrations in the bottom (hypolimnetic) waters of Biscay Pond during thermal stratification. Lower hypolimnetic dissolved oxygen concentrations are indicative of accumulating organic matter from both internal (i.e. decaying aquatic animal and vegetative matter) and external (i.e. leaf litter from watershed runoff) sources. As dissolved oxygen concentrations are reduced below 1 milligram per liter the potential for internal nutrient release (nutrients are released from the sediments) increases significantly.

6) For all measurements considered and averaged for the season, Biscay Pond is classified as a moderately productive, mesotrophic, lake.

7) The primary purpose of the Biscay Pond volunteer monitoring effort is to document long term changes in the pond's productivity and identify any improper land use practices within the watershed that are contributing to water quality degradation. However, "background" variability in seasonal precipitation and temperature patterns can actually mask the effects of cultural eutrophication, or in some cases, augment the process, and in turn make trend (eutrophication) detection difficult. Increases in precipitation will often result in increased nutrient loading to a lake that in turn stimulates primary productivity (plant and algal production), but can also result in increased flushing of the aquatic system that can mask the effects of internal nutrient loading (i.e. large precipitation events can dilute nutrient concentrations in highly productive lakes). Increasing temperature will also effect the aquatic community, as most aquatic organisms will increase their activity (i.e. higher chlorophyll a concentrations or decreased Secchi Disk transparencies) during these periods, reflecting the thermal variations but not necessarily variations in available nutrients or other limiting resources that are commonly associated with poor land-use practices. As more data become available, the impact and inter-relationship of these variables can be assessed for the study lake and the impact of land use changes can be evaluated.

A second important component of trend assessment involves the frequent collection of water quality data. The most basic measurement, water clarity (measured as Secchi Disk transparency), is commonly used as an indicator of algal productivity (measured as chlorophyll a), although it also reflects the impact of dissolved colored (organic) compounds as well as suspended sediments. Chlorophyll a levels undergo daily fluctuations which require frequent monitoring to document short term fluctuations in chlorophyll a concentrations. Likewise, the dissolved color and total phosphorus concentrations can vary, particularly early in the season during and following "peak" watershed runoff, as well as, following summer storm events. Only through frequent monitoring can these short term water quality perturbations be documented, which is
important since they are often precursors to more detrimental "long-term" shifts in the trophic state (productivity). We therefore recommend continued monitoring on a frequent basis (bi-weekly or preferably weekly) during the summer months to more accurately identify both short term fluctuations (weekly and at times daily fluctuations) and long term trends in water quality measurements.
Figure 19. Biscay Pond, 1996. Seasonal water transparency (Secchi Disk Depth) trends of lay monitor Site 1 North. The dotted horizontal lines on the plot border the ranges common to oligotrophic, mesotrophic and eutrophic lakes. Secchi Disk measurements are reported to the nearest tenth (0.1) of a meter.

Figure 20. Biscay Pond, 1996. Seasonal chlorophyll α trends of lay monitor Site 1 North. The dotted horizontal lines on the plot border the ranges common to oligotrophic, mesotrophic and eutrophic lakes. Chlorophyll α concentrations are reported as parts per billion (ppb) of chlorophyll α.

Figure 21. Biscay Pond, 1996. Seasonal dissolved color trends of lay monitor Site 1 North. The dotted horizontal line represents the dissolved color average for participating Pemaquid Watershed lakes. Dissolved color is expressed as chlorophlatinate color units (ptu).
Figure 22. Comparison of the 1996 Biscay Pond lay monitor Secchi Disk transparency data with previous yearly data. The patterns of the bars display the minimum, average and maximum values for the respective years sampled while the length of the bars represents the total range of values. The shaded regions on the graph denote the Maine DEP Secchi Disk standards for low, moderate and high water clarities. The higher the Secchi Disk value the clearer the water. Secchi Disk readings are measured to the nearest tenth (0.1) of a meter.

Figure 23. Comparison of the 1996 Biscay Pond lay monitor chlorophyll a data with previous yearly data. The patterns of the bars display the minimum, average and maximum values for the respective years sampled while the length of the bars represents the total range of values. The shaded regions on the graph denote the Maine DEP chlorophyll a standards for low, moderate and high chlorophyll a concentrations. The higher the chlorophyll a value, the greener the water (more algal growth).
BISCAY POND - SITE 1 NORTH
LAY MONITOR SECCHI DISK DATA

LEGEND:
KEY:
MINIMUM
AVERAGE
MAXIMUM
1988
1989
1990
1991
1992
1993
1994
1995
1996
0
2
4
6
8
10
12
14
Secchi Disk Depth (meters)

The higher value = clearer water

BISCAY POND - SITE 1 NORTH
LAY MONITOR CHLOROPHYLL a DATA

LEGEND:
KEY:
MINIMUM
AVERAGE
MAXIMUM
1988
1989
1990
1991
1992
1993
1994
1995
1996
0
2
4
6
8
10
12
14
Chlorophyll a (ppb)

The higher value = more algal growth
Table 4. Boyd Pond - Trophic Indicators, 1996

Lakes Lay Monitoring Program, U.N.H.
[lay Monitor Data]

Boyd Pond, Maine
-- subset of trophic indicators, all sites, 1996

1996 SUMMARY
Average transparency: 3.8 (1996: 11 values; 3.4 - 4.7 range)
Average chlorophyll: 5.1 (1996: 11 values; 1.9 - 8.7 range)
Average Lake Phos.: 12.9 (1996: 6 values; 11.5 - 14.0 range)
Average color, 440: 55.4 (1996: 11 values; 43.8 - 71.3 range)

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<th>Total Phos (ppb)</th>
<th>Alk. Phos (gray) ph 5.1</th>
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<< End of 1996 listing, 14 records >>
BOYD POND

1996 NON-TECHNICAL SUMMARY

Bi-weekly water quality data were collected at the Boyd Pond deep sampling station, Site 1 Center, between May 5, 1996 and October 6, 1996 (refer to Table 4 and Figures 24 through 26). The following section summarizes the 1996 Boyd Pond water quality data and when applicable, incorporates historical data into the interpretation. A more detailed discussion of the water quality parameters is included in the section of the report titled “Discussion of Lake Monitoring Measurements”.

Table 5: Boyd Pond Water Quality Summary Table (1996) and Maine DEP Water Quality Classification Criteria.

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1) The 1996 Boyd Pond water clarity (Secchi Disk transparency) measurements are representative of a moderately productive lake bordering more “enriched” eutrophic conditions based on the water quality criteria employed by the Maine Department of Environmental Protection (Table 5). The 1996 seasonal water transparency average of 3.8 meters (12.5 feet) decreased for the third consecutive year and matched the historical seasonal average water transparency minima documented in 1989 and 1991 (Figure 27).

2) The 1996 Boyd Pond microscopic plant “algal” concentrations (reported as chlorophyll α) measured in the surface waters were moderate to high (range 1.9 to 8.7 milligrams per cubic meter; mg m⁻³). The seasonal average chlorophyll α concentration (5.1 milligrams per cubic meter; mg m⁻³) falls within the Maine DEP criteria for a moderately productive lake (Table 5 and Figure 28). The 1996 seasonal average Boyd Pond chlorophyll α concentration increased relative to the 1995 seasonal average chlorophyll α concentration and was at the highest level since volunteer water quality monitoring of Boyd Pond was initiated in 1989.

3) The 1996 Boyd Pond seasonal average dissolved lakewater color levels (a measure on naturally occurring “background” color) was moderate (55.4 chloroplatinate color units; ptu) and slightly greater than the 1995 seasonal average dissolved color concentration of 50.9 ptu.

4) 1996 Boyd Pond total phosphorus (generally considered the limiting nutrient for plant growth in freshwater systems) concentrations were moderate to high in the sur-
face waters and ranged from 11.5 to 14.0 parts per billion; ppb. The 1996 total phosphorus concentrations remained within the range of historical total phosphorus values recorded by the NH LLMP and the Maine DEP and fall within the range characteristic of a marginally moderately/highly productive lake (Table 5).

5) Boyd Pond temperature profiles collected by Peter Fischer indicate the upper mixed layer of water extended to about 4.0 meters (13.2 feet) during the period of summer thermal stratification, typical of a northern temperate lake. Historical dissolved oxygen data, collected by the Maine DEP (1990 and 1994), indicate reduced dissolved oxygen concentrations in the bottom (hypolimnetic) waters of Boyd Pond during periods of thermal stratification. Lower hypolimnetic dissolved oxygen concentrations are indicative of accumulating organic matter from both internal (i.e. decaying aquatic animal and vegetative matter) and external (i.e. leaf litter from watershed runoff) sources. As dissolved oxygen concentrations are reduced below 1 milligram per liter the potential for internal nutrient release (nutrient are resuspended from the sediments) increases significantly.

6) For all measurements considered and averaged for the season, Boyd Pond is classified as a borderline moderately productive/highly productive lake.

7) The primary purpose of the Boyd Pond volunteer monitoring effort is to document long term changes in the pond’s productivity and identify any improper land use practices within the watershed that are contributing to water quality degradation. However, “background” variability in seasonal precipitation and temperature patterns can actually mask the effects of cultural eutrophication, or in some cases, augment the process, and in turn make trend (eutrophication) detection difficult. Increases in precipitation will often result in increased nutrient loading to a lake that in turn stimulates primary productivity (plant production), but can also result in increased flushing of the aquatic system that can mask the effects of internal nutrient loading (i.e. large precipitation events can dilute nutrient concentrations in highly productive lakes). Increasing temperature will also effect the aquatic community, as most aquatic organisms will increase their activity (i.e. higher chlorophyll a concentrations or decreased Secchi Disk transparencies) during these periods, reflecting the thermal variations but not necessarily variations in available nutrients or other limiting resources that are commonly associated with poor land-use practices. As more data become available, the impact and inter-relationship of these variables can be assessed for the study lake and the impact of land use changes can be evaluated.

A second important component of trend assessment involves the frequent collection of water quality data. The most basic measurement, water clarity (measured as Secchi Disk transparency), is commonly used as an indicator of algal productivity (measured as chlorophyll a), although it also reflects the impact of dissolved colored (organic) compounds as well as suspended sediments. Chlorophyll a levels undergo daily fluctuations which require frequent monitoring to document short term fluctuations in chlorophyll a concentrations. Likewise, the dissolved color and total phosphorus concentrations can vary, particularly early in the season during and following “peak” watershed runoff, as well as, following summer storm events. Only through frequent monitoring can these short term water quality perturbations be documented, which is important since they are often precursors to more detrimental “long-term” shifts in the

38
trophic state (productivity). We therefore recommend continued monitoring on a frequent basis (bi-weekly or preferably weekly) during the summer months to more accurately identify both short term fluctuations (weekly and at times daily fluctuations) and long term trends in water quality measurements.
Figure 24. Boyd Pond, 1996. Seasonal water transparency (Secchi Disk Depth) trends of lay monitor Site 1 Center. The dotted horizontal lines on the plot border the ranges common to oligotrophic, mesotrophic and eutrophic lakes while the double solid horizontal line denotes the maximum site depth. Secchi Disk measurements are reported to the nearest tenth (0.1) of a meter.

Figure 25. Boyd Pond, 1996. Seasonal chlorophyll a trends of lay monitor Site 1 Center. The dotted horizontal lines on the plot border the ranges common to oligotrophic, mesotrophic and eutrophic lakes. Chlorophyll a concentrations are reported as parts per billion (ppb) of chlorophyll a.

Figure 26. Boyd Pond, 1996. Seasonal dissolved color trends of lay monitor Site 1 Center. The dotted horizontal line represents the dissolved color average for participating Pemaquid Watershed lakes. Dissolved color is expressed as chloroplatinate color units (ptu).
BOYD POND - SITE 1 CENTER

SECCHI DISK TRANSPARENCY 1996

- EUTROPHIC

- MESOTROPHIC

LAKE BOTTOM AT SITE

DATE

05/05 05/25 06/14 07/04 07/24 08/13 09/02 09/22 10/12 11/01

CHLOROPHYLL a CONCENTRATION 1996

- EUTROPHIC

- MESOTROPHIC

- OLIGOTROPHIC

SITE 1 CENTER

05/05 05/25 06/14 07/04 07/24 08/13 09/02 09/22 10/12 11/01

DISSOLVED COLOR CONCENTRATION 1996

1996 PEMAAJID PONDS AVERAGE

SITE 1 CENTER
**Figure 27.** Comparison of the 1996 Boyd Pond lay monitor Secchi Disk transparency data with previous yearly data. The patterns of the bars display the minimum, average and maximum values for the respective years sampled while the length of the bars represents the total range of values. The shaded regions on the graph denote the Maine DEP Secchi Disk standards for low, moderate and high water clarities. The higher the Secchi Disk value the clearer the water. Secchi Disk readings are measured to the nearest tenth (0.1) of a meter.

**Figure 28.** Comparison of the 1996 Boyd Pond lay monitor chlorophyll $a$ data with previous yearly data. The patterns of the bars display the minimum, average and maximum values for the respective years sampled while the length of the bars represents the total range of values. The shaded regions on the graph denote the Maine DEP chlorophyll $a$ standards for low, moderate and high chlorophyll $a$ concentrations. The higher the chlorophyll $a$ value, the greener the water (more algal growth).
BOYD POND - SITE 1 CENTER
LAY MONITOR SECCHI DISK DATA
YEARLY COMPARISONS (1989-1996)

LEGEND:
KEY:
MINIMUM
AVERAGE
MAXIMUM
1989
1990
1991
1992
1993
1994
1995
1996
LOW
MODERATE
HIGH

Secchi Disk Depth (meters)

The higher value = clearer water

BOYD POND - SITE 1 CENTER
LAY MONITOR CHLOROPHYLL a DATA
YEARLY COMPARISONS (1989-1996)

LEGEND:
KEY:
MINIMUM
AVERAGE
MAXIMUM
1989
1990
1991
1992
1993
1994
1995
1996
LOW
MODERATE
HIGH

Chlorophyll a (ppb)

The higher value = more algal growth
# Table 6. Duckpuddle Pond - Trophic Indicators, 1996

Lakes Lay Monitoring Program, U.N.H.
[ Lay Monitor Data ]

Duckpuddle Pond, Maine
-- subset of trophic indicators, all sites, 1996

**1996 SUMMARY**
Average transparency: 2.6 (1996: 11 values; 1.6 - 3.8 range)
Average chlorophyll: 6.8 (1996: 11 values; 4.4 - 16.2 range)
Average Lake Phos.: 22.1 (1996: 36 values; 13.0 - 43.3 range)
Average color, 440: 96.4 (1996: 11 values; 86.8 - 111.7 range)

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<th>Total Phos (ppb)</th>
<th>Alk. (gray)</th>
<th>Alk. (pink)</th>
<th>Color Pt-Co units</th>
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<< End of 1996 listing, 36 records >>
**DUCKPUDDLE POND**

**1996 NON-TECHNICAL SUMMARY**

Bi-weekly water quality data were collected at the Duckpuddle Pond deep sampling station, Site 1 Basin, between May 5, 1996 and October 14, 1996 (Refer to Table 6 and Figures 29 through 43). The following section summarizes the 1996 Duckpuddle Pond water quality data and when applicable, incorporates historical data into the interpretation. A more detailed discussion of the water quality parameters is included in the section of the report titled “Discussion of Lake Monitoring Measurements”.

**Table 7: Duckpuddle Pond Water Quality Summary Table (1996) and Maine DEP Water Quality Classification Criteria.**

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<td>Water Clarity (meters)</td>
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<td>4.0-7.0</td>
<td>&lt;4.0</td>
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<td>Chlorophyll a (ppb)</td>
<td>&lt;2.0</td>
<td>2.0-7.0</td>
<td>&gt;7.0</td>
<td>6.8</td>
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<tr>
<td>Total Phosphorus (ppb)</td>
<td>&lt;6.0</td>
<td>6.0-13.0</td>
<td>&gt;13.0</td>
<td>20.3 *</td>
</tr>
</tbody>
</table>

* denotes data collected in the surface waters (composite sample) only.

1) The 1996 Duckpuddle Pond water clarity (Secchi Disk transparency) measurements are representative of a marginally moderately/highly productive lake based on the water quality criteria employed by the Maine Department of Environmental Protection (Table 7 and Figure 32). The 1996 seasonal water transparency average of 2.6 meters (8.6 feet) is higher than the 1995 seasonal average water transparency (1.7 meters) but remains within the range of historical water quality data (range: 0.3 to 3.8 meters).

2) The 1996 Duckpuddle Pond microscopic plant “algal” concentrations (reported as chlorophyll a) were moderate to high when measured in the surface waters. The seasonal average chlorophyll a concentration (6.8 milligrams per cubic meter; mg m⁻³) falls within the Maine DEP criteria for a “transitional” moderately productive lake that borders a more productive “enriched” lake (Table 7 and Figure 33). The 1996 seasonal average chlorophyll a concentration decreased relative to the 1995 seasonal average chlorophyll a concentration (10.0 mg m⁻³) and was at the lowest level since 1990 when the seasonal average chlorophyll a concentration measured 6.5 mg m⁻³ (Figure 33).

3) The 1996 Duckpuddle Pond seasonal average dissolved lakewater color level (a measure on naturally occurring “background” color) was high (96.4 chloroplнатinate color units; ptu) and higher than the seasonal average dissolved color concentration documented between 1989 and 1995 (range 78.3 to 96.0 ptu).
4) The 1996 Duckpuddle Pond total phosphorus (generally considered the limiting nutrient for plant growth in freshwater systems) concentrations, measured in the surface waters, were high when sampled by the lay monitors and ranged from 13.0 to 34.3 parts per billion; ppb. Additional total phosphorus concentrations measured in the bottom waters (metalimnion) included elevated total phosphorus concentrations (range: 17.0 to 43.3 ppb), relative to the surface total phosphorus concentrations, which suggest internal nutrient loading (nutrient released from the bottom sediments). The 1996 total phosphorus concentrations are high but remain within the range of historical total phosphorus values recorded by the NH LLMP and the Maine DEP and fall within the range characteristic of a highly productive lake (Table 7).

5) Duckpuddle Pond temperature profiles collected by David Libby indicate the upper mixed layer of water extended to about 4.0 meters (13.2 feet) during the period of summer thermal stratification, typical of a northern temperate lake. Dissolved oxygen data, collected by David Libby (May 5 through September 22, 1996), indicate the deeper waters become anoxic following the development of thermal stratification (Figures 34 through 43). By mid July (July 21) the dissolved oxygen concentration was reduced below 3 parts per million (the minimum dissolved oxygen concentration required for the successful growth and reproduction of most warmwater fish) at about 5 meters, which is similar to the 1993 through 1995 data. Furthermore, by July 21 the dissolved oxygen concentrations in the bottom two meters of Duckpuddle pond were reduced below 1 milligram per liter; at which time the potential for internal nutrient loading increases and can favor a buildup of phosphorus in the deeper waters (what is known as internal nutrient loading). The dissolved oxygen concentrations remained below 1 milligram per liter on August 4 in the bottom one meter of and in the bottom two meters of water on August 19 and September 1. Subsequent dissolved oxygen sampling indicate Duckpuddle Pond became thermally constant (turned over) by September 22, at which time the dissolved oxygen concentrations remained above 6 milligrams per liter throughout the water column. Lower dissolved oxygen concentrations near the lakebottom are indicative of accumulating organic matter from both internal (i.e. decaying aquatic animal and vegetative matter) and external (i.e. leaf litter and grass clipping) sources.

6) For all measurements considered and averaged for the season, Duckpuddle Pond is classified as a highly productive, eutrophic, lake based on the classification scheme employed by the Maine DEP.

7) The primary purpose of the Duckpuddle Pond volunteer monitoring effort is to document long term changes in the pond's productivity and identify any improper land use practices within the watershed that are contributing to water quality degradation. However, "background" variability in seasonal precipitation and temperature patterns can actually mask the effects of cultural eutrophication, or in some cases, augment the process, and in turn make trend (eutrophication) detection difficult. Increases in precipitation will often result in increased nutrient loading to a lake that in turn stimulates primary productivity (plant production), but can also result in increased flushing of the aquatic system that can mask the effects of internal nutrient loading (i.e. large precipitation events can dilute nutrient concentrations in highly productive lakes). Increasing temperature will also effect the aquatic community, as most aquatic organisms
will increase their activity (i.e. higher chlorophyll α concentrations or decreased Secchi Disk transparencies) during these periods, reflecting the thermal variations but not necessarily variations in available nutrients or other limiting resources that are commonly associated with poor land-use practices. As more data become available, the impact and inter-relationship of these variables can be assessed for the study lake and the impact of land use changes can be evaluated.

A second important component of trend assessment involves the frequent collection of water quality data. The most basic measurement, water clarity (measured as Secchi Disk transparency), is commonly used as an indicator of algal productivity (measured as chlorophyll α), although it also reflects the impact of dissolved colored (organic) compounds as well as suspended sediments. Chlorophyll α levels undergo daily fluctuations which require frequent monitoring to document short term fluctuations in chlorophyll α concentrations. Likewise, the dissolved color and total phosphorus concentrations can vary, particularly early in the season during and following “peak” watershed runoff, as well as, following summer storm events. Only through frequent monitoring can these short term water quality perturbations be documented, which is important since they are often precursors to more detrimental “long-term” shifts in the trophic state (productivity). We therefore recommend continued monitoring on a frequent basis (bi-weekly or preferably weekly) during the summer months to more accurately identify both short term fluctuations (weekly and at times daily fluctuations) and long term trends in water quality measurements.
**Figure 29.** Duckpuddle Pond, 1996. Seasonal water transparency (Secchi Disk Depth) trends of lay monitor Site 1 Basin. The dotted horizontal lines on the plot border the ranges common to oligotrophic, mesotrophic and eutrophic lakes while the double solid horizontal line denotes the maximum site depth. Secchi Disk measurements are reported to the nearest tenth (0.1) of a meter.

**Figure 30.** Duckpuddle Pond, 1996. Seasonal chlorophyll a trends of lay monitor Site 1 Basin. The dotted horizontal lines on the plot border the ranges common to oligotrophic, mesotrophic and eutrophic lakes. Chlorophyll a concentrations are reported as parts per billion (ppb) of chlorophyll a.

**Figure 31.** Duckpuddle Pond, 1996. Seasonal dissolved color trends of lay monitor Site 1 Basin. The dotted horizontal line represents the dissolved color average for participating Pemaquid Watershed lakes. Dissolved color is expressed as chloroplatinate color units (ptu).
Figure 32. Comparison of the 1996 Duckpuddle Pond lay monitor Secchi Disk transparency data with previous yearly data. The patterns of the bars display the minimum, average and maximum values for the respective years sampled while the length of the bars represents the total range of values. The shaded regions on the graph denote the Maine DEP Secchi Disk standards for low, moderate and high water clairities. The higher the Secchi Disk value the clearer the water. Secchi Disk readings are measured to the nearest tenth (0.1) of a meter.

Figure 33. Comparison of the 1996 Duckpuddle Pond lay monitor chlorophyll a data with previous yearly data. The patterns of the bars display the minimum, average and maximum values for the respective years sampled while the length of the bars represents the total range of values. The shaded regions on the graph denote the Maine DEP chlorophyll a standards for low, moderate and high chlorophyll a concentrations. The higher the chlorophyll a value, the greener the water (more algal growth).
The higher value = clearer water

The higher value = more algal growth
Figure 34. Duckpuddle Pond, Site 1 Basin, temperature and dissolved oxygen profiles collected on May 5, 1996. The temperature and dissolved oxygen data were collected at one meter increments and are reported in degrees Centigrade (°C) and in parts per million (ppm), respectively.

Figure 35. Duckpuddle Pond, Site 1 Basin, temperature and dissolved oxygen profiles collected on May 19, 1996. The temperature and dissolved oxygen data were collected at one meter increments and are reported in degrees Centigrade (°C) and in parts per million (ppm), respectively.
Figure 36. Duckpuddle Pond, Site 1 Basin, temperature and dissolved oxygen profiles collected on June 8, 1996. The temperature and dissolved oxygen data were collected at one meter increments and are reported in degrees Centigrade (°C) and in parts per million (ppm), respectively.

Figure 37. Duckpuddle Pond, Site 1 Basin, temperature and dissolved oxygen profiles collected on June 22, 1996. The temperature and dissolved oxygen data were collected at one meter increments and are reported in degrees Centigrade (°C) and in parts per million (ppm), respectively.
Figure 38. Duckpuddle Pond, Site 1 Basin, temperature and dissolved oxygen profiles collected on July 7, 1996. The temperature and dissolved oxygen data were collected at one meter increments and are reported in degrees Centigrade (°C) and in parts per million (ppm), respectively.

Figure 39. Duckpuddle Pond, Site 1 Basin, temperature and dissolved oxygen profiles collected on July 21, 1996. The temperature and dissolved oxygen data were collected at one meter increments and are reported in degrees Centigrade (°C) and in parts per million (ppm), respectively.
Figure 40. Duckpuddle Pond, Site 1 Basin, temperature and dissolved oxygen profiles collected on July 4, 1996. The temperature and dissolved oxygen data were collected at one meter increments and are reported in degrees Centigrade (°C) and in parts per million (ppm), respectively.

Figure 41. Duckpuddle Pond, Site 1 Basin, temperature and dissolved oxygen profiles collected on August 18, 1996. The temperature and dissolved oxygen data were collected at one meter increments and are reported in degrees Centigrade (°C) and in parts per million (ppm), respectively.
Figure 42. Duckpuddle Pond, Site 1 Basin, temperature and dissolved oxygen profiles collected on September 1, 1996. The temperature and dissolved oxygen data were collected at one meter increments and are reported in degrees Centigrade (°C) and in parts per million (ppm), respectively.

Figure 43. Duckpuddle Pond, Site 1 Basin, temperature and dissolved oxygen profiles collected on September 22, 1996. The temperature and dissolved oxygen data were collected at one meter increments and are reported in degrees Centigrade (°C) and in parts per million (ppm), respectively.
billion; ppb. The 1996 total phosphorus concentrations remain well within the range of historical total phosphorus values recorded by the NH LLMP and the Maine DEP and fall within the range characteristic of a moderately to highly productive lake (Table 9).

5) McCurdy Pond temperature profiles collected by the volunteer monitors indicate the upper mixed layer of water extended to about 6.5 meters during the period of summer thermal stratification, typical of a northern temperate lake. Historical dissolved oxygen data, collected by the Maine DEP (1975 and 1985), indicate reduced dissolved oxygen concentrations in the bottom (hypolimnetic) waters of McCurdy Pond during periods of thermal stratification. Lower hypolimnetic dissolved oxygen concentrations are indicative of accumulating organic matter from both internal (i.e. decaying aquatic animal and vegetative matter) and external (i.e. leaf litter from watershed runoff) sources. As dissolved oxygen concentrations are reduced below 1 milligram per liter the potential for internal nutrient release (nutrients are resuspended from the sediments) increases significantly and might explain elevated total phosphorus concentrations historically documented near the lakebottom (hypolimnnion) in McCurdy Pond.

6) For all measurements considered and averaged for the season, McCurdy Pond is classified as a moderately productive, mesotrophic, lake.

7) The primary purpose of the McCurdy Pond volunteer monitoring effort is to document long term changes in the pond’s productivity and identify any improper land use practices within the watershed that are contributing to water quality degradation. However, “background” variability in seasonal precipitation and temperature patterns can actually mask the effects of cultural eutrophication, or in some cases, augment the process, and in turn make trend (eutrophication) detection difficult. Increases in precipitation will often result in increased nutrient loading to a lake that in turn stimulates primary productivity (plant production), but can also result in increased flushing of the aquatic system that can mask the effects of internal nutrient loading (i.e. large precipitation events can dilute nutrient concentrations in highly productive lakes). Increasing temperature will also effect the aquatic community, as most aquatic organisms will increase their activity (i.e. higher chlorophyll a concentrations or decreased Secchi Disk transparencies) during these periods, reflecting the thermal variations but not necessarily variations in available nutrients or other limiting resources that are commonly associated with poor land-use practices. As more data become available, the impact and inter-relationship of these variables can be assessed for the study lake and the impact of land use changes can be evaluated.

A second important component of trend assessment involves the frequent collection of water quality data. The most basic measurement, water clarity (measured as Secchi Disk transparency), is commonly used as an indicator of algal productivity (measured as chlorophyll a), although it also reflects the impact of dissolved colored (organic) compounds as well as suspended sediments. Chlorophyll a levels undergo daily fluctuations which require frequent monitoring to document short term fluctuations in chlorophyll a concentrations. Likewise, the dissolved color and total phosphorus concentrations can vary, particularly early in the season during and following "peak" watershed runoff, as well as, following summer storm events. Only through frequent monitoring can these short term water quality perturbations be documented, which is important since they are often precursors to more detrimental "long-term" shifts in the
trophic state (productivity). We therefore recommend continued monitoring on a frequent basis (bi-weekly or preferably weekly) during the summer months to more accurately identify both short term fluctuations (weekly and at times daily fluctuations) and long term trends in water quality measurements.
**Figure 44.** McCurdy Pond, 1996. Seasonal water transparency (Secchi Disk Depth) trends of lay monitor Site 1 Basin. The dotted horizontal lines on the plot border the ranges common to oligotrophic, mesotrophic and eutrophic lakes. Secchi Disk measurements are reported to the nearest tenth (0.1) of a meter.

**Figure 45.** McCurdy Pond, 1996. Seasonal chlorophyll $a$ trends of lay monitor Site 1 Basin. The dotted horizontal lines on the plot border the ranges common to oligotrophic, mesotrophic and eutrophic lakes. Chlorophyll $a$ concentrations are reported as parts per billion (ppb) of chlorophyll $a$.

**Figure 46.** McCurdy Pond, 1996. Seasonal dissolved color trends of lay monitor Site 1 Basin. The dotted horizontal line represents the dissolved color average for participating Pemaquid Watershed lakes. Dissolved color is expressed as chloroplatinate color units (ptu).
Figure 47. Comparison of the 1996 McCurdy Pond lay monitor Secchi Disk transparency data with previous yearly data. The patterns of the bars display the minimum, average and maximum values for the respective years sampled while the length of the bars represents the total range of values. The shaded regions on the graph denote the Maine DEP Secchi Disk standards for low, moderate and high water clarities. The higher the Secchi Disk value the clearer the water. Secchi Disk readings are measured to the nearest tenth (0.1) of a meter.

Figure 48. Comparison of the 1996 McCurdy Pond lay monitor chlorophyll a data with previous yearly data. The patterns of the bars display the minimum, average and maximum values for the respective years sampled while the length of the bars represents the total range of values. The shaded regions on the graph denote the Maine DEP chlorophyll a standards for low, moderate and high chlorophyll a concentrations. The higher the chlorophyll a value, the greener the water (more algal growth).
MCCURDY POND - SITE 1 BASIN
LAY MONITOR SECCHI DISK DATA

LEGEND:
KEY:
MINIMUM
1988
1989
1990
1991
1992
1993
1994
1995
1996
AVERAGE
MAXIMUM
LOW
MODERATE
HIGH

Secchi Disk Depth (meters)

The higher value = clearer water

MCCURDY POND - SITE 1 BASIN
LAY MONITOR CHLOROPHYLL a DATA

LEGEND:
KEY:
MINIMUM
1988
1989
1990
1991
1992
1993
1994
1995
1996
AVERAGE
MAXIMUM
LOW
MODERATE
HIGH

Chlorophyll a (ppb)

The higher value = more algal growth
Table 10. Paradise Pond - Trophic Indicators, 1996

Lakes Lay Monitoring Program, U.N.H.
[Lay Monitor Data]

Paradise Pond, Maine
-- subset of trophic indicators, all sites, 1996

1996 SUMMARY
Average transparency:  3.7 (1996: 13 values;  3.5 - 3.8 range)
Average chlorophyll:  3.6 (1996: 13 values;  2.7 - 4.7 range)
Average Lake Phos.:  17.9 (1996: 4 values;  14.8 - 20.5 range)
Average color, 440:  64.6 (1996: 13 values;  52.4 - 79.9 range)

<table>
<thead>
<tr>
<th>Site</th>
<th>Date</th>
<th>Transparency (m)</th>
<th>Chl a (ppb)</th>
<th>Total Phos (ppb)</th>
<th>Alk. Phos (gray)</th>
<th>Alk. Phos (pink)</th>
<th>Color Pt-Co units</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 North</td>
<td>05/12/1996</td>
<td>bottom</td>
<td>2.7</td>
<td>14.8</td>
<td>-----</td>
<td>-----</td>
<td>73.0</td>
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<tr>
<td>2 North</td>
<td>05/19/1996</td>
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<td>4.7</td>
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<td>-----</td>
<td>-----</td>
<td>79.9</td>
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<tr>
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<td>bottom</td>
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</tr>
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<td>72.2</td>
</tr>
<tr>
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<td>06/30/1996</td>
<td>bottom</td>
<td>4.0</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
<td>61.8</td>
</tr>
<tr>
<td>2 North</td>
<td>07/14/1996</td>
<td>bottom</td>
<td>4.0</td>
<td>-----</td>
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<td>58.4</td>
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<td>67.0</td>
</tr>
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<td>65.3</td>
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<tr>
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<td>08/24/1996</td>
<td>bottom</td>
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<td>18.8</td>
<td>-----</td>
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<td>61.8</td>
</tr>
<tr>
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<td>09/07/1996</td>
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<td>-----</td>
<td>-----</td>
<td>-----</td>
<td>53.3</td>
</tr>
<tr>
<td>2 North</td>
<td>09/15/1996</td>
<td>bottom</td>
<td>3.8</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
<td>52.4</td>
</tr>
<tr>
<td>2 North</td>
<td>10/05/1996</td>
<td>bottom</td>
<td>3.3</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
<td>57.6</td>
</tr>
<tr>
<td>2 North</td>
<td>10/19/1996</td>
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<td>-----</td>
<td>-----</td>
<td>60.1</td>
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<td>-----</td>
<td>20.5</td>
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<td>-----</td>
<td>-----</td>
</tr>
<tr>
<td>2A North</td>
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<td>-----</td>
<td>17.5</td>
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</tr>
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</table>

<< End of 1996 listing, 15 records >>
PARADISE POND
1996 NON-TECHNICAL SUMMARY

Bi-weekly water quality data were collected at the Paradise Pond deep sampling station, Site 2 North, between May 12, 1996 and October 19, 1996 (Refer to Table 10 and Figures 49 through 53). The following section summarizes the 1996 Paradise Pond water quality data and when applicable, incorporates historical data into the interpretation. A more detailed discussion of the water quality parameters is included in the section of the report titled “Discussion of Lake Monitoring Measurements”.

Table 11: Paradise Pond Water Quality Summary Table (1996) and Maine DEP Water Quality Classification Criteria.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Water Clarity (meters)</td>
<td>&gt;7.0</td>
<td>4.0-7.0</td>
<td>&lt;4.0</td>
<td>XXXXXXXXXXX</td>
</tr>
<tr>
<td>Chlorophyll a (ppb)</td>
<td>&lt;2.0</td>
<td>2.0-7.0</td>
<td>&gt;7.0</td>
<td>3.6</td>
</tr>
<tr>
<td>Total Phosphorus (ppb)</td>
<td>&lt;6.0</td>
<td>6.0-13.0</td>
<td>&gt;13.0</td>
<td>17.9</td>
</tr>
</tbody>
</table>

1) The 1996 Paradise Pond water clarity (Secchi Disk transparency) measurements ranged from 3.2 to 3.8 meters (at which time the Secchi Disk rested on the lakebottom). Due to the shallowness of the pond, water clarity measurements cannot be classified based on the criteria employed by the Maine Department of Environmental Protection (DEP).

2) The 1996 Paradise Pond microscopic plant “algal” concentrations (reported as chlorophyll a) measured in the surface waters were moderate (Figure 50). The seasonal average chlorophyll a concentration (3.6 milligrams per cubic meter; mg m⁻³) falls within the Maine DEP criteria for a moderately productive lake (Table 11 and Figure 53). The 1996 seasonal average Paradise Pond chlorophyll a concentration decreased relative to the 1995 seasonal average chlorophyll a concentration (4.1 mg m⁻³) and remained within the range of historical values (range: 1.8 to 12.3 mg m⁻³).

3) The 1996 Paradise Pond seasonal average dissolved lakewater color level (a measure on naturally occurring “background” color) was moderate (64.6 chloroplatinate color units; ptu) and similar to the 1995 seasonal average dissolved color concentration of 64.5 ptu.

4) The 1995 Paradise Pond total phosphorus (generally considered the limiting nutrient for plant growth in freshwater systems) concentrations collected on May 12 and August 24, 1996 were high and ranged from 14.8 to 20.5 parts per billion; ppb). The 1996 total phosphorus concentrations exceed the range of historical total phosphorus
values recorded by the NH LLMP and the Maine DEP and fall within the range characteristic of a highly productive lake (Table 11).

5) Paradise Pond temperature profiles collected by Steve O’Bryan indicate Paradise Pond remained thermally constant (i.e. no temperature change from the pond surface to the pond bottom) throughout the summer sampling season, typical of shallow water bodies. With the lack of temperature stratification, the pond remains well oxygenated throughout the water column. However, during periods of inclement weather, there is a greater chance of resuspending accumulated matter off the bottom of Paradise Pond than would occur in a deeper, stratified lake or pond (i.e. Biscay Pond, McCurdy Pond and Pemaquid Pond). The resuspension of particulate matter can diminish water clarity and mobilize nutrients, which adhere to the sediment and detrital (decaying organic matter) particles, and can than be utilized by certain algal forms.

6) For all measurements considered and averaged for the season, Paradise Pond is classified as a moderately productive, mesotrophic, lake. However, the total phosphorus concentrations are more characteristic of a higher level of productivity; eutrophy.

7) The primary purpose of the Paradise Pond volunteer monitoring effort is to document long term changes in the pond’s productivity and identify any improper land use practices within the watershed that are contributing to water quality degradation. However, “background” variability in seasonal precipitation and temperature patterns can actually mask the effects of cultural eutrophication, or in some cases, augment the process, and in turn make trend (eutrophication) detection difficult. Increases in precipitation will often result in increased nutrient loading to a lake that in turn stimulates primary productivity (plant production), but can also result in increased flushing of the aquatic system that can mask the effects of internal nutrient loading (i.e. large precipitation events can dilute nutrient concentrations in highly productive lakes). Increasing temperature will also effect the aquatic community, as most aquatic organisms will increase their activity (i.e. higher chlorophyll a concentrations or decreased Secchi Disk transparencies) during these periods, reflecting the thermal variations but not necessarily variations in available nutrients or other limiting resources that are commonly associated with poor land-use practices. As more data become available, the impact and inter-relationship of these variables can be assessed for the study lake and the impact of land use changes can be evaluated.

A second important component of trend assessment involves the frequent collection of water quality data. The most basic measurement, water clarity (measured as Secchi Disk transparency), is commonly used as an indicator of algal productivity (measured as chlorophyll a), although it also reflects the impact of dissolved colored (organic) compounds as well as suspended sediments. Chlorophyll a levels undergo daily fluctuations which require frequent monitoring to document short term fluctuations in chlorophyll a concentrations. Likewise, the dissolved color and total phosphorus concentrations can vary, particularly early in the season during and following “peak” watershed runoff, as well as, following summer storm events. Only through frequent monitoring can these short term water quality perturbations be documented, which is important since they are often precursors to more detrimental “long-term” shifts in the trophic state (productivity). We therefore recommend continued monitoring on a frequent basis (bi-weekly or preferably weekly) during the summer months to more accu-
rately identify both short term fluctuations (weekly and at times daily fluctuations) and long term trends in water quality measurements.
Figure 49. Paradise Pond, 1996. Seasonal water transparency (Secchi Disk Depth) trends of lay monitor Site 2 North. The double solid horizontal line denotes the maximum site depth. Secchi Disk measurements are reported to the nearest tenth (0.1) of a meter.

Figure 50. Paradise Pond, 1996. Seasonal chlorophyll $a$ trends of lay monitor Site 2 North. The dotted horizontal lines on the plot border the ranges common to oligotrophic, mesotrophic and eutrophic lakes. Chlorophyll $a$ concentrations are reported as parts per billion (ppb) of chlorophyll $a$.

Figure 51. Paradise Pond, 1996. Seasonal dissolved color trends of lay monitor Site 2 North. The dotted horizontal line represents the dissolved color average for participating Pemaquid Watershed lakes. Dissolved color is expressed as chloroplatinate color units (ptu).
Figure 52. Comparison of the 1996 Paradise Pond lay monitor Secchi Disk transparency data with previous yearly data. The patterns of the bars display the minimum, average and maximum values for the respective years sampled while the length of the bars represents the total range of values. The shaded regions on the graph denote the Maine DEP Secchi Disk standards for low, moderate and high water clarities. The higher the Secchi Disk value the clearer the water. Secchi Disk readings are measured to the nearest tenth (0.1) of a meter.

Figure 53. Comparison of the 1996 Paradise Pond lay monitor chlorophyll $a$ data with previous yearly data. The patterns of the bars display the minimum, average and maximum values for the respective years sampled while the length of the bars represents the total range of values. The shaded regions on the graph denote the Maine DEP chlorophyll $a$ standards for low, moderate and high chlorophyll $a$ concentrations. The higher the chlorophyll $a$ value, the greener the water (more algal growth).
PARADISE POND - SITES 1 & 2
LAY MONITOR SECCHI DISK DATA

LEGEND:
KEY:
MINIMUM
AVERAGE
MAXIMUM
1988
1989
1990
1991
1992
1993
1994
1995
1996
LOW
MODERATE
HIGH

Secchi Disk Depth (meters)

The higher value = clearer water
Note: * denote years when the Secchi Disk reached the lakebottom before disappearing from view.

PARADISE POND - SITES 1 & 2
LAY MONITOR CHLOROPHYLL a DATA

LEGEND:
KEY:
MINIMUM
AVERAGE
MAXIMUM
1988
1989
1990
1991
1992
1993
1993
1994
1995
1996
LOW
MODERATE
HIGH

Chlorophyll a (ppb)

The higher value = more algal growth
Table 12. Pemaquid Pond - Trophic Indicators, 1996

Lakes Lay Monitoring Program, U.N.H.
[Lay Monitor Data]

Pemaquid Pond, Maine
-- subset of trophic indicators, all sites, 1996

1996 SUMMARY
Average transparency: 4.6 (1996: 8 values; 4.4 - 4.8 range)
Average chlorophyll: 4.0 (1996: 8 values; 2.6 - 5.7 range)
Average Lake Phos.: 9.1 (1996: 8 values; 6.8 - 15.3 range)
Average color, 440: 40.1 (1996: 8 values; 31.6 - 47.2 range)

<table>
<thead>
<tr>
<th>Site</th>
<th>Date</th>
<th>Transparence</th>
<th>Chl a (ppb)</th>
<th>Total Phos (ppb)</th>
<th>Alk. (gray)</th>
<th>Alk. (pink)</th>
<th>Color Pt-Co units</th>
</tr>
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<tr>
<td>1 Basin</td>
<td>06/17/1996</td>
<td>4.4</td>
<td>3.6</td>
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<td>----</td>
<td>----</td>
<td>44.7</td>
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<td>8.0</td>
<td>----</td>
<td>----</td>
<td>47.2</td>
</tr>
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<td>07/16/1996</td>
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<td>3.0</td>
<td>7.0</td>
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<td>----</td>
<td>40.4</td>
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<td>2.6</td>
<td>7.8</td>
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<< End of 1996 listing, 12 records >>
PEMAQUID POND
1996 NON-TECHNICAL SUMMARY

Bi-weekly water quality data were collected at the Pemaquid Pond deep sampling station, Site 1 Basin, between June 17, 1996 and October 18, 1996 (Refer to Table 12 and Figures 54 through 58). The following section summarizes the 1996 Pemaquid Pond water quality data and when applicable, incorporates historical data into the interpretation. A more detailed discussion of the water quality parameters is included in the section of the report titled “Discussion of Lake Monitoring Measurements”.

Table 13: Pemaquid Pond Water Quality Summary Table (1996) and Maine DEP Water Quality Classification Criteria.

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
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</thead>
<tbody>
<tr>
<td>Water Clarity (meters)</td>
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<td>4.0-7.0</td>
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<td>Chlorophyll a (ppb)</td>
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<td>&gt;7.0</td>
<td>4.0</td>
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<td>Total Phosphorus (ppb)</td>
<td>&lt;6.0</td>
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<td>&gt;13.0</td>
<td>9.1</td>
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</table>

1) The 1996 Pemaquid Pond water clarity (Secchi Disk transparency) measurements are representative of a moderately productive lake based on the water quality criteria employed by the Maine Department of Environmental Protection (DEP). The 1996 seasonal water transparency average of 4.6 meters (15.2 feet) falls within the range of historical water transparency readings (Figure 57).

2) The 1996 Pemaquid Pond microscopic plant “algal” concentrations (reported as chlorophyll a) were moderate when measured in the surface waters (Figure 55). The seasonal average chlorophyll a concentration (4.0 milligrams per cubic meter; mg m⁻³) falls within the Maine DEP criteria for a moderately productive lake (Table 13 and Figure 58). The 1996 seasonal average Pemaquid Pond chlorophyll a concentration increased relative to the 1995 seasonal average chlorophyll a concentration (3.2 mg m⁻³) but remained within the range of historical seasonal chlorophyll a averages.

3) The 1996 Pemaquid Pond seasonal average dissolved lakewater color level (a measure on naturally occurring “background” color) was moderate (40.1 chloroplattinate color units; ptu) but slightly less than the 1995 seasonal average dissolved color average of 45.4 ptu.

4) 1996 Pemaquid Pond total phosphorus (generally considered the limiting nutrient for plant growth in freshwater systems) concentrations were moderate to high when measured in the surface waters on June 17, June 30, July 16 and August 5, 1996 and ranged from 6.8 to 15.3 parts per billion; ppb. The 1996 Pemaquid Pond total phosphorus concentrations remain within the range of historical total phosphorus values re-
corded by the NH LLMP and the Maine DEP and fall within the range characteristic of a moderately productive lake (Table 13).

5) Pemaquid Pond temperature profiles collected by David McLeod indicate the upper mixed layer of water extended to about 9.0 meters during the period of summer thermal stratification, typical of a northern temperate lake. Historical dissolved oxygen data, collected by the Maine DEP (1975, 1976, 1977, 1978, 1981, 1984 1988, 1987 1991), indicate reduced dissolved oxygen concentrations in the bottom (hypolimnetic) waters of Pemaquid Pond during thermal stratification. Lower hypolimnetic dissolved oxygen concentrations are indicative of accumulating organic matter from both internal (i.e. decaying aquatic animal and vegetative matter) and external (i.e. leaf litter from watershed runoff) sources. As dissolved oxygen concentrations are reduced below 1 milligram per liter the potential for internal nutrient release (nutrients are resuspended from the sediments) increases significantly.

6) For all measurements considered and averaged for the season, Pemaquid Pond is classified as a moderately productive, mesotrophic, lake.

7) The primary purpose of the Pemaquid Pond volunteer monitoring effort is to document long term changes in the pond's productivity and identify any improper land use practices within the watershed that are contributing to water quality degradation. However, “background” variability in seasonal precipitation and temperature patterns can actually mask the effects of cultural eutrophication, or in some cases, augment the process, and in turn make trend (eutrophication) detection difficult. Increases in precipitation will often result in increased nutrient loading to a lake that in turn stimulates primary productivity (plant production), but can also result in increased flushing of the aquatic system that can mask the effects of internal nutrient loading (i.e. large precipitation events can dilute nutrient concentrations in highly productive lakes). Increasing temperature will also affect the aquatic community, as most aquatic organisms will increase their activity (i.e. higher chlorophyll a concentrations or decreased Secchi Disk transparencies) during these periods, reflecting the thermal variations but not necessarily variations in available nutrients or other limiting resources that are commonly associated with poor land-use practices. As more data become available, the impact and inter-relationship of these variables can be assessed for the study lake and the impact of land use changes can be evaluated.

A second important component of trend assessment involves the frequent collection of water quality data. The most basic measurement, water clarity (measured as Secchi Disk transparency), is commonly used as an indicator of algal productivity (measured as chlorophyll a), although it also reflects the impact of dissolved colored (organic) compounds as well as suspended sediments. Chlorophyll a levels undergo daily fluctuations which require frequent monitoring to document short term fluctuations in chlorophyll a concentrations. Likewise, the dissolved color and total phosphorus concentrations can vary, particularly early in the season during and following “peak” watershed runoff, as well as, following summer storm events. Only through frequent monitoring can these short term water quality perturbations be documented, which is important since they are often precursors to more detrimental “long-term” shifts in the trophic state (productivity). We therefore recommend continued monitoring on a fre-
quent basis (bi-weekly or preferably weekly) during the summer months to more accurately identify both short term fluctuations (weekly and at times daily fluctuations) and long term trends in water quality measurements.
Figure 54. Pemaquid Pond, 1996. Seasonal water transparency (Secchi Disk Depth) trends of lay monitor Site 1 Basin. The dotted horizontal lines on the plot border the ranges common to oligotrophic, mesotrophic and eutrophic lakes. Secchi Disk measurements are reported to the nearest tenth (0.1) of a meter.

Figure 55. Pemaquid Pond, 1996. Seasonal chlorophyll $a$ trends of lay monitor Site 1 Basin. The dotted horizontal lines on the plot border the ranges common to oligotrophic, mesotrophic and eutrophic lakes. Chlorophyll $a$ concentrations are reported as parts per billion (ppb) of chlorophyll $a$.

Figure 56. Pemaquid Pond, 1996. Seasonal dissolved color trends of lay monitor Site 1 Basin. The dotted horizontal line represents the dissolved color average for participating Pemaquid Watershed lakes. Dissolved color is expressed as chloroplatinate color units (ptu).
Figure 57. Comparison of the 1996 Pemaquid Pond lay monitor Secchi Disk transparency data with previous yearly data. The patterns of the bars display the minimum, average and maximum values for the respective years sampled while the length of the bars represents the total range of values. The shaded regions on the graph denote the Maine DEP Secchi Disk standards for low, moderate and high water clarities. The higher the Secchi Disk value the clearer the water. Secchi Disk readings are measured to the nearest tenth (0.1) of a meter.

Figure 58. Comparison of the 1996 Pemaquid Pond lay monitor chlorophyll a data with previous yearly data. The patterns of the bars display the minimum, average and maximum values for the respective years sampled while the length of the bars represents the total range of values. The shaded regions on the graph denote the Maine DEP chlorophyll a standards for low, moderate and high chlorophyll a concentrations. The higher the chlorophyll a value, the greener the water (more algal growth).
PEMAQUID POND - SITE 1 DEEP
LAY MONITOR SECCHI DISK DATA

The higher value = clearer water

PEMAQUID POND - SITE 1 DEEP
LAY MONITOR CHLOROPHYLL a DATA

The higher value = more algal growth
Figure 59. Comparison of the historical Pemaquid Pond, Site 1 Basin and Site 2 North (2 Basin), Secchi Disk transparency data. The patterns of the bars display the minimum, average and maximum values for the respective years sampled while the length of the bars represents the total range of values. The shaded regions on the graph denote the Maine DEP Secchi Disk standards for low, moderate and high water clarities. The higher the Secchi Disk value the clearer the water. Secchi Disk readings are measured to the nearest tenth (0.1) of a meter.
PEMAQUID POND - SITE INTERCOMPARISON: SITES 1 BASIN AND SITE 2 (NORTH) LAY MONITOR SECCHI DISK DATA YEARLY COMPARISONS (1984-1992)

The higher value = clearer water
COMMENTS AND RECOMMENDATIONS

1) We recommend that each participating association, including the Pemaquid Watershed Association, continue to develop its database on lake water quality through continuation of the long-term monitoring program. The data base currently provides information on the short and long-term cyclic variability that occurs in Biscay Pond, Boyd Pond, Duckpuddle Pond, McCurdy Pond, Paradise Pond and Pemaquid Pond and through continued monitoring will enable more reliable predictions of water quality trends.

2) We recommend continued in-lake total phosphorus sampling during the 1996 sampling season. Total phosphorus samples should be obtained from Duckpuddle Pond on a bi-weekly basis. These should include integrated samples (collected with the weighted garden hose) supplemented by point “grab” samples collected 1 meter off the lakebottom whenever the pond is thermally stratified. You should continue taking replicate samples at least monthly. This type of sampling will help eliminate “random” inaccuracies which can occur when only single samples are analyzed. Note: this recommendation was proposed by Roy Bouchard of the Maine DEP.

Total Phosphorus sampling on Biscay Pond, Boyd Pond, McCurdy Pond, Paradise Pond and Pemaquid Pond is also recommended on a monthly basis. Phosphorus sampling should include integrated samples as well as supplemental “grab” samples during periods of thermal stratification. The “grab” samples would be most useful if dissolved oxygen samples were collected concurrently (See # 4 below).

3) We recommend collecting Secchi Disk measurements on intermittent weeks, when chlorophyll a samples are not taken, to document the short term fluctuations which occur in the Pemaquid Ponds. If new monitors are interested, we can set up a training session to familiarize the participants with the methodologies employed by the NH LLMP.

4) We recommend collecting bi-weekly dissolved oxygen profiles in the deeper ponds (Biscay, McCurdy and Pemaquid Ponds) to monitor the rate of oxygen depletion following the onset of thermal stratification. Continued collection of dissolved oxygen profiles in Duckpuddle Pond is also recommended. The data will provide a more complete assessment of the trophic state of these ponds and will add to the baseline data that have been generated. Knowledge of the dissolved oxygen concentrations is also useful when assessing the condition of the ponds’ fisheries, as well as, to what degree internal nutrient cycling is contributing to the nutrient (phosphorus) pool.

5) We recommend continued algal (microscopic plant) sampling to detect seasonal differences in the phytoplanktonic community structure. Knowledge of the algal forms will provide additional insight into the trophic state of the Pemaquid Ponds. Since the
cost associated with this type of sampling is currently subsidized by the NH LLMP, this type of sampling is highly recommended.

6) We suggest continued collection of daily precipitation data from locations near the participating PWA ponds (additional rain gauges are available through the NH LLMP free of charge). The data generated through this endeavor will help discern the influence of precipitation levels on seasonal fluctuations in the trophic parameters (i.e. Secchi Disk, chlorophyll a, dissolved color and total phosphorus). Contact Bob Craycraft (603-862-3546) for further information.

7) We recommend reinitiating water quality monitoring in the Northerly Pemaquid Pond sampling station (Figure 7). Historical seasonal average water clarity data collected at Site 2 North were consistently lower than the seasonal average water clarities collected at the more southerly sampling site (Site 1 Basin) and warrant further investigation (Figure 59). The collection of chlorophyll a, dissolved color, Secchi Disk and total phosphorus data are recommended to help discern the cause of the water clarity variations between the sites. If necessary, further efforts can focus on more localized areas of concern if desired. Contact Bob Craycraft (603-862-3546) for further information.
Figure 60. Seasonal chlorophyll a trends in Biscay Pond, Boyd Pond, McCurdy Pond, Paradise Pond and Pemaquid Pond. The dotted horizontal lines on the plot border the ranges common to oligotrophic, mesotrophic and eutrophic lakes. Chlorophyll a concentrations are reported as parts per billion (ppb) of chlorophyll a.

Figure 61. Seasonal dissolved color trends in Biscay Pond, Boyd Pond, McCurdy Pond, Paradise Pond and Pemaquid Pond. The dotted horizontal line represents the dissolved color average for participating Pemaquid Watershed lakes. Dissolved color is expressed as chloroplatinate color units (ptu).
DISCUSSION OF LAKE AND STREAM MONITORING MEASUREMENTS

The section below details the important concepts involved for the various testing procedures used in the New Hampshire Lakes Lay Monitoring Program. Where appropriate, summary statistics of 1995 results from all participating lakes are included. Certain tests or sampling performed at the time of the optional Freshwater Biology Group field trip are indicated by an asterisk (*).

Thermal Stratification in the Deep Water Sites

Lakes in New England display distinct patterns of temperature stratification, that develop as the summer months progress, where a layer of warmer water (the epilimnion) overlies a deeper layer of cold water (hypolimnion). The layer that separates the two regions characterized by a sharp drop in temperature with depth is called the thermocline or metalimnion (figure 62). Some shallow lakes may be continually mixed by wind action and will never stratify. Other lakes may only contain a developed epilimnion and metalimnion. The deeper Pemaquid Ponds (Biscay, McCurdy and Pemaquid) became stratified into three distinct thermal layers, discussed above, while Duckpuddle and Boyd Ponds became only partially stratified, forming an epilimnetic and metalimnetic layer. No thermal stratification was documented in Paradise Pond as this pond is shallow and is continually circulated due to wind induced mixing.

Water Transparency

Secchi Disk depth is a measure of the water transparency. The deeper the depth of Secchi Disk disappearance, the more transparent the lake water; light penetrates deeper if there is little dissolved and/or particulate matter (which includes both living and non-living particles) to absorb and scatter it.

In the shallow areas of many lakes, the Secchi Disk will hit bottom before it is able to disappear from view (what is referred to as a "Bottom Out" condition). Thus, Secchi Disk measurements are generally taken over the deepest sites of a lake. Based on the water quality criteria employed by the
Maine DEP, transparency values greater than 7 meters are generally considered an indication of clear, unproductive lakes, while values of 4 meters or less are generally an indication of productive lakes. Water clarity values between 4 and 7 meters are considered typical of a moderately productive lake. In 1996, the average transparency for lakes participating in the NH LLMP was 5.4 meters with a range of 1.5 to 14.6 meters.

The 1996 seasonal average Secchi Disk transparencies collected at Biscay Pond, Boyd Pond, McCurdy Pond and Pemaquid Pond remained within the range common to a moderately productive, mesotrophic, lake. The seasonal average water clarity of Duckpuddle Pond, on the other hand, was typical of an “enriched” eutrophic lake. Refer to Table 14 for the 1996 Pemaquid Ponds summary Secchi Disk data (note: data from Paradise Pond are not characterized trophically due to the shallowness of the pond).

<table>
<thead>
<tr>
<th>Site</th>
<th>Transparency (m)</th>
<th>Transparency (m)</th>
<th>Transparency (m)</th>
<th>Trophic State</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biscay</td>
<td>4.0</td>
<td>4.8</td>
<td>6.3</td>
<td>Moderate</td>
</tr>
<tr>
<td>Boyd</td>
<td>3.4</td>
<td>3.8</td>
<td>4.7</td>
<td>Moderate</td>
</tr>
<tr>
<td>Duckpuddle</td>
<td>1.6</td>
<td>2.6</td>
<td>3.8</td>
<td>Poor</td>
</tr>
<tr>
<td>McCurdy</td>
<td>5.4</td>
<td>6.4</td>
<td>7.8</td>
<td>Moderate</td>
</tr>
<tr>
<td>Paradise</td>
<td>3.5</td>
<td>3.7</td>
<td>3.8</td>
<td>XXXXXX</td>
</tr>
<tr>
<td>Pemaquid</td>
<td>4.4</td>
<td>4.6</td>
<td>4.8</td>
<td>Moderate</td>
</tr>
</tbody>
</table>

Table 14. 1996 Lay Monitor Secchi Disk Data comparison of the Pemaquid Ponds.

Chlorophyll α

The chlorophyll α concentration is a measurement of the standing crop of phytoplankton and is often used to classify lakes into categories of productivity called trophic states. The following classification scheme is based on the standard employed by the Maine DEP. Eutrophic lakes are highly productive with large concentrations of algae and aquatic plants due to nutrient enrichment. Characteristics include accumulated organic matter in the lake basin and lower dissolved oxygen in the bottom waters. Summer chlorophyll α concentrations average above 7 mg m⁻³ (7 milligrams per cubic meter; 7 parts per billion). Oligotrophic lakes have low productivity and low nutrient levels and average summer chlorophyll α concentrations are generally less than 2 mg m⁻³. These lakes generally have cleaner bottoms and high dissolved oxygen levels throughout. Mesotrophic lakes are intermediate in productivity with concentrations of chlorophyll α generally between 2 mg m⁻³ and 7 mg m⁻³ (note: reports written between 1988 and 1992 employed a classification scheme devised by Forsberg and Rydig (1980) while the 1993 through 1995 reports employ a classification scheme devised by the Maine DEP). In 1996, the average chlorophyll α concentration for lakes participating in the NH LLMP was 3.1 mg m⁻³ with a range of 0.4 to 22.4 mg m⁻³.

The 1996 seasonal average chlorophyll α data collected at Biscay Pond, Boyd Pond, McCurdy Pond, Paradise Pond and Pemaquid Pond remain within the range characteristic of a moderately productive, mesotrophic, lake while the Duckpuddle Pond seasonal average chlorophyll α concentration falls within the range characteristic of a borderline “transitional” mesotrophic “enriched” eutrophic lake. Refer to Table 15 for a summary of the 1996 Pemaquid Ponds chlorophyll α data.
Table 15. 1996 Lay Monitor Chlorophyll a Data comparison of the Pemaquid Ponds.

<table>
<thead>
<tr>
<th>Site</th>
<th>Chl a (ppb) Minimum</th>
<th>Chl a (ppb) Average</th>
<th>Chl a (ppb) Maximum</th>
<th>Trophic State</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biscay</td>
<td>2.9</td>
<td>4.3</td>
<td>7.1</td>
<td>Moderate</td>
</tr>
<tr>
<td>Boyd</td>
<td>1.9</td>
<td>5.1</td>
<td>8.7</td>
<td>Moderate</td>
</tr>
<tr>
<td>Duckpudle</td>
<td>4.4</td>
<td>6.8</td>
<td>16.2</td>
<td>Poor</td>
</tr>
<tr>
<td>McCurdy</td>
<td>1.1</td>
<td>2.9</td>
<td>3.1</td>
<td>Moderate</td>
</tr>
<tr>
<td>Paradise</td>
<td>2.7</td>
<td>3.6</td>
<td>4.7</td>
<td>Moderate</td>
</tr>
<tr>
<td>Pemaquid</td>
<td>1.9</td>
<td>3.2</td>
<td>5.4</td>
<td>Moderate</td>
</tr>
</tbody>
</table>

Testing is sometimes done to check for metalimnetic algal populations, algae that layer out at the thermocline and generally go undetected if only epilimnetic (point or integrated) sampling is undertaken. Chlorophyll concentrations of a water sample collected in the thermocline is compared to the integrated epilimnetic sample. Greater chlorophyll levels of the point sample, in conjunction with microscopic examination of the samples (see Phytoplankton section below), confirm the presence of such a population of algae. These populations should be monitored as they may be an indication of increased nutrient loading into the lake.

**Turbidity**

Turbidity is a measure of suspended material in the water column such as sediments and planktonic organisms. The greater the turbidity of a given water body the lower the Secchi Disk transparency and the greater the amount of particulate matter present. Turbidity is measured as nephelometric turbidity units (NTU), a standardized method among researchers. Turbidity levels are generally low in New Hampshire reflecting the pristine condition of the majority of our lakes and ponds. Increasing turbidity values can be an indication of increasing lake productivity or can reflect improper land use practices within the watershed which destabilize the surrounding landscape and allow sediment flushing into the lake.

While Secchi Disk measurements will integrate the clarity of the water column from the surface waters down to the depth of disappearance, turbidity measurements are collected at discrete depths from the surface down to the lakebottom. Such discrete sampling can identify layering algal populations (previously discussed) that are undetectable when measuring Secchi Disk transparency alone.

**Dissolved Color**

The dissolved color of lakes is generally due to dissolved organic matter from humic substances, which are naturally-occurring polyphenolic compounds leached from decayed vegetation. Highly colored or "stained" lakes have a "tea" color. Such substances generally do not threaten water quality except as they diminish sunlight penetration into deep waters. Increases in dissolved watercolor can be an indication of increased development within the watershed as many land clearing activities (construction, deforestation, and the resulting increased run-off) add additional organic material to lakes. Natural fluctuations of dissolved color occur when storm events increase drainage from wetlands areas within the watershed. As suspended sediment is a difficult and expensive test to undertake, both dissolved color and chlorophyll information is important when interpreting the Secchi Disk transparency.

Dissolved color is measured on a comparative scale that uses standard chloroplatinacite dyes and is designated as a color unit or ptu. Lakes with color
below 10 ptu are very clear, 10 to 20 ptu are slightly colored, 20 to 40 ptu are lightly tea colored, 40 to 80 ptu are tea colored and greater than 80 ptu indicates highly colored waters. Generally the majority of New Hampshire lakes have color between 20 to 30 ptu. In 1995 the average dissolved color for participating NH LLMP lakes was 27.1 ptu with a range of 3.4 to 111.7 ptu. Refer to Table 16 for the 1996 Pemaquid Ponds dissolved color summary statistics.

Table 16. 1996 Lay Monitor Dissolved Color Data comparison of the Pemaquid Ponds.

<table>
<thead>
<tr>
<th>Site</th>
<th>Color (ptu) Minimum</th>
<th>Color (ptu) Average</th>
<th>Color (ptu) Maximum</th>
<th>Color (ptu)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biscay</td>
<td>35.2</td>
<td>43.2</td>
<td>56.7</td>
<td>Moderate</td>
</tr>
<tr>
<td>Boyd</td>
<td>43.3</td>
<td>55.4</td>
<td>71.3</td>
<td>Moderate</td>
</tr>
<tr>
<td>Duckpudle</td>
<td>86.8</td>
<td>96.7</td>
<td>111.7</td>
<td>High</td>
</tr>
<tr>
<td>McCurdy</td>
<td>17.2</td>
<td>23.2</td>
<td>26.6</td>
<td>Low</td>
</tr>
<tr>
<td>Paradise</td>
<td>52.4</td>
<td>64.6</td>
<td>79.9</td>
<td>Moderate</td>
</tr>
<tr>
<td>Pemaquid</td>
<td>31.8</td>
<td>40.1</td>
<td>47.2</td>
<td>Moderate</td>
</tr>
</tbody>
</table>

Generally, in the more pristine lakes, phosphorus values are higher after spring melt when the lake receives the majority of runoff from its surrounding watershed. The nutrient is used by the algae and plants which in turn die and sink to the lake bottom causing surface water phosphorus concentrations to decrease as the summer progresses. Lakes with nutrient loading from human activities and sources (Agriculture, Logging, Sediment Erosion, Septic Systems, etc.) will show greater concentrations of nutrients as the summer progresses or after major storm events.

The Maine DEP classifies lakes containing 6 ppb total phosphorus or less as unproductive while those containing total phosphorus concentrations of 13 ppb and greater fall into the classification of a productive lake. Lakes with total phosphorus concentrations between 6 ppb and 13 ppb are considered moderately productive.

1996 total phosphorus data collected in Biscay Pond, McCurdy Pond and Pemaquid Pond remained within the range characteristic of a moderately productive, mesotrophic, lake while data collected in Boyd pond were characteristic of a borderline mesotrophic/eutrophic lake. The 1996 total phosphorus data collected in Duckpudle and Paradise Ponds were characteristic of an “enriched” eutrophic lake. Table 17 characterizes the trophic state of the Pemaquid Ponds based on the 1996 in-lake total phosphorus data and the corresponding Maine DEP criteria (note: the total phosphorus data summarized in Table 17 are the averages of replicate phosphorus samples).
Table 17. 1996 Epilimnetic Total Phosphorus Results and the Corresponding Maine DEP Trophic Classification.

<table>
<thead>
<tr>
<th>Lake</th>
<th>Date</th>
<th>Total Phos. (ppb)</th>
<th>Maine Water Quality Category</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biscay</td>
<td>05/19</td>
<td>7.3</td>
<td>Moderate</td>
</tr>
<tr>
<td></td>
<td>08/21</td>
<td>8.2</td>
<td>Moderate</td>
</tr>
<tr>
<td>Boyd</td>
<td>05/05</td>
<td>13.2</td>
<td>High</td>
</tr>
<tr>
<td></td>
<td>05/31</td>
<td>11.8</td>
<td>Moderate</td>
</tr>
<tr>
<td></td>
<td>10/06</td>
<td>13.8</td>
<td>High</td>
</tr>
<tr>
<td>Duckpuddle</td>
<td>05/05</td>
<td>16.0</td>
<td>High</td>
</tr>
<tr>
<td></td>
<td>05/19</td>
<td>19.5</td>
<td>High</td>
</tr>
<tr>
<td></td>
<td>06/08</td>
<td>17.2</td>
<td>High</td>
</tr>
<tr>
<td></td>
<td>06/22</td>
<td>15.7</td>
<td>High</td>
</tr>
<tr>
<td></td>
<td>07/07</td>
<td>17.7</td>
<td>High</td>
</tr>
<tr>
<td></td>
<td>07/21</td>
<td>17.3</td>
<td>High</td>
</tr>
<tr>
<td></td>
<td>08/04</td>
<td>26.4</td>
<td>High</td>
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<tr>
<td></td>
<td>08/18</td>
<td>17.8</td>
<td>High</td>
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<td></td>
<td>09/01</td>
<td>26.6</td>
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<td></td>
<td>09/22</td>
<td>20.7</td>
<td>High</td>
</tr>
<tr>
<td></td>
<td>10/14</td>
<td>27.9</td>
<td>High</td>
</tr>
<tr>
<td>McCurdy</td>
<td>05/04</td>
<td>11.1</td>
<td>Moderate</td>
</tr>
<tr>
<td></td>
<td>10/06</td>
<td>11.5</td>
<td>Moderate</td>
</tr>
<tr>
<td>Paradise</td>
<td>05/12</td>
<td>17.7</td>
<td>High</td>
</tr>
<tr>
<td></td>
<td>06/24</td>
<td>18.2</td>
<td>High</td>
</tr>
<tr>
<td>Pemaquid</td>
<td>06/17</td>
<td>12.3</td>
<td>Moderate</td>
</tr>
<tr>
<td></td>
<td>06/30</td>
<td>8.5</td>
<td>Moderate</td>
</tr>
<tr>
<td></td>
<td>07/16</td>
<td>7.5</td>
<td>Moderate</td>
</tr>
<tr>
<td></td>
<td>08/05</td>
<td>7.3</td>
<td>Moderate</td>
</tr>
</tbody>
</table>

pH *

The pH is a way of expressing the acidic level of lake water, and is generally measured with an electrical probe sensitive to hydrogen ion activity. The pH scale has a range of 1 (very acidic) to 14 (very "basic" or alkaline) and is logarithmic (i.e.: changes in 1 pH unit reflect a ten times difference in hydrogen ion concentration). Most aquatic organisms tolerate a limited range of pH and most fish species require a pH of 5.5 or higher for successful growth and reproduction.

Alkalinity

Alkalinity is a measure of the buffering capacity of the lake water. The higher the value the more acid that can be neutralized. Typically lakes in New Hampshire have low alkalinitities due to the absence of carbonates and other natural buffering minerals in the bedrock and soils of lake watersheds.

Decreasing alkalinity over a period of a few years can have serious effects on the lake ecosystem. In a study on an experimental acidified lake in Canada by Schindler, gradual lowering of the pH from 6.8 to 5.0 in an 8-year period resulted in the disappearance of some aquatic species, an increase in nuisance species of algae and a decline in the condition and reproduction rate of fish. During the first year of Schindler's study the pH remained unchanged while the alkalinity declined to 20 percent of the pre-treatment value. The decline in alkalinity was sufficient to trigger the disappearance of zooplankton species, which in turn caused a decline in the "condition" of fish species that fed on the zooplankton.

The analysis of alkalinity employed by the Freshwater Biology
Group includes use of a dilute titrant allowing an order of magnitude greater sensitivity and precision than the standard method. Two endpoints are recorded during each analysis. The first endpoint (gray color of dye; pH endpoint of 5.1) approximates low level alkalinity values, while the second endpoint (pink dye color; pH endpoint of 4.6) approximates the alkalinity values recorded historically, such as NH Fish and Game data, with the methyl-orange endpoint method.

The average alkalinity of lakes throughout New Hampshire is low, approximately 6.5 mg per liter (calcium carbonate alkalinity). When alkalinity falls below 2 mg per liter the pH of waters can greatly fluctuate. Alkalinity levels are most critical in the spring when acid loadings from snowmelt and run-off are high, and many aquatic species are in their early, and most susceptible, stages of their life cycle.

The classification scheme employed by the Maine DEP considers alkalinity concentrations of less than 4 ppm as low (more susceptible to acidification) while lakes with alkalinities greater than 10 ppm are considered highly alkaline (more resistant to acidification).

Specific Conductivity *

The specific conductance of a water sample indicates concentrations of dissolved salts. Leaking septic systems and deicing salt runoff from highways can cause high conductivity values. Fertilizers and other pollutants can also increase the conductivity of the water. Conductivity is measured in micromhos (the opposite of the measurement of resistance ohms) per centimeter, more commonly referred to as micro-Siemans (μS).

Dissolved Oxygen and Free Carbon Dioxide *

Oxygen is an essential component for the survival of aquatic life. Submerged plants and algae take in carbon dioxide and create oxygen through photosynthesis by day. Respiration by both animals and plants uses up oxygen continually and creates carbon dioxide. Dissolved oxygen profiles determine the extent of declining oxygen concentrations in the lower waters. High carbon dioxide values are indicative of low oxygen conditions and accumulating organic matter. For both gases, as the temperature of the water decreases, more gas can be dissolved in the water.

The typical pattern of clear, unproductive lakes is a slight decline in hypolimnetic oxygen as the summer progresses. Oxygen in the lower waters is important for maintaining a fit, reproducing, cold water fishery. Trout and salmon generally require oxygen concentrations above 5 mg per liter (parts per million) in the cool deep waters. On the other hand, carp and catfish can survive very low oxygen conditions. Oxygen above the lake bottom is important in limiting the release of nutrients from the sediments and minimizing the collection of undecomposed organic matter.

Bacteria, fungi and other decomposers in the bottom waters break down organic matter originating from the watershed or generated by the lake. This process uses up oxygen and produces carbon dioxide. In lakes where organic matter accumulation is high, oxygen depletion can occur. In highly stratified eutrophic lakes the entire hypolimnion can remain unoxygenated or anaerobic until fall mixing occurs.
The oxygen peaks occurring at surface and mid-lake depths during the day are quite common in many lakes. These characteristic heterograde oxygen curves are the result of the large amounts of oxygen, the by-product of photosynthesis, collecting in regions of high algal concentrations. If the peak occurs in the thermocline of the lake, metalimnitic algal populations (discussed above) may be present.

**Underwater Light**

Underwater light available to photosynthetic organisms is measured with an underwater photometer which is much like the light meter of a camera (only waterproofed!). The photic zone of a lake is the volume of water capable of supporting photosynthesis. It is generally considered to be delineated by the water’s surface and the depth that light is reduced to one percent surface iridescence by the absorption and scattering properties of the lake water. The one percent depth is sometimes termed the compensation depth. Knowledge of light penetration is important when considering lake productivity and in studies of submerged vegetation. Discontinuity (abrupt changes in the slope) of the profiles could be due to metalimnetic layering of algae or other particulates (discussed above). The underwater photometer allows the investigator to measure light at depths below the Secchi Disk depth to supplement the water clarity information.

**Indicator Bacteria**

Certain disease causing organisms, pathogenic bacteria, viruses and parasites, can be spread through contact with polluted waters. Faulty septic systems, sewer leaks, combined sewer overflows and the illegal dumping of wastes from boats can contribute fecal material containing these pathogens. Typical water testing for pathogens involves the use of detecting coliform bacteria. These bacteria are not usually considered harmful themselves but they are relatively easy to detect and can be screened for quickly. Thus, they make good surrogates for the more difficult to detect pathogens.

*Total coliform* includes all coliform bacteria which arise from the gut of animals or from vegetative materials. *Fecal coliform* are those specific organisms that inhabit the gut of warm blooded animals. Another indicator organism *Fecal streptococcus* (sometimes referred to as *enterococcus*) also can be monitored. The ratio of fecal coliform to fecal strep may be useful in suggesting the type of animal source responsible for the contamination. In 1991, the State of New Hampshire changed the indicator organism of preference to E. Coli which is a specific type of fecal coliform bacteria thought to be a better indicator of human contamination. The new state standard requires Class A “bathing waters” to be under 88 organisms (referred to as colony forming units; cfu) per 100 milliliters of lakewater.

Ducks and geese are often a common cause of high concentrations of coliform at specific lake sites. While waterfowl are important components to the natural and aesthetic qualities of lakes that we all enjoy, it is poor management practice to encourage these birds by feeding them. The lake and surrounding area provides enough healthy and natural food for the birds and feeding them stale bread or crackers does nothing more than import additional nutrients into the lake and allows for increased plant growth. As birds also are a host to
the parasite that causes "swimmers itch", waterfowl roosting areas offer a greater chance for infestation to occur. Thus while leaving offerings for our feathered friends is enticing, the results can prove to be detrimental to the lake system and to human health.

**Phytoplankton**

The planktonic community includes microbial organisms that represent diverse life forms, containing photosynthetic as well as non-photosynthetic types, and including bacteria, algae, crustaceans and insect larvae (the insect larvae and zooplankton are discussed below in separate sections). Because planktonic algae or "phytoplankton" tend to undergo rapid seasonal cycles on a time scale of days and weeks, the levels of populations found should be considered to be most representative of the time of collection and not necessarily of other times during the ice-free season, especially the early spring and late fall periods.

The composition and concentration of phytoplankton can be indicative of the trophic status of a lake. Seasonal patterns do occur and must be considered. For example diatoms, tend to be most abundant in April-June and October-November, in the surface or epilimnetic layers of New Hampshire lakes. As the summer progresses, the dominant types might shift to green algae or golden algae. By late season Blue-green bacteria generally dominate. In nutrient rich lakes, nuisance green algae and/or bluegreen bacteria might dominate continually. After fall mixing diatoms might again be found to bloom.

**Zooplankton**

There are three groups of zooplankton that are generally prevalent in lakes: the protozoa, rotifers and crustaceans. Most research has been devoted to the last two groups although protozoa may be found in substantial amounts. Of the rotifers and the crustaceans, time and budgetary constraints usually make it necessary to sample only the larger zooplankton (macrozooplankton; larger than 80 or 150 microns; 1 million microns make up a meter). Thus, zooplankton analysis is generally restricted only to the larger crustaceans. Crustacean zooplankton are very sensitive to pollutants and are commonly used to indicate the presence of toxic substances in water. The crustaceans can be divided into two groups, the cladocerans (which include the "water fleas") and the copepods.

Macrozooplankton are an important component in the lake system. The filter feeding of the herbivorous ("grazing") species may control the population size of selected species of phytoplankton. The larger zooplankton can be an important food source for juvenile and adult planktivorous fish. All zooplankton play a part in the recycling of nutrients within the lake.

As discussed above for phytoplankton, zooplankton undergo seasonal population cycles and their results discussed below are most representative of the collection dates and not necessarily of other times during the ice-free season, especially during the early spring and late fall.

**Macroinvertebrates**

Macroinvertebrates generally refer to the aquatic insect community living near the bottom substrate (i.e. sediments) while other invertebrate groups such as the crayfish, leeches and the aquatic worms are also included. Like the phytoplankton and
zooplankton, previously discussed, the macroinvertebrates undergo seasonal cycles and are most representative of conditions for particular periods of the year. The mayflies are probably the most well known example of a seasonal aquatic macroinvertebrate as mayfly populations metamorphosize into adults as the water temperatures increase in the spring and thus giving rise to the name “mayflies”. Macroinvertebrates are also sensitive to environmental conditions such as streamflow, temperature and food availability and are most representative of particular habitats along the stream continuum (i.e. some organisms prefer slower moving stream reaches while others prefer rapidly flowing waters).

Macroinvertebrates are an essential component to a healthy aquatic habitat. Macroinvertebrates help decompose organic matter entering the system such as leaves and twigs and also serve as a food source for many fish species.

While some macroinvertebrates are capable of breathing air as we do, others have gills and utilize oxygen dissolved in the water much as fish do. Macroinvertebrates also vary in their tolerance to depleting dissolved oxygen concentrations making them a good indicator of pollutants coming into the water body. The caddisflies (Trichoptera), the mayflies (Ephemeroptera) and the stoneflies (Plecoptera) are often considered highly sensitive to pollution while the “true” flies (Diptera) are often considered highly tolerant to pollution. However, exceptions to the above categorizations are often encountered.

A variety of indices have been proposed to characterize water bodies over a gradient of pollution levels ranging from least polluted to most polluted scenarios and often designated by assigning a numerical delineator (i.e. 1 is least polluted while 10 is most polluted). Such an index, the Hilsenhoff Biotic Index (HBI), or a modification thereof, is commonly used by stream monitoring programs around the country. Macroinvertebrate data are useful in discerning the more impacted areas within the watershed where corrective efforts should be directed. Unlike chemical measurements that represent ambient conditions in the water body, the macroinvertebrate community composition integrates the water quality conditions over a longer period (months to years) and can identify “hot” spots missed by chemical sampling. If you are interested in more information regarding macroinvertebrate monitoring contact the LLMP coordinator.

**Fish Condition**

The assessment of fish species “health” is another biological indicator of water quality. Because fish are at the top of the food chain, their condition should reflect not only water quality changes that affect them directly but also those changes that affect their food supply. The fish condition index utilized by the New Hampshire Fish Condition Program is based on two components; fish scale analysis and a fish condition index.

Like tree trunks, fish scales have annual growth rings (annuli) that reflect their growth history and hence, provide a long-term record of past conditions in the lake. The fish condition index, based upon length and weight measurements, is a good indicator of the fish’s health at the time of collection.

The resulting fish condition data can be compared among different lakes or among different years, or the index for a particular species can be compared
to standard length-to-weight relationships that have been developed by fisheries biologists for many important fish species. In the end, the “health” of the various fish species reflects the overall water quality in the respective lake or pond.

Zebra Mussels

Zebra mussels (*Dreissena polymorpha*) are non-native, freshwater mollusks. The veligers (larval form) are free swimming, nearly invisible, and profuse. Adult zebra mussel shells are elongate (D-shaped), about the size of a thumbnail and are usually striped. Zebra Mussels are the only freshwater mussel that can attach to objects using sticky threads (byssal threads like those found on the marine blue mussels). These threads allow them to colonize quickly and reach densities of 100,000 or more mussels per square yard. The mussels have an average lifespan of 3.5 to 5 years. A gritty feeling on your boat’s hull or other immersed surfaces might indicate that larval zebra mussels have settled.

Zebra mussels originated in the drainage basins of the Black, Caspian, and Aral seas of eastern Europe and have been in western Europe freshwaters since the 1700s. Since first being introduced to North America in 1986, zebra mussels have dramatically altered the balance of freshwater systems and fisheries. These small water dwelling animals have also caused millions of dollars in expenses for industrial water users, drinking water facilities, commercial and recreational boaters, farmers, and other groups and organizations in Canada and the Great Lakes region.

The range occupied by these unwelcome visitors has expanded and continues to grow rapidly. In North America, sightings have been recorded as far north as the Saint Lawrence River near Quebec, as far east as the lower portion of the Hudson River, as far south as the Mississippi River near Vicksburg, and as far west as the Arkansas River in Oklahoma.

In 1993, zebra mussel sightings were confirmed in New England (Lake Champlain). The Lake Champlain population has existed for at least three years, if not longer. Thus, New Hampshire residents and boaters are being encouraged to arm themselves with knowledge about the natural history and geographic spread of the mussels. Interstate boaters and anglers, in particular, should become familiar with boating and fishing practices that decrease the likelihood that zebra mussels will be transferred from an infested water body to an uninfested one.

The infestation risk factor for any particular water body is determined mainly by the amount and type of boat traffic it supports and the chemical characteristics and temperature it maintains. While the goal is to prevent the mussels from becoming established in New England waters, zebra mussels have proven to be adaptable creatures able to survive in a growing range of environmental conditions. Cooperative monitoring activities coordinated by the New Hampshire Lakes Lay Monitoring Program will help determine if and when zebra mussels become established in this region. If zebra mussels are found, information about control techniques can help those concerned choose the best method to reduce the destructive impacts of the mussels.

Take responsibilities for our waters. If you’ve been boating in fresh water outside of New England within the past 10 days and plan to launch locally, please...
Inspect your boat and trailer for weeds. Remove and discard any you find. Zebra mussels are commonly found on aquatic plants in areas of infestation. Flush the cooling system, bilge areas and live wells with tap water.

Leave unused bait behind and discard bait bucket water away from surface waters.

Keep your boat out of water to dry for 48 hours. If it is visibly fouled by algae, leave it out until the exterior is completely dry or...

Wash down the hull at a car wash. Hot (140 degree F) water kills zebra mussels and veligers and high pressure spray helps remove them. Wash fouling off your boat away from water sources!

Learn more about the zebra mussel threat in order to be forewarned of the situation and prevent costly repairs or destructive responses.

Share information, ideas and monitoring tasks with other members of your lake association, watershed council, marina club, conservation commission, angling group or civic organization.

Report any sightings to the New Hampshire Lakes Lay Monitoring Program. Preserve specimens in alcohol if possible, note the location where they were found, and send them in to confirm the identification.

To receive more information, request an educational presentation for your next group meeting, become involved in monitoring efforts, or confirm an identification, contact:

Jeff Schloss
Lakes Lay Monitoring Program
109 Pettee Hall
University of New Hampshire
Durham NH 03824-3512
(603) 862-3848

or

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Rainfall... People... and Lake Water Quality

By:  Alan L. Baker
Professor of Aquatic Ecology
University of New Hampshire

Reprinted from the Summer 1995 issue of Lakeside
A Publication of the New Hampshire Lakes Association

High quality lakes will always remain an invaluable attraction to people, thus an important element of New Hampshire’s economy. Questions about changes in water quality and clarity are often asked. Now data which have been gathered by University of New Hampshire researchers, in cooperation with many volunteer monitors, are beginning to provide some answers to questions such as: Have our lakes degraded in this century? Is water quality currently deteriorating? What is causing changes to occur? Now we can begin to answer these questions.

Dynamic Lakes

In order to understand the answers, one must have some awareness of Limnology - the study of the geologic, physical, chemical and biological dynamics of lakes. It is important to be alert to the changing nature of lakes, their sensitivity to disturbances, and their likelihood to degrade or improve in quality in response to poor or good protection strategies.

It is possible to identify many characteristics that determine the uniqueness of each lake and help to distinguish a blue jewel from a septic waste depot. Volunteer monitors from the N.H. Lay Lake Monitoring Program (LLMP) have amassed data from more than 100 New Hampshire lake sites over the past decade. The objective of this effort, established in 1978, was to develop information to scientifically document long-term trends in water quality.

It is now possible to understand the kinds of disturbances that modify the characteristics of a lake for better or worse. This cooperative effort between lakeshore property owners and UNH researchers has established how lake water quality changes over the decades. Based upon accumulated data it is possible to use a model to predict these events.

The Overview

Although each New Hampshire lake is unique, and there is a diversity of lake types in the state, the LLMP data reveal a remarkably common pattern in the "behavior" of most lakes. Researches anticipated that multiple sites within any given lake would have the same characteristics. There is also strong evidence that large and small lakes follow a similar pattern of changes, within the ice-free period of a single year as well as
through nearly two decades of observations. This is quite a surprise! \textit{How can unique lakes in unique watersheds "behave" in such a similar manner?}

The "long-term" changes in water quality characteristics are not always monotonously negative, but appear to fluctuate corresponding to 11-year cycles of solar flares or sunspots. What is the role of human behavior? There is no cyclic pattern to human activity on lakes.

Why, for example, did Squam Lake become greener from 1979 through 1984, then suddenly clarify in 1985? Why did the clarity of nearly all lakes in the LLMP program improve in 1985? Why did the chlorophyll (the major pigment in microscopic plants) decrease significantly in the same year? Furthermore, why was total phosphorus in the water very low in 1985? Why was there a relatively high Acid Neutralizing Capacity in that year? (ANC is the capacity of a lake to absorb or buffer higher levels of acidity in the water). Finally, why have all these water quality parameters changed together in the reverse direction from 1986 to 1993?

A few lakes have "misbehaved" and followed opposite trends during the same period, but this can be attributed to their unique characteristics, and to site-specific circumstances.

\textbf{The Hunch}

New Hampshire is a relatively small state. Despite other diversities, our lakes are all subjected to the climate we enjoy at 43° to 44° North latitude. The whimsical nature of New England weather, difficult to predict, variable from season to season and year to year, is well known. \textit{Could it be that our lakes are responding to climatic variation and global warming? What was unique about 1985?}

A reasonable hunch was that changes in total rainfall could be the "pied piper" playing the tune to which the lakes have danced. A comparison of rainfall data from 30 National Oceanographic and Atmospheric Administration weather stations confirmed that the state is basically a single climate region. While rainfall is much higher in some areas than others, the pattern is similar no matter where one looks. A dry year is a dry year and a wet year is a wet year, statewide. The record rainfall between July 1984 and June 1985 occurred during a period of sub-normal rainfall relative to 30-year averages.

So! We have a clue.

\textbf{The Model}

The majority of New Hampshire's lakes are what is known as "nutrient limited." This means that certain nutrients, especially phosphorus and nitrogen, when present in lake water stimulate high levels of growth in microscopic aquatic plants such as algae and phytoplankton. Humans, along with other creatures, process these nutrients quickly and deposit them in lakes or in water flowing down a watershed.

In addition, most watersheds in New Hampshire are small and have steep topography. The streams within these watersheds are typically short and fast-flowing, delivering rainwater to lakes very quickly. Thus, episodes of high rainfall deliver more nutrients by washing them into lakes from watersheds. Prolonged periods (up to one year) of high rainfall lead to more nutrient loading and higher total phosphorus levels, therefore greener and less transparent lakes. In addition, sulfur dioxide in rainwater—the ingredient that causes acid rain -- and solutes (dissolved acids) collected within the
watershed, lowers the ANC of our lakes, i.e., the capacity of lakes to buffer the effects of acidity is diminished.

At its present state of development, the LLMP model suggests that the total volume of rainfall is the cause of both seasonal and long-term annual changes in lake water quality throughout New Hampshire. Most lakes "improved" in dry years such as 1985 and "degrade" in wetter years such as 1984 and 1986. The model works to the extent that the loading of nutrients into nutrient-deprived lakes is dependent on rainfall, and this appears to be the case.

Further verification of the model comes from the few more productive lakes, i.e., those higher in naturally occurring levels of nutrients. The "richer" in nutrients a lake, the "greener" it tends to be. Such "rich" lakes tend to be "diluted" by the loading of stormwater running off the watershed. This again directly implicates rainwater as the "piedpiper" which causes such lakes to be somewhat less productive, therefore "improved," during wet years.

Implications

At least two important predications can be developed when interpreting the LLMP model. First, changes in rainfall volume associated with global warming will influence lake water quality directly. If New Hampshire becomes drier, the lakes will tend to remain transparent and on that basis, will likely "improve" in water quality. Otherwise, a wetter future will likely deplete water quality to some extent.

Second, the model provides substantial evidence that our lakes are sensitive to changes in nutrient loading. Such loading can be controlled to a large extent by the choices people make with regard to activities within a watershed area. Such activities include land use and development patterns and practices within the watershed area, as well as along the shoreland areas of lakes and streams. Human activity on the water can also have some impact on nutrient loading of lakes (see Spring 1995 Lakeside).

Efforts to minimize nutrient loading can make a difference. Such practices as:

- routine pumping of septic systems
- erosion control
- maintaining buffer and wooded areas near lakes and within watershed
- control of storm water run-off from roof tops, impermeable driveways and parking lots

all help to minimize nutrient transport to lakes.

Future Concerns

While we can predict lake water quality parameters based upon weather patterns in a given year or over a period of years, there are a number of issues that require more comprehensive and thoughtful policy development if New Hampshire's lakes are going to remain the blue gems that we take for granted.

Here are some of the unresolved issues:

- The survival of each lake given the multiple uses which they receive now, and will receive in the next millennium.
- The study of lake capacity, or use beyond which a lake becomes undesirable.
• The possibility that lakes will lose their aesthetic and economic value if they visibly degrade over time.
• The establishment of a comprehensive statewide lake use plan to manage our lakes effectively.
The Zebra Mussel Threat to New Hampshire

The Zebra Mussel, a non-native freshwater mollusk that has successfully invaded a host of lakes and rivers throughout northeastern and central North America, continues its expansion towards New Hampshire. In the past three years, primarily due to the efforts of state agencies like New Hampshire Fish Game and New Hampshire Department of Environmental Services (DES), the New Hampshire Lakes Association as well as local lake associations, residents and visitors have started to become aware of this non-native aquatic nuisance. All of these groups have been assisted by the University of New Hampshire (UNH) SeaGrant and Water Resource Extension Programs of the Northern New England Mussel Watch.

These tenacious little shellfish have caused almost a billion dollars worth of trouble in the Great Lakes region of the US and Canada. More recently, they impacted water suppliers and a federal fish hatchery on Lake Champlain in neighboring Vermont to the tune of millions of dollars. Thus, there is great concern with this potential threat to New Hampshire’s precious fresh waters. But given the fact that many lakes and streams have very soft waters (they contain low mineral content especially that of calcium which is important for reproduction and shell construction) how concerned should we be?

Table 18 breaks down the colonization potential of Zebra Mussels according to the water conditions they encounter. As can be seen, most of our fresh waters meet their temperature, algae, salinity and oxygen requirements. Limiting colonization for a majority of our lakes is pH and calcium content. It is ironic that the conditions that

**TABLE 18: ZEBRA MUSSEL COLONIZATION POTENTIAL**
Based on environmental tolerances of known wild and lab populations in Europe and North America (modified from C. O’Neill, NY SeaGrant Zebra Mussel Clearing House 6/95)

<table>
<thead>
<tr>
<th>Variable</th>
<th>High Potential</th>
<th>Moderate Potential</th>
<th>Low Potential</th>
<th>Very Low Potential</th>
<th>NH Summer Range</th>
<th>NH Summer Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>SALINITY (ppt)</td>
<td>0 - 1</td>
<td>1 - 4</td>
<td>4 - 10</td>
<td>10 - 35</td>
<td>none</td>
<td>&lt;1 - 32</td>
</tr>
<tr>
<td>CALCIUM (mg/L)</td>
<td>&gt; 25</td>
<td>20 - 25</td>
<td>9 - 20</td>
<td>&lt; 9</td>
<td>4.4 - 9.6</td>
<td>6.0</td>
</tr>
<tr>
<td>pH (units)</td>
<td>7.4 - 8.5</td>
<td>7.0 - 7.4</td>
<td>6.5 - 7.0</td>
<td>&lt; 6.5</td>
<td>9.3 - 9.5</td>
<td>9.6</td>
</tr>
<tr>
<td>WATER TEMP. (°C)</td>
<td>18 - 25</td>
<td>16 - 18</td>
<td>9 - 15</td>
<td>&gt; 8</td>
<td>9.8 - 20</td>
<td>varies by depth</td>
</tr>
<tr>
<td>DISSOLVED OXYGEN (ppm)</td>
<td>8 - 10</td>
<td>6 - 8</td>
<td>4 - 6</td>
<td>&lt; 4</td>
<td>0 - 12</td>
<td>generally &gt; 6 in upper layer</td>
</tr>
<tr>
<td>CONDUCTIVITY (μhos at 25°C)</td>
<td>&gt; 93</td>
<td>37 - 82</td>
<td>22 - 36</td>
<td>&lt; 21</td>
<td>13 - 350</td>
<td>55</td>
</tr>
<tr>
<td>CHLOROPHYLL</td>
<td>Greater than 2 ppb</td>
<td>CHL a (algae level)</td>
<td>&gt; 0.1 - 144</td>
<td>7.2</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Summer upper water (epilimnetic) layer data from UNH Freshwater Biology Group and NH DES Limnology Center data bases 1978 to 1993; total of 597 NH lakes sampled.  
> = greater than; < = less than.
hurt us most in combating acid rain impacts may be our saving grace in preventing dense colonies of mussels. Of the two parameters, calcium is the more critical in that the pH of even the softest waters can increase to more tolerable levels due to the photosynthetic activity of submerged plants and algae (the removal of carbon dioxide from the water raises the pH in dense weed beds and in more productive lakes).

Care must be taken in concluding how safe we really are from infestation. These data are only from known zebra mussel habitats. In the lab, zebra mussels have successfully reproduced at salinities as high as 15 parts per thousand. Also, the lower limit of the calcium requirement continues to fall with time.

So which of our waters are most susceptible to Zebra Mussel colonization? Table 19 lists those waters with calcium concentrations of 9 parts per million or greater. There are two lakes that have water conditions highly conducive to colonization, three lakes with moderate potential and at least 16 lakes with low potential (an additional 8 lakes have calcium levels just under 9 parts per million). Most are located somewhere near the Connecticut River that has limestone deposits that can contribute calcium to nearby waters. The others are in the lower Merrimack River valley. There are also some close to the sea coast. UNH Sea Grant has initiated monitoring for adult mussels on the majority of these lakes through existing NH LLMP (UNH), VLAP (DES) and Cooperative Extension/SeaGrant monitoring programs.

While our current understanding of the mussels may allow for a brief sigh of relief on the part of our low calcium lakes, boaters and anglers should still continue to take the proper precautions on all waters. We are still continuing to amass all of the available information and research on these persistent little shellfish. The most frightening information indicates that these critters are becoming more at home in a wider range of water conditions; the water conditions within the mussels American range are much wider than those found in the mussels native habitat in Central Europe. Zebra Mussels have only been in our country since sometime around 1988 while they have been known to occur in large freshwater lakes such as the Black, Caspian and Aral seas for hundreds if not thousands of years. This means that the invading mussels have been adapting quickly. Remember also that our native shellfish have adapted very well to our soft waters.

Table 19. Lakes Most Susceptible to Zebra Mussel Colonization.

<table>
<thead>
<tr>
<th>Lake</th>
<th>Town</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horseshoe</td>
<td>(low risk)</td>
</tr>
<tr>
<td>Harris Pond</td>
<td>Pelham</td>
</tr>
<tr>
<td>Kimball Pond</td>
<td>Canterbury</td>
</tr>
<tr>
<td>Post Pond</td>
<td>Lyme</td>
</tr>
<tr>
<td>Sebbins Pond</td>
<td>(med. risk)</td>
</tr>
<tr>
<td>Wilder Lake</td>
<td>Lebanon</td>
</tr>
<tr>
<td>Cobbute Pond</td>
<td>Windham</td>
</tr>
<tr>
<td>Crystal Lake</td>
<td>Manchester</td>
</tr>
<tr>
<td>Ogotz Lake</td>
<td>Lyman</td>
</tr>
<tr>
<td>Moses Pond</td>
<td>Plainfield</td>
</tr>
<tr>
<td>Dorrs Pond</td>
<td>Manchester</td>
</tr>
<tr>
<td>World End Pond</td>
<td>Salem</td>
</tr>
<tr>
<td>Otternick Pond</td>
<td>Hudson</td>
</tr>
<tr>
<td>Fish Pond</td>
<td>Columbia</td>
</tr>
<tr>
<td>Flints Pond</td>
<td>Hollis</td>
</tr>
<tr>
<td>Taylor River</td>
<td>Hampton</td>
</tr>
<tr>
<td>Kendall Pond</td>
<td>Londonderry</td>
</tr>
<tr>
<td>Stevens Pond</td>
<td>Manchester</td>
</tr>
<tr>
<td>Lime Pond</td>
<td>(high risk)</td>
</tr>
<tr>
<td>Mill Pond</td>
<td>Portsmouth</td>
</tr>
</tbody>
</table>

That is the reason zebra mussel warning signs have been posted with information posters and pamphlets at public areas and boat-launch sites. These materials are in place at lakes with higher calcium levels as well as high boat traffic areas. In addition, these precautions will minimize the risk of introducing non-native weeds like mil-
foil and other new plant and animal invaders that could eventually find a way into New Hampshire.

By: Jeff Schloss
UNH Cooperative Extension
Water Resource Specialist

Reprinted from the August 1995 issue of Lakeside
A Publication of the New Hampshire Lakes Association
REFERENCES


GLOSSARY OF LIMNOLOGICAL TERMS

Aerobe.- Organisms requiring oxygen for life. All animals, most algae and some bacteria require oxygen for respiration.

Algae.- See phytoplankton.

Alkalinity.- Total concentration of bicarbonate and hydroxide ions (in most lakes).

Anaerobe.- Organisms not requiring oxygen for life. Some algae and many bacteria are able to respire or ferment without using oxygen.

Anoxic.- A system lacking oxygen, therefore incapable of supporting the most common kind of biological respiration, or of supporting oxygen-demanding chemical reactions. The deeper waters of a lake may become anoxic if there are many organisms depleting oxygen via respiration, and there is little or no replenishment of oxygen from photosynthesis or from the atmosphere.

Benthic.- Referring to the bottom sediments.

Bacterioplankton.- Bacteria adapted to the "open water" or "planktonic" zone of lakes, adapted for many specialized habitats and include groups that can use the sun's energy (phytoplankton), some that can use the energy locked in sulfur or iron, and others that gain energy by decomposing dead material.

Bicarbonate.- The most important ion (chemical) involved in the buffering system of New Hampshire lakes.

Buffering.- The capacity of lakewater to absorb acid with a minimal change in the pH. In New Hampshire the chemical responsible for buffering is the bicarbonate ion. (See pH.)

Chloride.- One of the components of salts dissolved in lakewater. Generally the most abundant ion in New Hampshire lakewater, it may be used as an indicator of raw sewage or of road salt.

Chlorophyll a.- The main green pigment in plants. The concentration of chlorophyll a in lakewater is often used as an indicator of algal abundance.

Circulation.- The period during spring and fall when the combination of low water temperature and wind cause the water column to mix freely over its entire depth.

Density.- The weight per volume of a substance. The more dense an object, the heavier it feels. Low-density liquids will float on higher-density liquids.
**Dimictic** - The thermal pattern of lakes where the lake circulates, or mixes, twice a year. Other patterns such as polymictic (many periods of circulation per year) are uncommon in New Hampshire. (See also meromictic and holomictic).

**Dystrophy** - The lake trophic state in which the lakewater is highly stained with humic acids (reddish brown or yellow stain) and has low productivity. Chlorophyll a concentration may be low or high.

**Epilimnion** - The uppermost layer of water during periods of thermal stratification. (See lake diagram).

**Eutrophy** - The lake trophic state in which algal production is high. Associated with eutrophy is low Secchi Disk depth, high chlorophyll $a$, and high total phosphorus. From an esthetic viewpoint these lakes are "bad" because water clarity is low, aquatic plants are often found in abundance, and cold-water fish such as trout and salmon are usually not present. A good aspect of eutrophic lakes is their high productivity in terms of warm-water fish such as bass, pickerel, and perch.

**Free CO2** - Carbon dioxide that is not combined chemically with lake water or any other substances. It is produced by respiration, and is used by plants and bacteria for photosynthesis.

**Holomixis** - The condition where the entire lake is free to circulate during periods of overturn. (See meromixis.)

**Humic Acids** - Dissolved organic compounds released from decomposition of plant leaves and stems. Humic acids are red, brown, or yellow in color and are present in nearly all lakes in New Hampshire. Humic acids are consumed only by fungi, and thus are relatively resistant to biological decomposition.

**Hydrogen Ion** - The "acid" ion, present in small amounts even in distilled water, but contributed to rain-water by atmospheric processes, to ground-water by soils, and to lakewater by biological organisms and sediments. The active component of "acid rain". See also "pH" the symbolic value inversely and exponentially related to the hydrogen ion.

**Hypolimnion** - The deepest layer of lakewater during periods of thermal stratification. (See lake diagram)

**Lake** - Any "inland" body of relatively "standing" water. Includes many synonyms such as ponds, tarns, loches, billabongs, bogs, marshes, etc.

**Lake Morphology** - The shape and size of a lake and its basin.

**Littoral** - The area of a lake shallow enough for submerged aquatic plants to grow.

**Meromixis** - The condition where the entire lake fails to circulate to its deepest points; caused by a high concentration of salt in the deeper waters, and by pecu-
liar landscapes (small deep lakes surrounded by hills and/or forests. (Contrast holomixis.)

Mesotrophy- The lake trophic state intermediate between oligotrophy and eutrophy. Algal production is moderate, and chlorophyll $a$, Secchi Disk depth, and total phosphorus are also moderate. These lakes are esthetically "fair" but not as good as oligotrophic lakes.

Metalimnion- The "middle" layer of the lake during periods of summer thermal stratification. Usually defined as the region where the water temperature changes at least one degree per meter depth. Also called the thermocline.

Mixis- Periods of lakewater mixing or circulation.

Mixotrophy- The lake condition where the water is highly stained with humic acids, but algal production and chlorophyll $a$ values are also high.

Oligotrophy- The lake trophic state where algal production is low, Secchi Disk depth is deep, and chlorophyll $a$ and total phosphorus are low. Esthetically these lakes are the "best" because they are clear and have a minimum of algae and aquatic plants. Deep oligotrophic lakes can usually support cold-water fish such as lake trout and land-locked salmon.

Overturn- See circulation or mixis

pH- A measure of the hydrogen ion concentration of a liquid. For every decrease of 1 pH unit, the hydrogen ion concentration increases 10 times. Symbolically, the pH value is the "negative logarithm" of the hydrogen ion concentration. For example, a pH of 5 represents a hydrogen ion concentration of $10^{-5}$ molar. [Please thank the chemists for this lovely symbolism -- and ask them to explain it in lay terms!] In any event, the higher the pH value, the lower the hydrogen ion concentration. The range is 0 to 14, with 7 being neutral 1 denoting high acid condition and 14 denoting very basic condition.

Photosynthesis- The process by which plants convert the inorganic substances carbon dioxide and water into organic glucose (sugar) and oxygen using sunlight as the energy source. Glucose is an energy source for growth, reproduction, and maintenance of almost all life forms.

Phytoplankton- Microscopic algae which are suspended in the "open water" zone of lakes and ponds. A major source of food for zooplankton. Common examples include: diatoms, euglenoids, dinoflagellates, and many others. Usually included are the blue-green bacteria.

Parts per million- Also known as "ppm". This is a method of expressing the amount of one substance (solute) dissolved in another (solvent). For example, a solution with 10 ppm of oxygen has 10 pounds of oxygen for every 999,990 pounds (500 tons) of water. Domestic sewage usually contains from 2 to 10 ppm phosphorus.

Parts per billion- Also known as "ppb". This is only 1/1000 of ppm, therefore much less concentrated. As little as 1 ppb of phosphorus will sustain growth of
algae. As little as 10 ppb phosphorus will cause algal blooms! Think of the ratio as 1 milligram (1/28000 of an ounce) of phosphorus in 25 barrels of water (55 gallon drums)! Or, 1 gallon of septic waste diluted into 10,000 gallons of lakewater. It adds up fast!

**Plankton**- Community of microorganisms that live suspended in the water column, not attached to the bottom sediments or aquatic plants. See also "bacterioplankton" (bacteria), "phytoplankton" (algae) and "zooplankton" (microcrustaceans and rotifers).

**Saturated**- When a solute (such as water) has dissolved all of a substance that it can. For example, if you add table salt to water, a point is reached where any additional salt fails to dissolve. The water is then said to be saturated with table salt. In lakewater, gaseous oxygen can dissolve, but eventually the water becomes saturated with oxygen if exposed sufficiently long to the atmosphere or another source of oxygen.

**Specific Conductivity**- A measure of the amount of salt present in lakewater. As the salt concentration increases, so does the specific conductivity (electrical conductivity).

**Stratum**- A layer or "blanket". Can be used to refer to one of the major layers of lakewater such as the epilimnion, or to any layers of organisms or chemicals that may be present in a lake.

**Thermal Stratification**- The process by which layers are built up in the lake due to heating by the sun and partial mixing by wind.

**Thermocline**- Region of temperature change. (See metalimnion.)

**Total Phosphorus**- A measure of the concentration of phosphorus in lakewater. Includes both free forms (dissolved), and chemically combined form (as in living tissue, or in dead but suspended organisms).

**Trophic Status**- A classification system placing lakes into similar groups according to their amount of algal production. (See Oligotrophy, Mesotrophy, Eutrophy, Mixotrophy, and Dystrophy for definitions of the major categories)

**Z**- A symbol used by limnologists as an abbreviation for depth.

**Zooplankton**- Microscopic animals in the planktonic community. Some are called "water fleas", but most are known by their scientific names. Scientific names include: *Daphnia, Cyclops, Bosmina*, and *Kelliottia*. 