Linda Bacon
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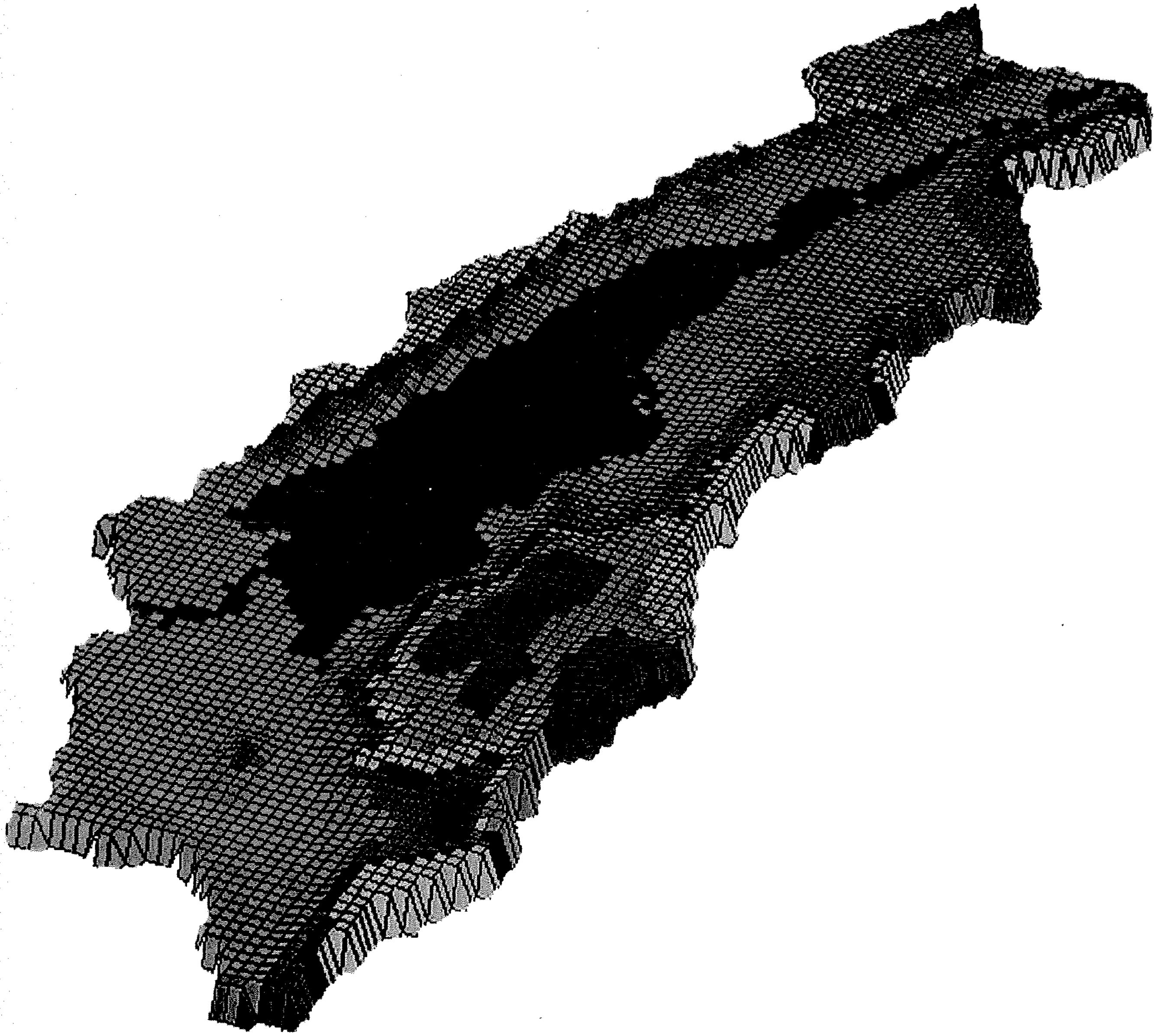
LAND USE PATTERNS IN RELATION TO LAKE WATER QUALITY IN THE MESSALONSKEE LAKE WATERSHED



Biology 493
Problems in Environmental Science
Colby College
Waterville, ME 04901
1998

MEMO

DATE: March 18, 1998

TO: Report recipients

FROM: Professors David Firmage and Russell Cole

RE: Class report on Messalonskee Lake and its watershed

We make this report available in the hope that the work contained herein may be of interest or help to others interested in the problem addressed. We realize that some areas of the study could and perhaps should be expanded. We feel confident of the quality of the work done and only wish the time had been available so that the students could fulfill their desire to conduct a more comprehensive study.

This report is the work of students enrolled in the Problems in Environmental Science course (Biology 493) taught at Colby College during the fall semester of 1997. The course is taken by seniors who are majoring in Biology with a concentration in Environmental Science. The students work as though they were an environmental consulting firm. The object of the course is to teach the students how to approach a problem, how to develop a workplan, and what is necessary to implement the plan successfully. As part of this learning process the students use methods and tools they have learned in other courses and they are also introduced to new methodology as needed. Standard methods of analysis are used as well as state of the art instrumentation for any of the original analysis done. The methods used were those approved by EPA and the DEP. However, there are time constraints involved in the study since all requirements for the course must be completed within the fall semester. These constraints mean that much of the new data can only be gathered during the months of September through early November and, typically, that extensive analysis can not be done. Some of the water quality data were gathered during the previous summer and made available to the class for analysis in addition to their fall sampling. Also, in order to teach various techniques and to have the students consider a problem from a number of angles, the project is expanded to more areas than a group might normally take on for a short term project. This means that in some areas we sacrifice some depth for more breadth.

While the class was constrained by time, they have managed to accomplish an amazing amount of work during that period and we are very pleased with the quality of that work! We hope that you find it useful.

AUTHORS

This study of Messalonskee Lake was conducted by the students of the Biology 493: Problems in Environmental Science class at Colby College, Waterville, ME. The Students were:

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INTRODUCTION

GENERAL NATURE OF THE STUDY

Lakes are natural resources which have many effects on the land surrounding them. They support adjacent communities by providing water and regulating temperatures, helping to define the surrounding ecosystem, and serving as sources of drinking water as well as recreation. The prolonged presence of human activity in a watershed can disturb the physical and chemical cycles of the lake and its surrounding ecosystems (Henderson-Sellers and Markland 1987).

Over time, lakes undergo a process called eutrophication, a natural aging process during which the nutrient levels increase and dissolved oxygen levels decrease (Smith 1992). As the lake ages or becomes more eutrophic, organic material gradually collects in the lake basin. For a period of time, the increased organic matter raises the nutrient level in the lake and causes higher productivity. As the lake becomes more eutrophic, dissolved oxygen (DO) levels fall because of the high levels of organic material decomposing in the water. Organisms that cannot live under low dissolved oxygen levels begin to die. Over time, as DO levels continue to drop the diversity and overall health of the lake decrease until only a few highly tolerant species remain (Henderson-Sellers and Markland 1987).

Human activity within the watershed can greatly accelerate the eutrophication process by increasing the rate at which nutrients such as phosphorus and nitrogen enter the lake (Fernandez, Kahl, Nieratko 1992). Increased nutrient loading causes dramatic increases in algal populations resulting in algal blooms. Many New England lakes develop a greenish tint because of algal blooms during early summer or early fall (Smith 1992). Populations of bacteria which feed on organic material rise because of increased food supply. Bacterial activity decreases the level of dissolved oxygen in the lake (Henderson-Seller and Markland 1987). A sharp decrease in dissolved oxygen levels can cause massive death of many lake fauna especially fish, a process known as fish kill. While this process is not yet occurring in Messalonskee Lake, also known as Snow Pond, it could occur in the future depending on the activity of local residents. Messalonskee Lake watershed includes the communities of Belgrade, Oakland, Sidney and as shown on United States Geological Survey topographical maps. The watershed is located in the Belgrade Lakes region of south-central Maine .

Messalonskee Lake receives nutrient inputs from many different sources both natural and anthropogenic. Natural input sources such as Belgrade Stream, Bang's Brook and Ellis Brook carry nutrients from their drainage basins to the lake attached to suspended particles and dissolved in the water. Activities and developments such as roads, residential and industrial construction, logging, and human waste disposal (in subsurface waste disposal systems) have negative effects on water quality. These anthropogenic inputs contribute unnaturally high levels of nutrients and suspended particles into the lake through its tributaries.

Historically Messalonskee Lake has not suffered from algal blooms like neighboring East Pond which experiences seasonal algal blooms because of high nutrient levels (BI493 1991). However, if human activity is not monitored and development carefully controlled, the nutrient cycle of Messalonskee Lake could be accelerated resulting in algal blooms, poor water quality, and fish kills.

The main purpose of this study is to assess the current land use patterns and their influences on the water quality of Messalonskee Lake, including the biotic and abiotic parameters which are involved. More specifically, four main objectives where proposed. First, was to calculate the water budget and flushing rate for Messalonskee Lake. Second, was to determine the influence of current and historical land use patterns on lake water quality. Third, was to utilize gathered information to construct a phosphorus model, which will enable future water quality predictions to be made. Out fourth and final objective was to make recommendations to the Messalonskee Lake Association, and the towns of Belgrade, Oakland, and Sidney based on our findings.

The water quality and land use assessment of the Messalonskee Lake watershed was conducted by the Colby Environmental Assessment Team (CEAT) during the fall of 1997.

BACKGROUND

Lake Characteristics

Difference Between a Lake and a Pond

Lakes and ponds are natural or man-made inland bodies of water (Niering 1985). Environmental conditions may vary from lake to pond, but there are certain characteristics that are shared between the two (Smith 1992).

The amount of light that is able to penetrate the surface water in a pond or lake is an important feature of both. It is primarily surface area and depth that distinguishes between the two types of water bodies (Niering 1985). Ponds tend to be smaller and have larger littoral zones (shallow area of the water body where light reaches the bottom) than lakes.

Temperature, which changes with the seasons and depth, is an important factor in both pond and lake ecosystems (Smith 1992). Because water is most dense at approximately 4° C, many species are able to survive in an aquatic environment throughout the year, since ice remains on the surface and prevents most lakes from freezing solid. During the summer, lake water stratifies, establishing an upper, warm water layer called the epilimnion, and a lower cold water layer called the hypolimnion. Between the epilimnion and the hypolimnion is an area of rapid temperature change called the metalimnion. Thermal stratification prevents mixing of oxygen and nutrients within a lake. Ponds, due to their shallow waters, typically do not thermally stratify during the summer months. In some lakes, the shallow depth prevents stratification, and therefore the lake does not experience changes in dissolved oxygen (DO) associated with depth. Variations in oxygen and temperature strongly influence the adaptations for life and the buffering capabilities for pollutants in ponds and lakes (Smith 1992).

General Characteristics of Maine Lakes

Lakes are a vital natural resource in Maine (Davis et al. 1978). They provide fresh water for swimming, fishing, drinking, livestock and agriculture. The aesthetic beauty of Maine's lakes draw many tourists throughout the year and are important habitats for wildlife. Nine percent of Maine's approximately 5700 lakes have areas greater than 5.6 mi^2, and there has been little research conducted to examine their watersheds, ecosystems and potential for development, and or recreational utilization (Davis et al. 1978).

The majority of Maine lakes were formed during the most recent glaciation (Wisconsin) of the Pleistocene period (about 10,000 years ago) (Davis et al. 1978). As a result of glacial activity in Maine, most lake substrates are dominated by glacial till, bedrock, and glaciomarine clay-silt. Generally these deposits and the underlying bedrock (typically granitic) are of an "infertile" nature. This characteristic helps account for the fact that few lakes in Maine are naturally eutrophic (old and nutrient saturated), or even mesotrophic (middle-aged and nutrient rich). Many lakes in this region are oligotrophic (recently formed and nutrient poor).

The movement of the glaciers in Maine was predominantly southeasterly explaining the orientation of many of lakes in Maine. They are often long and relatively narrow in the southeastern direction (Davis et al. 1978). This feature of a lake is important to consider, particularly with reference to the seasonal changes which take place in the water body. Surface area and shape play a fundamental role, for instance, in the effect of wind on the water body, a critical function of its turnover effectiveness.

With few exceptions, lakes in Maine are located in lowland areas among hills (Davis et al. 1978). They are generally frozen on the surface four to five months out of the year. While Davis et al. (1978) noted that much of the lake watersheds within the state were forested, these stands have recently come under increasing pressure from the timber industry. Residential development of watersheds and increased construction of lake recreation facilities have also posed a significant threat to the water quality in many of lakes and ponds in Maine. In watersheds where agricultural practices have been less significant, both residential development and forestry practices may be the most acute causes of anthropogenic, or human caused, nutrient loading.

The level of dissolved matter (including sodium ions, potassium ions, phosphorus and organic matter) in lakes act as a standard measure of lake water quality. In Maine, several factors exist which serve as a function of water quality: proximity to the ocean, location within the state, residence time of water within the soil, wetland influences, and bedrock chemistry (Davis et al. 1978). Physical factors also play a critical role in the water quality. Particular terrestrial and aquatic vegetation, as well as unique habitat types, will also affect the water quality. Also, lake morphometry, as mentioned above, (e.g., depth and surface area) can function to change lake temperature, nutrient cycles, and effective turnover.

Lake Basin Characteristics

The physical properties of the lake basin drastically affect the biological and chemical processes of the lake. The morphometry, hydrologic cycles, and sediments of a basin contribute to the processes which affect the nutrient cycling and seasonal changes in the lake ecosystem. Most temperate lakes illustrate a degree of turnover, and lakes that turnover completely in both the spring and fall are referred to as dimictic (Smith 1992).

Stratification is such a vital component in lake ecosystem functioning that its implications should be understood. Water has the unique property of a maximum density at 4° C. Whereas the density of all other substances increase with a decrease in temperatures. Therefore ice, which freezes at 0° C, actually floats in water which is above the freezing point. The process of stratification is created by the different densities in lake water due to differences in temperature. This stratification follows a seasonal epilimnion (Figure 1). While usually no deeper than about 7 m to 8 m in northeastern lakes, the pattern in conjunction with the changes in solar radiation received by the lake water. Direct radiation of the upper levels of the water column warms that layer of water forming the epilimnion hosts the most abundant floral communities (Davis et al. 1978). This creates an oxygen rich stratum due to the photosynthetic capacities of these communities. Nutrients in the epilimnion, however, get depleted by algal populations growing in the water column (Cole, pers. comm.), and may remain depleted until the turnover of early fall (Smith 1992).

Below the epilimnion is a layer of sharp temperature decline, known as the metalimnion (Smith 1992). Within this stratum is the greatest temperature gradient in the lake, called the thermocline, which tends to decrease approximately 1° C per meter depth (Smith 1992). This thermocline separates the epilimnion from the hypolimnion, the lowest layer of a lake. The hypolimnion is beyond the depth to which sufficient light can penetrate in order to facilitate effective photosynthesis. It is an area in which most decomposition of organic material takes place through both aerobic and anaerobic biological processes. While aerobic (requiring oxygen) bacteria break down organic matter more quickly, they also significantly deplete the oxygen at these depths (Davis et al. 1978).

Both the spring and fall turnovers serve to reoxygenate the lower depths and mix the nutrients throughout the upper strata. These turnovers are a function of several factors which include the geographic position and shape of the lake, seasonal changes in temperatures, the interaction of the wind on the waters' surface, and the depth of the lake (Davis et al. 1978). The cold water near the surface can hold high levels of oxygen and since the demand for oxygen is considerably less due to decreased activities of aquatic organisms at these temperatures, it is crucial for deep water organisms that seasonal turnovers occur (Smith 1992). A snow cover, however, will affect the photosynthetic processes during the winter months by blocking solar radiation. In the later winter months, oxygen levels may become so depleted as to cause substantial fish kills (Cole, pers. comm.). As the winter passes, and the ice layer melts, the upper layers of the lake begin to warm once more and wind begins to mix the lake. Oxygen may be carried down the water column while nutrients pervade the epilimnion. As late spring approaches, solar radiation increases and stratification will again become evident, and the temperature profiles return to that of the summer (Smith 1992).

Trophic Status of Lakes

There are many ways of characterizing a lake, and each way has its limitations. One of the most useful biological classifications was originally proposed by Thienemann and later elaborated by others (Maitland 1990). Thienemann's characterization is based primarily on the nutrient levels within a lake. Lakes are generally divided into four major categories: oligotrophic, mesotrophic, eutrophic, and dystrophic (Table 1). It is important to note, that the mesotrophic characterization is not included in Table 1, because it is generally referred to as a transitional stage between oligotrophic and eutrophic

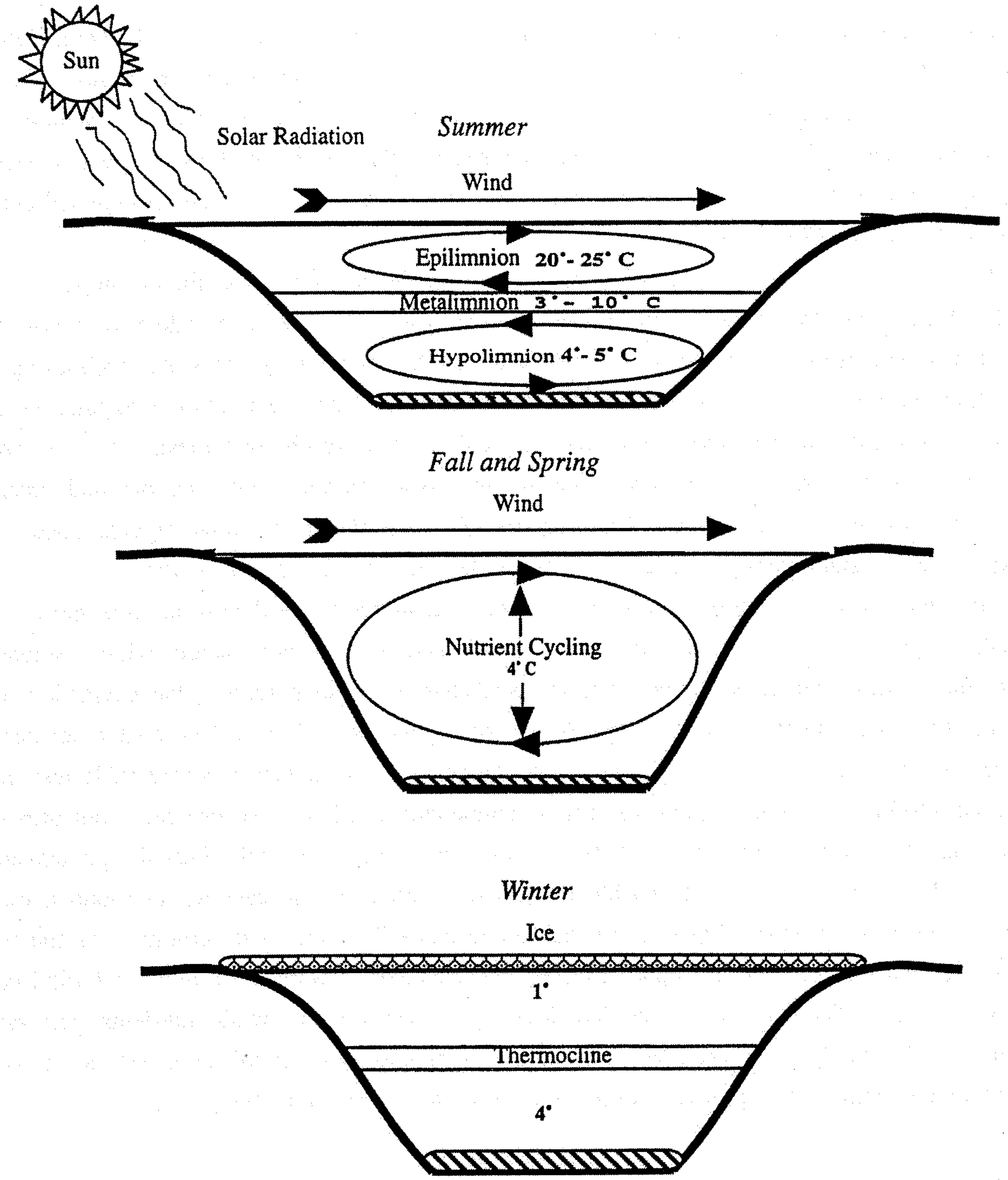

Figure 1. Mixing by means of lake turnover in dimictic lakes. During the summer, lakes are stratified into three layers (epilimnion, metalimnion, and hypolimnion). During the fall and spring, the isothermal temperature and density facilitate the lake turnover and redistribution of nutrients. In the winter, the lake is again stratified, with the slightly warmer water on the bottom of the lake and the ice at the surface.

states (Chapman 1996). Young or oligotrophic lakes are usually lacking in nutrients, while eutrophic lakes are nutrient rich (Niering 1985). Oligotrophic lakes tend to be deep and oxygen rich with steep-sided basins. There is a low surface to volume ratio. They are characterized as nutrient deficient, even though they may be high in nitrate levels. They are primarily deficient in phosphorus, which is the limiting nutrient for plant productivity in most freshwater ecosystems. The shape of a lake can also determine its productivity. Steep-sided oligotrophic lakes are not conducive to extensive growth of rooted vegetation; there is no shallow margin for attachment. Eutrophic lakes, partially due to sediment loading over years, tend to be relatively shallow and bowl shaped, which allows for the productivity of rooted plants (Table 1).

Eutrophic lakes are nutrient enriched (Chapman 1996) and typically have a relatively high surface to volume ratio (Maitland 1990). These lakes are generally rich in phytoplankton, which is supported by the increased availability of dissolved nutrients (Table 1). A eutrophic lake supports a tremendous amount of planktonic algae and is usually low in dissolved oxygen. Low dissolved oxygen levels at the bottom of the lake lead to the release of phosphorus and other nutrients from the bottom sediments, resulting in their eventual recycling through the water column (Chapman 1996). This stimulates even further growth of phytoplankton (Smith 1992). There is relatively little biotic diversity in a highly eutrophic lake, except for the phytoplankton and the decomposers that maintain the low levels of oxygen.

Lakes that receive large amounts of organic matter from the surrounding land, particularly in the form of humic (dead organic) materials, are termed dystrophic lakes (Smith 1992). The large quantity of humic materials stains the water brown. Dystrophic lakes generally have highly productive littoral zones (shallow area along the lake basin where light penetrates to the bottom). The littoral zone allows submergent, floating, and emergent vegetative growth.

High oxygen levels, high macrophyte productivity, and low phytoplankton amounts are characteristic of dystrophic lakes (Table 1). Eventually the invasion of rooted aquatic macrophytes chokes the aquatic habitat with plant growth, and the lake basin is filled in, resulting in the development of a terrestrial ecosystem (Goldman and Home 1983).

Over time, lakes tend to be enriched by introduced nutrients and eventually become eutrophic (Niering 1985). No matter how a lake basin originated, the lake will undergo succession (Goldman and Home 1983). Nutrient enrichment and the filling in of lakes are a natural phenomena. These processes, however, can be greatly affected by anthropogenic activities which increase the rate at which nutrient loading occurs. The United States Environmental Protection Agency (USEPA) characterizes the process of eutrophication by the following criteria:

1) Decreasing hypolimnetic dissolved oxygen concentrations;

2) Increasing nutrient concentrations in the water column;

3) Increasing suspended solids, especially organic material;
4) Progression from a diatom population to a population dominated by blue-green algae and/or green algae;
5) Decreasing light penetration (e.g., increasing turbidity);
6) Increasing phosphorus concentrations in the sediments (Henderson-Sellers and Markland 1987).

Table 1. Generalized characteristics of oligotrophic, eutrophic, and dystrophic lakes (adapted from Maitland 1990).

Character	Oligotrophic	Eutrophic	Dystrophic
Basin shape	Narrow and deep	Broad and shallow	Small and shallow
Lake shoreline	Stony	Weedy	Stony or peaty
Water transparency	High	Low	Low
Water color	Green or blue	Green or yellow	Brown
Dissolved solids	Low, deficient in N	High, especially in N and Ca	Low, deficient in Ca
Suspended solids	Low	High	Low
Oxygen	High	High at surface, deficient under ice and thermocline	High
Phytoplankton	Many species, low numbers	Few species, high numbers	Few species, low numbers
Macrophytes	Few species, rarely abundant, yet found in deeper water	Many species, abundant in shallow water	Few species, some species are abundant in shallow water
Zooplankton	Many species, low numbers	Few species, high numbers	Few species, low numbers
Zoobenthos	Many species, low numbers	Few species, high numbers	Few species, low numbers
Fish	Few species, salmon and trout characteristic	Many species, especially minnows	Extremely few species, often none

As a lake ages, it continues to fill up through the deposition of dead organic matter and sediment from various inputs. Lakes may also receive mineral nutrients from streams, groundwater, and runoff. As nutrient availability increases, so does primary productivity. Increased productivity leads to more dead organic material which accumulates in lentic ecosystems (pertaining to standing water, as lakes and ponds). Lakes are created and destroyed by biological and geological processes. In time, lakes will fill in, decrease in size, and may finally be replaced by a terrestrial community (Smith 1992).

Phosphorus and Nitrogen

In a freshwater lake, phosphorus and nitrogen are the two major nutrients that are important for the growth of algae and macrophytes. Each nutrient has its own complex chemical cycle within the lake (Overcash and Davidson 1980). It is necessary that we understand these cycles so that we may devise better techniques to control high levels of these nutrients.

Phosphorus is generally considered the most important nutrient in lakes because it is the limiting nutrient for plant growth in freshwater systems (Maitland 1990). Phosphorus naturally occurs in lakes in minute quantities (measured in ppb), however this is all that is needed for plant growth due to the high efficiency with which plants can assimilate phosphorus (Maitland 1990). There are multiple external sources that contribute phosphorus to a lake (Williams 1992), but a large source is also within the lake itself (Henderson-Sellers and Markland 1987). The cycle of phosphorus in a lake is extremely complex, with some models including up to seven different forms of phosphorus (Frey 1963). For the purposes of this study, it is only necessary to understand that there are two broad categories of phosphorus in a lake: dissolved phosphorus (DP), and particulate phosphorus (PP). The basic cycle that these forms of phosphorus follow in a stratified lake is summarized in Figure 2. DP is an

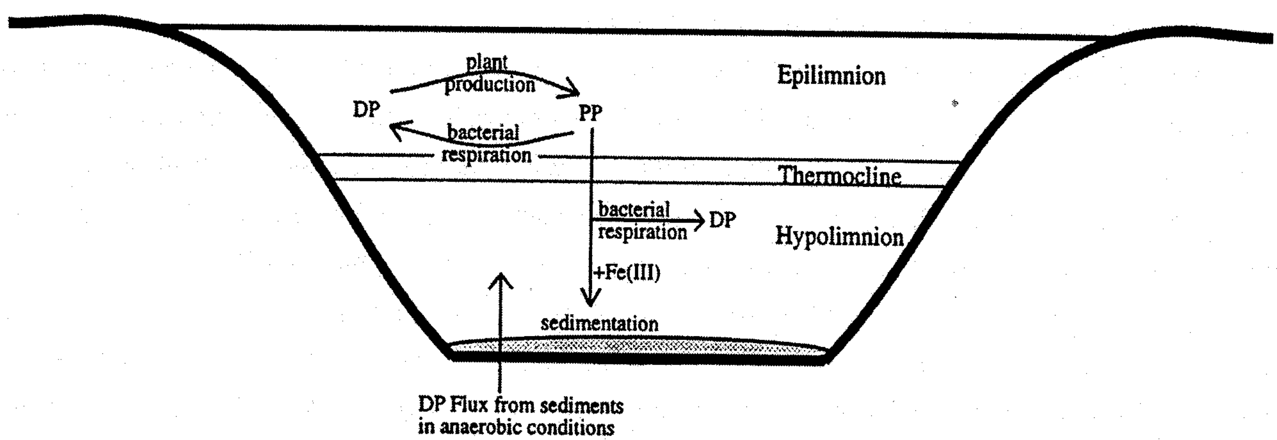

Figure 2. A model of the cycle of the major forms of phosphorus, dissolved (DP) and particulate (PP), within a lake ecosystem. The sedimentation of DP through complexation with Fe (III) contributes to the build-up of DP in the sediments. Note the production of DP in the hypolimnion due to bacterial decomposition as well as from the release of DP from the Fe complex in the sediments during anaerobic conditions. The fact that the thermocline prevents DP from mixing between the surface and bottom water is critical to the cycle because it can allow for build up of DP in bottom waters (adapted from Lerman 1978).

inorganic form of phosphorus which is readily available for plant use in primary production; it is this form of phosphorus which is limiting to plant growth. PP is phosphorus which is incorporated into organic matter such as plant and animal tissues. DP is converted into PP through the process of primary production, which occurs in the epilimnion. Much of this PP then gradually settles into the hypolimnion in the form of dead organic matter. If there is oxygen present, PP will be converted to DP through decomposition by aerobic bacteria. When there is little or no oxygen present, which is often the case in the sediments of a stratified lake, anaerobic bacterial decomposition will result in the conversion of PP to DP (Lerman 1978).

In oxygenated water an important reaction occurs which involves DP and the oxidized form of iron, Fe(III) (Chapman 1996). This form of iron can bind with DP to form an insoluble complex, ferric phosphate, which can effectively tie up large amounts of phosphorus as it settles into the bottom sediments. Upon decreasing the oxygen levels at the sediment-water interface, such as after extended periods of stratification, the Fe(III) will be reduced to Fe(II) which results in the release of DP. The ferric phosphate complex, combined with the anaerobic bacterial conversion of PP to DP, can lead to a significant build-up of DP in anoxic, or oxygen devoid, sediments. In fact, the sediments of a lake can have phosphorus concentrations of 50-500 times the phosphorus concentration of the water (Henderson-Sellers and Markland 1987). This allows a lake's sediment to be an even larger source of phosphorus than external inputs. Because nutrients are inhibited from mixing into the epilimnion during the summer by stratification processes, DP concentrations that are formed in the sediments and lower hypolimnion waters can build up until fall turnover.

The fall turnover results in a large flux of nutrients to the region of the lake where plant growth can occur, creating the potential for algal blooms. If an algal bloom does occur, DP will be converted to PP in the form of algal tissues. The algae will die as winter approaches and the dead organic matter will settle to the bottom where PP will be converted back to DP and build up again, allowing for another large nutrient input to surface waters during spring overturn (Chapman 1996).

The other major plant nutrient, nitrogen, is not usually the limiting factor for plant growth in a lake (Chapman 1996). However, it is still important to understand its cycle because high concentrations can lead to algal blooms in the presence of phosphorus. Also, levels greater than 10 ppm can lead to the development of the condition in infants known as methemoglobinemia, if the water is used as a source of drinking water (Greenberg, Clesceri, and Eaton 1992). Available nitrogen exists in lakes in three major chemical forms: nitrates (NO_3^-), nitrites (NO_2^-), and ammonia (NH_3). Their relative positions in the nitrogen cycle are summarized in Figure 3.

The majority of free nitrogen in a lake exists in the form of nitrates (Maitland 1990). This form of nitrogen is directly available for assimilation by algae and macrophytes (Figure 3). In eutrophic lakes, there may be so much algae and macrophyte growth that most of the nitrates of the lake are incorporated into their tissues (Maitland 1990). Nitrites, however, cannot be used by plants. Nitrate-forming bacteria in aerobic conditions convert nitrites to nitrates. Ammonia enters the lake ecosystem as a product of the decomposition of plant and animal tissues and their waste products. It can follow

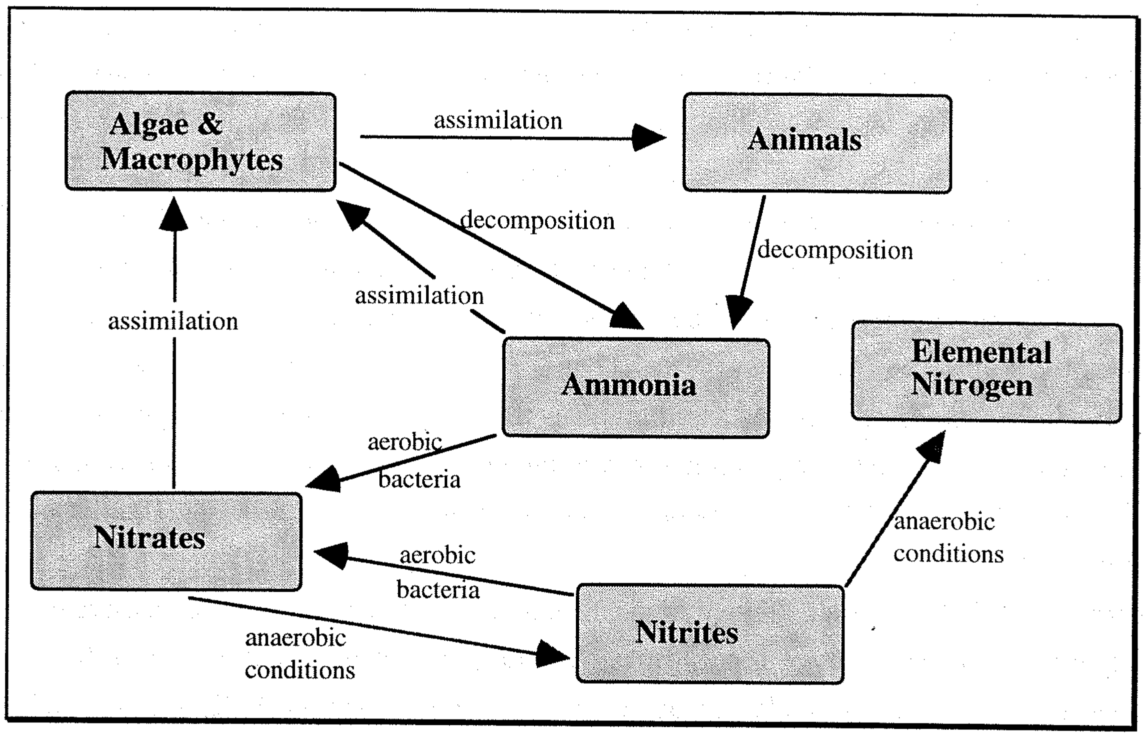

Figure 3. A diagram of the various forms of nitrogen that occur in the nitrogen cycle within a lake ecosystem. It is important to note that in aerobic conditions both ammonia and nitrites are converted to nitrates which are available for use by plants.

one of three paths. First, many macrophytes can assimilate ammonia directly into their tissues. Alternatively, in aerobic conditions, certain bacteria will convert the ammonia directly to the more usable form of nitrogen, nitrates. Finally, in the case of anaerobic decomposition, which commonly occurs in the sediments of stratified lakes, nitrates can be reduced to nitrites. If these anaerobic conditions persist, the nitrites can be entirely broken down to elemental nitrogen (N_2). This form is not available to any plants without the aid of nitrogen-fixing bacteria, as only bacteria have the capability to convert nitrogen to nitrates through nitrogen fixation (Overcash and Davidson 1980). The underlying pattern that is evident from this cycle is that whatever form of nitrogen is added to the lake it will eventually become available for plant use. In order to understand the amount of this nutrient available for plant growth, one must take into account not only the various forms of nitrogen, but also the oxygen concentrations (aerobic and anaerobic conditions) of the water.

Several in-lake mitigation techniques exist to deal with the problem of excessive nutrients once they are present in the lake (Henderson-Sellers and Markland 1987). All of these techniques take advantage of the information we have explaining how phosphorus cycles in a lake. None of these techniques are without disadvantages, but for lakes with serious algal growth problems they may be necessary (Henderson-Sellers and Markland 1987).

One of the easiest methods used to eliminate excessive nutrients is to decrease the lake water level rapidly (Henderson-Sellers and Markland 1987). For example, if dams are used to control the outflow of the lake, opening these widely, so that the lake loses a large volume of water in a short period of time, may cause many of the nutrients located in the epilimnion to be flushed from the lake. This is a relatively simple technique, however in cases where the lake drains into another lake or significant water body, the problem of an overload of nutrients may not be eliminated, but simply shifted to another site. Additionally this may only be a temporal solution because the source of nutrients from the hypolimnion will not be affected; thus it will continue to supply nutrients to the rest of the lake.

Another approach of nutrient reduction involves removing the nutrient rich hypolimnetic water. By inserting a large pipe into the hypolimnion and pumping the water out in such a way that it would not go directly back into the lake, the nutrient levels in the water would be reduced (Henderson-Sellers and Markland 1987).

Chemical precipitation is a relatively simple technique which requires some expensive equipment. It is based on the natural process of iron complexing with phosphorus. Adding salt to the water will complex the DP to form an insoluble compound that will immobilize the P (Henderson-Sellers and Markland 1987). This is an effective technique but, due to the cost, is not practical for very large lakes. Furthermore, the P will eventually be released from this complex, requiring reapplication after several years.

Aeration of the hypolimnion is a process that requires some expensive machinery to perform. It operates on the principle that an increase in the oxygen levels in the lower strata of the hypolimnion will reduce the amount of DP released from the sediments. If there is oxygen present where the sediment and water interface, there will be no conversion of iron to its reduced form, so there will be no DP released from the ferric phosphate complex (Henderson-Sellers and Markland 1987).

Another approach, in lakes with large macrophyte production, is to harvest the plants. This method can be expensive due to the cost of equipment used and the frequency with which the harvesting must be performed. This procedure removes all the nutrients that are tied up in the plants at the time of the harvest and prevents them from re-entering the lake cycle (as long as the harvested plants are not stored on shore, allowing the nutrient rich water in the plants to flow back into the lake). There is some debate over the effectiveness of this method, because plants also act as a sink for nutrients. At the time of removal, the nutrients that would normally have been taken up by the plants will be available to algae, perhaps resulting in an algal bloom (Chapman 1996). On the other hand, if only the foliage of the plants is harvested, then the plants will still be able to fulfill their role of taking up nutrients from the water.

One final management option is to dredge, which removes the nutrients from the sediments by removing the sediments themselves. Although dredging is effective it is extremely expensive due to the large cost of the equipment needed (Henderson-Sellers and Markland 1987). Also, there is some question as to ecologically disruptive effects that actions such as this may have on the lake ecosystem.

In terms of eliminating nutrients once they have built up in a lake, it is evident from these less-than-ideal techniques that it is a very challenging task especially due to the complexity of the cycling within the lake. The ideal method for controlling nutrients in a lake is to regulate and monitor the input sources, so that the natural processes of nutrient cycling and nutrient uptake by flora and fauna will be able to compensate without progressive eutrophication of the lake.

Freshwater Wetlands

Wetlands are important transitional areas between aquatic and terrestrial ecosystems. They support a wide range of biotic species (MLURC 1976). Table 2 gives descriptions of fresh inland wetlands. More importantly, they are useful for the balance of an aquatic ecosystem because of their efficiency in nutrient uptake by vegetation. Wetlands have the potential to reduce heavy metals and nutrients from various sources including mine drainage, sewage, and industrial wastes (Smith 1990). Agricultural runoff adds excess nitrogen and phosphorus, the primary limiting agents in a lake ecosystem, into the lake. Wetlands are able to absorb some of these nutrients, thereby improving the overall water quality, and store the nutrients in sediment which can later be used by the surrounding plant life (Niering 1985).

Usually, wetlands have a water table near, at, or above the level of the land. Wetland soil is periodically or perpetually saturated, and contains non-mineral substrates such as peat. Wetlands also contain hydrophytic vegetation which is adapted for life in saturated and anaerobic soils (Chiras 1991). In the Messalonskee Lake watershed, there are several wetlands located around various water sources (see Developmental Implications of Land Characteristics: Land Use Suitability).

Watershed Land Use

Land Use Types

A watershed is defined by the total land area that contributes a flow of water to a particular body of water. The watershed is bounded by the highest points surrounding the body of water and its tributaries. The assessment of land use within this area is essential in determining factors that may affect the lake water quality. Different types of land use have varying effects on nutrient loading to lakes. Nutrients can bind to soil, and if eroded, this soil can add to the nutrient load. Nutrients from anthropogenic sources have had a substantial effect on water quality in numerous Maine lakes (MDEP 1992b).

Areas that have been cleared for agricultural, residential, or urban uses can contribute to nutrient loading. The combination of removing vegetation and compacting soil may result in a significant increase in surface runoff. Surface runoff can increase erosion of sediments and various wastes of human origin. Products such as fertilizers, pesticides, and herbicides associated with human activity can contain nitrogen, phosphorus, other plant nutrients, and miscellaneous chemicals (MDEP 1992a). These sediments can have adverse effects on water quality.

Table 2. Descriptions of site characteristics and plant populations of different types of fresh inland wetlands (Smith 1990).

Type	Site Characteristics	Plant Populations
Seasonally flooded basins or flats	Soil covered with water or waterlogged during variable periods, but well drained during much of the growing season; in upland depressions and bottomlands	Bottomland hardwoods to herbaceous growth
Fresh meadows	Without standing water during growing season; waterlogged to within a few inches of surface	Grasses, sedges, broadleaf plants, rushes
Shallow fresh marshes	Soil waterlogged during growing season; often covered with 15 cm or more of water	Grasses, bulrushes, spike rushes, cattails, arrowhead, pickerel weed
Deep fresh marshes	Soil covered with 15 cm to 1 m of water	Cattails, bulrushes, reeds, spike rushes, wild rice
Open freshwater	Water less than 3 m deep	Bordered by emergent vegetation such as pondweed, wild celery, water lily
Shrub swamps	Soil waterlogged; often covered with 15 cm of water	Alder, willow, buttonbush, dogwoods
Wooded swamps	Soil waterlogged; often covered with 0.3 m of water; along sluggish streams, flat uplands, shallow lake basins	Tamarack, arbor vitae, spruce, red maple, silver maple
Bogs	Soil waterlogged; spongy covering of mosses	Heath shrubs, sphagnum moss, sedges

Natural areas, such as forested land, offer better protection against soil erosion and surface runoff. The canopy provides a cover over the soil, lessening the impact of rain, and reducing soil erosion. The root systems of the trees further reduce soil erosion and slow the rate of runoff, allowing water to percolate into the soil. Forested areas act as buffering systems by absorbing the nutrients when they are located between sources of nutrients and water bodies. Forests cover much of Maine, therefore expansion of residential areas usually results in forest clearing. By clearing forested areas that serve as natural buffer strips, nutrient loading due to erosion, can increase with subsequent decline in lake water quality. Also, the resulting development provides impervious surfaces that increase the amount of surface runoff. A study concerning phosphorus loading in Augusta, Maine revealed that a residential area produced ten times more phosphorus than an adjacent forested area (Dennis 1986; Figure 4).

Residential areas are separated into shoreline and nonshoreline homes that can be either permanent or seasonal residences. Residential areas in a watershed generally contain lawns, driveways, parking areas, rooftops, and other impervious surfaces that reduce percolation, thereby causing increased runoff. Since year-round homes produce more phosphorus through extended use of septic systems, they may pose more of a threat to nutrient loading than seasonal homes.

The use of household products in and around the home is also potentially harmful to water quality. Due to their proximity to the lakes, shoreline homes can provide direct sources of nutrients to the lake. Products used in the household (e.g., detergents and soaps) often contain phosphorus. Lawns and gardens are maintained with fertilizers that are high in phosphorus. These products used around the home can leak into the groundwater and subsequently enter the lake. Storms can also carry away these high nutrient products due to increased surface runoff near residences. The nutrients enter the water column and lead to lake eutrophication. In addition, when improperly designed or used, septic systems found at year round or seasonal homes can potentially be large sources of nutrients (USEPA 1980).

Commercial uses of forested land, such as logging and tree harvesting, remove the cover of the canopy, thereby exposing the soil to direct rainfall, which facilitates erosion. Skid trails may pose a problem when they run adjacent to or through streams (Hahnel, pers. comm.). Shoreline zoning ordinances have established that a 75 ft strip of vegetation be maintained between a skid trail and the normal high water line of a water body or upland edge of a wetland to alleviate the potential impact harvesting may have on a water body (MDEP 1990). Two studies by the Land Use Regulation Commission on tree harvesting sites noted that erosion and sedimentation problems occurred on 50% of the active and 20% of the inactive logging sites selected (MDC 1983).

Roads can also provide excessive surface runoff if poorly designed or maintained. Their contribution also depends on regulations enforced by local governments. Roads are divided into four

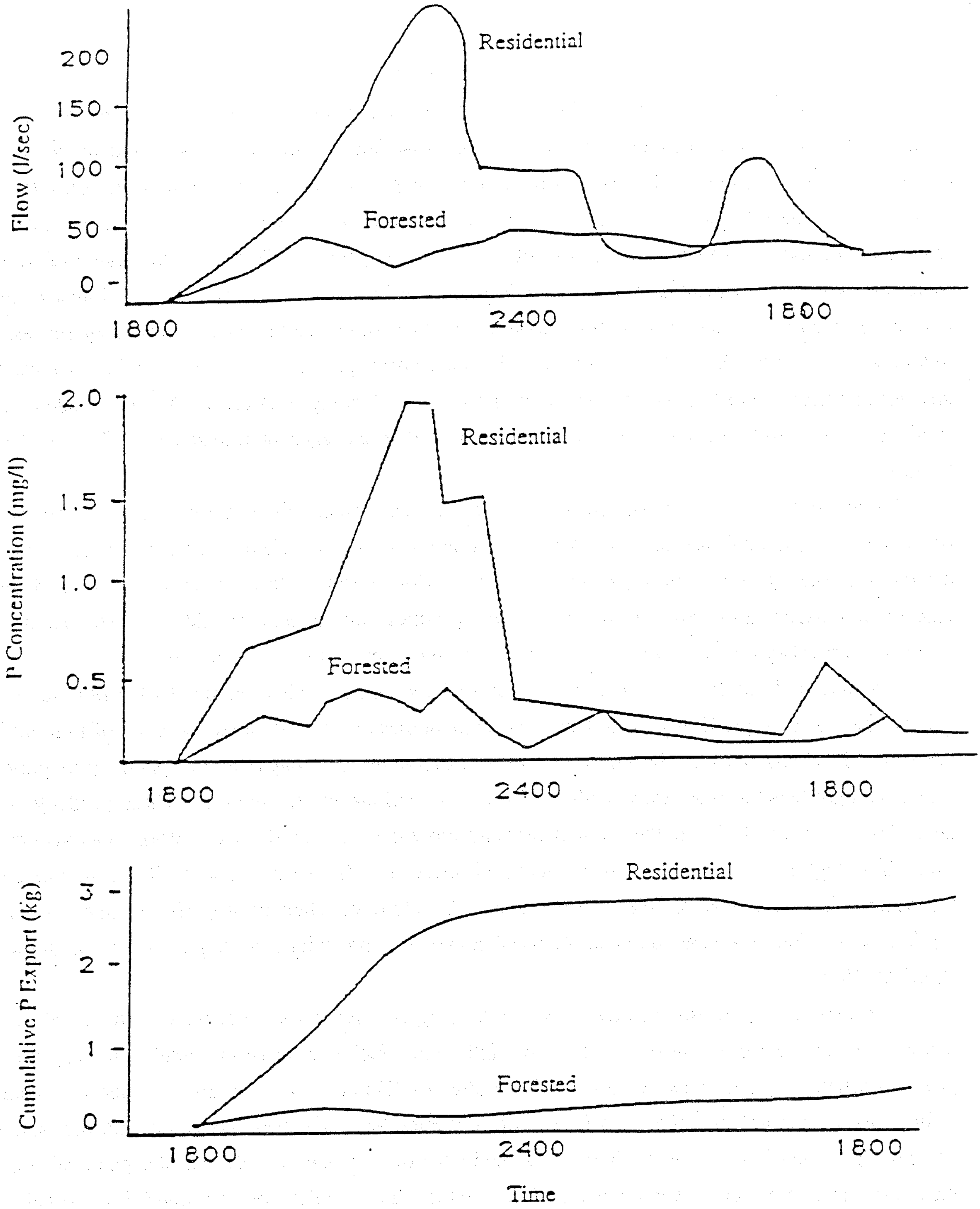

Figure 4. Comparisons of runoff after an April rain storm in two neighboring watersheds near Augusta, ME. Top: volume of immediate runoff over a 12 hour period; Middle: phosphorus concentration in the runoff; Bottom: total amount of phosphorus exported into local streams and lakes from the storm (Dennis 1986).

main types (state, municipal, dirt, and fire roads) and can have varying degrees of nutrient loading potential. Roads and driveways leading down to shoreline areas or streams provide easy access to the lake for runoff. This can cause the movement of large amounts of nutrients if the roads and driveways are not well constructed or maintained (Michaud 1992). Land use is an important determinant of lake water quality. Before new development can occur it is important to identify particular considerations such as soil type or the phosphorus loading coefficient. These considerations need to be taken into account and shared with developers as guidelines to minimize impact on the lake. To maintain water quality there must be state and local regulations in place that moderate nutrient loading from various land uses. Investigation of impacts from land use practices and possible future development will help preserve a healthy lake system.

Buffer Strips

Buffer strips are important for control of nutrients entering the lake (MDEP 1990). Increased levels of nutrients can promote algal growth and increase the lake's eutrophication rate. According to the Belgrade Shoreline Zoning Ordinance, one should have "a strip of land extending 75 ft, horizontal distance, inland from the normal high-water line of a great pond or a river flowing to a great pond, and 75 ft, horizontal distance, from any other water body, tributary stream, or the upland edge of a wetland" as a buffer strip (Belgrade 1991). An example of an ideally buffered home is shown in Figure 5. This home has a winding path down to the water. Runoff is diverted into the woods where nutrients will be absorbed by the forest litter. The house is set back from the water 100 ft, and has a

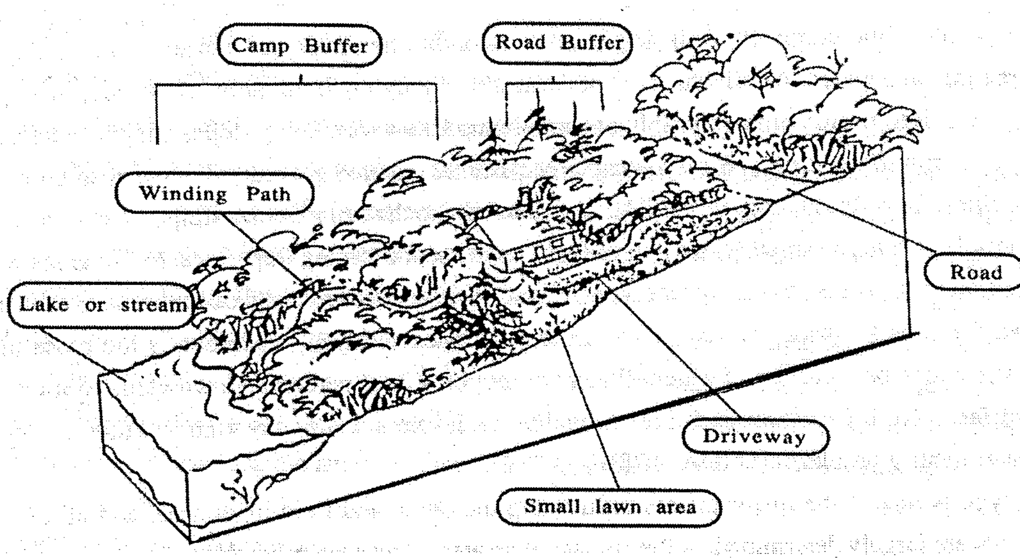

Figure 5. Diagram of an ideally buffered home.

buffer strip between it and the water consisting of a large canopy which can absorb nutrients and break the impact of precipitation hitting the ground (MDEP 1990). The driveway curves down to the house.

This curving allows the water to be diverted into the woods and then filtered by the forest litter. The runoff is allowed time to be naturally filtered by the surrounding forest rather than running directly into the lake. Many buffer strips on Messalonskee Lake are not in accordance with the above shoreline zoning ordinance and may provide insufficient nutrient absorption. Some houses surrounding the lake have natural woodland buffer strips, but there are many houses on Messalonskee Lake which are surrounded by large green lawns. Such lawns do not provide adequate nutrient uptake before runoff enters the lake.

Nutrient Loading

Nutrient loading into a lake can be affected by both natural and anthropogenic processes (Hem 1970). Human activity usually accelerates the loading of nutrients and sediments into a lake. The water quality can be adversely affected in a short period of time. Clearing away forests and constructing roads and buildings with impervious surfaces increase runoff, carrying nutrients from agricultural, residential, and industrial products and uses (such as detergent, fertilizer, and sewage) into the lake. Since phosphorus and nitrogen are the limiting nutrients in algal growth, and algal growth affects the trophic state of a lake, increases of phosphorus and nitrogen from these sources can lead to a decrease in lake water quality and eventually eutrophication.

Total phosphorus loading to a lake can be determined using a phosphorus loading model (see Analytical Procedures and Findings: Phosphorus Loading). This model takes into account the various aspects upon which the phosphorus concentration in the lake basin is dependent, such as lake size, volume, flushing rate, and land use patterns within the watershed (Cooke et al. 1986). This model is useful because it allows for the projection of the impacts that various factors may have on phosphorus loading. It enables the making of predictions of lake responses to changes in land use. The accuracy of the predictions is based on the accuracy of the assumptions (USEPA 1990).

Soil Types

Nutrient loading in lake ecosystems is a function of the soil types and their respective characteristics. Both the physical characteristics of soil, such as permeability, depth, particle size, organic content, and the presence of an impermeable layer (fragipan), as well as the environmental features (slope, average depth of the water table, and depth to the bedrock) which influence them, are important to consider in deciphering the nutrient loading functions (USDA 1978). These factors can determine appropriate land uses such as forestry, agriculture, and residential or commercial development. The soils most capable of accommodating such disturbances, by preventing extreme erosion and runoff of both dissolved and particulate nutrients, are those which have medium permeability, moderate slopes, deep water tables, low rockiness and organic matter, and no impermeable layer (USDA 1992). Soils that do not meet all of these criteria must be considered carefully before implementing a development, forestry, or agricultural plan.

Zoning and Development

The purpose of zoning and development ordinances are to maintain safe, healthy conditions, control water pollution, protect wildlife and freshwater wetlands (control building and placement of structures as well as other types of land use) conserve rural nature, and anticipate the impacts of development (Belgrade 1991). Shoreline zoning ordinances regulate development along the shoreline in a manner that reduces the deterioration of lake water quality. Uncontrolled development along the shoreline within sensitive areas can result in a severe drop in water quality that is not easily corrected. In general, these regulations have become more stringent as increased development has caused water quality to decline in many watersheds (MDEP 1992b). If no comprehensive plan or town ordinances have been enacted, the state regulations are used by default.

Shoreline Residential Areas

Shoreline residential areas are of critical importance to water quality due to their proximity to the lake. Any nutrient additives from residences (such as detergents) have only short distances to travel to reach the lake. Buffer strips along the shore are essential in acting as a sponge for the nutrients flowing from residential areas to the lake (Woodard 1989). These buffer strips consist of an area of natural vegetation growing between a structure and the body of water in question. Town ordinances in Belgrade regulate buffer strip widths, thereby influencing phosphorus loading to the lake (see Background, Watershed Land Use: Buffer Strips).

Residences that have lawns leading directly down to the shore have no obstacles to slow runoff, thus causing phosphorus to pass easily into the lake. Buffer strips, when used in conjunction with appropriate setback laws for house construction, can dramatically reduce the proximity effects of the shoreline residences (MDEP 1992b).

Maine seasonal residences, located on or near the shoreline in a cluster, can contribute disproportionately to phosphorus loading into the lake ecosystem. Such clusters of camps usually exist because they have been grandfathered, and thus do not follow shoreline zoning laws. Although seasonal, they may involve large numbers of people. Therefore, phosphorus export from these areas is likely to increase during periods of heavy use. The effects of these plots on nutrient loading depend on factors such as septic system location and condition (see Background, Watershed Land Use: Sewage Disposal Systems).

Nonshoreline Residential Areas

Although not as important in phosphorus loading as shoreline areas, nonshoreline residential areas can also have an impact on nutrient loading. Runoff, carrying the phosphorus from soaps, detergents, and fertilizers usually filters through buffer strips consisting of forested areas several acres wide, rather than a few feet wide (as with shoreline buffers). In these cases, phosphorus has the opportunity to be absorbed into the soils and vegetation. The majority will not reach the lake directly, but will simply enter the forest's nutrient cycle.

However, residences located up to one half mile away from the lake can supply the lake with phosphorus almost directly when badly constructed roads persist. Runoff collected on roofs and driveways may travel unhindered down roads to the lake. Although nonshoreline homes are not as threatening as shoreline residences, watersheds having large residential areas with improper drainage can have a significant effect on phosphorus loading.

Tributaries can make nonbuffered, nonshoreline residences every bit as much of a nutrient loading hazard as a shoreline residence with a large lawn . Phosphorus washed from residential lawns without buffer strips can enter into a stream and eventually into the lake. Even when far from the shoreline, a residences can have a significant impact, especially if it is near a stream which leads into the lake. Therefore, similar restrictions and regulations as those for shoreline residences apply to nonshoreline homes that are located along streams.

Sewage Disposal Systems

Subsurface wastewater disposal systems are defined in the State of Maine Subsurface Wastewater Disposal Rules as: "a collection of treatment tank(s), disposal area(s), holding tank(s), alternative toilet(s), or other devices and associated piping designed to function as a unit for the purpose of disposing of wastewater in the soil" (MDHS 1988). These systems are generally found in areas with no municipal disposal systems such as sewers. Examples of these subsurface disposal systems include pit privies and septic systems, both of which are found in the Messalonskee Lake watershed.

Pit Privy

Pit privies are also known as outhouses. Most privies are found in areas with low water pressure systems. They are simple disposal systems consisting of a small, shallow pit or trench. Human excrement and paper are the only wastes that are able to be decomposed and treated. Little water is used with pit privies. Therefore chances of contamination of ground water are reduced. Contamination may occur if the privy is located too close to a body of water due to infiltration of waste into the upper soil levels.

Holding Tank

Holding tanks are watertight, airtight chambers, usually with an alarm, that hold waste for periods of time. The tanks are durable and made of either concrete or fiberglass (MDHS 1988). The minimum capacity for a holding tank is 1500 gallons. These must be pumped or else they could back up into the structure or may leak into the ground, causing contamination. According to Bob Martin (pers. comm.), the plumbing inspector for Belgrade, holding tanks are, "the system of last resort." The reason for his opinion may be that although purchasing a holding tank is inexpensive, the owner is then required to continually pay to have that holding tank pumped.

Septic System

Septic systems are the most widely used subsurface disposal system. They are also the most complex system for wastewater disposal. The system includes a building sewer, treatment tank, effluent line, disposal area, distribution box, and occasionally, a pump. The pump enables the effluent to be moved to a more suitable location if the location of the treatment tank is unsuitable for a leaching field (MDHS 1983). Figure 6 shows the basic layout of the components of a typical septic system. They are an efficient and economical alternative to a sewer system, provided they are properly installed. Unfortunately, many septic systems that are not installed properly may lead to nutrient loading and groundwater contamination. The location of the systems and the soil characteristics determine the effectiveness of the system.

The distance between a septic system and a body of water should be sufficient so that there is no contamination of the water. The shoreline regulations in Belgrade state that septic systems need to be at least 100 ft away from a lake and 75 ft away from streams (Belgrade 1991). Unfortunately, many parcels of land are grandfathered, which means their septic systems were installed before the passage of current regulations. Therefore, those systems may be closer to the shore than is currently permitted. However, any replacement systems in these grandfathered areas must reflect the new regulations. Replacement systems can either be completely relocated, or an effluent pump installed on the outside of the existing treatment tank can be used to move the sewage uphill to a new disposal area that is away from the pond (MDHS 1983).

Human waste and gray water can be transferred from the house through the building sewer to the treatment tank. There are two kinds of treatment tanks, aerobic and septic (MDHS 1983). The aerobic tanks rely on aerobic bacteria, which are more active. Unfortunately, they are also more susceptible to condition changes. These tanks also require energy to pump in fresh air, more maintenance, and are more expensive. For these reasons, the septic tank is preferable. Septic tanks rely on anaerobic bacteria. Both tanks are water-tight, durable, and usually made of concrete or fiberglass. Raw materials are held until they are more suitable for discharge (MDHS 1983).

As the physical, chemical, and biological breakdowns occur, scum and sludge are separated from the effluent. Figure 7 shows the cross section of a typical treatment tank. Scum is the layer of grease, fats, and other particles that are lighter than water and move to the top of the treatment tank. Scum is caught in the baffles so that it cannot escape into the disposal area. Sludge is composed of the solids that sink to the bottom of the tank. Over time, much of the scum and sludge is broken down by anaerobic digestion. The effluent, which has received a primary treatment, then travels through the effluent line to the disposal area.

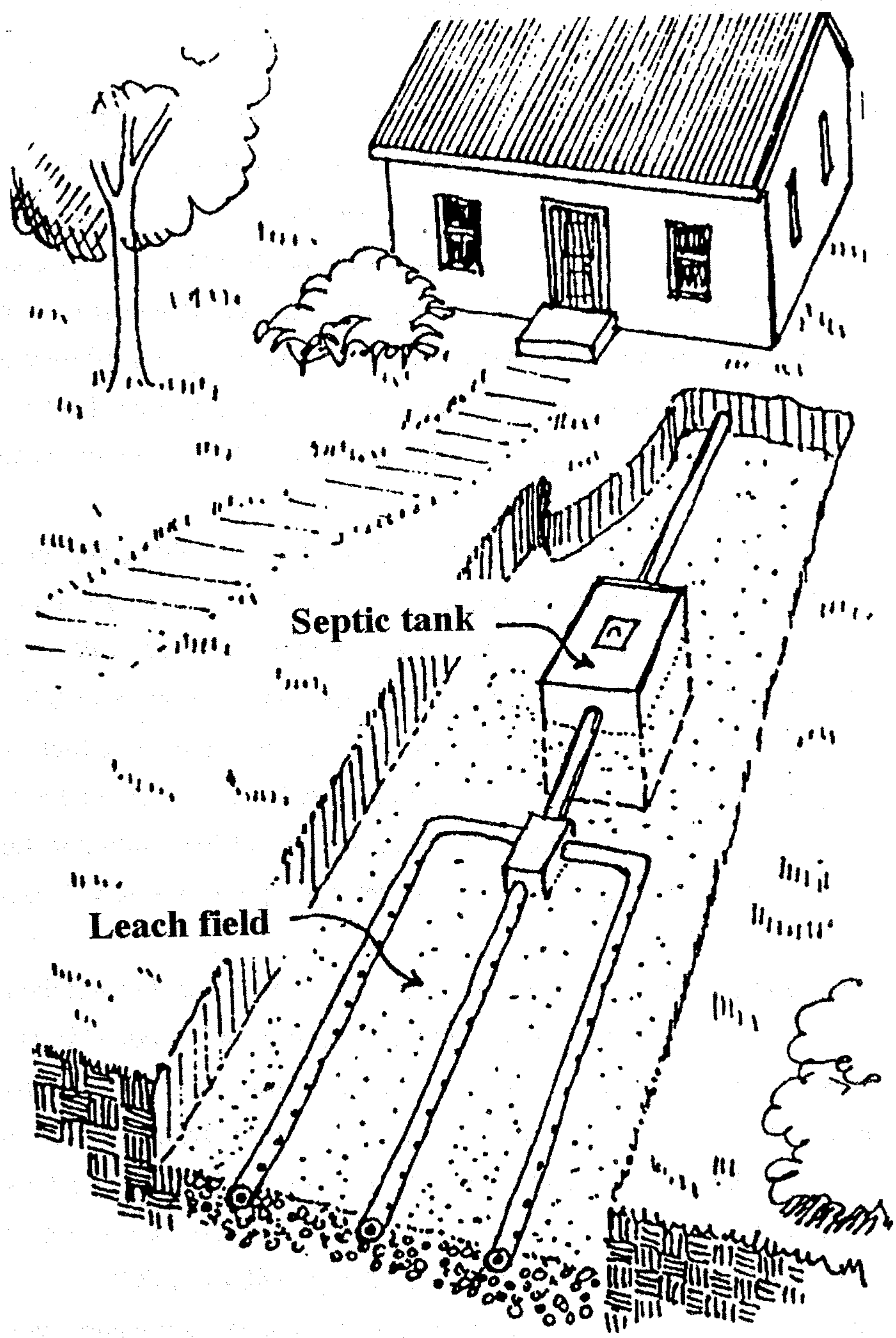

Figure 6. The layout of a typical septic system (Williams 1992)

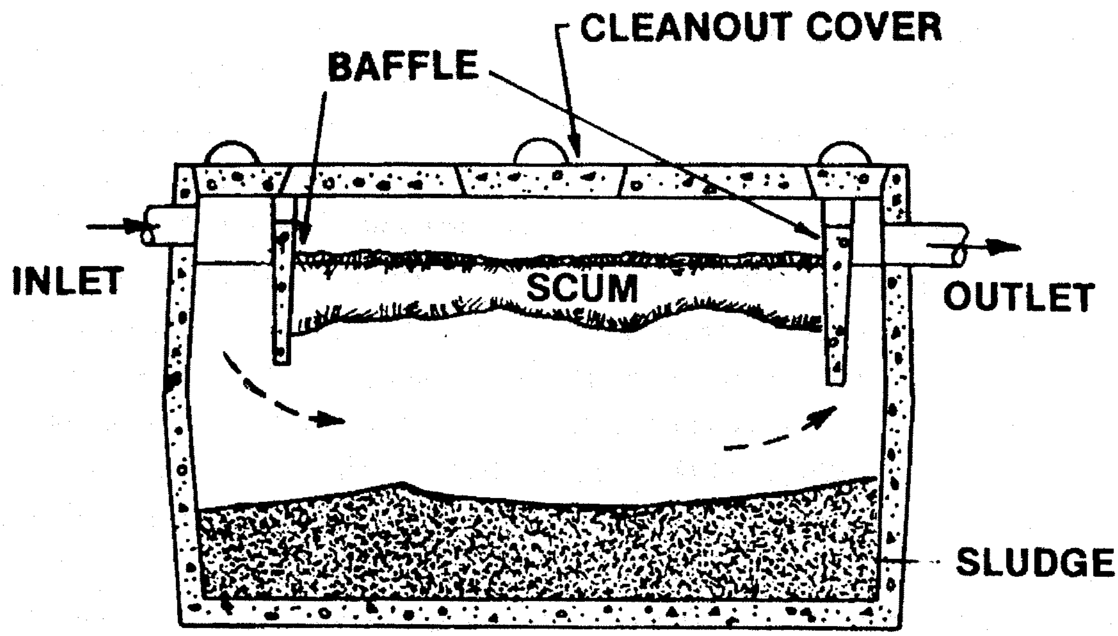

Figure 7. The cross-section of a typical treatment tank showing the movement of effluent through the tank as well as the separation of the scum and sludge (MDHS 1983).

The purpose of a disposal area is to provide additional treatment of the waste water. The disposal area can be one of three types: bed, trench, or chamber (MDHS 1983). Beds are wider than trenches, and usually require more than one distribution line; typically, beds need a distribution box. Chambers are made of pre-cast concrete. The size of the disposal area depends on the volume of water and soil characteristics. The soils in the disposal area serve to distribute and absorb effluent, provide microorganisms and oxygen for treatment of bacteria, and remove nutrients from the wastewater through chemical and cation exchange reactions (MDHS 1983). Effluent is anaerobic as it leaves the treatment tank, therefore will need to be treated aerobically in the disposal field to kill the anaerobic bacteria before treatment is considered complete. If the effluent is not treated completely, it can be a danger to the water body and the organisms within it, as well as to human health. Three threats to lakes include organic particulates which increase biological oxygen demand (BOD), nutrient loading, and water contamination through the addition of viruses and bacteria (MDHS 1983).

BOD is the oxygen demanded by decomposers to break down organic waste in water. Organic matter will increase if there is contamination from human and animal wastes. As the amount of organic material increases, BOD increases. If the BOD exceeds dissolved oxygen, species within the lake may begin to die. If the flushing rate is low, dissolved oxygen content and increasing organic matter could become problematic.

The three major types of wastes that travel into the septic system include garbage disposal wastes, black water, and gray water. The garbage disposal wastes can easily back up the septic system and therefore should not be added to the septic system. Black water and gray water are significant contributors of phosphorus. Black water also contributes nitrogen, toilet wastes, and microorganisms. Gray water brings in chemicals and nutrients. Once a system is clogged or a leak develops, humans are exposed to potential bacterial and viral contamination (MDHS 1983).

Reducing the chances of clogging will allow septic systems to be the most efficient. Year-round residents should have their septic tanks pumped every two to three years, or when the sludge level fills half the tank (Williams 1992). Seasonal residents should pump their septic tanks every five to six years to prevent clogging from occurring in the disposal field. Garbage disposals place an extra burden on a septic system (Williams 1992). Cigarette butts, sanitary napkins, and paper towels are not easily broken down by the microorganisms and end up filling the septic tank too quickly. The disposal of chemicals, such as pouring bleach or paint down the drain, may also affect septic systems by killing microorganisms. Water conservation slows the flow through the septic system and allows more time for bacteria to treat the water. By decreasing the amount of water passing through the disposal field, the septic system can work more effectively and recover after heavy use (Williams 1992). Odors, extra green grass around the septic cover, and slow drainage are symptoms of a septic system that has been used heavily, and is now having problems.

When constructing a septic system, it is important to determine the best place on the lot for the system based on soil characteristics and topography. An area with a gradual slope (10 to 20%) that allows for gravitational pull is necessary for proper sewage treatment (MDHS 1988). Too little a slope causes stagnation, while too steep a slope drains the soil too quickly. Time for treatment is cut short and water is not treated properly. Adding or removing soils to decrease or increase the slope can solve this problem.

Soil containing loam, sand, and gravel allows the proper amount of time for runoff and purification (MDHS 1983). Table 3 shows the soil conditions and types that are needed to install an effective septic system. Soil cannot be too porous, otherwise water runs through too quickly and is not sufficiently treated. Depth of bedrock is another important consideration. If the bedrock is too shallow, the waste will not be able to sink and will rise back up to the surface of the soil. Clays and thin (fine) soils do not allow for water penetration and again water will run along the surface untreated. A solution to this would be to add loam and sand to improve the permeability. If a soil drains too quickly, loam and clay can be added to slow the movement down.

Federal, state, and local laws are established to protect the land and water quality. The federal government sets the minimum standards for subsurface waste disposal systems. The states then can make these rules more strict. The states set new minimums according to the federal laws. Examples include minimum setback for septic systems and no new septic systems on a flood plain (MDHS

Table 3. Soil Characteristics that determine the soil suitability for a septic system (MDHS 1983).

PARENT MATERIAL	SOIL PROFILE	TEXTURAL CLASSIFICATION and DESCRIPTIONS	SOIL CONDITIONS: SHALLOW to BEDROCK — A BEDROCK — I [illegible]	II 10" to 14"	III [illegible]	DRAINAGE — B WELL DRAINED Ground Water Table greater than 48"	C MODERATELY WELL DRAINED Ground Water Table between [illegible]	D SOMEWHAT POORLY DRAINED Ground Water Table between [illegible]	E VERY POORLY DRAINED Ground Water Table less than [illegible]	DISPOSAL AREA RATING SEC. 12
GLACIAL TILL	1	Silt loam soils which tend to become more compact with depth. A restrictive layer may be present. Angular coarse fragments may be present.		4	2	1	1	3	4	LARGE
GLACIAL TILL	2	Loam to sandy loam soils which do not have a restrictive layer. Angular coarse fragments may be present.		4	2	1	1	3	4	MEDIUM LARGE
GLACIAL TILL	3	Loam, sandy loam to loamy sand soils with a restrictive layer. Angular coarse fragments may be present.		4	2	1	1	3	4	MEDIUM LARGE
GLACIAL TILL	4	Sandy loam to loamy sand overlying loamy sand soils derived from ablation till. Coarse fragments (angular to rounded) may be present. No restrictive layer throughout profile.		4	2	1	1	3	4	MEDIUM
STRATIFIED DRIFT	5	Loam to sandy loam soils overlying stratified fine and medium sands. Rounded coarse fragments may be present.		4	2	2	2	3	4	MEDIUM
STRATIFIED DRIFT	6	Loamy sand soils overlying stratified sands and gravel. Round coarse fragments may be present.		4	2	2	2	3	4	SMALL
MIXED ORIGIN	7	Loamy sand to sand overlying a restrictive layer of silt to silty clay which occurs at a depth of 15 inches or greater. Coarse fragments may be present in upper horizons, but usually absent in lower horizons.		4	2	1	1	3	4	MEDIUM LARGE
LACUSTRINE MARINE	8	Loam to fine sand overlying firmer silt loam to silt. A restrictive layer may be present. Coarse fragments usually absent. Stratified lenses of very fine sand, silts and clays may be present in the substratum.		4	2	1	1	3	4	LARGE
LACUSTRINE MARINE	9	Silt loam soils overlying firm silt loams to silty clays exhibiting a restrictive layer of coarse fragments are usually absent.		4	2	1	1	3	4	EXTRA LARGE
ORGANIC	10	Soils composed of organic materials in various stages of decomposition.								
ALLUVIAL, DUNE, BEACH	11	Variable in texture. Exhibiting very little weathering. Deposited in flood plain, sand dune or beach environment.				5	5			SEC. 11.F 11.G

ALL SYSTEMS PERMITTED
Note 1 See 11.C.2.a.I for Separation Distances.
Note 2 See 11.C.2.a.II and 11.C.2.b for Separation Distances

Severe Limitations REPLACEMENT SYSTEMS MAY BE PERMITTED (Sec. 15)
Note 3 See Sec. 15 for Replacement System Variance by LPI. See 11.C.2.a & 11.C.2.b for Separation Distances.

Very Severe Limitations REPLACEMENT SYSTEMS MAY BE PERMITTED if no alternative. NEW SYSTEMS NOT PERMITTED.
Note 4 See Sec. 15 for Replacement System Variance with Department Review. See 11.C.2. for Separation Distances.

Extremely Severe Limitations. SYSTEMS NOT PERMITTED
Note 5 See Sec. 11.F for Coastal Sand Dune limitations. See Sec. 11.G for Flood Plain limitations.

1983). Maine's Comprehensive Land Use Plan sets the standard regulations that each city and town must follow. Each town can set up their own land use plan, according to the state regulations, but many just develop local ordinances that consider specific things such as shoreline zoning. The MDEP, Department of Conservation, and local Code Enforcement Officers are responsible for overseeing the enforcement of these laws.

Since 1974, state mandates have prevented septic systems from being installed without a site evaluation or within 100 ft from the high water mark. Other regulations state that there must be no less than 300 ft between a septic system disposal field and a well that uses more than 2000 gallons per day and no systems can be built less than 100 ft away from any well when the septic system uses less than 2000 gallons per day (MDHS 1988). Also, 20% is the maximum slope of the original land that can support a septic system. These regulations are in place for the safety of the people living in the Messalonskee lake watershed as well as for the ecosystem within the lake. By following these mandates, safe and efficient septic systems can be installed and used.

Roads

Roads can greatly contribute to water quality deterioration by adding to phosphorus loading within the watershed. They do this by creating an easy access route for runoff from the land into the lake. This is especially prevalent for roads that lead directly down to the water. Besides adding phosphorus, they may allow easy access for runoff of other nutrients and organic pollutants into the lake via improperly constructed culverts and ditches. Improper construction and maintenance can increase the nutrient input caused by roads.

Proper drainage of roads is very important when trying to control phosphorus loading within a watershed. Construction materials, such as pavement, dirt, or gravel, may influence the amount and rate of runoff (Woodard 1989). The inevitable erosion of these building materials due to road traffic causes deterioration of the road surface. Storms help to deteriorate the road even more rapidly by dislodging particles from the road surface and carrying them away. These particles may then runoff as sediment into the lake, carrying a large amount of phosphorus with them. Roads may therefore be a large source of phosphorus loading to a lake if poor construction, maintenance, and/or erosion control practices occur (Michaud 1992).

Road construction should try to achieve the following long-term goals: minimize the surface area covered by the road, minimize runoff and erosion with proper drainage and the placement of catch basins (as well as culverts and ditches), and maximize the lifetime and durability of the road (MDEP 1990). Thus, a well constructed road should allow surface water to run off away from the road and divert road surface waters to prevent excessive amounts of surface runoff, phosphorus, and other nutrients from entering the lake. This may be done by considering the following items before road construction begins: road location, road area, road surface material, road cross section, road drainage (ditches, diversions, and culverts), and road maintenance (MDEP 1992a).

The location of a road is typically determined by the area in which homes are built, although the State of Maine has set guidelines to control the location of roads (MDEP 1990). All roads must be set back at least 100 ft from the shoreline of a lake if they are for residential use, and 200 ft for industrial, commercial, or other non-residential uses involving one or more buildings (MDEP 1991). Along with this limit, a new road in Belgrade should not be built with a grade of more than 10%, except for short segments of less than 200 ft (Belgrade 1991).

The surface area that a road occupies can also lead to an increased potential for erosion and runoff, and therefore must be limited. Thus, it is very important to design a road with its future use in mind. For instance, a road should be constructed no longer than is absolutely necessary. A particular road should not be extended past the last structure that is to be serviced by that road. The width of a road, which is often based upon the maintenance capabilities of the area, must also be considered (Cashat 1984). If a group is not able to maintain the proposed road because of maintenance costs, it should build a road that is not as wide so that maintenance costs will be lower. Proper planning for maintenance is typically a more effective, practical, and less expensive way to develop the road area (Woodard 1989).

Road surface material is another important factor to consider when building a road. Studies have shown that phosphorus washes off a road at a higher rate from a paved surface than it does from a sand and gravel surface (Lea, Landry, and Fortier 1990). On the other hand, sand and gravel roads erode more quickly and therefore have the potential for emptying more sediment, and therefore more nutrients, into a water body. Consequently, pavement is chosen for roads with a high volume of traffic, while sand and gravel roads are typically used for low traffic areas or seasonal use patterns. Both types of roads need proper maintenance and road surfaces should be periodically replaced and properly graded so that a stable base may be maintained and road surface erosion will be minimized.

The road cross section is another important factor to consider when planning to build a road. A crowned road cross section allows for proper drainage to take place and helps in preventing deterioration of the road surface (MDOT 1986). This means that if the road is pictured in cross section, it will slope downward from the middle, towards the outer edges. The crown should have a slope of 1/8 to 1/4 inches per foot of width for asphalt and 1/2 in to 3/4 in per foot of width for dirt roads (Michaud 1992). This slope allows the surface water to run off down either side of the road as opposed to running over its whole length. Road shoulders should also have a slightly steeper cross slope than the road itself so that runoff can flow into a ditch or buffer zone (Michaud 1992).

The drainage of a road must also be considered when constructing it. Both ditches and culverts are used to help drain roads into buffer zones so that runoff will not enter the lake directly and buffer strips will absorb some of the nutrients from the road. These measures are also used in situations for handling runoff that may be blocked by road construction. Ditches are necessary along wide or steep stretches of road to divert water flow off the road and away from a body of water. They are ideally parabolic in shape with a rounded bottom and are of a sufficient depth, not exceeding a depth to width ratio of 2:1. The ditch should also be clean and free of debris, and covered with abundant vegetation to reduce erosion (Michaud 1992). These ditches must also be constructed of proper soil that will not erode easily from the velocity of waters passing through them.

Culverts are hollow pipes that are installed beneath roads to channel water in proper drainage patterns. The most important factor to consider when installing a culvert is its size. It must be large enough to handle the expected amount of water which will pass through it. If this is not the case, water will tend to flow over and around the culvert and wash out the road. This may increase the amount of erosion that is occurring on the road and thus increase the sediment load that may enter the lake. The culvert must be set in the ground at a 30° angle down slope with a pitch of 2% to 4% (Michaud 1992). A pitch greater than 4% can lead to rapid velocity of water flowing through. An increase in velocity can cause erosion to fill the culvert and result in washout on the low side below the road. It is also important to have a proper crown above the culvert to avoid creating a low center point in the culvert. The standard criteria for crowning above culverts is one inch of crown for every 10 ft of culvert length (Michaud 1992). The spacing of culverts is based upon the road grade.

Diversions allow water to be channeled away from the road surface into wooded or grassy areas. These are important along sloped roads, especially those leading towards a lake. By diverting the water into wooded or grassy areas, natural buffers are used to filter sediment and decrease volume through infiltration before the water reaches the lake, along with preventing the water from gaining velocity (Michaud 1992). Efficient installation and spacing of diversions can also eliminate the use of culverts (Michaud 1992).

Maintenance is very important to keep a road in good working condition as well as to prevent it from causing problems for the lake. Over time, extensive use and wear will cause a road to deteriorate. These problems will only become worse if ignored and will therefore cost more money in the long run to repair. Roads should be periodically graded, ditches and culverts cleaned and regularly inspected to assess any problems that may develop. These practices will help to preserve the water quality of the lake and will add to its aesthetic value.

Agriculture and Livestock

Agriculture can cause many problems within the watershed of a lake. Plowed fields and livestock grazing areas are potential sources of erosion, which could carry sediments and nutrients to the lake and have an adverse effect on the water quality (Williams 1992). To minimize these problems there are ordinances that prohibit new tilling of soil and new grazing areas within 100 ft of a lake or river. Problems can still exist, however, with areas that were in use before these ordinances were passed by the State of Maine in 1990. According to the Shoreline Zoning Act, these areas can be maintained as they presently exist and therefore may result in decreased water quality and increased erosion (MDEP 1990). Additional solutions to the problems related to tilling of soil are to plow with the contour lines (across as opposed to up and down a slope) and to strip crop.

Another potential agricultural impact on water quality is manure from livestock. Manure becomes a problem when it is spread as a fertilizer, which is a common agricultural practice. Manure spreading can lead to nutrient loading, especially in the winter when the ground is frozen and the nutrients do not have a chance to filter into the soil. These problems become worse with the tendency to over fertilize. To help prevent these problems the state has passed zoning ordinances which prohibit the storage of manure within 100 ft of a lake or river (MDEP 1990). Another solution may be to avoid spreading manure in the winter. The town may provide subsidies as an incentive if the problem is large enough. These solutions, though, do not address the problem of livestock that defecate close to water bodies that they may be drinking near. One solution for this may be to put up fences to keep the cattle away from the water. Runoff from the use of artificial fertilizers and pesticides is another way in which nutrients and other pollutants may end up in the lake. These problems can be minimized by only fertilizing during the growing season and not before storms. Pesticides can also lead to negative impacts on water quality. Alternative methods of pest control are available however, including biological controls like integrated pest management and inter-cropping, which is a planting alternating rows of different crops in the same field.

Forestry

Forestry is another type of development that can contribute to nutrient loading through erosion and runoff. The creation of logging roads and skidder trails may direct runoff into the lake. The combination of erosion, runoff, and pathways can therefore have a large impact on the water quality of a lake (Williams 1992). Again, there are state shoreline zoning ordinances which relate to these specific problems to minimize the damage done to a lake. For example, timber harvesting equipment, such as skidders, cannot use streams as travel routes unless the streams are frozen and traveling on them causes no ground movement (MDEP 1990). There is also a local ordinance which prohibits clear-cutting within 75 ft of the shoreline of the lake or river running to the lake. At distances greater than 75 ft, harvest operations cannot create clear-cut openings greater than 10,000 ft^2 in the forest canopy, and if they exceed 500 ft^2, they have to be at least 100 ft apart. These regulations are intended to minimize erosion (MDEP 1990). In order for these laws to be effective they have to be enforced. This may be a difficult task for most towns since they do not have the budgets necessary to regulate these areas. Therefore, illegal forestry techniques may occur and negatively impact lake water quality.

Tree farms are also a component of many watersheds, including the Messalonskee Lake watershed. These farms can be managed privately or federally. A problem may occur here depending on the purposes of the farm. For example, a tree farm may have been purchased to conserve the area, in which case there would be limited runoff. This is because forests have the ability to act as a natural buffer for the nutrients going into a lake, if left undisturbed. On the other hand, most tree farms are raised for economic reasons, namely to harvest the trees. This use may be a problem if the farmer does not consider the value of the forest, other than timber production, before clear-cutting the area (Clawson 1975). Pesticides and fertilizers are sometimes used on tree farms, therefore, logging practices and tree harvesting are important issues in considering water quality. There are a few areas which have been logged recently and several tree farms located in the Messalonskee Lake watershed.

Cleared Land

Cleared land also presents problems of erosion and nutrient runoff due to the large areas that have been cleared of trees and other vegetation which act as natural filters. Sediments from these cleared areas could create a problem because they carry large amounts of nitrogen, phosphorus, other plant nutrients, and chemicals to the lake. Without vegetation acting as a buffer these problems are made even worse. Since pasture land is created by the replacement of natural vegetation with forage crops, it is included in this category. Also included in this category are large grassy areas, such as lawns and parks.

The MDEP (1990) has established some guidelines for cleared land. For example, there can be no cleared openings greater than 250 ft^2 in the forest canopy within 100 ft of a lake or river. Where there are cleared lands, some solutions to minimize erosion may be to build terraces, which would decrease the flow of storm water down a slope allowing the nutrients to settle out before they get to the lake. Plowing parallel to the contour lines, as suggested for agricultural uses, will decrease the flow of storm water. These two solutions may prevent erosion by breaking up large areas of tilled soil.

Reverting Land

Before any form of development occurred in the Messalonskee Lake watershed, the entire watershed was covered primarily in forest. As a result of population increases in the 1920s and 1930s, much of the forest surrounding the lake was cleared for multiple purposes such as agricultural, residential, industrial and recreational. In recent years, much of the land in the Messalonskee Lake watershed has been allowed to return to its natural state through the process of succession (see Background: Lake Characteristics).

Succession is the replacement of one vegetative community by another which results in a mature and stable community referred to as a climax community (Smith 1992). An open field ecosystem moves through various successional stages before it develops into a mature forest. Reverting land characterizes the earliest stages of open field succession involving the establishment of smaller trees and shrubs throughout a field. Intermediate and later successional stages involve the growth of larger, fuller tree species. The canopy of this forest is more developed, as a result, less light reaches the forest floor. This land use type, in which a forest is nearing maturity and contains over 50% mature trees, has been referred to as regenerating land.

Wetlands

There are different types of wetlands that may be found in a watershed. A bog, which is dominated by sphagnum moss, sedges and spruce, has a high water table (Nebel 1987). Fens are open wetland systems that are nutrient rich and may include such species as sedges, sphagnum moss, and bladderwort. Marshes have variable water levels and may include cattails and arrowheads (Nebel 1987). Swamps are waterlogged soils and can either be of woody or shrub types. Shrub swamps consist of alder, willow, and dogwoods while woody swamps are dominated by hemlock, red maple, and eastern white cedar (Nebel 1987). Wetlands are important because they contain a variety of animals, such as waterfowl and invertebrates (Nebel 1987).

The type of wetland and its location in a watershed are important factors when determining whether the wetland is a nutrient sink or source, that is, whether it prevents nutrients from going into the lake or contributes nutrients to the lake. It is also important to note that one wetland may be both a source and a sink for different nutrients. This characteristic may vary with the season as well, depending on the amount of input to the wetland. Vegetation is important because different flora take up different nutrients. For example, willow and birch store more nitrogen and phosphorus than sedges and leatherleaf (Nebel 1987). This indicates that shrub swamps are a better nutrient sink than the other types of wetlands. Also, if nutrient sink wetlands are located closer to the lake, they will act more as a buffer, as opposed to ones further back in the watershed. Wetlands that do filter out nutrients are an important factor in controlling the water quality of a lake. These wetlands also help moderate the impact of erosion near the lake. Unfortunately, there are not enough incentives or regulations to protect these areas (SFI 1991). Without these regulations, water quality in some areas may decrease.

Although there are some regulations controlling wetland use, a lack of enforcement leads to development in, and therefore destruction of, wetlands. These areas should be protected by the Resource Protection Districts, which limit development to 250 ft away from the wetland. Wetlands, however, may be found in desirable areas, such as near a lake, which increases the likelihood of development even though these regulations exist (Nebel 1987). Therefore, the decrease of wetlands caused by development will most likely have negative effects on the water quality of a lake due to runoff, erosion, and a decrease of natural buffering.

Messalonskee Lake Characteristics

Geological and Hydrological Perspectives

Messalonskee Lake, along with the other lakes in the Belgrade region, was formed by continental collision and glacial scouring. During the Ice Ages, several continental glaciers covered the state of Maine extending down from the Arctic Circle through Canada. Large debris, particularly granites from the northern regions of Maine, caught in the ice scoured the land during the slow migration of the glaciers to the sea. As the glaciers melted, the debris, known as glacial outwash, was sorted and stratified, leaving deltas of distinct layers stacked on top of each other. These deltas were formed as the outwash from the melting glaciers ran into the Atlantic Ocean which, at times, extended past (northwest of) the Belgrade Lakes region (Nelson, pers. comm.).

Continental collision is a phenomenon that has occurred several times over the history of the Earth. During these periods of contact, the North American continental plates were forced against the European plates causing extensive folding in the surficial and bedrock deposits both along the coast and throughout southern and central Maine.

Messalonskee Lake was first formed by the folding of the native bedrock (Nelson, pers. comm.). Here the large pieces of bedrock were folded due to pressure from the south-east, causing a "sandwiching" of nonbedrock material between the harder bedrock. This material trapped between the native bedrock was then scoured out by the large rocks and smaller sediments carried by the slow moving glaciers towards the sea. The result was a deep lake basin oriented in a southwestern to northeastern fashion. Currently, the lake is slowly being filled in by the deposition of the small sediments carried in by tributaries and runoff.

Long periods of glacial meltwater flow left well sorted glacial outwash sediments, consisting mostly of sand and gravel, throughout the state of Maine. Many of these sand and gravel deposits have been and are presently being excavated for use as concrete and gravel material. Because these sediments are so well sorted, they are very porous, drain quickly and hold little drinkable water. Due to this high permeability, little subsurface ground water is flowing through the Messalonskee Lake watershed. Most of the underground water is trapped in small joints and fractures in the bedrock (Nelson, pers. comm.). These small reservoirs require most homeowners to dig separate wells as the groundwater availability is not enough to support multiple houses on a single well.

Historical Perspectives

In 1905, the first dam was built on Messalonskee lake, in Oakland where the present dam is currently operated. The installation of this dam resulted in a three to four foot rise in the water level of the lake. Many shoreline areas were flooded and most of the vegetation present in that zone was killed (Bacon, E., pers. comm.). Eighteen years later in 1923, Central Maine Power rebuilt the original dam and installed one of the region's first hydroelectric generators to meet the growing demand for electricity, primarily from the electric street cars running daily between Oakland and Waterville (Bacon, E., pers. comm.). The hydroelectric generator also provided the first source of consistent energy for the surrounding areas. The next major project to affect the lake, was the construction of the Oakland water system in 1934, which supplied water to many homes and businesses (Bacon, E., pers. comm.).

Before the advent of modern transit, trains and horses were the predominant forms of transportation. In 1947, the paving of Route 23 was completed and regular automobile and tractor use allowed for more accessibility during winter months (Hume, pers. comm.). Even before reliable and efficient over-land travel was made available, people had been living on Messalonskee Lake for several decades. As a result of partial isolation, particularly in winter months, self-sufficiency was an important concern to most residents. Subsistence agriculture was practiced to ensure year-round food availability. Farmland acreage peaked in the mid to late 1930s at an estimated 6500 acres that produced tremendous yields of corn, string beans, and potatoes (Bacon, E., pers. comm.). The majority of the farmland was concentrated along the lake's perimeter, where water for irrigation and livestock was easily accessible. Many of the young people in the area who did not farm, or who needed to supplement their incomes, worked at the Oakland cannery where they canned corn and string beans grown in the area. In addition to corn and beans, potatoes were extensively harvested, loaded onto trains and shipped south to Portland, Boston, and Connecticut. The timber industry also supplied employment for non-farmers. Trees were cut and shipped by train to many cities throughout New England and were used for boat building, construction, or paper pulp (Bacon, E., pers. comm.).

World War II brought significant changes to the region's land use as young men left the area, traveled south, and found jobs in the war time labor force. Earning a predictable wage and working a fraction of the time they were used to, these men returned in the mid to late 1940s with a completely different perspective on earning a living (Bacon, E., pers. comm.). As a result of increased commercial and industrial growth, more options for employment, and the construction of better roads, the amount of cultivated land began to decline rapidly.

During the early 1960s, the towns surrounding the lake agreed that the construction of camp roads and the subdivision of large farm plots on the shoreline would increase residential development and would consequently be beneficial for commercial and municipal profit and growth (Bacon, E., pers. comm.). These predictions were correct. Seasonal residential development has increased drastically, so much so that currently there is very little available shoreline property left. Today, only about 1400 acres are currently under cultivation, mostly producing hay and corn (see Land Use: Cleared Land). The remaining 5100 acres which were previously farmed, have or are going through the processes of regenerating or reverting back to the native woodland species.

In recent years development has continued. However, now the majority of construction is for year-round residences (Bacon, L., pers. comm.). Most of these homes are built to accommodate the growing number of people moving away from urban settings like Augusta and Waterville. Increases in year-round residences in addition to increased boat, plane, and jet ski traffic, have implications for phosphorus loading which leads to progressive eutrophication of the lake.

Biological Perspectives

Messalonskee Lake is a dimictic, marginally eutrophic lake. Dimictic lakes are characterized by seasonal stratification of the water column (Chapman 1996). The trophic status of a lake is based mainly upon the amount of primary production, defined as the conversion of light or chemical energy into organismal tissue (Davis et al. 1978). There are several ways to determine the trophic status of lakes (see Background: Trophic Status of Lakes). Common indicators of trophic status are transparency, chlorophyll-a, and total phosphorus concentrations in the water column. Transparency is a measure of the amount of suspended solids and phytoplankton, and it is commonly measured with a Secchi disk. Lower transparencies indicate higher primary productivity levels which are characteristic of eutrophic lakes.

The concentration of chlorophyll-a and total phosphorus reflects the extent of primary production. Sharp increases in the amount of primary production, such as algal blooms, can turn lakes an unnatural color or even make the water poisonous for animals to drink (Reid 1961). Messalonskee Lake, like most Maine lakes, has moderate primary productivity (NKRPC 1990).

Another important characteristic of lakes is their buffering capacity, the ability of a lake to neutralize acid from a source like acid rain. The alkalinity of a lake determines its ability to buffer acid. Alkalinity is a measure of calcium carbonate in the water (Pearsall 1991). As a pH buffer and inorganic carbon reserve, calcium carbonate affects the water's capacity to support algal growth and other aquatic life. Lakes with an alkalinity of less than 4 ppm of calcium carbonate can be damaged by acid rain. Lakes with an alkalinity higher than 10 ppm can endure acid rain and maintain a stable environment for their inhabitants. Maine lakes range from 4 ppm to 20 ppm calcium carbonate (Pearsall 1991) with a mean value of 12.2 ppm as reported by the MDEP based on a sample size of 533 lakes. Problems with excessively low pH or alkalinity are not evident in the average Maine lake (Stauffer 1990). By neutralizing acid, the lake maintains a relatively constant pH. The pH reflects the concentration of hydrogen ions in the water. The pH of Maine lakes typically range from 6.1 to 6.8 (Davis et al. 1978) with a mean of 6.7 (MDEP 1994a).

Plants and animals are sensitive to changes in pH, and some species have narrow ranges in which they can exist. Increased acidity decreases the viability of some aquatic organisms and can lead to local extinction of a species (Pearsall 1991). pH levels of 6.0 or lower cause the death of snails and crustaceans; a pH of 5.5 kills salmon and whitefish; at 5.0 perch and pike die, and pH levels of 4.5

have an effect on eel and brook trout. Slight variations in the trophic status or pH of a lake can cause drastic changes in the composition of local and surrounding ecosystems.

Lakes define and influence surrounding habitats. The boundaries of local habitats have highly characteristic zonation and stratification (Smith 1992). Messalonskee Lake supports a wide variety of habitats ranging from the surface film and open water to the bottom and littoral zones and the surrounding wetlands which support many different species (MLURC 1976; see Introduction: Freshwater Wetlands). Autotrophic organisms such as bacteria, protists, and plants form the base of the food chain. Nutrients and energy move through both the grazing and detrital food chains (Smith 1992). Primary producers take inorganic nutrients and solar energy and fix them in organic molecules. Grazers feed off the primary producers and carnivores in turn eat the grazers. Detritivores recycle nutrients tied up in dead organic material and return them to the nutrient pool.

The major groups of freshwater algae are green algae, euglenoids, dinoflagellates and diatoms (Reid 1987). Cyanobacteria are also present. Two species of cyanobacteria, *Aphani zomenon* flos-aqua and *Anabaena planktonica*, were part of the algal blooms of the 1970's in Salmon Lake (Nichols, Sowles, and Lobao 1984). Diatoms often account for the majority of the phytoplankton community in Maine lakes (Dennis 1975). While phytoplankton populations peak in middle and late summer, they decrease during winter and spring (Davis et al. 1978). Fungi, liverworts, and mosses also inhabit freshwater areas. Many species of vascular plants are associated with lakes. Common lake flora are discussed in the wetlands section of the introduction of this report. Freshwater areas also support animal inhabitants. These include the simplest unicellular organisms, sponges, hydroids and worms, and the more commonly seen animals such as arthropods (insects and crayfish), snails, clams, and mussels. Vertebrates, such as fish, amphibians, reptiles, birds and mammals, are also found near or in lakes.

Messalonskee Lake, along with the rest of the Belgrade Lakes chain, has long been important for recreation, especially fishing. Messalonskee Lake has supported productive landlocked salmon (*Salmo salar*) and brook trout (*Salvelinus fontinalis*) fisheries in the past, but in recent years, a severe decline in the success of these fisheries has been observed (McNeish, pers. comm.). A brief stocking history of the lake and description of some of the problems facing the fishery help to put these changes into context.

Records of stocking in Messalonskee Lake have been kept by the Department of Inland Fisheries and Wildlife from 1954 to the present. The two major species stocked in the lake over the past fifty years have been brook trout and landlocked salmon (McNeish 1997). Brook trout were stocked from 1954 to 1958, and again from 1976 to 1992. Salmon were stocked on a yearly basis from 1959 to 1993 (with the exception of 1964) and comprised the main cold water fishery associated with Messalonskee Lake. Both of these fisheries were particularly strong in the 1960s but declined in productivity during the 1980s and 1990s. Splake, a hybrid cross between a brook trout and a lake trout, were introduced into Messalonskee Lake in the summer of 1994 and appeared to thrive (McNeish, pers. comm.). With the landlocked salmon fishery having been abandoned, the prospect of a splake fishery being introduced to replace it was very appealing. A three year experimental stocking program was proposed and implemented. During the course of May and June of 1997, approximately 31,000 splake were introduced into Messalonskee Lake. After three years, the program will be assessed and a decision will be made regarding the continued stocking of splake.

Among the important factors surrounding the decline in the salmon fishery in the past thirty years in Messalonskee Lake are depleted oxygen in the hypolimnion of the lake (see Background: Lake Characteristics), an increase in the number of predators in the lake, the lack of a strong forage base for the salmon and possibly an increase in the number of piscivorous, fish eating, birds in the watershed (McNeish 1997). Most salmon fisheries are cold water fisheries that are dependent on a high content of dissolved oxygen in the water. Following the spring turnover of the water column in most lakes, there is an increase in the amount of dissolved oxygen in the water. There is also an influx of phosphorus into the lake which causes increased algal and macrophytic growth and an overall decrease in the amount of dissolved oxygen in the lake (see Background: Lake Characteristics). It is likely that these lower levels of oxygen are associated with the failing salmon fishery (McNeish, pers. comm.).

Another possible problem associated with the decline in the salmon fishery in Messalonskee Lake is the increased number of predators in recent years (McNeish 1997). Northern pike (*Esox lucius*), white perch (*Morone americana*), and chain pickerel (*Esox niger*) are all popular game fish. While these species are native to Maine, not all of these predators are native to Messalonskee Lake. There are an unusually high number of predatory fish in the Belgrade Lakes due primarily to the enhancement of game fishing in the area (McNeish, pers. comm.). Northern pike were introduced during the late 1980s and have since become established in the Belgrade Lakes chain. Pike are voracious predators and are known to prey on salmon. In recent years, sampling of the adult salmon population in Long Pond has provided evidence supporting the theory of northern pike predation. The Department of Inland Fisheries and Wildlife has caught adult salmon with scars on their bodies, presumably from attacks by northern pike (McNeish, pers. comm.). The salmon, which are stocked in Messalonskee Lake, are generally no larger than 4 inches to 6 inches in length and are easily preyed upon by the larger predators. The population of salmon in the lake, therefore, may be thinned by heavy predation.

A third problem associated with the cold water fishery in Messalonskee Lake is the lack of a good forage base for the salmon (McNeish 1997). Salmon usually feed on smelt. The size of the salmon population and the rate at which it grows is dependent on the forage base. In Messalonskee Lake however, the smelt are particularly large and the salmon are not able to utilize them as a forage base (their main food supply) (McNeish, pers. comm.). This results in a slower growth rate for the salmon and ultimately a weaker fishery because the salmon are more readily attacked by predators and small salmon are not particularly reproductively successful.

Another factor limiting the success of the salmon fishery in Messalonskee Lake is the presence of a variety of piscivorous birds. These predatory birds cause a considerable amount of the mortality of the spring and fall yearlings (Wilson, pers. comm.). Some piscivorous species observed during our study of Messalonskee Lake include bald eagles, loons, double breasted cormorants, osprey, belted kingfishers, and black terns.

While these explanations for the decline of the salmon fishery are plausible, the size of the lake and the complexity of the system would indicate that there are other factors involved. For example, a comparison of Long Pond and Messalonskee Lake shows that the lakes are very similar in area, depth, biotic and abiotic factors (McNeish, pers. comm.). Despite these similarities, Long Pond supports a relatively successful salmon fishery while Messalonskee Lake does not. This example helps to demonstrate the complexity of the problem.

In addition to supporting a vast array of fish and waterfowl, the Messalonskee Lake watershed is home to many animal species which are of particular interest to the public (McNeish, pers. comm.). For example, deer, beaver, and muskrat are some of the species sought after by hunters and trappers. Also of particular interest are the pair of nesting bald eagles, the endangered black terns which nest in the marsh at the south end of the lake, the turkey vultures which have been seen circling overhead, and a sandhill crane which was sighted in July 1997. These animals are important not only to the ecology but also to the aesthetics of the lake.

Regional Land Use Trends

Several land use trends can be observed in the Belgrade Lakes region. There has been an overall decrease in the amount of land used for agriculture in the Messalonskee Lake, East Pond, and North Pond watersheds since the 1960s (Figure 8). Reverting and regenerating land increased overall as previously cultivated or cleared land was allowed to lie fallow (see Land Use: Reverting Land and Regenerating Land). In each of the three descriptive watersheds, residential development has increased over the last three decades (see Background: Historical Perspectives). This is indicative of the increased population of the Augusta and Waterville areas and the transition of seasonal residences to year-round residences. Forest cover has remained high in the region, and has even increased (e.g., in the Messalonskee Lake watershed; Figure 9).

Resource Protection

Resources are viewed as components of the environment that are of potential value to humans. Resource protected zones occur where development would negatively affect the biological

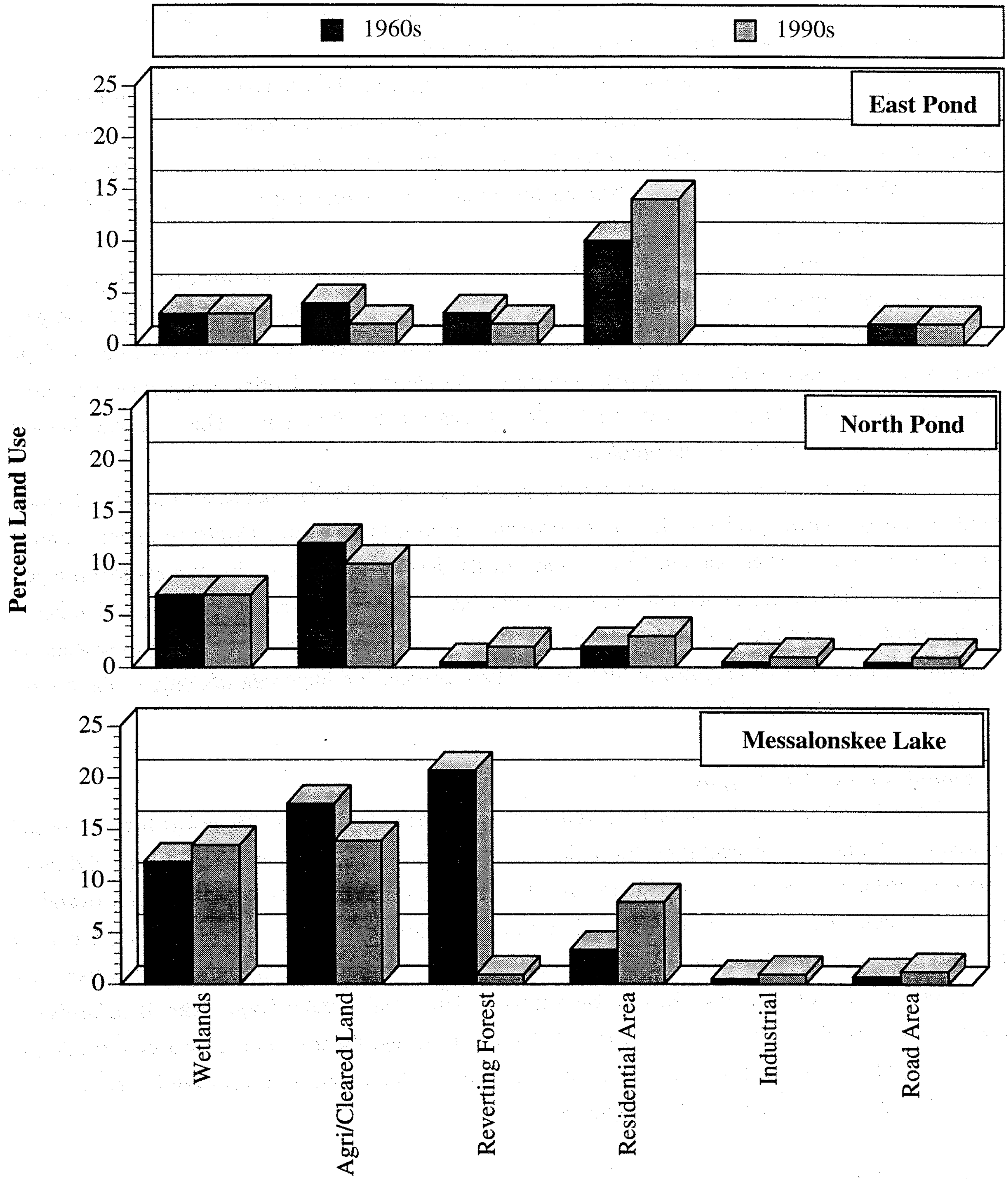

Figure 8. Percent regional land use in East Pond, North Pond, and Messalonskee Lake watersheds in the 1960s and 1990s (BI493 1997). Industrial area was not included in the East Pond watershed study.

characteristics, such as water quality or habitat, of the natural areas (MDEP 1994b). Each town has their own zoning maps, located in the town offices, that display where resource protected areas can be found. The most common areas of resource protection are wetlands, streams, and shoreline areas. Areas where rare animal species are found could also be protected from future development in order to ensure a biologically diverse region.

Wetlands are a particularly important area for protection. One of the greatest values of wetlands is their biological diversity (WWF 1992). Other reasons wetlands are protected include water quality control, erosion prevention, and recreation. Wetlands act as nutrient sinks, concentrating nutrients and keeping them from diffusing across the entire body of water. Streams need to be protected from development to ensure that water quality of both the streams and the bodies of water they empty into do not become degraded. Building or development too close to a stream will not only affect the stream, but also the downstream areas.

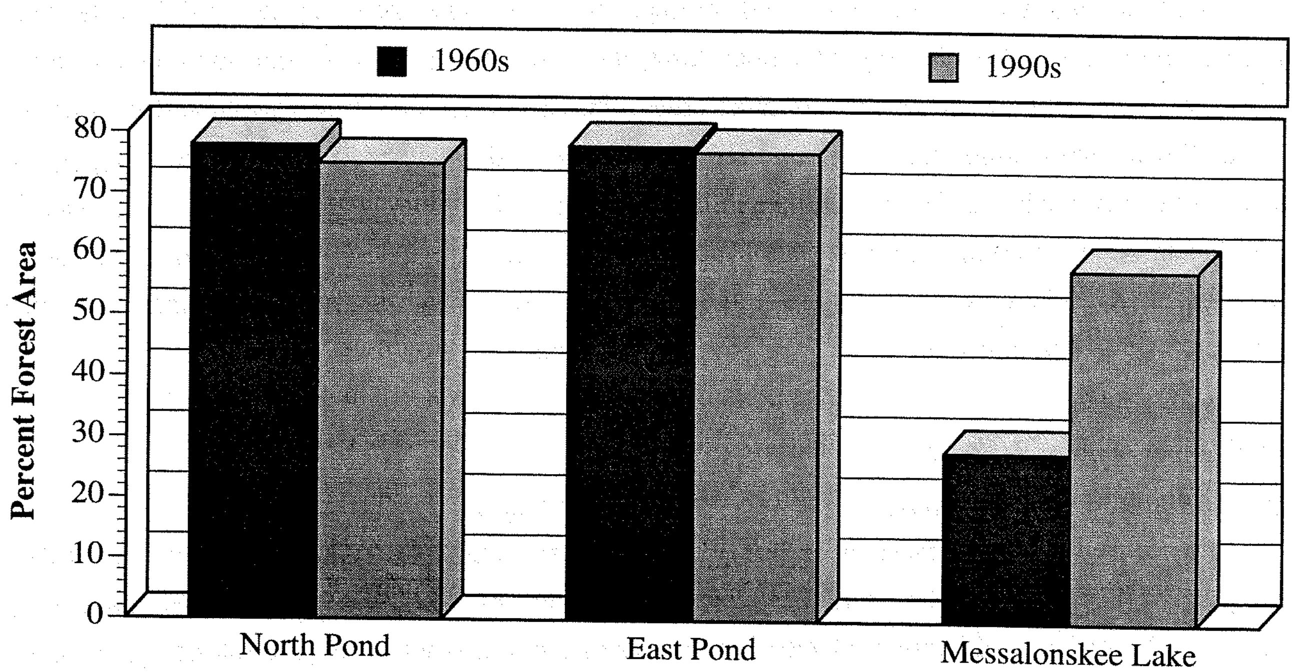

Figure 9. Percentage of forested area in the 1960s and the 1990s for the North Pond, East Pond, and Messalonskee Lake watersheds (BI493 1997). Regenerating forests was included in forest area.

STUDY OBJECTIVES

Water Quality Assessment

Messalonskee Lake

The purpose of this study was to quantify the overall general health of the Messalonskee Lake and to identify possible problem areas. Water quality was evaluated based on physical parameters including dissolved oxygen, temperature, transparency, turbidity, and conductivity and chemical parameters including phosphorus, nitrate, hardness, color, pH, and alkalinity. Water quality was then evaluated in relation to land use patterns such as industry, agriculture, recreation, and development.

The water quality of Messalonskee Lake was investigated through preliminary analyses performed and measurements taken during the summer of 1997 and by a more concentrated effort made in the fall of 1997 by Colby Environmental Analysis Team (CEAT). The purpose of these studies was to compare the overall current water quality status of Messalonskee Lake to past studies performed by Maine Department of Environmental Protection (MDEP) and Colby College. In addition, the aim of the study was to evaluate the quality of the Messalonskee Lake in relation to other lakes throughout Maine, with a particular emphasis on other Belgrade Lakes.

Tributaries

Tributaries input water, nutrients, and sediment from the watershed area directly into the lake. Since tributaries often flow through developed land, they can carry pollutants and nutrient-rich runoff into the lake from shoreline and nonshoreline areas, thus adversely affecting water quality. For this reason, all tributaries exhibiting measurable flow were measured for flow rate, dissolved oxygen, and temperature, and analyzed for turbidity, phosphorus, and pH. These measurements were used to determine the relative contribution of each tributary and its drainage basin to the overall lake body. Those with higher flow rates and larger drainage basins were considered more important since they have more of a potential impact on the lake than smaller tributaries.

Land Use Assessment

Effect of Land Use Patterns on Water Quality of Messalonskee Lake

All activities that take place in a lake watershed may affect the quality of the water flowing through the watershed and ultimately the quality of the water in the lake. Messalonskee Lake is no exception. According to Chapman (1996), a majority of the world-wide degradation of water quality is due to the influences of human activities. In this study, current land use patterns were evaluated to determine what possible point and nonpoint source pollution contributors exist in the Messalonskee Lake watershed. The Maine Department of Environmental Protection (MDEP) defines these types of pollution in the following manner:

> Point source pollution: pollution discharged directly from a specific site such as a municipal sewage treatment plant or industrial outfall pipe.
>
> Nonpoint source pollution: contaminated runoff from many diffuse and/or small-scale sources (such as gardening, lawn care, recreational boating, pesticide use, improper septic system maintenance, building construction, and the use and disposal of household toxins) (Schauffler 1990).

Pollutants can enter lake ecosystems as gases, dissolved substances, and/or particulate matter (Chapman 1996). Development of any sort in the watershed can produce these pollutants which may contribute to the decrease in lake water quality:

> Development, not just during the building phase, but long after everything has stabilized, can increase phosphorus concentrations in storm water by up to 10 times its natural concentration by eliminating natural "filters" and "sponges" (such as trees, bushes, and puddles) and by creating hard, easily washed surfaces (such as lawns, driveways, roads, and rooftops) (COLA 1992).

Important factors that lead to the deterioration of lake water quality are eutrophication, trace elements, organic micropollutants and acidification (Chapman 1996). In Messalonskee Lake, the latter three factors are not of immediate concern since the watershed contains no major point source (such as a factory releasing effluent into the lake) and the lake is not suffering from acidification (see Lake Water Quality Measurements and Analysis: Chemical Measurements; pH). Culturally influenced eutrophication (a rapid process of eutrophication due to pollutants, especially phosphorus, from human related activities and development) appears to be the primary threat to the Messalonskee Lake watershed. According to the MDEP (Schauffler 1990), changes in land use patterns, specifically the trend of low-density residential development replacing forested, undeveloped land, have resulted in nonpoint source pollution in the form of runoff with higher phosphorus concentrations than before development occurred.

This study was conducted to provide information on the roles of various land uses in the watershed. Residential development, in particular, was examined for its affect on water quality. Nonpoint source pollution from residential development can result from fertilizers and pesticides applied to gardens or lawns, recreational boating, improper septic system maintenance, building construction and the use and disposal of household toxins (Schauffler 1990). Since each of these nonpoint source pollutants occurs in the presence of residential development, it is important to monitor their affect on water quality. Agriculture (through the use of fertilizers and pesticides, and the disposal of animal waste) and forestry (through soil compaction and the removal of vegetation and subsequent erosion) also contribute to nonpoint source pollution.

ANALYTICAL PROCEDURES AND FINDINGS

WATER MEASUREMENTS AND CALCULATIONS

Water Budget

Water quality of a lake is determined by many factors including determination of the water budget, movement of water into a lake and lake level management, along with water chemistry tests. Water budget determines the flushing rate of a lake; a measure of how many times the volume of the lake is replaced in one year. Movement of water into a lake includes tributaries, precipitation, groundwater, and runoff. Lake level management analyzes the use of dams and how the increase and decrease in water level affects water quality.

Methods

The water budget was calculated to determine the I_{net} and flushing rate of Messalonskee Lake (see Appendix E). The I_{net} is the amount of water that enters the lake from runoff, precipitation, and upstream lakes, ponds, and tributaries, minus the amount of evaporation the lake experiences in a year (BI493 1997). The I_{net} for a lake is determined by the following equation:

$$\mathbf{I_{net}} = (\text{Runoff x Land Area}) + (\text{Precipitation x Lake Area}) - (\text{Evaporation x Lake Area})$$

The flushing rate is the number of times the volume of the lake is replaced in one year. Flushing rate is determined by summing the I_{nets} for Messalonskee Lake plus the I_{nets} of the lakes that contribute flow to Messalonskee Lake and dividing the resulting value by the volume of Messalonskee Lake. The volume of Messalonskee Lake was determined by multiplying the mean depth by the lake surface area:

$$\textbf{Flushing Rate} = \frac{I_{nets}\text{ of contributing ponds and lakes} + I_{net}\text{ of Messalonskee Lake}}{\text{Mean Depth Messalonskee Lake x Lake Area}}$$

There are many inputs to Messalonskee Lake; however, it is impossible to obtain I_{nets} for some inputs because they are too small to measure. The ponds and streams for which I_{nets} are available from MDEP and previous BI493 studies that contributed to Messalonskee Lake are: Long Pond North Basin, Long Pond South Basin, Watson Pond, Whittier Pond, McIntire Pond, Kidder Pond, Moose Pond, Ingham Pond, and Belgrade Stream. The I_{net} for Great Pond includes the I_{nets} of East Pond, Serpentine Stream, Salmon Lake, North Pond, and Little Pond (Figure 10).

The watershed area that was used to determine the water budget was the combined areas of Belgrade Stream and Messalonskee Lake. The boundary used by MDEP for Messalonskee Lake equals this combined area. The areas for the watershed and lake were determined using a planimeter and topographical maps (see Land Use: Land Use Methodology). The land area was determined by subtracting the lake area from the watershed area. The mean depth was obtained from MDEP (MDEP 1994a).

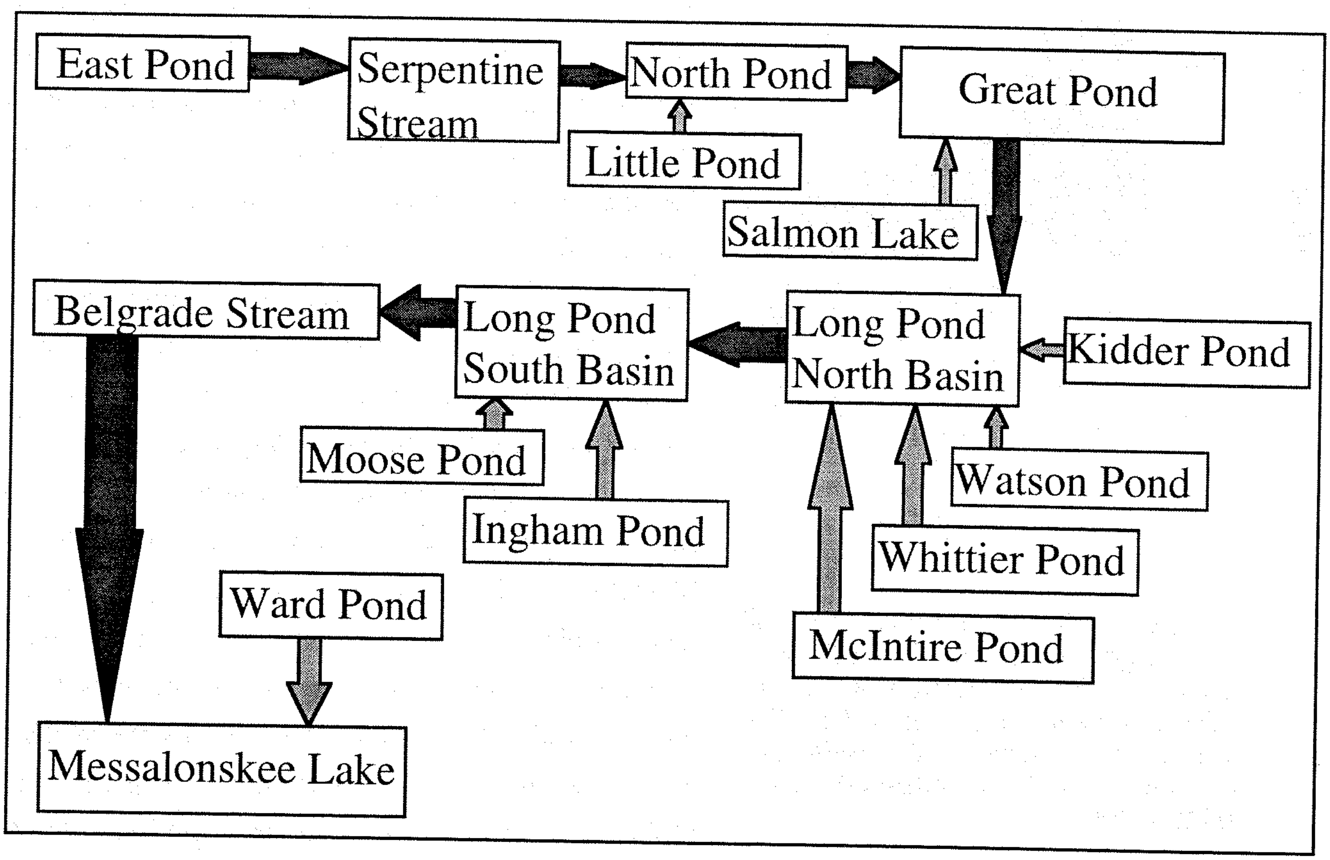

Figure 10. Diagrammatic representation of the flow of water from East Pond to Messalonskee Lake. Box sizes do not correlate with lake size. Beginning at East Pond, water flows through to Messalonskee Lake, and continues through other rivers and streams to the ocean. Darker arrows indicate direct flow of the Belgrade chain, lighter arrows are smaller inputs into the larger ponds and lakes.

The runoff constant used in the water budget calculation was a ten-year average of runoff in the Kennebec River basin from 1958 to 1967 (BI493 1995). The precipitation value was determined from a ten-year average of data from National Oceanic Atmospheric Association data from weather stations in Augusta and Waterville (NOAA 1986-1996). The evaporation constant was determined in a study of the Lower Kennebec River basin (Prescott 1969).

Results and Discussion

There are three main factors that influence the flushing rate of a lake. One factor is the amount of inputs from upstream lakes, ponds, and tributaries. If there are a great number of inputs into a lake or there are few inputs with a large volume of flow, the lake will have a high flushing rate. This is because there of the larger volume of water entering the lake. The second factor that directly affects

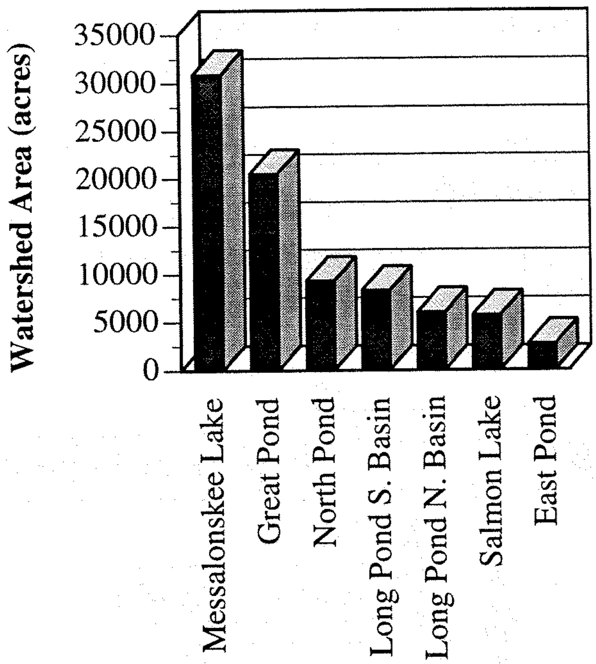

Figure 11. The watershed areas of the major lakes in the Belgrade chain. The watershed area for Messalonskee lake includes the watershed area of Belgrade Stream. Values obtained from BI493 1991.

flushing rate is watershed size. In general, a larger watershed area will contribute to a higher flushing rate (Figure 11, 12). This is because there is a larger area from which water can enter the lake through precipitation and runoff, and therefore a larger volume of water. Thirdly, the volume of the lake affects the flushing rate. A deep lake that has a large surface area, and therefore a large volume, will have a slower flushing rate than a shallower, less voluminous lake. This is because a smaller lake has a smaller volume allowing the water to be moved through the lake more times in one year than through a larger lake.

The flushing rate for Messalonskee Lake was calculated at 1.59 flushes per year (see Appendix E). Messalonskee Lake has one significant point source input (Belgrade Stream) along with other smaller tributaries that do not contribute as significantly to the lake. Messalonskee Lake has the largest watershed size but the second largest volume in the Belgrade chain (Table 4). All of these factors contribute to the moderate flushing rate.

Flushing rate is one factor in determining the water quality of the lake, along with other water chemistry and physical tests (see Messalonskee Lake Water Quality: Lake Water Quality Measurements and Analysis). Water movement through the lake must also be considered when discussing water quality. Orientation of the lake to the prevailing winds, direction of flow, and lake morphology all affect water movement.

A higher flushing rate results in a healthier lake. If water is replaced more than one time per year, the flow rate is fairly high. This prevents nutrients from building up in the water column and therefore slows the process of eutrophication (Firmage, pers. comm.). The opposite is true with a slow flushing rate. A slow flushing rate allows nutrients (including phosphorus) to build up in the water column or settle to the lake bottom, leading to eutrophication and algal blooms (see General Nature of the Study).

Directional orientation of the lake affects water flow. If the lake is oriented with the prevailing winds, the water will move through the lake more quickly because the winds will push the water through the lake. Also, if the water flows in a straight line through the lake, the actual turnover will be more complete and most likely faster, than if there are barriers, bays, or if the water must flow around obstacles such as islands in order to reach the next largest body of water (Firmage, pers. comm.). The flow direction turns from North Pond through Great Pond into Long Pond requiring water to turn east and flow around two large islands before leaving Great Pond. Also, Great Pond has a number of bays in which water can become trapped, slowing the rate of turnover. In contrast, Messalonskee Lake is very straight and there are no bays in which water might become trapped for a significant amount of time. This allows for the water to move at an even rate through the lake. Bathymetry (the bottom contour of the lake) also affects water movement (Cole, pers. comm.). If the bottom of the lake is flat without any ridges or deep holes, the water will be able to move more easily.

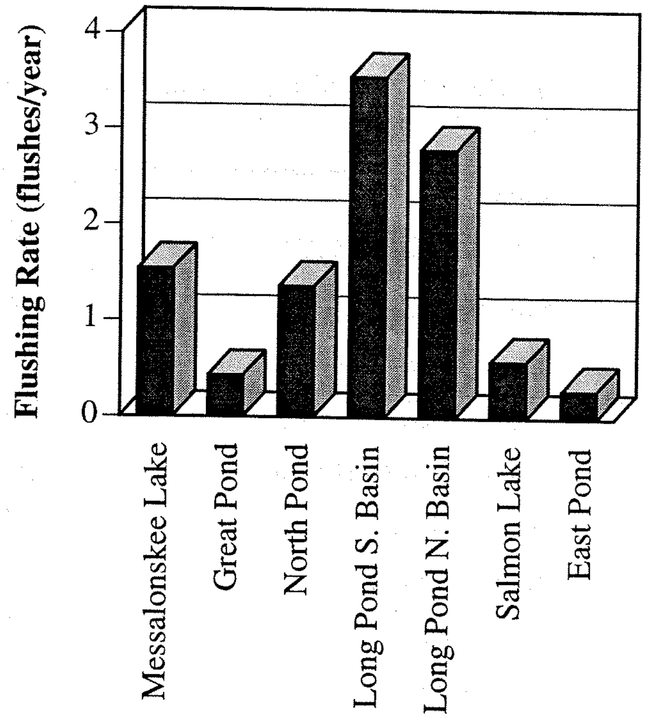

Figure 12. The flushing rates of the major lakes in the Belgrade chain. Value obtained from BI493 1991.

Messalonskee Lake has a rounded bottom and a fairly uniform depth (mean = 10.0 m). It is funnel-shaped, forcing the volume of water into a smaller area, and is long and narrow. There is one deep hole (mean depth=30 m) that is fairly small and most likely does not slow down the water flow significantly. Also, the lake is oriented to the northeast, which is along the same direction of the south-south-west prevailing winds (Koons, pers. comm.). When the winds are high, they aid the flow rate by pushing water through the lake, especially when the orientation of the lake is along the same axis as the winds.

Movement of Water into the Lake

Tributaries

A tributary brings flowing water and its contents into a lake. Tributaries do not necessarily flow all year; often they are ephemeral, only flowing during the spring after the winter thaw. Six tributaries were sampled on 22-Sep-97, all of which were flowing. There were many more ephemeral tributaries surrounding the lake that were identified but not sampled because they were not flowing at that time. Tributaries are an important source of input from the watershed to the lake because they contain nutrients from runoff and perhaps from other lakes. The most damaging runoff occurs at areas of

Table 4. Flushing rates and watershed areas of inputs to Messalonskee Lake.*

Lakes	Watershed Area (in acres)	Volume (m^3)	Flushing Rate (flushes/year)
Messalonskee Lake	30909.3[a]	150,249,096	1.59
Great Pond	20540.4	240,649,445	0.43
Long Pond South Basin	9617.3	47,032,200	3.55
North Pond	7640.5	37,148,856	1.36
Long Pond North Basin	5971.2	46,276,529	2.80
Salmon Lake	5714.6	28,410,750	0.59
Ingham Pond	3796.5	1,333,644	8.55
East Pond	2775.0	33,848,120	0.25
Whittier Pond	2476.3	3,361,621	5.92
Moose Pond	625.8	533,452	3.18
Kidder Pond	409.8	256,400	3.54
McIntire	155.5	N/A	N/A
Ward Pond	76.6	1,103,229	1.59
Watson Pond	51.9	879,055	1.41

* Values were not available for Serpentine Stream, or Little Pond
[a] Includes watershed area of Messalonskee Lake and Belgrade Stream

greatest elevational change in the watershed because water moving rapidly over the land cannot percolate effectively into the soil.This fast water flow is likely to cause more erosion (Cole, pers. comm.). Tributaries often have a higher phosphorus content than the lake to which they contribute because they are shallower and narrower, creating turbulence, thus eroding the banks of the tributary and mixing sediment into the water column (Cole, pers. comm.). Tributaries also collect runoff from roads and lawns increasing the amount of phosphorus reaching the lake. CEAT measured the flow rates, depths and widths of six tributaries flowing into Messalonskee Lake (see Tributary Water Quality).

Precipitation

Precipitation is the condensation of atmospheric moisture and is a major source of water to lakes in the form of rain, runoff, and tributaries (Foster 1948). Evaporation is the amount of water that is lost to the atmosphere. Infiltration is the amount of water that soaks into the ground of the watershed

(Caswell 1979). In Maine, 50% of the precipitation accumulates in streams, 30% to 40% evaporates back to the atmosphere, and 10% to 20% infiltrates the soil and becomes groundwater (Caswell 1979).

Precipitation = Evaporation + Infiltration + Stream Flow

Precipitation has different effects on the soil and runoff volume depending on the degree, force, and volume of the precipitation. If a large amount of water hits the ground within a short time period, there will be a higher volume of runoff because the water does not have the opportunity to infiltrate the ground. As the water hits the soil, erosion occurs and sediments are taken up by the moving water. A higher runoff volume carries more nutrients and sediment into the lake, increasing the amount of phosphorus reaching the lake. On the other hand, if there is just a light rain, the runoff volume is low and water is more likely to soak into the ground. This is different from a downpour when the water is moving quickly and does not have time to percolate into the soil (Cole, pers. comm.).

Groundwater

Groundwater is water that infiltrates the sediment and sits in the void within the soil and rocks in the earth (Foster 1948, Caswell 1979). The ability of groundwater to seep into the soil depends upon the type of soil and rock through which the groundwater flows. Water can flow more easily in porous soil and rock as opposed to compact, clay-like soil. Also, it is easier for water to move through a homogeneous large soil particle layer where all of the particles are roughly the same size and shape as opposed to a heterogeneous large soil particle layer. If the soil consists of a homogeneous small soil particle layer, it is difficult for water to move. When the conditions are ideal (homogeneous, large soil particle layer) groundwater can flow at several feet per day (Caswell 1979). Groundwater is not considered to be a large source of phosphorus because as the water infiltrates the soil, phosphorus is taken up by the soil (Firmage, pers. comm.). In some cases, however, where the bedrock has a shallow depth there can be high subsurface runoff that contributes phosphorus to the lake. Soils are given soil retention coefficients for use in the phosphorus budget to determine how well different types of soil are able to retain phosphorus and prevent it from running into the lake (see Phosphorus Budget).

Runoff

Runoff is the water that drains into the lake from the watershed after any absorption or evaporation has occurred (Foster 1948). There are numerous depressions in the ground in which water can become trapped. Once these depressions become filled, water moves to the next depression, pulled by gravity. The water that moves along from depression to depression is runoff (Foster 1948). There are three main sources of runoff which all originate from precipitation: rainfall, snowmelt, and groundwater (Foster 1948). Of these three types of runoff, the most common cause is impervious surfaces like roads that lead directly to the lake without any ditching or diversions. Lawns are also a major contributor to runoff because they do not readily take up water.

Runoff can be a major problem because it travels on top of the soil and grass, picking up sediments and nutrients that are attached to the soil particles (see Background: Watershed Land Use). If runoff is not diverted into the woods or a ditch and travels down the road, erosion can occur, forming gullies. Roads can be a major contributor to runoff into the lake if there are not diversion barriers on roads to redirect flow and deposit sediment in the forest (see Background: Watershed Land Use and Land Use: Roads). Runoff volume can be decreased if there are buffer strips between a lawn and the lake. Buffer strips slow the flow of water over the land surface enabling a greater chance of percolation into the soil. They also prevent water that is carrying a high concentration of nutrients from directly entering the lake (see Land Use: Residential Land: Shoreline Buffer Strips).

Runoff is affected by the type of soil in the watershed (see Background: Watershed Land Use). Soil that is mostly sand and gravel is porous allowing for absorption of water and less runoff. On the other hand, if the soil is mostly clay, it is not easy for water to seep into the soil because clay is compact, preventing water from percolating the soil thus there will be more runoff.

The type of vegetation in the watershed also affects runoff. Vegetation slows down the rate at which water flows to the lake. By slowing down the water, there is a greater chance that the water will be absorbed into the soil. In general, the more vegetation there is, the lower the volume of runoff. Typically, water that falls in the forest will not have a high volume of runoff into the lake because most of it will be dispersed by the trapped canopy and vegetation on the forest floor (Cole, pers. comm.). In addition, water that falls in a meadow will not contribute a large volume to runoff because the vegetation is fairly dense and breaks up the flow of water, facilitating infiltration. Neither the forest nor cleared land has surface vegetation as dense as lawns. Grass may slow down the rate of water movement into the lake as opposed to bare soil, however, it may also contribute greatly to runoff because lawns usually have a thick grass mat which prevents water from soaking into the ground especially during a heavy rain storm (Cole, pers. comm.).

Cleared areas of bare soil are susceptible to erosion and contribute significantly to runoff. A downpour, however, has a larger impact than a light rain because the water has time to seep into the dirt during a light rain, decreasing the volume of runoff. A high volume of runoff occurs because there are no barriers to slow down the water and allow percolation into the soil, allowing water and the sediment it carries to head directly to the lake.

Lake Level Management

There are two dams which control the water level of Messalonskee Lake. The Wings Mills dam, found at the southern end of Long Pond, controls the flow of water into Belgrade Stream which empties into Messalonskee Lake. The Snow Pond dam is found at the northern end of Messalonskee Lake and controls the outflow of water from the lake into Messalonskee Stream.

The Wings Mills dam is a gate release dam that was built in 1915 of concrete and timber and is controlled by two motor powered gates. The dam is monitored and controlled by the Belgrade Area Dams Committee, which is made up of appointed residents from each town on Long Pond (Mackenzie, pers. comm.). The chairman of the committee, Dick Mackenzie, said that the goals of the dam committee are to maintain a stable water level in Long Pond, to carry out daily monitoring, control storm flooding, and to draw down the fall water level in preparation for the spring runoff.

The Snow Pond dam is a gate release dam that was first built in 1905 and then rebuilt in 1923 by Central Maine Power (CMP). The installation of the dam caused a 3 ft to 4 ft increase in the water level of Messalonskee Lake (Gervais, pers. comm.; see Historical Perspectives). Today, Snow Pond dam is maintained by the Northern Hydroelectric division of CMP. The main functions of the dam are to create hydroelectric power when needed, maintain a stable water level within the lake, control storm flooding and to draw down the water level in the fall in preparation for the spring runoff. CMP employees lower the water level of Messalonskee Lake 1 ft in the fall and control the water level to within 0.4 ft during other times of the year (Gervais, pers. comm.). When the Wings Mills dam releases water the dam committee notifies CMP so that they may make the necessary adjustments to maintain a stable water level, to within 0.4 ft, in Messalonskee Lake (Gervais, pers. comm.).

The draw down of lake water also has many effects, both positive and negative, on the water quality of the lake (Cooke et al. 1986). The release of water during draw down flushes out water, carrying nutrients with it. After lake draw down, shoreline aquatic plants are exposed to freezing and thawing conditions which kill their roots, thus reducing macrophyte populations along the shoreline and improving the water quality of the lake. The lower water level also makes it easier to perform repairs on docks and maintain other shoreline features that are surrounded by water when the water level is higher (Cooke et al. 1986).

Draw down in lakes also has negative effects. In some cases, algal blooms have been noted after the reflooding in the spring (Cooke et al. 1986). Although the reduction of macrophyte populations may increase water quality in lakes, this reduction in turn may negatively impact the density and diversity of invertebrates, by decreasing their natural habitat (shoreline macrophytes) in this area of the lake. Fish populations may also be negatively affected if the incoming water during the spring is rich in nutrients and organic matter (Cooke et al. 1986). If the draw down and subsequent refilling processes of the lake are poorly managed, higher water levels could occur which would increase phosphorus loading by increasing shoreline erosion (Firmage, pers. comm.).

MESSALONSKEE LAKE WATER QUALITY

Study Sites

There were fifteen sample sites used for water chemistry analysis. There are three types of sites: characterization sites, spot sites, and tributary sites (Figure 13). Characterization sites were chosen to get a full profile of the lake. In addition, the characterization sites were sites within the lake at which a comprehensive chemical analysis was completed. Tests were completed from the surface to the bottom of the lake at these sites. Spot sites were tested to analyze the effects of possible problems, such as boat ramps, on the lake. Tributary sites were selected to determine the quality of the input of the water to the lake.

Characterization Sites

For characterization sites, CEAT utilized the MDEP sites, for which data had been previously collected, to enable the comparison of the lake quality from the past to the present.

Site 1: MDEP Site 1 Latitude: 49° 29' 5318N
Longitude: 69° 46' 3100W

Site 1 was the deep hole, 34 m deep, and located on the eastern side of the lake approximately 200 m from the shore. It was directly out from a red house with an open lawn and flagpole on the eastern side of the lake at the above latitude and longitude. This site was south of New England Music Camp which is located on the eastern shore of the lake.

Site 2: MDEP Site 2 Latitude: 44° 31' 1320N
Longitude: 69° 45' 0533W

Site 2 was located equidistant from Blake Island and the next northern protrusion along the western shoreline. Site 2 was also equidistant from both the west and the east shores of Messalonskee Lake. It was 11.5 m deep and is protected from the prominent north blowing winds.

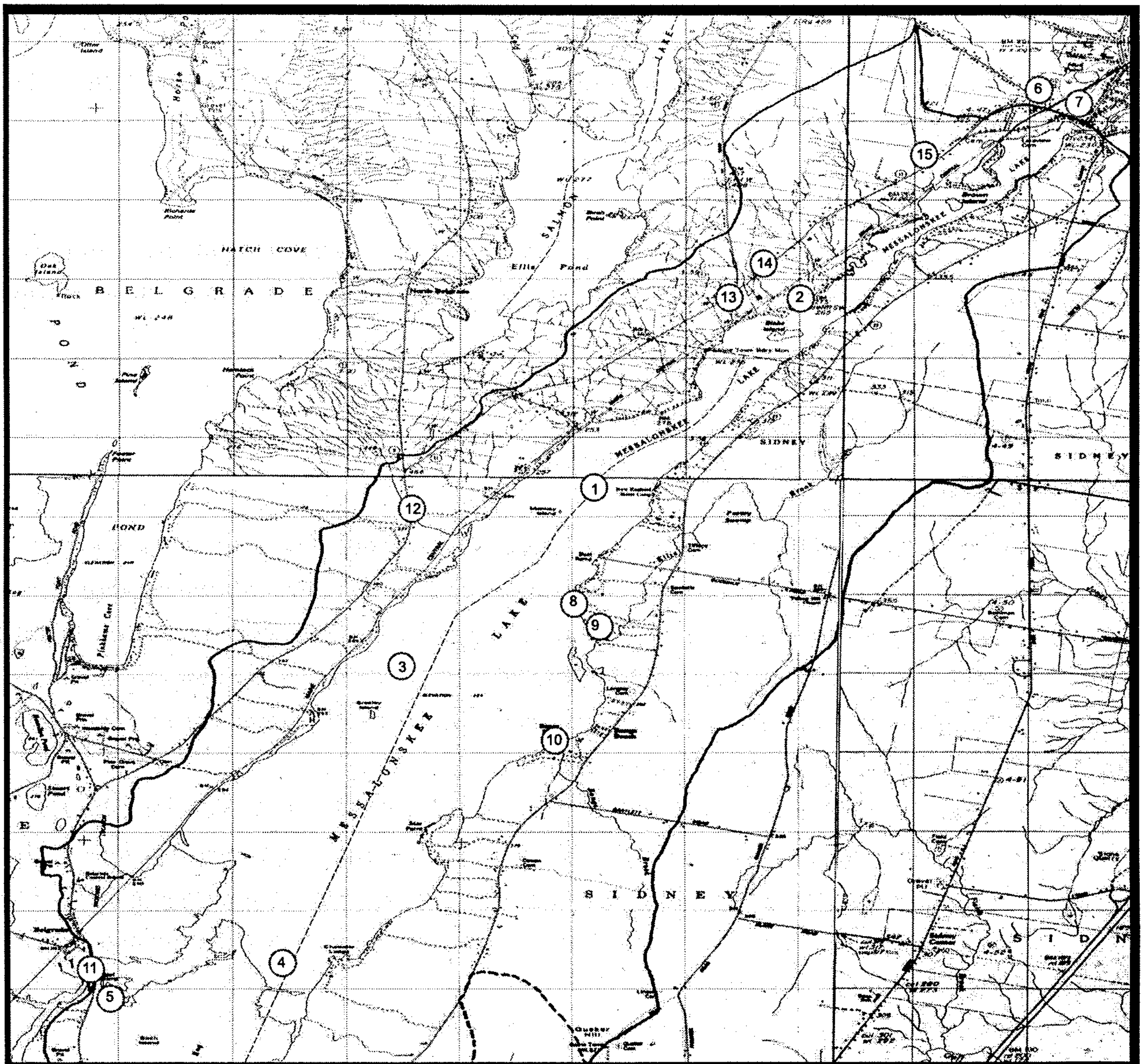

Figure 13. CEAT water quality sampling sites, including Characterization Sites 1, 2, and 4, Spot Sites 3, 5-8, and Tributary Sites 9-14, in the Messalonskee Lake watershed.

Site 4: MDEP Site 4 Latitude: 44° 27' 0637N
Longitude: 69° 48' 2133W

Site 4 was the most southern site and was 3.8 m deep. It was located 50 m off the eastern edge of the marsh and was located directly out from the last house on the eastern shore of the lake.

Spot Sites

Spot sites were chosen in areas around the lake where high nutrient input, from runoff of the surrounding area, was possible. Five spot sites were sampled to determine their phosphorus concentrations (Figure 13).

Site 3: MDEP Site 3 Latitude: 44° 28' 4491N
Longitude: 69° 47' 2391W

Site 3 was located in the lake approximately 1/3 the width of the lake off the western shore. This site was 11.5 m deep and was north of Greeley Island towards the western side of the lake. It was unprotected from the prevailing winds. This site was chosen because the MDEP had tested it in the past, but CEAT did run a full set of tests on this site during fall sampling due to its proximity to the characterization sites that were already being tested.

Site 5: Boat ramp on the southwest side of the lake

At Site 5, there was a sand and gravel boat ramp that leads directly into the lake. The samples were taken by standing on shore, reaching arms length into the lake. The boat ramp lead into the boat channel within a marsh, overgrown with aquatic plants. This site was chosen to investigate the effects of both the marsh macrophytes growing there and the run-off from the boat ramp.

Site 6: Boat ramp on the northwest side of the lake

Site 6 was near a paved, public boat ramp that leads directly into the northwest end of the lake. The sample was collected approximately 50 m off the western shore. The boat ramp adjacent to a graveyard on one side and a small grassy park on the other side. This site was chosen to determine the effects of the runoff from the boat ramp.

Site 7: On the lake side of the dam, near the north end of the lake

This site was within the lake, but the samples were taken form the bridge over the outlet of the lake, approximately 75 ft from the dam. This site was chosen to investigate the quality of the water leaving Messalonskee Lake.

Site 8: Boat ramp at the end of Hosta Lane

Hosta Lane, a road on the northeastern side of the lake, was a paved road that changed into a dirt road close to the water. Site 8 was located 50 m off the shoreline at the end of this boat ramp. This site was chosen to look at the effects of the nutrient loading from this dirt road that directly leads down to the lake.

Tributary Sites

Six tributary sites were sampled from the Messalonskee Lake watershed (Figure 13). These sites were chosen on the basis of their phosphorus loading potentials and flowing water for the lake area. Sites 9 and 10 (Ellis Brook and Bangs Brook respectively) are located on the east side of the lake, Site 11 is located on the south end of the lake, and Sites 12, 13, 14, and 15 are located on the west side of the lake.

Site 9: Ellis Brook is located at the base of Fire Road S-18 on the east side of the lake, approximately 15 ft before from the "No Trespassing Sign" indicating a private property boundary. The tributary can be reached by walking perpendicularly north from the road, through the woods, approximately 150 ft. Samples were taken 3 ft downstream from a lake obstruction, possibly a beaver dam (or 10 ft downstream from the river bend). This site was chosen as a larger water source, to investigate the influence of Ellis Brook on Messalonskee Lake.

Site 10: Bangs Brook is located off of Rte. 23 on the east side of the lake, north of the S26 and Rte. 23 intersection, approximately 15 ft upstream from the lake. Samples were collected downstream from two culverts: one culvert with a diameter of 5 ft and the other with a diameter of 1.5 ft located upstream from S26. This site was chosen to determine the influence of Bangs Brook on the watershed.

Site 11: Belgrade Stream flows into the south end of the lake. It was the largest input of water into Messalonskee Lake. Located across from Hayden Park, data samples were collected upstream off of the bridge on Rte. 27. This site was chosen to determine phosphorus loading associated with the wetlands as well as the other Belgrade Lakes.

Site 12: Site 12 is located just south of the Rte. 8 and Rte. 11 intersection. Samples were not collected however, due to the lack of flowing water.

Site 13: Site 13 is located off camp road B-4d. Follow B-4 toward the lake taking a left at the first fork, followed by a left at the second fork. Samples were taken upstream from the railroad tracks approximately 15 ft from the edge of the lake. This site was chosen to determine the water quality entering Messalonskee Lake.

Site 14: Site 14 is located at the end of fire road B-2, 50 ft downstream of the culvert and approximately 150 ft upstream from the lake. Site 14 was chosen to determine the water quality from the Town of Belgrade entering Messalonskee Lake.

Site 15: Site 15 is located at the end of fire road B-1. Samples were taken downstream from the culvert and railroad track. This site was chosen to determine the influence of Brown Brook on the lake.

Water Quality Methodology

Sampling for characterization, spot, and tributary sites was accomplished by the use of boats, canoes, and cars. Physical qualities that were measured included temperature, dissolved oxygen, transparency, color and conductivity. Chemical analyses included total phosphorus, nitrates, alkalinity, hardness, and pH. Specific tests that were performed depended upon the individual site (see Appendix A). All water samples were collected and standard procedures were followed (see Appendix B). The results of all tests are given in Appendix C.

Samples were taken from 1-Jul-97 to 10-Oct-97 for the characterization sites and from 15-Sep-97 to 3-Nov-97 for the spot sites and tributaries. The first sampling was conducted on 1-Jul-97 for Characterization Sites 1, 2, and 4 and continued through 10-Oct-97. Measurements of transparency, water depth, temperature, pH and DO were conducted on site while all others were performed at the Colby Environmental Laboratory. Samples collected for hardness were treated with HNO_3 and samples collected for total nitrogen were treated with H_2SO_4 to preserve the samples until analyzed. Samples were collected in acid rinsed bottles for general water samples and triple acid rinsed bottles for phosphorus samples. All water samples were kept on ice until transferred to the refrigerator or analyzed in the Colby Environmental Laboratory.

Water collection procedures included profile sampling at the surface, middle depth, bottom and epicore sampling (see Appendix A). Surface samples were taken by hand from just beneath the water surface, and epicore samples were taken with the epicore sampler which was used to collect a representation of the epilimnion, middle depth, and bottom samples were collected using the Kemmerer Water Sampler. Splits and spikes were collected to test laboratory techniques and duplicates were used to test field accuracy. These samples accounted for 10% of total samples taken from all fourteen sites. Sampling techniques and quality assurance were followed as described in QAP (Appendix B).

Bottles were labeled according to test site, water depth, collection date, and bottle number. The bottle number was determined by the location of the water sample, (characterization site, spot site, tributary site), location from south to north of the lake (Belgrade Stream clockwise around

Messalonskee Lake), water depth (surface, middle depth, bottom, duplicate, spike, split), and collection date (earliest to latest dates).

Lake Water Quality Measurements and Analysis

Physical Measurements

Introduction

Aquatic environments are constrained by the physical conditions of water. For this reason, CEAT measured physical parameters including dissolved oxygen, transparency, turbidity, and conductivity to evaluate the general health of Messalonskee Lake. These measurements provided information regarding the overall nature of the lake and built a foundation for further investigations.

Dissolved Oxygen and Temperature

Methods

Dissolved oxygen (DO) is the measure of the concentration of oxygen in the water column (Chapman 1996). DO concentrations indicate the general health of the lake by providing an indirect measure of pollution from organic matter, the decomposition of organic substances, and self-purification levels of the lake (Chapman 1996). Most aquatic organisms are dependent upon oxygen for maintaining metabolic processes; one exception would be anaerobic (oxygen independent) bacteria (Pearsall 1991, Stednick 1991, Chapman 1996). High DO abundance in the water column tends to promote lake health, while depletion of oxygen levels may show adverse effects on the overall biological diversity and health of a lake (Chapman 1996). For example, only certain species such as *Tubifex* worms are able to tolerate low DO concentrations (Cole, pers. comm.). As a result, species which may be rare in well oxygenated lakes may out compete non-tolerant species in an oxygen depleted system (Chapman 1996).

This phenomenon may in turn lead to a loss of biodiversity and change the dynamics of the ecosystem. The oxygen content of lake water and tributaries varies as a function of temperature, inputs from the photosynthetic activity of aquatic plants, and absorption of oxygen from the atmosphere and respiration (Pearsall 1991, Chapman 1996). Biological respiration, including those processes related to biological decay, may contribute to the reduction of DO concentrations within lakes (Chapman 1996).

Temperature also plays an important role in lake ecology. Rates of biological activity such as algae production, fish growth, and biological decay tend to increase in response to warming lake temperatures (Pearsall 1991). In addition, increasing temperature above 4° C lower the density of water and its ability to retain oxygen (Stednick 1991; see Background: Lake Characteristics). Lake profiles were constructed by measuring DO and temperature at one meter intervals using an Orion model 840 DO meter at Characterization Sites 1, 2, and 4 (see Appendices A and B).

Results and Discussion

DO surface measurements at Site 1 ranged from 6.8 ppm to 9.3 ppm during the summer of 1997. A decrease in oxygen levels of 8.5 ppm to 1.5 ppm was observed further down the water column at a depth of approximately 10 m (Figure 14). This drop represented a depletion of oxygen existing within the metalimnion (see Background: Lake Characteristics). This depletion of oxygen may have resulted from the presence of respiring zooplankton or perhaps a concurrent drop in photosynthesizing phytoplankton at this level of the water column (Chapman 1996). A rise in surface temperature was observed at Site 1 between the two summer recordings. Temperatures ranged from 19.8° C at the lake surface to 8.4° C at the lake bottom on 18-Jun-97 and increased slightly to a range from 23.0° C to 9.2° C on 19-Aug-97. This increase in the surface temperature may be attributed to warming of the surface water by solar radiation over the summer months. Extremely low DO measurements of 0.1 ppm and 0.8 ppm were taken at the lake bottom and may be the result of contact between the DO meter and the substrate. The Site 1 profiles indicated a pronounced stratification of both oxygen and temperature during the summer months at this deep hole in Messalonskee Lake.

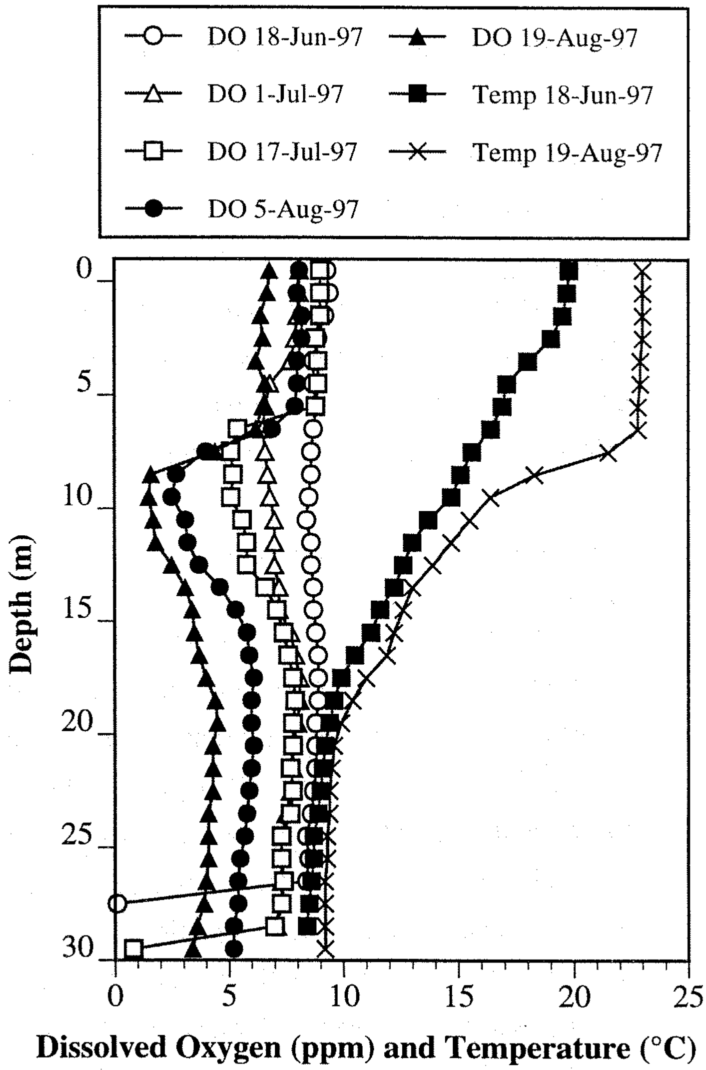

Figure 14. The dissolved oxygen (DO) and temperature profiles recorded at Messalonskee Lake Site 1 during the summer of 1997. See Figure 13 for site location.

In the early fall, the oxygen depletion zone was observed further down the water column than in the summer. For example, oxygen depletion was observed with DO levels of 8 ppm on 22-Sep-97 at a depth of 19 m and 3 ppm on 6-Oct-97 at a depth 17 m (Figure 15). Fall surface water to lake bottom temperatures respectively at values of 18.6° C to 9.2° C showed a decrease from the summer temperatures of 23° C to 8.4° C. This may have demonstrated a cooling of surface water in response to the seasonal temperature changes.

These data showed a stratification of both oxygen and temperature during the early fall, which indicated that fall overturn and subsequent mixing had not occurred by 6-Oct-97. The accuracy of the depth measurement on 22-Sep-97 was questionable because measurements were performed on a windy day when the boat collecting samples was not well anchored. As a result of the drifting boat, the DO cable may not have dropped straight down in the water column thus contributing to inaccurate measurements. DO surface measurements at Site 2 ranged from 7.6 ppm to 9.1 ppm during the summer of 1997 (Figure 16). As measurements were taken further down in the water column, a constant decrease in DO was observed. A DO depletion zone with readings declining from 9.0 ppm to 1.6 ppm was observed at a depth of approximately 9 m for all summer measurements taken at the site. This pattern suggested a pronounced stratification of oxygen among the lake layers. Temperature remained within a constant range of 23.0° C to 13.0° C between the summer sampling dates. Temperatures measured from the surface water to a depth of 9 m at the lake bottom on 19-Aug-97 decreased less rapidly down the water column than those on 17-Jul-97. These data suggested a summer

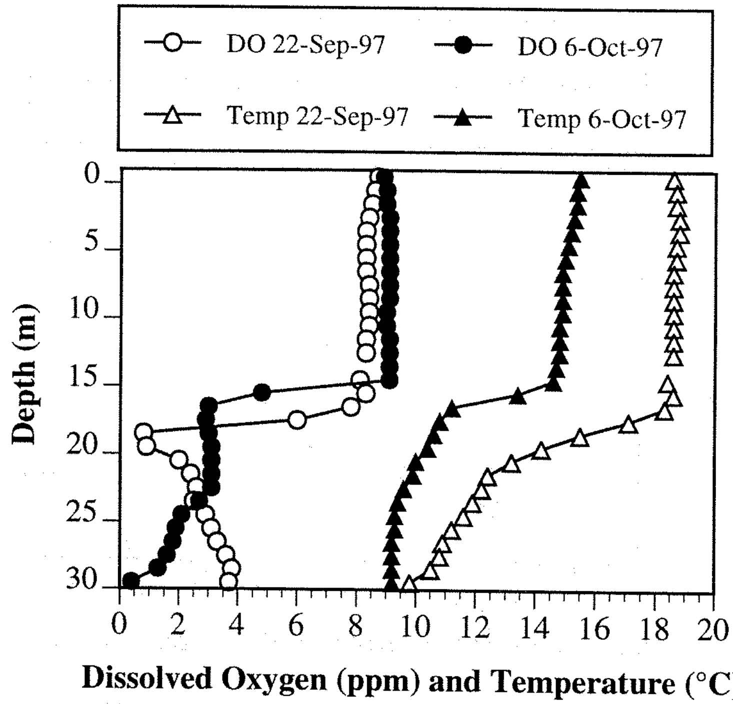

Figure 15. The dissolved oxygen (DO) and temperature profiles recorded at Messalonskee Lake Site 1 during the fall of 1997. See Figure 13 for site location.

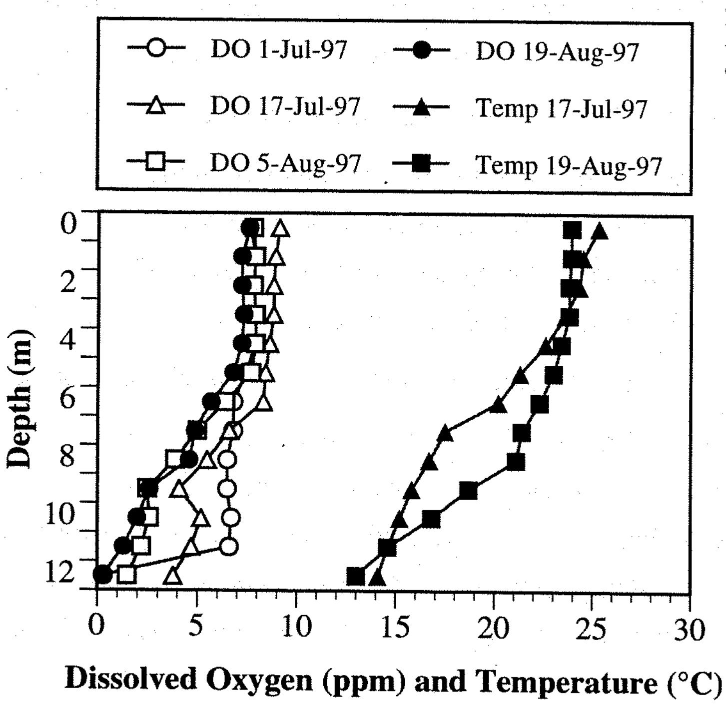

Figure 16. The dissolved oxygen (DO) and temperature profiles recorded at Messalonskee Lake Site 2 during the summer of 1997. See Figure 13 for site location.

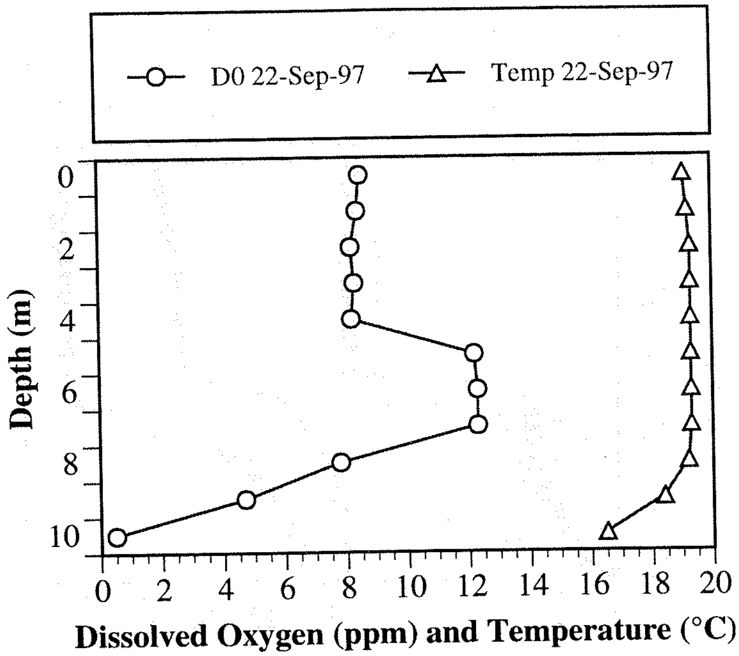

Figure 17. The dissolved oxygen (DO) and temperature profiles on 22-Sep-97 recorded at Messalonskee Lake Site 2 during the fall of 1997. See Figure 13 for site location.

stratification of both oxygen and temperature during this time period.

Relative to the first 6 meters, the data on 22-Sep-97 showed an increase in the DO of approximately 4 ppm between the depths of 6 m to 8 m at Site 2 (Figure 17). The change in DO levels may be attributed to the rise in photosynthetic activity during the summer months and the associated oxygen production from phytoplankton and algal growth, while algal decay further down the water column may have accounted for DO depletion at lower depths.

Alternatively, depth measurements may have been slightly inaccurate on 22-Sep-97 as described for Site 1. Temperature, conversely, remained relatively consistent throughout the water column with a range of 18.4° C to 19.3° C , while a low temperature of 16.5° C was observed at the maximum depth of 10 m. This relatively uniform temperature distribution suggests that fall mixing was beginning at this site concurrent with the DO increase observed on 22-Sep-97 (see Background: Lake Characteristics).

DO and temperature data were not collected at Site 4 during the summer months. The fall DO and temperature levels remained consistent throughout the water column at approximately 9.0 ppm DO and 6.8° C. The total depth of Site 4 was only 3.8 m. DO concentrations were relatively high at this site in comparison to Sites 1 and 2. High levels of DO and the uniform distribution of oxygen and temperature may have resulted from frequent mixing associated to the shallow depth of Site 4.

Depletion of oxygen within the hypolimnion has been hypothesized as a contributing factor to a marked decline in the landlocked salmon (*Salmo salar*) population of Messalonskee Lake (McNeish, pers. comm.; see Messalonskee Lake: Biological Perspectives; Background: Lake Water Characteristics). Typically, DO levels of less than 5 ppm may stress cold water fisheries (Davis et al. 1978, Pearsall 1991). These dangerously low DO concentrations were not generally observed in the hypolimnion of the Messalonskee Lake by CEAT. However, oxygen depletion was observed at lower depths in the water column with levels reaching below 2 ppm which may promote the internal recycling of phosphorus and inhibit fishery productivity.

Transparency

Methods

Transparency measures the clarity of water and is reduced by suspended solids such as silt, clay, fine particles of organic and inorganic matter, soluble organic compounds and microscopic organisms within the water column (Pearsall 1991, Chapman 1996). Transparency is an indirect measure of total phosphorus and color and is therefore considered an important indicator of algal growth (Davis et al. 1978). Transparency readings were measured using a Secchi disk at Sites 1 and 2 (see Appendices A and B).

Trophic status is closely linked to transparency. Trophic State Index (TSI) measures the nutrient supply available to support the primary production within a lake on a continuum from 0 to 100 based on either Secchi disc transparency values, chlorophyll-*a* concentrations, or phosphorus levels (Davis et al. 1978). For this study, TSI_{sd} was calculated based on Secchi disc readings. The mean monthly Secchi disc readings for samples taken during the sampling period from 18-Jun-97 to 22-Sep-97 were used to determine the TSI_{sd} for Messalonskee Lake using the following formula (Pearsall 1993; see Appendix A):

$$\mathbf{TSI}_{sd} = 70 \log [(105 / (\text{mean Secchi disk}^2 + 0.7)]$$

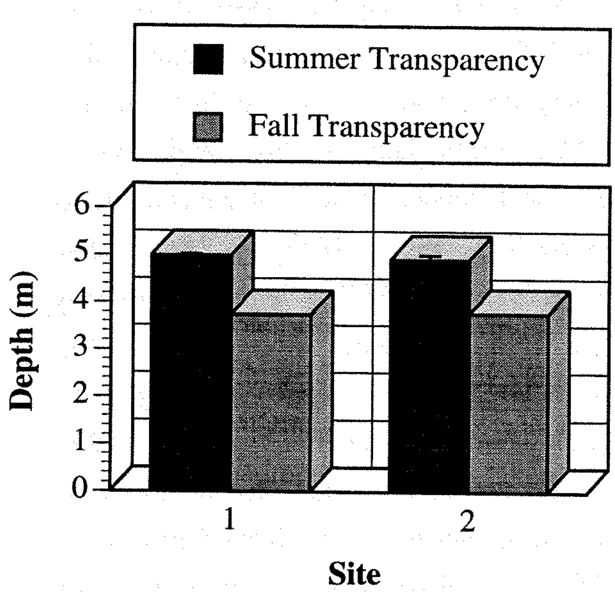

Figure 18. The mean (± SE) summer (sampled on 18-Jun-97 to 22-Sep-97) and fall (sampled on 22-Sep-97) secchi disc transparency readings recorded at Messalonskee Lake Sites 1 and 2. See Figure 13 for site locations.

Results and Discussion

The mean (± standard error) Secchi disc transparency reading for Site 1 was 5.0 ± 0.02 m in the summer (sample size (N) = 6) and only 3.5 m in the fall (N=1) (Figure 18). Site 2 had a mean Secchi disc transparency reading of 4.9 ± 0.1 m in the summer (N=6) and only 3.8 m in the fall (N=1). These transparency readings demonstrated little variation during a specific season between Sites 1 and 2 but lower transparency was observed in fall than summer readings for both sites. In 1978, Maine lakes were reported to have a transparency range of 3.0 m to 7.0 m with a mean of 5.6 ± 0.2 m (Davis et al. 1978). The historical mean of Messalonskee Lake from 1970 to 1994 was 5.9 ± 0.3 m which is relatively moderate in comparison to other lakes within the Belgrade chain (MDEP 1994a). For example, the historical mean of North Pond was 4.0 ± 0.1 m, East Pond was 4.6 ± 0.1 m, Salmon Lake was

5.1 ± 0.2 m, Great Pond was 6.6 ± 0.1 m, and Long Pond was 6.8 ± 0.1 m. All of these historical means for Belgrade lakes were within the range reported for Maine lakes by Davis et al (1978), as did the CEAT measurements recorded at Sites 1 and 2. Exhibiting a mean below the reported mean for Maine, however, indicated that Messalonskee Lake may have had a lower transparency and greater productivity than other lakes in Maine.

Transparency varied seasonally according to biological activity in the water column and surface runoff (Chapman 1996). Accordingly, both Sites 1 and 2 showed a decrease in transparency readings as the seasons progressed from summer to fall (see Appendix A). This decrease in transparency in the early fall readings may have been due to increased runoff and nutrient loading from more intensive land use during the summer months and late summer rains (see Land Use: Residential Land). Thus, an increase in phosphorus loading, therefore, may have been responsible for the decrease in transparency due to an increase in algal growth. In addition, warmer temperatures and deeper sunlight penetration into the lake during the summer may have accounted for this increased build-up of algae in the water column shortly following the summer months (Pearsall 1991).

The mean (± SE) for all four months of Secchi disc readings at Site 1 was 4.6 ± 0.4 m and at Site 2 was 4.6 ± 0.3 m. Pearsall (1991) reported that a lake is considered to be productive at a Secchi disc transparency reading of 4 m or less, moderately productive at a reading between 4 m and 7 m, and unproductive at a transparency reading above 7 m. Additionally, lakes may be classified as either oligotrophic, mesotrophic, eutrophic, or dystrophic (Chapman 1996). For example, oligotrophic lakes are relatively clear with low nutrient concentrations and primary production to support fisheries and other aquatic life (Chapman 1996; Bouchard, pers. comm.). Mesotrophic lakes are lakes experiencing a stage of transition between oligotrophic and eutrophic lakes with moderate nutrient concentrations and primary productivity (Chapman 1996). Eutrophic lakes are dying lakes which suffer from algal blooms and low biodiversity in response to nutrient-rich conditions (Smith 1990). Such lakes display extremely high nutrient concentrations and associated biomass production (Chapman 1996). Dystrophic lakes are organically rich lakes receiving large amounts of organic material from surrounding land and have high macrophytic but low phytoplanktonic productivity (Smith 1990). Dystrophic lakes, however, are progressing towards a terrestrial ecosystem where transparency is too low to be measured using a Secchi disc. Secchi disk readings of greater than 8 m, from 4 m to 8 m, and less than 4 m are ranges used to classify lakes in Maine as oligotrophic, mesotrophic, and eutrophic, respectively (MDEP 1996). Messalonskee Lake, with a mean Secchi disc reading of 4.6 m was consequently classified as mesotrophic and moderately productive, but is on the low end of these categories.

A mesotrophic classification was concurrent with the visual observations noted during the field reconnaissance. In addition, Chapman (1996) suggested that perch tends to be a dominant fish species within temperate mesotrophic lakes. This hypothesis was supported by the prevalent white perch (*Morone americana*) population within the Messalonskee Lake (McNeish, pers. comm.; see Background: Biological Perspectives). Additionally, the depression of dissolved oxygen in the hypolimnion during summer stratification (typical of mesotrophic lakes) was observed at Sites 1 and 2 (see Lake Water Quality Measurements and Analysis: Physical measurement; Dissolved Oxygen and Temperature).

CEAT transparency readings were slightly lower than those reported by the MDEP (1997b) for Messalonskee Lake over the past three decades. Readings reported by decade at Site 1 from 12-Dec-70 to 18-Nov-96 for the 1970s, 1980s, and the first six years of the 1990s all had exactly the same mean (± SE) for all three decades of 5.4 ± 0.1 m. MDEP data demonstrated constant productivity and algal growth levels over these decades. The most recent MDEP readings performed in 1996 at Site 1 between 17-Jun-96 and 18-Oct-96 and had a mean of 4.9 ± 0.2 m, which was below the reported mean for the 1990s. The mean transparency of 4.6 ± 0.4 m observed by CEAT at Site 1 sampled from 18-Jun-97 to 22-Sep-97 was still even further below the mean reported for the 1990s by MDEP. These data, therefore, suggested a possible decreasing transparency in Messalonskee Lake over recent years.

Using the mean of 4.6 m for Sites 1 and 2, a Trophic Status Index (TSI_{sd}) of 53 TSI_{sd} was calculated for Messalonskee Lake (Pearsall 1991). Lakes with TSI values greater than 60 may have supported algal blooms whereas values at or just below 100 suggest intense productivity. Productive lakes with stable water quality, however, may support values over 70 TSI without supporting blooms (Pearsall 1991). The calculated 53 TSI_{sd} for Messalonskee Lake was within the mesotrophic range (25 TSI_{sd} to 60 TSI_{sd}) suggesting moderate productivity (MDEP 1996).

A distribution of 239 Maine lakes as reported by the MDEP in 1991 showed a mean of 42 TSI_{sd} with a range of 8 TSI_{sd} to 119 TSI_{sd} (MDEP 1991; Figure 19). The value of 53 TSI_{sd} for Messalonskee Lake exceeded the 30 TSI_{sd} to 40 TSI_{sd} range which was exhibited by most of the Maine lakes sampled by MDEP in the study. A difference of 10 TSI units or more suggests a notable difference between lake bodies (Pearsall 1991). This parameter, therefore, suggested that the presence of algal growth in Messalonskee Lake may have been higher than that observed in most Maine lakes during 1991.

Reported TSI_{sd} levels indicated that Messalonskee Lake was a mesotrophic lake with comparatively higher phosphorus levels and nutrient loading than other Maine lakes. This trend indicated progression towards eutrophication, nutrient loading, and relatively higher levels of phytoplankton within the lake. This may be attributed to the decomposition of macrophytes and other organic material, nutrient-rich runoff entering the lake, or human induced silt and nutrient loading of nitrogen, phosphorus, or other organic matter into the lake (Smith 1990, Chapman 1996).

It may be noted that the CEAT samples were only taken for four consecutive months instead of the recommended five month sampling period. All of the other criteria for calculating TSI_{sd} were met including sampling from open water sites, sampling by June, and sampling performed during consecutive months (Pearsall 1993).

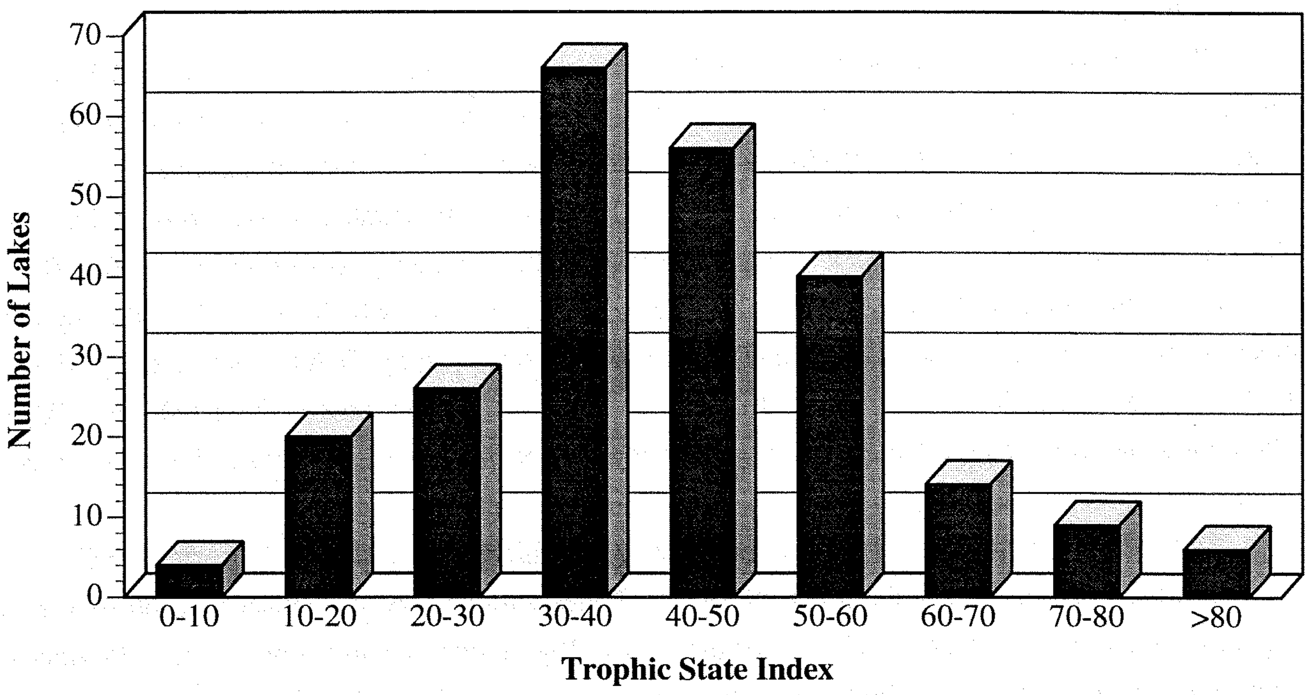

Figure 19. Distribution of lakes among Trophic State Index (TSI) categories based on Secchi disc readings in 239 Maine lakes as reported by the MDEP in 1991 with a reported mean of 42 TSI within a range from 8 TSI to 119 TSI (BI 493 1994).

<u>Turbidity</u>

Methods

Turbidity is a measurement of the amount of suspended solids in the water. Suspended solids include particles of silt, clay, soluble organic compounds, plankton, and microscopic organisms. These components scatter and absorb light, producing turbidity (Chapman 1996). Determining levels of suspended solids provides an indication of potential phosphorus loading, since much of the phosphorus entering the lakes is attached to soil particles (Pearsall 1991). Also, high turbidity levels may indicate increased concentrations of algal biomass (Chapman 1996). Sources of suspended solids include biological processes in the lake, weather disturbances, erosion, and human activity, such as plowing or clearing. Acceptable levels for turbidity range from 5 Formazin Turbidity Units (FTU) for drinking water to 50 FTU for boating and fishing (van der Leeden, Troise, and Todd 1990, Chapman 1996).

CEAT collected surface samples from all sites on 22-Sep-97 (see Appendix A). All samples were analyzed within 48 hours using the HACH Attenuated Radiation Method and a HACH Spectrophotometer 4000. Turbidity was measured in Formazin Attenuation Units (FAU), which were roughly equivalent to both Nephelometric Turbidity Units (NTU) and Formazin Turbidity Units (FTU) (HACH 1997).

The HACH Attenuated Radiation Method gave an approximate measurement of turbidity; it was not an EPA approved method (HACH 1997). To check the accuracy of our results, Sites 8, 9, 10, and 11 were resampled on 17-Nov-97, and turbidity was measured using a newly purchased HACH Model 2100P Portable Turbidimeter, a USEPA approved method. Turbidity levels in NTU were found, and the same samples were tested using the Attenuated Radiation Method (results in FAU). The results from each method were compared and found to correspond fairly well, indicating that the Attenuated Radiation Method used to measure at all sites gave a reasonable estimate of turbidity levels.

Results and Discussion

Turbidity at the characterization and spot sites ranged from 2 FAU to 17 FAU, with a mean (± SE) of 5 ± 2 FAU (Figure 20). The characterization sites were less turbid than the spot sites, ranging from only 2 FAU to 3 FAU. These values, which were below the drinking water limit of 5 FTU, probably reflect the sites' location in the center of the lake. With one exception, the spot sites were all below 10 FAU, a range acceptable for bathing and swimming (van der Leeden, Troise and Todd 1990). Site 8 (Hosta Lane) was particularly high, with a reading of 17 FAU. The boat ramp, which draws boat traffic that stirs up sediments, and farmland adjacent to this site may have been contributing high amounts of suspended sediment to the lake.

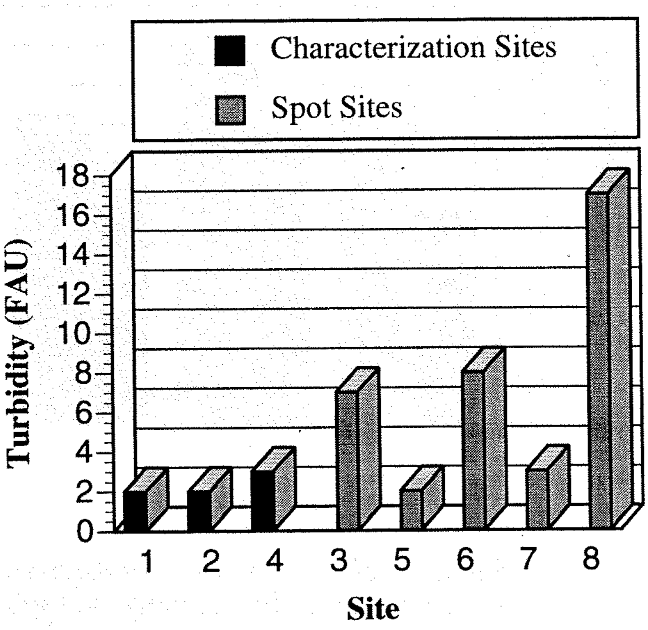

Figure 20. Turbidity measurements for surface samples taken from Characterization Sites 1, 2 and 4 and Spot Sites 3, 5, 6, 7, and 8 on 22-Sep-97.

Turbidity results for other lakes in the Belgrade chain were generally lower than those for Messalonskee Lake. Salmon Lake, Long Pond, and North Pond all had means below 3 FTU (BI493 1994, BI493 1996, BI493 1997). East Pond was slightly higher, with a mean of 4 FTU (BI493 1991). Overall, however, the turbidity levels for Messalonskee Lake seemed to be in a non-problematic range.

Conductivity

Methods

Conductivity measures the ability of water to conduct an electrical current. It indicates the amount of solutes present in the water, and is especially sensitive to changes in salts and other ions (Chapman 1996). Increases in conductivity may occur due to increased amounts of sediment, nutrients, and algae, which are indicators of lake eutrophication. Measurements are expressed in micromhos per centimeter (µMHOs/cm). Conductivity in freshwater typically ranges from 10 µMHOs/cm to 1000 µMHOs/cm, and may exceed 1000 µMHOs/cm in areas of high runoff (Chapman 1996). Values for Maine lakes have historically been low, ranging from 20 µMHOs/cm to 40 µMHOs/cm (Pearsall 1991).

CEAT collected epicore samples from characterization sites on 22-Sep-97 and 6-Oct-97 (see Appendix C). Conductivity was measured using the Model 31A YSI Conductance Bridge.

Results and Discussion

Conductivity values for Messalonskee Lake ranged from 27 µMHOs/cm to 46 µMHOs/cm, with a mean (± SE) of 36 ± 3 µMHOs/cm (Figure 21).

A study conducted in 1978 found a mean of 41 µMHOs/cm and a range of 38 µMHOs/cm to 46 µMHOs/cm (Davis et al. 1978). There was very little difference in these data, suggesting that conductivity values had not changed greatly since the 1970s. Other lakes in the Belgrade chain had similar conductivity levels. The mean for East Pond was 29 µMHOs/cm (BI493 1991), the mean for Long Pond was 35 µMHOs/cm (BI493 1996), and the mean for North Pond was 27 µMHOs/cm (BI493 1997). Salmon Lake exhibited very high

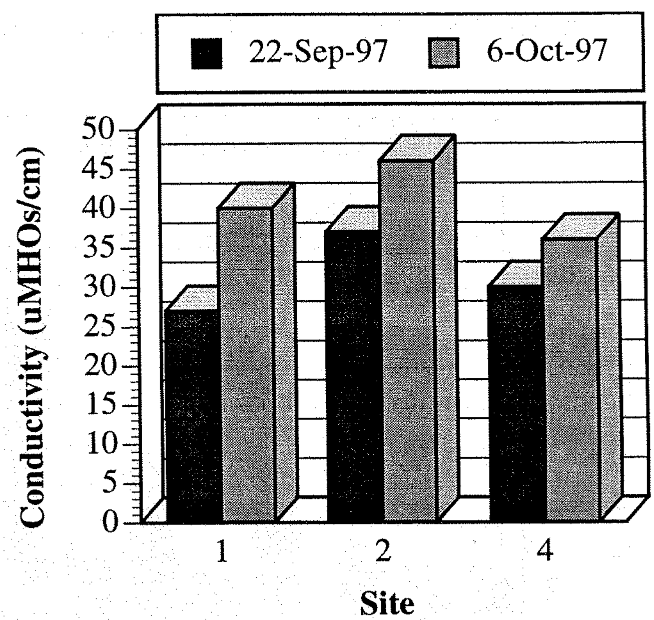

Figure 21. Mean conductivity measurements for epicore samples taken from Messalonskee Lake Characterization Sites 1, 2 and 4 on 22-Sep-97 and 6-Oct-97.

conductivity values, with most results being between 50 μMHOs/cm to 60 μMHOs/cm (BI493 1994). Considering that drinking water in the United States ranges from 50 μMHOs/cm to 1000 μMHOs/cm (Chapman 1996), conductivity levels in Messalonskee Lake appear healthy.

Color

Methods

Color is a measurement of the concentration of natural dissolved organic acids such as tannins and lignins which are leached from decaying vegetation in the watershed (Pearsall 1991). Natural minerals such as ferric hydroxide and organic substances such as humic acids also are contributing factors to true color (Chapman 1996). Color does not directly contribute to algal production, but instead may reduce transparency readings (see Background: Lake Characteristics). Color may limit the depth of light transmission into lakes (Mays 1996). This, in turn, may control the amount of primary production possible within a water body by constraining the location of photosynthetic algae within the water column. Apparent color is influenced by phytoplankton and zooplankton and often takes on the color of red, blue, green, and brown algae. For this reason, water must be filtered in order to determine true color without the influence of algae, diatoms, dinoflagellates, and zooplankton in the water (Chapman 1996).

Samples were collected from Sites 1, 2, and 4 on 22-Sep-97 and color was measured using the MDEP approved Platinum-Cobalt method on the HACH 4000 Spectrophotometer and expressed in Standard Platinum Units (SPU) which are equivalent to ppm (HACH 1997; see Appendices A and B).

Results and Discussion

Color measurements performed at Sites 1, 2, and 4 by CEAT on 22-Sep-97 had a mean (± SE) of 50 ± 12 SPU and ranged from 44 SPU to 58 SPU. These data were higher than the mean color measurement of 38 SPU reported by Davis et al. (1978) for water samples collected in 1971 and 1972 based on four to six samplings per year. More specifically, the CEAT color measurement of 49 SPU on 22-Sep-97 at Site 1 was higher than most measurements reported at the site by the MDEP (1997b). Measurements reported by MDEP (1997b) for Site 1 between 11-Sep-97 and 30-Aug-97 had an overall mean of 34 ± 5 SPU and ranged (with the exception of a high measurement of 90 SPU observed on 11-Sep-76) from 19 SPU to 49 SPU (MDEP 1997; Figure 22). The high variability among MDEP color values suggested fluctuation in lake color over time. Thus, the color analysis on 22-Sep-97 may have suggested high readings on this day but does not necessarily indicate an overall increase in lake color since the 1970s. Samples having less than 25 SPU were defined as uncolored while those with greater than 25 SPU were defined as colored (Pearsall 1991). CEAT measurements were all above this lower limit of 25 SPU while most measurements by Davis et al. (1978) and MDEP

(1997b) were also above or varied around this limit. The data, therefore, suggested that Messalonskee Lake generally maintained a colored status which varied in degree over time.

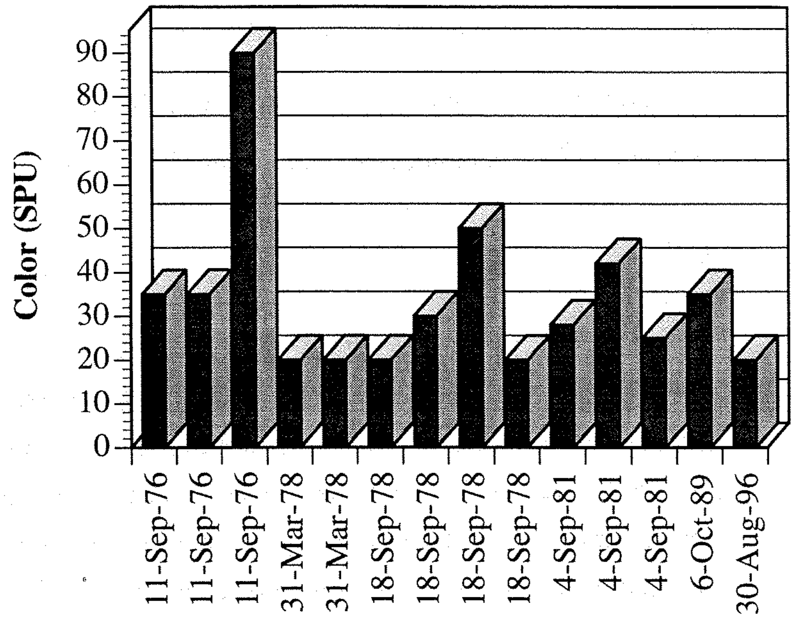

Figure 22. Color measurements at Messalonskee Lake Site 1 collected by MDEP between the dates of 11-SEP-76 and 30-AUG-96 (MDEP 1997). See Figure 13 for site location.

Chemical Tests

Introduction

CEAT measured six chemical factors on Messalonskee Lake. By looking at the levels of both total phosphorus and nitrate in the water, the current eutrophic level of the lake was determined. Other chemical tests contribute to the overall evaluation of the health of Messalonskee Lake including hardness, color, pH, and alkalinity.

Phosphorus: Characterization and Spot Sites

In Maine lakes, phosphorus is often the nutrient that limits growth of plants and controls primary productivity (Chapman 1996). Although lake plants need phosphorus to grow, excessive amounts are not healthy for the lake. Because algae only require very small concentrations of phosphorus to live, excess phosphorus can cause extensive algal growth resulting in large algal blooms. Increasing occurrence of algal blooms is part of the eutrophication process (see Background: Phosphorus and Nitrogen Cycles). Levels of phosphorus in healthy bodies of water range from 5 ppb to 15 ppb (parts per billion) (Novotny and Olem 1994). The critical limit for phosphorus is 15 ppb. Levels of phosphorus above this critical limit may result in algal blooms, fish kills, and accelerated eutrophication (Pearsall 1991). Although the phosphorus concentration of 15 ppb is the widely accepted critical limit, MDEP suggests that a phosphorus concentration of 12 ppb can sustain algal blooms (Bouchard, pers. comm.).

Many different factors may contribute phosphorus to the lake (see Background: Phosphorus and Nitrogen Cycles). Inorganic phosphates include the ions bound to soil particles and phosphates present in laundry detergents. Weathering rock, untreated domestic wastewater, industrial effluents, fertilizer runoff, and runoff from roads all may contribute to increased phosphorus levels (Novotny and Olem 1994). These factors, combined with the decomposition of plants and the resulting anoxic conditions on the lake bottom, augment phosphorus levels. When anoxic conditions (low dissolved oxygen levels) occur at the bottom of lakes, the barrier is no longer effective and the bond between the phosphorus and iron is broken. The breaking of the bond allows the phosphorus to be free in the water and therefore increase the phosphorus level and algal activity.

Methods

The phosphorus study on Messalonskee Lake centered around total phosphorus concentrations, the sum of organic and inorganic phosphorus in parts per billion (ppb) (Lotse 1973). Three site types were analyzed: characterization sites, spot sites and major tributaries in the watershed (see Tributary Water Quality: Total Phosphorus). The samples for the Characterization Sites 1, 2, and 4 and Spot Site 3 were taken over several months from 1-Jul-97 to 10-Oct-97 (see Appendix A). Spot Sites 3, 5, 6, 7, and 8 were sampled on 15-Sep-97 and 22-Sep-97 (see Appendix A). To ensure precise field and lab technique, splits, spikes and duplicates (10% of the total number of samples) were used in accordance with quality assurance guidelines (see Appendix B).

Lake samples (50 ml) were digested, within a few hours of collection, using 1.25 ml of 11N sulfuric acid and 1 ml of 1.75N ammonium peroxydisulfate. The samples were autoclaved at 15 psi for 30 minutes to ensure complete digestion of the phosphorus. After the samples were cooled, 1.25 ml of sodium hydroxide was added to neutralize the pH. The digested sample was then colorimetrically analyzed using the Ascorbic Acid method for total phosphorus analysis and a Milton Roy Spectronic 1001+ Spectrophotometer (Eaton, Clesceri and Greenberg 1995). The methods for total phosphorus analysis were outlined in Eaton, Clesceri and Greenberg (1995), with modifications by G. Hunt and C. Elvin from the MDEP and CEAT. An eight point standard curve of 0 ppb to 80 ppb phosphorus was run using a premixed phosphate standard and stored in the spectrophotometer prior to sample digestion. A trophic state index was calculated for total phosphorus using surface and epicore total phosphorus concentrations from Sites 1, 2, 3, and 4. The equation used to calculate the trophic state index is (Pearsall 1993):

$$\mathbf{TSI_p} = 70 \log [0.33 \times \text{mean total phosphorus} + 0.7]$$

Results and Discussion

Characterization Sites

Total phosphorus concentrations for surface, mid-depth and epicore samples were compared to a critical limit of 12.0 ppb and 15.0 ppb (mid-depth samples were counted only when the depth at which the epicore was taken surpassed that of the mid-depth sample). The critical limit is a concentration of total phosphorus, that when sustained, may result in algal blooms (Bouchard, pers. comm.). Characterization Site 2 was the only characterization site that had a mid-depth sample concentration of total phosphorus (15.4 ppb) above the critical limit of 15.0 ppb between 1-Jul-97 and 10-Oct-97 (see Appendix C, Table 4). However, the MDEP found that sustained total phosphorus concentrations of

12.0 ppb may lead to measurable changes in lake transparency (Bouchard, pers. comm.). Both Site 1 and 4 were above the 12.0 ppb critical limit during this time period (13.5 ppb and 12.3 ppb, respectively).

Site 1 was the deepest site on Messalonskee Lake (34 m), thus it has a greater possibility of anoxic conditions towards the end of the summer and early fall (Chapman 1996). The mean phosphorus concentrations for the surface, mid-depth and epicore samples were 13.5 ppb, 12.8 ppb and 11.5 ppb respectively. While the concentrations for the surface and epicore never exceeded the 15.0 ppb limit (13.5 ppb and 11.5 ppb respectively), they did pass or come close to the 12.0 ppb limit (Figure 23). Concentrations of this magnitude are indicative of a highly productive lake (Pearsall 1991). Furthermore, additional small increases of total phosphorus in the long run could cause significant damage to the ecosystem of Messalonskee Lake.

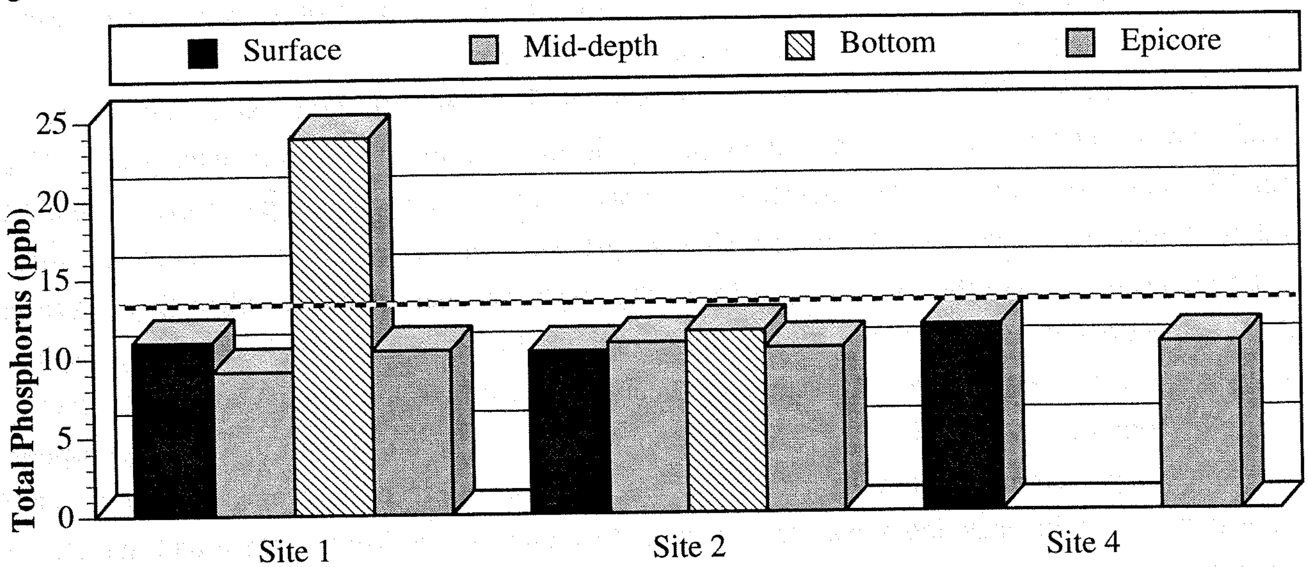

Figure 23. Mean total phosphorus concentration at Characterization Sites 1, 2, and 4, on Messalonskee Lake, for surface, mid-depth, bottom and epicore samples from 1-Jul-97 to 10-Oct-97 (see Appendix C; Table 4). Dotted line indicates 12 ppb is the critical phosphorus limit: The concentration of total phosphorus, that when sustained, may cause algal blooms occur (Bouchard, pers. comm.). Site 4 has no mid-depth or bottom samples because it was too shallow (2 m to 3 m). See Figure 13 for site location.

The bottom sample concentrations of total phosphorus at Site 1, between 17-Jul-97 and 10-Oct-97, were much higher than the bottom samples from Characterization Site 2 (see Appendix C, Table 4). The mean concentration of total phosphorus for bottom samples at Site 1, from 1-Jul-97 to 10-Oct-97, was 23.9 ppb (Figure 23). On 17-Jul-97, 15.0 ppb total phosphorus was observed. While the total phosphorus concentration declined slightly on 7-Aug-97, it sharply rose on 20-Aug-97 and continued its climb to 52.4 ppb on 10-Oct-97. When compared to previous data collected by MDEP, it was apparent that there had been a significant increase in total phosphorus levels for bottom samples at Site 1 from the early 1970s to the present time (MDEP 1997b; Figure 24).

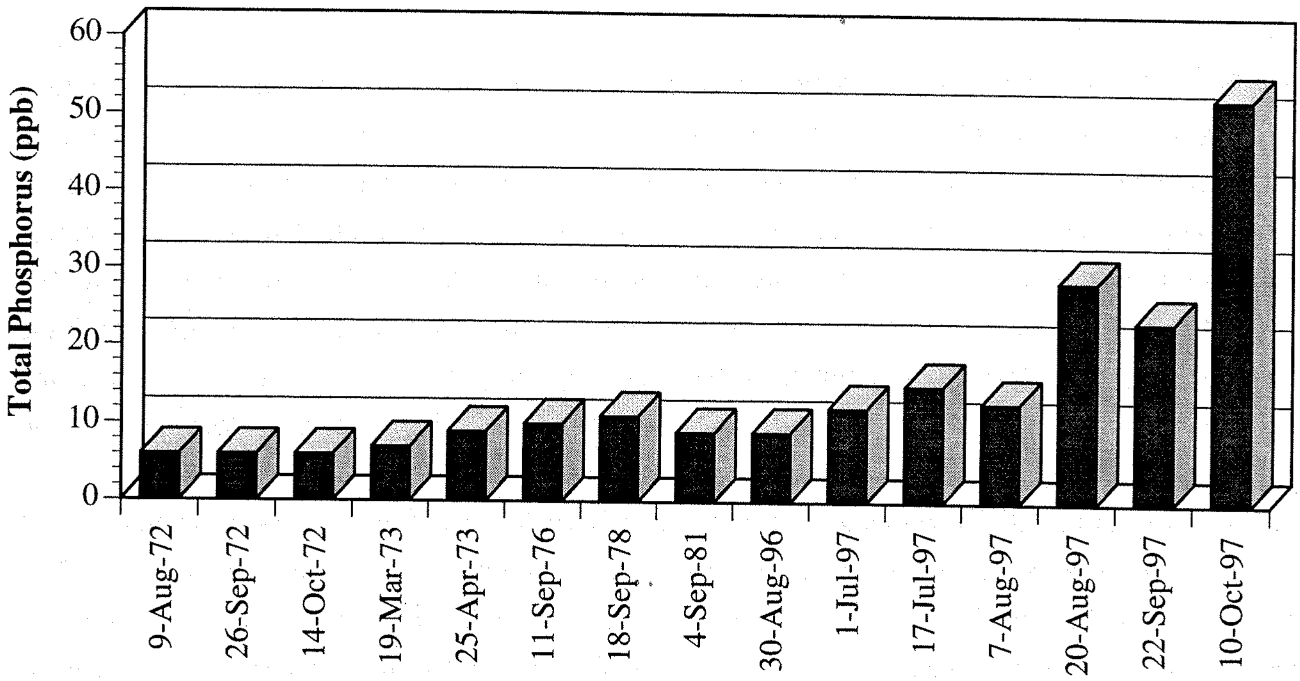

Figure 24. Total phosphorus concentrations at Characterization Site 1, on Messalonskee Lake, for bottom samples from 9-Aug-72 to 10-Oct-97. Samples taken prior to 1-Jul-97 were analyzed by MDEP; all other samples were analyzed by Colby Environmental Assessment Team (MDEP 1997; see Appendix C, Table 4). See Figure 13 for site locations.

There are many possible explanations for the excessively high phosphorus levels at Site 1, including internal recycling, decomposition of algae or other organic matter, and sampling or lab error (Wetzel and Likens 1990). The possibility that sampling or lab error occurred when dealing with these bottom samples was unlikely given the repeated high concentrations of total phosphorus and the accuracy of lab technique. Internal recycling from the substrate is likely in an anoxic lake at depth (Fitzgerald 1970; see Background: Phosphorus and Nitrogen Cycles). The DO reading for the bottom depth at Site 1 was approximately 3 ppm on 20-Aug-97 and 22-Sep-97 (3.4 ppm and 3.5 ppm, respectively); however this did not overrule the possibility of internal loading because the final measurement for the DO was taken one meter from the bottom and not directly above the substrate. Cases of phosphorus loading from aerobic lake muds have also been documented (Fitzgerald 1970). The resulting increase in total phosphorus levels is due to phosphorus saturating the mud; thus phosphorus is released because the mud cannot absorb any more (Fitzgerald 1970). This occurrence may explain why the total phosphorus concentrations were so high on the 20-Aug-97 and 22-Sep-97, given the DO readings at the time (see Physical Measurements: Dissolved Oxygen).

The high phosphorus concentration of the bottom sample seen on 10-Oct-97 might have been caused by internal recycling. A 1.3 ppm DO reading recorded on 6-Oct-97 could have created a condition for high total phosphorus concentration on 10-Oct-97 for the bottom sample. The sample from 10-Oct-97 had some organic debris floating in it, which also contributed to its high total phosphorus level. The sample was taken again 2 meters off the bottom on the opposite end of the boat and still small particles of organic debris were present. It was possible that the substrate was disturbed by the anchor or a large fish. The potential decomposition of organic matter and the subsequent release of phosphorus was also a very likely source for phosphorus loading at this site. On 19-Aug-97, leaves and organic debris were raised on the anchor from the bottom of Site 1. This, coupled with the low DO reading four days prior, pointed to the possibility of phosphorus loading from decaying organic matter and the break up of phosphorus-iron bonds (see Background: Phosphorus and Nitrogen Cycles).

Characterization Site 2 had much lower total phosphorus concentrations overall than Site 1. On 1-Jul-97, a concentration of 15.4 ppb total phosphorus was recorded for the mid-depth sample. This was the only time that Site 2 was over the critical limit of 12.0 ppb. While the critical limit normally applies to only surface and epicore samples (where algal growth is most prevalent) (Firmage, pers. comm.), it was extended to include the mid-depth samples for Site 2. The mid-depth sample for Site 2 was taken at six meters, where algal growth may occur. Site 2 had a mean total phosphorus concentration of 11.5 ppb, with a range from 8.6 ppb to 15.4 ppb (Figure 23). The majority of the phosphorus concentrations for surface, mid-depth and epicore samples were 1 ppb to 2 ppb less than the 12.0 ppb critical limit (see Appendix C, Table 4).

The mid-depth sample from 1-Jul-97 that was above the critical limit could have been high for several reasons: high algal or zooplankton activity in the mid-depth of the water column, or phosphorus loading from the flow at Site 14. Zooplankton, such as daphnia, have been seen in numerous samples taken from mid-depth. The total phosphorus concentration would therefore increase with the presence of zooplankton (Firmage, pers. comm.). While no specific mention (in lab notes) was made on 1-Jul-97 about the presence of zooplankton in samples, it is possible that there could have been some present. Zooplankton are very small and often go unnoticed. Site 14, a nearby tributary, empties into the lake close to Site 2. The mouth of the tributary was surrounded by numerous macrophytes. It may have been possible that phosphorus from sediments or the decomposition of macrophytes, washed in from Site 14 during the rain storms that occurred prior to sampling, caused the increased concentration of total phosphorus on 1-Jul-97.

Previous data for Site 2 from the MDEP were scarce, so it was difficult to estimate how Messalonskee Lake had changed over the years. The MDEP data for Site 2 starts on 8-Jun-91 and ends on 26-Oct-91. The average and range of values (10.6 ppb; 8.0 ppb to 17.0 ppb respectively) for total phosphorus concentrations for this period of time were very similar to CEAT findings over roughly the same time period (MDEP 1997b; see Appendix C, Table 4). It was therefore, difficult to determine a trend in the given data, except for the fact that there seemed to be no significant increases in the amount of total phosphorus present at Site 2 in the 1990s. The epicore samples for Site 2 from 1991 and 1997 were again very similar in concentration. A slight increase in the total phosphorus concentrations for the epicore samples may have occurred, but there were not enough data from the 1980s or mid-1990s to draw concrete conclusions (Figure 25).

Characterization Site 4 had total phosphorus concentrations that were close to the critical level of 12.0 ppb, except for the 7-Aug-97 surface sample that was above the critical limit (12.3 ppb). The concentration range for Site 4 was 11.5 ppb to 12.3 ppb total phosphorus (Appendix C, Table 3). Site 4 is the shallowest site, approximately three meters deep, and is near a highly productive marsh, which may explain the moderate levels of total phosphorus. There was only one past phosphorus concentration available for comparison to the sample concentrations analyzed by CEAT at Site 4, taken on 12-Aug-91 with a concentration of 8.0 ppb. It was therefore hard to draw conclusions from this single point of data about the history of this site, but it could be inferred from the CEAT samples that the total phosphorus concentrations were high relative to the critical limit and should be monitored

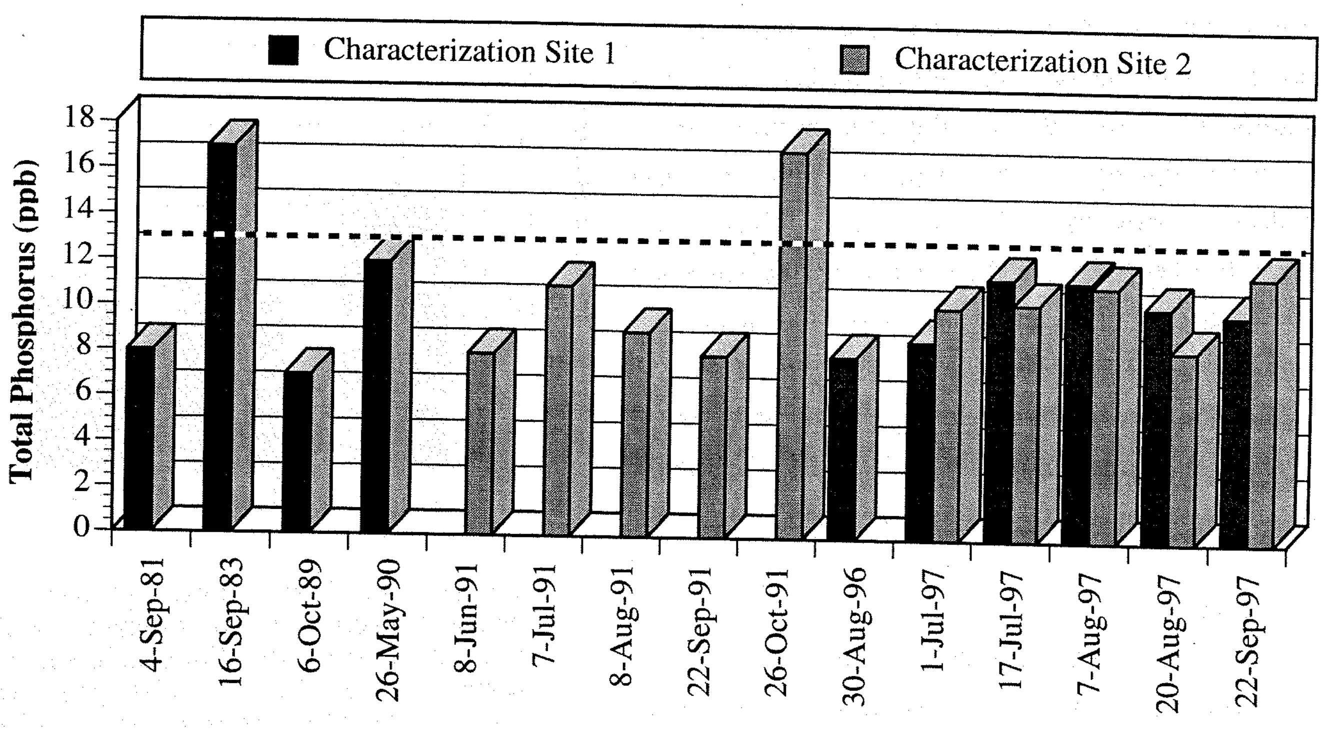

Figure 25. Total phosphorus concentration for epicore samples at Characterization Sites 1 and 2, on Messalonskee Lake, from 4-Sep-81 to 22-Sep-97. Samples taken prior to 1-Jul-97 were analyzed by MDEP; all other samples were analyzed by Colby Environmental Assessment Team (MDEP 1997; see Appendix C, Table 4). Dotted line indicates 12 ppb is the critical limit for total phosphorus: The concentration of total phosphorus, that when sustained, algal blooms occur (Bouchard, pers. comm.). See Figure 13 for site location.

closely (Figure 23). Moreover, a further build up and potential saturation of phosphorus in the nearby marsh might lead to greater phosphorus loading for this site in the future (Fitzgerald 1970).

Finally, when looking at the total phosphorus concentrations over the decades, (the 1970s, 1980s and 1990s) it was apparent that Messalonskee Lake had a high level of phosphorus in the 1970s (mean=16.3 ppb, S.E. ± 7.13 ppb). The level of total phosphorus decreased in the 1980s (mean=10.7 ppb, S.E. ± 3.18 ppb) and remained unchanged in the 1990s (mean=10.7 ppb, S.E. ± 0.50 ppb) (Figure 26). The standard error for the data in the 1970s was rather high (SE ± 7.3 ppb). This can be explained by the fact that there were only three total phosphorus concentrations available to average, while the 1980s and 1990s had many more data points.

Several conclusions were drawn from the total phosphorus data obtained for the three characterization sites. The levels of total phosphorus have been increasing at the bottom depth of Site 1 over the past twenty-five years (Figure 24). The total mean phosphorus concentrations were unchanged between the 1980s and the 1990s, showing no increase in total phosphorus levels (Figure 26). The trophic state index for Messalonskee Lake, calculated from CEAT data, was 44. When compared to the trophic state index for Secchi disk readings (54 TSI_{sd}) it was lower (see Physical Measurements: Transparency). The difference was possibly due the fact that Messalonskee Lake was significantly colored (see Physical Measurements: Color). Finally, it was apparent from the data collected between 1-Jul-97 and 10-Oct-97 on Messalonskee Lake for the characterization sites and the trophic state index, that the lake was at or very close to the critical limit of 12.0 ppb (Figure 23). A plan of action to limit the levels of phosphorus loading will therefore be beneficial to the future health and well-being Messalonskee Lake.

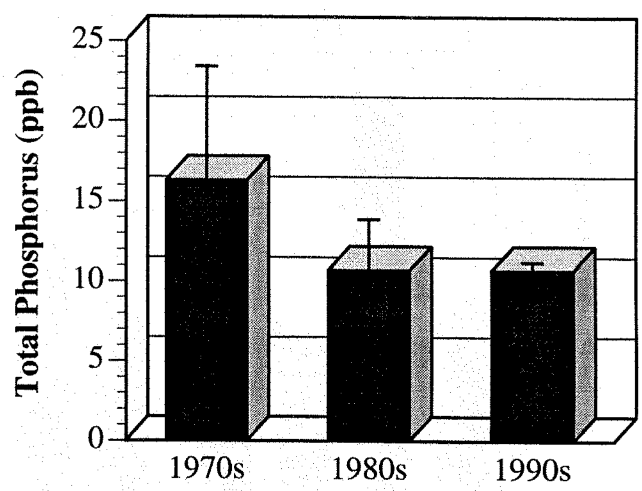

Figure 26. Mean total phosphorus concentrations for Messalonskee Lake over three decades. Each column is a mean of surface, mid-depth and epicore samples taken during a given decade form Characterization Sites 1, 2, and 4. Samples taken prior to 1-Jul-97 were analyzed by MDEP; all other samples were analyzed by Colby Environmental Assessment Team (MDEP 1997; see Appendix C, Table 4). See Figure 13 for site locations.

Spot Sites

On 28-Aug-91, a bottom sample from Site 3 was measured for its total phosphorus concentration. The level in that sample was 8.0 ppb, while the bottom sample collected on 20-Aug-97 had a phosphorus level of 8.5 ppb. This slight difference suggested that there had been little change to this site over the past six years. On 22-Sep-97, both the

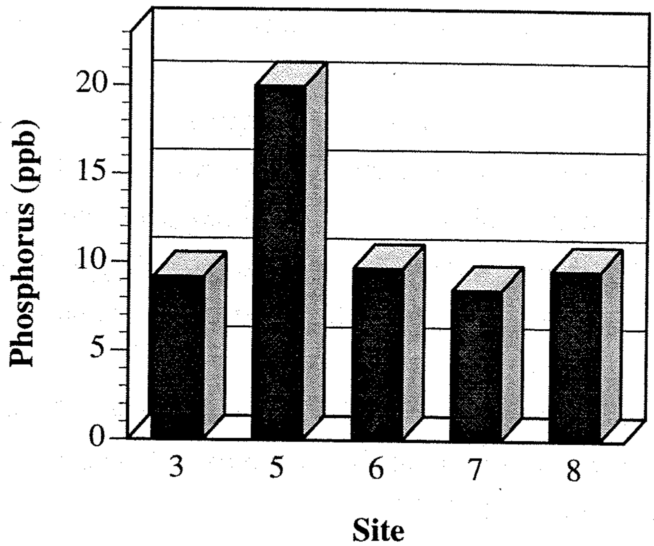

Figure 27. Total phosphorus concentrations for spot site surface samples of Messalonskee Lake. Samples for these sites were collected 22-Sept-97. See Figure 13 for site locations.

epicore sample, 9.8 ppb, and the surface grab, 9.2 ppb, values for Site 3, although a little higher than in 1991, were well within the range of a healthy lake and were similar to the phosphorus values found at other sites within the lake (Figure 27).

The level of phosphorus for Site 5 (20 ppb) was much higher than any of the other spot sites (Figure 27). This high level of phosphorus may have been caused by its location. The runoff from the dirt boat ramp at Site 5 flowed into the water and may have caused an increase in the phosphorus level (Chapman 1996). When this boat ramp becomes fully saturated with water from precipitation, the water may flow directly into the lake (MDEP 1992). While this run off travels over the dirt and gravel, it accumulates particles which, when deposited into the lake, contribute to the increase in the phosphorus concentration. In addition to the phosphorus loading from the boat ramp, phosphorus was probably released by the decomposition of plants in the surrounding marsh.

The composition of both Sites 6 and 8 were similar as were their phosphorus levels. Neither Site 3 or 7 were directly affected by runoff because they were located within the lake. The phosphorus levels for Site 6, 7, 8, and 9 were all within the range of a healthy lake (Figure 27).

Nitrates

Methods

Nitrate (NO_3^-) is the most common form of the element nitrogen found in natural waters. It can be produced from igneous rock, land runoff, and plant and animal refuse (Chapman 1996). Nitrate is an oxidized form of nitrogen that is assimilated by plants and microorganisms, which convert it into organic nitrogen. In low dissolved oxygen environments, it can be reduced by microbes (See Background, Nitrogen Cycle). Nitrate is an important nutrient in plant and algal growth, and seasonal fluctuations can be caused by plant growth and decay. Concentrations above 0.20 parts per million (ppm) stimulate algal growth and speed eutrophication (Pearsall 1991). Usually, levels of phosphorus limit the growth of algae in lake waters. It is important, however, to measure both phosphorus and nitrate levels in order to compare them and ascertain whether phosphorus is indeed the limiting factor (Pearsall 1991).

The natural nitrate concentration for freshwater is about 0.10 ppm NO_3^- (Chapman 1996). High levels can be caused by municipal and industrial wastewater and inorganic fertilizer runoff. Lakes in the eastern United States usually have nitrate concentrations of about 0.05 ppm to 0.20 ppm (Novotny and Olem 1994). An EPA study of 17 Maine lakes determined a mean concentration of 0.01 ppm NO_3^- for the state (Norton et al. 1989). Nitrate levels greater than 5.00 ppm indicate serious contamination (Chapman 1996).

CEAT collected epicore samples from Characterization Sites 1, 2, and 4 on 6-Oct-97 (see Appendix A). The HACH UV Direct Reading Method was used to analyze the nitrate concentrations of the samples with the HACH 4000 Spectrophotometer (HACH 1997).

Results and Discussion

All three characterization sites had concentrations of 0.10 ppm NO_3^-. A 1978 study found the mean for Messalonskee Lake to be 0.04 ppm NO_3^- (Davis et al. 1978), so nitrate levels seem to have risen over the past nineteen years. Values for the Belgrade Lakes chain collected from 1991 to 1996 ranged from 0.00 ppm to 0.07 ppm (BI493 1991, BI493 1994, BI493 1996, BI493 1997). Nitrate concentrations in Messalonskee Lake, although within the "clean lake" limit of 0.10 ppm (Pearsall 1991), seemed to be high for this region. High nitrate levels may have occurred due to poor land use practices such as overuse of fertilizer, excessive runoff, and sewage system leakage.

Hardness

Methods

Hardness is the characteristic of water that represents the total concentration of calcium (Ca^{+2}) and magnesium (Mg^{+2}) ions expressed as milligrams per liter (mg/L) of calcium carbonate ($CaC0_3$) (Stednick 1991). Hardness is used to classify waters on a continuum from soft to very hard and measures the soap-consuming capacity of water resulting from cations forming insoluble compounds with soap (Mays 1996). The American Water Works Association suggested that water should ideally have a hardness of no more than 80 mg/L $CaCO_3$ (USGS 1989). In general, public drinking water supplies are often softened to 100 mg/L $CaCO_3$ of hardness. At levels higher than 100 mg/L $CaCO_3$ of hardness, ordinary domestic use of water is classified as hazardous (USGS 1989).

Hardness measurements may be influenced by a variety of factors. For example, hardness measures mineral deposits in the water body derived from the bedrock and sediments of a lake. Hardness may also indicate industrial pollution. Pollution may enter lakes from the precipitation of calcium carbonates in cooling towers or boilers, the interference with soaps and dyes in cleaning and textile industries, or from emulsifiers used for developing photographs (Mays 1996).

Surface samples were taken at Sites 1, 2, 4, 5, and 7 on 22-Sep-97 and the USEPA approved HACH Titration Method adapted from EDTA Titrimetric Method was used to measure hardness (HACH 1997; see Appendices A and B).

Results and Discussion

The mean (± SE) hardness measurement was 14.8 ± 0.3 mg/L $CaCO_3$ (Figure 28). This hardness level was similar to the mean hardness of 21.2 ± 5.5 mg/L $CaCO_3$ for Long Pond, South Basin recorded on 18-Sep-95 (BI493 1996).

Long Pond is situated upstream and feeds into Messalonskee Lake. Messalonskee Lake and Long Pond, South Basin share a common bedrock of folded metamorphic rock while other lakes within the Belgrade chain have granite dominated bedrock. In Central Maine, metamorphic rock tends to release higher concentrations of Ca^{+2} and Mg^{+2} ions into a lake body than granite (Nelson, pers. comm.). Similarities between Messalonskee Lake and Long Pond, South Basin data, therefore, may have been due to a shared geographical location, common bedrock, or flow from Long Pond entering Messalonskee Lake.

This hypothesis was supported by relatively higher hardness levels reported by CEAT for Messalonskee Lake and Long Pond, South Basin than for other lakes within the chain with the exception of ponds comprising Salmon Lake (BI493 1994, BI493 1995, BI493 1997). For example, North Pond and Little Pond had a mean hardness of 10.1 ± 0.4 mg/L $CaCO_3$ and Long Pond, North Basin had hardness values between 12.1 mg/L $CaCO_3$ to 13.9 mg/L $CaCO_3$, while the ponds making up Salmon Lake (McGrath Pond and Ellis Pond) had mean hardness values of 26.5 mg/L $CaCO_3$ and 24.5 mg/L $CaCO_3$, respectively. These hardness values suggested an overall trend of soft water lakes within the Belgrade chain (BI493 1996).

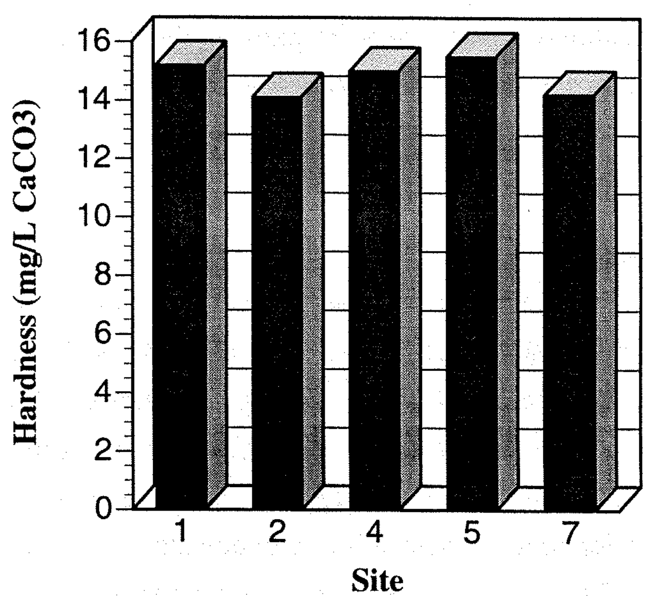

Figure 28. Hardness measurements from surface samples collected on 22-Sep-97 from Messalonskee Lake Sites 1, 2, 4, and 7; Site 5 was sampled on 6-Oct-97. See Figure 13 for site locations.

The sample collected at Site 5 on 6-Oct-97 with a hardness of 15.5 mg/L $CaCO_3$ was just above the range of hardness values observed at Sites 1, 2, 4, and 7 on 22-Sep-97 of 14.1 mg/L $CaCO_3$ to 15.2 mg/L $CaCO_3$ (Figure 28). The sample collected on 22-Sep-97 at Site 5 was visibly yellow, and lab analysis suggested an average hardness of 24.3 mg/L $CaCO_3$ when splits were performed. The consistency between the splits ensured lab technique and suggested that the extremely high hardness levels may have resulted from contaminants in the sample which may be attributed to sediments from the boat ramp (see Appendix B).

The hardness estimate for Messalonskee Lake of 14.8 mg/L $CaCO_3$ was less than the maximum threshold proposed by the American Water Works Association of 80 mg/L $CaCO_3$ for safe drinking water and efficient domestic use of water (USGS 1989). In addition, the observed low levels of hardness suggested that Messalonskee Lake was subject to limited industrial pollution at this time despite the presence of a cement plant near Sites 4 and 5 (Mays 1996). The Belgrade Bog is situated at the southern end of Messalonskee Lake and may have served as a sink for Ca^{+2} and Mg^{+2} ions, thus filtering pollution from the water at Site 4 and 5 before it enters the lake (see Messalonskee Lake Water Quality: Site Map).

In general, softer water is more susceptible to toxins and pollutants than harder water (Uhlmann 1982, Chapman 1996). The softness of water samples collected, therefore suggested that Messalonskee Lake may be particularly vulnerable to toxins entering the lake. Moreover, future monitoring may be necessary to reevaluate the impacts of industry in this area for years to come.

pH

Methods

The pH of a solution is a measure of the hydrogen (H^+) ion concentration and is used to determine acid-base status. The pH scale is logarithmic ranging from zero to 14.0, with 0 being extremely acidic, 7.0 representing a neutral condition, and 14.0 being extremely alkaline (Stednick 1991, Chapman 1996). A range of pH values from 6.0 to 8.5 is observed in most natural waters, but lower values occur in dilute waters of high organic content and higher values occur in waters experiencing eutrophication, groundwater brines, or salt lakes (Chapman 1996).

The pH of water is a determining factor in most natural processes and plays a critical role within many biological systems (Stednick 1991). Consequently, the pH of lakes may be a diagnostic factor for determining the species composition of a lake (Pearsall 1991). The values of pH are often controlled by the balance between carbon dioxide, carbonate, and bicarbonate ions and indicate the activity of dissolved chemical compounds and biochemical processes within water solutions (Chapman 1996).

Acid lakes tend to have low productivity, be relatively clear, and have little or no natural buffering capacity (Chapman 1996). For example, fish are often negatively affected by low pH. Industrial effluents and atmospheric deposition of acid-forming substances may disturb the natural acid-base balance (Chapman 1996). Pearsall (1991) estimated that approximately one hundred acid lakes exist in Maine.

The pH was measured at Sites 1, 2, 3, 4, 5, 6, 7, and 8 using the B213 Horiba Compact pH meter on 22-Sep-97 (see Appendices A and B).

Results and Discussion

The mean (± SE) pH value for the lake sites was 6.98 ± 0.11 with an overall range from 6.65 to 7.53 for lake sites. Maine lakes tend to be slightly acidic, having pH values ranging from 6.1 to 6.8 (Pearsall 1991). In comparison to other Maine lakes, the observed range of pH values for Messalonskee Lake was slightly more alkaline. Messalonskee Lake and Long Pond, South Basin have folded metamorphic bedrock, while all other lakes in the Belgrade chain have a low buffering capacity bedrock of granite (Nelson, pers. comm.). Lakes with granite bedrock are more prone to acidification than those with a higher buffering capacity of metamorphic bedrock. Messalonskee Lake had a neutral pH and did not appear to be experiencing acidification which is typical of lakes with a metamorphic bedrock (Nelson, pers. comm.). Moreover, the lake appears to be relatively undisturbed by industrial effluents and atmospheric deposition of acid-forming substances. This study suggested that the pH levels of the Messalonskee Lake were not negatively impacting the majority of fisheries and other organisms within the lake.

<u>Alkalinity</u>

Methods

Alkalinity is a measurement of the acid-neutralizing (buffering) capacity of the water (Chapman 1996). It indicates levels of the ions carbonate, bicarbonate, and hydroxide. The higher the alkalinity, the greater the ability of the lake is to buffer changes in pH. If alkalinity drops below 4 parts per million (ppm), the lake will be susceptible to the effects of acid rain and other acidifying inputs (Pearsall 1991). If acidity is a problem, alkalinity will change before pH, making it a good warning indicator. Alkalinity also measures the inorganic carbon reservoir of the lake, which determines the ability of the water to support algal growth and aquatic life (Pearsall 1991). In Maine lakes, alkalinity generally ranges from 4 ppm to 20 ppm (Pearsall 1991), with a mean of 10 ppm (Davis et al. 1978). A level above 10 ppm indicates that the lake can more easily withstand the effects of acid rain.

CEAT collected epicore samples from characterization sites on 22-Sep-97 and 6-Oct-97 (see

Appendix A). The potentiometric method was used to obtain alkalinity expressed as ppm $CaCO_3$ (Eaton, Clesceri, and Greenberg 1995).

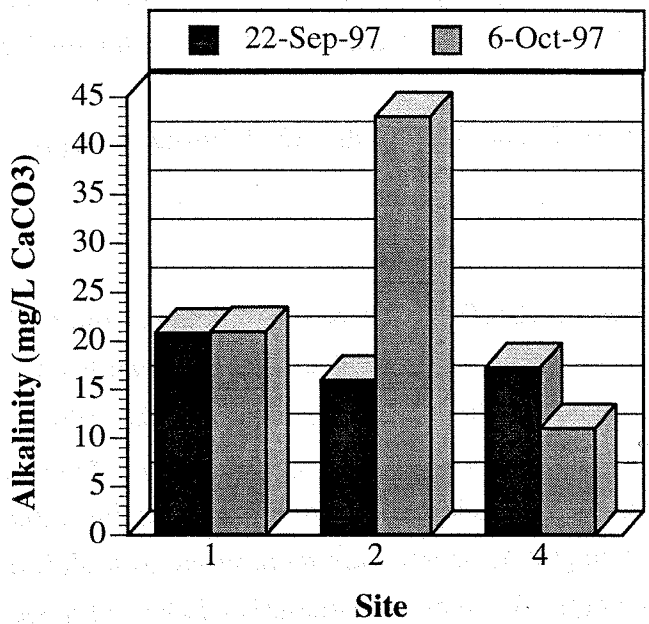

Figure 29. Mean alkalinity measurements for epicore samples taken from Messalonskee Lake Characterization Sites (Sites 1, 2, and 4) on 22-Sep-97 and 6-Oct-97.

Results and Discussion

The results from 22-Sep-97 ranged from 16 ppm to 21 ppm $CaCO_3$, with a mean (± SE) of 18 ± 1 ppm. Results from 6-Oct-97 ranged from 11 ppm to 43 ppm $CaCO_3$, with a mean of 25 ± 9 ppm (Figure 29).

The results from 6-Oct-97 were much more variable, and the value for Site 2 (43 ppm) was particularly high. The reasons for this discrepancy were unknown. Without the Site 2 outlier, the mean for 6-Oct-97 was 16 ppm, and the mean for both sampling days was 17 ppm. These levels seemed consistent with historical alkalinity levels for the region. In a 1978 study of Messalonskee Lake, the alkalinity was determined to be 9 ppm, with a range from 7 ppm to 12 ppm (Davis et al. 1978). Studies of the Belgrade Lakes conducted in the 1990s found alkalinity levels from 7 ppm to 12 ppm (BI493 1991, BI493 1995, BI493 1996). These results revealed a regional trend toward levels in the low teens. Messalonskee Lake appeared to have alkalinity levels higher than other local lakes, but not abnormally high for Maine. The water seemed to be well-buffered against changes in pH.

Tributary Water Quality

Physical Measurements

Introduction

The physical parameters tested at tributary sites were flow rate, dissolved oxygen, temperature, and turbidity. These measurements helped to determine the quality of the water each tributary added to Messalonskee Lake, which was useful in ascertaining the overall health of the lake.

Flow Rate

Methods

Flow rate is a measure of the amount of water moving past a certain point in a tributary over time. It was essential to determine the flow rate of each tributary studied in order to identify its relative contribution of flow to the lake. The amount of water, nutrient, and other dissolved material contributed by each tributary was influenced by its flow rate. Factors such as drainage area, slope, and stream basin configuration may have affected flow rate.

CEAT measured flow rates at Tributary Sites 9, 10, 11, 13, 14, and 15 on 22-Sep-97. Site 12 was not measured because it was not flowing at the time of sampling. The flow rates were determined using the Marsh-McBirney, Inc. Flow Mate flow meter. Each tributary was divided along a transect into sections (cells), and the flow rate was measured in each cell. The total width of the tributary was recorded, and flow in each cell was calculated using the following formula:

Flow Rate per cell(cfs) = [length of cell (ft)] x [mean depth of cell (ft)] x [mean cell velocity (ft/s)]

The flow rates for all cells along the transect were combined to calculate the overall flow rate of the tributary in cubic feet per second (cfs).

Results and Discussion

Flow rate results revealed that the main input to Messalonskee Lake came from Belgrade Stream (see Appendix D). Belgrade Stream had a flow rate of 23.00 cfs, 70 times to 700 times larger than the 0.03 cfs to 0.34 cfs calculated for the other tributaries. It also drained a much larger area than the other tributaries; the watershed for Belgrade Stream was almost as large as that of Messalonskee Lake. This stream drained Long Pond and entered Messalonskee Lake at its southern tip.

Other tributaries, such as Site 12, had little or no water flowing at the time of sampling. These were probably ephemeral, flowing in periods of high runoff and evaporating when precipitation was low. Some of these seasonal tributaries had large culverts, indicating that they could handle large amounts of water during the spring rains and floods. Examination of a topography map for the region indicated that Ellis Brook (Site 9) and Bang's Brook (Site 10) had the largest drainage areas after Belgrade Stream (Site 11). Belgrade Stream, however, was so large, and the flow rates for other tributaries were so small, that its contributions to Messalonskee Lake dwarfed those of the smaller tributaries.

Dissolved Oxygen and Temperature

Methods

DO and temperature measurements at tributaries may indicate sources of oxygenated water and sources of warmed or cooled water entering the lake (Chapman 1996). DO and temperature were measured using an Orion model 840 DO meter at Tributaries 9, 10, 11, 13, 14, and 15 on 22-Sep-97 (see Appendices A and B).

Results and Discussion

The data revealed that tributaries of Messalonskee Lake had a mean (± SE) oxygen concentration of 8.4 ± 0.7 ppm and a mean temperature of 14.6° C ± 0.6° C (Table 5).

These DO and temperature measurements were consistent with the data recorded for the overall lake body (see Lake Water Quality Measurements and Analysis: Dissolved Oxygen and Temperature). In general, the tributaries of Messalonskee Lake were relatively well oxygenated and had DO levels higher than the accepted lower limit of 5 ppm which poses stress on cold water fisheries (Davis et al. 1978, Pearsall 1991, Chapman 1996).

These data were consistent with the hypothesis that tributaries are generally well aerated due to constant mixing of water flowing through tributary basins as suggested by Pearsall (1991), Stednick (1991), and Chapman (1996). The high flow rates of the Belgrade Stream may also have contributed to the mixing of atmospheric oxygen into the water column at Site 11. The highly oxygenated water flow may have had a positive impact on the overall health of Messalonskee Lake by contributing oxygen to support the biological processes of aquatic life.

Table 5. The dissolved oxygen (DO) (ppm) and temperature (° C) measurements taken on 22-Sep-97 for Tributary Sites 9, 10, 11, 13, 14, and 15 with a mean (± SE) DO of 8.4 ± 0.7 ppm and temperature of 14.6 ± 0.6° C. See Figure 13 for site locations.

Tributary Site	Dissolved Oxygen (ppm)	Temperature (°C)
9	9.4	13.1
10	9.5	14.3
11	8.2	17.6
13	8.7	14.1
14	10.7	14.3
15	7.8	13.4

Turbidity

Methods

Turbidity measures the amount of suspended solids in the water (see Lake Water Quality: Turbidity). In tributaries, turbidity indicates the amount of particulate matter entering the lake. This matter can have high levels of phosphorus and other nutrients, which may cause algal blooms and eutrophication in the lake.

CEAT collected surface samples from all tributary sites on 22-Sep-97 (see Appendices A and C) and analyzed them using the HACH Attenuated Radiation Method on the HACH Spectrometer 4000 (HACH 1997). Turbidity was measured in Formazin Attenuation Units (FAU), which were roughly equivalent to both Nephelometric Turbidity Units (NTU) and Formazin Turbidity Units (FTU) (HACH 1997). The accuracy of the Attenuated Radiation Method was checked with a HACH Model 2100P Portable Turbidimeter (see Lake Water Quality Measurements and Analysis; Turbidity).

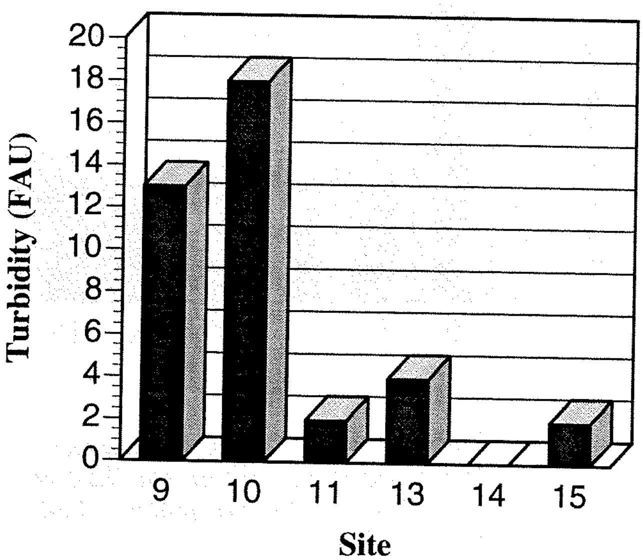

Figure 30. Turbidity measurements for surface samples taken at tributary sites (Sites 9 to 15) on 22-Sep-97 (Site 12 not sampled due to lack of flow). Site 14 had a measurement of 0 FAU.

Results and Discussion

Turbidity measurements for tributaries varied widely, ranging from 0 FAU to 18 FAU). Site 9 (Ellis Brook) and Site 10 (Bang's Brook) had very high levels of 13 FAU and 18 FAU, respectively (Figure 30). Evidently these tributaries contributed a higher level of suspended solids to the lake. Turbidity levels of tributaries to other Belgrade Lakes have ranged from 0 FAU to 39 FAU (BI493 1991, BI493 1994, BI493 1995, BI493 1996), so the levels for tributaries to Messalonskee Lake seemed to be comparable for this region.

Chemical Measurements

<u>Introduction</u>

Tributaries are relatively small bodies of water that empty into larger bodies of water. They transport nutrients, minerals, and sediments until reaching its termination point and serves as a phosphorus loading source (see Background: Nutrient loading). Fluctuations for tributary measurements will naturally vary with environmental conditions. Caution was taken to ensure that each sample was homogenous and representative of the area.

<u>Total Phosphorus</u>

Methods

Surface grabs were used to obtain samples from Tributary Sites 9, 10, 13, 14, and 15 while a Kemmerer Water Sampler was used to collect surface water from Site 11 located at Belgrade Stream (Figure 13). Site 12 was never sampled due to a lack of flow from the tributary. Samples were collected from specific and documented areas (see Appendix A). Water samples were taken at tributaries from 15-Sep-97 to 3-Nov-97.

Results and Discussion

Tributary sites were sampled on 22-Sep-97 and phosphorus values ranged from 10.1 ppb at Site 14 to 36.3 ppb at Site 9 (Figure 31). Ellis Brook was a shallow and slow flowing tributary that contained visibly suspended sediment that could easily be disturbed and stirred up. The rapid burial and decomposition of organic matter in the top ten centimeters of sediment in productive lakes, like

Messalonskee Lake, is easily released by turbulent conditions such as rain (Hannula and Rock 1983). On 22-Sep-97, the other tributary sites resulted in comparable levels of phosphorus which fell below the critical lake phosphorus limit of 12 ppb (Bouchard, pers. comm.).

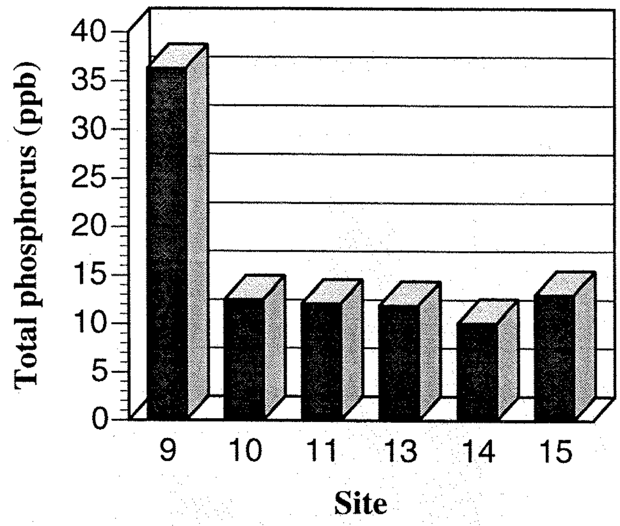

Figure 31. Total phosphorus from samples taken on 22-Sep-97 from Messalonskee Lake tributaries.

The phosphorus level analyzed at Site 9 was found to fluctuate from 26.2 ppb to 46.0 ppb (Figure 32). These results are well above the 12 ppb critical level of phosphorus for lakes (Bouchard, pers. comm.). The data collected showed an increase in phosphorus levels as the season, and rain, progressed. The turbulent conditions occurring within the watershed caused the release of phosphorus. The increase of precipitation characteristic of the fall, aided in flushing out the nutrients that would have otherwise built up and remained within the soil sediment.

At Belgrade Stream (Site 11), samples were taken between 15-Sep-97 and 3-Nov-97 (Figure 32). The samples taken fluctuated from 10.1 ppb on 20-Oct-97 to 30.8 ppb on 3-Nov-97. Belgrade Stream served as a large input of phosphorus for Messalonskee Lake. Belgrade Stream is the main artery connecting the water from other Belgrade Lakes to Messalonskee Lake. The increase in phosphorus observed late in the season may have been the result of the increased decomposition represented by the combination of vegetative decay and the increase of precipitation.

Messalonskee Lake tributaries were previously studied in 1976 for total phosphorus levels (Davis et al. 1978). Both 1997 and 1976 samples were collected during the fall. The results from the five tributaries examined in the 1976 study, showed a mean phosphorus total of 3.8 ppb whereas the six tributaries examined by CEAT, resulted in a mean of 21.3 ppb. The increase in overall phosphorus is attributed to many factors further examined in this 1997 CEAT study (Background: Nutrient Loading).

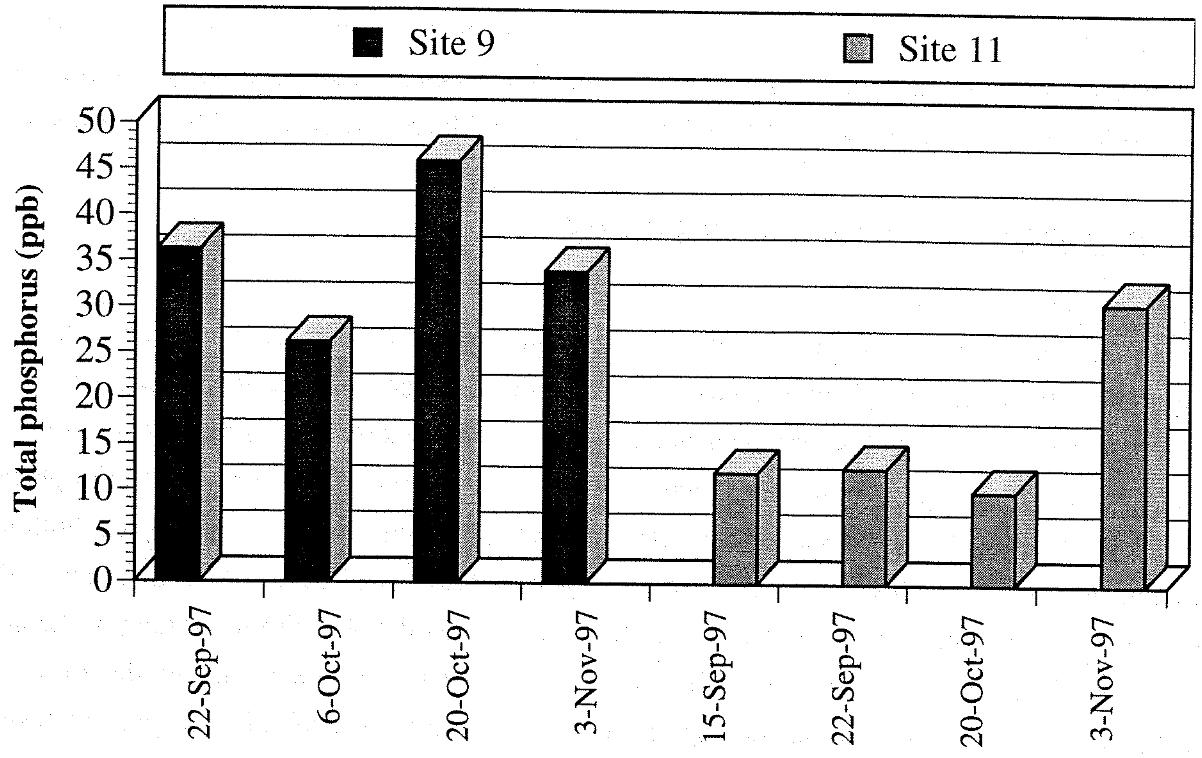

Figure 32. Total phosphorus concentration at Sites 9 and 11 for surface samples collected at Messalonskee Lake from 15-Sep-97 to 3-Nov-97.

pH

Methods

The pH values of tributaries are especially important because they measure whether the water entering the lake is acidic, neutral, or alkaline (see Lake Water Quality Measurements and Analysis:

Chemical Tests; pH). This analysis of tributaries may aid in identifying sources such as industrial effluents, acidic bedrock, or atmospheric deposition of acid-forming substances which may contribute acidic water to the overall lake body (Chapman 1996). The pH measurements were obtained at Tributaries 9, 10, 11, 13, and 14 using the B213 Horiba Compact pH meter on 22-Sep-97.

Results and Discussion

The mean (± SE) pH value for the tributary sites was 7.01 ± 0.18 with an overall range from 6.55 to 7.60. The pH measurements all represented an approximately neutral condition. The tributaries exhibited pH values similar to those found in the lake. The lake sites had a mean pH of 6.98 ± 0.11 and a range of 6.65 to 7.53 (see Lake Water Quality Measurements and Analysis: Chemical Measurements; pH). The pH values measured at tributaries were just above the estimated pH values reported for the State of Maine in 1991 which ranged from 6.1 to 6.8 (Pearsall 1991).

Overall, the tributaries appeared to carry neutral water relatively unaffected by industrial effluents, acidic bedrock, or atmospheric deposition of acid-forming substances to the lake body. Consequently, the tributaries did not appear to be notable point sources for acidic runoff entering Messalonskee Lake.

WATERSHED LAND USE PATTERNS

Introduction

The eutrophication of a lake is often greatly influenced by the land use patterns in the surrounding watershed. Residential development and the clearing of land for agriculture, lawns, industry and commercial development can greatly increase the amount of runoff into a lake. This runoff, often high in phosphorus, nitrogen, and particulate matter can lead to significant eutrophication of the lake. Our study of Messalonskee Lake examined various types of land uses within the watershed, including shoreline residential zoning, septic systems, land usage and soil types. These factors were examined in an effort to determine their impact upon the phosphorus loading of the lake.

Changes in land use patterns over the past 35 years were also examined to determine their possible effects upon the phosphorus loading of the lake. In addition to their effects upon the lake, the changes in land use were important in formulating projections of both future trends as well as making recommendations for how best to manage the watershed in years to come.

Watershed Residential Shoreline Zoning

The shoreline zoning ordinances concerning the construction of residences, the installation of septic systems, and the criteria for appropriate buffer strips were examined. The shoreline zoning ordinances for Belgrade, Oakland, and Sidney contain a high degree of similarity since all three townships designed their ordinances based upon those set by the State of Maine. The zoning ordinances of all three townships define the Shoreline Zone in the following way:

> Land area located within two hundred and fifty (250) feet, horizontal distance, of the normal high-water line of any great pond, river, or saltwater body; within 250 feet of the upland edge of a coastal or freshwater wetland; or within seventy-five (75) feet of the normal high-water line of a stream (Sidney 1997).

Residences constructed before the zoning ordinances took effect are referred to as "non-conforming." These non-conforming residences are exempt or "grandfathered" from the zoning ordinances passed after their construction. The zoning ordinances are designed in such a way that a non-conforming residence can be expanded as much as desired only if it does not increase the non-conformity of the residence. Since January 1, 1989, however, the expansion of a non-conforming residence must comply with the following:

> .....if any portion of a structure is less than the required setback from the normal high-water line of a water body or upland edge of a wetland, that portion of the structure shall not be expanded in floor area or volume, by 30% or more, during the lifetime of the structure (Sidney 1997).

All three townships have the same regulations regarding the construction of residences. These regulations state that all new residences must be constructed "one hundred (100) horizontal feet from the normal high-water line of a great pond and rivers that flow into great ponds..." or "...seventy-five (75) horizontal feet from the normal high-water line of a stream" (Belgrade 1997; see Background: Septic Systems). For Belgrade, and Oakland, the minimum lot size on which these residences can be constructed must include 200 ft of shorefront and cover no less than 40,000 ft^2 (Oakland 1997). Sidney, however, has written their zoning ordinance so that the minimum lot size must cover an area of no less than one acre (43,560 ft^2) (Sidney 1997).

Septic systems must also comply with the same minimum distances as those mandated for the construction of a residence (see Background: Septic Systems). All new septic systems must also be installed above the existing water table. Prior to 1974, there were no zoning ordinances mandating the specific type of septic system that had to be installed on a property or a minimum distance from the water at which a septic system could be installed. As a result, many of the septic systems installed prior to 1974 were little more than pit privies or perforated 55 gallon drums sunk into the soil. Little regard was given to the distance from the lake at which they were installed or the potential environmental degradation that resulted.

Since 1974, however, all new septic systems installed on a property must be designed according to the specific needs of the property. The two characteristics upon which the size of the septic system depends are the number of bedrooms in the residence and the quality of the soil in which the septic system is to be installed (Fuller, pers. comm.). The number of bedrooms in a residence is used to approximate the number of people using the septic system. In regards to soil, properties with poor, less permeable soils must have larger leach fields for proper drainage to occur. Properties with good, suitably permeable soils, however, can have smaller leach fields because less soil is needed to achieve the same amount of drainage (Fuller, pers. comm.).

For the creation of buffer strips on newly developed shoreline lots, the following regulations must be followed:

> Within a shoreland area zoned for Resource Protection abutting a great Pond, there shall be no cutting of vegetation within the strip of land extending 75 feet, horizontal distance, inland from the normal high-water line, except to remove safety hazards (Sidney 1997).

The creation of footpaths through the buffer strip is permissible but may not "exceed ten (10) feet in width as measured between tree trunks..." and must ensure that, "a cleared line of sight to the water through the buffer strip is not created" (Sidney 1997). By ensuring that the maximum widths of footpaths are kept to a minimum and do not run directly into the lake, phosphorus loading and other negative side effects of runoff are minimized (see Background: Buffer Strips).

Since most of the existing shoreline lots were developed before the zoning ordinances were enacted, most do not contain the appropriate 75 ft of buffering. For those shoreline lots developed after the ordinances were enacted, compliance has been very good. Owners of these newly developed shoreline lots seem to be very conscious of the impact that development has upon the lake and have done a good job of establishing proper buffer strips (Lussier, pers. comm.).

Septic Systems

Methods

Since direct observation of the septic systems was not possible, it was important to use three different methodologies to develop a reliable qualitative assessment of the overall condition of the septic systems within the watershed. The first method involved driving surveys of all residences within the watershed. The surveys were conducted by driving past the residences and evaluating them to determine their age. Determining the age of a residence was difficult without being able to interview the individual property owners. The ages of residences were evaluated using several characteristics including architecture, structural condition and surveyor judgment.

The goal of these surveys was to determine the number of shoreline and nonshoreline residences as well as which residences were constructed before and after 1974 (see Shoreline Zoning for an explanation of the importance of 1974). From the surveys, the approximate number of pre 1974, and post 1974, shoreline, and nonshoreline, septic systems in use within the watershed could be estimated. For the purposes of this report a residence that was built within 200 ft of the lake was classified as a shoreline residence. Any residence constructed beyond 200 ft from the lake was classified as a nonshoreline residence.

Since the driving surveys were highly subjective, the plumbing inspectors of the different towns were also interviewed to ascertain their outlook on the overall condition of the septic systems. It was believed that the plumbing inspectors would have detailed knowledge of the septic systems within their towns and thus could provide relatively accurate estimates regarding the number of pre 1974 and post 1974 septic systems in use.

The third methodology used in assessing the septic systems in the watershed was random sampling of property cards which was conducted at the various town offices. Property cards are records of the characteristics of each property that are kept in files at the respective town offices. The random sampling was conducted to quantify both the percentages of residences with septic systems as well as the percentages of the different types of septic systems (i.e., holding tanks, cesspools or the newer post 1974 septic systems with proper leach field systems) (see Background: Sewage Disposal

Systems). The random sampling of property cards was also conducted to determine the age of the various septic systems within the watershed.

Results and Discussion

Oakland: Through driving surveys, it was determined that out of 576 residences surveyed, 242 were shoreline residences. Of these 242 shoreline residences, 144 (59.5%) were constructed prior to 1974 while the other 98 (40.5%) were constructed after 1974 (Figure 33). The remaining 334 residences surveyed were nonshoreline residences. Of the 334 nonshoreline residences, 194 (58.1%) were constructed prior to 1974 while the other 140 (41.9%) were constructed after 1974 (Figure 33).

The total number of residences constructed prior to 1974 out-numbered the total number of residences constructed after 1974 (338 residences to 238 residences, respectively). These numbers would suggest that there are a minimum of 238 post 1974 septic systems in use within the watershed. If, however, the surveys were accurate, the actual number of post 1974 septic systems should be higher due to the periodic replacement of pre 1974 systems over the past 23 years. Replacements could have been installed for various reasons including the malfunctioning of the existing system, the addition of a bedroom to a residence, or the "seasonal conversion" of a residence. When a seasonal residence is converted to a year-round residence, the septic system must be enlarged to handle the subsequent increase in use.

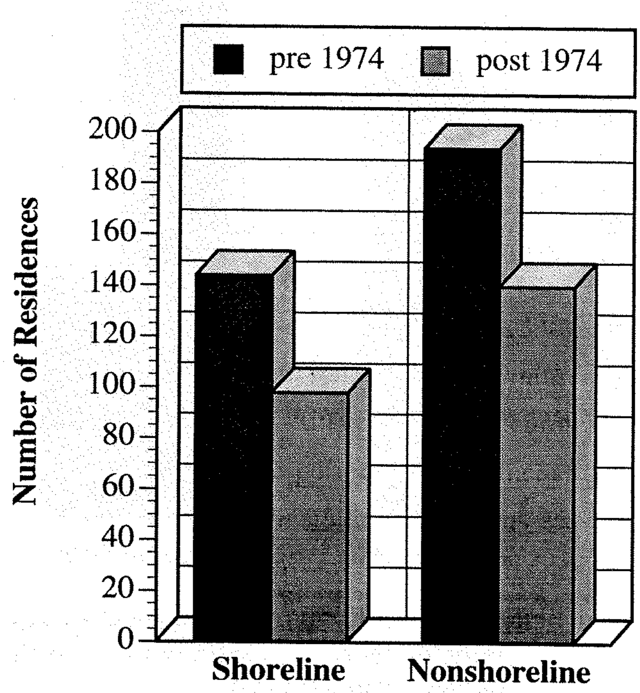

Figure 33. Oakland shoreline and nonshoreline residences constructed before or after 1974.

The plumbing inspector for the town of Oakland, Mr. Paul Lussier, offered a "very optimistic" estimate of 75% as being representative of the number of pre 1974 septic systems still in use. That would mean that of the 576 residences surveyed in Oakland, only 144 residences (25%) have post 1974 septic systems. Both Lussier's estimate and the data collected by CEAT indicate that the majority of septic systems in use were installed prior to 1974. The variability in the numbers also points to the difficulty of making exact predictions of a residence's age.

The results from the random sampling of property cards did not prove to be as useful as anticipated. While the property cards did denote whether or not a property had a septic system, they did not indicate the specific type of system. For Oakland, the property cards listed properties as having "Septic", "Cesspool" or "Public". Fifteen of the 20 shoreline property cards sampled revealed that the residences had "Septic" while the remaining five had "Public"[1].

In addition to not listing the type of system contained on a property, none of the property cards indicated the date on which a septic system had been installed or replaced. Even today, if a property were to have a new system installed, the date of installation would not be recorded, and it would only be noted that the property in question was equipped with "Septic" (Lussier, pers. comm.).

To illustrate the problem created by the lack of detail recorded on the property cards, when one card was sampled, the property was listed as having a building that contained "No Utilities". When Lussier was asked about the property, however, he indicated through personal knowledge that the property contained a holding tank. Such a determination of the type of "Septic" on the property would have been impossible without this knowledge. This lack of detailed record-keeping prevented Lussier or the Tax Assessor, Ms. Kathleen Martin, from accurately determining the number of pre 1974 and post 1974 septic systems in use in the Oakland watershed.

Belgrade: Surveying determined that out of 205 residences surveyed, 90 were shoreline residences. Of these 90 residences, 68 (75.6%) were constructed prior to 1974 while the other 22 (24.4%) were constructed after 1974 (Figure 34). The remaining 115 residences surveyed were nonshoreline residences and of these, 80 (69.6%) were constructed prior to 1974 while the other 35 (30.4%) were constructed after 1974 (Figure 34). Of the 205 total residences surveyed, a total of 148 (72.2%) were constructed prior to 1974. The remaining 57 residences (27.8%) were built after 1974. Since 57 represents the minimum number of post 1974 septic systems, it is anticipated that the actual number of post 1974 septic systems is higher due to the periodic replacement of pre 1974 septic systems over the past 23 years.

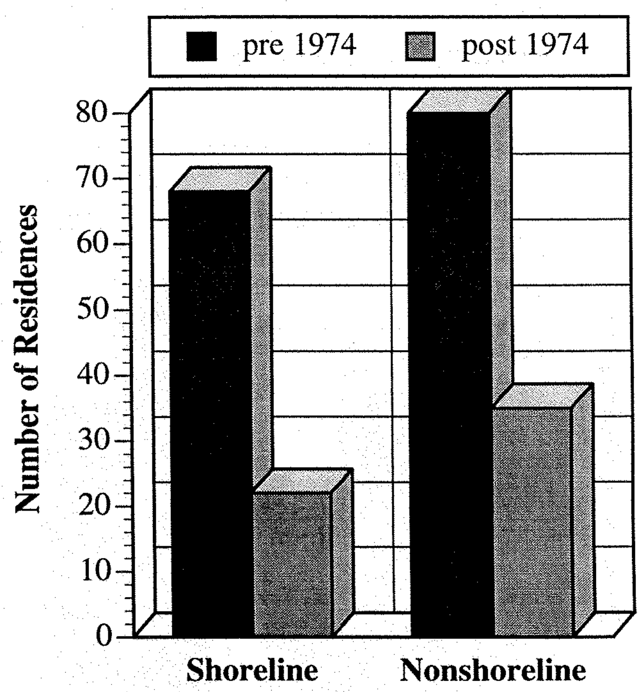

Figure 34. Belgrade shoreline and nonshoreline residences built before or after 1974.

Mr. Bob Martin, Plumbing Inspector for the town of Belgrade, described the overall condition of the septic systems as being quite good. Martin also discussed the fact that he has seen a lot of replacement systems installed in recent years. Though he was

[1] There are only eight (8) residences in the entire Belgrade Lakes chain which are on a public sewer line. All eight of these residences are located in Oakland at the northern end of Messalonskee Lake (Lussier, pers. comm.).

unable to approximate the number of pre 1974 and post 1974 septic systems outside of the shoreline zone, he did estimate that 75% of all shoreline septic systems in use today have been installed since 1974 (Martin, B., pers. comm.).

Survey data indicated that 24.4% of the shoreline residences have post 1974 septic systems. This figure (24.4%) did not, however, take into account the replacement of pre 1974 systems over the past 23 years. Because a large part of the 75% figure indicated by Martin was due to the replacement of pre 1974 systems, this would suggest that there has been a high rate of replacement of pre 1974 septic systems. Such a high rate of replacement of pre 1974 septic systems is beneficial for Messalonskee Lake since septic systems installed after 1974 are designed for the specific property which makes them much more effective in treating waste and reducing the chances of lake pollution.
The random sampling of property cards for Belgrade produced the same results as those in Oakland. Again, there was no way to determine the type of system that was installed on a given property or the date of installation. As was the case with Oakland, the information contained on Belgrade's property cards was too vague to be of any real use to this study.

Sidney: Through driving surveys it was determined that out of 507 residences surveyed, 171 were shoreline residences. Of these, 73 (42.7%) were constructed prior to 1974 while the other 98 (57.3%) were constructed after 1974 (Figure 35). The remaining 336 residences surveyed were nonshoreline residences and of these, 154 (45.8%) were built prior to 1974 while the other 182 (54.2%) were constructed after 1974 (Figure 35). Out of the total residences surveyed, 227 (44.7%) were constructed prior to 1974. The remaining 280 residences (55.2%) were determined to have been built after 1974. Since 280 represents the minimum number of post 1974 septic systems, it is anticipated that the actual number of post 1974 systems is larger than 280 due to the periodic replacement of pre 1974 systems over the past 23 years.

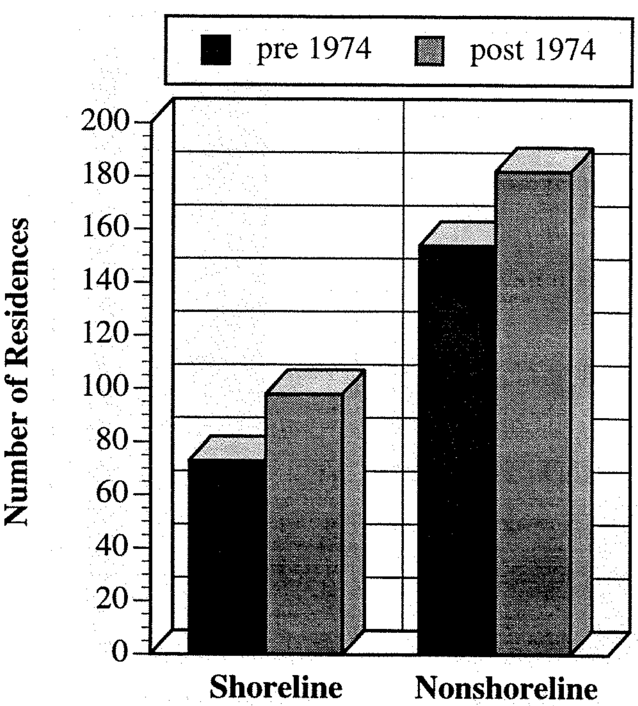

Figure 35. Sidney shoreline and nonshoreline residences construced before or after 1974.

Mr. Gary Fuller, Plumbing Inspector for the town of Sidney, described the overall condition of the septic systems as being good. Fuller did not, however, feel comfortable making even the broadest approximation of pre 1974 versus post 1974 septic systems currently in use. As he described it, such a guess would be a "complete shot in the dark." Fuller did, however, indicate that he is starting to see an increase in the number of pre 1974 septic systems being replaced. This comment would seem to verify that the data collected by the surveys is conservative and that the actual number of post 1974 septic systems now in use is actually higher than those counted.

The random sampling of property cards conducted in Oakland and Belgrade was not conducted for Sidney. After speaking with Fuller it was determined that the information contained on the property cards would be identical to that contained on the property cards for Oakland and Belgrade. As a result, it was decided that random sampling would be of no practical value and thus was not performed.

Watershed: As might be expected, for all three townships there were a larger number of nonshoreline residences than shoreline residences within the watershed area (Figure 36). This is due to the relatively limited amount of shoreline property. For both Oakland and Belgrade the majority of the shoreline and nonshoreline septic systems were installed prior to 1974. In Sidney, however, the majority of shoreline and nonshoreline systems were installed after 1974.

While an old system does not necessarily equate to a bad system, pre 1974 systems were installed with little regard to the environment. As many of these older systems begin to malfunction, the lake is endangered by contaminated runoff containing high concentrations of phosphorus and nitrogen.

In many cases, property owners may not be aware that their septic system is malfunctioning until there is visible above ground runoff from the system. By the time this occurs, the lake has already received sub-surface runoff high in phosphorus and nitrogen. Though few property owners are aware, grant money from the MDEP is available to repair or replace malfunctioning septic systems. This does not mean, however, that any property owner whose system is malfunctioning is a candidate for a

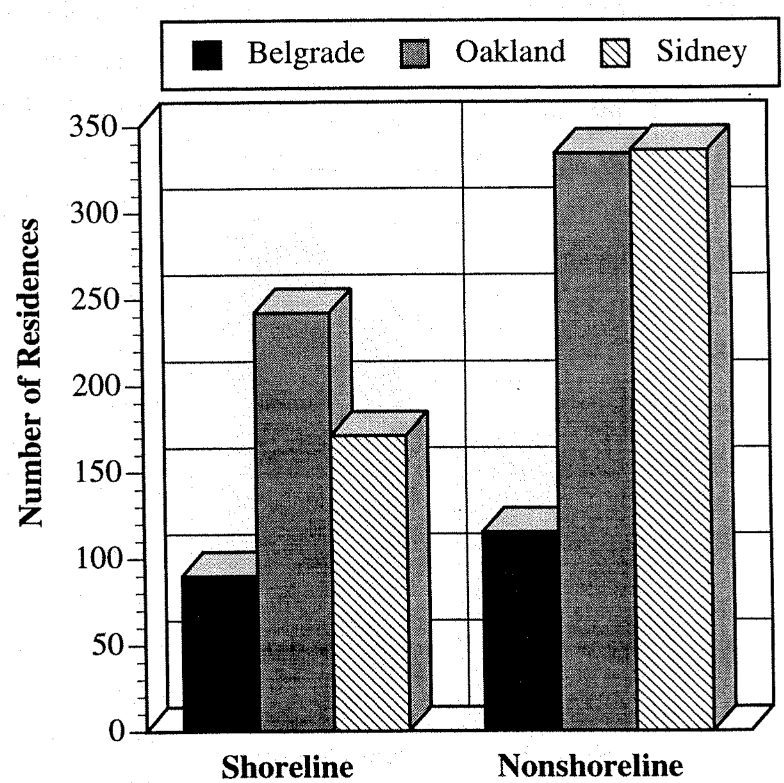

Figure 36. Shoreline and nonshoreline residences for the townships of Belgrade, Oakland, and Sidney, ME.

grant. Grants are given or denied on a case by case basis.

One interesting event concerning septic systems occurred nearly six years ago in the township of Vassalboro. At that time, the Vassalboro Town Council enacted legislation declaring that all pre 1974 septic systems had to be replaced within the next five years. After the five years, any residences found to be violating the legislation would be taken to court (Lussier, pers. comm.). Interviews with the different plumbing inspectors from Belgrade, Oakland, and Sidney revealed a mixture of thoughts regarding the actions of the Vassalboro Town Council. Some felt that the legislation was too strict, especially for those with a limited income. Others, however, thought that if any real action is to be taken to reduce the environmental problems created by faulty pre 1974 systems then similar legislation must be enacted in other townships.

Land Use

Land Use Methodology

In order to determine the nonpoint sources responsible for phosphorus loading in the Messalonskee Lake watershed, different land use types were identified and measured. Various map types were used, including topographic maps from 1957 and 1988, aerial photographs from 1991/1992 and 1965/1966, and infrared aerial photographs from 1985. The primary piece of equipment used along with the maps and the photographs was a Tamaya Digitizing Area-Line meter Super Planix ß planimeter (Tamaya Technics, Inc. 1997).

The area of the watershed was determined by using the planimeter together with USGS topographic 1:24,000 scale maps of NW/4 Augusta 15 minute quadrangle from 1988 of Messalonskee Lake and the surrounding areas. The watershed of Messalonskee Lake, determined by MDEP, was traced on to the topographic map. The watershed of Messalonskee Lake was subdivided into a Belgrade Stream watershed and a lake watershed. The lake and stream were separated at the site where Rt. 11 crosses over the Belgrade Stream. The planimeter was used to determine the area of the watershed and the surface area of Messalonskee Lake. The watershed area of the Belgrade Stream was found but discounted for the purposes of the land use part of this study.

Aerial photographs of the Messalonskee Lake watershed from 1965/66 and 1991/92 were obtained from the United States Department of Agriculture High Altitude Photography Program. They were used to determine the different types of land uses found within the watershed. Aerial photographs from 1940 and 1956 were available and were used only for visual comparisons (see Background: Historical Perspectives).

Before CEAT could begin analyzing the photographs, watershed boundary and town boundary lines were drawn on the nine 1965/66 and the four 1991/92 aerial photographs. Each aerial photograph was covered with mylar. An overhead version of the USGS culture map of Messalonskee

Lake and its surrounding areas was projected on the aerial photographs. After the aerial photograph and the culture map were lined up, the town boundaries and watershed boundaries were drawn on all of the photographs.

Once the watershed was traced on all the aerial photographs, it was necessary to find the appropriate scale for each photograph. This was done through field reconnaissance. Short, flat areas were found on roads lying on the aerial photographs of the watershed. The length of these areas was measured in feet three times with a measuring wheel and a mean length was computed. Corresponding road segments were found on the aerial photographs and this distance was measured in feet using the planimeter. By dividing the field distance by the photograph distance, a ratio was computed. Depending on the aerial photograph being analyzed, the appropriate scale for each photograph was entered into the planimeter.

The aerial photographs were then analyzed for land use types. Eight different types of land uses were categorized within the watershed boundary of Messalonskee Lake: cleared land, reverting land, regenerating land, mowed fields, forests, industrial land, wetlands, and agricultural land. For calculating purposes, pasture fields, mowed fields, crop row agriculture land and livestock grazing agriculture land were combined under the heading of cleared land. Reverting and regenerating land refereed to two different stages of open field succession; reverting land includes the earliest successional stages while regenerating land refers to the intermediate successional stages. Industrial land included the cement factories, quarries and gravel pits found within the watershed. Various types of wetlands including bogs, fens, marshes and swamps were all recorded under the general heading of wetlands.

Determining land use areas involved examination of aerial photographs, topographical maps and field reconnaissance. Field reconnaissance was occasionally used to discriminate among agricultural, cleared and mowed fields. There may have been a degree of error in using field reconnaissance because the cleared areas in 1991/92 may have been somewhat different than they were at the time of the study. Road and residential areas were measured using the planimeter in the 1961/62 photographs. In the 1991/92 photographs, roads and residential areas were computed through field reconnaissance.

After different land use types on each photograph were delineated, the areas of each respective type were measured. The scale for the selected photograph was entered into the planimeter, and the areas were measured in square feet for the 1991/92 photographs and in meters squared for the 1965/66 photographs. Each separate area was measured ten times and all the values were averaged. The mean areas were entered into a spreadsheet where conversions into meters squared, percents and acres were calculated. All fourteen photographs were examined, land use types were separated, planimeterized and entered into the computer. This information was used to create a macGIS land use map (see Developmental Implications of Land Characteristics: Land Use Suitability).

Past CEAT water quality reports of various central Maine lakes include similar land use analysis techniques. In this study of the Messalonskee Lake watershed, the land use types differs from previous reports due to the use of reverting and regenerating categories. Previous years have included reverting/regenerating land use types under the forest category. Except for this minor difference, land use type categories are similar from one report to another and therefore data is comparable between reports.

General Land Use Trends Overview

The total area of the Messalonskee Lake watershed is 27,196.6 acres. The MDEP estimated the Messalonskee Lake watershed to be 29,459.9 acres (MDEP 1994a). Both of these areas included the total area of watershed land including the area of the Belgrade Stream watershed which was measured as 14,181.5 acres. The difference in acres reported by the CEAT and the MDEP is 7.7% and could be explained by human error using the planimeter. In addition, CEAT used an alternative definition of the watershed for the purpose of this particular study. CEAT regarded the Belgrade Stream as separate from the Messalonskee Lake watershed for the purpose of land use analysis, and therefore reported the area of the Messalonskee Lake watershed as 13,015.1 acres (Table 6).

The Belgrade Stream is a point source input of the Messalonskee Lake watershed, and its watershed was analyzed to determine the water budget of Messalonskee Lake. The watershed includes three towns: Belgrade, located in the southwest, has 3344.8 acres within the watershed (25.0% of the watershed); Oakland, in the north, has 2408.6 acres within the watershed (18.3% of the watershed), and Sidney, located in the southeast, has 7261.8 acres within the watershed (55.1% of the watershed).

In 1965/66, mature forested land was the most abundant land use type (27.6% of the total watershed area) (Figure 37). Most of the forested land was contained within the Town of Sidney; 28.5% of its area was forested land (Figure 38).Other dominant land uses of the Messalonskee Lake watershed in the 1965/66 were reverting and regenerating land. Reverting land occupied 20.7% of the watershed and regenerating land occupied 17.8% of the watershed.

Agricultural land was also a prominent land use type in 1965/66. At this time, it was already displaying a declining trend in total area. It was not quantified separately (see Land Use: Land Use Methodology) and instead was grouped in the total cleared land category. Evidence suggests, however, that there was substantial agricultural land in 1965/66. The total area of agricultural land in 1965/66 had already decreased in the past decades. Aerial photographs from 1940 and 1956 illustrate that there was a greater amount of agricultural land within the Messalonskee Lake watershed than in 1965/66. By viewing the aerial photographs, it was evident that agriculture was one of the dominant land use types in 1940 and 1956. Moreover, much of the agricultural land was located along the shoreline. In 1965/66, much of the agricultural land had moved away from the water's edge and was situated in nonshoreline locations.

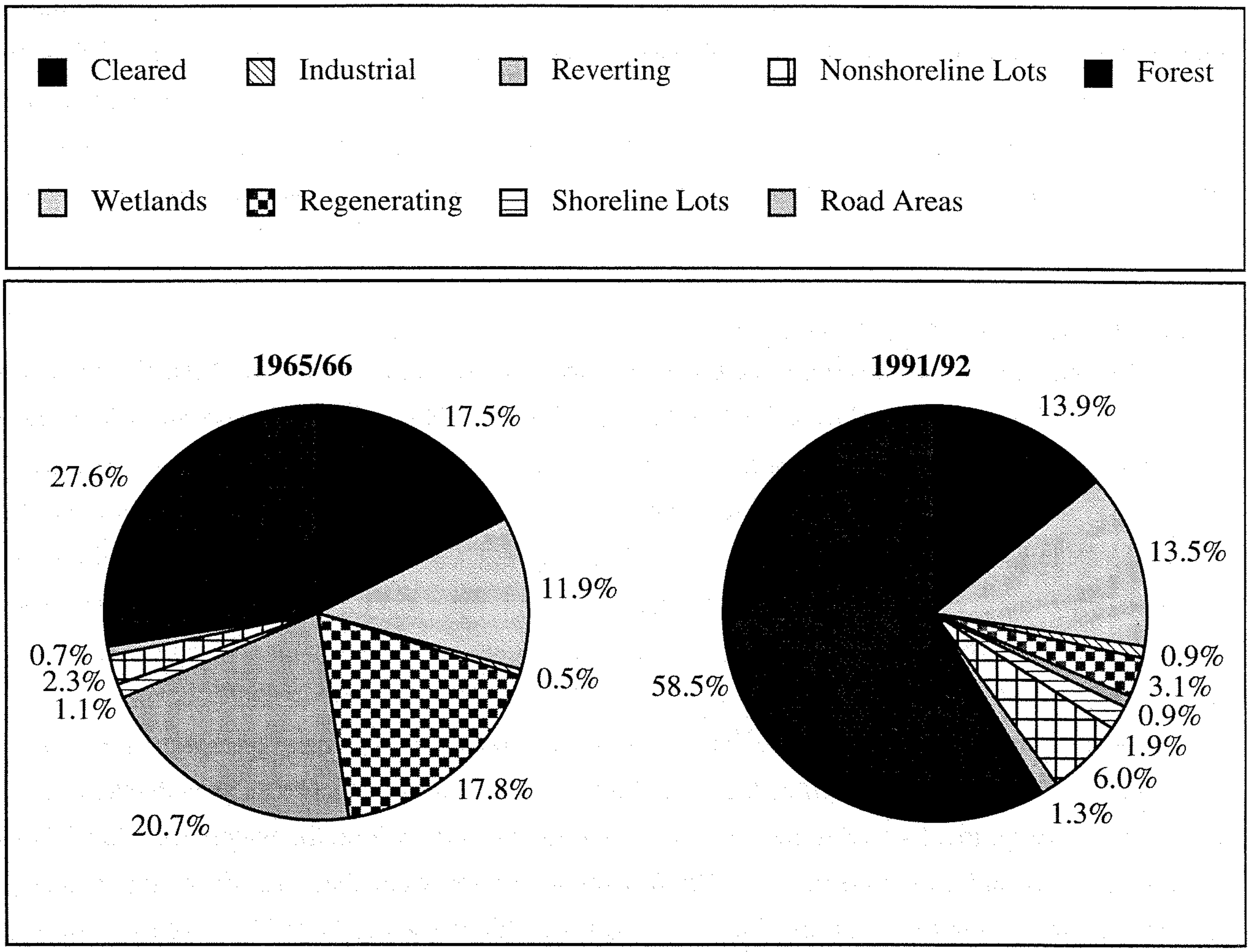

Figure 37. Percentage of land use types in the Messalonskee Lake watershed in 1965-66 and 1991-92 determined from aerial photographs.

In 1991/92, mature forested land was the dominant land use type. Forested land was 58.4% of the total watershed area (Figure 37). The majority of forested land was located within the Town of Sidney; 66.8% of its area was forested land (Figure 38). Other important land use types in 1991/92 were total cleared areas and wetlands which comprised 13.9% and 13.5% of the total watershed area, respectively.

The various land uses within the watershed have changed over time with respect to the percentage of total watershed area. The land uses that changed the most in total area were reverting, regenerating, and forested areas. From 1965/66 to 1991/92, reverting land decreased from 20.7% of the total watershed area to 1.0% of the total watershed area (Figure 37). Regenerating land displayed a similar pattern. In 1965/66, 17.8% of the total watershed area consisted of regenerating land. In

Table 6. The percentages and acreage of developed lots (with a residence) and undeveloped lots (without a residence) and then the percentages of seasonal and year-round residences. The actual number of developed and undeveloped lots for each town is given in parenthesizes. All information is separated by shoreline and nonshoreline lots for all towns in the Messalonskee watershed as of Oct-97.

	SHORELINE			
	Belgrade (115 lots)	Oakland (216 lots)	Sidney (217 lots)	Total Watershed (548 lots)
Developed Lots				
% Developed	78.3 (90)	76.4 (165)	78.8 (171)	77.7 (426)
% Undeveloped	21.7 (25)	23.6 (51)	21.2 (46)	22.3 (122)
Acreage				
Developed Acreage on Lots[a]	45.0	82.5	85.5	213.0
Undeveloped Acreage on Lots[b]	12.5	25.5	23.0	61.0
Residence Status				
% Seasonal	77.8	54.5	55.6	59.0
% Year-round	22.2	45.5	44.4	41.0

	NONSHORELINE			
	Belgrade (295 lots)	Oakland (425 lots)	Sidney (541 lots)	Total Watershed (1261 lots)
Developed Lots				
% Developed	39.0 (115)	78.6 (334)	62.1 (336)	62.3 (785)
% Undeveloped	61.0 (180)	21.4 (91)	37.9 (205)	37.7 (476)
Acreage				
Developed Acreage on Lots[c]	230.3	334.0	343.4	907.7
Undeveloped Acreage on Lots[d]	1491.2	1899.1	6088.2	9478.5
Residence Status				
% Seasonal	2.6	1.2	9.5	5.0
% Year-round	97.4	98.8	90.5	95.0

[a] Number of developed lots multiplied by 0.5 acres, the MDEP's standard acreage value for shoreline lots (Bouchard, pers. comm.)
[b] Number of undeveloped lots multiplied by 0.5 acres
[c] Number of developed lots multiplied by 1.0 acres, the MDEP's standard acreage value for nonshoreline lots and added the acreage values for industrial use (Table 7)
[d] Total acreage for forest, cleared land, regenerating areas, and reverting land (Table 7)

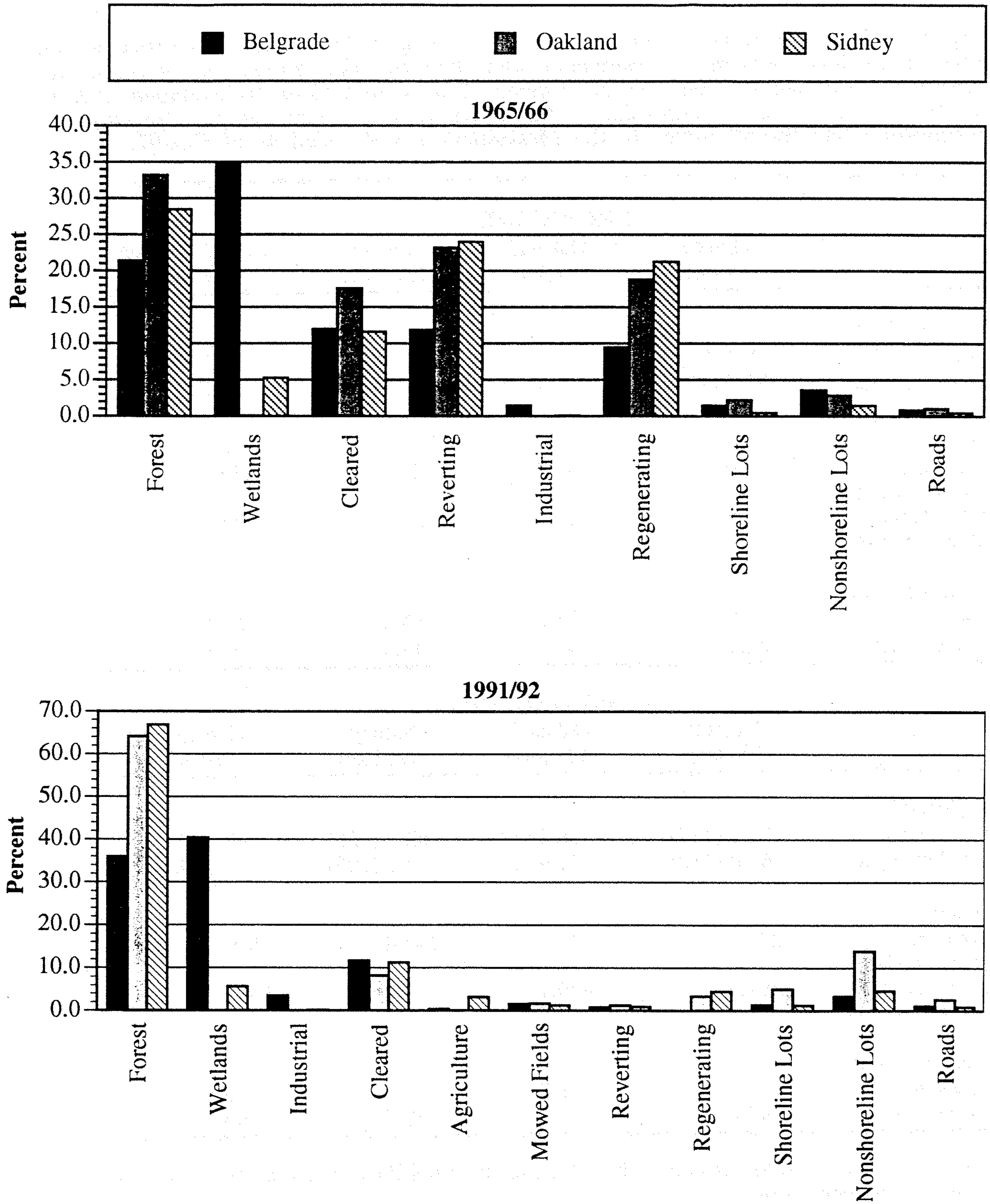

Figure 38. Land use types for each town in 1965/66 and 1991/92 as a percentage of the total watershed area of Messalonskee Lake.

1991/92, however, only 3.1% of the total watershed area was regenerating land. Forested land displayed a corresponding increase in percentage of total watershed area from 27.6% in 1966/66 to 58.4% in 1991/92. These decreases in reverting and regenerating land, and the subsequent increase in mature forested land, indicated that the reverting and regenerating areas were succeeding into mature forested land.

The other land use type that had decreased in total area was total cleared land (including agricultural and mowed fields) from 17.5% in 1965/66 to 13.9% in 1991/92. Other land use types that had increased in total area over time in the Messalonskee Lake watershed were wetlands (11.9% to 13.5%) and industrial areas (0.5% to 0.9%) (Figure 37). Wetland areas, however, typically do not increase. The reported difference in wetland areas from 1965/66 to 1991/92 may have been due to human error in quantifying the areas with the planimeter as the boundaries of the wetlands were not always visible on the aerial photographs due to tree cover. The true boundaries, therefore, would not have been measured.

Industrial Land

Methods

In this study, industrial areas were defined as non-vegetated areas used for the extraction or production of materials for commercial purposes. Industrial areas included quarries, gravel pits, and a cement factory. They were determined by comparing gravel pits on topographic maps to areas on the aerial photographs. Field reconnaissance was used to verify ambiguous areas on the aerial photos for 1991/92. There were commercial buildings (including parking areas) within the watershed. The areas around the buildings, however, were included in cleared areas and the buildings were not designated into any category.

Results and Discussion

In 1965/66, 0.5% of the total watershed area of Messalonskee Lake was industrial land (Figure 37). The majority of these areas were within the town of Belgrade which had 84.4% of the total industrial area.

In 1991/92, 0.9% of the total watershed area of Messalonskee Lake was industrial land (Figure 37). The Town of Belgrade supported the majority of the industrial areas. Belgrade had 94.0% of the total industrial land use. This area included five active gravel pits, and one cement factory. Sidney had one abandoned quarry. Oakland contained no industrial areas.

By comparing the area of industrial land use over time, it was evident that the total area of industrial land had increased 108.0% from 1965/66 to 1991/92. Industrial areas more than doubled, although they only occupied a small percentage of the total watershed area. The majority of the industrial areas were concentrated in Belgrade, as they were in 1965/66. This apparent increase, although not very large, may have been an explanation for a slight decrease in overall area of other land use types. Industrial land use may have partially replaced land use types such as agriculture, cleared, or mowed fields. The increase in industrial land, although small, may have a negative effect of water quality. A greater number of gravel pits and quarries results in more particulate matter being stirred into the air. In addition, there may be an increase in the leaching of sediments into the lake.

Cleared Land

Methods

Cleared lands include hay fields and other grassy fields, but do not include lawns. Cleared land was identified on the aerial photographs as open fields without or row crops. Differentiating between cleared land, agricultural land, and mowed fields was difficult in some areas of the 1991/92 photographs, so field reconnaissance was used to help classify these areas. Without the option of field reconnaissance for the 1965/66 photographs these land uses were not separated.

Results and Discussion

Total cleared land (cleared land, agricultural, and mowed fields) in 1965/66 was determined to be 2275.4 acres (17.5%) of the watershed area (Figure 37). In 1991/92, total cleared land comprised 1812.8 acres (13.9%). This drop shows that agricultural uses (e.g., row crops, hay fields, and pastures) in the area have declined. Of the three towns, Oakland had the largest decline in total cleared land, 46.6% (Figure 38; Table 7). Sidney had a 15.6% decline, and Belgrade had a 9.5% decline. Sidney had the largest area of total cleared land, accounting for 58.3% of the total cleared land within the watershed in 1965/66 and 61.8% in 1991/92.

Cleared land alone accounted for 10.8% of the watershed in 1991/92. Sidney had the largest area, with 57.9% of the cleared land in the watershed. Belgrade had 27.9% of the cleared land, and Oakland had 14.1%. These percentages reflect the relative sizes of the towns; however, the amounts of cleared land as percentages of the area of the watershed within each town were very similar (8.2% to 11.7%).

Much of the land that had been cleared in 1965/66, but was no longer cleared in 1991/92 had been left to revert into forest or was subdivided into residential areas. Many of the large field areas had been fragmented into smaller blocks of cleared land with natural vegetation or residences in between the fields.

Table 7. Land use types (acres) of the Messalonskee Lake watershed divided by town.

	Belgrade[b]		Oakland[c]		Sidney[d]		Total[e]	
	1965/66	1991/92	1965/66	1991/92	1965/66	1991/92	1965/66	1991/92
Forest	716.2	1202.2	799.8	1543.2	2069.7	4849.6	3585.6	7594.9
Wetlands	1165.4	1351.1	1.6	0.0	384.4	405.5	1551.3	1756.6
Total Cleared[a]	501.4	453.8	446.6	238.7	1327.4	1120.3	2275.4	1812.8
Cleared	-	391.2	-	197.9	-	811.4	-	1400.5
Agriculture	-	10.4	-	0.0	-	224.6	-	235.0
Mowed Fields	-	52.2	-	40.8	-	84.3	-	177.3
Reverting	396.7	26.5	557.9	27.6	1744.8	68.1	2699.4	122.2
Regenerating	316.1	0.0	452.7	81.3	1544.9	325.7	2313.7	407.0
Shoreline Lots	49.5	45.0	53.5	121.0	37.5	85.5	140.5	251.5
Nonshoreline Lots	120.0	115.0	69.0	334.0	107.0	336.0	296.0	785.0
Industrial	49.7	115.3	0.0	0.0	9.2	7.4	58.9	122.7
Roads	29.7	35.8	27.6	62.8	36.9	63.7	94.2	162.3

[a] Total Cleared includes cleared, agriculture and mowed fields. Due to difficulties differentiating among cleared, agriculture, and mowed fields on the 1965/1966 photos, these numbers were combined.
[b] Total area of Belgrade within the watershed is 3344.8 acres
[c] Total area of Oakland within the watershed is 2408.6 acres
[d] Total area of Sidney within the watershed is 7261.8 acres
[e] Total area of the watershed is 13015.1 acres

Agricultural Land

Methods For the purposes of this study, agricultural land was defined as cleared areas containing row crops and pasture land containing livestock. For the purpose of quantification, agricultural areas were determined by the appearance of areas with no visible trees or shrubs, and with visible rows or tractor marks. Field reconnaissance was used to determine areas containing livestock and to aid in the verification of ambiguous areas on the 1991/92 photographs (see Land Use: Land Use Methodology). Agricultural areas were not identified on 1965/66 aerial photographs due to the difficulty of differentiating between agriculture and cleared areas, and the inability to utilize field reconnaissance. Agricultural areas were combined with cleared areas and mowed fields for the analysis of 1965/66 aerial photos.

Results and Discussion

In 1991/92, 1.8% of the Messalonskee Lake watershed was agricultural land (Figure 37). The Town of Sidney had the most agricultural land with 95.6% of the total agricultural land area. The Town of Belgrade supported the remainder of the total agricultural area. Oakland had no agricultural areas.

There were no empirical data for total agricultural area in 1965/66, although it was evident that there was a greater total area of agricultural land in 1965/66 compared to 1991/92. This was concluded because there was a large percentage of cleared areas in the watershed, quantified from the 1965/66 aerial photographs. In addition, photographs from 1940 and 1956 had even more agricultural areas (see Background: Historical Perspectives). The examination of the photographs in sequence displayed the decline in agricultural land.

There were several reasons for this apparent decrease in agricultural land (see Background: Historical Perspectives). One possibility was the increase in development, particularly residential development, around Messalonskee Lake (see Land Use: Residential Land). Land that was once used for agricultural purposes may now be used for other purposes such as industrial or municipal uses. In addition, agricultural land may now be reverting or regenerating land. The decrease in agricultural land has a positive effect on water quality as the runoff containing fertilizers (including manure from livestock) and pesticides is decreased.

Mowed Fields

Methods

Mowed fields were defined as grass areas that were mowed frequently. These areas were not directly associated with residences and therefore were not included in residential land use. Mowed fields were generally found at entrances to subdivisions, along roads and in cemeteries. Due to difficulties in differentiating among mowed fields, cleared land and agricultural land without field reconnaissance, mowed fields were not calculated for 1965/66.

Results and Discussion

The total area of mowed fields in 1991/92 was 177.3 acres (1.4%) of the watershed (Figure 37). Sidney had the largest percent (47.5%) of mowed fields in the watershed, Belgrade had 29.4% and Oakland had 23.0% (Figure 38, Table 7). As with cleared land, the amounts of mowed fields as percentages of town areas were very similar (1.2% to 1.7%) While this was not determined for 1965/66, it appears that the amount of mowed fields had increased. This increase was probably due to the construction of more residential neighborhoods with large grass entrances. While mowed fields were a very small portion of the watershed, they are worth noting because the pesticides and fertilizers used on them can have an impact on water quality (see Background: Land Use Types).

Reverting Land

Methods

Reverting land includes both logged and agricultural land that was once cleared but is beginning to undergo succession towards a mature, climax forest. The trees and shrubs that make up a reverting field are not as close together nor as full as a mature forest. On the aerial photographs, reverting land appeared as blotches of lighter gray vegetation where areas of cleared land existed between trees. If, on the aerial photographs, it appeared that less than 50% of the land was covered with new trees and shrubs, the area was considered reverting.

Results and Discussion

In 1961/62, 20.7% of the entire watershed was found to be reverting land (Figure 37). This type of land made up the second largest category. Forest encompassed the greatest amount of land in the watershed. Since one quarter of all the land in the watershed in 1961/62 was returning to its natural state this suggested a positive trend for the area.

In 1961/62, the town of Sidney contained the largest percentage of reverting land in its total watershed land area (24.1%) relative to Oakland (23.2%) and Belgrade (11.9%) (Figure 38). Since most of the Belgrade watershed area was wetlands, it had the lowest percentage of reverting land of the three towns. Oakland is in close proximity to Waterville which has turned the town into a suburb, and therefore, the high amount of reverting land in its watershed was probably the result of converting agricultural land for alternative purposes. In the mid-1960s, interest in vacation and residential property around the lake increased (Bacon, E., pers. comm.). Due to the decreased value of agricultural and cleared land, property owners in the watershed may have permitted their land to revert.

In the 1991/92 photographs, a substantially lower percentage of reverting land, 0.9%, existed within the watershed. There was, however, a significant increase in overall forest coverage from 1965/66 to 1991/92 and therefore, between 1961/62 to 1991/92, a large amount of the reverting land reached maturity (Figure 38). All three towns in 1991/92 had low percentages of their watershed, approximately 1%, designated as reverting (Figure 37). The maturation of reverting forests was a trend seen in each town.

Regenerating Land

Methods

As reverting land continues to mature, it becomes more dense with trees and less patchy, and reaches an intermediate successional stage. This land type was designated as regenerating land. On the aerial photographs, regenerating land appeared more dense and darker in color with fewer open space than reverting land. If 50% or greater canopy coverage was viewed on the aerial photographs, then the area was considered regenerating.

All cleared land, whether cleared for agriculture or logging purposes, can undergo conversion to a mature forest. During the process of determining land use types in the watershed of Messalonskee Lake, regenerating logged, and regenerating agricultural land were not distinguished from one another.

Results and Discussion

In 1961/62, 17.7% of the entire watershed was in the regenerating stage (Figure 37). Regenerating land is more beneficial for the welfare of the lake than reverting land because of the increased erosion buffering effects from larger trees.

Sidney, with 21.3% of its land area within the watershed designated as regenerating, contained the majority of the regenerating land in the watershed. Oakland was similar to Sidney with 19.0% of its watershed land regenerating, while Belgrade had the least with 9.5% of its watershed land (Figure 38). Trends in regenerating land mirrored those trends found in reverting land from the 1960s (see Land Use Types: Reverting).

In 1991/92, regenerating land made up a small amount (3.1%) of the watershed. There was more land regenerating in 1992 than reverting (Figure 37). This was the result of much of the reverting land of the 1960s reaching maturity in the 1990s.

It is unknown if logging practices had occurred on regenerating land during the 1960s. After examining the aerial photographs from 1991/92, it became obvious that these regenerating areas were left to reach maturity because mature forest covered land that was designated regenerating in the 1960s. If selective logging, therefore, did occur on regenerating land during the 1960s, it did not seem to have prevented the forest from maturing.

The same trends that were found in the watersheds of each town for reverting land were found for regenerating land. The watershed of Sidney contained the largest amount of regenerating land with 4.5% designated as regenerating. The watershed of Oakland had 3.4% designated as regenerating. No regenerating land was found in the Belgrade watershed (Table 7). It appeared that most of the regenerating land from 1961/62 in Belgrade had reached maturity by 1991/92.

Forested Land

Methods

Forested land was characterized as an area with a fully developed canopy of mature trees in close proximity to each other. On the aerial photographs, forested land was distinguished from regenerating and reverting land by the dark shade characteristic of a thick canopy devoid of any patchy cleared areas (see Land Use: Reverting Land and Regenerating Land). The measurement of forested land was not done directly; all non-forested areas in the watershed were quantified, using the planimeter, and then subtracted from the total land area of the watershed. The remaining value was used as the area of the forested land.

Results and Discussion

In 1965/66, forested land made up 27.6% (3,585.6 acres) of the total watershed area, whereas in 1991/92 forested land accounted for 58.4% (7,594.9 acres) of the total watershed area (Table 7). The increase of 4,009.3 acres of forested land, from 1965/66 to 1991/92, might be due to the decrease in reverting and regenerating land areas by 2,577.2 acres and 1,906.8 acres, respectively (total decrease: 4,483.9 acres).

The forested land in Belgrade, Oakland, and Sidney increased by 485.9 acres, 743.4 acres and 2,779.9 acres respectively, from 1965/66 to 1991/92. Reverting and regenerating total land areas in Belgrade, Oakland and Sidney decreased from 1965/66 to 1991/92 by 686.3 acres, 901.6 acres and 2,955.9 acres respectively. From 1965/66 to 1991/92 forested land increased dramatically while reverting and regenerating land decreased dramatically. The most likely explanation for this scenario is that the new forested land arose from some of the old reverting and regenerating land. The remainder of the reverting and regenerating land was most likely replaced by the increased development (i.e., shoreline and nonshoreline residences, roads, mowed fields, industrial land) that occurred from 1965/66 to 1991/92 (Table 7).

Forested land generally has a positive impact on water quality within a watershed (see MDEP 1990). Forests filter out nutrients from water runoff which could potentially increase the eutrophication of the lake. Unlike cleared land, forests have a canopy which slows runoff by breaking up rainfall on the way to the forest floor, thus facilitating percolation of nutrient rich water into the soil. The significant increase in forested land areas from 1965/66 to 1991/92 should help to slow the eutrophication process of Messalonskee Lake via this filtration process.

Although it is beneficial to the lake that mature forest makes up 58.4% of the watershed, this forested land is susceptible to logging. Logging has many negative effects on nutrient loading in a watershed. Clearcutting, strip cutting, logging roads, and skidder trails increase erosion and subsequent nutrient loading into the lake (see Background: Forestry). Clearcutting and strip cutting create cleared land, thus eliminating the forest canopy and increasing the potential for erosion during heavy rains (see Background: Cleared Land). Logging roads and skidder trails create big ruts in the land which can funnel nutrient rich runoff to the lake or tributaries. One step to ensure the trophic stability of Messalonskee Lake would be to restrict or regulate logging in the watershed. When logging is necessary, skidder paths should be minimized, should not cross streams or use stream beds as trails, and should be repaired after the logging job is complete. Efforts also need to be made to leave a suitable buffer between the logged area and the lake or stream. Present zoning ordinances require a 75 ft buffer when clearing vegetation near a lake or stream (see Septic Systems).

Wetlands

<u>Methods</u>

Wetlands are usually found near a water body, such as a river or lake, or at low elevation, such as a basin or kettlehole (BI493 1996). The general locations of wetland areas were determined using topographic maps. These tentative wetland locations were then compared with aerial photographs, from 1965/66 and 1991/92, and aerial infrared photographs, from 1985, to identify the specific wetland locations and boundaries.

Results and Discussion

In 1965/66, the wetland areas accounted for 11.9% (1,551.3 acres) of the entire watershed (Figure 37; Table 7). Although, in general, wetlands are stable and do not grow and proliferate rapidly, a slight increase in total wetland area from 1965/66 to 1991/92 was calculated. In 1991/92, wetland areas accounted for 13.5% (1,756.6 acres) of the total watershed. The slight change may be a result of actual expanding wetland areas, cleared land that was reverting back to its natural state, or a calculation error on the 1965/66 aerial photographs due to the lack of 1965/66 infrared photographs for a cross-reference of the boundary locations.

In 1991/92, all of the wetland acreage in Belgrade, within the watershed, was found in one location, the Belgrade Bog. This large bog made up 40.4% (1,351.1 acres) of the watershed land area in the town of Belgrade and comprised the largest single land area within the Belgrade section of the watershed. In 1965/66 the total area of Belgrade Bog was 1,165.4 acres. Part of Belgrade Bog also lies within the Sidney town boundary. In addition to this section of the Belgrade Bog, five other separate wetland areas comprised the 405.5 acres (1991/92) of the total wetland area in Sidney (Table 7).

In 1991/92 there were no wetlands found in Oakland, but in 1965/66 there were 1.6 acres surrounding a stream. The most likely reason that no wetlands were found in 1991/92 is that in 1965/66 the single wetland area was between two areas of reverting land which progressed to mature forests by 1991/92. The wetland area that was found in 1965/66 was probably not visible on the aerial photographs due to the fully developed canopy of the mature forest. It was probably still present in 1991/92 but we were not able to find it when ground truthing our land areas.

Different wetland types have distinct hydrogeological and biological characteristics. There are two general categories of wetlands that are characterized by the vegetation making up the wetland and how that vegetation interacts with the nutrients flowing into the wetland area (BI493 1996). One type acts as a nutrient sink whereas the other acts as nutrient source, but one wetland area may act as both depending on the season (see Background: Wetlands). If the wetland is made up of dense vegetation, the nutrients will be caught and stored by the sediments surrounding the roots, therefore acting as a nutrient sink. Conversely, a wetland made up of vegetation with a high rate of evapotranspiration can act as a nutrient source. The nutrients will be taken up quickly by the evapotranspiration process of the plant foliage and then returned to the lake water when the foliage dies and decays.

Residential Land

<u>Residence Count</u>

Methods

A total residence and lot count were performed for all areas of Belgrade, Oakland, and Sidney that fell within the Messalonskee Lake watershed. The residence count was completed using driving surveys, tax maps with their accompanying map/lot listings, and property cards. The driving survey was conducted with the use of the Residence Survey Form along all the roads within the watershed by CEAT on 29-Sep-97, 6-Oct-97, 19-Oct-97, and 20-Oct-97 (see Appendix I). It was determined whether or not the residences were shoreline or nonshoreline, and seasonal or year-round. A shoreline residence was defined as being within 200 ft from the lake, and a nonshoreline residence was greater than 200 ft from the lake shoreline. To delineate between seasonal and yearly residences, visual keys were used including the general nature of the house, cars in the driveway, boarded-up windows, boats still in the water, presence or absence of chimneys, open or closed bottom beneath the residence, and the presence of a large firewood supply. Finally, the roads (with the residences on them) were categorized by the three towns in order to determine the number of residences in each town. For later classification, each residence was characterized as being on a developed lot to determine the percentages and acreages of developed and undeveloped lots.

Tax maps from Belgrade, Oakland, and Sidney Town Offices (1997 copies) were used to obtain the number of lots each town holds in the watershed. The approximate watershed boundaries of Messalonskee Lake were drawn on the appropriate maps in order to exclude lots outside of the watershed. The number of shoreline and nonshoreline lots were then counted and grouped by town. To estimate the number of undeveloped lots for each town, the total developed lots or total residences were subtracted from the total number of lots. The percentage of developed and undeveloped lots was calculated individually for each town and broken down into shoreline and nonshoreline areas. Within each of the three towns, the number of developed shoreline lots was tallied by using the map and lot listing book, and property cards at the town offices in addition to the driving surveys. The map and lot listing book and the property cards indicated whether a particular lot on the tax map contained a building of a specific value. If the value of the building was above $10,000, it was thought to be a residence, otherwise, it was probably a garage or shed (Martin, K., pers. comm.). This count was done to check the driving survey, since a remarkably large number of residences were counted by CEAT on the shoreline of Oakland. As a result, only the number of developed shoreline lots from the map and lot listing book was used instead of the data from the driving survey.

The acreage of developed and undeveloped areas was then calculated. The undeveloped acreage was calculated in order to indicate the potential area for future development by towns. Two different protocols were used for shoreline and nonshoreline lots. For the shoreline lots, acreage values were obtained by multiplying the numbers of developed and undeveloped lots by 0.5 acres, the MDEP's standard acreage value for a shoreline lot (Bouchard, pers. comm.). A different method was used for the acreage values of nonshoreline areas. The MDEP's acreage value for a nonshoreline lot was one acre, which was multiplied by the number of developed lots, and the acreage value for the industrial use found in each town were added. Finally, to obtain the acreage of undeveloped lots, acreage values for forest, cleared land, regenerating areas, and reverting land were summed within each town (Table 7). These land use areas were summed as potential land for future development. However, all the land in the above categories may not be able to be completely developed for different reasons; one example is an area with too steep of a slope for development.

After the acreage calculations were completed, the percent residence status (seasonal or year-round) of all the developed shoreline and nonshoreline lots (residences) was calculated. Within Oakland, the driving residence count data had to be used to obtain the percent of seasonal and year-round residences, as the map and lot listing book gave no indication of resident status.

There were several potential sources of error within the residence count study. Counting residences, predicting the status as seasonal or year-round, and measuring the distance from the lake could have been subjective at times. Predicting whether a residence was seasonal or year-round was probably the hardest to determine from just a visual survey and the town offices carried no information on this status. In addition, residences may have been missed from the roads if they were hidden within the woods. A few extra buildings may have been counted including garages and sheds, and some residences may have been counted twice. In addition, while drawing the watershed boundaries on the individual tax maps, lots may have been excluded or extras may have been counted.

Finally an index of shoreline development was calculated for each town and then for the entire watershed. The map wheel was used to measure the length of shoreline in each town. The relative density of residences was expressed as the number of residences per 1000 ft of shoreline.

Shoreline Results

Along the entire shoreline of Messalonskee Lake, there were 426 residences: 90 in Belgrade, 165 in Oakland, and 171 in Sidney. In each of the towns, more than half of the residences were seasonal: Belgrade (77.8%), Oakland (54.5%), and Sidney (55.6%). Within the total watershed, 59.0% of the shoreline residences were seasonal (Table 6).

Of the total lots in the Belgrade area of the watershed (115 lots), 28.0% were on the shoreline. Within Oakland, 33.7% of its total lots (216 lots) were shoreline. In Sidney, 28.6% of the total lots (217 lots) were shoreline. Finally, within the entire nonshoreline watershed, 30.3% of the total lots (1809 lots) were on the shoreline. Looking at the percent of the developed lots that were on the shoreline, Belgrade had the highest, with 43.9% found on the shoreline. Oakland had 42.0% of its total developed lots on the shoreline, while Sidney only had 33.7% on the shoreline. Finally, 39.1% of all the developed lots were found to be shoreline (Table 6).

Within the boundaries of the watershed, all three towns had at least three and a half times as many acres on the shoreline developed than undeveloped. Oakland and Sidney both had similar shoreline lot acreages, with 82.5 acres and 85.5 acres developed, and with 25.5 acres and 23.0 acres undeveloped. Meanwhile, Belgrade had 45.0 acres of developed lots and only 12.5 acres of undeveloped (Table 6).

Using the map wheel, the perimeter of Messalonskee Lake was measured to be approximately 484,000 ft including: 193,000 ft of shoreline in Belgrade; 154,000 ft in Oakland, and 137,000 ft in Sidney. Compared to the entire Messalonskee Lake shoreline which contained approximately 0.88 residences/1000 ft, Belgrade was had the lowest relative density with 0.47 residences/1000 ft. Oakland was higher with 1.07 residences/1000 ft, and Sidney was had the greatest relative density with 1.25 residences/1000 ft. The mean density found for the three towns was 0.93 residences/1000 ft.

Nonshoreline Results

Within the nonshoreline area of the Messalonskee Lake watershed, there were 785 residences: 115 in Belgrade, 334 in Oakland, and 336 in Sidney. In the total nonshoreline area, 95.0% of the residences were year-round (Table 6).

Of the 1809 lots in the Messalonskee Lake watershed, 69.7% were nonshoreline. Looking at the towns individually, 72.0% of the Belgrade lots were nonshoreline. Then 66.3% of the Oakland lots were nonshoreline, and 71.4% of the Sidney lots were nonshoreline. Within the entire watershed, 60.9% of the total developed lots were not on the shoreline. In Belgrade, 56.1% were nonshoreline, then Oakland had 58.0% of its developed lots as nonshoreline. Sidney had the highest percent with 66.3% of the towns developed lots not on the shoreline (Table 6).

Finally, for acreage values, Belgrade and Oakland were similar with 230.3 acres and 334.0 acres of developed nonshoreline lots, and 1491.2 acres and 1899.1 acres of undeveloped nonshoreline lots. Sidney was very different with 343.4 acres developed and 6088.2 undeveloped (Table 6).

Discussion of Residences

Both shoreline and nonshoreline residential areas are of critical importance to lake water quality due to their potential effect on phosphorus loading. Because of their close proximity to the lake, shoreline residential areas have a greater influence on phosphorus loading than nonshoreline residences. Any nutrient additives from shoreline households (such as detergents) have only short distances to travel to reach the lake. The potential for soil erosion from residential sites increases, because stormwater runoff flows at a greater volume and speed from residential areas where the forest has been replaced with hard or smooth surfaces such as buildings, driveways, and lawns (MDEP

1997). Inland areas can also have an impact on nutrient loading, especially in densely populated residential areas with improper drainage; however the effect is not as important in phosphorus loading as with shoreline areas (see Background: Nutrient Loading and Shoreline/Nonshoreline Residential Areas).

Development around Messalonskee Lake was found to be very extensive. The tax map and driving surveys showed that just above three-fourths of the shoreline lots of the Messalonskee Lake were developed. There were 122 undeveloped lots around the lake, however, this did not include the lots around the large area of Belgrade Bog at the south end. The bog includes wetlands where development is not permitted within 100 ft of the wetland boundary (see Watershed Residential Areas Zoning: Shoreline). Within the northern half of the lake, there was a greater amount of shoreline development compared to the southern half, where there was more open land available for development (not including the wetland area).

Before comparing the acreage of each town, it was necessary to show the total acreage each town held within the entire watershed. Sidney contained the most acreage with 7188.3 acres, while Belgrade and Oakland had much less with 3265.2 acres and 2387.8 acres respectively (Table 7). It was calculated that Sidney had the highest acreage of undeveloped lots with a total of 6111.2 acres including 6088.2 acres nonshoreline and 23.0 shoreline acres. This was expected due to the large size of Sidney within the watershed relative to Belgrade and Oakland. Within Belgrade, 12.5 shoreline acres and 1491.2 nonshoreline acres were undeveloped. Oakland had slightly more acres available as undeveloped even though the town occupied less total acres within the watershed than Belgrade. The town of Oakland had 25.5 shoreline acres and 1899 nonshoreline acres undeveloped (Figure 39). It was calculated that there were 9539.5 acres of undeveloped lots in the entire Messalonskee Lake watershed of 12841.3 acres (Table 7). As of October 1997, 74.3% of the Messalonskee Lake watershed was undeveloped (Table 6). Similar to Messalonskee Lake, the North Pond watershed, as of September 1997, had 10421.3 acres of undeveloped lots within the total 14384 acres of the watershed (72.5% undeveloped) (BI493 1997). The average acreage values for shoreline and nonshoreline lots were only estimates and not precise measurements.

Many of the shoreline residences were grandfathered, and were therefore not required to meet the current minimum acreage and other zoning ordinances in terms of zoning regulations. The lot sizes of these residences were much smaller than recently built residences, creating a high concentration of residences. There was a much higher concentration of closely built residences on the northern end where most of the residences lacked buffer strips and were built within 50 ft of the water's edge (see Land Use: Residential Land; Shoreline Buffer Strips).

Within Oakland, our data were slightly skewed because driving surveys showed a high number of developed lots. At first, 242 residences were counted on the shoreline within Oakland; however,

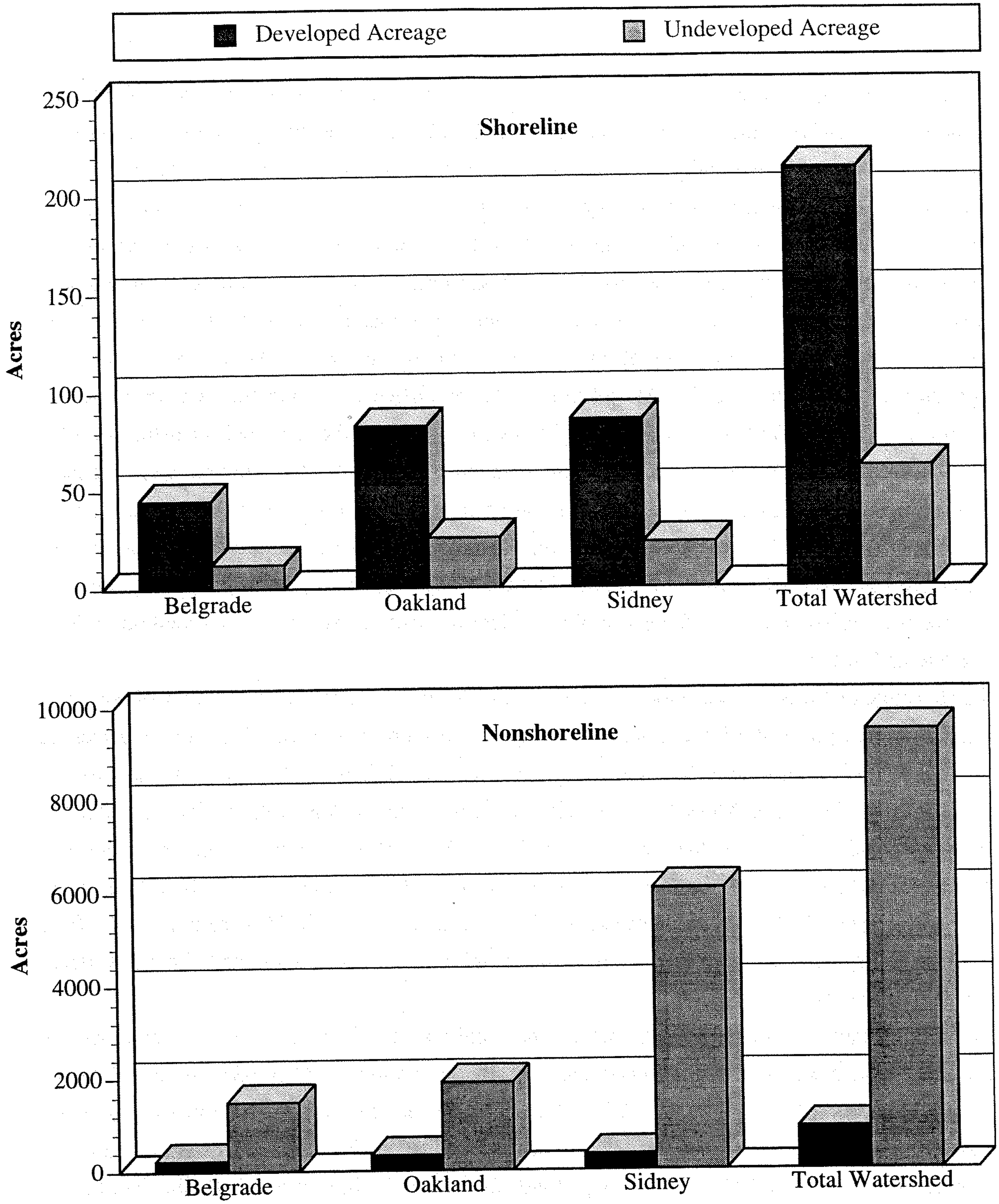

Figure 39. Approximate developed and undeveloped acreage on shoreline and nonshoreline lots in the Messalonskee Lake watershed.

this amount became suspect after only 216 lots were counted on the tax maps of Belgrade. CEAT may have counted houses twice while on the driving surveys. In addition, one theory for the high number was that within Oakland specifically, the seasonal "tourist" cabin areas may have been counted incorrectly. In these areas, where there exist multiple units on one lot with one central septic system, all the units may have been accidentally counted. These lots should only have been counted as one residence as only one septic system is used for the entire seasonal camp. For this reason, the number of residences within each of the 216 lots was recounted via map/lot listings and came to 165 residences. In order to check the validity of this counting method compared to the driving surveys, the same procedure was used at the Belgrade and Sidney Town Offices. During the driving survey in Belgrade, 90 shoreline residences were counted. Then with the use of the map and lot listing book at the Belgrade Town Office, 90 residences were again counted. The fact that the numbers were identical validated the map and lot listing count as a viable source for counting residences. During the driving survey in Sidney, 171 shoreline residences were counted, and with the map and lot listing book, 165 residences were counted a difference of only 6 residences. Both surveying techniques were validated because there was no significant difference in the resident numbers between the two methods within both Belgrade and Sidney.

The shoreline of Messalonskee Lake was even more closely examined with the index of shoreline development, a measurement of the relative density of residences expressed as the number of residences per 1000 ft of shoreline. The index value for the shoreline of each town was compared to the mean value for the entire Messalonskee Lake shoreline, which was 0.93 residences/1000 ft. Belgrade was the only town below the mean with 0.47 residences/1000 ft showing that this town had the lowest density of shoreline development of all three towns. Oakland and Sidney both had higher densities than the mean with 1.07 residences/1000 ft and 1.25 residences/1000 ft respectively. Both these town had very similar densities of shoreline development, but Sidney had the most dense shoreline of all three towns.

In order to gain a better understanding of the significance of the shoreline development of Messalonskee Lake, it was instructive to consider the lake in relation to other lakes of the Belgrade Lakes region. Messalonskee Lake had 77.7% of its shoreline lots developed. In comparison, North Pond was found to have 66.7% of its shoreline developed (BI493 1997), and Salmon Lake had 70% of its shoreline developed (BI493 1994). Long Pond, the North Basin and South Basin, had 63.4% and 66.2% of their shoreline line developed (BI493 1995, BI493 1996). Long Pond has been said to have the best water quality of the Belgrade Lakes (BI493 1997); however, Salmon Lake was known to have algal blooms which may have resulted from residential phosphorus loading. Messalonskee Lake is not currently experiencing sustained algal blooms, although development trends are similar to those of Salmon Lake. After looking at these numbers, it becomes apparent that the percent of development alone has little correlation with water quality. There are many other factors that affect the water quality of a highly developed lake such as the lake size, width, flushing rate, and tributary flow. An increase in development on the lake can increase the risk of decreasing the water quality of the lake.

This survey suggested that Messalonskee Lake has an above average percentage of shoreline development relative to other Belgrade Lakes (Table 6). This study also showed that only 59.0% of the developed shoreline lots were seasonal, which was remarkably lower than for North Pond (88.3% seasonal shoreline residences). Within the entire North Pond watershed, 54.7% of the residences were seasonal. This higher summer population causes increased septic use, and therefore increased phosphorus loading during those months. In comparison to North Pond, the entire Messalonskee Lake watershed had a much lower percentage of total seasonal residences (26.1%), and a higher number of year-round residences (73.9%) (Figure 40). This high number of year-round residences in the Messalonskee Lake watershed could be a result of the lake's close proximity to the town centers of Oakland, Augusta, and Waterville compared to the other Belgrade Lakes.

Describing Messalonskee Lake residence areas in more general terms can help us to see how the shoreline and nonshoreline areas may affect phosphorus loading. On Messalonskee Lake, most of the shoreline lots (typically small, grandfathered, and lacking buffer strips), were developed, which can have huge negative effects on the lake (see Background: Shoreline Residential Areas). Only 59.0% of

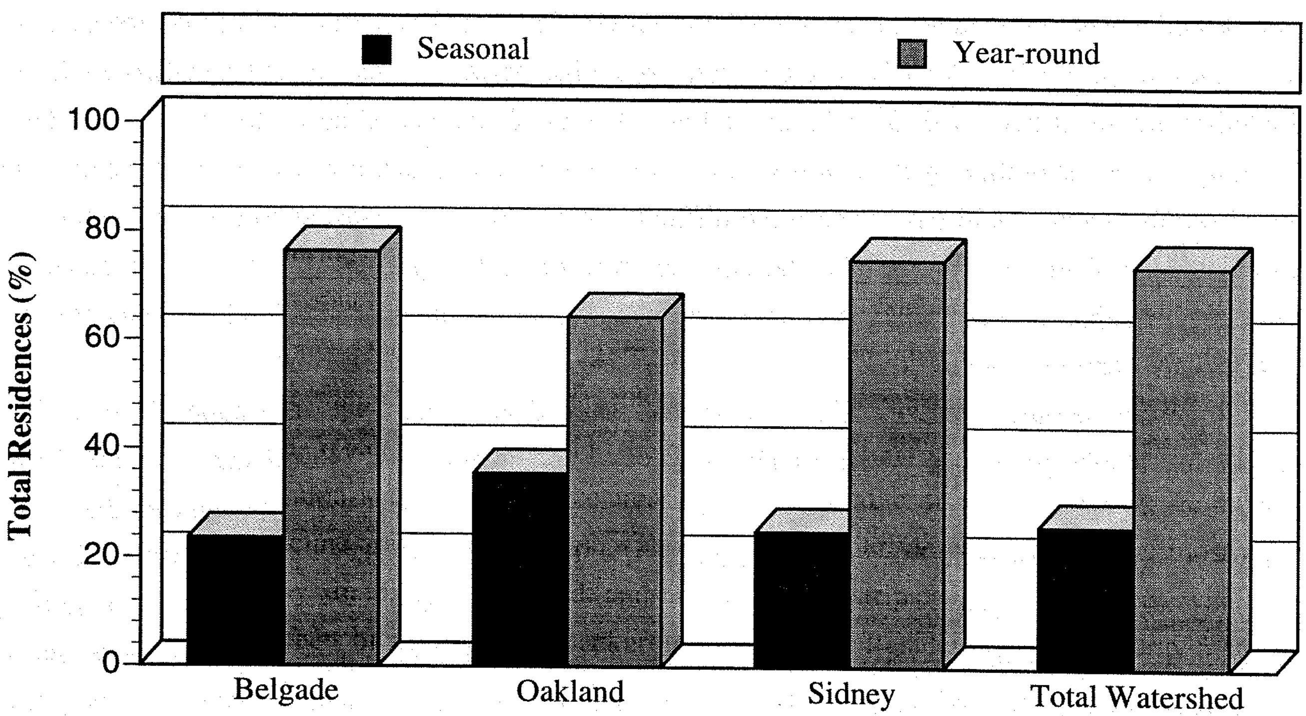

Figure 40. Percentages of the seasonal and year-round residences in each town of the Messalonskee Lake watershed, as of Oct-97.

the shoreline residences were seasonal; this high number of year-round residences compared to other Belgrade Lakes could lead to an increase in the amount of phosphorus loading entering the lake (Table 6).

However, there are differing opinions as to how the status of the residence effects the phosphorus loading. Seasonal residences built before 1974, when converted into year-round residences, are required to have their septic systems updated. Having new septic systems in year-round residences might decrease the amount of phosphorus entering the lake.

Generally, all the nonshoreline residences were year-round residences, many of which were buffered by extensive woodland areas. Some of these residences, however, could still be in close proximity to tributaries where buffering between the lot and the water may not exist. Within nonshoreline areas, there is much room for expanded growth in the future. Currently, only 33.1% of lots remain undeveloped; however, there are 9539.5 acres of undeveloped land. Future development, which destroys the natural buffering forest, could contribute to increased phosphorus loading.

Shoreline Buffer Strips

Methods

The buffer strips around Messalonskee Lake were assessed on 15-Sep-97 by CEAT from the water. The lake had previously been divided into five distinct regions (A through E) with the use of the islands as land marks (Figure 41). Area A included the shoreline south of Greeley Island. Then areas B and C were defined as the shoreline between Greeley Island and Blake Island on the east and west sides respectively. Area D was the entire shoreline between Blake Island and Brown Island (including the residence on Blake Island), and area E was all the shoreline north of Brown Island. Dividing the lake shoreline by the towns would have been more expedient; however, identifying town lines from the water would have been more difficult. A visual survey was performed on each of the different areas from the boats. The shoreline in front of each residence was closely examined to determine whether or not an adequate buffer strip was present. Some groups also added a category for a partially buffered residence.

An adequate buffer strip would ideally be characterized as having a width of about 75 ft, a slope of less than a 30% grade, many deep-rooted, large trees, and a very thick layer of native Maine shrubs and saplings (Table 8). Footpaths accessing the water should be winding and no greater than 10 ft wide as measured between the tree trunks of the path (MDEP 1994b; see Background: Buffer Strips). Linear coverage across the property was the focus of this visual survey due to the difficulty of judging the width of the coverage from the water. An adequately buffered residence had a complete line of dense vegetation in front of the property, while partial buffers were defined as having nonvegetated areas between the vegetation causing gaps in the buffer strip. Finally, an inadequately buffered residence had no vegetation in front of the property.

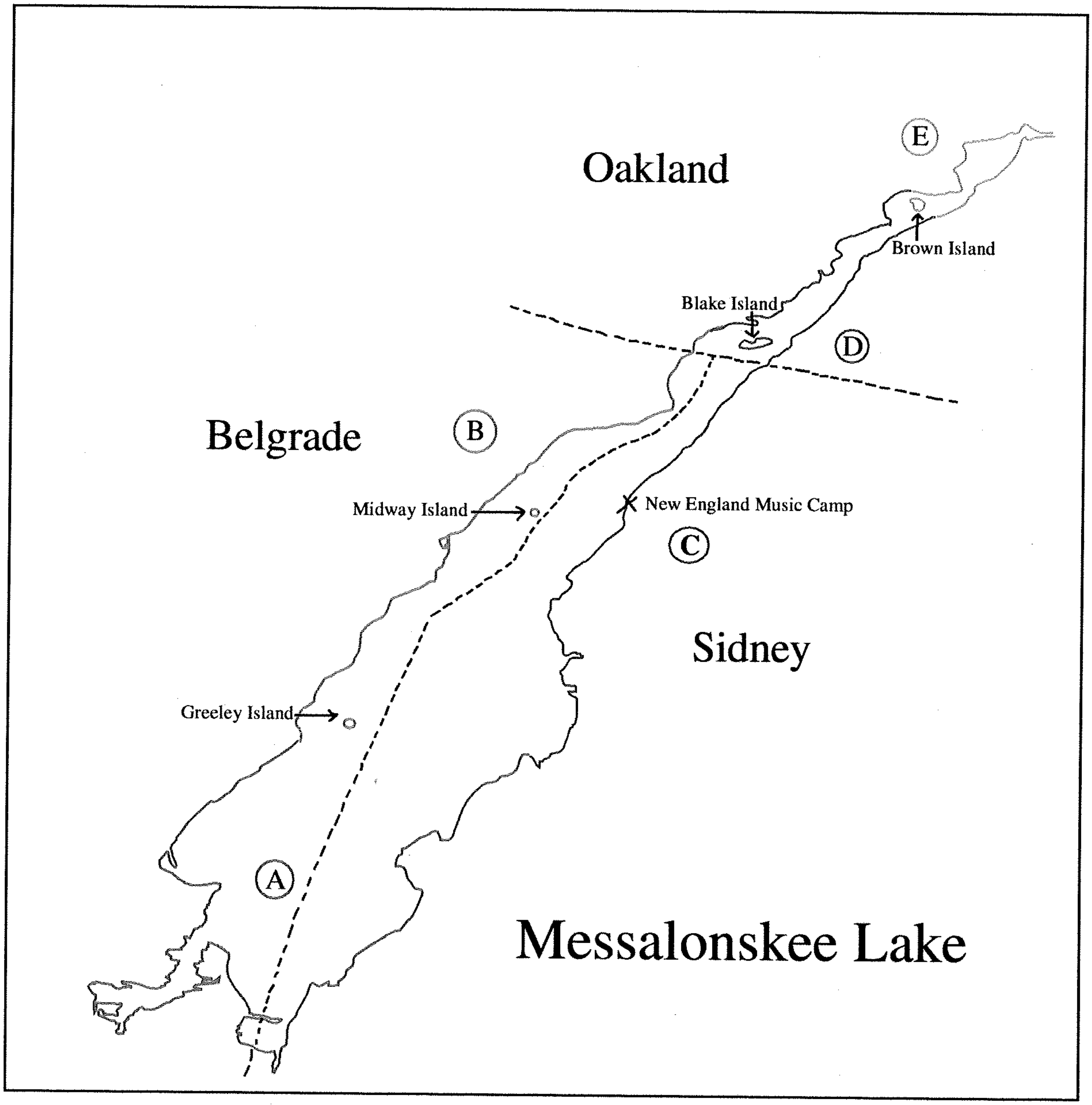

Figure 41. Map of five different buffer stips areas (A, B, C, D, and E) located around Messalonskee Lake. Areas were determined via island landmarks on maps prior to performing shoreline survey by boat. Areas were selected to assist the study so certain areas of the lake could be closely examined for buffer strip adequacy.

Table 8. Suggested vegetation for buffer strips: an adequately buffered residence has a 75 ft wide buffer between the building and the shoreline consisting of a large canopy of deep rooted, large trees, and a very thick layer of shrubs, ground cover and saplings (courtesy of Cumberland County SWCD, Fact Sheet #05).

	Deciduous Trees	
Red Maple [a]	Green Ash [a]	Honey Locust
Sugar Maple [a]	Crabapple	Littleleaf Linden
Silver Maple	Red Oak [a]	
Norway Maple	Paper Birch	
	Evergreen Trees	
Red Pine	Eastern Hemlock [a]	White Pine
Australian Pine	White Cedar	
	Shrubs	
Forsythia	Honeysuckle	Arrowood
Cranberry Bush	Rhododendrons	Barberry
Lilacs	Juniper	Burning Bush
Red Twig Dogwood	Korean Spice Viburnum	Doublefile Viburnum
Winterberry	Spiraea [a]	Potentilla
High Bush Blueberry	Gray Dogwood	Rugosa Rose
Bayberry	Autumn Olive	Serviceberry
Azaleas		
	Vines and Ground Covers	
Ferns [a]	Plantain Lily	Bittersweet
Honeysuckle	Lowbush Blueberry [a]	Daylily
Virginia Creeper	Crown Vetch	

[a] Plant species Native to Maine

Results and Discussion

Most buffer strips on Messalonskee Lake were not in accordance with the above guidelines. Some houses had natural woodland buffer strips, while others were surrounded by large lawns. Phosphorus input into lakes from residential runoff of lawns in residential areas is five to ten times higher than that of undeveloped land (see Background: Shoreline Residential). The result is a higher phosphorus concentration in lakes with developed shoreline areas (McGrath Pond-Salmon Lake Association 1997).

Around Messalonskee Lake, 25.0% of the shoreline residences were adequately buffered. Similarly, in the Long Pond South Basin study, 28.0% of the shoreline residences were adequately buffered (BI493 1996). Around the south end of Messalonskee Lake, areas A, B, and C, the percentages of adequately buffered residences were approximately 10% lower than the poorly buffered percentages. These three areas, A, B, and C, had 46.0%, 38.9%, and 39.0% of their residences as poorly buffered, while both areas D and E on the northern end were identical with 86.6% of residences poorly buffered (Figure 41 and 42). This high number of poorly buffered residences on the northern end of the lake, where most of the developed lots exist, potentially adds high levels of phosphorus to the lake via surface runoff. Though people enjoy their landscaped lawns running down to the water and clear scenic views, there are other ways of creating a beautiful garden while enjoying access to the lake and preserving its beauty. Many landowners may prefer the appearance of a landscaped buffer; if properly designed, they can also be very effective (MDEP 1997a).

Camps

Methods

Information about the names of summer camps in the Messalonskee Lake watershed was acquired by contacting the Belgrade Oakland, and Sidney, town offices. The owners/directors of the camps were then contacted for specific information.

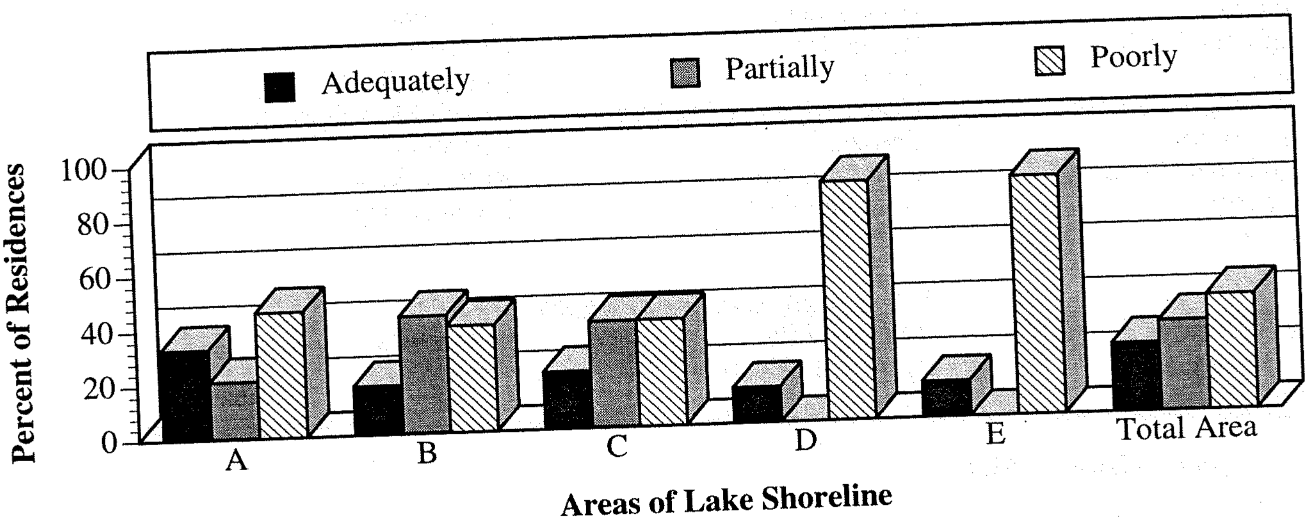

Figure 42. Percent of adequately, partially, and poorly buffered shoreline residences along Messalonskee Lake in five different areas. Adequate buffer coverage has significant trees, shrubs, and ground cover between the residence and the water. A poorly buffered residence had little or no vegetation between the property and the shoreline. The categories used in the survey were adequately, partially, and poorly buffered. Within Areas D and E, surveyors did not use a partially buffered category (see Figure 41 for area locations).

Results and Discussion

The New England Music Camp, located on 197 acres on fire road S10 off Rt. 23, is the only summer camp of its kind on Messalonskee Lake. The camp runs for eight weeks during the summer and nearly three hundred campers are admitted annually (Wiggin, pers. comm.). The camp employs about twenty-five counselors during the summer who partially comprise a support staff numbering between 105 and 110. These counselors, along with the summer support staff, are on the camp grounds for a total of ten weeks each summer. A small maintenance group keeps-up the grounds year-round. The camp's regular summer sessions typically run from the last week in June to the end of August. The New England Music Camp's bathroom facilities include 75 to 100 toilets that are plumbed into three septic systems.

Roads

Methods

A comprehensive roads analysis serves to determine the amount of phosphorus loading that occurs due to the roads in the watershed. Furthermore, the application of a scoring scale for roads facilitates a more objective analysis of road conditions. Serving as both a source and pathway for the transport of sediments, roads are major conveyors of phosphorus toward the lake (MDEP 1992a). In the event of a storm or general surface water runoff, phosphorus can be channeled from distant watershed areas directly into the lake and/or its tributaries by roadways (Lea, Landry, and Fortier 1990; See Background: Phosphorus and Nitrogen Cycles). Flowing water erodes road surfaces and ditch channels, accumulating phosphorus-containing sediments that end up in the lake (COLA 1992).

The potential for increased phosphorus loading into the lake is accelerated by poor construction and maintenance methods. An estimated 85% of erosion and sedimentation problems can be attributed to negligent construction and improper maintenance of camp roads (Michaud 1992). Proper erosion and sediment control practices, coupled with appropriate seasonal timing of construction, are critical in mitigating the adverse environmental impacts of road construction. Long-term goals of dirt road construction should concentrate on minimizing the surface area covered by a road. Larger surface areas on roads facilitate accelerated erosion of phosphorus-containing sediment. Well-constructed roads serve to limit the amount of precipitation and runoff that stays on the road surface (see Background: Roads). In addition to environmentally sensitive construction techniques, proper long-term road maintenance is important. Planting and/or preserving a forested buffer area downslope from the road facilitates slow seepage of water into the soil substrate. Other road management goals include promoting ditch vegetation, adding water diversions and culverts where needed, and reducing steeply inclined roads that filter directly into the water body (Lea, Landry, and Fortier 1990).

To determine the nature of roads in the watershed and their phosphorus loading potential, overall road characteristics need to be examined including the road surface condition and usage, the degree of road inclination, and the presence and quality of road ditching, culverts, and water diversions (Michaud 1992). Roads that meet the highest standards for each of these indicators have a lower phosphorus loading potential than other roads (Michaud 1992).

Road surface condition and usage are important aspects of overall road quality because varying road surfaces and usage rates impact the phosphorus loading potentials differently. Road surfaces are made up of a variety of substrates, both permeable and impermeable to surface water runoff. Gravel and sandy substrates maintain the integrity of the road surface because water tends to percolate through the spaces between their grains. In contrast, hard packed dirt and clay surfaces prevent water percolation, thereby promoting increased surface erosion and gullying. In addition to the surface condition, the crowning of the road is of particular importance, because crowning serves to direct water off the road surface and into road-side ditches (See Background: Roads). A good surface crown rises 0.5 in for every foot of road width (Michaud 1992; Figure 43). In other words, a 12 ft wide road should have a 6 in crown.

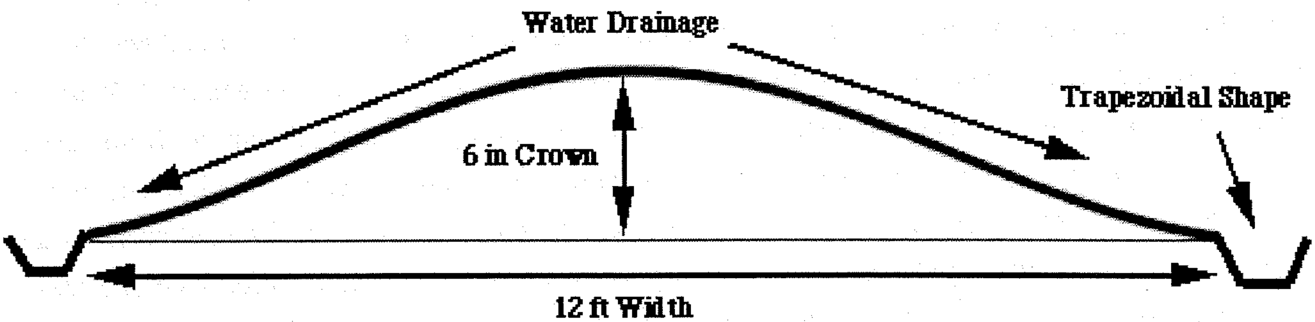

Figure 43. A "good" camp road has a 6 in crown for a 12 ft wide road. The crown serves to direct surface runoff into road side ditches. Beyond the ditches, vegetation serves as a buffer for phosphorus-containing sediments (Michaud 1992).

The presence and character of road ditches is a useful constituent to evaluate the phosphorus loading potential of a road. Ditches serve to manage surface runoff of the road, and are particularly important to storm water management. Ditches need to accommodate the highest possible level of storm water and seasonal runoff in order to remain effective (COLA 1992). The design and size of road ditches are crucial to their effectiveness. Vegetated and/or stone-lined ditches that are U-shaped, not V-shaped, are the most effective in managing road surface runoff (COLA 1992). Proper placement of ditches is equally important. Ditches serve as a storage area for precipitation and runoff, therefore, they need to be situated along road-sides where properly crowned roads can direct water into them. Ditches need to be maintained free of debris to guarantee runoff transport. Furthermore, rip rap, the lining of ditches with stones, grass, and other types of vegetation is encouraged to help slow down the erosive force of water in the ditch (Figure 44). A good network of ditches involves several turnouts where flowing water can be channeled away from the lake and into a well buffered area (Michaud 1992).

Culverts serve as another important tool in mitigating the phosphorus impact of roads on the water body. Culverts are drains or channels crossing beneath a road, allowing water to flow downslope beneath the road system. Culverts often channel water into a road-side ditch, thereby easing the erosive force of diverted water (See Background: Roads). Culverts are constructed of

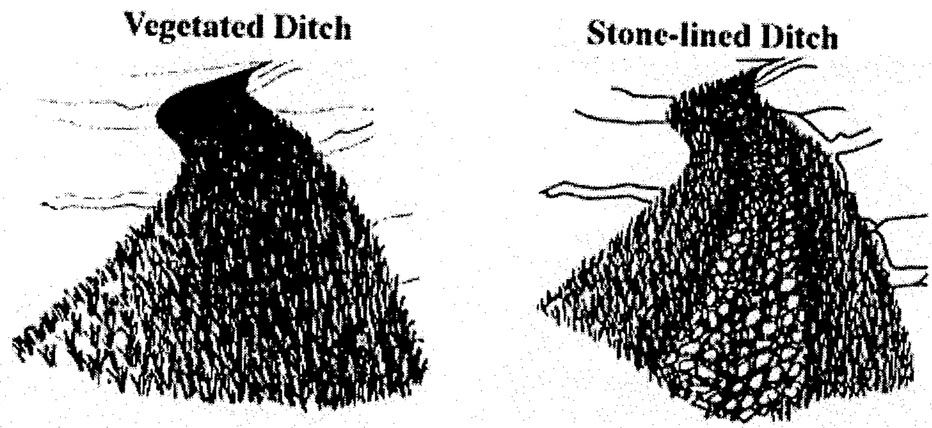

Figure 44. (Modified from Michaud 1992). Two viable options to facilitate absorption of water into ditches include vegetation and stones. Vegetation helps to slow down flowing water and absorbs phosphorus-containing water. Rock-lined ditches slow rapid flowing water, helping to prevent erosion (Michaud 1992).

wood, plastic, metal, and concrete typically in a cylindrical shape. Proper maintenance of culverts is critical to their function. Their internal frame should be complete and cleaned of debris and sediment (Michaud 1992; Figure 45).

Road diversions intercept runoff from precipitation and channel the water off the road surface into well-buffered regions of grass and forest that serve as a phosphorus sink (COLA 1992). Without careful precautions to divert runoff, all soluble pollutants, including phosphorus, will eventually enter the lake. Diversions are useful to prevent water flow from gaining velocity by decreasing its volume and increasing chances of filtration. By structuring a diversion to direct and spread water over a large area, phosphorus-containing water can filter into a vegetated area, not the lake body itself (Michaud 1992; See Background: Roads).

The overall slope of a road can impact the amount of phosphorus that is added to the lake. Road length and gradient influence the velocity and volume of surface runoff (Michaud 1992). Steep slopes encourage surface erosion and runoff, enabling precipitation to scour and gully road surfaces and ditches. Lower slope gradients reduce the velocity of surface runoff, serving to limit surface erosion (COLA 1992).

A complete field survey of unpaved and paved camp and non-camp roads was conducted in the Messalonskee Lake watershed on the dates of 22-Sep-97, 29-Sep-97, 06-Oct-97, and 20-Oct-97. The focus of the field survey was to evaluate the overall quality of the roads in the watershed and their varying phosphorus contribution to Messalonskee Lake. The field survey employed the use of two road survey techniques: the detailed road survey and the non-detailed road survey. Detailed road

Figure 45. This "good" culvert is diverting water beneath the road surface. Characteristics of a good culvert include adequate width for managing seasonal and storm-water runoff, correct placement, a channel free of debris, and over a foot of clearance between the top of the culvert and the road surface (Michaud 1992).

surveys were administered on all camp roads that did not specifically meet the criteria of a good camp road.

A camp road was defined as any paved or unpaved road that began from the two lake perimeter roads Rt. 11 and Rt. 23 and ran toward the lake. Good quality camp roads were defined as any camp road that had a six inch crown, hard dirt or gravel surface, no mounds of sediment known as berms lining the street and preventing water runoff, adequate road ditching, correct placement and size of culverts, functioning water diversions, and an overall gentle slope of less than 10%.

Non-detailed road surveys were conducted on all non-camp roads in the watershed as well as some good quality camp roads identified in the initial field reconnaissance. A non-camp road was defined as any paved or unpaved road that ran outside of the two perimeter roads, Rt. 11 and Rt. 23. Private driveways and chained camp roads were not analyzed. The Detailed Survey Form for Camp Roads was adopted and modified from the MDEP (Michaud 1992; see Appendix J). The non-detailed road survey was conducted with the use of the Residential Survey Form designed by CEAT and used for both the non-detailed road survey and the house count survey (see Appendices I and M).

The detailed road survey involved teams of four surveyors to assess roads in the watershed. The four person team divided into teams of two. One team surveyed the overall slope for the entire length of the road using a clinometer and distance wheel. The other team divided the road into 0.10 mile segments and analyzed the type and quality of road surface and the presence and quality of road ditching, culverts, and water diversions for each road segment. Road average widths were determined in feet, while culvert and ditch size were assessed in inches. Surface crowning was measured in inches using a yard stick and attached string. The overall lengths of roads in miles in the watershed were measured with vehicle trip odometers. The detailed road survey form included a description of the road surface, road ditching, culverts, water diversions, and slope percentage (see Appendix J). The non-detailed road survey employed teams of two, who measured the length of roads with a vehicle trip odometer and the widths of roads with a standard measuring tape. Quantitative assessment of camp roads was conducted by developing a series of indices, the numbers of which were formulated by a scoring technique for each road. Each index had its own respective phosphorus loading factor associated with it; higher factor numbers reflected greater phosphorus loading potential. The total phosphorus loading potential of each road could then be calculated.

To determine the overall quality of the road surface of a detail surveyed road, a *Surface Total Index* was derived. The road surface was evaluated in segments and scores were ranked ranging from "good" to "big problem". This evaluation was used to measure the adequacy of crown, surface, edge, and road material. Special attention was paid to determining the road material substrate: surveyors labeled roads gravel, gravel/sand, dirt, sand/clay, or clay. Seasonal or year round usage of the road was noted based on the character of residences on the road. The overall surface condition was rated on a spectrum between "100% good" to "0% good" (see Appendix J). The product of the road surface analysis, usage rate, and overall surface condition constituted the *Surface Total Index.*

A specific analysis of road ditching was also conducted on each road that received a detailed survey. Ditches were assessed to determine whether or not they were present and properly placed, the degree of their depth and width, the presence and abundance of vegetation, the depth of sediments in the ditch, and the shape of the ditch. For each category, the ditch was rated on a scale of "good" to "big problem".

Scores for each 0.10 mile segment studied were then tallied and averaged to give an average ditch description total. A summary of ditch condition followed where ditches were classified as a "100% good" or "0% good" (see Appendix J). Road ditches that were over 2 ft deep, well vegetated, and parabolic or trapezoidal in shape were denoted as "100% good" (Figure 46). A "0% good" ditch described the condition where there was no ditch present where needed. The product of the ditch description total and condition generated a *Ditch Total Index* for each road surveyed.

The *Culvert Total Index* was a summary of the overall state of the culverts on a particular road. The summary criteria included: need, wear, size, insides full or partly full of sediment, and the amount of covering material. The need for a culvert was evaluated based on the presence or absence of

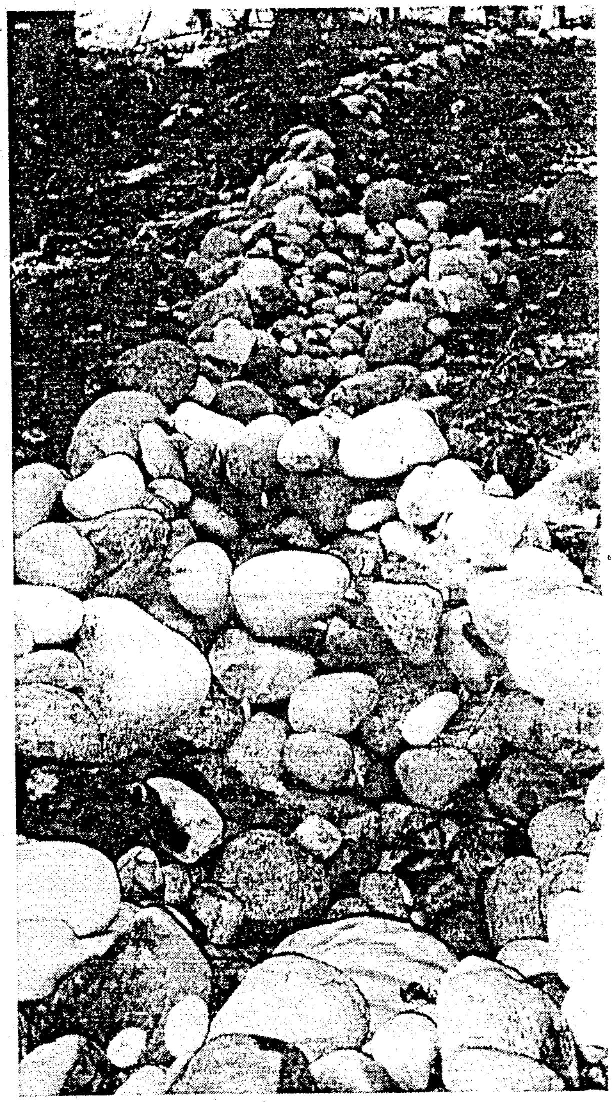

Figure 46. This "good" ditch has been lined with boulders in order to manage seasonal and storm water runoff.

culverts where standing or flowing water was present along the road side. The insides of culverts were surveyed to determine whether or not they were clogged with debris that may inhibit proper function.

Culverts were evaluated based on the above criteria, and ranked on a scale from "good" to "big problem" (see Appendix J). The correct placement and upkeep of culverts was also noted, as appropriate location is necessary for proper function. "Good" culverts diverted flowing water from seasonal and year-round streams under the road surface, and into an area with sufficient drainage away from the road surface. Poor culverts were either rusted, clogged with leaves, rocks, and sediment, or lacked sufficient covering sediment and organic material between the top of the culvert and the road surface.

An analysis of the overall presence and condition of water diversions provided for the development of a *Water Diversions Total Index* . The components of the overall water diversion condition included the presence of water diversions where needed, and the direction that surface and/or storm water runoff was maintained by current diversions. Criteria were ranked on a scale ranging from "good" to "big problem". The need for water diversions was clear where cracking, gullying, and pot holes were easily identifiable. A "good" water diversion diverted water into a well drained vegetated area like a forest, whereas a "big problem" water diversion directed flow into the lake body (see Appendix J).

The *Slope Road Segment Average* was developed from a segment grade analysis of every road surveyed in detail. Segments were defined as a length of camp road, either 50 ft, 100 ft, 200 ft, 500 ft, or 1000 ft that was relatively continuous in percent grade. Each segment received a score based on the product of the road segment distance and its respective percent grade. Segment scores were then summed to derive a road segment total; this index was instrumental in identifying steep-sloped roads. Multiplying the number of road segments with a particular length and percent grade by erosion potential coefficients provided the soil erosion potential of each road segment. Segment scores were then averaged to provide the *Slope Road Segment Average* (see Appendix J). Roads with a high percent gradient contribute more phosphorus loading potential than roads with a slope of lesser degree.

The sum of the *Surface, Ditches, Culverts, and Diversions Total Indices* was computed in order to quantify the overall score of the road, the *Road Total Index*. The product of the *Road Total Index* value and the *Road Segment Average* value constituted the *Total Road Value*. The *Slope Road Segment Average* was not included in deriving the *Road Total Index*. Qualitative road analysis was developed based on mock road evaluations. For example, in generating the classification of an ideal camp road, CEAT completed a detailed survey form on the basis of the qualifications that an ideal camp road would have. Scores for individual roads may vary: "ideal" camp roads received a score between 0 to 16, "acceptable" roads around 63, "fair" roads around 189, poor roads around 434, and "big problem" roads around 817.

An ideal camp road with a score of 0 to 16 had characteristics of superb crowning, firm surface substrate, no berm or ridge, and a gravel/sand road surface. Road ditches were well placed, with over 2 ft depth and 8 ft width, and a presence of buffering vegetation. No sediments had accumulated in the ditch and the ditch possessed a parabolic shape. Culverts were present where needed, new in appearance, appropriate in size for the amount of storm water or spring melt for the area, and contained covering material greater than 1 ft. Water diversions were well placed and diverted water into well drained woods. In contrast, a "big problem" road had no surface crown, a dusty and loose surface and mud-like conditions in rain. There may have been a berm/ridge which inhibited surface runoff, forcing water to erode away at an impermeable clay surface substrate. Road ditching was missing where most needed. If a road ditch existed, there was bare soil with sediment deposits of greater than 4 in deep, and the shape of the ditch was square or irregular. Culverts were needed, and ones that did exist were clogged or had the top of the culvert showing through and damaged on the road surface. Water diversions were badly needed as indicated by road gullying. Where present, diversions usually directed water into a tributary of the lake or the lake body itself.

Following the completion of the detailed road survey, it was important to develop a system to categorize and target good and problematic roads in the watershed. The *Road Total Index* figures for every road were used to separate roads on the basis of their overall phosphorus loading potential. Good camp roads received scores below 100, while roads with scores totaling 100 and beyond warrant concern. Camp roads with scores beyond 300 need immediate attention. Roads that received a *Road Total Index* score between 1 to 99 were placed in Class 1, scores between 100 to 199 were placed in Class 2, scores between 200 to 299 were placed in Class 3, scores between 300 to 399 were placed in Class 4, scores between 400 and 499 were placed in Class 5, and roads with a score at or beyond 500 were placed in Class 6 (see Appendix L). A comparison of the *Road Total Index* values

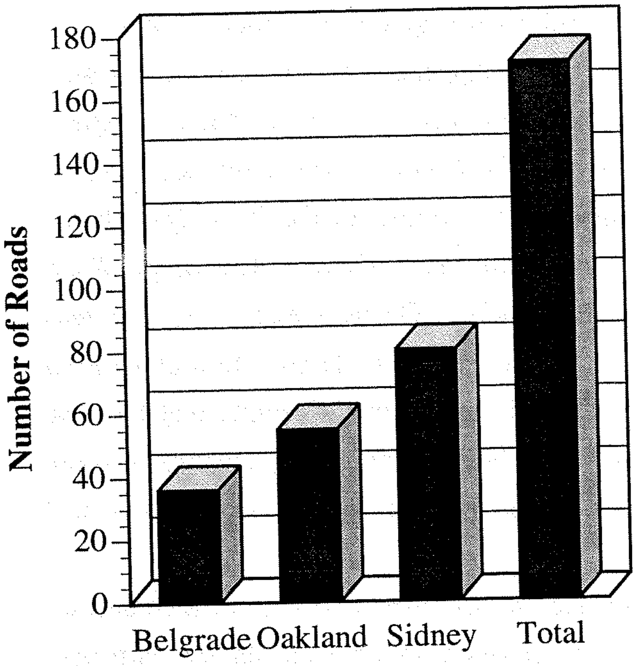

Figure 47. Total number of roads within each town comprising the Messalonskee Lake watershed, and the total within the watershed itself.

allows for the identification of good quality 'model' camp roads and roads of poor quality that warrant concern and modification.

Results and Discussion

There were approximately 172 paved and dirt roads in the Messalonskee Lake watershed (Figure 47), making up almost 70 miles of roads (Figure 48). These roads made up an approximate area of 154 acres. There were significantly more dirt roads than paved roads in the watershed (about 80% were dirt), and dirt roads also occupied a greater area. Roads that were roped or chained off were not surveyed; however, the vast majority of the roads within the watershed were surveyed in some manner, producing a good representation of the condition of the roads.

One hundred seven roads within the Messalonskee Lake were surveyed using the Detailed Survey Form for Camp Roads (see Appendix J). These surveys were summarized to obtain an idea of the relative condition and slope of each road.

The surveyed roads were categorized into six classes according to their condition; class one roads were in the best condition, and class six roads were in the worst condition. Forty-eight percent of the roads were in class one, and 34% of the roads were in class two; therefore, 82% of the roads had a *Road Total Index Value* of between 0 to 199 (Figure 49). Consequently, the vast majority of the roads were in good to fair condition. Nine of the roads scored in the 200 to 299 range, which was below what was considered to be fair,

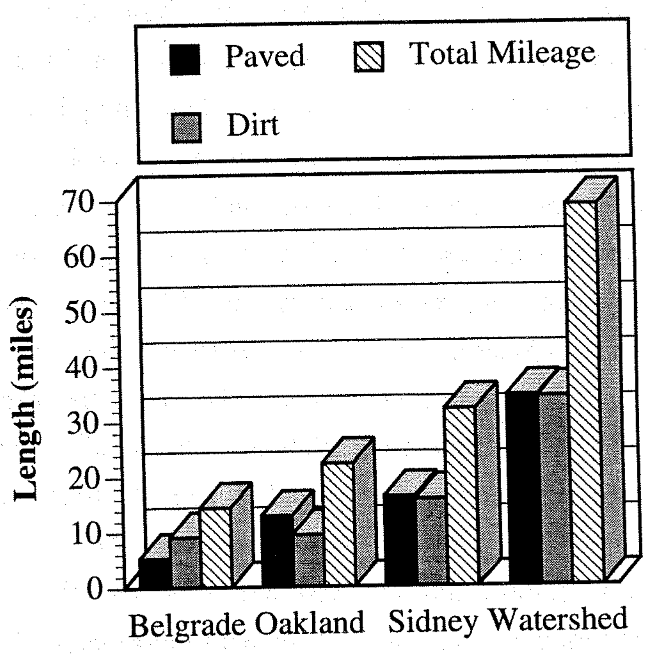

Figure 48. Length (in miles) of all dirt and paved roads within the Messalonskee Lake watershed, divided by town. Total milage within each town also given.

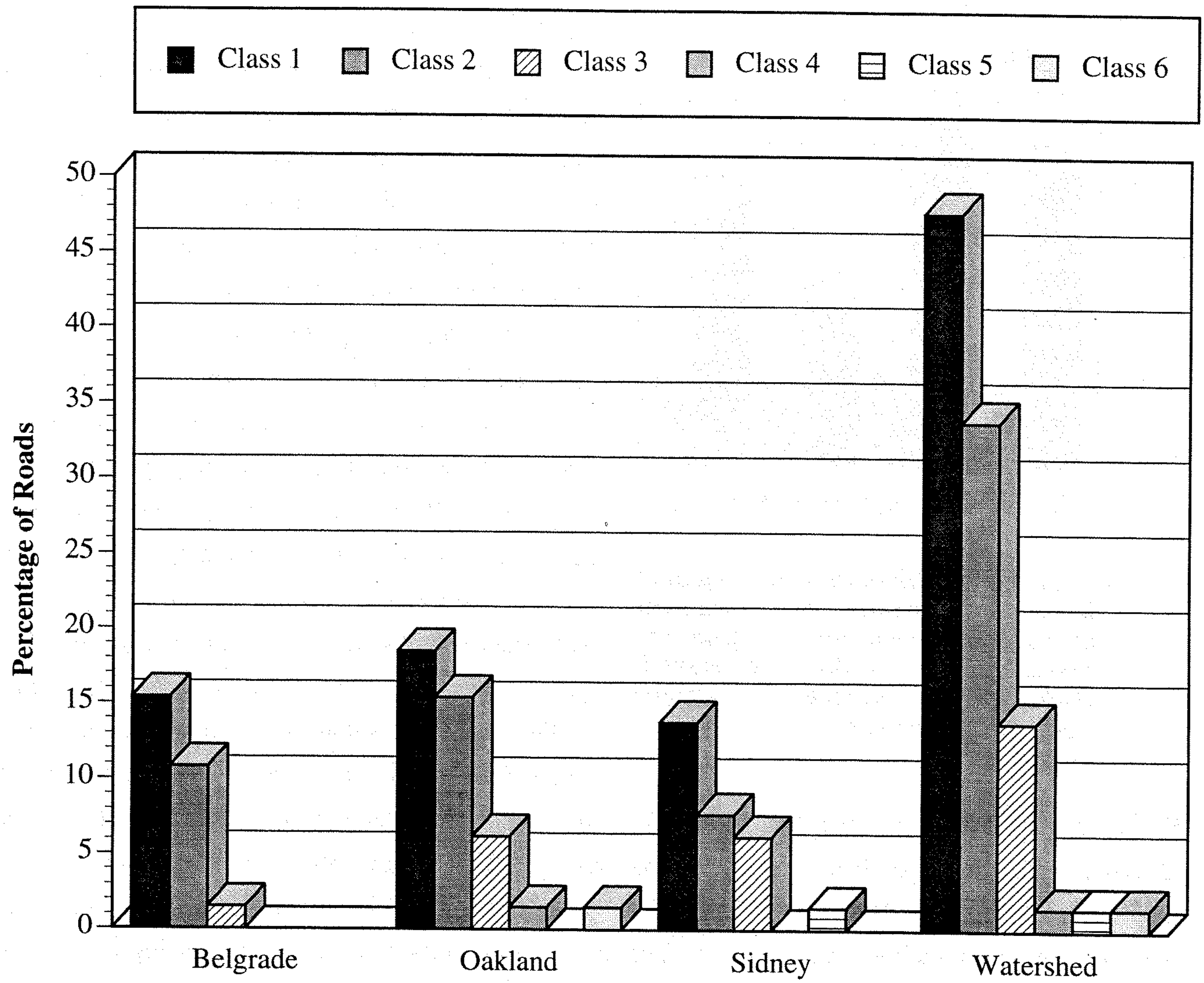

Figure 49. Percentage of roads within the Messalonskee Lake watershed in each of the six classes of Road Total Index values (Appendix M). These values are based on road total values from the camp road surveys. The values ranged from 7.0 to 560.0. Roads were divided into six groups of equal units. Class 1 indicates roads in the best condition, and Class 6 are the worst roads.

and three roads had scores above 300, suggesting they were in poor condition. In general, of the roads surveyed in the Messalonskee Lake watershed, Belgrade's roads were in the best condition (Figure 49).

One purpose of the detailed camp road surveys was to analyze the slope of the camp roads. The range of values for the *Road Segment Total* was 1.3 to 167.0. The mean value for the watershed was 43.8, but the median was 31.0. The mean was much higher than the median due to a few outliers. The median, therefore, was used when comparing towns because it was more representative of the typical *Road Segment Total*. The median for Sidney (19.0) was much lower than the other two towns. The median for Oakland was 39.5, and the median value for Belgrade was 34.6 (Figure 50). It was

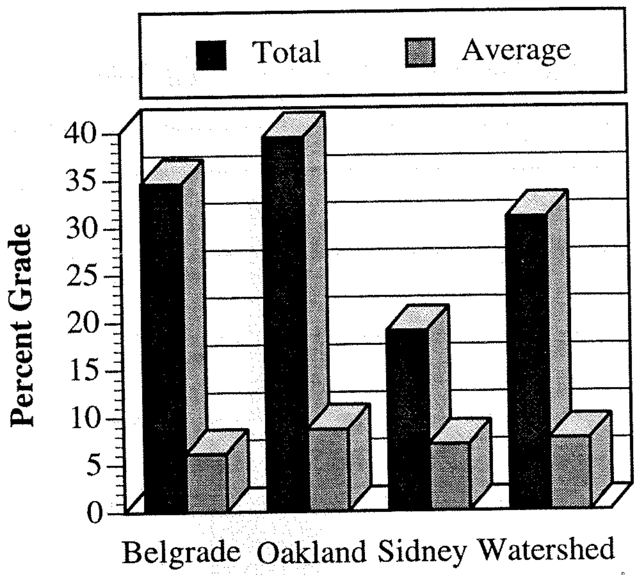

Figure 50. Median road segment total and median road segment average for each town within the Messalonskee Lake watershed. High values indicate a greater potential for erosion.

important to look at the mean values because these outliers have a considerable impact on the phosphorus loading of the lake. The three towns had similar means (Belgrade was 34.6, Oakland was 43.4, and Sidney was 43.6). All three towns had a few roads with a few high values which brought the mean much higher than the median.

The *Road Segment Average* value was important for determining the soil erosion potential for the entire road. The soil erosion potential has an impact on the phosphorus loading potential. A value of 23.0 or greater was considered to be particularly unfavorable, indicating a need for greater attention (Michaud 1992). The range for the watershed was 4.4 to 47.0, with a mean of 10.3. Again, the mean was affected by a few high outliers, and the median was a more representative value for comparing towns. The median for Belgrade was the lowest of the three towns (6.2), the median for Sidney was in the middle (7.0), and Oakland had the highest median road segment average (8.7) (Figure 50). The means of the three towns were as follows: Belgrade, 9.3; Sidney 10.0; and Oakland, 11.5. Even when taking the means with the outliers, they were not in the "unfavorable" range, although the mean was higher than the median.

The *Total Road Value* combined the road condition and the slope of the road, giving a more complete picture of the phosphorus loading potential of the road (see Background: Phosphorus and Nitrogen cycles). These values ranged from 38.5 to 11,760.0 (see Appendix H). A low number indicated a road with low phosphorus loading potential, and a high value meant the road had a high phosphorus loading potential. The lower the phosphorus loading potential, the less impact surface runoff has on the quality of the lake water. Belgrade had the lowest median total road value, 667.6, which was well below the median for the entire watershed, 1000.0 (Figure 51).

Less of an emphasis was placed on the paved roads within the watershed, for several reasons. First, paved roads typically carry less sediment into the water, thereby contributing less to the phosphorus loading of the lake. Secondly, paved roads tended to be in better condition than unpaved roads (although certainly this was not always the case). And lastly, there were very few paved camp roads. Camp roads were studied more intensely because they are likely to play a much more important role in the phosphorus loading of the lake due to their close proximity to the water.

It was important to look at the condition of the road, because a road in poor condition would carry significantly more sediment down to the lake than one in good condition. The *Road Total Index* values addressed these issues. This index included many different components: road surface, ditches, culverts, and water diversions. Common road surface problems in the watershed included poor crowning, ruts in the road, and berms present (see Background: Roads). The biggest problem regarding ditches seen in the watershed was roads where ditches were obviously needed, but did not exist. Culverts in general were not as problematic as ditches in the watershed. The biggest problem regarding culverts seen in the watershed was where culverts were needed, but not present. In general, water diversions were in good condition throughout the watershed. Bad scores resulted where diversions were needed but not present. A few of the roads in the watershed that scored extremely high *Road Total Index* values were P3B, P3C, and S9 (see Appendix H). These roads all had poor surfaces, specifically due to ruts and berms which prevent proper drainage, and were missing ditches. A low score does not necessarily mean that maintenance is not necessary, however a high score indicates a definite need for maintenance.

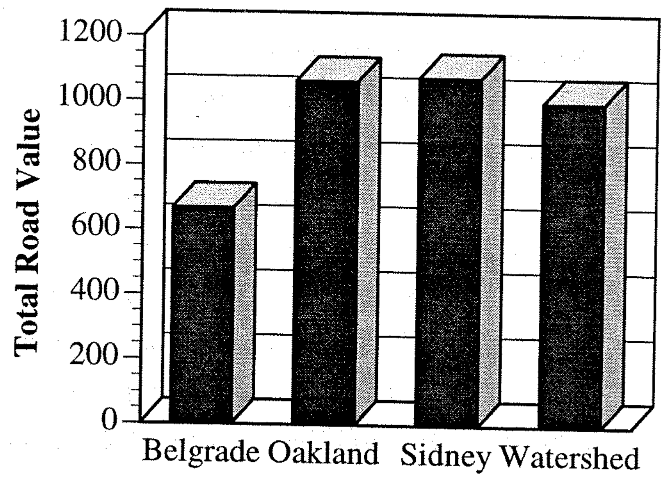

Figure 51. Mean Total Road Values for each municipality within the Messalonskee Lake watershed. The Total Road Value combines the road condition and the slope of the road. A lower value indicates roads with a lesser phosphorus loading potential, and a high value indicates roads with greater phosphorus loading potential.

It is important to look at the slope of the roads in the Messalonskee Lake watershed. Dirt camp roads were carefully studied because of their close proximity to the lake (many of them ran right down to the water) and because of their composition (dirt roads carry more sediment into the lake, and consequently more phosphorus). Roads with steeper grades carry considerably more surface runoff into the water, especially during periods of high rainfall and during spring runoff (see Background: Roads). Some of the roads with higher *Road Segment Totals* were in clusters, for instance: P2 to P13 (northeastern end of the lake), and O6 to O9 (western middle of the lake) (see Appendix H). A few scattered roads in Sidney also had high *Road Segment Totals* (S4, S29, S30, and S30A) (see

Appendix H). Besides these extreme cases, most of the values were lower, indicating that many of the roads were not very steep.

The clustering was different for roads of high *Road Segment Averages* as than that of the *Road Segment Totals*. Some of the roads with high values included P3C to P6D (the northeastern end of the lake), O5, S23, and S30A (see Appendix H). Many of these roads were in the same areas where there were high *Road Segment Totals*, indicating a correlation between the roads of steep grade and those that will contribute significantly to the phosphorus loading of the lake.

The *Total Road Value* combines the road condition and the slope of the road, looking at the total picture of the road. This value indicates how much the road will contribute to the phosphorus loading of the lake. Belgrade had the lowest *Road Segment Average*, and the lowest *Road Total Index*, which is why its *Total Road Value* was also the lowest. Sidney had the highest *Total Road Value*, mostly due to its high *Road Total Index* value (the median *Road Total Index* value for Sidney was 145.0, whereas the median for Belgrade was 113.7). It was observed that good and poor roads were scattered throughout the entire watershed, although roads with similar scores were often clustered together. This may imply several issues: slope of the land may fluctuate, roads may reflect time of development (roads constructed more recently tend to be in better condition), and the quality of road maintenance may vary.

There were nine roads within the watershed that had extremely high *Total Road Values* (over 2000). These roads were (in decreasing order): P3C, O5, S23, P6C, S30, P6B, P6, B6, and SF9. The highest of these was P3C with a *Total Road Value* of 11,760 (see Appendix H). This road also had the highest *Road Index Total* (due to poor road surface, missing ditches, and missing water diversions), and a high *Road Segment Average*, indicating a high potential for phosphorus loading. The second worst road was O5. This road badly needed ditches, culverts, and water diversions, and had a substantial *Road Segment Average* score. S23 was the third worst road. This road had a poor surface, needed some ditches, and had a relatively high *Road Segment Average*. P6C scored a high *Total Road Value* due to a poor road surface, missing ditches, culverts, and water diversions, and a relatively high *Road Segment Average*. S30 had an unacceptable road surface, poor ditches and culverts, and a moderately high *Road Segment Average*. P6B had a poor ditch score, although the rest of the road condition was acceptable. This road had a very high *Road Segment Average*, having an effect on the *Total Road Value*. The last three roads, P6, B6, and SF9 all had unacceptable road surfaces, and needed ditches. See Appendix H for individual scores for all of the roads surveyed.

In general, the Messalonskee Lake watershed was found to have roads in better condition than some of the nearby watersheds. For example, the North Pond watershed was reported to have approximately fifty percent of their roads in class one and class two of the road total index values, compared with 82% in classes one and two in the Messalonskee watershed (BI493 1997). The

Salmon Lake watershed had twenty percent of their roads in the "three hundred plus" category (BI493 1994), compared with twenty-two percent of roads in the North Pond watershed (BI493 1997), and only five percent in the Messalonskee Lake watershed.

As demonstrated, roads can have a significant impact on the amount of phosphorus entering the lake, and therefore the water quality of Messalonskee Lake. This is why it is so important to keep roads, especially camp roads, well maintained and why new roads should be properly constructed. The majority of the roads that were in poor condition were seasonal roads, which may be why they are not maintained regularly. Major repair on roads (such as structural repair) can be very costly, but general monitoring may be more realistic.

GIS Methodology

Geographic Information System (GIS) is a computer based system used to analyze the characteristics of a specific geographic region. A data layer is composed of uniformly sized grid cells which are assigned numerical values that corresponds to geographic characteristics. A series of data layers, each dealing with specific characteristics, may be mathematically manipulated and then superimposed; new information becomes apparent when two characteristics are shown to coexist in a specific area. For example, a "soil type" data layer and a "slope" data layer may be superimposed to indicate areas of steep slope and highly erodible soils, suggesting a poor site for development.

Each data layer was referenced geographically to an appropriately scaled culture and drainage map. This was achieved by digitally scanning a culture and drainage map from the United States Geologic Survey (USGS) and assigning a specific number of columns and rows to the data layer so that they exactly matched the size of the scanned map image (Folder on back cover). In this study, each cell represented a 10 m^2 area. This particular size was used in order to achieve a high level of detail while maintaining manageable file sizes.

MacGIS 3.0, developed by Kit Larsen and David Hulse, was the program used to create all the data layers. The program was designed to allow for the mathematical manipulation and grouping of data to produce new useful information. The culture and drainage map served as the base for all subsequent maps. In this study, data layers were produced for soil type, land use, and elevation by manually entering the data, while forestry suitability, septic system limitations and erodibility were created by overlaying multiple data layers.

Soil Types

An understanding of soils is essential in order to determine suitable locations for development within a watershed. All recommendations regarding development are ultimately based on soil composition specific to individual circumstances such as slope and elevation. General suggestions can only be offered about development based on general soil characteristics. When planning to develop a plot of land it is necessary to examine sites on a case by case basis.

Methods

Twenty-seven different soil types are distinguished by the Kennebec County Maine USDA Soil Conservation Service in the Messalonskee Lake watershed (Table 9). These twenty-seven soil types were grouped into eight soil categories according to similarities in texture, hydric status, water table status, permeability, erodibility, and depth to bedrock (USDA 1978). These characteristics were chosen because of their direct relevance to different aspects of development and potential phosphorus loading. It is important to note that slope was not considered in these classifications. Slope is an important factor and will be discussed later, in conjunction with erodibility and septic suitability (see Developmental Implication of Land Characteristics: Erodibility; Methods).

Texture is a physical description of the particle size distribution of the soil that is important with respect to the permeability of soil to water and affinity for binding phosphorus molecules. Smaller particles, such as clay, are tightly packed and allow low permeability but high binding of phosphorus. Low permeability allows large amounts of polluted surface runoff to enter the lake. Conversely, large particles such as gravel, allow high permeability but low binding of phosphorus. In this case, leaching is uninhibited and phosphorus can contaminate ground water or pollute the lake through subsurface flow (Krall, pers. comm.). An ideal soil has a moderate permeability that allows phosphorus to come into contact with a large number of medium-sized soil particles, such as silt or fine sand. This not only allows for the binding of a large amount of phosphorus, it also gives microorganisms enough time to break down septic waste leaching through the soil (Christensen, pers. comm.).

Textures are described by particle size. The size categories, in terms of increasing particle size, are clay, silt, sand, and gravel (USDA 1990). Loam is a mixture of clay, silt, and sand found in varying concentrations throughout the watershed. Peat is strictly a marsh soil and is comprised of loosely aggregated decomposing organic matter.

Hydric soils are saturated with water year round, and have permanently high water tables. Because these soils exists in flooded lowlands, they are highly unsuitable for development. Some non-hydric soils become saturated on a seasonal basis, and can cause seasonal soil saturation and poor drainage. This can occur in the spring, and are caused by melting frost and spring precipitation. Soils with seasonal water tables pose a great barrier to proper septic drainage because they behave similar to the hydric marsh soils (see Developmental Implications of Land Characteristics: Septic Suitability; Methods). There are two types of seasonal water tables. Apparent water tables are due to an influx of water that compounds an already relatively high water table. This problem can be solved by building up the leach field to allow proper drainage of waste (15 inches for shoreline areas and 13 inches for

Table 9. Characteristics used for soil associations in the Messalonskee Lake watershed (USDA 1978). A higher K-factor indicates a higher level of erodibility.

Soil	Texture	Hydric Y/N	Seasonal Watertable	Permeability	Erodibility (K-Factor)	Depth to Bedrock (inches)
Berkshire	very stony fine sandy loam	N	N/A	MR-M	0.20-0.32	< 60
Berkshire	fine sandy loam	N	N/A	MR-M	0.20-0.32	< 60
Scio	very fine sandy loam	N	perched	M-MS	0.49-0.64	< 60
Hartland	very fine sandy loam	N	N/A	M-MS	0.49-0.64	< 60
Hinckley	gravely sandy loam	N	N/A	VR-R	0.17	< 60
Windsor	loamy sand	N	N/A	VR-R	0.17	< 60
Deerfield	loamy fine sand	N	apparent	VR-R	0.17	< 60
Lyman	loam	N	N/A	MR-M	0.20-0.32	10.0-20.0
Hollis	fine sandy loam	N	N/A	MR	0.20-0.32	10.0-20.0
Hollis	rock outcrop complex	N	N/A	MR	0.20-0.32	10.0-20.0
Ridgebury	fine sandy loam	Y	perched	MS-S	0.24-0.32	< 60
Ridgebury	very stony fine sandy loam	Y	perched	MS-S	0.24-0.32	< 60
Peru	fine sandy loam	N	perched	MS-S	0.20-0.32	< 60
Peru	very stony fine sandy loam	N	perched	MS-S	0.20-0.32	< 60
Woodbridge	fine sandy loam	N	perched	MS-S	0.20-0.32	< 60
Woodbridge	very stony fine sandy loam	N	perched	MS-S	0.20-0.32	< 60
Paxton	fine sandy loam	N	perched	MS-S	0.20-0.32	< 60
Paxton	very stony fine sandy loam	N	perched	MS-S	0.20-0.32	< 60
Rifle	mucky peat	Y	apparent	Marsh	< 0.10	< 60
Togus	fibrous peat	Y	apparent	Marsh	< 0.10	< 60
Vassalboro	fibrous peat	Y	apparent	Marsh	< 0.10	< 60
Biddeford	mucky peat	Y	apparent	S-VS	0.32-0.49	< 60
Buxton	silt loam	N	perched	S-VS	0.32-0.49	< 60
Scantic	silt loam	Y	perched	S-VS	0.32-0.49	< 60
Scarboro	mucky peat	Y	apparent	VR-R	0.17	< 60
Paxton-Charlton	fine sandy loam	N	perched N/A	MS-S/MR-M	0.20-0.32	< 60
Paxton-Charlton	very stony fine sandy loam	N	perched N/A	MS-S/MR-M	0.20-0.32	< 60

nonshoreline areas) (Martin, B., pers. comm.). Perched water tables are due to an impervious layer of soil found below the soil surface that hinders proper drainage. This impervious layer is called a fragipan layer, and is found in some glacial till soils (USDA 1990). If the fragipan layer is closer than 15 inches to the soil surface, the site is unsuitable for septic drainage. To avoid problems, the proposed leach field can be moved to a more suitable site, or, if suitable soil exists below the fragipan layer, the drainage pipe can actually be placed under the layer and the waste deposited there (Martin, B., pers. comm.).

Bedrock found below the soil surface can act in a similar manner to the fragipan layer. The difference is that a site with a shallow depth to bedrock cannot be manipulated fairly inexpensively the way a site with a perched water table can (USDA 1990). The only soil that has less than 60 in to bedrock is the Lyman/Hollis series (10.0 in to 20.0 in). These soils are not recommended for development because the bedrock contributes to a great deal of subsurface runoff that can ultimately pollute the lake (Krall, pers. comm.).

Erodibility is described by K-factor. This is a measurement of the cohesiveness of soil particles (the smaller the particles, the tighter they are packed) (USDA 1978). A positive correlation exists between K-factor and overall erodibility of a soil. Recommendations for development can only be made when slope is taken into account along with K-factor (see Developmental Implication of Land Characteristics: Erodibility; Methods).

Results and Discussion

The marsh soils comprise 15% of the watershed. The hydric status of a soil receives greater weight than the other factors when determining sites suitable for development. This is the rationale behind grouping Scantic and Scarboro with the true marsh soils (Rifle, Togus, Vassalboro, and Biddeford). The Buxton soil was also placed here on the basis of geographic proximity to the marsh and its small area, relative to the entire watershed. Although hydric, the Ridgebury series was categorized separate from the marsh soils because it is found predominately in the northeast quadrant of the watershed, while the marsh occurs largely at the southern end of Messalonskee Lake. The Ridgebury series has ideal permeability and good erodibility. Plots with these soils, more than any other, must be site visited and evaluated for septic suitability (Krall, pers. comm.).

The Peru/Woodbridge/Paxton soils comprise 36% of the watershed; the Paxton-Charlton soils (simply a mixture of Paxton and Charlton soils) comprise 14% of the watershed; the Lyman/Hollis soils comprise 13% of the watershed; the Ridgebury soils comprise 10% of the watershed; the Hinckley/Windsor/Deerfield soils comprise 6% of the watershed; the Scio/Hartland soils comprise 4% of the watershed; and finally, the Berkshire soils comprise 3% of the watershed. These soils were grouped according to the aforementioned soil characteristics. The only discrepancies, other than in the marsh soils, occur in the Scio/Hartland association and in the Hinckley/Windsor/Deerfield association. The Scio and Deerfield soils have seasonal watertables yet are grouped with soils that do not. All other characteristics are identical in the two associations. Very high K-factors set the Scio and Hartland soils apart, and very rapid permeabilities and very low K-factors set the Hinckley/Windsor/Deerfield soils apart

Most of the shoreline is occupied by either Peru/Woodbridge/Paxton or Paxton-Charlton soils (Figure 52). Both these soil associations have perched water tables that can potentially be overcome by methods described above. If septic systems are designed correctly, the shoreline area appears to be in very good condition for development. Nonshoreline soils, in general, are well suited for septic

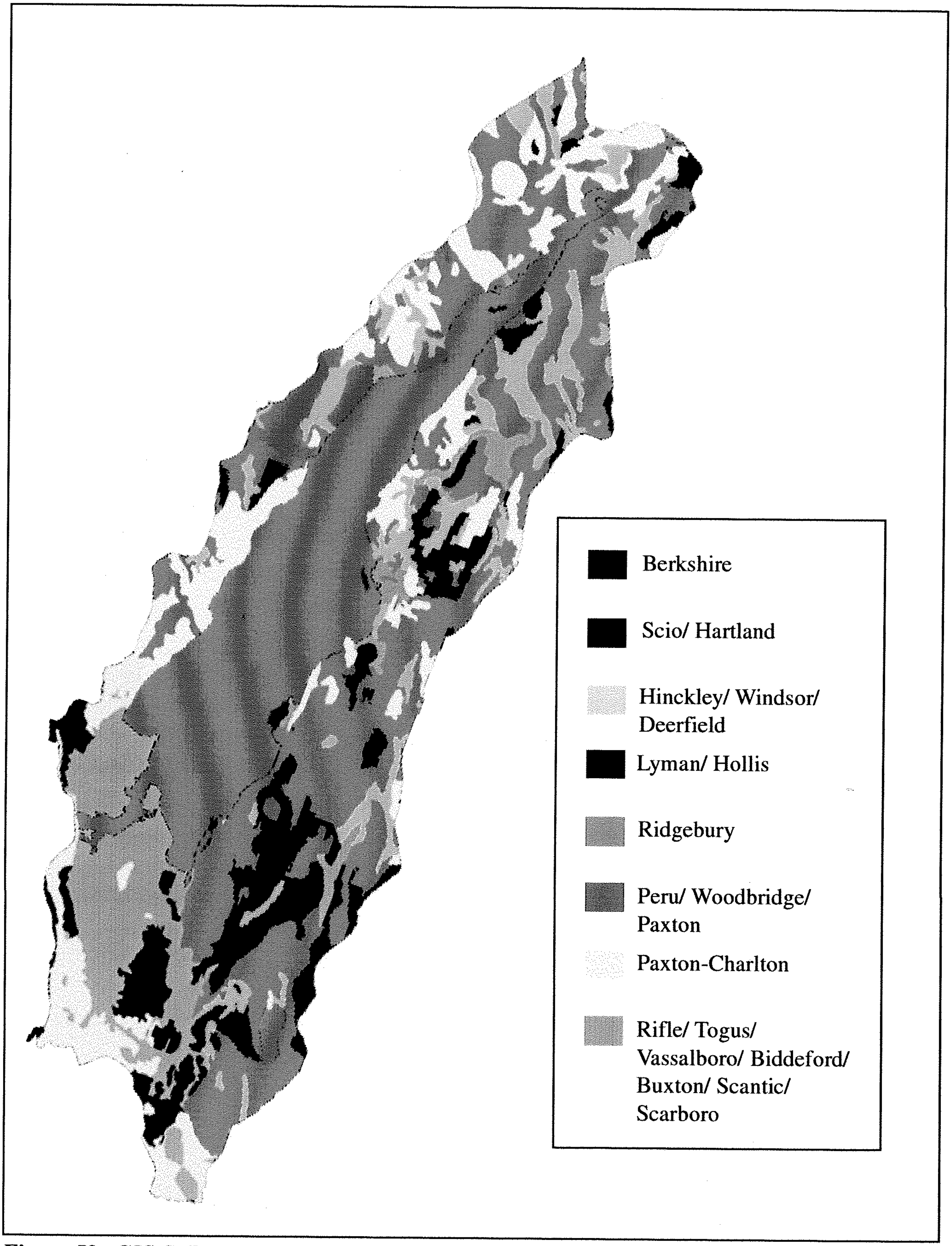

Figure 52. GIS-Soil map of the Messalonskee Lake watershed (USDA 1978). Approx. scale: 3/4 in = 1 mi.

development (slope not taken into account). Most of the soil is again Peru/Woodbridge/Paxton or Paxton/Charlton.

These soil classifications identify limitations to development associated with each soil group. The Berkshires are ideal soils for septic development (slope not taken into account) because they have no limiting factor. All other soils have at least one major problem which limits suitability for septic system construction (see Developmental Implications of Land Characteristics: Septic Suitability; Methods). These limiting factors should be taken into consideration when planning to develop a plot of land. Case by case inspection of plots should be carried out prior to development due to the large number of variables involved in defining appropriate sites.

Developmental Implications of Land Characteristics

Erodibility

Methods

Flowing water is the primary agent of erosion, resulting in sedimentation. If sediments and the nutrients they carry are not stopped by buffers, they may contaminate lakes. Sedimentation has a variety of adverse affects on water quality. Sediment carries pollutants and nutrients such as phosphates into water bodies, stimulates algal blooms, and accelerates the process of eutrophication (Novotny and Olem 1994).

Development activities such as logging, agriculture, and construction developments all contribute to soil erosion and sedimentation of water courses, which ultimately leads to degradation of water quality (Novotny and Olem 1994; see Background: Nutrient Loading). Erosion is a natural process and soil loss at some rates is tolerable (USDA 1989). Development and human activities often clear vegetation from the land, which increases the potential for erosion. It is important to understand where erodibility potentials are high in order to reduce the impact of development on sedimentation.

Erodibility is the ease with which materials are carried away during erosion (Novotny and Olem 1994). Several factors contribute to soil erodibility: particle size, water content, composition and texture, the presence or absence of protective surface cover such as vegetation, and degree of slope and length of slope (Novotny and Olem 1994). Soil types were grouped based on particle type, permeability, soil erodibility factor (K-factor), depth to bedrock, and water table information (see Soil Types: Methods). To determine the erodibility of areas within the watershed, the erodibility factor of each soil type was combined with the slope on which it was found.

The K-factor is a measure of potential soil erodibility, with values ranging from zero to one. Zero represents soils that are nonerodible and one represents soils that are severely erodible. The values are based on rates of rainfall erosion of soils on a 9% slope (Novotny and Olem 1994). K-factors alone are not sufficient to determine the true value of soil erodibility because steeper slopes increase the velocity of water flowing downslope, thereby increasing the erosion potential (Novotny and Olem 1994). Slope needed to be included into the criteria used to classify soils as severely, highly, moderately, or slightly erodible.

A slope data layer was created by differentiating elevation data (i.e., average difference in elevation values between adjacent grid cells) from USGS topographic maps for the area (Vassalboro, Belgrade, Readfield, Waterville, and Rome 7.5 minute Quadrangles). Both K-factor and percent slopes were taken into account to classify soils as slightly, moderately, highly, or severely erodible (Table 10). An erodibility composite map of the Messalonskee Lake watershed was created by combining criteria from the slopes data layer and soils data layer (Figure 53).

Results and Discussion

Particular locations within the Messalonskee Lake watershed that could be susceptible to rate of erosion above tolerable levels were determined through use of the GIS erodibility map (Figure 53). Slightly and moderately erodible soils were found throughout much of the watershed. Slightly erodible soils were found predominantly in the marsh areas and on minor slopes. Moderately erodible soils were found along the shoreline of Messalonskee Lake and on many slopes throughout the watershed. Only a small percentage of the watershed was made of soils that had erosion potentials that exceeded tolerable levels of erosion, yet these soils pose the greatest threat to phosphorus loading in Messalonskee Lake (USDA 1989). Many patches of highly and severely erodible soils were found in the southern area of the watershed. When these soils are found on hillsides sloping down to the lake there is a potential for large amounts of sediments and phosphorus to enter the lake, thereby

Table 10. The level of erodibility as determined by K-factor and percent slope.

K-factor	0-3%	4-8%	9-15%	16-30%	>30%
0.17	slight	slight	moderate	high	high
0.20	slight	moderate	moderate	high	high
0.24	slight	moderate	high	high	severe
0.32[a]	slight	moderate	- -	- -	- -
0.49	moderate	moderate	high	severe	severe

[a] The true marsh soils are only slightly erodible (K-factor <0.10) and are not found on slopes greater than 3%. The Biddeford, Buxton, and Scantic soils had been grouped with the true marsh soils, however they have a K-factor of 0.32 to 0.49 and are found on slopes of 4% to 8% (see Soil Methodology). Since slope affects erodibility these soils were isolated from the true marsh soils when the erodibility map was made.

accelerating the processes of eutrophication. It is important to know where these problem areas are located in order to reduce the contribution of human activities to phosphorus loading.

Slightly erodible soils constituted approximately 56% of the watershed land area. Much of this soil was found in marsh land or areas with low percent slope. Development may be suitable in these areas, excluding the marsh lands. Although development will, most likely, increase erosion in those

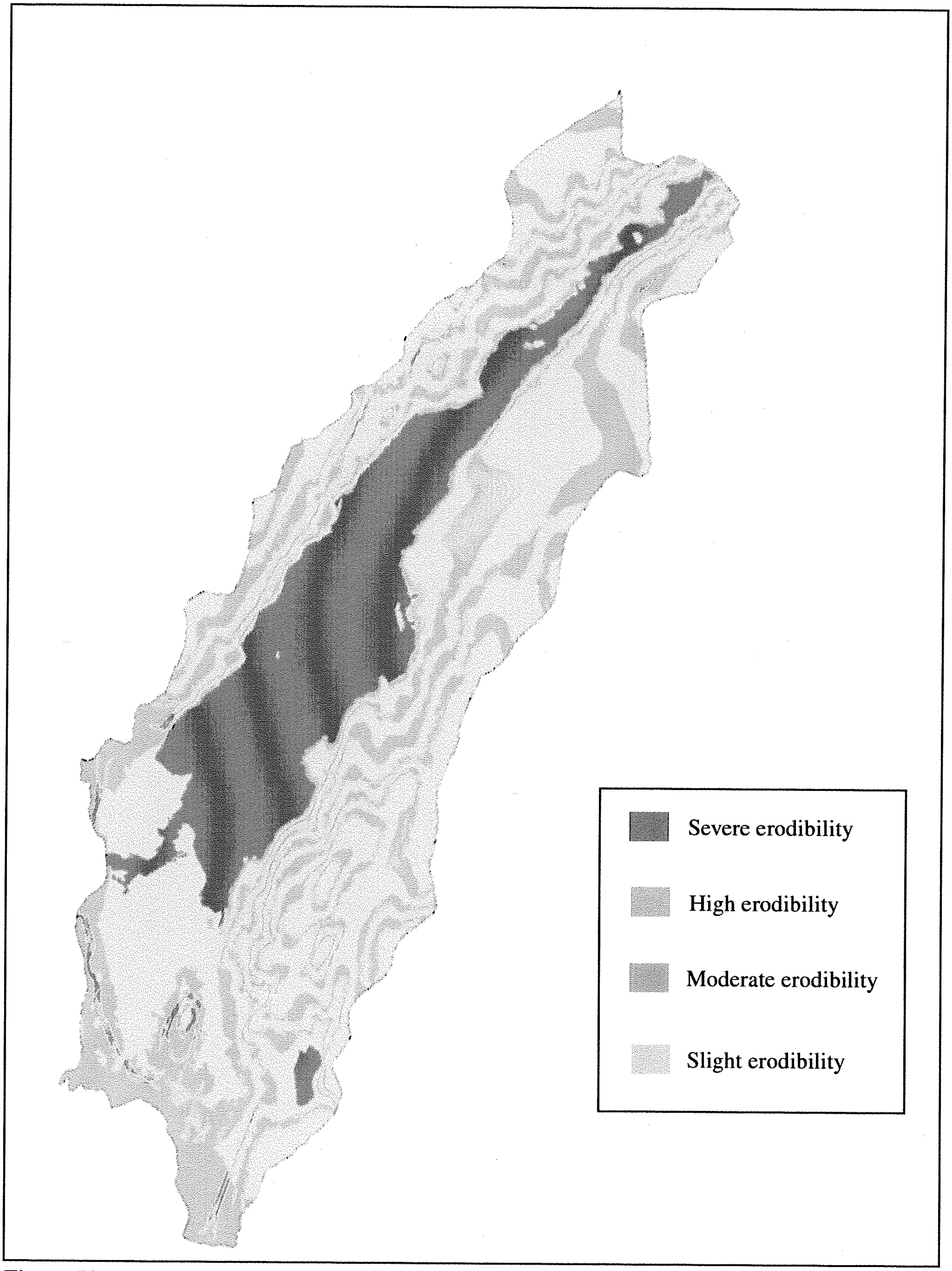

Figure 53. GIS-Soil erodibility in the Messalonskee Lake watershed. Approx. scale: 3/4 in = 1 mile.

areas, the rate at which it occurs will still be lower than if development were to occur in areas that experience higher erosion rates.

Approximately 34.5% of the Messalonskee Lake watershed was found to consist of moderately erodible soils. Much of the shoreline of the lake was lined with moderately erodible soils. Many roads and residences have been developed along the shoreline, yet until the early 1990s there were no shoreline zoning ordinances requiring homes to maintain 75 ft buffers to prevent sedimentation (see Watershed Residential Areas Zoning: Shoreline). Without adequate buffers along the shoreline these moderately erodible soils may experience high degrees of erosion, thereby resulting in sedimentation and nutrient loading directly into the lake.

Highly erodible soils made up 8.8% of the watershed land area and were found scattered throughout the watershed. Particular areas of interest were located on the southeast shoreline of Messalonskee Lake north of Chowder Ledge and south of Star Point. The hills in this part of the watershed rise over 300 ft in less than a mile. These long, steep slopes serve to increase the water velocity potential of runoff, thus increasing the erosion potential. This combination of highly erodible soils and long, steep slopes could potentially contribute a great deal of sedimentation to the lake. Furthermore, the development to the north of Chowder Ledge, could contribute to erodibility and sedimentation problems. Also found in this area, were many roads that went straight down the hill, which further increases water velocity and erosion potential.

Another area of high erodibility was found on the western shore of Messalonskee Lake, north of Greeley Island. The proximity of these highly erodible soils to the lake may have made this site a large contributor to sedimentation and nutrient loading. Also, on the northeastern shoreline, near Brown Island, were high levels of shoreline development. The numerous roads here need to be regularly maintained to prevent gullying and sedimentation into Messalonskee Lake (see Land Use: Roads). The eastern shoreline of Ward Pond was bordered with highly erodible soils. This sub-watershed flows into Messalonskee Lake. The effects of erosion and sedimentation in Ward Pond contributed to the eutrophication process in the main watershed.

Only 0.4% of the soils in Messalonskee Lake were found to be severely erodible. The southwest corner of the watershed contained the highest concentration of these soils. The Lyman/Hollis (0.20 K-factor to 0.32 K-factor) and Scio/Hartland (0.49 K-factor to 0.64 K-factor) soils near Mills Road were found on steep slopes. Where the slopes were steepest the soils were classified as severely erodible. The eastern slope of the hill runs down to Mills Creek. The creek cuts through the Belgrade Bog which may absorb some of the nutrients in the sediments washed off the hillside.

The other patches of severely erodible soils were found in the southwestern boundary of the watershed near several gravel pits, which would contribute to erodibility problems. Both of these areas drain into the marsh. Because the marsh vegetation absorbs nutrients, the potential impact from erosion on the lake water quality is reduced (see Background: Nutrient Loading and Land Use: Wetlands).

Another area of severe erodibility was north of Belgrade Stream, near the town of Belgrade. Here the Hinkley/Windsor/Deerfield (0.17 K-factor) soils and steep slopes could potentially contribute many sediments to the lake because of a high level of development and proximity to Belgrade Stream. The nearby marsh acts as a buffer, but the combination of severely erodible soils and high levels of development may result in a rapid rate of soil loss and the associated nutrient loading into Messalonskee Lake.

On the western shore of the Messalonskee Lake, just north of the marsh, there was another patch of severely erodible soil. This area could be a large contributor to phosphorus loading in the lake because of the proximity of these long, steep slopes to the lake as well as the presence of railroad tracks. In the northern portion of the watershed, there were a few more small patches of severely erodible soil that were found on steep slopes (Figure 53).

Septic Suitability

Methods

The septic suitability data layer denotes the major septic limitations for each area of the Messalonskee Lake watershed (Figure 54). It was created by grouping the soil associations in the soil type data layer (Figure 52). Prior to grouping, however, the soil type data layer had to be modified because the Scio-Hartland association fit into two septic suitability categories (see Soil Types).

The use of septic systems may be limited by any combination of the factors listed below, however, in each case, one factor, in particular, may be responsible for the majority of the septic limitation (USDA 1978). It was by this more prominent factor that the associations were grouped. For example, although the Ridgebury soils have very low permeabilities, they are also hydric and therefore, were associated with the hydric group because hydric status was more limiting.

Septic suitability is limited in hydric soils, which are soils that are permanently inundated in water, because the high water table would result in direct contamination of the groundwater by sewage. Septic suitability may also be limited by seasonally high water tables. During the spring, apparent and perched water tables may develop and result in similar conditions to those found in hydric soils (Krall, pers. comm.; see Soil Methodology).

A shallow depth to the bedrock may cause artificially high water tables and may also preclude a sufficiently deep leach field. Furthermore, during periods of high precipitation, shallow bedrock may substantially increase subsurface runoff (see Soil Types: Methods). It is possible to build septic systems on soils that have a limiting layer (e.g. bedrock, high watertable or fragipan) found at depths greater than 15 in (USDA 1989). It is strongly recommended, however, that at least 2 ft of depth exist

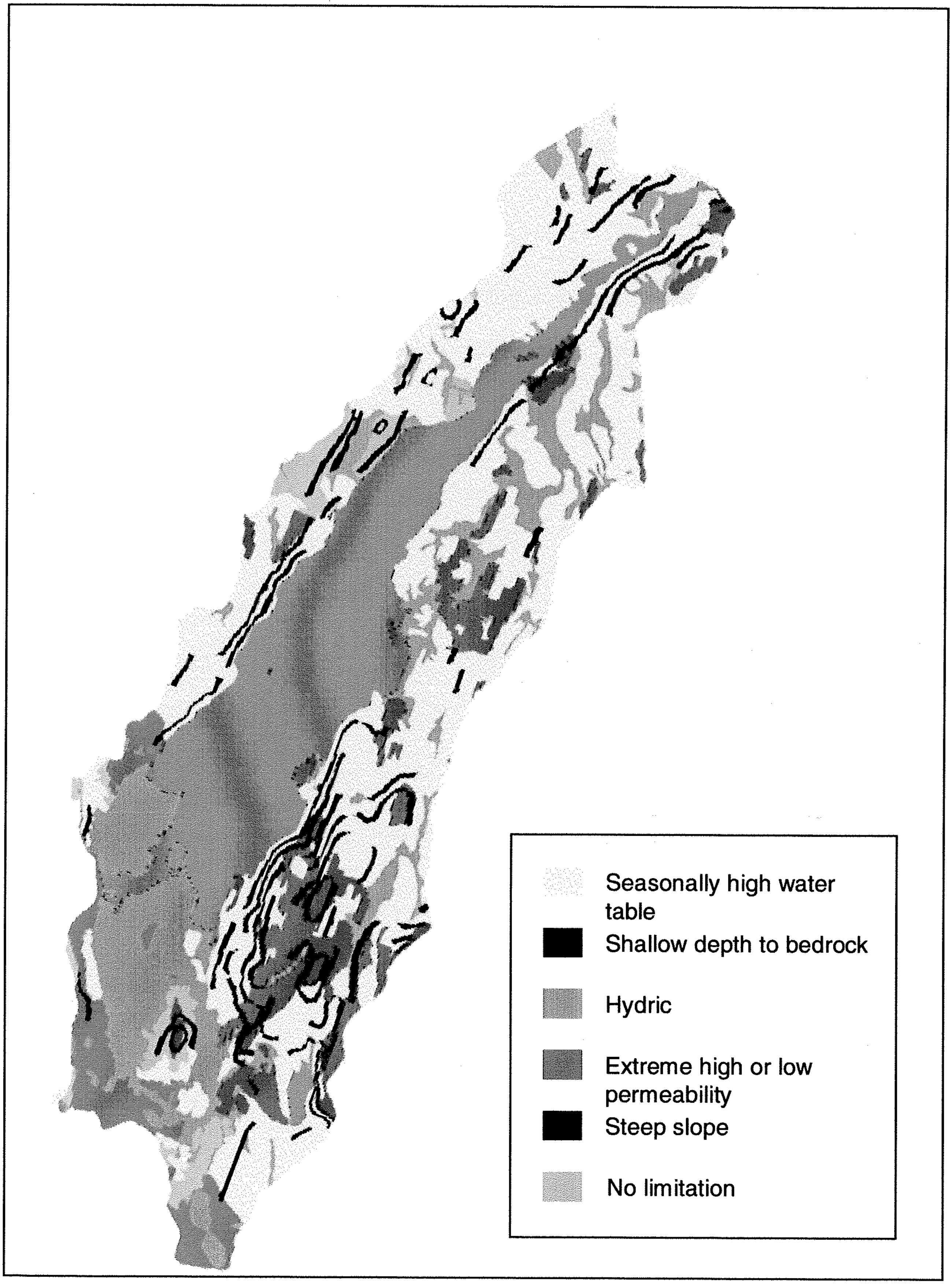

Figure 54. GIS-Primary factors limiting septic suitability in the Messalonskee Lake watershed. Approx. scale: 3/4 in = 1 mi.

between the soil surface and a limiting layer (Krall, pers. comm.).

Both low and high permeability may limit septic suitability. Very low permeability may increase runoff and prevent effluent from properly diffusing into the leach field. Conversely, very rapid permeability may allow effluent to move through the soils before the organic waste is sufficiently decomposed. As a result, the waste water may pollute groundwater (USDA 1978; see Soil Types: Methods).

The installation and use of septic systems in soils located on steep slopes is extremely dangerous. Steep slopes may cause lateral seepage, downslope flow of effluent and erosion (USDA 1978). In this study, any area located on a slope greater than 15% was considered unsuitable for the installation and use of a septic system.

The hydric soils were comprised of the Rifle, Togus, Vassalboro, Biddeford, Buxton, Scantic, Scarboro and Ridgebury soils. The soils most limited by seasonally high watertables were the Scio, Peru, Woodbridge, Paxton and Paxton-Charlton soils. Soils that limit septic suitability because of permeability were Hinkley, Windsor, Deerfield. The soils limited by a shallow depth to the bedrock were the Lyman and Hollis soils. The only soils considered to be suitable for maintaining a septic system, without making special modifications to the system or the installation of the system, were Berkshire and Hartland.

Results and Discussion

A soil that is not limited for the installation and efficient use of a modified septic system should have certain moderating characteristics. It should not be hydric and should not have a seasonal water table, although, it should be moderately permeable and have at least 15 inches of depth to the underlying bedrock (see Soil Types: Methods). Finally, the soil should have a low K-factor and be found in an area having less than a 15% slope to avoid erosion. These final two factors must be considered jointly as they are inversely related.

The predominant factor limiting septic suitability of the land within the Messalonskee Lake watershed was a seasonal water table. Most of the shoreline soils were limited by a seasonal water table. Some of the shoreline soils however, were hydric while smaller sections of the shoreline were limited by extreme permeability or a shallow depth to the bedrock. Scattered regions of the watershed also had a very steep slope, making the use of any septic system very dangerous. A majority of the soils were limited because of seasonal watertables, however, these limitations do not preclude the possibility for development. Many shoreline residences are seasonal. Thus, the period during which the septic system is in use may not coincide with the period when watertables are high. Those residences in which the septic systems are used during the seasons with high watertables should consider adaptations that may be made to the septic system. Different adaptations exist depending on whether there is a perched or apparent watertable.

The soils that were found to have a shallow depth to the bedrock may not be able to provide sections large enough to maintain septic systems. Soils with shallow bedrock as well as soils with seasonally high water tables may still be used in some cases, if proper adaptations are made. One such adaptation is to elevate the soil surface level by layering with new soil. This will provide a deeper leach field for the septic system.

Soils with rapid permeability may pollute the ground water; in the case of the Messalonskee Lake watershed, most of the soils that fell into this category were fine grain loamy sands, which retain more phosphorus than other soils with larger particles. Nevertheless, adaptations should be made to the septic system in order to allow the organic waste to sufficiently decompose. One such adaptation to a septic system may be to install a larger leach field (see Soil Types: Methods).

The regions with a slope greater than 15% are not recommended as suitable sites for septic system installation. Adjusting a septic system to account for steep slopes is extremely expensive. Furthermore, slopes of 15% or greater are likely to result in a great deal of erosion even when K-factor is low (see Erodibility: Methods).

Unless septic systems are built with special adaptations for the soils where they are located, they may cause extreme damage to the surrounding soils and water. In most cases, multiple options for dealing with septic limitations exist. It is important, however, to study each building site on a case by case basis since multiple limitations may exist and require simultaneous consideration before a septic system may be installed.

Land Use Suitability

Methods

A GIS map of the various types of land use in the Messalonskee Lake watershed was created to show where different land uses occur in the watershed (Figure 55). Land use types that had been defined and marked on aerial photographs of the watershed were digitized using a map of the watershed as a background template (see Land Use: Land Use Methodology). This map was combined, mathematically, with the erodibility data layer to create the forestry suitability map (Figure 56). A third GIS map, related to land use was created of development corridors in the watershed (Figure 57). Development corridors are defined as the area 300 ft on either side of each road (paved and gravel) in the watershed. The roads were traced from USGS maps from the 1980s.

Results and Discussion

Residential development, which occurs throughout the watershed, can contribute to lake pollution via household chemicals, septic systems, and the impervious surfaces of roads, driveways, lawns and roofs (impermeable surfaces allow contaminated runoff to proceed toward the lake). Special care should be taken when residential development occurs near the shoreline because of the

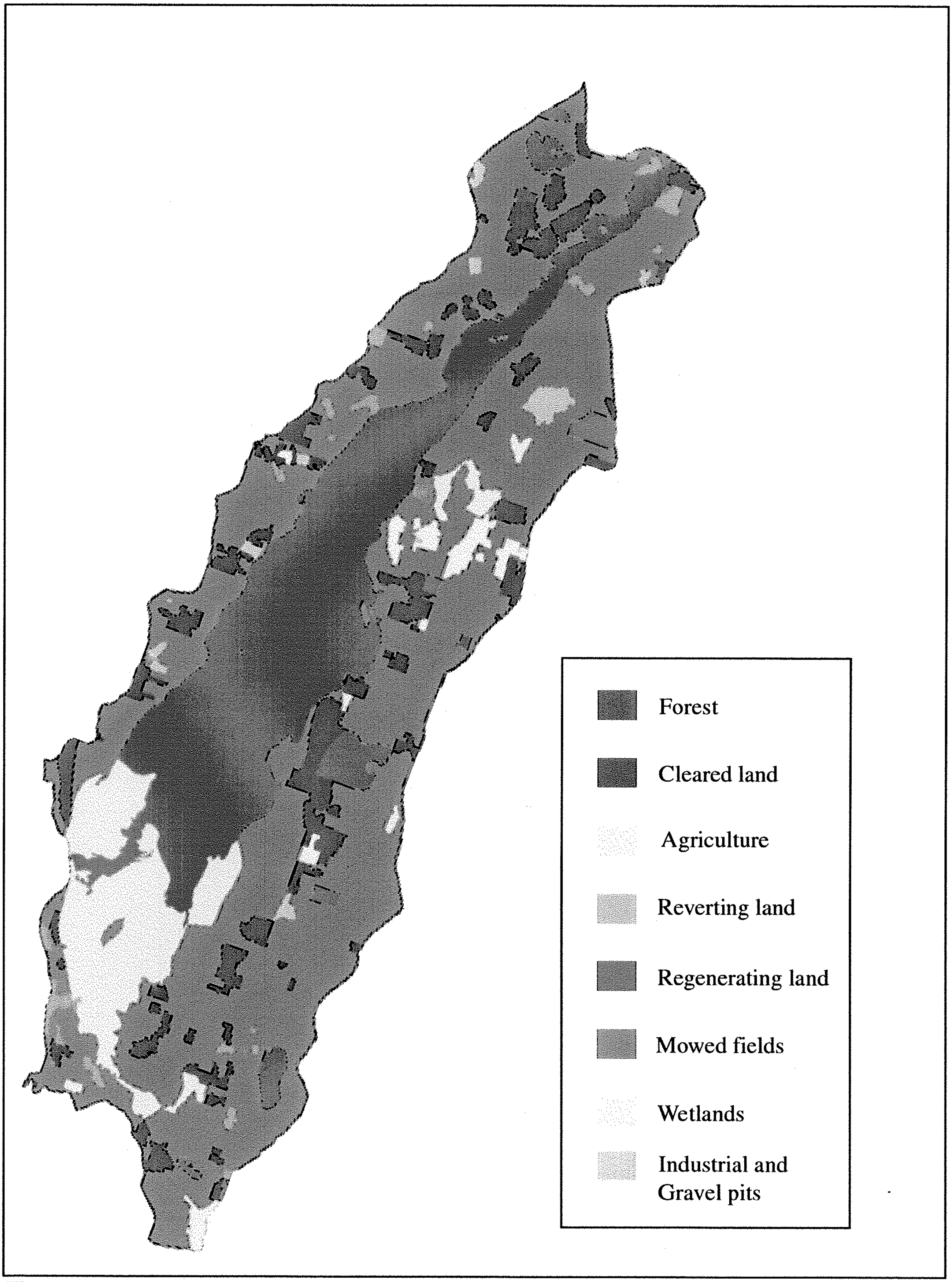

Figure 55. GIS-Land use types in the Messalonskee Lake watershed.
Approx. scale: 3/4 in=1 mile.

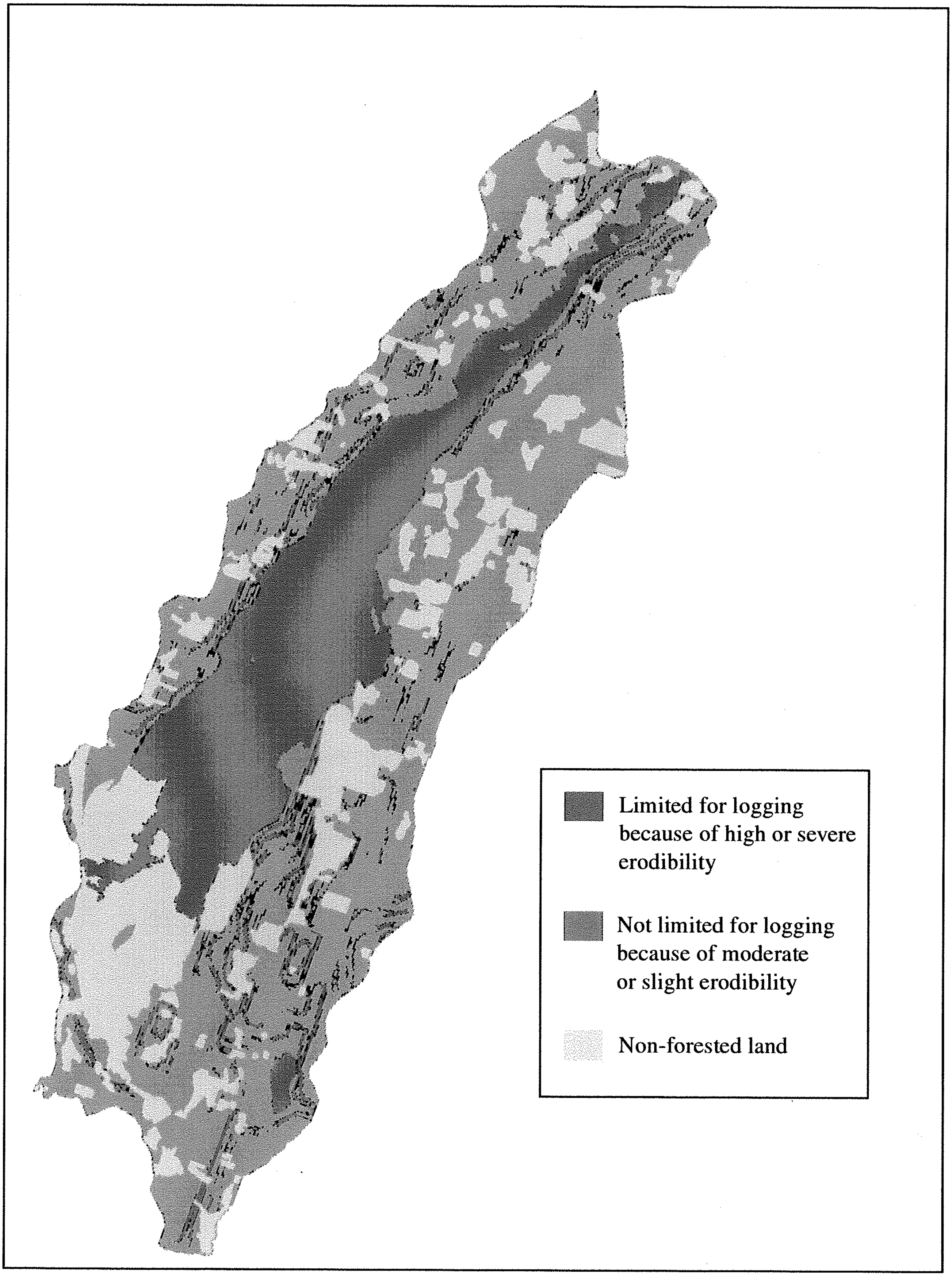

Figure 56. GIS-Logging suitability in the Messalonskee Lake watershed. Approx. scale: 3/4 in=1 mile.

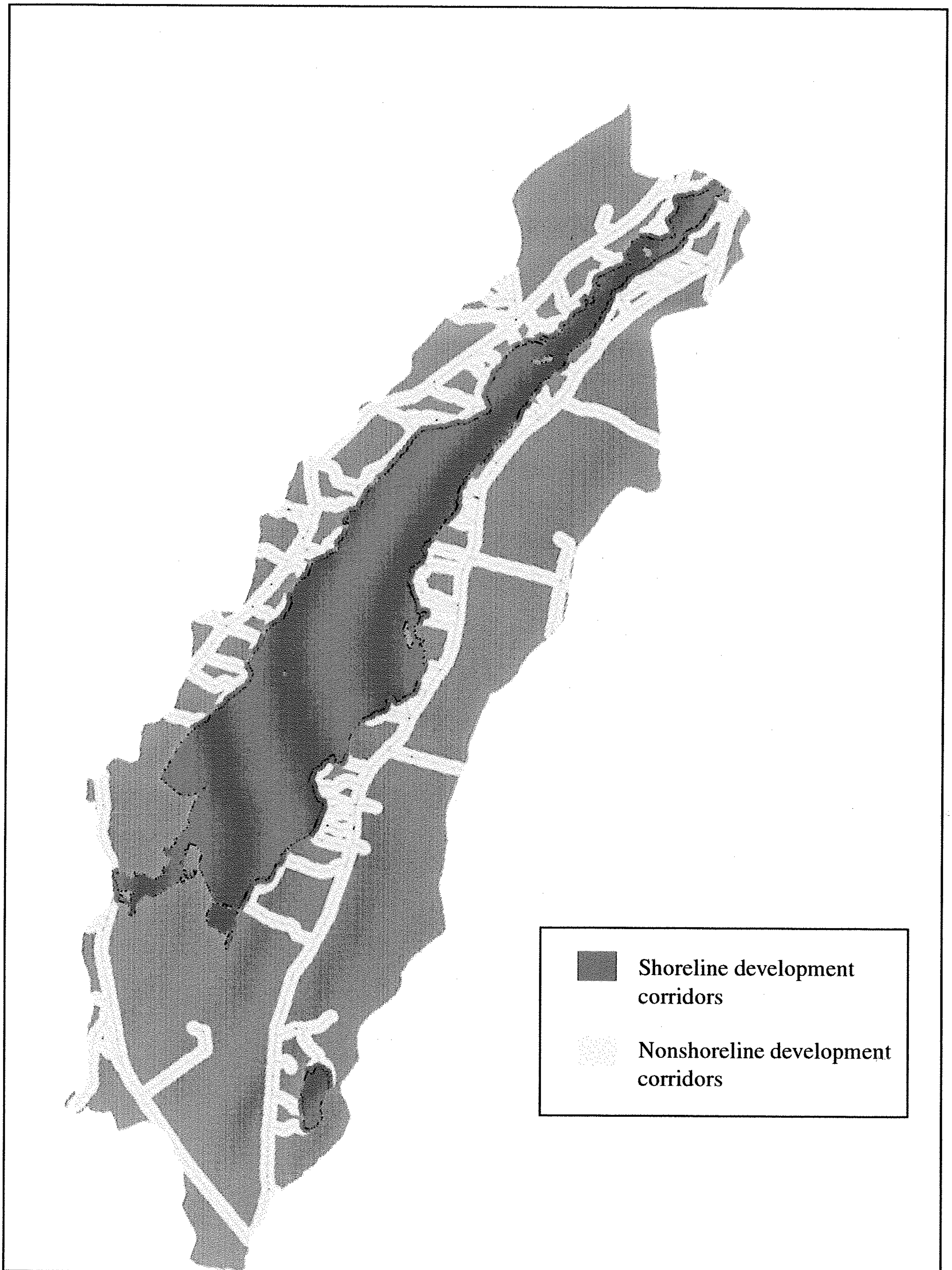

Figure 57. GIS-Development corridors in the Messalonskee Lake watershed (USGS Culture and Drainage maps: Belgrade, Readfield, Rome, Vassalboro, Waterville quadrangles). Approx. scale: 3/4 in = 1 mi.

close proximity to the lake. Along the shoreline, even more caution and preventative measures should be taken where the slope and/or soil type of the area contribute to high erodibility (Figure 53).

Residential development is most likely to occur or to have occurred in development corridors. Development corridors were chosen as 300 ft on either side of the roads because that is the distance from a road that Central Maine Power will extend residential power lines without an extra charge (BI493 1997). It is assumed that most residences will be or have been built within this area. Most of the shoreline has been developed already (Table 6) and nonshoreline development is most likely to proceed in the development corridors.

Agricultural land use can occur in much of the watershed and specific areas will be better suited to specific types of agriculture, depending largely on soil characteristics, as described in the Kennebec County Soil Survey capability classifications (USDA 1978). Generally, row crops (which require a plowed field) cannot be grown on slopes greater than 15% (Christensen, pers. comm.). Livestock would be best in flatter areas, away from the lake. Animal hooves can easily erode steep slopes and compact soil into a hard, impermeable surface. These characteristics allow phosphorus from manure and soil particles to wash toward the lake. As is the case with residential development, all types of agriculture should be practiced with extra care near the shoreline of Messalonskee Lake (see Background: Watershed Land Use: Agriculture and Livestock).

Logging may be a viable option on steeper slopes where plowed-field crops cannot be grown. Again, caution should be taken in the locating of logged areas within the watershed. Since the effects of compaction from heavy machinery and erosion are exacerbated by the loss of vegetation, logged areas should not occur on soils that are highly or severely erodible (Figure 56). The areas limited for logging in the Messalonskee Lake watershed are all narrow bands of very steep slopes, which would need to be evaluated on a case-by-case basis. Selective harvesting is environmentally preferable to clearcutting since vegetation is left to impede the path of contaminated water toward the lake (see Background: Watershed Land Use: Forestry).

Regardless of the type of development that occurs in the watershed, caution should be taken in the planning and use of the land, especially if it is close to the lake or a tributary.

PHOSPHORUS LOADING

Introduction

A model for total phosphorus loading is an important tool used to apportion the phosphorus load among different contributing sources as well as to identify problem sources of heavy phosphorus loading in the watershed (Reckhow and Chapra 1983). The model can also be used to predict consequences of residential and industrial development, or changes in distribution of land use type areas (see Future Trends: Factors Influencing Phosphorus Loading).

Methods

A model for total phosphorus loading in Messalonskee Lake was adapted from Reckhow and Chapra (1983) which approximates the total amount of phosphorus entering the lake from the atmosphere, point sources, and nonpoint sources (see Appendix F):

$$\mathbf{W} = (Ec_a \times As) + (Ec_f \times Area_f) + (Ec_{rf} \times Area_{rf}) + (Ec_{rl} \times Area_{rl}) + (Ec_w \times Area_w) + (Ec_c \times Area_c) + (Ec_r \times Area_r) + (Ec_s \times Area_s) + (Ec_n \times Area_n) + [(Ec_{ss} \times \#\ Capita\ years_1 \times (1 - SR_1)) + (Ec_{ns} \times \#\ Capita\ years_2 \times (1 - SR_2)) + (I \times (1 - SR_3))] + PSI$$

In this equation, **W** represents the total mass of phosphorus in kilograms per year entering Messalonskee Lake. The Ec terms represent export coefficients, or the expected amount of phosphorus loaded into the system from each source per unit area (subscript a = atmospheric input, f = forested land, rf = regenerating land, rl = reverting land, w = wetlands, c = cleared land, r = roads, s = shoreline development, n = nonshoreline development, ss = shoreline septic, ns = nonshoreline septic; As = area of lake, I = combined export coefficient and per capita years of institutional sources, PSI = total of all point source inputs, and SR = soil retention).

Shoreline septic and nonshoreline septic export coefficients were multiplied by the number of capita years (the number of people per residence per year (in days present) times the number of residences) and then multiplied by one minus the coefficient values for soil retention, SR. Capita years is smaller for shoreline residences because they are assumed to be occupied seasonally rather than year-round. Soil retention is a measure of how well phosphorus and other nutrients are retained by the soil in the watershed (see GIS Methodology). The total of all point source inputs (PSI) represents the phosphorus concentrations entering Messalonskee Lake at major points of inflow (see Appendix E).

Low and high export coefficient values were modified from values used in case studies of watersheds similar to the Messalonskee Lake watershed (Reckhow and Chapra 1983, BI493 1991, BI493 1993, BI493 1994, BI493 1995, BI493 1996). The range between low and high export coefficient values compensates for uncertainty in phosphorus loading estimates. Uncertainty is due to bias (human judgment errors), as well as natural fluctuations in biological systems. The actual value of phosphorus loading should be between the low and high estimates. The areas for each land use type within the watershed were determined using a planimeter, a USGS topographical map from 1980 for lake area, and aerial photographs from 1991 and 1992 for land use areas (see Land Use: Land Use Methodology). The areas of shoreline and nonshoreline residences were calculated using MDEP estimates for shoreline and nonshoreline lot sizes (see Land Use: Residential Land; Residence Count; Methods). Lot size adaptations were then multiplied by the number of shoreline and nonshoreline residences in the watershed to determine total area.

Using the low and high total phosphorus loading values (**W**) and the water budget data for Messalonskee Lake (see Appendix E and G), a low and high range estimate of the phosphorus concentration for the lake was determined using the following equations from Reckhow and Chapra (1983):

$$\mathbf{L} = W/As$$

Here **L** is the amount of phosphorus loaded from the watershed area into each square meter of the lake annually (annual areal phosphorus loading in $kg/m^2/yr$) and is calculated by dividing W (annual mass rate of phosphorus inflow in kg/yr) by As (surface area of the lake in m^2). $\mathbf{q_s}$ is the annual areal water loading (m/yr), and is calculated by dividing Q_{tot}, the total volume of inflow into the lake (m^3/yr), by As, the surface area of the lake in m^2 (see Appendix E).

$$\mathbf{q_s} = Q_{tot}/As$$

The following equation, which incorporates values obtained in previous calculations, was used to predict the concentration of phosphorus in the lake:

$$\mathbf{P} = L/(11.6 + 1.2q_s)$$

P is the predicted phosphorus concentration with low and high values for Messalonskee Lake. L is the annual areal phosphorus loading (see above), and the term (11.6 + 1.2qs) approximates the settling velocity of phosphorus in the lake (Reckhow and Chapra 1983). The actual phosphorus concentration in the lake as measured by CEAT fell in between the high and low values calculated using the model, lending credibility to the accuracy of the model. See Appendices F and G for detailed calculations and results.

Results and Discussion

The size of the contributing source area and the size of the export coefficient determine how great an impact in terms of phosphorus loading each source will have on the lake (Reckhow and Chapra

1983). For instance, one can expect similar phosphorus loading values for developed and undeveloped areas if the undeveloped area is very large with a small coefficient, or if the developed land export coefficient is very large but represents a small area.

The total mass input of phosphorus into the lake each year (**W**) as projected by the model is 3251 kg/yr for the low estimate and 7462 kg/yr for the high estimate. Belgrade Stream, the only major point source on Messalonskee Lake, is the largest contributor to phosphorus loading. It contributes 65% of the phosphorus to the low estimate, and makes up 42% of the high estimate. Because this PSI makes up such a large percentage of the overall phosphorus loading, it was left out of the percentage calculations for contributing sources (Figure 58). The greatest contributors to phosphorus loading in the lake from the various sources are mature forested land and atmospheric inputs (dust), both of which have small export coefficients (see Appendix F). The reason for their large contribution is the large amount of area they comprise. Forested land makes up over half the area of all land use types in the watershed area, and Messalonskee Lake has a large surface area (Table 7). Forested land contributes between 27.2% for the low estimate and 21.2% for the high estimate (Figure 58). Forested land makes up a smaller percentage of the high estimate because of an increase in percent phosphorus loading from other sources in the watershed. Atmospheric inputs range from 26.6% for the low estimate to 20.7% for the high estimate (Figure 58). Therefore, even though forested land and atmospheric inputs have small export coefficients, a large amount of phosphorus comes into the lake from those sources (see Background: Land Use Types and Nutrient Loading).

Nonshoreline development contributes between 9.8% and 10.6%, and shoreline development between 8.1% and 8.3% of phosphorus loading (Figure 58). These percentages represent high amounts of phosphorus loading from a relatively small area: shoreline development represents 1.96% of the total area of the watershed, and nonshoreline development makes up 6.11% of the area of the watershed (Table 7). Nonshoreline areas are assigned a smaller coefficient because they are farther from the lake (see Appendix F). Since the area of nonshoreline development is greater than that of shoreline development, however, the total amount of phosphorus it contributes is greater. Developed areas, which make up a relatively small portion of the total watershed area, are assigned a much higher export coefficient (see Appendix F), because they contribute large amounts of phosphorus per given area to the lake.

Cleared land, including agricultural land and mowed fields (14.12%), and wetlands (13.68%) represent similar area percentages of the watershed (Table 7). Cleared land, however, is a much greater contributor to the overall phosphorus loading (see Background: Land Use Types and Nutrient Loading). Cleared land contributes between 16.2% for the low estimate of phosphorus loading and 22.0% for the high estimate, while wetlands contribute 3.1% for the low estimate and 4.9% for the high estimate.

The only institutional input found on Messalonskee Lake is the New England Music Camp. Camps such as the New England Music Camp are important to include in a model because of the high impact from the waste facilities, and because of the close proximity to the water. This camp is located on soil which has some limitations for septic systems. Camps such as this typically contribute a high amount of phosphorus per unit area, and therefore are one of the highest-impact land use types.

Developed areas, including residential, agricultural, and institutional areas, have a much greater impact on nutrient loading than undeveloped areas (see Background: Land Use Types and Nutrient Loading). Shoreline residential development and institutional sources such as camps are the largest contributors per given area, roads and nonshoreline development are the next largest contributors per

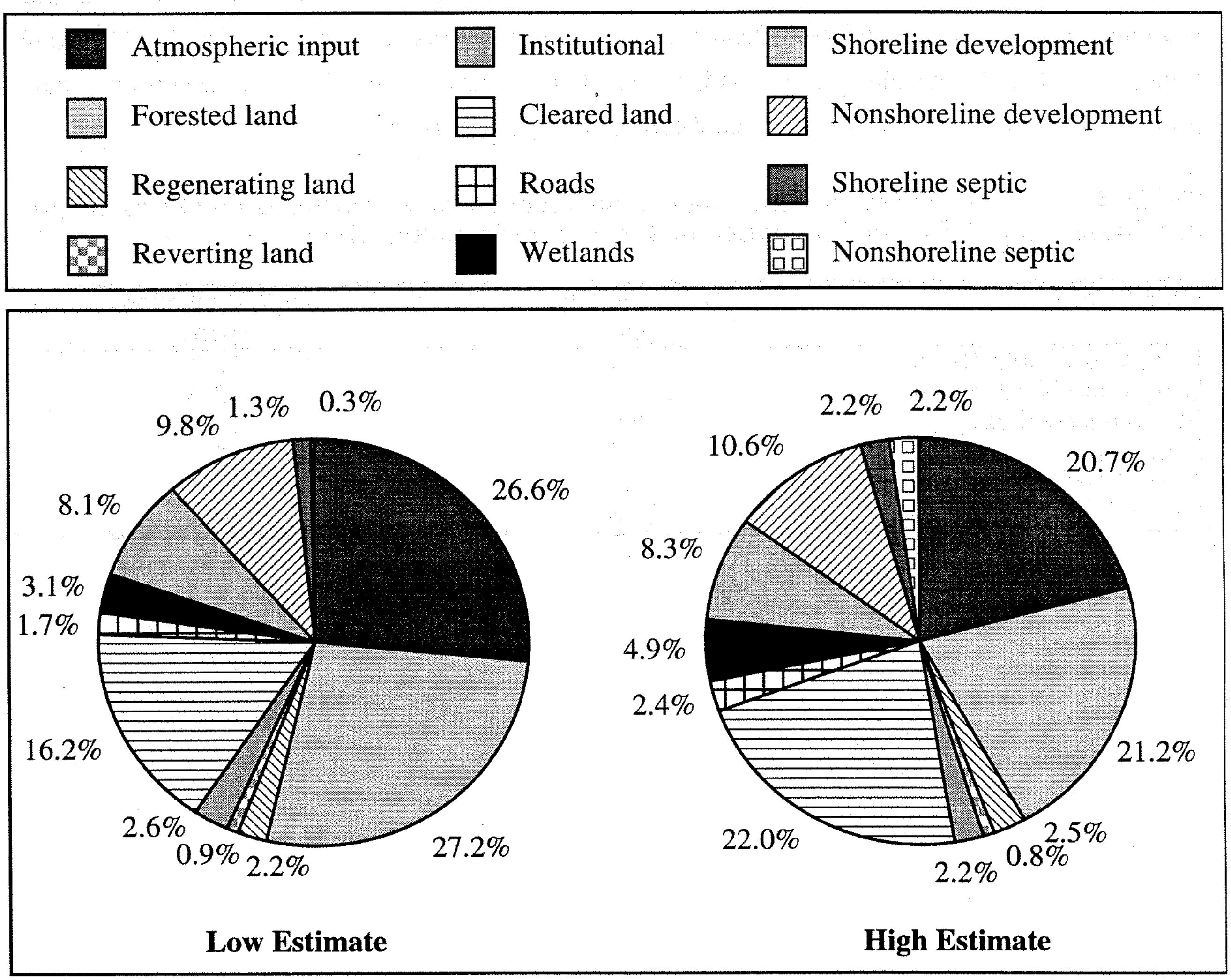

Figure 58. Low and high estimates of total phosphorus loading from each contributing source (except PSI) in the Messalonskee Lake watershed. For detailed explanation of these estimates and phosphorus budget calculations, see Appendices F and G.

given area, and shoreline septic systems are the third largest contributor (see Appendix F). Even though these areas make up small portions of the watershed compared with forests or the lake surface area, they can still have a large impact on the water quality of the lake.

The low value obtained for the phosphorus concentration in the lake using the model was 6.9 ppb, and the high value was 15.8 ppb. Because these values lie within the range found by CEAT (see Water Quality Measurements and Analysis: Chemical Tests; Phosphorus), it is believed that the model is an accurate predictor of the trophic status (a measure of lake age and condition) of Messalonskee

Lake. There is a wide range of phosphorus concentrations found by past CEAT studies (Table 11). These values all represent calculations made using a model. While Messalonskee Lake does not have a low, more healthy phosphorus concentration such as Long Pond South Basin (3.9 to 12.2), it is a much healthier lake than North Pond (7.7 to 27.3) or Salmon Lake (6.8 to 25.3). Messalonskee Lake, according to the phosphorus budget calculations, has a phosphorus concentration that will probably lead to algal blooms in the near future if action is not taken.

Table 11. Comparative low and high phosphorus concentration predictions in parts per billion (ppb) for various lakes in the Belgrade Lakes chain.

Lake Studied	Low Prediction (ppb)	High Prediction (ppb)
Long Pond South Basin	3.9	12.2
Long Pond North Basin	5.7	12.0
Messalonskee Lake	6.9	15.8
Salmon Lake	6.8	25.3
North Pond	7.8	27.3
Pattee Pond	11.8	34.8

FUTURE TRENDS

INTRODUCTION

The future of the water quality in Messalonskee Lake will be affected by population growth and development activities within the watershed. By examining the past population and development trends of the watershed, future projections can be made regarding population growth and what types of development can be expected. This will serve to help make predictions can be made concerning the impact of these activities on the water quality and phosphorus loading of Messalonskee Lake.

POPULATION TRENDS

The Messalonskee Lake watershed is located between two of Maine's larger cities: Augusta and Waterville. Belgrade, Oakland, and Sidney provide easy access to both of these cities and have seen a considerable population increase in the past three decades (Figure 59).

It is expected that populations in the Messalonskee Lake watershed will continue to grow as nearby metropolitan areas continue to expand. Population trends for Belgrade, Oakland, and Sidney were gathered from the Kennebec Valley Council of Governments (KVCOG 1996).

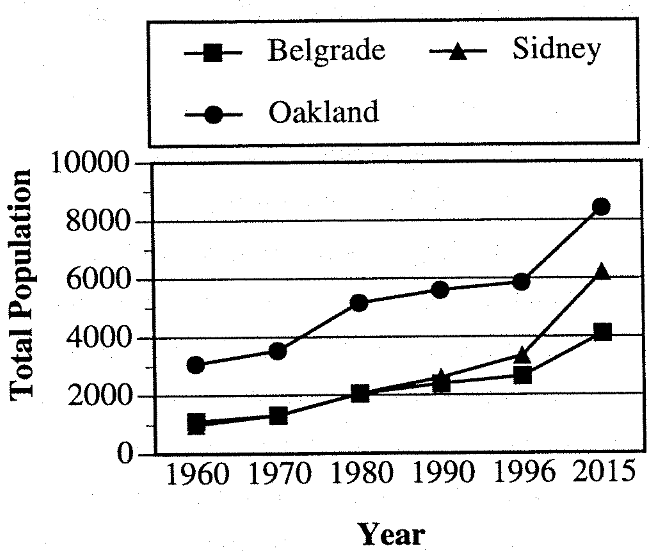

Figure 59. Total populations for Belgrade, Oakland, and Sidney in 1960, 1970, 1980, 1990, 1996, and projected populations for each town in 2015. Data were gathered from the KVCOG (1996).

The reports published by the KVCOG include the total populations of Belgrade, Oakland, and Sidney. Since the towns lie on the border of the Messalonskee Lake watershed studied by CEAT, only a portion of the populations reside within the watershed. These numbers reveal the population trends of the area, not necessarily of the watershed. An understanding of the population trends will expose the level of growth that is expected for each town and thus predictions can be made about the potential impact on the water quality of Messalonskee Lake.

Oakland, with a population of 5849 in 1996, is the largest town in the Messalonskee Lake watershed. It has experienced the slowest growth rates in the watershed over the last three decades, yet Oakland has always had the largest population in the watershed. It is expected to remain the largest town in the area with a projected population of 8400 in 2015. Belgrade is the smallest town in the watershed with a population of 2634 in 1996. The 2015 projected population for Belgrade is 4100. It is expected to remain the smallest town in the watershed. Sidney, however, has experienced astonishing population growth (KVCOG 1996).

The population in Sidney has tripled over the past thirty years. In 1960 the population was 988 individuals and in 1996 the population had reached 3346. This is most likely due to its proximity to Augusta (four miles south) and Waterville (five miles north) and easy access to I-95. The KVCOG in 1996 projected that by 2015, Sidney will have a population of 6200 people.

All of the towns in the Messalonskee Lake watershed experienced large population growths in the 1970s. During this period, the population increased 56.9% in Belgrade, 46.0% in Oakland, and 55.6% in Sidney. Growth slowed down considerably in the 1980s in all three towns within the watershed: Belgrade grew 16.3%, Oakland grew 8.4%, and Sidney grew 26.4% (KVCOG 1996).

The Kennebec Valley Council of Governments (1996) compared the growth from natural change (attributed to births and deaths in the area) to the increases from migration between 1980 and 1990. During this period the population in Belgrade increased 132 from natural change and 200 from migration. Oakland experienced the lowest percentage change for the decade with only 37 individuals migrating into the area and 396 people joining the population from natural demographic changes. During the 1980s, the population in Sidney experienced a natural increase of 205 individuals, while migration contributed 336 people to the population.

The KVCOG (1996) has also tabulated the number of year-round and seasonal residences for each of the towns. Through understanding the past trends regarding seasonal versus year-round use of residences, projections can be made about the potential impact of each additional residential unit on the water quality of Messalonskee Lake. Oakland may have the largest population but only relatively few seasonal residences. In 1980, Oakland had 339 seasonal residences which was 15.2% of the total residential units. By 1990, the number of seasonal residences decreased to 313, making up only 12.7% of the total residences. The trend has been a conversion from seasonal residences to year-round residences. Since 1990, however, six seasonal residences have been built in Oakland. This is startling since KVCOG shows that only two other seasonal residences have been built in the towns within the Messalonskee Lake watershed. These were built, not surprisingly, in Sidney.

In 1980, there were 144 seasonal residences in Sidney that made up 17.5% of the total residential units. By 1990 seasonal residences made up only 15.8% of the homes. In Belgrade, 635 seasonal residences made up 46% of the total residential units in 1980. The number of seasonal residences increased to 685 units by 1990, yet the percentage of the total residential units decreased to 42.3%.

This data, gathered from KVCOG, represents trends that can been seen in the Towns of Belgrade, Oakland, and Sidney. Since a portion of these towns lie outside of the Messalonskee Lake watershed area studied by CEAT, the numbers were higher than the actual populations living within the watershed boundary. Yet still, these data show the population trends of the area and are useful in estimating the future impact of population on the water quality of Messalonskee Lake.

DEVELOPMENT TRENDS

The future development of an area depends on its proximity to employment and services, accessibility, the number of undeveloped lots, and zoning regulations. Messalonskee Lake is situated between Augusta and Waterville, two major areas that provide employment and services to the region. The northern tip of the watershed is within the center of the town of Oakland, but the majority of the watershed is more rural. The Interstate Highway I-95 lies to the east of the lake, having two exits within a few miles of the lake. Also, well maintained state roads, Rts. 8, 11, and 23, circle the lake. This easy road access to the watershed and waterfront may facilitate future development.

CEAT determined that 22.3% of shoreline lots and 37.7% of nonshoreline lots are currently undeveloped (see Land Use: Residential Land). The larger of these can be subdivided into smaller lots for development of residential neighborhoods. A few new subdivisions have been built around the lake recently. All three towns are predicted to have large population increases in the next two decades (see Population Trends), therefore, more of these subdivisions may be built. Sidney, with its dramatic population increase, is especially susceptible to further residential development. Sidney also has the most acreage of undeveloped lands on which to build new residences. A large portion of the southern section of the watershed is protected from future development due to zoning regulations which prohibit development in wetlands (see Watershed Residential Areas Zoning). Located throughout the watershed are other Resource Protection areas in addition to wetlands on which development is limited.

An observable trend in the watershed is the conversion from seasonal to year-round residences. Along the shoreline, 61.9% of residences are seasonal. In the future, many of these may be converted to year round residences. Belgrade has the largest percentage of seasonal shoreline residences (see Land Use: Residential Land), and so is more likely to feel the effects of this trend. Seasonal residences only account for 5.2% of nonshoreline residences, therefore the trend of changing to year-round housing will not be as significant in the nonshoreline areas.

While outside of the Messalonskee Lake watershed, the new country club in Belgrade may influence future development in the region. The country club is expected to increase tourism in the region, which means an increase in supporting businesses and services. Due to the proximity of the country club to Messalonskee Lake, some of this supporting development may occur within the watershed.

Greater development in the watershed will affect the water quality of the lake. Construction of residential and industrial areas will lead to erosion from the disruption of the soil. New roads will carry more runoff towards the lake. Pesticides and fertilizers that are applied to the lawns may enter the lake through groundwater and runoff. Also, new residences will need septic systems, which are major contributors to phosphorus loading.

FACTORS INFLUENCING PHOSPHORUS LOADING

The Messalonskee Lake watershed is located in an area experiencing rapid population growth (see Future Trends: Population Trends). This increase in population will lead to a corresponding increase in residential development within the watershed. Subsequently, there is an increased potential for phosphorus loading which will negatively impact the water quality of the lake. Using the phosphorus budget equation (see Phosphorus Loading: Methods), phosphorus loading into Messalonskee Lake can be projected for the future based on population and development trends (Figure 59, 60).

The estimated population increase in the watershed for 2015 was 20% (see Future Trends: Population Trends). There are more nonshoreline lots available for future development (37.7% of the total number of nonshoreline lots) compared to shoreline lots (22.3%), so a greater increase was predicted in the nonshoreline sector (see Land Use: Residential Land). The population increase was therefore divided into a 5% increase in shoreline development and a 15% increase in nonshoreline development. Both shoreline and nonshoreline development were further divided into seasonal and year-round projections. Currently, 60% of shoreline residences and 5% of nonshoreline residences are seasonal.

The CEAT predicted that by 2015, there would be a 44% increase of year-round shoreline residences converted from seasonal ones assuming that all current seasonal residences are converted. The increased development in both shoreline and nonshoreline lots was coupled with an increase in the number of capita years for septic contributions. Other variables such as family size were not changed. The increase in developed land area was considered to be a direct decrease in mature forested land area. CEAT used the MDEP default value of one acre for nonshoreline lots and half an acre for shoreline lots (see Land Use: Residential Land). Assuming all available shoreline and nonshoreline lots are developed by 2015, shoreline lots (85.5 acres) will increase by 171 and nonshoreline lots (513 acres) will increase by 513. The total increase in developed land for 2015 is predicted to be 598.5 acres. Therefore, every one acre increase in developed land resulted in a one acre decrease in mature forested land. No other changes in land use areas or point source inputs were made for the future projections.

The current calculated low and high estimates for total phosphorus loading are 3244 kg-P/yr to 7440 kg-P/yr. The low and high projected total phosphorus loading estimates for 2015 are 3444 kg-P/yr to 8386 kg-P/yr. These low and high projections were calculated using current phosphorus loading coefficients. Due to an increase in residential development (both shoreline and nonshoreline) and a corresponding decrease in mature forested land, phosphorus concentrations in Messalonskee Lake are predicted to increase. Current phosphorus levels in the range of 6.9 ppb to 15.8 ppb are expected to increase to 7.3 ppb to 17.8 ppb by 2015. This results in a 5.7% increase in the low estimate and a 11.3% increase in the high estimate (Figure 60).

Increases in phosphorus concentrations following these forecasts could lead to perennial algal blooms and significantly impact both the health and the utility of the lake (see Background: Lake Characteristics). Regardless of the exact amount of development, an increase in population is directly related to an increase in phosphorus loading and progressive eutrophication of the lake. When examining increases in development, there are associated increases in septic inputs, road surface

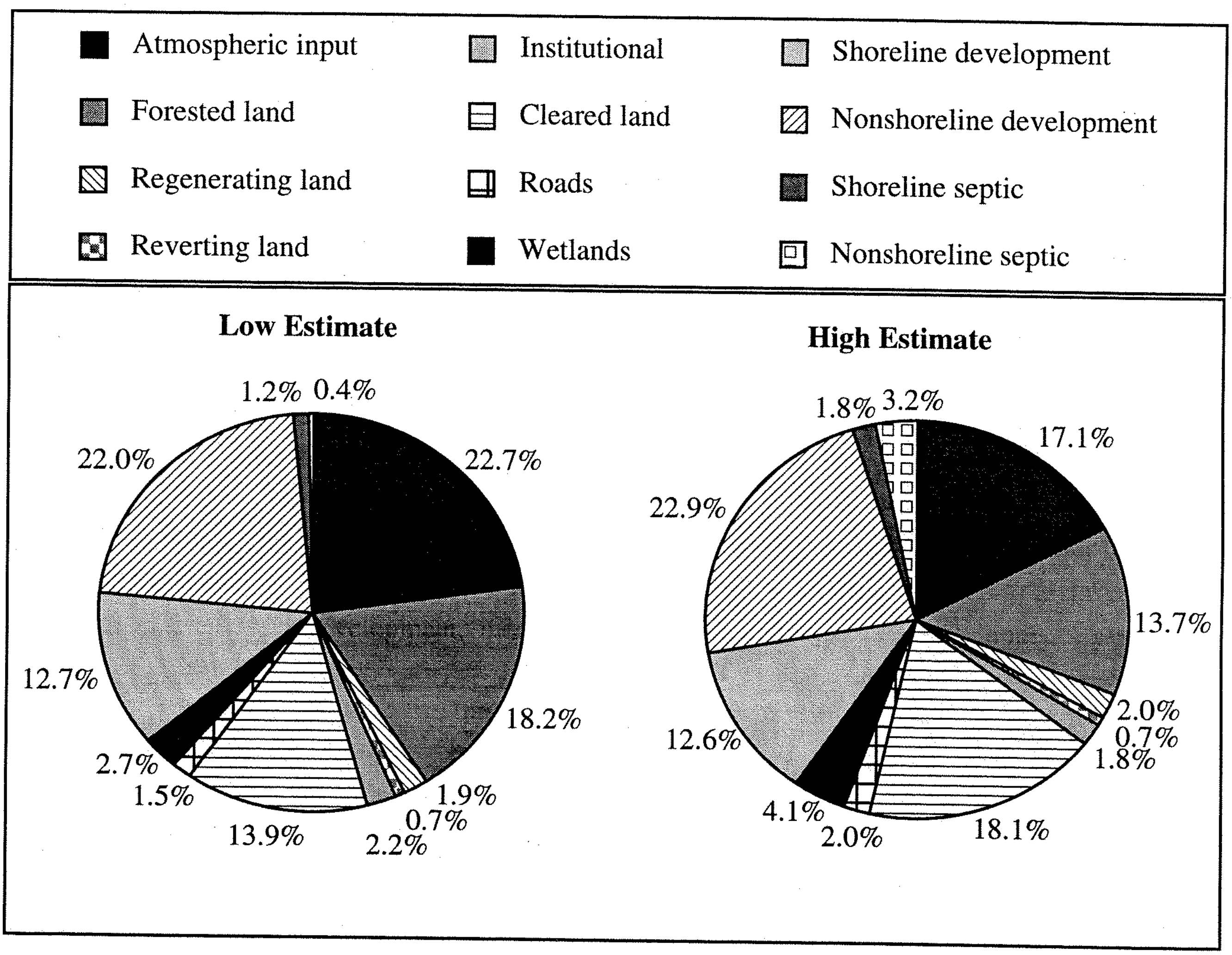

Figure 60. Low and high future estimates of total phosphorus loading from different land uses within the Messalonskee Lake watershed. For detailed explanation of these estimates and phosphorus budget calculations (see Appendices F and G).

runoff, and potential erosion from increases in cleared land. If development is done carefully, however, and strict guidelines are enforced, the impact will not be as great. Using the phosphorus budget model, state and local municipalities should examine the role of changing land use patterns on phosphorus loading potential, and focus zoning regulations on protecting the health of Messalonskee Lake.

SUMMARY

LAKE AND TRIBUTARY WATER QUALITY

Messalonskee Lake is at a critical point in its history. Although lake water quality is not poor, nutrient concentrations have reached a level that may promote algal blooms and accelerate eutrophication in the lake. Calculated inflow of phosphorus into the water body from various sources indicates high concentrations of phosphorus in Messalonskee Lake. The variety of influences that contribute to excessive nutrient loading in the watershed warrant concern. Fortunately, unlike the situation in many other lakes, it is not too late to reverse these dangerous trends. Immediate action is important to mitigate the current environmental stress on the lake and its future ramifications. While extensive algal blooms have not occurred, evidence indicates that increased conservation measures are vital to promoting the future environmental quality of Messalonskee Lake.

General Chemistry

An overall assessment of general water chemistry was important to developing a comprehensive evaluation of lake water quality. Transparency levels classified the lake as having mesotrophic status, which indicates moderate levels of biological productivity and diversity. This higher trophic classification suggests nutrient loading in Messalonskee Lake. If left unchecked, this may eventually lead to the decline of lake water quality and productivity. Furthermore, levels of nitrate, a limiting growth factor, were relatively high in the lake. These high levels may be due to an increase in fertilizer use, sewage system leakage, or an excess of surface runoff. In addition, Messalonskee Lake is classified as a colored lake, suggesting high concentrations of natural dissolved organic acids, such as tannins and lignins, which may inhibit adequate light penetration.

Several chemical tests indicated that the condition of the lake is worsening, while other tested parameters seemed relatively stable when compared to other Maine lakes and particularly the Belgrade chain. Conductivity levels in the lake were normal, and alkalinity levels indicated the lake was well-buffered against changes in pH. Messalonskee Lake had relatively neutral pH readings which are consistent with readings from other Maine lakes. Dissolved oxygen and temperature measurements increased from the summer to the fall, however, oxygen depletion was observed at lower depths which may have negative impacts on cold water fisheries. Low calcium and magnesium ion levels indicate that Messalonskee Lake is subject to limited industrial pollution despite the close proximity of the Belgrade municipal/industrial area. Water softness makes the lake especially susceptible to toxins. The majority of lake turbidity levels and tributaries were within acceptable limits with one exception; Site 13, near the Oakland boat ramp and road B4-d, had dangerously high turbidity levels.

Tributaries

Tributaries served as a major source for water and nutrients entering the lake body. Flow rate data revealed that Belgrade Stream was the biggest tributary in the watershed, and other tributaries were comparatively much smaller. All tributaries were characterized by highly oxygenated water flow experiencing continuous mixing, which seemed to have a positive impact on the overall health of the lake. Tributaries did not appear to be notable point sources for acidic runoff entering Messalonskee Lake. Tributaries carried neutral water unaffected by industrial pollution.

Phosphorus and Water Budget

In the past 30 years, the Messalonskee Lake community has witnessed dramatic changes in land-use and an increased human population living in the area. There is a direct relationship between phosphorus loading into Messalonskee Lake and population growth. Using a model for phosphorus loading into the lake, the phosphorus budget was calculated at 6.9 ppb for the low value, and 15.8 ppb for the high value, producing a mean of 11.3 ppb. These values were consistent with the values for total phosphorus found by CEAT. The MDEP indicates that lakes containing greater than 12 ppb of phosphorus warrant immediate action on the part of the communities surrounding the lake. Without shifts in land-use and a new watershed conservation plan, levels of phosphorus are expected to increase from 7.3 ppb to 17.8 ppb by the year 2015. In Messalonskee Lake, there seemed to be a seasonal increase of total phosphorus concentrations, especially apparent at bottom depths. During times of high precipitation, phosphorus levels increased. During storms, phosphorus was stirred up and suspended in flowing water from bottom sediments of tributaries. This increase may be attributed to the runoff from the surrounding tributaries and land areas.

The flushing rate was 1.59 flushes per year, which is a fairly high value considering the size of the lake. This value indicates that the total volume of water in the lake is replaced 1.59 times in a year. Movement of water was affected by the volume of the lake, morphology, inputs, directional orientation, direction of flow, and watershed size. High flushing rates improve water quality, therefore, the high flushing rate of Messalonskee Lake has likely helped to delay increased eutrophication within the lake.

LAND USE

Residential

Shoreline residences occupied slightly more than three percent of the total watershed area. In all three townships, the majority of residences were shoreline. Approximately 56% of the residences in Belgrade were shoreline, 58% of the residences in Oakland were shoreline, and 66% of Sidney's residences were shoreline. Nonshoreline residences occupied slightly more than two percent of the total watershed area. In Belgrade and Oakland, the majority of residences contained pre 1974 septic systems (76% in Belgrade were pre 1974, and 60% of Oakland residences were pre 1974). Sidney shoreline residences only contained 43% pre 1974 systems. However, qualitative analysis suggested that the data regarding post 1974 septic systems represents the minimum number of post 1974 systems, and the actual number in use is higher due to periodic replacement of pre 1974 systems over the past 23 years.

There has been an increase in residential development from the 1960s to the 1990s in the Messalonskee Lake watershed. Over three-fourths of the shoreline lots were developed, although there was a great amount of acreage still left for future development. Seventy-five percent of shoreline residences in the watershed did not have adequate buffer strips, meaning they had a larger impact on the water quality of the lake. There has also been a decreased percentage of seasonal residences (26%) and an increased number of year-round residences (74%). This large number of year-round residences for a lake community could be a direct result of the close proximity of the lake to the cities of Augusta and Waterville (Messalonskee Lake is the closest of the Belgrade Lakes to these Maine cities).

Roads

Only one percent of the area of the watershed was covered by roads. Of the 172 roads within the watershed, 34 were paved and 138 are dirt. Camp roads were surveyed with more detail, due to their greater environmental impact on the lake. One hundred seven roads within the watershed were surveyed using the Camp Road Survey form (see Appendix J). The majority of camp roads (82%) were in acceptable condition. However, there were several roads that scored in the fair to poor range (see Appendix H). Roads in poor condition have the potential to contribute to the phosphorus loading of the lake. Compared to other watersheds in the Belgrade Lakes region, the roads within the Messalonskee Lake watershed were in overall good condition, except for a few roads which badly need some maintenance work.

Managed Land

Land used for agriculture covered almost two percent of the total watershed area. There has been a significant decrease in land used for agriculture since the 1960s. In 1990, cleared land accounted for approximately 11% of the total watershed area. The area of cleared land (including agriculture and mowed fields) has decreased 20% from the 1960s to the 1990s. Agriculture and cleared land has been reverting to forest, or encroached on by residential development. There has been a significant increase in industrial development. Industrial land constituted approximately one percent of the total watershed land area in 1990, an increase of 108% since the 1960s.

Natural Land

Forested land has increased 135% from the 1960s to the 1990s. Forests made up 57% of the total watershed area in 1990. In the 1990's, wetlands accounted for approximately fourteen percent of the watershed area, a slight increase since the 1960s. Reverting land has decreased almost 100% from the 1960s to the 1990s. In 1990, regenerating land occupied less than one percent of the total watershed area. What was once reverting and regenerating land, has become mature forest.

CONCLUSIONS

The phosphorus levels of Messalonskee Lake have increased dramatically in the last twenty years. These levels are now at a point where there is concern for the health of the lake. Messalonskee Lake has higher phosphorus levels than many of the other lakes in the Belgrade area. There has been a substantial increase in development (both industrial and residential) in the area surrounding the lake, which will probably have a negative impact on the lake in future years. If phosphorus levels do not improve, the next twenty years may see algal blooms and eutrophication. This leads to unpleasant smells, declining appreciation of the lake's natural beauty, decline in biological diversity, and decreased enjoyment of the lake for recreation.

RECOMMENDATIONS

INTRODUCTION

Messalonskee Lake is slowly suffering the effects of water quality degradation. In the future, increases in the rate of phosphorus and nitrogen loading could further degrade the water quality of the lake. If changes and implementations of different watershed programs occur in the coming years, this process of declining water quality can be slowed and possibly stopped. CEAT has produced a set of guidelines that may help improve the overall health of Messalonskee Lake.

WATER QUALITY

In the past, the water quality of the Messalonskee Lake has not been monitored frequently. It is recommended that increased monitoring of the water quality of the lake occur. The best way to keep track of water quality changes is to take water samples and perform tests at numerous times during the year.

- test the lake six times a year: twice in the spring, twice in the summer and twice in the fall
- establish a network of volunteer water testers who are residents of the lake watershed
  - -monitoring equipment provided by the Lake Association or MDEP
- increase the number of characterization sites
  - -include the area where the Belgrade Stream enters the lake
  - -include the area close to the dam at the north end of the lake because this area is close to Oakland and is highly developed

Monitoring should include many of the same tests and measurements that were conducted in this study. These various tests and measurements helped CEAT asses the water quality of the lake and the same tests should be conducted in the future for comparative reasons. Tests/measurements should include:

- macrophyte growth monitoring
- dissolved oxygen (DO)
- transparency
- pH
- phosphorus

EDUCATION

Educating and informing watershed residents about the problems and needs of their lake is one of the best investments for improving water quality. The relationship between land use, development, and water quality may not be known to the general public. Informing individuals of the cause and effect relationship that exists in the watershed may motivate action among watershed residents. It is important to improve the accessibility and availability of information to the public.

- make this report available to every resident of the Messalonskee Lake watershed through the donation of the report to town libraries
- make the report available at Lake Association meetings
- condense the main message and lessons from this report and create different pamphlets on such topics as the relationship between land use and phosphorus loading or road management and phosphorus loading
- discuss water quality frequently at public meetings such as Lake Association meetings and town meetings
- create a newsletter or include information in the Lake Association's newsletter updating the public on changes in water quality and efforts being made
- start or expand on water quality education in the schools
- address issues of Maine lakes and rivers in school
- utilize the media such as TV news and local newspapers

DEVELOPMENT

Two areas of particular interest in limiting phosphorous loading into the lake fall under the category of development: land use and septic management. When land is being developed, there is an opportunity to prevent a great deal of negative impact on the lake by following certain guidelines. Similarly, the watershed area can be protected by proper maintenance of roads, properties, residences, and septic systems. Some suggestions follow.

<u>Roads</u>

- consistent and continued monitoring of roads in the watershed to pin point trouble spots
- proper maintenance of all roads with a particular emphasis on those roads which are currently in the worst condition

- encourage better participation of land owners of property on camp roads in road associations and maintenance crews
- improve ditches, culverts, and diversions especially those which CEAT has identified as trouble sites
- use low cost strategies for road maintenance including planting native vegetation in ditches, assigning maintenance crews to keep culverts clear, and installing water bars on steep slopes
- when new roads are built, particular emphasis should be placed on creating switchbacks where needed, establishing good crowning, and using a gravel base for all roads which will be used year round
- emphasize the elimination of berms
- develop adequate buffer strips between roads, railroad tracks and water bodies
- repair cracks and crowning in paved roads
- educate private land owners in road maintenance with particular emphasis on the fact that consistent maintenance is less expensive than attempting to fix things that have already gone wrong
- limit the development of new roads if possible
- encourage bike accessible roads that connect small complexes of residences

Septic Recommendations

- encourage the replacement of pre-1974 systems
- carry out maintenance of systems when and where needed
- educate people about the harmful effects of malfunctioning and poorly maintained systems
- encourage town offices to keep more accurate records about the septic systems found on properties in their respective areas, a lack of accurate information can lead to problems in regulation and maintenance
- give the plumbing inspector and code enforcement officer the power to levy fines against those who are in violation of codes and laws regarding septic systems

Other property types, in addition to that land which has been developed for road use and septic use, must be maintained. A high amount of the shoreline property around Messalonskee Lake has been cleared of trees and lawns have been planted on it. One easy way to prevent increased phosphorus loading into the lake is to maintain buffer strips between the edge of the lake and property surrounding the lake. Planting native shrubs and ground cover instead of lawns will prevent an increase of run off from entering into the lake, and it is an easy thing to do. There is very little maintenance needed if native species are used.

Nonshoreline properties can also use a variety of means to protect the lake watershed. In particular, changes in agriculture can help to prevent phosphorus loading. Some steps that can be taken are included below.

- attempt to reduce the amount of manure spread in the winter
- attempt to reduce over fertilization
- reduce pesticide use by using biological controls or integrated pest management instead

Resource Protection

As is the case with any ecological system, one can argue that the best way to maintain the system is to return it to its natural state. It would be impossible to return the Messalonskee Lake watershed to the way it may have been in the past. We can, however, strive to maintain as much of the natural habitat as possible. Restraints can be put on logging and tree farming. Zoning laws can be used to protect the watershed from additional development which would add to the phosphorus loading. A general sense of pride and ownership in the environment can be enhanced through education.

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PERSONAL COMMUNICATIONS

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Bob Martin	Plumbing Inspector for Belgrade
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David Miller	Maine Department of Environmental Protection
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APPENDICES

APPENDIX A. FIELD AND LABORATORY WATER QUALITY TESTS

Test or Measurement	Sample Date	Sample Sites
Physical Factors		
Depth[a]	22-Sep-97	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 13, 14, 15
DO/Temperature[a]	18-Jun-97	1, 2, 3
	1-Jul-97	1, 2, 3
	17-Jul-97	1, 2, 3
	7-Aug-97	1, 2, 3
	19-Aug-97	1, 2, 3
	22-Sep-97	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 13, 14, 15
	6-Oct-97	1
Flow Rate[a]	22-Sep-97	9, 10, 11, 13, 14, 15
Transparency[a]	18-Jun-97	1, 2, 3
	1-Jul-97	1, 2, 3
	17-Jul-97	1, 2, 3
	7-Aug-97	1, 2, 3, 4
	19-Aug-97	1, 2, 3
	22-Sep-97	1, 2, 3, 4
Conductivity[b]	22-Sep-97	1, 2, 4
	6-Oct-97	1, 2, 4
Turbidity[b]	22-Sep-97	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 13, 14, 15
Chemical Factors		
Total Phosphorus[b]	1-Jul-97	1, 2, 3
	17-Jul-97	1, 2, 3
	7-Aug-97	1, 2, 3, 4
	19-Aug-97	1, 2, 3
	15-Sep-97	7, 11
	22-Sep-97	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 13, 14, 15
	6-Oct-97	2, 9
	10-Oct-97	1
	20-Oct-97	9, 11
	3-Nov-97	9, 11
Alkalinity[b]	22-Sep-97	1, 2, 4
	6-Oct-97	1, 2, 4
Color[b]	22-Sep-97	1, 2, 4
Hardness[b]	22-Sep-97	1, 2, 3, 4, 5, 6, 7
	6-Oct-97	1, 2, 4, 5, 7
Nitrates/Nitrites[b]	22-Sep-97	1, 2, 4
	6-Oct-97	1, 2, 4
pH[a]	1-Jul-97	1, 2, 3
	17-Jul-97	1, 2, 3
	7-Aug-97	1, 2, 3, 4
	19-Aug-97	1, 2, 3
	22-Sep-97	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 13, 14, 15

[a] Measurements made on-site
[b] Analyses performed by Colby Environmental Assessment Team, Colby College, Waterville, ME, USA

APPENDIX B. QUALITY ASSURANCE

The Messalonskee Lake study followed a quality assurance plan based on previous collection and testing procedures performed by Colby Environmental Assessment Team. The following document was modified from BI493 (1995, 1996) and includes information from Potvin and Bacon (1993), HACH test kit manuals (HACH 1997) and Eaton, Clesceri, and Greenberg (1995).

Approaching site and sampling

1. When approaching the test site by boat, speed up first, then kill the engine and coast slowly to the sampling site.
2. Always sample from the bow of the boat, facing into the wind.
3. Sample surface water by holding the bottle upside down, placing it in water and pushing it horizontally away from the boat. Then lift the bottle out of the water and cap.
4. Sample taken at mid-depth and bottom depth using a bottom sampler. Lower sampler to appropriate depth and drop the weight down the line to close the sampler. Raise when a slight tug is felt. Push in the black spout on the sampler and let it run for a few seconds before filling the sample bottle.
5. Hands should never touch sample water or inside of bottle and bottle cap.
6. Bottle lids should never touch the bottom of the boat. Rinse the lids with E-pure water if they are dropped.

Sample Handling

1. Samples were immediately stored on ice in the field after sampling
2. Samples were then in laboratory refrigerator upon return from the field at less than 4° C until analysis.

Bottle Preparation

1. All sample bottles for total phosphorus analyses were triple acid rinsed with 1:1 HCL before use, to ensure that nothing would contaminate the sample.
2. 1:1 HCL is 1 L of E-pure water and 1 L of concentrated hydrochloric acid.
3. If an epicore was taken, the mixing bottle was triple acid rinsed once before each sampling trip and after that it was rinsed out with E-pure after each use.

Quality Control Sampling

1. E-pure samples were spiked (in groups of 10) with a known amount of a concentrated standard and run against a standard curve to confirm accuracy of technician before water samples were analyzed for each test. This accuracy test was run until the values of the test samples were within 10% of each other.
2. Duplicate samples were taken every tenth sample to test the accuracy of sampling procedures.
3. Samples were split every tenth sample in the laboratory to test lab precision.
4. A spike of 10 ppb phosphorus was put into a split of a field sample every tenth sample to determine percent recovery. The acceptable range of recovery was 80% to 120% recovery (Any values outside of this range are not accepted by the Maine Department of Environmental Protection).
5. Lab spikes into E-pure water were made on every run to test lab precision.
6. Reagent blanks were used to make a standard curve to determine the concentration of phosphorus studied. The standard curve should have a minimum of six points.

Depth

1. To determine depth, HONDEX PS-7 (LCD Digital Sounder) or a weighted depth line was used.
2. The weighted depth line must be dropped quickly and vertically, perpendicular to the water surface, to ensure the most accurate measurement possible.
3. Repeat the process again.

Dissolved Oxygen and Temperature

1. For every ten profiles, three duplicate readings should be made randomly.
2. Duplicate readings should not vary more than ± 0.2 ppm.
3. If readings vary more than 0.5 ppm, repair of the membrane or meter is advised.
4. The electrode must be in circulating water.
5. Record a DO measure immediately, and if the reading is decreasing, keep the electrode moving in the water.
6. The accuracy of these measurements using the Orion 840 DO/Temperature meter was ± 1.0% and ± 2.0° C.

Secchi Disk

1. One duplicate reading was taken for every 10 samples.
2. Aqua-scope was used to view the disk.
3. Disk was lowered until out of sight, then the depth was recorded.
4. Lower the disk an extra meter, and then bring it back up into sight. Record the depth.
5. Bring the disk back to the surface and repeated the process two more times.

Flow Rate

1. Divide the stream into sections by determining the topography of the stream bed. If the topography is uniform along the bottom, the stream is divided into two equal sections and then the flow is measured in the center of each section. If the topography varies, then the stream is divided into representative segments (ideally three or more).
2. Place the flow rate probe in the center of the section at 60% depth.
3. Make sure that sensor bulb is facing upstream.
4. If the stream is too deep or inaccessible for wading with a flow meter, measure flow at a culvert by timing how long it took to fill up a 1 liter bottle or a bucket depending on the volume of flow. Record the time and specify the volume of the bottle or bucket on the data sheet so flow can be calculated in the laboratory.

Epicore Sample

1. Determine the depth of the thermocline with the ORION 840 DO and Temperature meter.
2. Rinse the mixing bottle and cover 3 times with surface water; make sure that all interior surfaces have been in contact with surface water. This was not done for phosphorus samples. For samples that involved phosphorus a triple acid rinsed mixing bottle was used (see Bottle Preparation).
3. Rinse the epicore tube three times by lowering the epicore into the water at least 1 m deeper than the thermocline. Avoid hitting the bottom, epicore is not taken lower than 0.5 m from the bottom. Drain all of the water into the lake.
4. Obtain epicore samples, by lowering the epicore slowly to the appropriate depth. The water inside the epicore should be approximately the same as the level outside the epicore during the lowering procedure otherwise the water sample would be weighted with a disproportionate amount of water from lower levels.
5. Pinch the epicore tightly at the water surface to ensure that sample stays within the epicore tubing. If any of the sample is lost, a resampling must be conducted.

6. Only the weighted portion of the epicore enters the boat, the rest of the tubing remains in the water to prevent dripping that might contaminate the sample.
7. Hold the weighted end over opening of a mixing jug at an angle (to prevent run-off from the weight). Release the pinched end of tube and thoroughly drain the water into mixing bottle. Do not allow the opposite end of the epicore tube to take up water from the surface. Avoid contamination (e.g., with hands).
8. For adequate sample volume epicore sampling was repeated twice more, for a total of three samples.

Total Phosphorus

1. For every 10 samples, splits, spikes and duplicates were collected or made.
2. A standard curve was generated to determine concentration of total phosphorus.
3. At least one lab spike (in E-pure water) was run each day of analysis.
4. The accuracy of the Ascorbic Acid method used for total phosphorus analysis had a detection point less than 1 ppb.
5. Water samples were preserved for the analysis of total phosphorus by digesting them with sulfuric acid and ammonium peroxydisulfate, and then autoclaved at 15 psi for 30 minutes.
6. Analysis was conducted within 28 days of sampling date.

pH

1. Before any testing was done, the Fisher Scientific Accumet Basic pH meter was calibrated using a 3 point calibration method with standards of pH 4, 7, and 10. This needs to be done only once during the testing day as long as the meter's calibration is not accidentally deleted.
2. Check that the probe is working properly by measuring aerated de-ionized water. The meter should return to a value of 5.65.
3. Rinse probe with E-pure water prior to and following each measurement.
4. The Fisher Scientific Accumet Basic pH meter is accurate to 0.01 pH, within the range -1.99 to 19.99.

Hardness

1. One split, spike and duplicate sample were taken for every 10 samples.
2. Preserved the water samples for the analysis of hardness by adding nitric acid in the field until pH less than 2.

3. A HACH titration method, an adaptation from the EDTA Titrimetric Method was used to measure hardness (HACH 1997).
4. The limit of detection for the HACH DR/4000 spectrophotometer Hardness test is 0.03 mg/l $CaCO_3$. The range of the test is 0.03 mg/l to 4.00 mg/l $CaCO_3$.
5. Analysis was conducted within 6 months of sampling date.

Alkalinity

1. One duplicate sample taken for every 10 samples.
2. The Potentiometric Method was used to analyze the samples (Eaton, Clesceri, and Greenberg 1995)
3. Analysis was conducted within 14 days of sampling date.

Color

1. One duplicate sample taken for every 10 samples.
2. Color should not vary more than ± 5 SPU.
3. Color standards were kept in the dark and protected from evaporation.
4. The HACH Platinum-Cobalt Standard Method and HACH DR/4000U spectrophotometer were used to for the color test (HACH 1997).
5. The limit of detection for the test is 2 units Pt-Co. The range of the test is 0 to 500 units.
6. Analysis was conducted within 48 hours of sampling date.

Conductivity

1. One duplicate sample taken for every 10 samples.
2. Results should not vary more than 1 μmhos/cm^2.
3. De-ionized water should read less than 1 μmhos/cm^2.
4. Used the water sampler at the desired stratification.
5. Poured the water sample into its specified conductivity bottle.
6. A Model 31A YSI Conductance Bridge was used to measure conductivity in the Colby Environmental Laboratory.
7. The Model 31A YSI Conductance bridge had an accuracy of ± 1.0%.
8. Analysis was conducted within 28 days of sampling date.

Turbidity

1. One split, spike and duplicate sample were taken for every 10 samples.

2. Turbidity was measured using the HACH Attenuated Radiation Method and the HACH DR/4000U spectrophotometer (HACH 1997).
3. Analysis was conducted within 48 hours of sample date.

Nitrates

1. One split, spike and duplicate sample were taken for every 10 samples.
2. Nitrates were analyzed using the HACH UV Direct Reading and the HACH DR/4000U Spectrophotometer (HACH 1997).
3. The limit of detection for the test is 0.2 mg/l NO_3-N. The range for the test is 0.0 to 10.2 mg/l NO_3-N.
4. Analysis was conducted within 48 hours of sampling date.

APPENDIX C. RESULTS OF MESSALONSKEE LAKE WATER QUALITY TESTS

Table 1. Water Quality Results for September 22 and October 6, 1997

Date	Site	Type	Alkalinity (mg/L $CaCO_3$)	Nitrate (mg/L NO_3-N)	Turbidity (FAU)	Hardness	Flow Rate (cfs)
22-Sep	1	Char	20.9		2	15.2	
22-Sep	2	Char	16.0		2	14.1	
22-Sep	4	Char	17.3		3	15.0	
22-Sep	3	Spot			7		
22-Sep	5	Spot			2	24.3	
22-Sep	6	Spot			8		
22-Sep	7	Spot			3	14.2	
22-Sep	8	Spot			17		0.93
22-Sep	9	Trib			13		0.03
22-Sep	10	Trib			18		22.63
22-Sep	11	Trib			2		
22-Sep	13	Trib			4		0.34
22-Sep	14	Trib			0		0.22
22-Sep	15	Trib			2		0.15
10-Oct	1	Char	21.0	0.1			
10-Oct	2	Char	43.0	0.1			
10-Oct	4	Char	11.0	0.1			
10-Oct	3	Spot					
10-Oct	5	Spot				15.5	

Table 2. Water Quality Results for September 22 and October 6, 1997

Date	Site	Type	Depth (m)	Temp-erature (°C)	Dissolved Oxygen (ppm)	pH	Transparency (m)	Color (Pt-Co Units)	Conduc -tivity (uMHO/ cm)
22-Sep	1	Char	33.0	15.2	5.7	7.3	3.63	49	27
22-Sep	2	Char		18.9	8.3	5.9	3.78	58	37
22-Sep	4	Char	3.8	16.8	9.0	6.9	2.10	44	30
22-Sep	3	Spot	12.0	17.9	7.9	6.7	4.25		
22-Sep	5	Spot		15.4	4.5	6.7			
22-Sep	6	Spot	3.5	19.2	8.8	7.5			
22-Sep	7	Spot	4.5	19.0	8.2	6.8			
22-Sep	8	Spot	2.8			6.9			
22-Sep	9	Trib	0.2	19.0	9.4	6.8			
22-Sep	10	Trib	0.3	18.0	9.5	7.2			
22-Sep	11	Trib			8.2	6.9			
22-Sep	13	Trib			8.7	6.6			
22-Sep	14	Trib	0.6	15.0	10.7	7.6			
22-Sep	15	Trib			7.8				
10-Oct	1	Char		12.2	5.7				40
10-Oct	2	Char							46
10-Oct	4	Char							36
10-Oct	3	Spot							
10-Oct	5	Spot							

Table 3. Fall analyses for total phosphorus concentrations at all sites sampled on Messalonskee Lake by Colby Environmental Assessment Team between 22-Sep-97 to 3-Nov-97.

Site	Date	Stratification	Concentration (ppb)	Quality Control
1	22-Sep-97	S	13.5	
1	22-Sep-97	M	12.8	
1	22-Sep-97	M	8.4	duplicate
1	22-Sep-97	M	20.6	spike 10 ppb
1	22-Sep-97	B	23.4	
1	22-Sep-97	EC	10.0	
1	10-Oct-97	M	9.1	
1	10-Oct-97	M	9.1	duplicate
1	10-Oct-97	B	52.4	
2	22-Sep-97	S	9.1	
2	22-Sep-97	M	10.1	
2	22-Sep-97	B	8.9	
2	6-Oct-97	EC	11.7	
2	6-Oct-97	EC	11.7	split
3	22-Sep-97	S	9.2	
3	22-Sep-97	EC	9.8	
4	22-Sep-97	S	11.5	
4	22-Sep-97	S	11.7	split
5	22-Sep-97	S	20.0	
6	22-Sep-97	S	9.7	
7	22-Sep-97	S	8.5	
8	22-Sep-97	S	22.6	spike 10 ppb of duplicate
8	22-Sep-97	S	9.6	
8	22-Sep-97	S	10.3	duplicate
9	22-Sep-97	S	36.3	
9	6-Oct-97	S	26.2	
9	20-Oct-97	S	46.0	
9	3-Nov-97	S	34.0	
9	3-Nov-97	S	42.0	spike 10 ppb
10	22-Sep-97	S	12.5	
11	15-Sep-97	S	12.1	
11	22-Sep-97	S	12.6	
11	20-Oct-97	S	10.1	
11	20-Oct-97	S	13.2	duplicate
11	3-Nov-97	S	30.8	
11	3-Nov-97	S	30.4	split
13	22-Sep-97	S	11.9	
14	22-Sep-97	S	10.1	
15	22-Sep-97	S	13.0	
Spike	10-Oct-97	N/A	20.9	known spike 20 ppb

Table 4. Time series of total phosphorus concentrations from 1-Jul-97 to 10-Oct-97, for Characterization Sites 1, 2, 3[a], and 4 on Messalonskee Lake

Site	Date	Stratification	Concentration (ppb)	Quality Control
1	1-Jul-97	S	10.2	
1	1-Jul-97	M	8.3	
1	1-Jul-97	M	7.9	duplicate
1	1-Jul-97	EC	8.7	
1	1-Jul-97	B	12.1	
1	17-Jul-97	S	11.3	
1	17-Jul-97	M	8.2	
1	17-Jul-97	M	7.9	duplicate
1	17-Jul-97	EC	11.5	
1	17-Jul-97	EC	11.9	split
1	17-Jul-97	B	15.0	
1	7-Aug-97	S	7.3	
1	7-Aug-97	S	15.8	spike
1	7-Aug-97	M	7.5	
1	7-Aug-97	EC	11.4	
1	7-Aug-97	EC	10.6	split
1	7-Aug-97	B	12.8	
1	20-Aug-97	S	12.5	
1	20-Aug-97	M	9.4	
1	20-Aug-97	EC	10.3	
1	20-Aug-97	EC	11.4	split
1	20-Aug-97	B	28.5	
1	22-Sep-97	S	13.5	
1	22-Sep-97	M	8.4	duplicate
1	22-Sep-97	M	20.6	spike 10 ppb
1	22-Sep-97	M	12.8	
1	22-Sep-97	EC	10.0	
1	22-Sep-97	B	23.4	
1	10-Oct-97	M	9.1	
1	10-Oct-97	M	9.1	duplicate
1	10-Oct-97	B	52.4	
2	1-Jul-97	S	10.9	
2	1-Jul-97	M	15.4	
2	1-Jul-97	M	19.8	spike
2	1-Jul-97	EC	10.2	
2	1-Jul-97	EC	9.2	split
2	1-Jul-97	B	12.1	
2	17-Jul-97	S	10.5	
2	17-Jul-97	M	9.2	
2	17-Jul-97	EC	10.4	
2	17-Jul-97	B	11.7	
2	7-Aug-97	S	10.3	
2	7-Aug-97	M	8.6	
2	7-Aug-97	EC	11.2	
2	7-Aug-97	EC	9.6	split
2	7-Aug-97	B	13.1	
2	20-Aug-97	S	10.6	
2	20-Aug-97	M	10.5	
2	20-Aug-97	M	11.2	duplicate

Table 4. (cont'd)

Site	Date	Stratification	Concentration (ppb)	Quality Control
2	20-Aug-97	EC	8.4	
2	22-Sep-97	S	9.1	
2	22-Sep-97	M	10.1	
2	22-Sep-97	B	8.9	
2	6-Oct-97	EC	11.7	
2	6-Oct-97	EC	11.7	split
3	1-Jul-97	S	10.9	
3	1-Jul-97	M	11.9	
3	1-Jul-97	EC	11.0	
3	1-Jul-97	EC	11.0	split
3	1-Jul-97	B	8.3	
3	17-Jul-97	S	7.8	
3	17-Jul-97	M	10.6	
3	17-Jul-97	M	19.4	spike
3	17-Jul-97	EC	20.3	
3	17-Jul-97	EC	19.2	split
3	17-Jul-97	B	10.6	
3	7-Aug-97	S	7.5	
3	7-Aug-97	M	9.0	
3	7-Aug-97	M	8.0	duplicate
3	7-Aug-97	EC	9.8	
3	7-Aug-97	B	7.4	
3	20-Aug-97	S	10.4	
3	20-Aug-97	M	10.8	
3	20-Aug-97	M	20.3	spike
3	20-Aug-97	EC	12.1	
3	20-Aug-97	EC	13.0	split
3	20-Aug-97	B	8.5	
3	22-Sep-97	S	9.2	
3	22-Sep-97	EC	9.8	
4	7-Aug-97	S	12.3	
4	7-Aug-97	EC	10.6	
4	22-Sep-97	S	11.5	
4	22-Sep-97	S	11.7	split

S = Surface Sample
M = Mid-depth Sample
B = Bottom Sample
EC = Epicore Sample
[a] Site 3 was not one of the CEAT characterization sites, but it was sampled regularly over the summer (because it is a regularly sampled MDEP site like Sites 1, 2, and 4).

APPENDIX D. FLOW RATE RAW DATA

Tributary Site	Distance from Bank (ft)	Depth (ft)	Velocity (fps)	Cell Length (ft)	Average Cell Depth (ft)	Average Cell Velocity (fps)	Flow Rate (cfs)	Total Flow (cfs)
9	1.00	0.90	0.03					
	3.50	1.00	0.03	2.50	0.95	0.03	0.07	
	7.00	0.80	0.06	3.50	0.90	0.05	0.14	
	10.00	0.30	0.00	3.00	0.55	0.03	0.05	0.09
10	1.00	0.65	0.02					
	4.00	0.65	0.02	3.00	0.65	0.02	0.03	
	8.00	0.50	0.00	4.00	0.58	0.01	0.02	0.03
11	7.61	2.30	0.07					
	13.78	6.89	0.10	6.17	4.59	0.08	2.32	
	65.60	5.74	0.16	51.82	6.31	0.13	42.93	22.63
13	0.72	1.31	0.10					
	1.90	1.64	0.30	1.18	1.48	0.20	0.34	0.34
14	1.44	1.97	0.10					
	2.82	1.64	0.10	1.38	1.80	0.10	0.24	
	4.49	0.74	0.10	1.67	1.19	0.10	0.20	0.22
15	1.34	0.98	0.20					
	2.10	1.15	0.16	0.75	1.07	0.18	0.15	0.15

APPENDIX E. WATER BUDGET VALUES AND CALCULATIONS

Parameters	Units	Value
Runoff[a]	meters/year	0.622
Precipitation[b]	meters/year	0.996
Evaporation[c]	meters/year	0.560
Land Area	square meters	109,357,672
Lake Area	square meters	15,024,910
Average depth[d]	meters	10
I_{net} Messalonskee Lake	cubic meters/year	74,826,756
Q (Messalonskee Lake)	cubic meters/year	83,240,706
Q (Total)	cubic meters/year	246,897,951
Input Great Pond[e]	cubic meters	102,720,000
I_{net} Ingham Pond	cubic meters	9,707,924
I_{net} Long Pond North Basin	cubic meters	17,167,676
I_{net} Long Pond South Basin	cubic meters	23,273,902
I_{net} Watson Pond	cubic meters	1,319,689
I_{net} Whittier Pond	cubic meters	6,276,454
I_{net} Kidder Pond	cubic meters	1,082,515
I_{net} McIntire Pond	cubic meters	410,585
I_{net} Moose Pond	cubic meters	1,698,500
Sum Pond Inputs	cubic meters	163,657,245
Flushing Rate	flushes/year	1.59

[a] Runoff = constant obtained from ten-year average of runoff in the Kennebec River Basin from 1958-1967 (BI493 1995)

[b] Precipitation was determined from a ten-year average from data from NOAA (NOAA 1986-1996, Augusta, Waterville)

[c] Evaporation is a constant cited in a study of the Lower Kennebec River basin (Prescott 1969)

[d] Average depth was obtained from the MDEP MIDAS data (1994)

[e] Input Great Pond = I_{net} East Pond + I_{net} Serpentine + I_{net} Salmon Lake + I_{net} North Pond + I_{net} Little Pond

I_{net} = (Runoff x Land Area)+(Precipitation x Lake Area)-(Evaporation x Lake Area)

Flushing Rate = I_{net} Great Pond + I_{net} Ingham Pond + I_{net} Long Pond North Basin + I_{net} Long Pond South Basin + I_{net} Watson Pond + I_{net} Whittier Pond + I_{net} Kidder Pond + I_{net} McIntire Pond + I_{net} Moose Pond + I_{net} of Messalonskee Lake / Depth Messalonskee Lake x Lake Area

Q (Messalonskee Lake) = I_{net} Messalonskee + (Lake Area x Evaporation)

Q (Total) = Q (Messalonskee) + sum of pond inputs

APPENDIX F. PHOSPHORUS EQUATION

The following equation is used to determine how much phosphorus is loaded into a body of water annually, using information about land use types and other sources of phosphorus, population sizes, and point sources.

$$W = (Ec_a \times As) + (Ec_f \times Area_f) + (Ec_{rf} \times Area_{rf}) + (Ec_{rl} \times Area_{rl}) + (Ec_c \times Area_c) + (Ec_w \times Area_w) + (Ec_r \times Area_r) + (Ec_s \times Area_s) + (Ec_n \times Area_n) + [(Ec_{ss} \times \#\ Capita\ years_1 \times (1 - SR_1)) + (Ec_{ns} \times \#\ Capita\ years_2 \times (1 - SR_2)) + (I \times (1 - SR_3))] + PSI$$

Ec_a = export coefficient for atmospheric input (kilograms per hectare each year)

Estimated Range (ER) = 0.20 - 0.60

The export coefficient range for atmospheric input reported in Reckhow and Chapra (1983) was 0.15 to 0.60. A study of North Pond (BI493 1997) used a range of 0.15 to 0.55. The Messalonskee Lake watershed is similar to both Higgins Lake (Reckhow and Chapra 1983) and North Pond (BI493 1997) in that there is not a lot of agricultural land. North Pond reported one gravel pit very close to the water and some logging in the region. In the Messalonskee Lake watershed, however, there are five active gravel pits as well as a cement factory in the southwest region and several other gravel pits in the area nearby which probably increase the amount of airborne phosphorus (Figure 55). As a result, the low and high coefficient estimates for atmospheric input are higher than recent lake studies in the Belgrade chain have used (BI493 1995, BI493 1996, BI493 1997).

Ec_f = export coefficient for forested land (kg/ha-yr)

ER = 0.10 - 0.30

The mature forest coefficient range reported by Reckhow and Chapra (1983) was 0.10 to 0.30. The North Pond study used the same value (BI493 1997), and the Long Pond South Basin reported a similar value of 0.15 to 0.30 (BI493 1996). This coefficient is based on the percentage of mature forest in the watershed. Since the forest in the Messalonskee Lake watershed is similar to the Higgins Lake, North Pond, and Long Pond South Basin watersheds, the same coefficient range values were used (Reckhow and Chapra 1983, BI493 1996, BI493 1997).

Ec_{rf} = export coefficient for regenerating land (kg/ha-yr)

ER = 0.15 - 0.65

North Pond used a range of 0.20 to 0.70 (BI493 1997) and Long Pond South used 0.30 to 1.00 (BI493 1996). These values were based on the presence of openings in the canopy and skidder trails on steep slopes that increase erosion potential. No skidder trails were reported in the Messalonskee Lake watershed (see Land Use: Regenerating Land) and most of the regenerating forest was away from the shoreline and in areas of moderate slope. Because of this, a smaller export coefficient was used for Messalonskee Lake.

Ec_{rl} = export coefficient for reverting land (kg/ha-yr)

ER = 0.20 - 0.75

Reverting land is less than 50% forested, but still has more cover than cleared land, so is likely to contribute less phosphorus. The value used, therefore, is between the values for cleared and regenerating land.

Ec_c = export coefficient for cleared land (kg/ha-yr)

ER = 0.25 - 1.30

This range was modified from Reckhow and Chapra (1983) who reported an export coefficient range of 0.10 to 3.00 for agricultural land. The cleared land being studied in the Messalonskee Lake watershed includes mowed fields, agricultural land, and cleared land. Cleared land and mowed fields contribute less phosphorus than agriculture, so the coefficient was reduced.

Ec_w = export coefficient for wetlands (kg/ha-yr)

ER = 0.05 - 0.30

The coefficient range used by the North Pond (BI493 1997), Long Pond, South Basin (BI493 1996), Long Pond North Basin (BI493 1995), Pattee Pond (BI493 1992), and East Pond (BI493 1991) studies was 0.03 to 0.20. The wetland areas in Messalonskee Lake have more foliage than the wetland areas in the other studies cited above, so will act more like a nutrient source than the wetlands in other lakes (see Land Use: Wetlands). For this reason, a larger coefficient was used.

Ec_r = export coefficient for roads (kg/ha-yr)

ER = 0.30 - 1.60

The condition of roads in the Messalonskee Lake watershed was similar to that in the Salmon Lake watershed, so the same coefficient was used. Both watersheds have fairly good roads with few major problem areas. In contrast, a value of 0.80 to 4.00 was used for Pattee Pond (BI493 1992), which reflects the poorly maintained and eroding roads common in the watershed.

Ec_s = export coefficient for shoreline development (kg/ha-yr)

ER = 0.90 - 3.55

Reckhow and Chapra (1983) assigned a range of 0.50 to 5.00 to urban areas, and assigned Higgins Lake in Michigan range of 0.35 to 2.70 as it is mostly a residential and recreational area serviced by a municipal septic system. Pattee Pond (BI493 1992) was assigned a value of 1.50 to 5.00 because it has an equal amount of septic and holding tanks as well as many privies on shoreline property. North Pond was assigned 0.80 to 3.50 because many houses on the shoreline are not adequately buffered and have lawn extending to the water's edge (BI493 1997). The shoreline development around Messalonskee Lake is similar to that of North Pond, but the slopes approaching the edge of the water are steeper for Messalonskee Lake. Therefore, the estimates were raised.

Ec_n = export coefficient for nonshoreline development (kg/ha-yr)

ER = 0.35 - 1.45

Nonshoreline development has a much smaller impact on phosphorus loading than shoreline development due to the increased distance from the water, so a smaller coefficient was used. Because nonshoreline areas are similar among the Salmon Lake, Long Pond North and South Basin, and North Pond watersheds, the coefficient used was the same (BI493 1994, BI493 1995, BI493 1996, BI493 1997).

Ec_{ss} = export coefficient for shoreline septic tank systems (kg/ha-yr)

ER = 0.50 - 1.30

A coefficient range of 0.40 to 1.00 was used for Salmon Lake (BI493 1994) because it has a high percentage of grandfathered septic systems and soil with moderate septic suitability. The North Pond study used a range of 0.60 to 1.50 and had a high percentage of grandfathered systems and soil with moderate to poor septic suitability (BI493 1997). The soil in the Messalonskee Lake watershed has moderate to good septic suitability, but it was estimated that less than one-half of the residences have adequate septic systems (see Septic Systems). Therefore a value between those used in the Salmon Lake and North Pond reports (BI493 1994, BI493 1997) was used.

capita $years_1$ = number of persons contributing to shoreline septic tank systems =

(# persons x days/yr) x # shoreline living units

The Higgins Lake study in Michigan (Reckhow and Chapra 1983) used an estimate of 3.5 persons per living unit, as have all past reports on the Belgrade chain lakes (BI493 1991, BI493 1992, BI493 1994, BI493 1995, BI493 1996, BI493 1997). Days per year for year-round residences was estimated to be 355, slightly less than a year to account for vacations. Seasonal residence days per year was estimated to be 70. This value is the same as used in North Pond report and is based on communications with residents (BI493 1997). It was estimated that Messalonskee Lake, like North Pond, has a somewhat extended summer season. There were 297 seasonal shoreline residences, and 206 year round shoreline residences found during CEAT road surveys along Messalonskee Lake.

SR_1 = soil retention coefficient for shoreline development

ER = 0.85 - 0.65

Soil retention measures how well different soil types are able to hold phosphorus and other nutrients. Soils are ranked on a scale of 0 to 1, with 0 representing no phosphorus retention and 1 being full retention. The higher the value, the less phosphorus will be loaded into the water. The soil along the shoreline of Messalonskee Lake is a mix of soils with different septic suitabilities (see Soil Types). The soils around Messalonskee Lake have a better ability to retain phosphorus than those around North Pond, so a higher coefficient was used.

Ec_{ns} = export coefficient for nonshoreline septic tank systems (kg/ha-yr)

ER = 0.40 - 0.90

The soils around Messalonskee Lake are slightly better than those around North Pond and Salmon Lake with respect to suitability for septic system construction, so the same value for export coefficient was used as for those lakes.

capita $years_2$ = number of persons contributing to nonshoreline septic tank systems =
(# persons x days/yr) x # nonshoreline living units

The same estimate of 3.5 persons per living unit was used. The days per year number was estimated to be 355. Seasonal days per year was estimated at 70. There were 39 seasonal nonshoreline residences and 746 year round nonshoreline residences found through CEAT road surveys in the Messalonskee Lake watershed.

SR_2 = soil retention coefficient for nonshoreline development

ER = 1.00 - 0.85

Because nonshoreline residences are farther from the water, there is a greater chance that phosphorus will be absorbed by the soil before reaching the water. The retention coefficient for nonshoreline soil, therefore, was higher than that for shoreline soil.

I = combined export coefficient and number of capita years for institutional sources (summer camps).

ER = 74.36 kg/ha-yr - 157.59 kg/ha-yr

The design manual written by the USEPA (1980) lists pollutant concentrations of major residential wastewater fractions (23 mg/l) and wastewater flow from institutional sources (52.8 gal-day/unit to 106 gal-day/unit). New England Music Camp is open for 9 weeks each summer with approximately 300 people living there for the entire summer. Because the overall impact from New England Music Camp is similar to that of Pine Tree Camp (BI493 1997), the same values were used. The low combined export coefficient and number of capita years used was 74.36 kg/yr and the high combined coefficient was 157.59 kg/ha-yr.

SR_3 = soil retention coefficient for summer camps

ER = 0.60 - 0.40

Only one camp, the New England Music Camp, was studied. The soil around the camp is moderately suitable for septic systems, so a medium value for the coefficient was used.

PSI = point source input (kg/yr)

ER = 2120 - 3120

Point source inputs were calculated by multiplying the individual I_{net} for each major inflow into the lake by the amount of phosphorus found in those inflows. Belgrade Stream was the only major point source for Messalonskee Lake. Other tributaries had too little flow to be treated as point sources, but the phosphorus input from these sources was included in the runoff area from various land use types. The water flowing through Belgrade Stream, however, is a sum of the I_{net} of Belgrade Stream and the I_{nets} of all upstream lakes. The resulting Belgrade Stream Input was multiplied by the concentration of phosphorus determined by water quality test conducted by CEAT (see Appendix C; Lake and Tributary Water Quality Measurements and Analysis: Chemical Tests; Phosphorus). As CEAT measured the concentration in parts per billion (µg/L), this value was converted to kg/m^3 so that when the two values (Input m^3/yr and [P] kg/m^3) were multiplied the point source input in kg/yr was obtained. The range of high and low values was determined by subtracting and adding 500.00 kg/yr, which represents 20% of the original calculated value, from the original calculated value.

Areas for land use components (hectares) and values for capita years (# person-days/yr):

As_1 = area of Messalonskee Lake = 1502.49
$Area_f$ = area of forested land = 3073.54
$Area_{rf}$ = area of regenerating forest = 164.70
$Area_{rl}$ = area of reverting land = 49.45
$Area_c$ = area of cleared land = 733.64
$Area_w$ = area of wetlands = 710.89
$Area_r$ = area of roads = 65.69
$Area_s$ = area of shoreline development = 101.78
$Area_n$ = area of nonshoreline development = 317.68
capita $years_1$ = 199.36
capita $years_2$ = 701.25

APPENDIX G. PREDICTIONS FOR ANNUAL MASS RATE OF PHOSPHORUS INFLOW

Equations

For the phosphorus loading model used by CEAT, annual phosphorus input must be expressed as a loading (kilograms) per unit lake surface area (hectares). This was done by dividing annual mass rate of phosphorus inflow, **W**, by the lake surface area, $\mathbf{A_s}$ (Reckhow and Chapra 1983):

$$\mathbf{L} = W/A_s$$

where L = areal phosphorus loading (kg/ha-yr)
W = annual mass rate of phosphorus inflow (kg/yr)
A_s = surface area of the lake (m^2)

Areal water loading was calculated by dividing total inflow water volume by the surface area of the lake, A_s, (Reckhow and Chapra 1983):

$$\mathbf{q_s} = Q_{tot}/A_s$$

where q_s = areal water loading (m/yr)
Q_{tot} = inflow water volume (m^3/yr)

The lake phosphorus concentration could then be calculated, for both low and high estimates, by substituting in values of $\mathbf{q_s}$ and **L** (low and high) (Reckhow and Chapra 1983):

$$\mathbf{P} = L/(11.6 + 1.2q_s)$$

where **P** = lake phosphorus concentration (kg/m^3)

Constants for high and low predictions for Messalonskee Lake:

A_s = 15024909.68
Q_{tot} = 83678015.71
q_s = 5.57

Low Prediction:

W (low) = 4136.61 kg/yr
L (low) = 0.275 kg/m^2/yr
P (low) = **6.9 ppb**

High Prediction:

W (high) = 8210.99 kg/yr
L (high) = 0.547 kg/m^2/yr
P (high) = **15.8 ppb**

APPENDIX H. ROAD INDEX FIGURES

Table 1. Road surface total, ditch total, culvert total, water diversion total for the camp roads in Belgrade that received detailed road surveys[a,b]

Municipality	Road Surface Totals	Ditch Totals	Culvert Totals	Diversion Totals	Road Index Totals[c]	Road Segment Averages[d]	Total Road Values[e]
Belgrade							
O2	22.50	14.50	8.00	2.00	44.00	15.20	668.80
O3	9.50	19.80	5.00	2.00	36.30	6.00	217.80
O5	19.75	136.00	27.00	15.00	197.75	47.00	9294.30
O6	72.50	19.00	5.00	2.00	98.50	5.50	541.80
O8	125.00	28.50	5.00	2.00	160.50	5.80	930.90
O9	62.50	5.00	5.00	2.00	74.50	5.70	424.70
O9A	50.00	5.00	5.00	2.00	62.00	4.90	303.80
O9B	17.00	1.00	5.00	2.00	26.00	10.00	260.00
O12	28.60	125.00	5.00	2.00	160.60	6.60	1060.00
O12A	39.30	125.00	3.00	3.00	167.30	5.30	886.70
O12A extension	29.00	100.00	5.00	2.00	136.00	4.90	666.40
O13	80.00	37.80	8.00	2.00	127.80	9.50	1214.10
013 L5	12.20	40.00	8.00	2.00	62.20	6.60	410.50
O13 L0	15.00	26.00	8.00	2.00	51.00	7.20	367.20
O13 L3	15.00	78.00	5.00	2.00	100.00	10.00	1000.00
O14	116.00	92.40	5.00	3.00	216.40	5.40	1168.60
O14C	65.00	80.00	17.00	2.00	164.00	6.30	1033.20

[a] These values were calculated using the Detailed Camp Road Survey Form (see Appendix J).
[b] This list represents 107 camp roads that were surveyed with the Detailed Camp Road Survey Form. 62% of the roads within the watershed were surveyed in this manner.
[c] The road index total is the sum of the road surface total, ditch total, culvert total, and diversion total.
[d] The road segment average is a value representing the average percent grade of the road.
[e] The total road value is the product of the road index total and the road segment average.

Table 2. Road surface total, ditch total, culvert total, water diversion total for the camp roads in Oakland that received detailed road surveys[a,b] (see footnotes Appendix H: Table 1).

Municipality	Road Surface Totals	Ditch Totals	Culvert Totals	Diversion Totals	Road Index Totals[c]	Road Segment Averages[d]	Total Road Values[e]
Oakland							
B1A	65.00	55.50	5.00	4.00	129.50	7.80	1010.10
B1B	47.00	1.00	5.00	2.00	55.00	7.00	385.00
B1C	25.00	1.00	5.00	2.00	33.00	5.60	184.80
B3	25.00	35.40	5.00	2.00	67.40	5.20	350.50
B3A	73.00	37.40	8.00	2.00	120.40	6.10	734.40
B3B	70.00	51.00	5.00	2.00	128.00	8.30	1062.40
B5	107.00	74.10	5.00	2.00	188.10	7.80	1467.20
B6	236.25	25.00	8.00	3.00	272.25	10.60	2885.90
B6A	120.00	1.00	8.00	2.00	131.00	9.50	1244.50
B6B	90.00	1.00	5.00	2.00	98.00	7.50	735.00
B7	138.00	94.00	5.00	5.00	242.00	7.70	1863.40
P1	35.00	24.00	5.00	3.00	67.00	5.80	388.60
P2	135.00	4.80	8.00	6.30	154.10	6.60	1017.10
P3B	200.00	108.50	5.00	15.00	328.50	6.90	2266.70
P3C	360.00	180.00	5.00	15.00	560.00	21.00	11760.00
P4	52.50	22.60	17.00	2.00	94.1	19.54	1838.70
P6	220.50	42.78	7.00	8.30	278.58	10.90	3036.50
P6A	13.00	60.00	8.00	5.00	86.00	16.50	1419.00
P6B	34.00	80.00	8.00	5.00	127.00	29.70	3771.90
P6C	165.00	80.00	21.00	15.00	281.00	27.30	7671.30
P7	7.00	17.50	6.50	2.00	33.00	6.10	201.30
P9	27.50	1.00	5.00	2.00	35.50	6.60	234.30
P9A	96.70	10.00	5.00	2.00	113.70	8.67	985.80
P9B	96.70	10.00	5.00	2.00	113.70	8.67	985.80
P11A	60.00	1.00	5.00	2.00	68.00	9.25	629.00
P11B	80.00	11.00	5.00	2.00	98.00	10.20	999.60
P12	27.00	75.00	58.00	2.00	109.00	11.40	1242.60
P13	92.50	11.00	5.00	2.00	110.50	10.570	1168.00

Table 3. Road surface total, ditch total, culvert total, water diversion total for the camp roads in Sidney that received detailed road surveys[a,b] (see footnotes Appendix H: Table 1).

Municipality	Road Surface Totals	Ditch Totals	Culvert Totals	Diversion Totals	Road Index Totals[c]	Road Segment Averages[d]	Total Road Values[e]
<u>Sidney</u>							
S2	50.00	5.00	5.00	1.00	61.00	4.70	286.70
S2A	70.00	56.00	5.00	3.00	83.00	6.25	518.80
S4	195.00	56.00	5.00	3.00	259.00	4.40	1139.60
S4B	80.00	1.00	5.00	2.00	88.00	14.67	1290.60
SF9	300.00	170.00	5.00	2.00	477.00	6.00	2862.00
SF9A	105.00	51.00	5.00	2.00	163.00	6.60	1075.80
SF14	134.00	1.00	8.00	2.00	145.00	6.40	928.00
S19	45.00	5.00	5.00	2.00	57.00	7.60	433.20
S20	56.00	10.00	5.00	2.00	73.00	14.00	1022.00
S23	180.00	66.00	5.00	5.00	256.00	31.50	8064.00
S24	150.00	2.00	5.00	2.00	159.00	11.50	1828.50
S25A	170.00	63.00	5.00	3.00	88.00	7.00	616.00
S26	184.50	1.00	5.00	2.00	192.50	8.20	1578.50
S29	30.00	34.00	8.00	2.00	74.00	9.35	691.90
S29 North	51.00	1.00	5.00	2.00	59.00	5.00	295.00
S30	240.00	10.00	8.00	2.00	260.00	15.54	4040.40
SF30A	53.01	24.00	8.00	2.00	87.01	20.36	1771.50
Hosta N	137.00	1.00	5.00	2.00	145.00	6.50	942.50
Hosta S	195.00	1.00	8.00	2.00	206.00	5.30	1091.80

APPENDIX I. RESIDENTIAL SURVEY

Residential Survey

Date:________________

Surveyor's Name(s):____________________

	Residences < 200 ft of Water				Residences > 200 ft of Water						
	# Seasonal		# Yearly		# Seasonal		# Yearly				
Road	pre'74	post	pre'74	post	pre'74	post	pre'74	post	Total	Length	Width

APPENDIX J. DETAILED SURVEY FORM FOR CAMP ROADS

Detailed Camp Road Survey Form

DATE:_______________ SURVEYOR'S NAME(S):_______________________________
ROAD NAME/NUMBER:____

GENERAL DESCRIPTION

ROAD DIMENSIONS: Length (miles):____Average Width (feet):_____OVERALL SLOPE (%):_____

TOTAL NO. OF WATER DIVERSIONS:________NO. OF MISSING WATER DIVERSIONS:_____

NUMBER OF MISSING CULVERTS NEEDED:_____SIZE OF CULVERTS NEEDED:__________

DESCRIPTION OF ROAD SURFACE

Score each 0.1 mile section of road with checkmark [√] in appropriate column of each row. For roads with uniform surface conditions, simply divide road into one to three equal sections depending upon length of road. When survey is complete compute average score for each characteristic using values shown in parentheses.

	Good	Acceptable	Fair	Poor	Big Problem		Average Score
Crown	_____(1) 6 in.	_____(2) 4 in.	_____(4) 2 in.	_____(6) 0 in./potholes	_____(8) 0 in./ruts		_____
Surface (dry)	_____(1) hard w/o dust	ØØØØØØ ØØØØØØ	_____(3) hard w/ dust	_____(4) loose	_____(5) dusty & loose		_____
OR							
Surface (wet)	_____(1) hard	_____(2) hard & slick	_____(3) slick & loose	ØØØØØØ ØØØØØØ	_____(5) mud		_____
Edge	_____(0) no berm/ridge	ØØØØØØ ØØØØØØ	ØØØØØØ ØØØØØØ	ØØØØØØ ØØØØØØ	_____(5) berm/ridge prevents surface runoff		_____
Base	_____(1) gravel	_____(2) gravel/sand	_____(3) dirt	_____(4) sand/clay	_____(5) clay		_____
					SURFACE TOTAL	[a]	_____
USAGE	_____(1) seasonal	ØØØØØØ ØØØØØØ	ØØØØØØ ØØØØØØ	ØØØØØØ ØØØØØØ	_____(5) year round	[b]	_____
OVERALL SURFACE CONDITION	_____(1) 100% good	_____(2) 75% good	_____(3) 50% good	_____(4) 25% good	_____(5) 0% good	[c]	_____

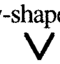
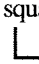
__________ X __________ X __________ = ______________
SURFACE [a] **USAGE [b]** **CONDITION [c]** **SURFACE TOTAL [d]**

DATE:________________ SURVEYOR'S NAME(S):________________________________

ROAD NAME/NUMBER:____

DESCRIPTION OF ROAD DITCHING

Score the quality of culverts for the entire road with checkmark [√] in appropriate column of summary evaluation. Use the descriptions provided to determine the overall ditch condition.

	Good	Acceptable	Fair	Poor	Big Problem		Average Score
Need	_____(1) ample/none needed	ØØØØØØ ØØØØØØ	_____(5) some needed	ØØØØØØ ØØØØØØ	_____(15) badly needed		_____
Depth	_____(1) 2 ft. (or road slopes into adjacent land)	_____(2) 3 ft.	_____(3) 4 ft.	_____(4) 1 ft.	_____(5) no ditch present but needed		_____
Width	_____(1) 8 ft. (or road slopes into adjacent land)	_____(2) 6 ft.	_____(3) 4 ft.	_____(4) 2 ft.	_____(5) no ditch present but needed		_____
Vegetation	_____(1) turf, wooded, or rip rap	_____(2) grass	_____(3) weeds	_____(4) brush	_____(5) bare soil		_____
Sediments	_____(1) none	_____(2) 1 inch deep	_____(3) 2 inches deep	_____(4) 4 inches deep	_____(5) >4 inches deep		_____
Shape	_____(1) parabolic 	_____(2) trapezoid 	_____(3) round 	_____(4) v-shaped 	_____(5) square 		_____
					TOTAL	[e]	_____
SUMMARY OF DITCH CONDITION	_____(1) 100% good, or none needed	_____(2) 75% good	_____(3) 50% good	_____(4) 25% good	_____(5) 0% good, or no ditch present but needed	[f]	_____

__________ X __________ = ______________

DITCHES [e] **CONDITION [f]** **DITCH TOTAL [g]**

DATE:________________ SURVEYOR'S NAME(S):____________________________

ROAD NAME/NUMBER:____

A road segment is defined as a particular length of road which has a relatively continuous angle of incline (% grade). Start and end segments so that their lengths fall into one of the column headings indicated. For each segment record the segment % grade in the upper table, and place a check [√] in the appropriate box of the lower table. <u>The upper table is used to identify particularly troublesome road segments, while the lower table is used to characterize the soil erosion potential of the road in general (shaded boxes represent high erosion potential).</u>

Segment							**Score = Segment Length x % Grade**
A	Length	50	100	200	500	1000	
	% Grade	( )	( )	( )	( )	( )	________
B	Length	50	100	200	500	1000	
	% Grade	( )	( )	( )	( )	( )	________
C	Length	50	100	200	500	1000	
	% Grade	( )	( )	( )	( )	( )	________
D	Length	50	100	200	500	1000	
	% Grade	( )	( )	( )	( )	( )	________
E	Length	50	100	200	500	1000	
	% Grade	( )	( )	( )	( )	( )	________
F	Length	50	100	200	500	1000	
	% Grade	( )	( )	( )	( )	( )	________
G	Length	50	100	200	500	1000	
	% Grade	( )	( )	( )	( )	( )	________
H	Length	50	100	200	500	1000	
	% Grade	( )	( )	( )	( )	( )	________
I	Length	50	100	200	500	1000	
	% Grade	( )	( )	( )	( )	( )	________
J	Length	50	100	200	500	1000	
	% Grade	( )	( )	( )	( )	( )	________
K	Length	50	100	200	500	1000	
	% Grade	( )	( )	( )	( )	( )	________
L	Length	50	100	200	500	1000	
	% Grade	( )	( )	( )	( )	( )	________
M	Length	50	100	200	500	1000	
	% Grade	( )	( )	( )	( )	( )	________
				ROAD SEGMENT TOTAL			________

	Segment Length (feet)				
% Grade	50	100	200	500	1000
0-5% Total	____(4) ____	____(5) ____	____(8) ____	____(12) ____	____(17) ____
6-10% Total	____(10) ____	____(14) ____	____(19) ____	____(31) ____	____(43) ____
11-15% Total	____(16) ____	____(23) ____	____(33) ____	____(51) ____	____(73) ____
16-20% Total	____(29) ____	____(41) ____	____(58) ____	____(91) ____	____(129) ____

After surveying road, multiply the number of checks in each box by the erosion potential coefficient for that box to obtain a box total. To obtain the Road Segment Average, add all of the box totals and divide by the total number of checks.

ROAD SEGMENT AVERAGE __= TOTAL OF ALL BOXES __÷ TOTAL # OF CHECKS __

DATE:________________ SURVEYOR'S NAME(S):____________________

ROAD NAME/NUMBER:______________________________________

DESCRIPTION OF CULVERTS

Score the quality of culverts for the entire road with checkmark [√] in appropriate column of summary evaluation. Use the descriptions provided to determine the overall culvert condition.

	Good	Acceptable	Fair	Poor	Big Problem		Average Score
Need	_____(1) ample/none needed	ØØØØØØ ØØØØØØ	_____(5] some not working	ØØØØØØ ØØØØØØ	_____(10) badly needed		_____
Wear	_____(1) new	_____(2) aging (some rust)	_____(3) old (rust holes)	_____(4) bottom gone	ØØØØØØ ØØØØØØ		_____
Size	_____(1) 2 ft. diam.	_____(2) 1-1/2 ft. diam	_____(3) 1 ft. diam.	_____(4) <1 ft. diam.	ØØØØØØ ØØØØØØ		_____
Insides	_____(1) clean	_____(2) some rocks and/or water	_____(3) ≤2 in. silt	_____(4) >2 in. silt	ØØØØØØ ØØØØØØ		_____
Covering Material	_____(1) at least 1 ft. thick or half diameter of large culverts	ØØØØØØ ØØØØØØ	_____(3) less than 1 ft. thick	_____(4) covering inadequate to prevent bent culvert	_____(5) top of culvert showing through road surface		_____
					TOTAL	[h]	_____
OVERALL CULVERT CONDITION	_____(1) 100% good, or none needed	_____(2) 75% good	_____(3) 50% good	_____(4) 25% good	_____(5) 0% good, no culvert present but needed	[i]	_____

_________ X _________ = _________

CULVERTS [h] **CONDITION [i]** **CULVERT TOTAL [j]**

DATE:________________ SURVEYOR'S NAME(S):____________________________
ROAD NAME/NUMBER:____

DESCRIPTION OF WATER DIVERSIONS

Score the quality of water diversions for the entire road with checkmark [√] in appropriate column of each row. Use the descriptions provided to determine the overall water diversion condition.

	Good	Acceptable	Fair	Poor	Big Problem		Average Score
Need	ample/none needed	ØØØØØØ	ØØØØØØ	ØØØØØØ	badly needed		_____
Where does diverted water go?	woods	field or lawn	gully in woods	stream	lake		_____
					TOTAL	[k]	_____
OVERALL WATER DIVERSION CONDITION	_____(1) 100% good, or none needed	_____(2) 75% good	_____(3) 50% good	_____(4) 25% good	_____(5) 0% good, no diversions present but needed	[l]	_____

_________ X __________ = _______________

WATER DIVERSIONS [k] CONDITION [l] WATER DIVERSIONS TOTAL [m]

FINAL EVALUATION OF THE ROAD

_________ + ________ + __________ + ______________ = _________

[d] SURFACE + [g] DITCHES + [j] CULVERTS + [m] WATER DIVERSIONS = ROAD TOTAL

The lower the total, the better the score for an individual road. Having a low or acceptable score does not mean that road maintenance is unnecessary, but a high score indicates the need for work, and can be used as a guide for making decisions about where and what type of work is needed. As a rule, if any item checked was worth more than two points, it should be given priority when developing a road maintenance plan.

ROAD SEGMENT TOTAL = ____________________

ROAD SEGMENT AVERAGE = ________________________

APPENDIX K. AREAS OF ROADS

Table 1. Areas (ft^2) of camp and non camp roads, paved and dirt, within the Messalonskee Lake watershed, separated by municipality[a].

Municipality	Camp Roads		Non camp Roads	
	Paved	Dirt	Paved	Dirt
Belgrade	10470.2	434,781.6	846,658.6	266,677.0
Oakland	67129.9	629,912.3	1,684,483.7	12144.0
Sidney	273,393.1	782,224.8	1,365,983.5	354,334.0
Watershed Total	350,993.3	5,759,918.8	3,897,125.6	633,155.0

[a] Values obtained through road surveys.

APPENDIX L. CLASSES OF ROAD TOTAL INDEX VALUE

Table 1: Classes of camp roads surveyed within the Messalonskee Lake watershed[a, b]

Class 1	Class 2	Class 3	Class 4	Class 5	Class 6
Belgrade					
O2	O8	O14			
O3	O12				
O6	O12A				
O9	O12A ext.				
O9A	O13				
O9B	O13L3				
O13L5	O14C				
O13L0					
Oakland					
B1B	B1A	B6	P3B		P3C
B1C	B3A	B7			
B3	B3B	P6			
B6A	B5	P6C			
P1	B6A	O14			
P4	P2				
P6A	P6B				
P6D	P9A				
P7	P9B				
P9	P12				
P11A	P13				
P11B	O5				
Sidney					
S2	SF9A	S4		SF9	
S2A	SF14	S23			
S4B	S24	S30			
S19	S26	Hosta S			
S20	Hosta N				
S25A					
S29					
S29 North					
SF30A					

[a]This list represents 107 camp roads that were surveyed as described in the Detailed Camp Road Survey form (see Appendix J). 62% of the roads within the watershed were surveyed in this manner.
[b]Class 1 indicates roads in the best condition, and Class 6 indicates roads in the worst condition.

APPENDIX M. LIST OF ALL NON-DETAILED SURVEY ROADS

Table 1. List of roads not surveyed with the Detailed Camp Road Survey form[a,b]

Road	Camp/ Noncamp	Paved/Dirt	Length (ft)	Average Width (ft)
		Belgrade		
O13	camp road	paved	528.0	19.8
Pinewood	non camp road	paved	1584.0	20.6
Rte. 11	non camp road	paved	21120.0	29.0
Bartlet Rd.	non camp road	paved	5280.0	21.0
Old Rte. 27	non camp road	paved	3168.0	18.4
O1	camp road	dirt	2112.0	14.3
unmarked road	camp road	dirt	1056.0	12.6
O14B	camp road	dirt	528.0	11.9
		Oakland		
B2	camp road	dirt	1056.0	15.3
B2A	camp road	dirt	528.0	9.8
B2B	camp road	dirt	2640.0	8.6
B2C	camp road	dirt	528.0	14.5
B4	camp road	dirt	1056.0	9.2
B4A	camp road	dirt	1056.0	10.0
B4B	camp road	dirt	2112.0	10.3
B4C	camp road	dirt	528.0	9.2
B6C	camp road	dirt	528.0	10.0
P3	camp road	dirt	528.0	18.2
P3D	camp road	dirt	1056.0	15.5
P5	camp road	dirt	1584.0	12.8
P8	camp road	dirt	1584.0	8.9
P2	camp road	paved	1584.0	15.0
P3	camp road	paved	1056.0	14.8
P10	camp road	paved	2112.0	13.1
Taylor Woods	non camp road	paved	2112.0	27.0
Grandview Rd.	non camp road	paved	1584.0	20.4
Axtell Rd.	non camp road	paved	2640.0	20.0
Town Farm Rd.	non camp road	paved	3168.0	25.0
Gallager	non camp road	paved	528.0	21.3
Webb Rd.	non camp road	paved	1056.0	21.3
Rte. 11	non camp road	paved	40128.0	29.0
Wentworth	non camp road	paved	2640.0	22.6
Rte. 23	non camp road	paved	11088.0	21.5
		Sidney		
S6	camp road	paved	528.0	10.2
S6A	camp road	paved	528.0	10.2
S7	camp road	paved	3696.0	22.1
S8	camp road	paved	4224.0	9.5
S13	camp road	paved	2112.0	18.6
S15	camp road	paved	3696.0	22.1
S22	camp road	paved	528.0	12.7
S33	camp road	paved	4224.0	9.5

Table 1 (cont'd)

Road	Camp/ Noncamp	Paved/Dirt	Length (ft)	Average Width (ft)
		Sidney		
Lakeridge	non camp road	paved	2640.0	19.3
Quaker Rd.	non camp road	paved	1056.0	21.0
Goodhue	non camp road	paved	4752.0	20.0
Tallwood	non camp road	paved	1584.0	12.4
Mt. Vista	non camp road	paved	1584.0	12.4
Lake View	non camp road	paved	2112.0	21.3
Rte. 11	non camp road	paved	3168.0	29.0
S1	camp road	dirt	(roped off)	(roped off)
S1A	camp road	dirt	1056.0	11.9
Azelia S.	camp road	dirt	1056.0	13.6
S3	camp road	dirt	528.0	16.3
fork off S4	camp road	dirt	528.0	13.0
S4A	camp road	dirt	528.0	15.6
S5	camp road	dirt	528.0	14.4
S6B	camp road	dirt	148.0	9.5
Foxglove Ln.	camp road	dirt	98.00	9.8
S10/S11	camp road	dirt	1056.0	16.3
Iris S.	camp road	dirt	100.0	9.3
S16	camp road	dirt	2112.0	16.0
S17	camp road	dirt	1584.0	9.8
S18	camp road	dirt	1584.0	8.3
Juniper S.	camp road	dirt	1056.0	12.8
S18A/Lily S.	camp road	dirt	1056.0	20.3
S18B	camp road	dirt	528.0	15.8
S21	camp road	dirt	528.0	13.0
S21A	camp road	dirt	528.0	13.4
S25	camp road	dirt	528.0	10.0

[a] Information obtained through road surveys.
[b] A less detailed road survey was conducted if the road was paved, a noncamp road, or an unpaved camp road in good condition.

APPENDIX N. FISH SPECIES LIST

A list of common fish species that occur in the Belgrade lakes, based on McNeish (1997). Taxonomy follows Everhart (1976).

Common Name	Scientific Name
American Eel	*Anguilla rostrata*
Black Crappie	*Pomoxis nigromaculatus*
Brown Trout	*Salmo trutta*
Bullhead	*Ictalurus nebulosus*
Chain Pickerel	*Esox niger*
Eastern Brook Trout	*Salvelinus fontinalis*
Fallfish	*Semotilus corporalis*
Four-Spine Stickleback	*Apeltes quadracus*
Golden Shiner	*Notemigonus crysoleucas*
Landlocked Salmon	*Salmo salar*
Largemouth Bass	*Micropterus salmoides*
Northern Pike	*Esox lucius*
Pumpkinseed Sunfish	*Lepomis gibbosus*
Rainbow Smelt	*Osmerus moradax*
Redbreast Sunfish	*Lepomis auritus*
Slimy Sculpin	*Cottus cognatus*
Smallmouth Bass	*Micropterus dolomieui*
Three-Spine Stickleback	*Gasterosteus aculeatus*
Walleye Pike	*Stizostedion vitreum*
White Perch	*Morone americana*
White Sucker	*Catostomus commersoni*