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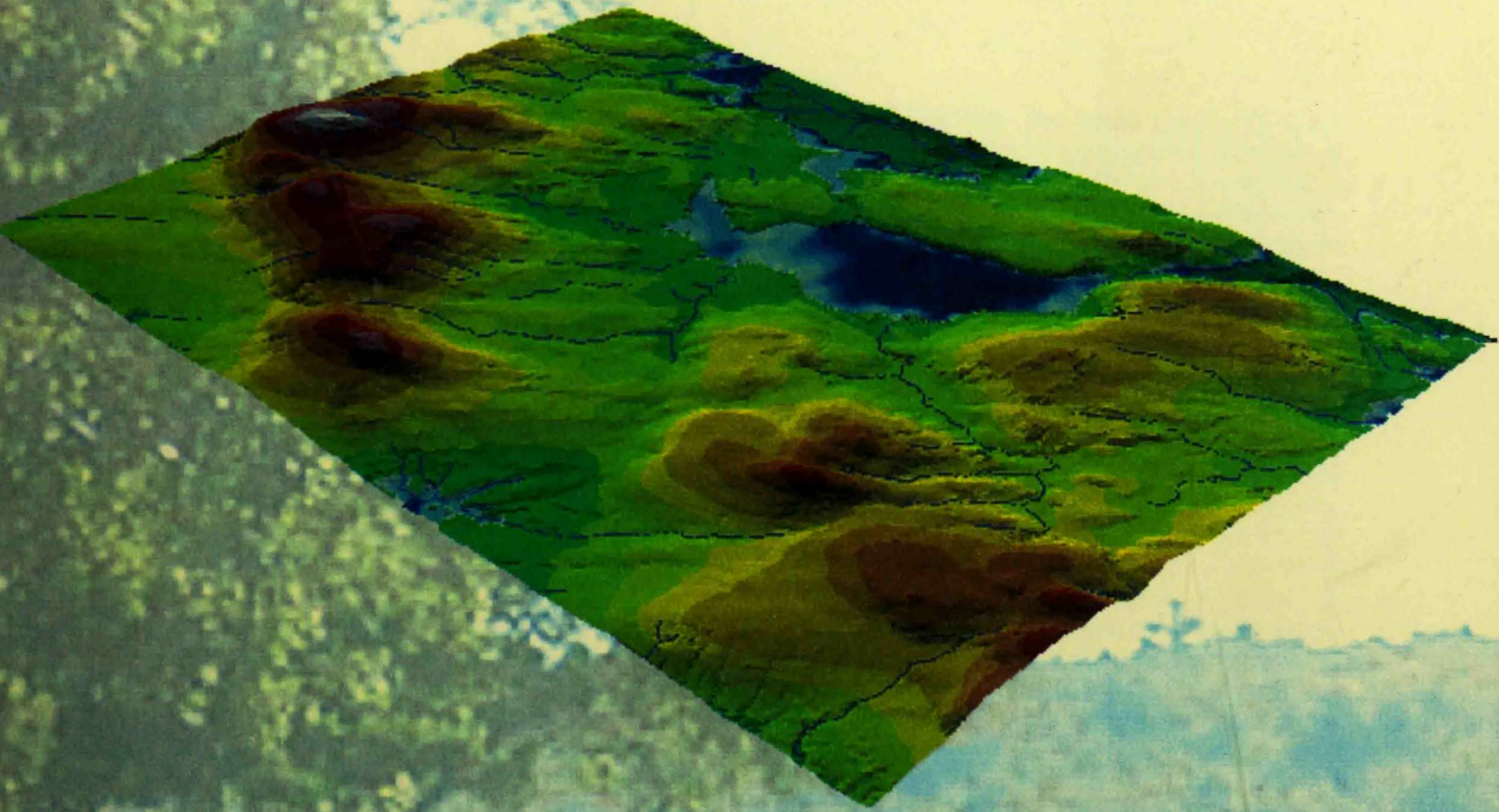
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LAND USE PATTERNS IN RELATION TO LAKE WATER QUALITY IN THE LAKE WESSERUNSETT WATERSHED



**Biology 493
Problems in Environmental Science
Colby College
Waterville, ME 04901
2001**



DATE: May 16, 2001

TO: Report recipients
FROM: Professors Russell Cole and David Firmage
RE: Class report on Lake Wesserunsett and its watershed

We have very much enjoyed working with the people concerned with the water quality of Lake Wesserunsett and hope that the work done by Colby students and herein reported will be of value to them and to other interested parties. 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 2000. The course is taken by seniors who are majoring in Biology, most 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/or 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 some 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. 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.

The first section of the report provides background material, somewhat general in nature, which will help readers who are not familiar with some basic concepts concerning lakes and their watersheds. There is also a small section discussing the general features of the lake itself. The majority of the report consists of the analysis done by the students during the fall semester class.

Authors

The analysis of the Lake Wesserunsett watershed was conducted by the students of the Biology 493: Problems in Environmental Science class at Colby College, Waterville, Maine.



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EXECUTIVE SUMMARY

The Colby Environmental Assessment Team (CEAT) engaged in an extensive data collection and analysis effort from September to December of 2000 to produce a comprehensive evaluation of the ecological health of the Lake Wesserunsett ecosystem. CEAT examined several factors related to lake water quality, including land use within the watershed, the impacts of residential and commercial development, and physical and chemical measurements of the lake itself. Lake water quality was the primary focus of the study due to its predictive value regarding overall watershed function and viability. The accumulation of nutrients in a lake due to surface runoff and erosion is a primary concern regarding lake water quality. If concentrations of nutrients, particularly phosphorus, reach threshold levels, a lake can experience algal blooms that decrease the aesthetic, recreational, ecological, and economic value of the lake.

A brief summary of CEAT findings in the Lake Wesserunsett watershed:

- During the period 1961-2000, the area of forest within the watershed increased by 9 percent, while the area of cleared land decreased by 17 percent. These changes in land use patterns exert a positive influence on the water quality of Lake Wesserunsett by reducing surface runoff and nutrient loading.
- Shoreline residential land area, as measured from aerial photographs, increased by 140 percent since 1961 (0.50 km² to 1.09 km²). Development and residential land use, particularly that which occurs near the shoreline, can have detrimental effects on lake water quality.
- Data from the CEAT house count and survey indicate that there are 213 total shoreline residences of which 68 percent are seasonal and 32 percent are year-round. Conversions of these seasonal residences to year-round will add to the potential nutrient loading in Lake Wesserunsett.

- Inadequate vegetative buffering along the shoreline creates a high risk of nutrient loading to the lake. Based on our study, only 35 percent of the properties along the shoreline of Lake Wesserunsett contain adequate buffer strips. The southeastern section of Lake Wesserunsett shoreline, which is subject to heightened wave action due to prevailing winds, is the most poorly buffered area, where only two percent of all properties surveyed have adequate buffer strips.
- Roads have a high potential to channel runoff containing phosphorus, various other nutrients, and sediment into the lake. Twenty-eight percent of the surveyed roads in the watershed are considered at high risk to lake water quality. To prevent adverse water quality effects, repair and maintenance of all roads and driveways in the watershed, especially those in close proximity to the lake, is essential.
- Most of the lakeshore has a high potential for erosion. Erosion potential was found to be highest in the Lakewood area and along the entire eastern shore of the lake, based on erosion hazard modeling developed using a Geographic Information System (GIS).
- The majority of the watershed is of moderate septic suitability. The land surrounding the north-east corner of the lake is best suited for the installation of septic systems. These conclusions are based on septic suitability modeling using GIS.
- Lake Wesserunsett has extremely soft water, leaving the lake susceptible to algal blooms at lower phosphorus concentrations than hard water lakes. Soft water may also compromise the health of organisms living in the lake, threatening the viability of fish populations.
- Transparency, color, turbidity, dissolved oxygen, temperature, pH, conductivity, alkalinity, and nitrates are all currently at safe levels in Lake Wesserunsett.

- Mean total phosphorus readings for spring, summer, and fall of 2000 were 12.0 ppb. The summer total phosphorus levels for Lake Wesserunsett averaged 15.1 ppb. These values are alarmingly close to the threshold level for lakes susceptible to algal blooms. Higher phosphorus levels in the summer may be due in part to the influx of seasonal residents and visitors.

Lake Wesserunsett is at a critical stage in the eutrophication process. Many human and natural processes are currently influencing the overall nutrient loading occurring in Lake Wesserunsett. Current development within the watershed poses an immediate threat to the balance of the lake ecosystem. Education, awareness, and community action will be instrumental in preserving the health of the Lake Wesserunsett ecosystem.

INTRODUCTION

GENERAL NATURE OF THE STUDY

Lakes are valuable natural resources. The lake and its surrounding watershed provide important habitats for numerous aquatic and terrestrial wildlife. In addition, lakes encourage the influx of both people and businesses because of the recreational opportunities they provide. Human activity has the potential to drastically alter the natural processes within a lake.

Lakes age through the natural process of eutrophication (Chapman 1996). A young, nutrient poor lake matures as nutrients are added from decaying organic matter as well as other sources. This increase in nutrients in turn promotes plant growth. Eutrophication is accelerated by human activities that increase the nutrients entering the lake. Phosphorus levels influence lake productivity because of their effect on plant growth. When nutrient levels become very high, algae populations bloom and cause the lake to become green and murky. Not only are algal blooms aesthetically unappealing, but they are also ecologically detrimental. Lower levels of dissolved oxygen as a result of algal blooms causes fishkills and decreased biodiversity (Chapman 1996).

The Lake Wesserunsett watershed was chosen as our study site. It is a characteristic New England lake located in Madison, Maine. Lake Wesserunsett is a popular site for recreation and development, and is home to many species of flora and fauna. This lake is at an intermediate stage of its life cycle. Although algal blooms have not yet occurred, human activities continue to contribute a substantial nutrient load. If the amount of nutrient input to the lake is carefully monitored and controlled, Lake Wesserunsett will remain healthy and productive.

The purpose of this study was to evaluate the impact of land use and development on the water quality of Lake Wesserunsett. The physical and chemical parameters of the lake were evaluated in order to determine the present water quality and trends over time. The current land use patterns were also examined and categorized with respect to their effect on water quality. Development within the watershed was evaluated through the assessment of residences, septic systems and roads. The water budget and flushing rate were also calculated. These test results were used to construct a phosphorus model, a tool used to predict present and future phosphorus loading. A

Geographic Information System (GIS) was used to construct models of land use and soil characteristics in the Lake Wesserunsett watershed. These models were used to predict future impacts of activities in the watershed on lake water quality. The results obtained from the lake and watershed analysis can be used to make recommendations concerning the health of Lake Wesserunsett. Water quality and land use assessment in this study was conducted by the Colby Environmental Assessment Team (CEAT) during the spring, summer and fall of 2000.

BACKGROUND

Lake Characteristics

Differences Between a Lake and a Pond

Lakes and ponds are inland bodies of standing water created either naturally, through geological processes or artificially, through human intervention (Smith and Smith 2001). Lakes and ponds differ in their size and depth profiles. Lakes most often have greater surface area and are deeper than ponds (Smith and Smith 2001). Lakes generally develop both vertical and horizontal stratification while ponds do not. Horizontal stratification in a lake divides the lake into zones based on sunlight penetration and the growth of vegetation. The littoral zone is the shallow-water zone in which sunlight can penetrate to the bottom allowing vegetation to grow from the substrate. The limnetic and profundal zones make up the deep-water area where sunlight cannot reach the bottom and rooted plants are not able to grow. A pond, on the other hand, does not have this zonation, as it is shallow enough that vegetation is rooted throughout (Smith and Smith 2001).

The vertical zonation found in a lake is dependent on density and water temperature. Deep lakes will stratify with the most dense water on the bottom and layers of less dense water toward the surface. Ponds and shallow lakes do not stratify because disturbance of wind and waves cause constant mixing and temperature distribution. Although Lake Wesserunsett does not stratify, it is considered a lake due to the lack of rooted vegetation throughout the lake basin.

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. Maine's beautiful lakes draw many tourists throughout the year and also serve as important habitats for wildlife.

The majority of Maine lakes were formed during the Wisconsinian glaciation of the Pleistocene period, which occurred about 10,000 years ago (Davis et al. 1978). As a result of glacial activity in Maine, glacial till, bedrock, and glaciomarine clay-silt dominate most lake basin substrates. Generally, these deposits and the underlying granitic bedrock, are of an infertile nature. As a result, most of Maine's lakes are relatively nutrient poor. The movement of glaciers in Maine was predominantly southeasterly, carving out Maine lakes in a northwest to southeast direction (Davis et al. 1978). This unique orientation, along with lake surface area and shape, play a fundamental role in the effect of wind on the water body. Wind is an important factor in lake turnover or the mixing of thermal layers.

Most lakes in Maine are located in lowland areas among hills (Davis et al. 1978). Many lake watersheds within the state are forested. These stands are potentially threatened by logging from timber companies. Residential development of watersheds and increased construction of lake recreation facilities may also pose a significant threat to the water quality in many lakes and ponds in Maine. In watersheds where agricultural practices are less significant, both residential development and forestry may be the most acute sources of anthropogenic, or human caused, nutrient loading (Davis et al 1978).

In Maine, many factors influence lake water quality. These include proximity to the ocean, location within the state, residence time of water within the soil, wetland influences, and bedrock chemistry (Davis et al. 1978). Terrestrial and aquatic vegetation as well as the presence of unique habitat types may also affect the water quality. Depth and surface area can affect temperature and turnover in the lake.

Annual Lake Cycles

Stratification is a vital component in lake ecosystem function, created by the different densities due to variations in temperature with depth. Water has the unique physical property of being most dense at 4° C (Smith and Smith 2001). Water decreases in density at temperatures above and below 4° C, allowing ice to float on the surface of lakes and ponds because it is less dense than the warmer water below it.

In the summer, direct radiation warms the upper levels of the water column forming the epilimnion, which hosts the most abundant floral communities (Davis et al. 1978). The photosynthetic capacities of the plants create an oxygen rich stratum. However, available nutrients in the epilimnion can be depleted by algal populations growing in the water column and may remain depleted until the turnover of early fall (Smith and Smith 2001). The process of lake cycling is summarized in Figure 1.

Below the epilimnion is a layer of sharp temperature decline, known as the metalimnion (Smith and Smith 2001). Within this stratum is the greatest temperature gradient in the lake, called the thermocline (Smith and Smith 2001). This thermocline separates the epilimnion from the hypolimnion, the lowest stratum of a lake. The hypolimnion, only found in the deepest lakes, is beyond the depth to which sufficient light can penetrate in order to facilitate effective photosynthesis (Figure 1). It is in the substrate of the hypolimnion, where most decomposition of organic material takes place through both aerobic and anaerobic biological processes. While aerobic (requiring oxygen) bacteria break down organic matter quicker than anaerobic bacteria, they also significantly deplete the oxygen at these depths (Davis et al. 1978).

As the months become colder, water temperature decreases and wind facilitates thermal mixing until the vertical profile of the water column is uniform in temperature. This event, known as turnover, reoxygenates the lower depths and mixes nutrients throughout the strata. The cold water near the surface can hold increased levels of oxygen, which is redistributed with turnover. Through this process, organisms at depth receive oxygenated water. A similar turnover event also occurs in the spring (Smith and Smith 2001).

In winter, lakes in Maine are covered with ice for 4-5 months. The stratification is reversed as

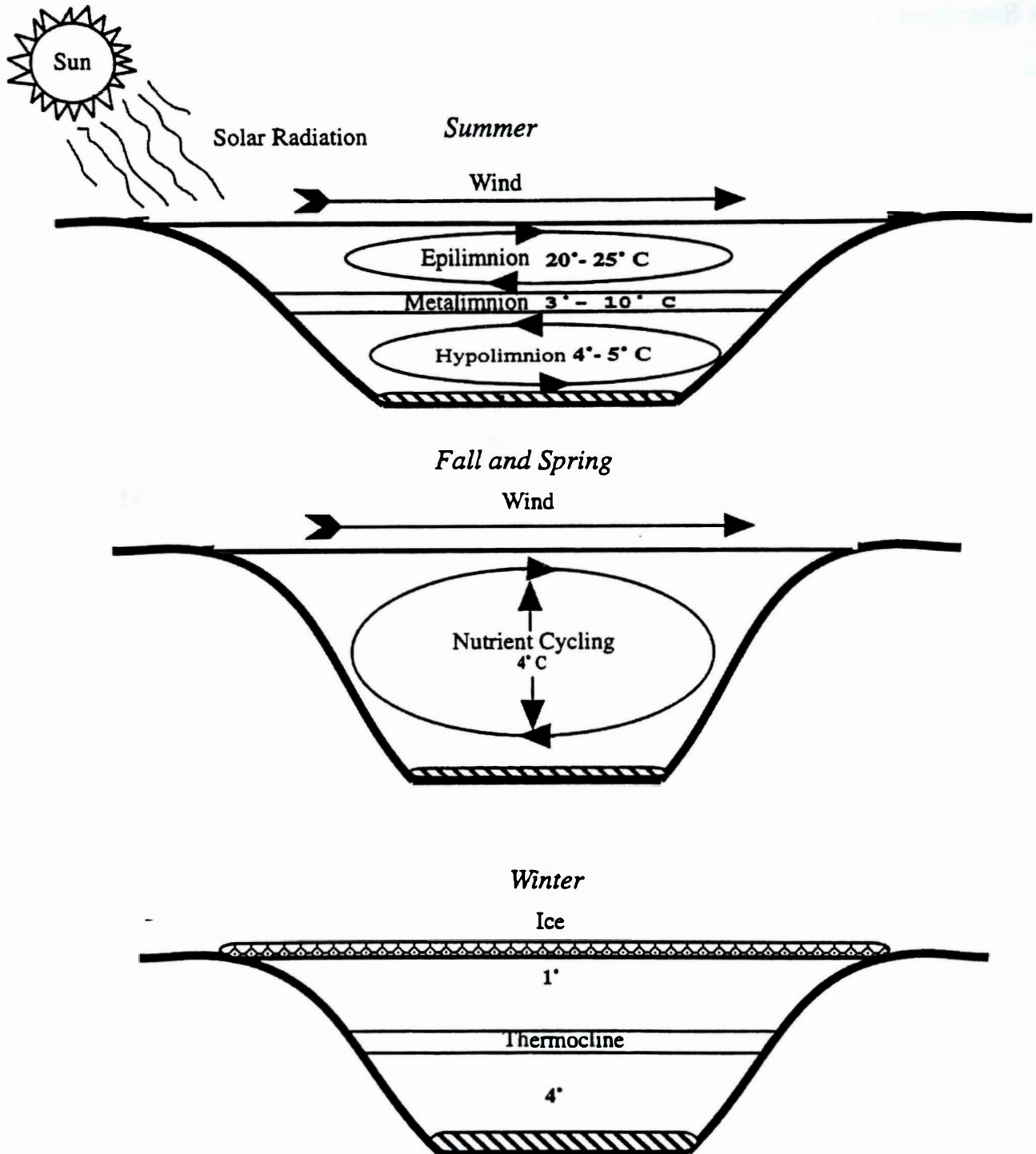


Figure 1. Mixing by means of lake turnover. During the summer, lakes are stratified into three layers (epilimnion, metalimnion, and hypolimnion). During the fall and spring, the isothermal temperature and density facilitate lake turnover and redistribution of nutrients. In the winter, the lake is again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

the coldest water (ice) is on the surface and the warmer water (4° C) is at depth. Significant snow cover on the ice may affect the photosynthetic processes during the winter months under the ice by blocking some of the incoming solar radiation. This situation can deplete oxygen levels enough to cause significant fishkills (Smith and Smith 2001).

In the spring solar radiation warms the upper stratum of the lake and the ice melts. Once the temperature in the water column is uniform, oxygen and nutrients are again mixed throughout the water column. As late spring approaches, solar radiation increases, stratification becomes evident and temperature profiles return to that of summer (Smith and Smith 2001).

Trophic Status of Lakes

One biological classification of lakes is based on nutrient levels (Maitland 1990). Lakes are divided into four major categories: oligotrophic, mesotrophic, eutrophic, and dystrophic (Table 1). The mesotrophic characterization is not included in Table 1, because it is referred to as a transitional stage between oligotrophic and eutrophic states (Chapman 1996). Young or oligotrophic lakes are lacking in nutrients, while eutrophic lakes are nutrient rich (Niering 1985). Oligotrophic lakes tend to be deep and oxygen rich with steep-sided basins creating a low surface to volume ratio. Although they may be high in nitrate levels, oligotrophic lakes are primarily deficient in phosphorus, the limiting nutrient for plant productivity in most freshwater ecosystems. The shape of a lake can also influence its productivity. Steep-sided oligotrophic lakes are not conducive to extensive growth of rooted vegetation because there is no shallow margin for attachment.

Eutrophic lakes are nutrient rich (Chapman 1996) and have a relatively high surface to volume ratio (Maitland 1990). These lakes have a large phytoplankton population that is supported by the increased availability of dissolved nutrients (Table 1). Low dissolved oxygen levels at the bottom of a eutrophic lake are a result of high decomposition activity. This activity leads to the release of phosphorus and other nutrients from the bottom sediments, resulting in their eventual recycling through the water column (Chapman 1996). This nutrient release stimulates even further growth of phytoplankton populations such as algae (Smith and Smith 2001). Due to sediment loading over the

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

years, eutrophic lakes tend to be shallow and bowl shaped, which allows for the establishment of rooted plants.

Dystrophic lakes receive large amounts of organic matter from the surrounding land, particularly in the form of humic (dead organic) materials (Smith and Smith 2001). The large quantity of humic materials stains the water brown. Dystrophic lakes have highly productive littoral zones, high oxygen levels, high macrophyte productivity, and low phytoplankton numbers (Table 1). Eventually, the invasion of rooted aquatic macrophytes chokes the habitat with plant growth. The lake basin is filled in, resulting in the development of a terrestrial ecosystem (Goldman and Home 1983).

The natural aging process of a lake begins as oligotrophic and progresses through eutrophication, eventually to become a terrestrial landscape (Niering 1985). This process can be greatly accelerated by anthropogenic activities, which increase nutrient loading. 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 cyanobacteria and/or green algae
- 5) Decreasing light penetration (e.g., increasing turbidity)
- 6) Increasing phosphorus concentrations in the sediments (Henderson-Sellers and Markland 1987)

As a lake ages, it fills with dead organic matter and sediment from various inputs that settle to the bottom. Lakes may receive mineral nutrients from streams, groundwater, and runoff as well as precipitation. The increase in nutrient availability promotes primary productivity. Increased productivity leads to more dead organic material that accumulates as sediment in lentic ecosystems (standing bodies of water such as lakes and ponds). Over time, lakes will fill in, decrease in size, and are eventually replaced by a terrestrial community (Chiras 1994).

Phosphorus and Nitrogen

In freshwater lakes, phosphorus and nitrogen are the two major nutrients required for the growth of algae and macrophytes (Smith and Smith 2001). Each nutrient has its own complex chemical cycle within the lake (Overcash and Davidson 1980). It is necessary to understand these cycles in order to devise better techniques to control high nutrient levels.

Phosphorus is 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 parts per billion (ppb). However, this concentration is sufficient for plant growth, due to the high efficiency with which plants can assimilate phosphorus (Maitland 1990). There are multiple external sources of phosphorus (Williams 1992), but a large supply is also found in the lake sediments (Henderson-Sellers and Markland 1987). The cycle of phosphorus in a lake is complex, with some models including up to seven different forms of phosphorus (Frey 1963).

For the purposes of this study it is necessary to understand two broad categories of phosphorus in a lake: dissolved phosphorus (DP), and particulate phosphorus (PP). The phosphorus cycle in a stratified lake is summarized in Figure 2. DP is an inorganic form of phosphorus, which is readily available for plant use in primary production. It is this form of phosphorus that is limiting to plant growth. PP is a form of phosphorus, which is incorporated into organic matter such as plant and animal tissues. DP is converted to PP through the process of primary production. PP then gradually settles into the hypolimnion in the form of dead organic matter. PP can be converted to DP through aerobic and anaerobic processes. In the presence of oxygen, PP will be converted to DP through decomposition by aerobic bacteria. In anoxic conditions, less efficient anaerobic decomposition occurs (Lerman 1978).

An important reaction occurs in oxygenated water, 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. Fe(III) is reduced to Fe(II) in the presence of decreased oxygen levels at the sediment water interface, resulting 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

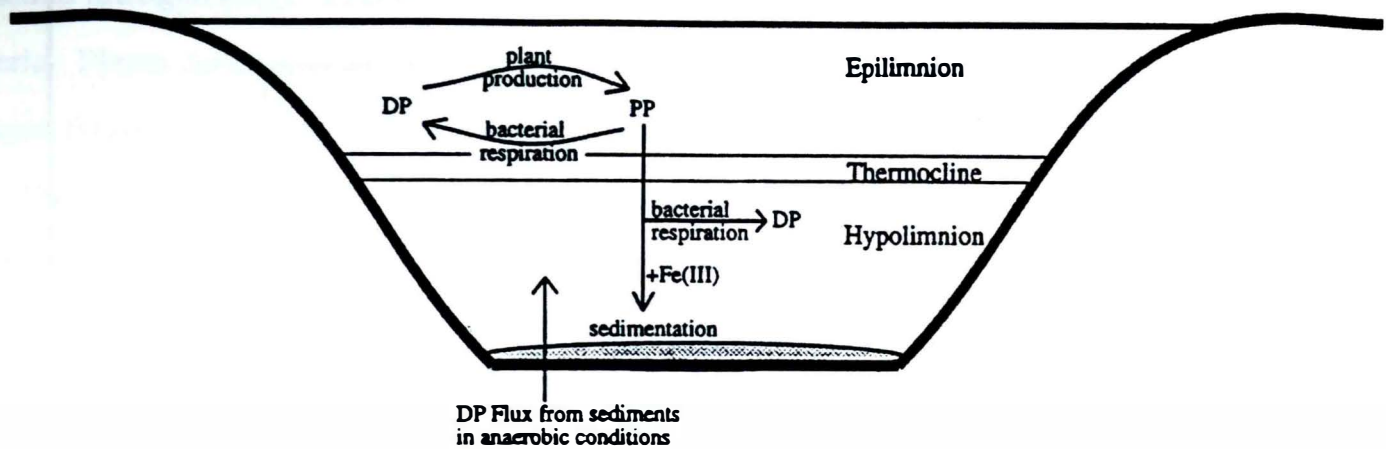


Figure 2. A model of the cycle of the major forms of phosphorus, dissolved (DP) and particulate (PP), within a lake ecosystem. The sedimentation of DP through complexation with Fe (III) contributes to the build-up of DP in the sediments. Note the production of DP in the hypolimnion due to bacterial decomposition 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).

anoxic sediments. The sediments of a lake can have phosphorus concentrations of 50-500 times the concentration of phosphorus in the water (Henderson-Sellers and Markland 1987). Sediments can be an even larger source of phosphorus than external inputs. Because nutrients are inhibited from mixing into the epilimnion during the summer by stratification, DP concentrations build up in the lower hypolimnion until fall turnover.

The fall turnover results in a large flux of nutrients creating the potential for algal blooms. Algal blooms can occur when phosphorus levels rise above 12 to 15 ppb. 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).

Nitrogen, the other major plant nutrient, 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 concentra-

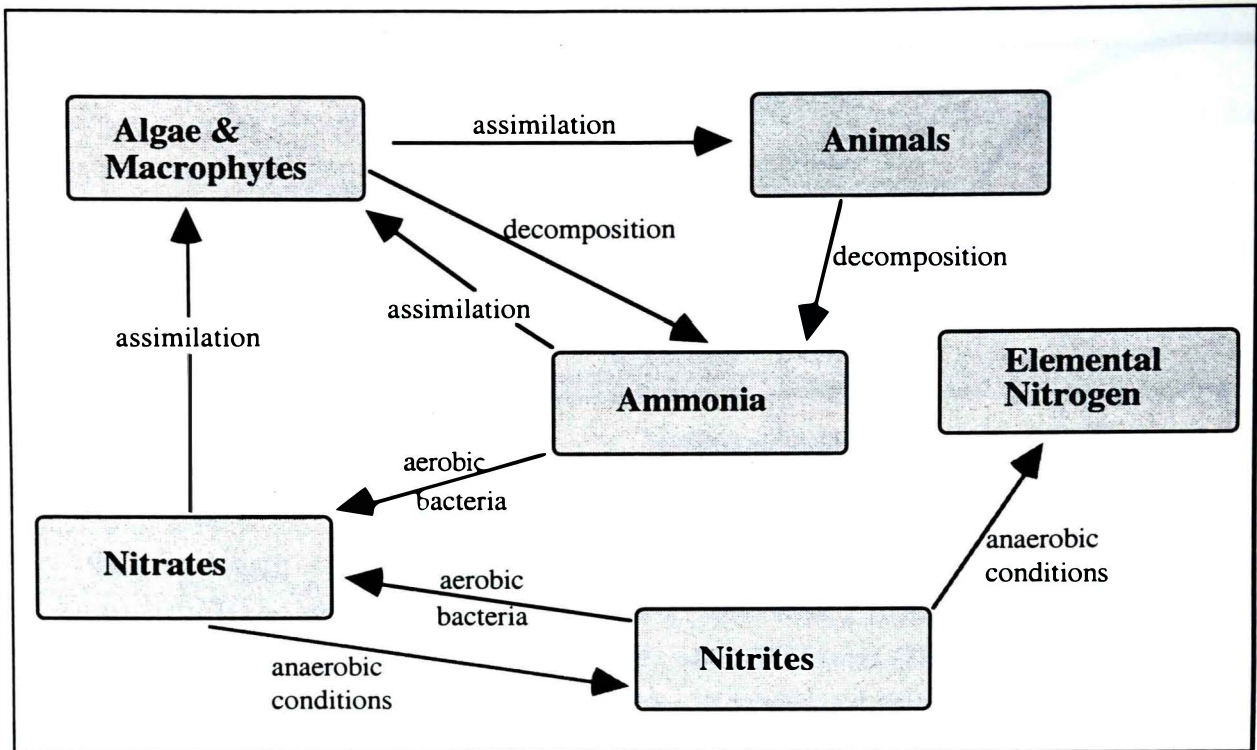


Figure 3. A diagram of the various forms of nitrogen that occur in the nitrogen cycle within a lake ecosystem. It is important to note that in aerobic conditions both ammonia and nitrites are converted to nitrates which are available for use by plants.

tions can lead to algal blooms in the presence of phosphorus.

Available nitrogen exists in lakes in three major chemical forms: nitrates (NO_3^-), nitrites (NO_2^-), and ammonia (NH_3). The nitrogen cycle is 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. In eutrophic lakes, there may be so much algae and macrophyte growth that most of the nitrates in the lake are incorporated into plant 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 one of three paths. First, many macrophytes can assimilate ammonia directly into their tissues. In aerated conditions, aerobic bacteria will convert the ammonia directly to nitrates, the more usable form of nitrogen. In 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 broken down to

elemental nitrogen (N_2). This form is not available to any plants without the aid of nitrogen-fixing bacteria. Plants depend on these bacteria to convert nitrogen to nitrates through the process of nitrogen fixation (Overcash and Davidson 1980).

The underlying pattern evident from this cycle is that all forms of nitrogen added to the lake will eventually become available for plant use. The various forms of nitrogen as well as the oxygen concentrations (aerobic and anaerobic conditions) of the water must be considered in order to understand the availability of this nutrient for plant growth.

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). 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 technique used to eliminate excessive nutrients is to rapidly decrease the water level of the lake (Henderson-Sellers and Markland 1987). A lake controlled by a dam can quickly be flushed by releasing a large volume of water. The result may be the rapid export of many nutrients from the epilimnion of the lake. However, in cases where the lake drains into another lake or significant water body, the problem may not be eliminated, but simply shifted to another site. Additionally this may only be a temporary solution because if the nutrient source is not eliminated it will continue to supply nutrients to lake.

Another approach to 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. It is based on the natural affinity of iron to complex 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 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, and therefore, no DP will be 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 tied up in the plants at the time of harvest, preventing them from re-entering the lake cycle. It is important that harvested plants are not left along the shore, allowing nutrients from decomposing plants to leach into the lake. There is some debate over the effectiveness of this method because macrophytes also act as a sink for nutrients. At the time of removal, the nutrients that would normally have been taken up by the macrophytes 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 take up nutrients via the roots.

One final management option is dredging. This process extracts the nutrients from the sediments by removing the sediments themselves. Although dredging is effective, it is extremely expensive due to the large amount of labor and equipment cost needed (Henderson-Sellers and Markland 1987). There are additional questions as to the ecological disruption that these actions may have on the lake ecosystem.

It is evident from these techniques that eliminating nutrients once they have built up in a lake is a challenging task. The ideal method for controlling nutrients in a lake is to regulate and monitor the input sources. This allows the natural processes of nutrient cycling and uptake by flora and fauna to compensate for nutrient inputs without accelerated eutrophication of the lake.

Freshwater Wetlands

Wetlands are important transitional areas between lake and terrestrial ecosystems. They support a wide range of biotic species (MLURC 1976). Table 2 gives descriptions of freshwater inland

Table 2. Descriptions of site characteristics and plant populations of different types of freshwater inland wetlands (Smith and Smith 2001).

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
Freshwater meadows	Without standing water during growing season; waterlogged to within a few inches of surface	Grasses, sedges, broadleaf plants, rushes
Shallow freshwater marshes	Soil waterlogged during growing season; often covered with 15 cm or more of water	Grasses, bulrushes, spike rushes, cattails, arrowhead, pickerel weed
Deep freshwater 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

wetlands. Wetlands also help to maintain lower nutrient levels in an aquatic ecosystem because of the efficiency in nutrient uptake by their vegetation (Smith and Smith 2001). Wetlands have the potential to absorb heavy metals and nutrients from various sources including mine drainage, sewage, and industrial wastes (Chiras 1994). Agricultural runoff adds excess nitrogen and phosphorus to the lake. Wetlands are able to improve the overall water quality by the absorption and storage of nutrients through their assimilation into organic plant tissues (Niering 1985).

Wetlands usually have a water table 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 that is adapted for life in saturated and anaerobic soils (Chiras 1994).

Watershed Land Use

Land Use Types

A watershed is the total land area that contributes a flow of water to a particular basin. The boundary of a watershed is defined by the highest points of land that surround a lake or pond and its tributaries. Any water introduced to a watershed will be absorbed, evaporate (including transpiration by plants), or flow into the basin of the watershed.

Nutrients bind to soil particles. If eroded, nutrient-rich soil will add to the nutrient load of a lake, hastening the eutrophication process and leading to algal blooms (USEPA 1990). Due to influence on erosion and runoff, different types of land use have distinct effects on nutrient loading in lakes. Assessment of land use within a watershed is therefore essential in the determination of factors that affect lake water quality.

A land area cleared for agricultural, residential, or commercial use contributes more to nutrient loading than a naturally vegetated area such as forested land (Dennis 1986). The combination of vegetation removal and soil compaction involved in the clearing of land results in a significant increase in surface runoff. This amplifies the erosion of sediments carrying nutrients and pollutants of human origin.

Naturally vegetated areas offer protection against soil erosion and surface runoff (Firmage,

pers. comm). The forest canopy reduces erosion by diminishing the direct physical impact of rain on soil. The root systems of trees and shrubs reduce soil erosion by decreasing the rate of runoff, allowing water to percolate into the soil. Roots decrease the nutrient load in runoff through direct absorption of nutrients for use in plant structure and function. Due to these features, a forested area acts as a buffering system by decreasing surface runoff and absorbing nutrients before they enter water bodies.

Residential areas are a significant threat to lake water quality for a number of reasons. These areas generally contain lawns, driveways, parking spaces, roof-tops and other impervious surfaces that reduce percolation and thereby increase surface runoff. Due to their proximity to lakes, shoreline residences are often direct sources of nutrients to the water body.

Because forests cover much of Maine, the development or expansion of residential area often necessitates the clearing of wooded land. New development dramatically increases the amount of surface runoff because natural ground cover is replaced with impervious surfaces (Dennis 1986). Evidence of increased surface runoff due to development and consequent effects on nutrient transport is presented in a study concerning phosphorus loading in Augusta, Maine (Figure 4). The study revealed that surface runoff from a residential area contained ten times more phosphorus than runoff from an adjacent forested area. The study concluded that the surface-runoff flow rate of residential area can be in excess of four times the rate recorded for forested land.

The use of chemicals in and around the home is potentially harmful to water quality. Products associated with cleared and residential land include fertilizers, pesticides, herbicides, and detergents that often contain nitrogen, phosphorous, other plant nutrients and miscellaneous chemicals (MDEP 1992a). These products can enter a lake by leaching directly into ground water or traveling with eroded sediments. Heavy precipitation aids the transport of these high nutrient products due to increased surface runoff near residences (Dennis 1986). Upon entering a lake, these wastes have adverse effects on water quality.

Septic systems associated with residential and commercial land are significant sources of nutrients when improperly designed, maintained, or used (USEPA 1980). Proper treatment and disposal of nutrient rich human waste is essential in maintaining high lake water quality.

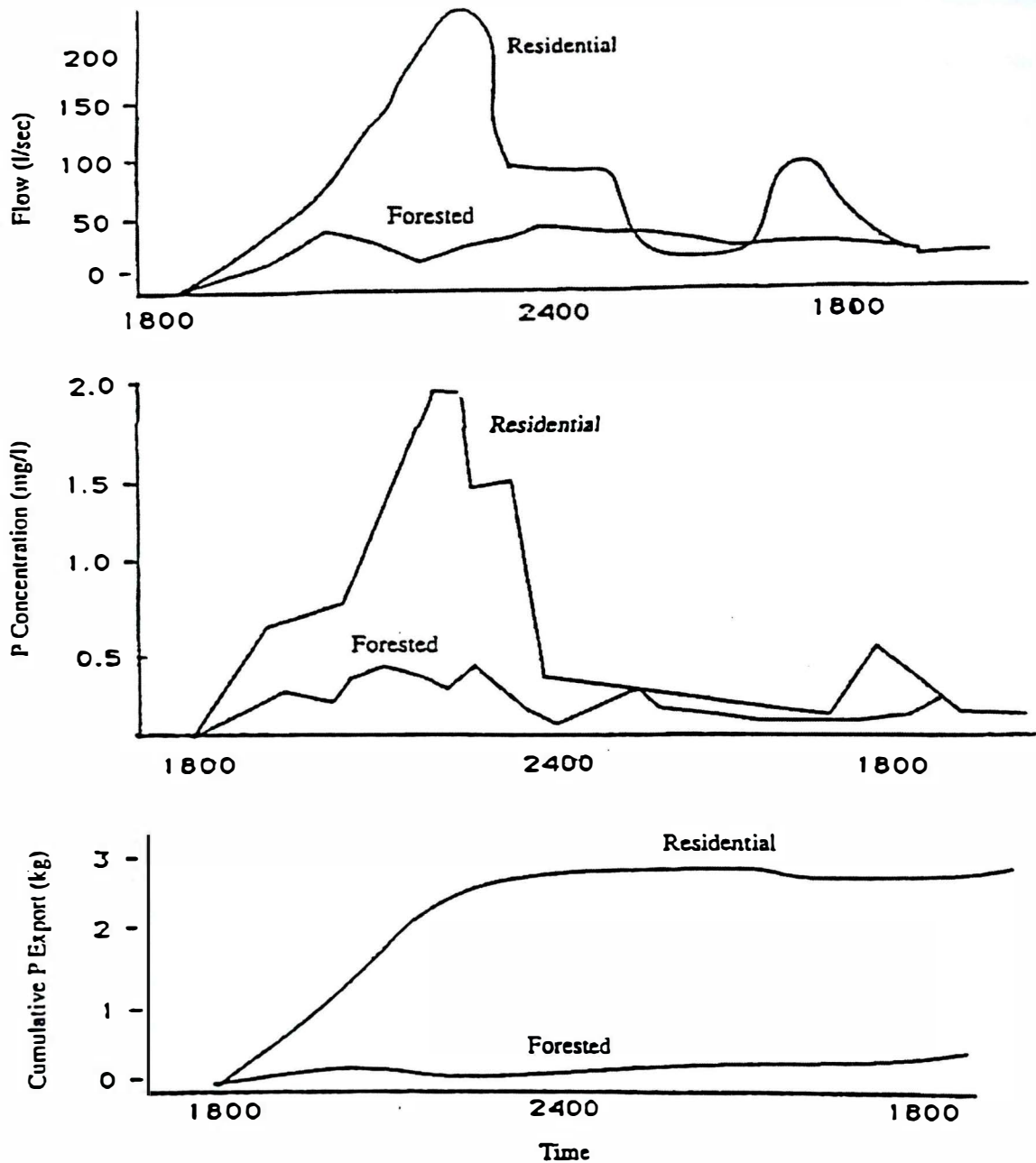


Figure 4. Comparisons of runoff after an April rain storm in two neighboring watersheds near Augusta, ME. Top: volume of immediate runoff over a 12 hour period; Middle: phosphorus concentration in the runoff; Bottom: total amount of phosphorus exported into local streams and lakes from the storm (Dennis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

Commercial uses of forested land can have detrimental effects on lake water quality. Activities that remove the cover of the canopy and expose the soil to direct rainfall increase erosion. Two

studies by the Land Use Regulation Commission on tree harvesting sites noted that erosion and sedimentation problems occurred in 50 percent of active and 20 percent of inactive logging sites selected (MDC 1983). Skidder 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 must be maintained between a skidder trail and the normal high water line of a body of water or upland edge of a wetland to alleviate the potential impact of harvesting on the water body (MDEP 1990).

Roads are a source of excessive surface runoff if they are poorly designed or maintained (Michaud 1992). Different road types have varying levels of nutrient loading potential. In general, roughly 80% of the nutrient loading problems are caused by only 20% of the culverts or crossings. Furthermore, roads and driveways leading to shoreline areas or tributaries can cause runoff to flow directly into a lake.

As land use conversion occurs, it is critical that factors influencing nutrient loading are considered. Public education and state and local regulations that moderate nutrient loading are essential in maintaining lake water quality. Understanding the effects of changing land use practices is critical in evaluating the ecological health of a watershed ecosystem and making predictions about its future.

Buffer Strips

Buffer strips play an important role in absorbing runoff, thereby helping to control the amount of nutrients entering a lake (MDEP 1990). Excess amounts of nutrients such as phosphorus and nitrogen can promote algal growth and increase the eutrophication rate of a lake (MDEP 1990). According to the Shoreline Zoning Ordinance for the Municipality of Madison, “within a strip of land extending 100 ft horizontal distance inland from the normal high water line of Lake Wesserunsett, and 75 ft horizontal distance from any other water body, tributary stream, or the upland edge of a wetland, a buffer strip of vegetation should be observed” (Madison 1995).

A good buffer should have several vegetation layers and a variety of plants and trees to

maximize the benefit of each layer (MDEP 1990). Naturally occurring vegetation forms the most effective buffer. Trees and their canopy layer provide the first defense against erosion by lessening the impact of rain and wind on the soil. Their deep root systems absorb water and nutrients while maintaining the topographical structure of the land. The shallow root systems of the shrub layer also aid in absorbing water and nutrients, and help to hold the soil in place. The groundcover layer, including vines, ornamental grasses, and flowers slows down surface water flow, and traps sediment and organic debris. The duff layer, consisting of accumulated leaves, needles, and other plant matter on the forest floor, acts like a sponge to absorb water and trap sediment. Duff also provides a habitat for many microorganisms that break down plant material and recycle nutrients (MDEP 1990).

An example of an ideally buffered home is shown in Figure 5. This home has a winding path down to the shoreline. Runoff is diverted into the woods where it can be absorbed in the forest litter. The house itself is set back from the shoreline 100 ft, and has a dense buffer strip between it and the water. The buffer is composed of a combination of canopy trees, understory shrubs and

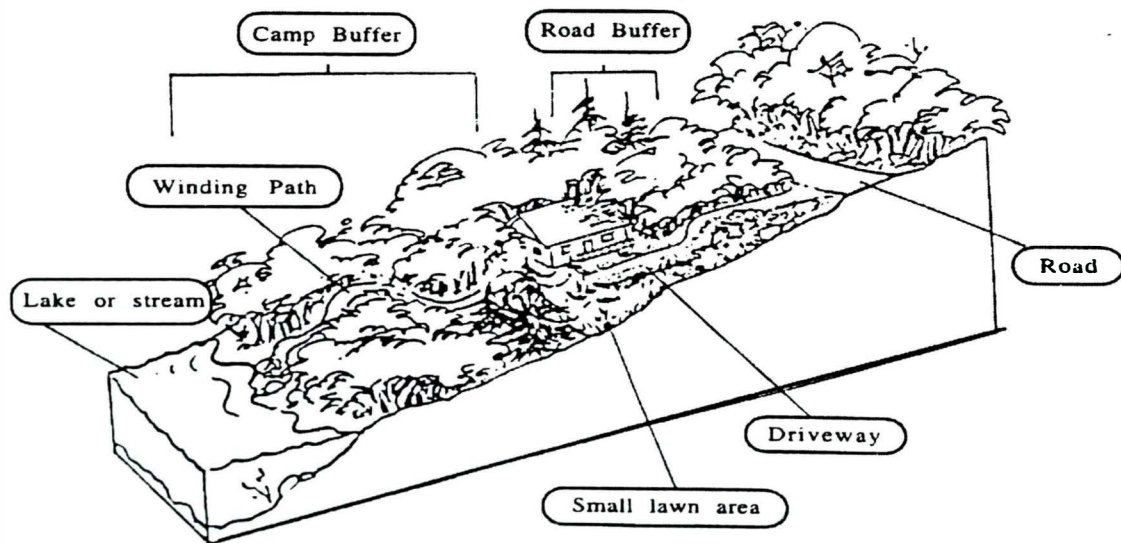


Figure 5. Diagram of an ideally buffered home.

groundcover. In addition, the driveway is curved. This allows for runoff that is accumulating on these surfaces to be deposited into a number of diversions along its path down the slope of the land. As opposed to a steep, straight, and paved path that leads directly into the water, a curved driveway

can be a very effective deterrent to runoff. Slopes within a buffer strip that are less than two percent are most effective at slowing down the surface flow and increasing absorption of runoff (MDEP 1998). Steep slopes are susceptible to heavy erosion and will render buffer strips ineffective.

In addition to buffer strips, riprap can be an effective method of preventing shoreline erosion by protecting the shoreline and adjacent shoreline property against heavy wave action (MDEP 1990). Riprap consists of three primary components: the stone layer, the filter layer, and the toe protection. The stone layer consists of rough, large, angular rock. The filter layer is composed of a special filter cloth that allows groundwater drainage and prevents the soil beneath the riprap from washing through the stone layer. The toe protection prevents settlement or removal of the lower edge of the riprap. Riprap depends on the soil beneath it for support, and should therefore be built only on stable shores or bank slopes (MDEP 1990).

Nutrient Loading

Nutrient loading into a lake can be affected by natural and anthropogenic processes (Hem 1970). Human activity usually accelerates the loading of nutrients and sediments into a lake. In this way, the water quality can be adversely affected in a short period of time. Clearing away forests to construct roads and buildings with impervious surfaces increases runoff, carrying nutrients from agricultural, residential, and industrial products (such as detergent, fertilizer, and sewage) into the lake. Since phosphorus and nitrogen are the limiting nutrients to 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 eventual eutrophication.

Total phosphorus loading to a lake can be determined using a phosphorus loading model. 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). The model allows for the projection of the impact that various factors may have on phosphorus loading and generates predictions of lake responses to changes in land use. The accuracy of the predictions is determined by the accuracy of the assumptions (USEPA 1990).

Soil Types

Nutrient loading in a lake ecosystem is partially 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 to the water table, and depth to the bedrock) which influence them, are important to consider in determining 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 these criteria should be considered carefully before implementing a development, forestry, or agricultural plan.

Zoning and Development

The purpose of shoreline zoning and development ordinances is to control water pollution, protect wildlife and freshwater wetlands, monitor development and land use, conserve wilderness, and anticipate the impacts of development (Madison 1995). Shoreline zoning ordinances regulate development along the shoreline in a manner that reduces the chances for adverse impacts on lake water quality. Uncontrolled development along the shoreline can result in a severe decline in water quality that is difficult to correct. 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. This study considered houses less than 200 feet from the shoreline to be shoreline residences. Any nutrient additives from residences (such as fertilizers) have only a short distance 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 building and the body of water in question. Town ordinances in Madison regulate buffer strip widths, which help to control phosphorus loading in the lake.

Residences that have lawns leading directly down to the shore have no obstacles to slow runoff, allowing 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 shoreline residences (MDEP 1992b).

Seasonal residences, especially older ones 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 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 location and condition of septic systems also effects the nutrient loading from these plots (see: Sewage disposal systems).

Non-Shoreline Residential Areas

Nonshoreline residential areas (greater than 200 feet from the shoreline) can also have an impact on nutrient loading, but generally less than that of shoreline residential areas. Runoff, carrying fertilizers and possibly phosphorus containing soaps and detergents, 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 potentially supply the lake with phosphorus almost directly when poorly constructed roads persist. Runoff collected on

roofs and driveways may travel unhindered down roads or other runoff channels 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. Therefore, similar restrictions and regulations as those for shoreline residences apply to nonshoreline homes that are located along many 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.

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 can be decomposed and treated. Little water is used with pit privies therefore chances of ground water contamination are reduced. Contamination due to infiltration of waste into the upper soil levels may occur if the privy is located too close to a body of water

Holding Tank

Holding tanks are watertight, airtight chambers, usually with an alarm, which 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 leak into the ground, causing contamination. According to Paul Lussier (pers. comm.), the plumbing inspector for Waterville, holding tanks are “the system of last resort”. Although purchasing a holding tank is inexpensive, the owner is then required to pay to have the holding tank pumped on a regular basis.

Septic System

Septic systems are the most widely used subsurface disposal system. The system includes a building sewer, treatment tank, effluent line, disposal area, distribution box, and often a pump. The pump enables the effluent to be moved to a more suitable leach field 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. Septic systems are an efficient and economical alternative to a sewer system, provided they are properly installed, located, and maintained. Unfortunately, many septic systems that are not installed or located 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 to prevent contamination of the water by untreated septic waste. The shoreline regulations in Madison state that septic systems need to be at least 100 ft away from a lake and 50 ft away from streams. Unfortunately, many parcels of land are grandfathered, which means their septic systems were installed before the passage of current regulations. 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 an alternative

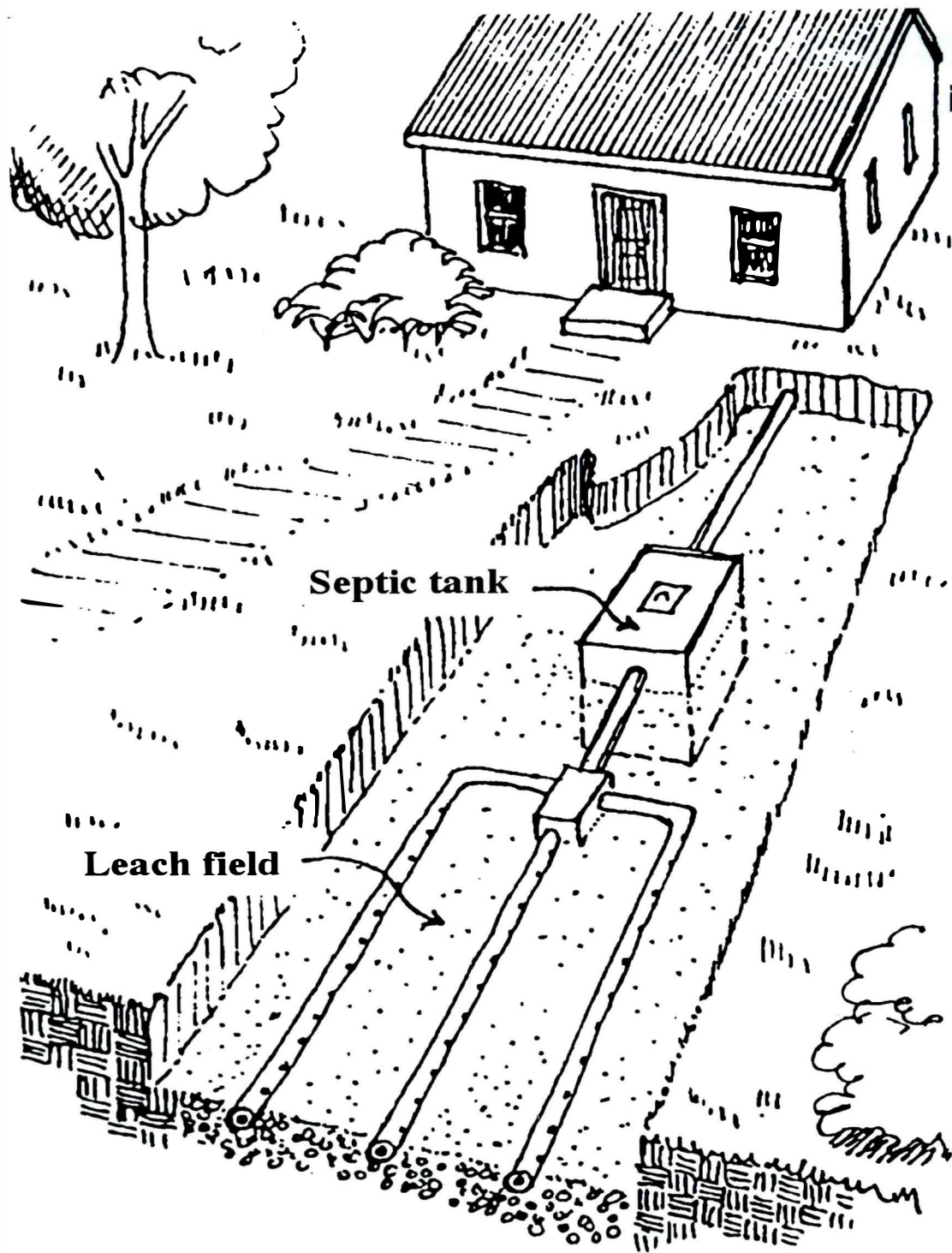


Figure 6. The layout of a typical septic system (Williams 1992)

disposal area further from the water body (MDHS 1983).

Human waste and gray water are transferred from a residence through the building sewer to the treatment tank. There are two kinds of treatment tanks, aerobic and septic, both of which are tight,

durable, and usually made of concrete or fiberglass (MDHS 1983). The aerobic tanks rely on aerobic bacteria, which are more active than anaerobic bacteria. Unfortunately, aerobic bacteria are also more susceptible to condition changes. These tanks also require more maintenance, energy to pump in fresh air, and are more expensive. For these reasons, septic tanks are preferable. Septic tanks rely on anaerobic bacteria. Solids are held until they are sufficiently decomposed and suitable for discharge (MDHS 1983).

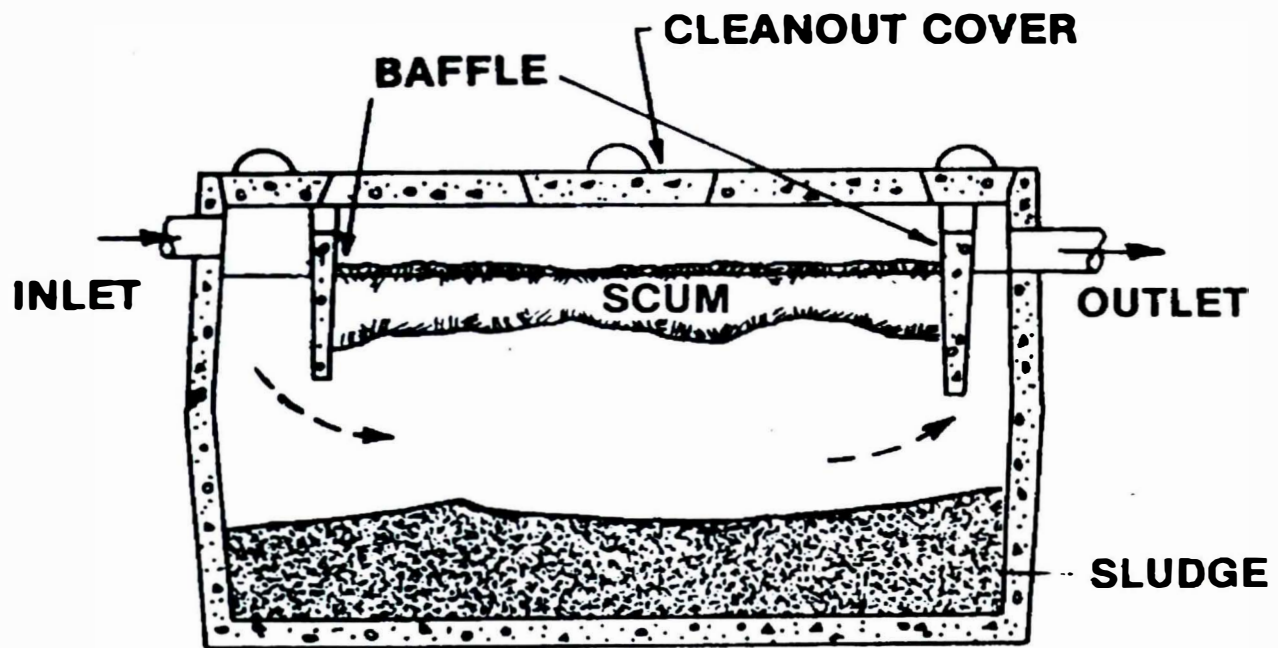


Figure 7. The cross-section of a typical treatment tank showing the movement of effluent through the tank as well as the separation of the scum and sludge (MDHS 1983).

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 by 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 then travels through the effluent line to the disposal area.

The purpose of a disposal area is to provide additional treatment of the wastewater. 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 contains anaerobic bacteria as it leaves the treatment tank. Treatment is considered complete when aerobic action in the disposal field has killed the anaerobic bacteria. If the effluent is not treated completely, it can be a danger to a water body and the organisms within it, as well as to human health. Incomplete treatment of the effluent is also a threat to groundwater. Three threats to lakes include organic particulates, nutrient loading, and water contamination through the addition of viruses and bacteria (MDHS 1983). Organic particulates also increase the biological oxygen demand (BOD).

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 depletes dissolved oxygen, species within a lake may begin to die. If a lake's flushing rate is low, reduced dissolved oxygen levels and increasing organic matter could become problematic.

The three major types of wastes that travel into the septic system are garbage disposal wastes, black water, and gray water. Garbage disposal wastes can easily back up the septic system and therefore should not be discharged to a 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 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 should never be disposed of in septic systems as they are not easily broken down by the microorganisms and fill 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 over the disposal field, and slow drainage are symptoms of a septic system that has been subject to heavy use and not functioning properly

When constructing a septic system, it is important to consider soil characteristics and topography when determining the best location. An area with a gradual slope (10 to 20 percent) that allows for gravitational pull is necessary for proper sewage treatment (MDHS 1988). Too gradual of a slope causes stagnation, while too steep a slope drains the soil too quickly. Treatment time is cut short and water is not treated properly. Adding or removing soils to decrease or increase the slope is one solution to this problem.

Soil containing loam, sand, and gravel allows the proper amount of time for runoff and purification (MDHS 1983). Soils 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, waste will remain near the soil surface. Fine soils such as clay do not allow for water penetration, again causing wastewater to run along the soil surface untreated. Adding loam and sand to clay-like soils would help alleviate this problem. In the opposite case, if a soil drains too quickly, loam and clay can be added to slow down the filtration of wastewater.

Federal, state, and local laws are in place to protect land and water quality. The federal government sets minimum standards for subsurface waste disposal systems. States can then choose to make their rules stricter but not more lenient than federal guidelines.. Maine's Comprehensive Land Use Plan sets standard regulations that each city and town must follow. Individual municipalities

have the ability to establish their own comprehensive land use plan in accordance with the state regulations. However, many towns develop local ordinances that consider specific issues such as shoreline zoning. The Maine Department of Environmental Protection (MDEP), Maine Department of Conservation (MDC), 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 (MDHS 1988). Also, 20 percent is the maximum slope of the original land that can support a septic system. These regulations are in place for the safety of people living in the Lake Wesserunsett watershed as well as for the aquatic ecosystem.

Roads

Roads can significantly contribute to the deterioration of water quality by adding phosphorus to runoff and creating a route to the lake for the runoff to travel down. They may allow easy access for runoff of other nutrients and organic pollutants into the lake via improperly constructed culverts and ditches. Improper road construction and maintenance can increase the nutrient load entering the lake.

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 increase road deterioration by dislodging particles from the road surface. Nutrients attached to these particles are transported to the lake by runoff from the roads (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). A well constructed road should divert road surface waters into a vegetated area to prevent excessive amounts of surface runoff, phosphorus, and other nutrients from entering the lake. Items which should be considered before construction begins include: road location, road area, road surface material, road cross section, road drainage (ditches, diversions, and culverts), and road maintenance (MDEP 1992a).

Although the State of Maine has set guidelines to control the building of roads, road location is typically determined by the area in which homes are built (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).

Designing a road with future use in mind is very important. 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). Proper planning for maintenance is a more effective, practical, and economical way to develop the road area (Woodard 1989).

Road surface material is another important factor to consider in road construction. Studies have shown that phosphorus washes off paved surfaces at a higher rate than from sand and gravel surfaces (Lea, Landry, and Fortier 1990). On the other hand, sand and gravel roads erode more quickly and have the potential for emptying more sediment and nutrients, into a body of water. 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 areas. Both types of roads need proper maintenance and gravel road surfaces should be periodically replaced and properly graded so that a stable base may be maintained and road surface erosion minimized.

The road cross section is another important factor to consider when planning road construction. A crowned road cross section allows for proper drainage 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 gravel roads (Michaud

1992). This slope allows the surface water to run off down either side of the road as opposed to running along 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 and the land that surrounds it must also be considered during construction or maintenance projects. Both ditches and culverts are used to help drain roads into buffer zones where nutrients added by the road can be absorbed by vegetation. 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, are of a sufficient depth, and do not exceed a depth to width ratio of 2:1. The ditch should be free of debris and covered with abundant vegetation to reduce erosion (Michaud 1992). Ditches must also be constructed of a proper soil that will not be easily eroded by the water flowing 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 that will pass through it during the peak flow periods of the year. 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 sediment load entering the lake. The culvert must be set in the ground at a 30° angle down slope with a pitch of 2 percent to 4 percent (Michaud 1992). A proper crown above the culvert is necessary to avoid creating a low center point in the culvert. The standard criteria for covering a culvert 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 runoff into wooded or grassy areas, natural buffers are used to filter sediment and decrease the volume of water through infiltration before the it reaches the lake (Michaud 1992). Efficient installation and spacing of diversions can also reduce 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 a lake. Over time, roads deteriorate. Problems will only become worse if

ignored and will cost more money in the long run to repair. Roads should be periodically graded, and ditches and culverts cleaned and regularly inspected to assess any problems that may develop. Furthermore, any buildup of sediment on the sides of the road (especially berms), which prevents water from running off into the adjacent ditches, must be removed. These practices will help to preserve the water quality of a lake and improve its aesthetic value.

Agriculture and Livestock

Agriculture within a watershed can contribute to nutrient loading in a lake. Plowed fields and livestock grazing areas are potential sources of erosion, which can carry sediments and nutrients to a lake (Williams 1992). Animal wastes are also sources of excess nutrients. 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. However, problems can still exist in areas that were utilized for agriculture prior to the enactment of these ordinances 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 relatively high levels of erosion and decreased water quality (MDEP 1990). Some methods to reduce erosion are to plow with the contour lines (across as opposed to up and down a slope), and to strip crop. Both solutions will reduce soil erosion and sediment deposition in the lake.

Another potential agricultural impact on water quality comes from livestock manure. Improper storage of manure may result in excess nutrient loading. Manure also becomes a problem when it is spread as a fertilizer, a common agricultural practice. Manure spreading can lead to nutrient loading, especially in winter when the ground is frozen and 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 is to avoid spreading manure in the winter. 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. One solution for this may be to put up fences to keep the cattle away from the water.

Runoff containing fertilizers and pesticides may also add nutrients and other pollutants to a lake. This problem can be minimized by fertilizing only during the growing season and not before storms. Pesticides can also have negative impacts on water quality. Alternative methods of pest control may be appropriate, including biological controls such as integrated pest management and inter-cropping, which is 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 a lake. The combination of erosion, runoff, and pathways can have a large impact on the water quality of a lake (Williams 1992). Again, there are state and municipal shoreline zoning ordinances in place to tackle these specific problems. 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 disturbance (MDEP 1990). Also, there is a ordinance that prohibits clear-cutting within 75 ft of the shoreline of a lake or a river running to the lake. At distances greater than 75 ft, harvest operations cannot create clear-cut openings greater than 10,000 ft² in the forest canopy, and if they exceed 500 ft², 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. Illegal forestry practices may occur and negatively impact lake water quality.

Cleared Land

Cleared land also presents potential problems of erosion and nutrient runoff especially when large areas are cleared of trees and vegetation that once acted as natural filters. Sediments from these cleared areas could create a problem if they carry large amounts of nitrogen, phosphorus, other plant nutrients, and chemicals to a lake. Without vegetation acting as a buffer, 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 specific guidelines for cleared land. There can be no cleared openings greater than 250 ft² in the forest canopy within 100 ft of a lake or river. Where there are cleared lands, some solutions to minimize erosion are construction of terraces and plowing parallel to the contour lines. Both techniques decrease the flow of storm water down a slope, allowing the nutrients to settle out before they get to the lake. These two solutions also may prevent erosion by breaking up large areas of tilled soil.

Transitional Land

Before any form of development occurred in the Lake Wesserunsett watershed, the entire area was covered primarily by forest. As population increased, much of the forest surrounding the lake was cleared for agricultural, residential, industrial and recreational use. In recent years, land use has changed as some agricultural area has been allowed to revert back to forested land.

Succession is the replacement of one vegetative community by another that results in a mature and stable community referred to as a climax community (Smith and Smith 2001). An open field ecosystem moves through various successional stages before it develops into a mature forest. The earliest stages of open field succession involve the establishment of smaller trees and shrubs throughout a field (reverting land). Intermediate and later successional stages involve the growth of larger, more mature tree species. The canopy of this forest is more developed, resulting in less light reaching the forest floor. This land use type, in which a forest is nearing maturity and contains over 50 percent mature trees, is 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 characterized by waterlogged soils and can either be of woody or shrub types, depending on the vegetation. In Maine, 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, either preventing nutrients from going into a lake or contributing nutrients to a 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, depending on the amount of input to the wetland. Vegetation type within a wetland is important because different flora absorb different nutrients. For example, willow and birch assimilate more nitrogen and phosphorus than sedges and leatherleaf (Nebel 1987). This indicates that shrub swamps are better nutrient sinks than many other types of wetlands. When nutrient sink wetlands are located closer to the lake, the buffering capacity is greater than those located further back from the water body. Wetlands that filter out nutrients are important in controlling the water quality of a lake. These wetlands also help moderate the impact of erosion near the lake.

Although there are regulations controlling wetland use, a lack of enforcement leads to development and destruction of wetlands. These areas should be protected by the Resource Protection Districts and other means, which limit development to 250 ft away from the wetland. Due to the nature of their location, wetlands along the shoreline may be more prone to development (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.

Lake Wesserunsett Characteristics

Geological and Hydrological Characteristics

The formation of the youngest bedrock in Maine occurred approximately 120 million years before the Pleistocene ice age (MGS 2000). During the Pleistocene Epoch from 1.5 million to 10,000 years ago, continental glaciers extended across Maine. This slow-moving glacial ice scraped over previously existing mountains and valleys, transporting rock debris miles from their original location and changing the superficial geology of the area. Glaciation caused old stream patterns to be disrupted, as well as the creation of hundreds of ponds and lakes scattered across the state (MGS 2000).

The most recent glacial episode in Maine began when the Laurentide ice sheet overspread New England about 25,000 years ago (MGS 2000). The ice sheet was centered over Eastern Canada. It flowed easterly to southeasterly across Maine and was thousands of feet thick. The ice sheet reached its most southerly position at Long Island, New York. It then began receding due to climatic warming approximately 21,000 years ago. The ice margin withdrew from the continental shelf east of Long Island and reached the Maine coast 15,000 to 14,000 years ago. The Earth's crust was depressed by the mass of the ice sheet, and consequently the sea flooded southern Maine as the glacier retreated to the northwest. Marine submergence reached current elevations of 420 ft in the central part of the state, extending up the Kennebec and Penobscot valleys, and lasting until 11,000 years ago. By 12,000 years ago, the glacier had shrunk to a local ice cap covering northern Maine as well as parts of Quebec and New Brunswick. The last remnants of glacial ice disappeared from Maine 10,000 years ago. After this time period, Lake Wesserunsett was no longer glaciated (MGS 2000).

In glaciated regions, land was eroded on a local scale below the soil level. This formed natural depressions, especially localized along faults, in areas of weak or weathered rock, and along preglacial valleys. About 14,000 years ago, the glacially formed lake basins were filled in with water as the Wisconsinian ice sheet retreated from coastal Maine (Tucker and Marvinney 1989).

Lake basins in Maine were formed by granular disintegration of plutonic rocks and by stream and glacial erosion of metasedimentary rocks (Tucker and Marvinney 1989). During and immediately following deglaciation, all Maine lake basins were sites of glacial-moraine or glacial-lacustrine sedimentation. Melt water carried glacial sediments to these basins while glacial ice was still present within the watersheds (Tucker and Marvinney 1989).

Lakes are present throughout Maine, but most occur in two broad belts: one in North-Central Maine and the other in the coastal region (Tucker and Marvinney 1989). Both belts are characterized by the presence of numerous plutonic rock bodies. Plutonic rocks are igneous rock bodies that cooled underground, composed primarily of Devonian granite. Lakes occur on about 11 percent of the surface area of plutons and on less than 3 percent of areas underlain by sedimentary and metasedimentary rocks. The weathering and erosion of plutons formed more than 500 lake basins in Maine. Fluvial and glacial erosion of sedimentary rocks formed about 800 lake basins in the state. In addition, erosion along faults in both sedimentary and igneous rocks caused the formation of several lake basins. The damming of stream valleys by glacial drift also formed lake basins (Tucker and Marvinney 1989).

The glacial history of Lake Wesserunsett is common to many lake basins in Maine. Glaciers and meltwater streams eroded the land below the water table and carved out natural depressions, such as the basin of Lake Wesserunsett. This evidence is supported by the southeasterly orientation of the lake, the predominant direction in which the Laurentide ice sheet traveled. The bedrock of the lake basin is most likely a plutonic or sedimentary rock body as those are the primary rock types of this region (Nelson, pers. comm.).

General Characteristics of Lake Wesserunsett

Lake Wesserunsett is located in the town of Madison, Somerset County, Maine. The lake is listed as having an area of 5,851,754 m² (1,446 acres) and a maximum depth of 6.71 m (22 ft) (MDIF&W 1995). However, we and others have measured sites with at least 7.0 to 7.5 m depths. The orientation of Lake Wesserunsett is southeasterly. Several wetlands are located along the north

and west shores of Lake Wesserunsett. Four inlets are located on the western shore of the lake and one outlet on the western shore. There are many small tributaries adjacent to wetlands, as well as one major tributary, Hayden Brook. This tributary runs through the Lakewood golf course and other development on the western shore. The outlet flows east into the West Branch of Wesserunsett Stream, which is a part of the Kennebec River System. The principle flow of water into the lake is from west to east (MDIF&W 1995).

Basin Characteristics

Lake bathymetry (the study of depths in a body of water), prevailing winds, and shoreline shape influence water movement within a lake (Chapman 1996). The basin of Lake Wesserunsett is relatively shallow. Lake bathymetry is shown in (Figure 8). During the summer, the combination of shallow depth and strong wave action allows for constant mixing and prevents stratification. The south central area of Lake Wesserunsett is the deepest section. In this area most depths are between 8 and 22 ft (5.5 and 6.7 m). The northern part of the lake is fairly shallow with depths between 2 and 13 ft (0.6 and 3.9m). The northeast and southeast ends of Lake Wesserunsett narrow into coves. The prevailing winds are from the north and often travel along the length of the lake, which cause it to be very choppy on windy days. Storms from the northeast and southeast can cause considerable wave action and therefore erosion (Reid, pers. comm.).

Lake Comparisons

Lakes in central Maine contain a wide variety of lake bottom morphologies (Davis et al. 1978). This feature is important in considering the environmental health of a lake. Lake Wesserunsett has an average depth of 15 ft (4.5m) with one deep section in the southern basin, and two shallower coves in the northeast and southeast corners (MDIFW 1995). Compared to other local lakes, Lake Wesserunsett is similar in average depth to East Pond in the Belgrade Lakes Region (BI493 1999). Great Pond has a different lake basin morphology with several deep holes, bays and

two basins. Its maximum depth is more than twice that of Lake Wesserunsett (BI493 1998). Another Belgrade Lake, Messalonskee Lake, has a rounded bottom and a fairly uniform depth with an average of approximately 33 ft (10.0 m). It is funnel-shaped, long, narrow, and lacks any bays (BI493 1997). The basin characteristics of these various lakes cause the water movement into, around and out of each body of water to be different in speed and direction.

Regional Land Use Trends

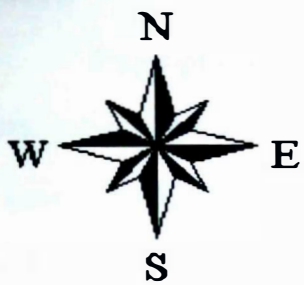
A comparison of 1960's land use with current land use illustrates two predominant trends in South Central Maine. One significant trend is a decrease in agricultural land use. This trend has been observed in the East Pond, North Pond, and Messalonskee Lake watersheds (BI493 1999). Increases in forested land observed over this period in the Messalonskee Lake and Wesserunsett Lake watersheds can be attributed in part to successional transition of agricultural land (see Watershed Assessment:: Land Use Assessment). Another apparent trend in the watersheds is a profound increase in the area of shoreline residential land. This trend is common to each of the watersheds mentioned above (BI493 1999).

It is important to note that these two trends have generally opposing implications for watershed ecosystem health. The conversion of agricultural area to land use types with increased vegetative cover reduces the nutrient loading potential of a watershed. In contrast, increases in residential land area, specifically on the shoreline, often have detrimental effects on lake water quality (see Watershed Land Use).

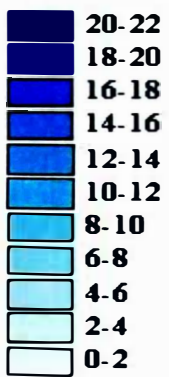
Biological Characteristics

Lake Flora

Lake Wesserunsett contains many types of flora, including both macrophytes and phytoplankton. These organisms are very important in maintaining a balanced lake ecosystem as they



Depth (feet)



0.5 0 0.5 Miles

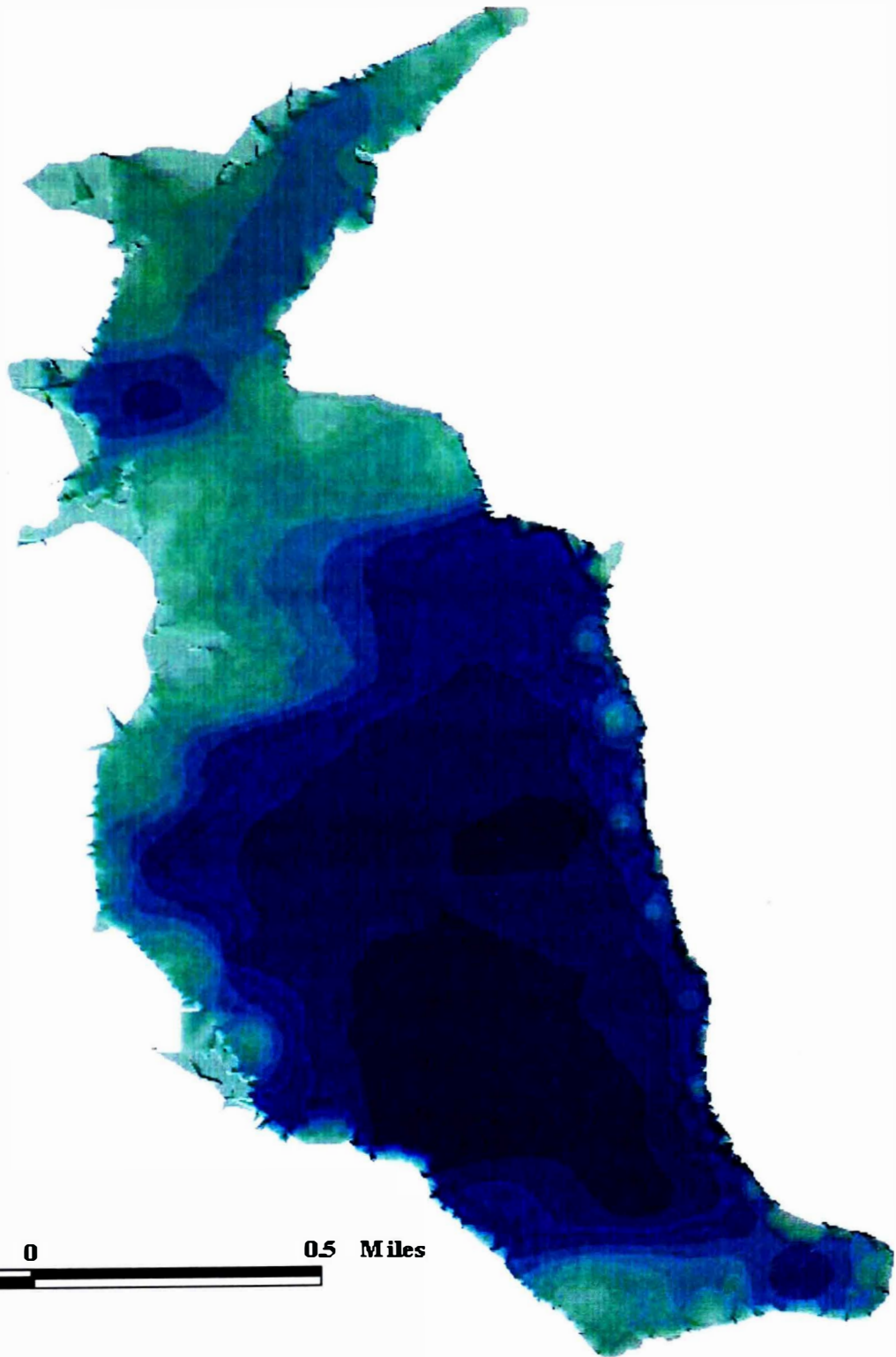


Figure 8. Bathymetry map of Lake Wesserunsett. Data adapted from Somerset County Wesserunsett Lake Depth Map, 1964.

contribute to the primary production and are a link in the nutrient cycling of a lake (Smith and Smith 2001).

Phytoplankton are small photosynthetic organisms that float in the upper layers of a lake, where light is most concentrated (Smith and Smith 2001). This area is known as the limnetic zone of a lake. In Maine lakes, the most numerous type of phytoplankton are the cyanophytes. Other prominent phytoplankton are chrysophytes and unicellular flagellates (Davis et al. 1978). Chrysophytes dominate the biomass in Maine lakes because of their relatively large size.

Phytoplankton populations vary seasonally in Maine lakes, becoming most abundant in the mid to late summer months (Davis et al. 1978). Population densities also vary according to lake nutrient level and are most often limited by phosphorus (Smith and Smith 2001). The abundance of phytoplankton may indicate a nutrient loading problem in a lake. Algal blooms occur when phytoplankton numbers are very high, causing the water to become green and cloudy.

Macrophytes are multicellular aquatic plants. Some macrophytes common in this area are listed in Table 3. Most macrophytes exist in the littoral, or shallow- water zone. Light is able to reach the lake bottom in this zone to stimulate the growth of these rooted plants (Figure 9). Macrophytic plants are the major primary producers in a lake. They provide energy from sunlight to other aquatic organisms through photosynthesis. Macrophytic plants also influence lake nutrient levels, dissolved organic and inorganic carbon, oxygen, and pH of a lake (Jeppesen et al. 1998). Plants absorb nutrients from the sediment and release oxygen as they photosynthesize, helping to renew the dissolved oxygen supply in the water. However, decomposers use oxygen as they consume dead plant matter, returning nutrients to the soil or water column (Smith and Smith 2001).

Many factors can influence macrophyte populations (Jeppesen et al. 1998). A change in light penetration or light intensity will affect the growth rate of these plants. A change in herbivorous fish populations may also alter these plant populations. Higher nutrient levels in the sediment will significantly increase macrophytic growth. A high density of macrophytes may indicate a source of sediment or nutrient loading. Changes in macrophyte populations can signify a change in either biotic or abiotic characteristics in a lake (Jeppesen et al. 1998).

Table 3. Common macrophytes in Lake Wesserunsett grouped by zonation.

Common name	Scientific name
Emergent	
arrowhead	<i>Sagittaria latifolia</i>
burreed	<i>Sparganium eurycarpum</i>
cattail	<i>Typha</i> spp.
great bulrush	<i>Scirpus acutus</i>
pickerel weed	<i>Pontederia cordata</i>
sweet flag	<i>Acorus calamus</i>
wild rice	<i>Xizania</i> spp.
Floating	
floating brownleaf	<i>Potamogeton natans</i>
scented pond lily	<i>Nymphaea odorata</i>
tapegrass	<i>Vallisneria americana</i>
water milfoil	<i>Myriophyllum</i> spp.
water shield	<i>Brasenia schreberi</i>
yellow pond lily	<i>Nuphar advena</i>
Submerged	
bladderwort	<i>Utricularia</i> spp.
coontail	<i>Ceratophyllum</i> spp.
elodea	<i>Elodea canadensis</i>
muskgrass	<i>Chara</i> spp.
northern pipewort	<i>Eriocaulon septangulare</i>

Invasive Plant Species

Invasive plant species are a potential threat to the health of lake ecosystems in Maine, but are not yet a serious problem (Bouchard, pers. comm.). Invasive plants are hearty, resilient, highly adaptive and more aggressive than native plants. They have a competitive advantage in both establishment and competition with native plants (Williams 1992). The only invasive species currently present in Maine lakes is the variable milfoil (*Myriophyllum heterophyllum*). This species has been found in Messalonskee Lake, which is approximately 25 miles south of Lake Wesserunsett. This species is native to several regions of North America, but not New England, where it is considered an invasive species because it has never previously occurred in the region (MDEP 2000b).

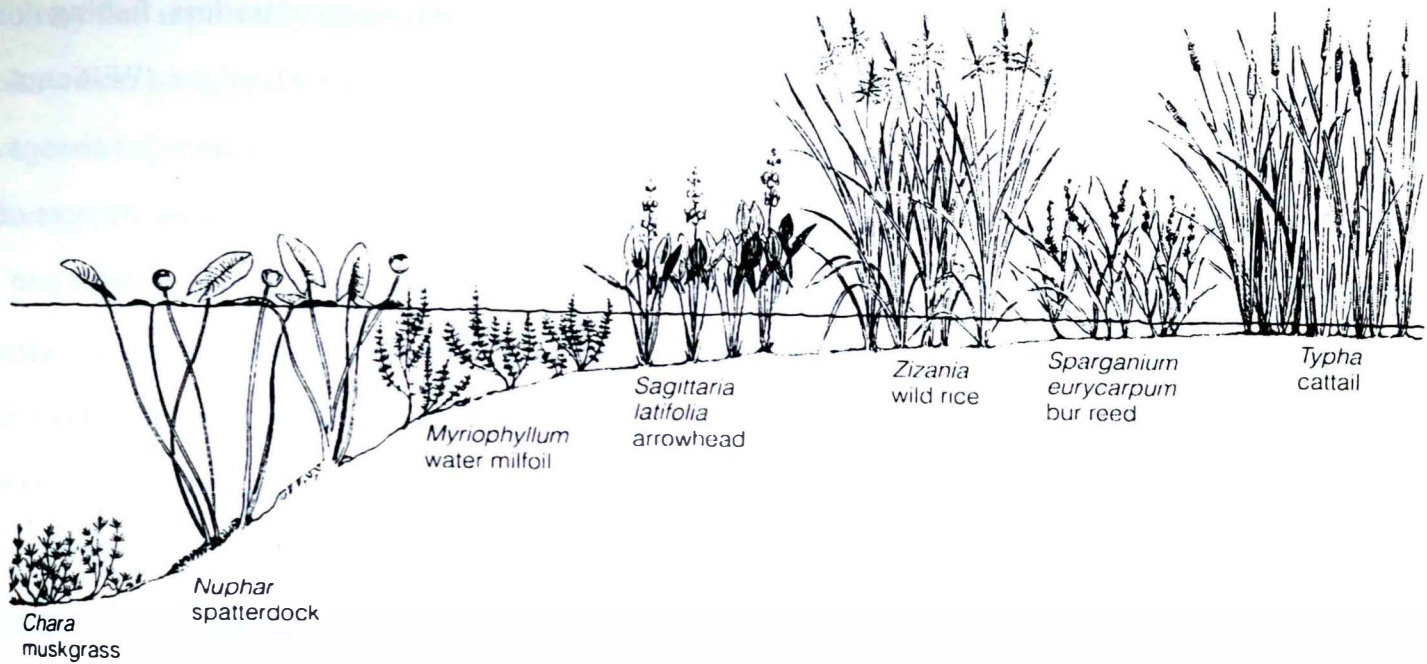


Figure 9. Common macrophytes in the submerged, floating and emergent zones at the edge of a lake or pond (from Smith and Smith 2001).

Many potentially damaging invasive plant species are present in the lakes of nearby states, such as New Hampshire, Vermont, Massachusetts, and Connecticut (MDEP 2000b). These potentially threatening species include Eurasian watermilfoil (*Myriophyllum spicatum*), fanwort (*Cabomba caroliniana*) and water chestnut (*Trapa natans*). Invasive plant species possess ecological adaptations that enable them to rapidly colonize and infest lakes. For example, the Eurasian water milfoil grows in extremely large, dense mats in water depths of up to 15 ft. Variable milfoil is found along the shore in dense mats growing to depths of 10 to 12 ft. These species are a serious threat to lakes and ponds throughout the United States due to their rapid growth and ability to overrun an entire lake starting from only a single fragment. Both types of milfoil are virtually impossible to eradicate once invasion has occurred. Fanwort is commonly used in aquariums, and is introduced into lakes and ponds when aquarium water is dumped into bodies of waters. This species has recently become a nuisance in many neighboring New England states (MDEP 2000b). The cord-like plant stems of water chestnut are able to reach depths of 16 ft. It was originally introduced from Europe to New York in the late 1800's because of its ornamental appearance (MDEP 2000b).

Fragmentation occurs when pieces of plants are attached to boats, motors, trailers, fishing traps, nets, bait bucket, and other human contrivances that are transported to another lake (Williams 1992). Cleaning all boating and fishing gear of plant materials between lakes can reduce the chance of introduction and establishment. Posting signs near public boat launches informing boat owners of regulations against plant material transport, as well as public information sessions for lake users can decrease the probability of invasive plant introduction (Williams 1992).

Invasive plants can cause numerous problems in lake ecosystems. Some of the problems associated with invasive plants include impaired boating, fishing and swimming opportunities, reduced lake water quality and a decline in shorefront property values. The best way to approach the problem is to take preventative measures and to detect the presence of these invasive plants prior to full infestation. Descriptions and photos of invasive plant species located in New England can be found on the MDEP website (<http://www.mainedep.com>).

Lake Fauna

Wildlife in the Watershed

Many species of birds, mammals, reptiles, amphibians, invertebrates, and fish depend on the Lake Wesserunsett watershed for food, protection and a habitat in which to live. Information on species specific to the Lake Wesserunsett watershed was obtained through personal communication with William Reid and William Pottle, both residents of the area. Numerous species of frog, salamander, snake and turtle, as well as typical aquatic invertebrates including crayfish and insects such as dragonfly, damselfly and mayfly larvae inhabit Lake Wesserunsett and are prey for larger animals in the area.

Lake and shore birds in the Lake Wesserunsett watershed that rely on the fish community for food include the common loon (*Gavia immer*), red breasted merganser (*Mergus serrator*), belted kingfisher (*Ceryle alcyon*), bald eagle (*Haliaeetus leucocephalus*) and osprey (*Pandion haliaetus*). Many birds also breed in the Lake Wesserunsett watershed. The great blue heron (*Ardea herodias*) has previously nested in the Lake Wesserunsett watershed. They are still present at the lake, but the

colony has reportedly abandoned the nesting site this year. Birds, such as the mallard (*Anas platyrhynchos*), black duck (*Anas rubripes*) and Canada goose (*Branta canadensis*) feed on aquatic vegetation growing in the lake. Some shore birds depend on Lake Wesserunsett as a stop-over point during fall migration.

Mammals, including beaver (*Castor canadensis*), muskrat (*Ondatra zibethicus*) and river otter (*Lutra canadensis*), inhabit Lake Wesserunsett and its tributaries. The greater watershed area is an important habitat for other mammals, including moose (*Alces alces*), white-tailed deer (*Odocoileus virginianus*), black bear (*Ursus americanus*) and raccoon (*Procyon lotor*).

Fish Populations in Lake Wesserunsett

Lake Wesserunsett contains a variety of native and introduced fish species (Table 4). These populations are important in maintaining the balance of the food chain and providing sport fisheries. Warm water fish species such as chain pickerel and white perch dominate the fish community, but Lake Wesserunsett also supports a small population of cold water brown trout (MDIF&W 1981).

Many of the fish in Lake Wesserunsett were previously introduced or are currently stocked. Smallmouth bass were first stocked in Maine in 1869 and largemouth bass were introduced in the early 1900's (MDIF&W 2000a). Trout, the only cold water fish family found in Lake Wesserunsett, thrive in water temperatures at or below 15° C. The brown trout was brought from Europe to the United States in 1884 because anglers preferred its larger size. Brook trout are the only trout species native to this area. They were the first fish in this country to be widely pursued for sport and their numbers greatly decreased as other trout species were introduced (MDIF&W 2000a).

In Lake Wesserunsett, fish have been stocked for many years and the Maine Department of Inland Fisheries and Wildlife (MDIF&W) has kept stocking records since 1946 (Figure 10). Until 1973 fish were stocked somewhat sporadically, varying in age and numbers. Brook trout have been stocked, but with little success due to their low tolerance for the relatively warm water. The entire white perch population stems from a single successful stocking in 1952 (Bourque, pers. comm.). The 1999 data comparing Lake Wesserunsett to North, East and Great Ponds indicate that Lake

Wesserunsett is more heavily stocked with brown trout per unit surface than other area lakes (MDIF&W 2000b) (Table 5). This could indicate that Lake Wesserunsett is a more popular fishing

Table 4. Fishes present in Lake Wesserunsett based on data from Maine Department of Fisheries and Wildlife lake inventory, 2000 update (MDIF&W 2000b).

Fishes Present	Scientific Name
Alewife ^a	<i>Pomolobus pseudo-harengus</i>
American Eel	<i>Anguilla rostrata</i>
Blacknose Dace	<i>Rhinichthys atratulus</i>
Brook Trout	<i>Salvelinus fontinalis</i>
Brown Trout ^b	<i>Salmo trutta</i>
Chain Pickerel ^b	<i>Esox niger</i>
Creek Chub	<i>Semolitus atromaculatus</i>
Brown Bullhead	<i>Ictalurus nebulosus</i>
Largemouth Bass ^b	<i>Micropterus salmoides</i>
Pumpkinseed Sunfish	<i>Lepomis gibbosus</i>
Redbreast Sunfish	<i>Lepomis auritus</i>
Smallmouth Bass ^b	<i>Micropterus dolomieu</i>
White Perch ^b	<i>Morone americana</i>
White Sucker	<i>Catostomus commersoni</i>
Yellow Perch	<i>Perca flavescens</i>

^aAnadromous: living in oceans and spawning in lakes and rivers

^bPrincipal fishery

site than the Belgrade Lakes. Another reason may be that the cold water fish have a higher survivorship in the Belgrade Lakes and do not need to be stocked as heavily. In contrast, Lake Wesserunsett is too shallow to adequately support a cold water fishery, which may explain the larger number of stocked fish.

The MDIF&W has monitored the angler activity of Lake Wesserunsett for the past 30 years. The results from surveys conducted between 1976 and 1987 indicate trends in fishing, and the success of fish stocking programs. Figures 11 and 12 display the variability in brown trout catching success during the summer and winter seasons. From 1984 to 1987 there was a clear decline in the

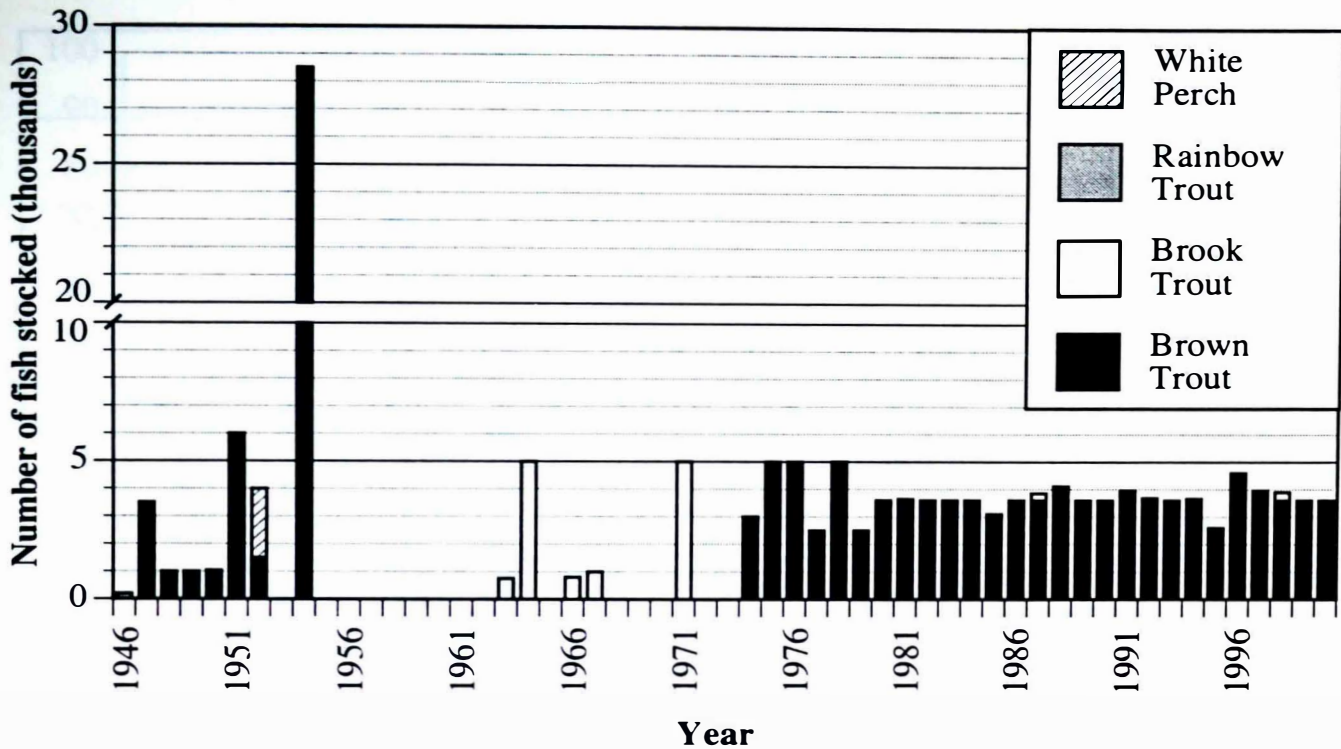


Figure 10. Number of fish stocked in Lake Wesserunsett between the years 1946 and 1999 (MDIF&W 1999; Appendix A).

brown trout catch among summer and winter anglers, which can be attributed to the general observed variability of the fishery (Bonney 1988).

White perch display an initial downward trend first observed in 1971 before official reports were generated. This decline can be partially explained by the introduction of brown trout, which prey upon young perch (Bonney 1988). Another explanation could be competitive exclusion by brown trout (MDIF&W 1981). Chain pickerel catching success, although highly variable during the census period, indicates that pickerel are being fished quite heavily overall (Bonney 1980).

Table 5. Number of brown trout stocked per km² surface area in Lake Wesserunsett and other Belgrade Lakes in the year 1999 (MDIF&W 1999).

Body of Water	# Trout Stocked	Lake Surface Area (km ²)	Trout Stocked/km ²
Lake Wesserunsett	3600	5.72	629
North Pond	1000	9.12	110
East Pond	1800	6.77	266
Great Pond	6120	33.34	184

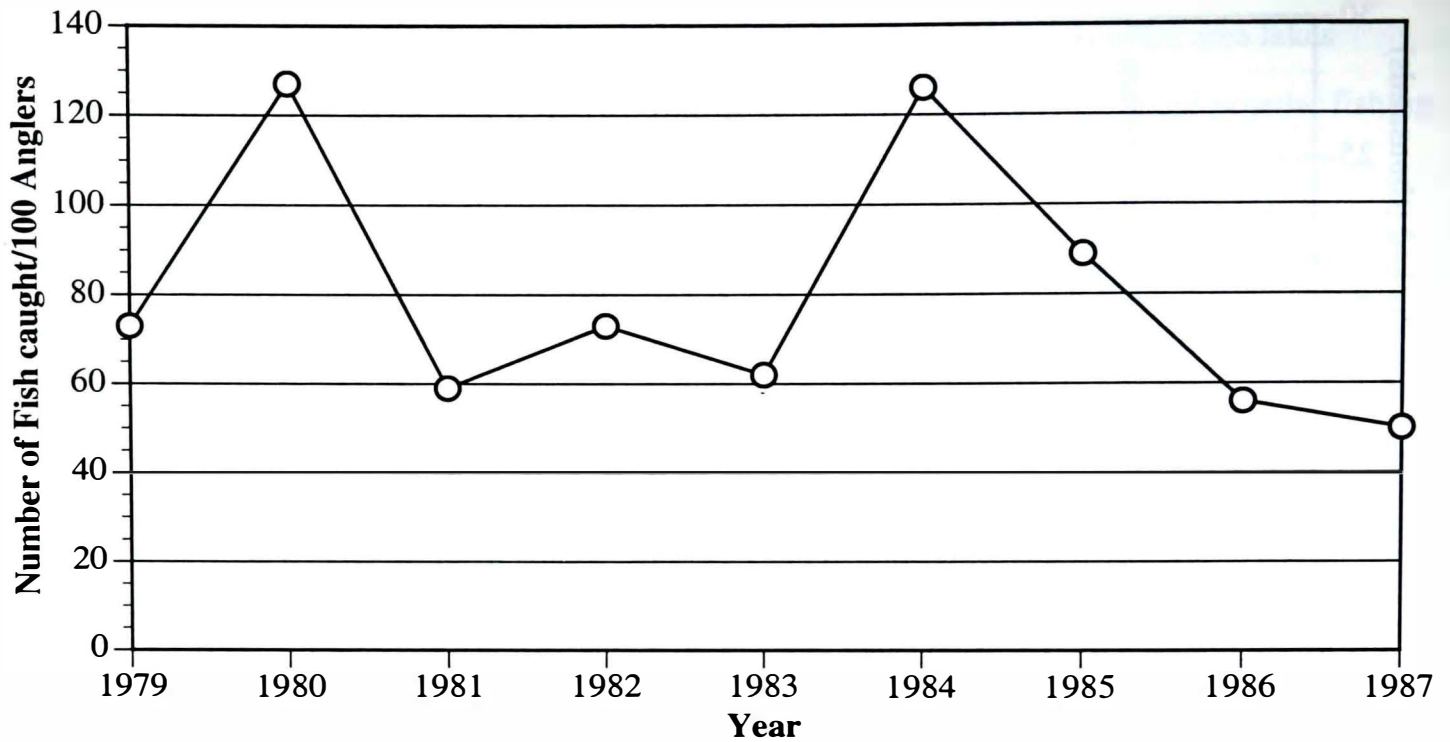


Figure 11. Number of Brown Trout caught per 100 anglers in the summers from 1979 to 1987 at Lake Wesserunsett (modified from Bonney 1980, Bonney 1984, Bonney 1988).

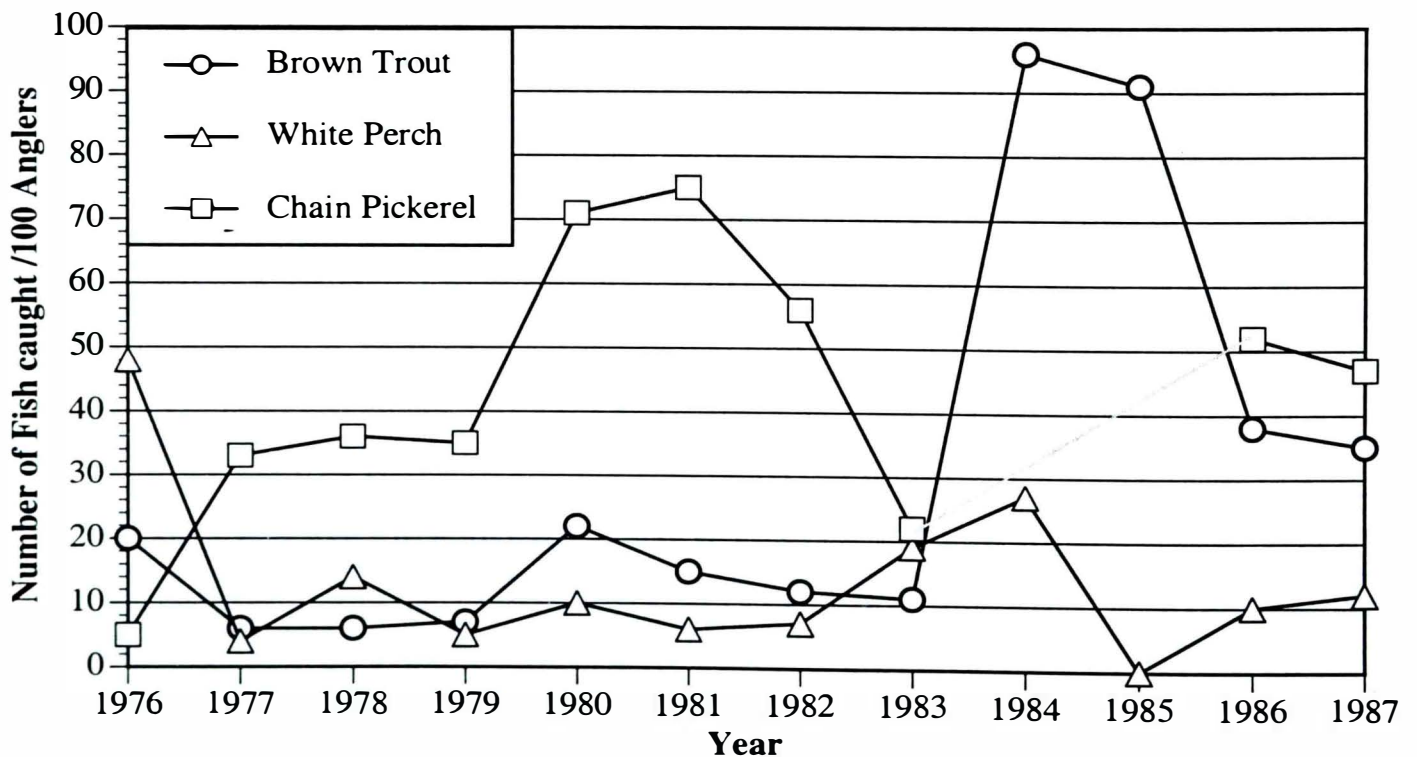


Figure 12. Number of Brown Trout, White Perch and Chain Pickerel caught per 100 anglers in the winters from 1976-1987 at Lake Wesserunsett (modified from Bonney 1980, Bonney 1984, Bonney 1988). (Gap indicates missing data.)

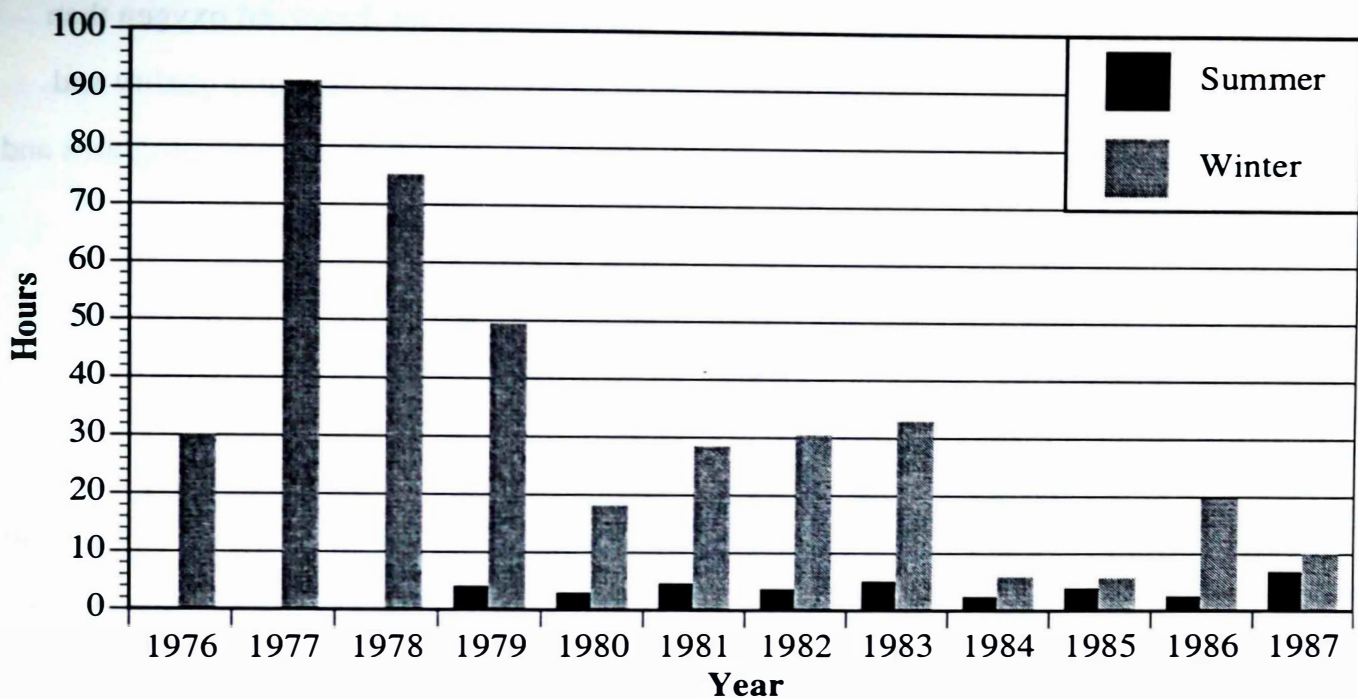


Figure 13. Hours taken to catch a legal fish in the summer and winter from 1976 to 1987 at Lake Wesserunsett. Data not taken for summers from 1976-79 (modified from Bonney 1980, Bonney 1984, Bonney 1988).

Another indication of fish density is the hours taken to catch a legal fish (Figure 13). For the winter months between 1977 and 1987, the length of time declined sharply, indicating higher overall fish densities.

The current nature of the fisheries in Lake Wesserunsett is best assessed through the observations of residents and anglers on Lake Wesserunsett. In recent years fishing success has remained high (Pottle, pers. comm.). An increase in bass tournaments and guided bass fishing excursions may indicate a healthy bass population. Anglers are catching white and yellow perch as well as hornpout and chain pickerel. The number of ice fishing shacks in some years has been over 50 at the winter peak, though only 12 were observed last year (Reid, pers. comm). This may or may not be indicative of poorer fishing, but rather related to the economic prosperity of the last few years as anglers are working instead of fishing.

Water quality and fishing are very closely linked. In order to preserve the current fish populations, it is crucial that water quality be maintained. The presence or absence of certain fish species

is indicative of lake water quality. Because cold water fish require more dissolved oxygen than warm water fish, a historical decline of coldwater fish can signify decreasing water quality and possible lake eutrophication. It is important to monitor the progress of fish stocking programs and water quality in order to protect this highly valued resource (Firmage, pers comm.).

Alewife Restoration in Lake Wesserunsett

Alewives are small, planktivorous fish. They are anadromous, living in the ocean for most of the year and travelling inland from early May to early June to spawn (Squiers 1988). Shortly after laying eggs, the adults return to the sea. Young alewives hatch and grow in lakes, streams and rivers until they begin their journey to the sea between mid-July and early December (Squiers 1988).

Alewives were once plentiful in Maine's lakes and rivers, but multiple dams have been built along the Kennebec River, preventing the fish from swimming upriver from the ocean. Lake Wesserunsett, which drains into the Kennebec River system, was once an alewife-spawning site. However, four dams on the Kennebec River and four dams on Wesserunsett Stream prevent alewives from traveling upriver to Lake Wesserunsett (Figure 14; Squiers et al. 1986). The dam closest to the mouth of the Kennebec River, the Edward's Dam, was removed in the summer of 1999 (Thompson, pers. comm.). This allows anadromous fish access to a greater part of the river system.

Starting in 1985, the Department of Marine Resources (DMR) and the MDIF&W initiated a plan to restore alewives and other anadromous fish to their historical range in the Kennebec River system. Funded by the Kennebec Hydro Developers Group (KHGD), the plan consists of trapping and sorting anadromous fish at the Edward's Dam in Augusta in May, during their inland migration. Once trapped and sorted, the fish are trucked inland to certain target lakes, which are stocked with six alewives per acre of lake surface (Squiers et al. 1986). After the alewives are stocked, they lay eggs in the lakes and migrate downstream, over the dams, returning to the ocean. Since the removal of the Edwards Dam, alewives are trapped and trucked from Fort Halifax on the Sabastacook River (O'Donnell, pers. comm.). This is a temporary collecting site, as the KHGD plan proposes the

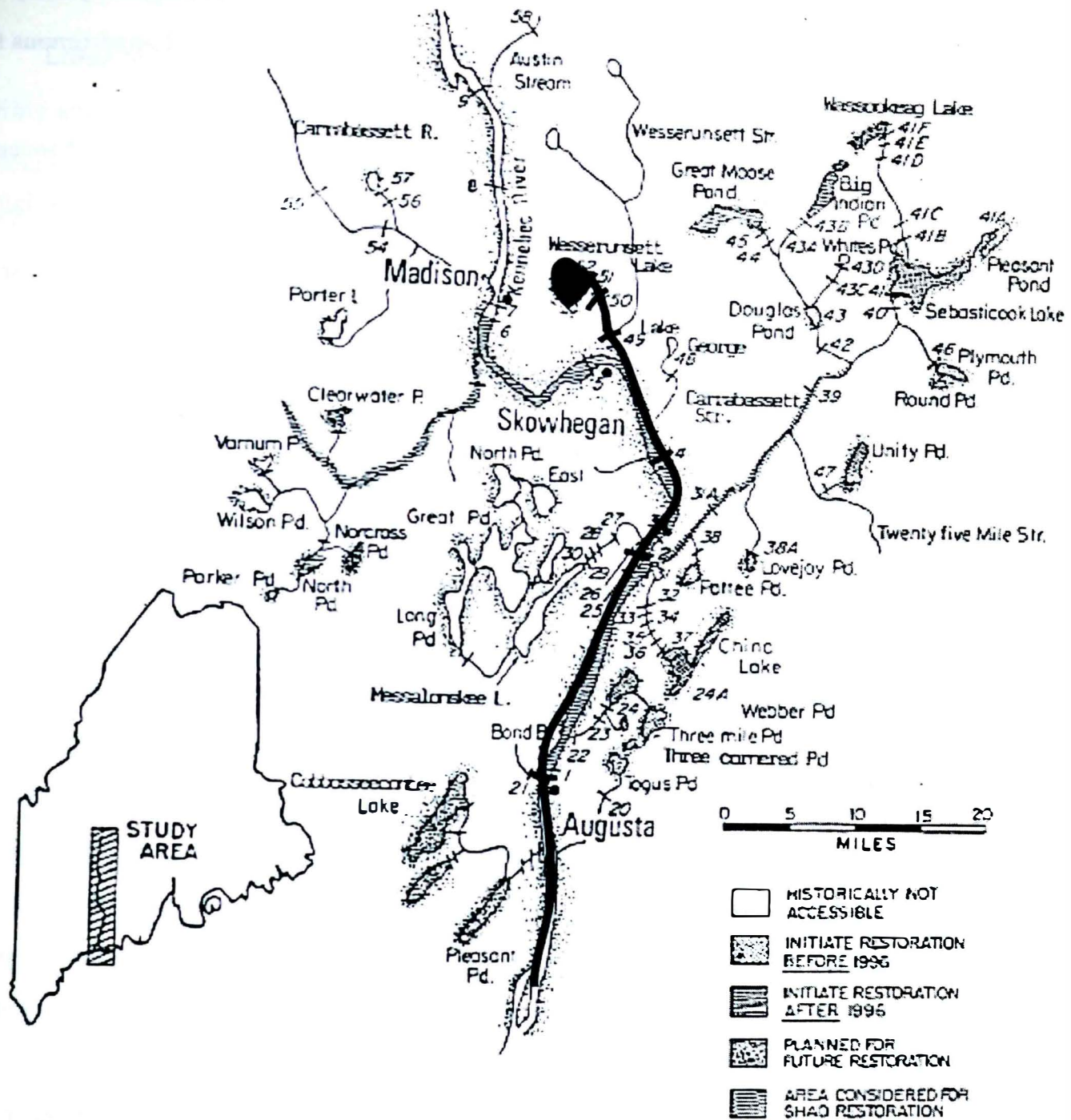


Figure 14. Kennebec River drainage anadromous fish restoration program. Alewife migration blocked by numbered dams. Dam 1: Edward's Dam (Removed in 1999); 3: Winslow Dam; 4: Shawmut Dam; 49: Malbons Mills; 50: Lower West Branch Wesserunnett Stream; 51: Lower West Branch Wesserunnett Stream; 52: Hayden Lake Outlet (Squiers et al. 1986).

creation of upstream passages in all dams currently blocking anadromous fish passage. By the year 2006, Lake Wesserunsett will be open to both upstream and downstream passage of anadromous fish (O'Donnell, pers. comm.).

Lake Wesserunsett was first stocked with alewives in 1996. The current presence of juvenile alewives in Lake Wesserunsett is proof of the success of the alewife stocking program. In the fall, the fish are able to swim downstream over the dam spillway when the water level is sufficient (Squiers et al. 1986).

Alewife stocking has been controversial in many lakes. Many people are opposed to the stocking of alewives because the fish eat zooplankton. Removal of zooplankton often causes an increase in phytoplankton, which in turn may cause more frequent algal blooms (Squiers 1988). However, there are many other factors that influence the zooplankton and phytoplankton populations in a lake, and alewife population density has not been proven to have a direct effect on either (Mower 1978).

Alewives have, in fact, been found to have a positive effect on lakes. In a study by MDEP, alewives were added to Little Pond in Maine as an attempt to improve water potability (Mower 1978). With the addition of alewives to Little Pond, zooplankton experienced a decline in population, and complaints of water quality problems ceased after the project was started. MDEP also hypothesized that alewives remove phosphorus from the lake as they eat phosphorus-containing materials, then carry it out with them during migration downriver. The fish in the Little Pond study did carry a small amount of phosphorus out of the pond, but not enough to make a significant reduction in the total phosphorus load (Mower 1978).

The presence of alewives in lakes and rivers is beneficial to people as they provide other important resources. Young alewives may provide an abundant food source for some of the major sport fishery populations, especially brown trout. Alewives were once the most economically valuable anadromous fish population in Maine because they are used as lobster bait (Squiers 1988). In the 1970's, 3.4 million pounds of alewives were caught annually (DMR, 2000). Today, less than 1.0 million pounds are harvested. The restoration of alewife populations will increase the availability of lobster bait, thereby supporting one of Maine's most valuable industries (Squiers 1988).

Resource Protection and Nesting Areas

Lakes in Maine are popular sites for tourism. The appeal of lakes is based on their ecological stability and attractiveness. Revenue from tourism has positive effects on the residents of the area, but tourists can have negative effects on the lake itself as increased usage can pollute and disrupt the ecosystem. Since many people come to Maine for a vacation near a lake and enjoy water sports, the degradation of the lakes will eventually decrease tourist appeal.

Lake Wesserunsett contains many resources that are valuable to the surrounding region. In addition to the ecological resources that a lake provides, Lake Wesserunsett is also economically important to the surrounding community. The large number of seasonal residences and campgrounds around Lake Wesserunsett indicate that summer tourism is an important economic resource for this area (see Watershed Assessment: Residences).

The most biologically productive areas of Lake Wesserunsett are the wetlands in the northern area of the water body (see Watershed Land Use: Wetlands). Wetlands are important in their buffering capacity. They contain many emergent and submergent plants, which cycle nutrients quickly and absorb excess nutrients that might be entering the lake from external sources (Etherington 1983). This nutrient cycling provides a very productive habitat for many animal species. Unique populations of benthic organisms live in the anoxic substrate created by the large amount of decaying matter (Etherington 1983). Ducks and other birds feed on vegetation in wetlands (Weller 1994), and the common loon nests in the emergent plant zone (CWS 1999).

Wetland areas and the organisms that inhabit them are highly vulnerable to human activity. Changes in water levels can quickly destroy a large area of wetland by either exposing or submerging the vegetation. The inconsistent regulation of the outlet dam in Lake Wesserunsett could have detrimental effects on nesting birds (see Background: Lake Level Management). Birds nesting in this area are especially sensitive to water level changes as a slight increase can submerge a nest or make nests more accessible to predators. Motor boats with large wakes can have the same effect on nesting birds (CWS 1999). Flat-bottomed bass boats allow fishermen to motor into very shallow wetland areas, leading to possible loon egg and chick mortality (Reid, pers. comm.).

Lake Wesserunsett is also very attractive to tourists for recreational fishing. Residents of Maine take day trips to Lake Wesserunsett because it is known as a prime location for freshwater fishing (Stahlnecker, pers. comm.). The fish in Lake Wesserunsett depend on a healthy lake ecosystem (see Fish Populations in Lake Wesserunsett). The annual increase in human activity on Lake Wesserunsett can change the water quality and affect the fish community.

The aesthetic quality of Lake Wesserunsett is very important as it attracts summer tourists to the lakeshore campgrounds for activities such as boating and swimming. Lake recreation depends on maintaining water quality, since excess algae or pollution would make recreation unappealing.

Several Maine state agencies maintain the resources provided by the lakes. The MDIF&W protects the habitats of plant and animal species living in Maine lakes (MDIF&W 2000c). MDIF&W also monitors wetland size and health in addition to stocking and monitoring recreational fisheries. The Maine Department of Environmental Protection (MDEP) regulates lakeshore land uses. MDEP has very specific laws on land use and building ordinances on shoreline property (MDEP 2000a). Buffer strip maintenance and proper setback distances around Lake Wesserunsett will protect it from excess nutrients and other pollutants (see Watershed Assessment: Buffer Zone Survey). Madison has a Shoreline Zoning Ordinance adapted from the state ordinance that modifies certain restrictions to ensure the protection of Lake Wesserunsett.

Lake Wesserunsett provides ecological resources such as food and habitat area for both aquatic and terrestrial animals. Economic resources such as tourism for fishing, camping, boating and other lake recreation also depend on the health of Lake Wesserunsett. By understanding the current status of the lake, the future generations can be ensured the enjoyment of the same resources.

Lake Level Management

Water levels in Lake Wesserunnett are controlled by a dam located at Wesserunsett Stream on the eastern shore. According to registration information provided by the MDEP, there has been a dam in place since 1800 (Murch, pers. comm.). It was most likely built to control the release of water for mills located downstream. The dam that is currently in place was built in 1962, and the

ownership rights belong to the town of Madison. These were transferred from the MDEP and will expire in 2008 (Dean, pers. comm.). The town road commissioner is responsible for maintaining the water level agreed upon by the town. The goal is to keep water levels constant. Future decisions may be made to reduce this level (Dean, pers. comm.).

Residents along Lake Wesserunsett have expressed concern about the current management practices of the outlet dam. Individual citizens have been able to lower and raise the lake levels without official permission. A few weeks before CEAT monitored the lake, the dam had been tampered with to lower the lake level. The dam has since been repaired and water levels have returned to normal.

Changes in water levels can influence the lake biota. If the water is drawn too low, an increase in aquatic plant mortality along the shoreline can occur. This leads to a loss of habitat for many aquatic invertebrates and consequential decreases in their populations as well as the populations that depend on these invertebrates for food (Cooke et al. 1986).

Fluctuating water levels promote the disruption of bottom sediments, which releases nutrients into the water column and may contribute to algal blooms (Cooke, et al. 1986). Varying water levels also impact transitional landscapes. If water levels are drawn too low, wetlands can be transformed into terrestrial areas, significantly influencing the ecology of the lake (see Watershed Land Use: Wetlands).

In addition to fluctuating water levels, another problem exists with the alewife restoration project. These anadromous fish depend upon access to the outlet so they can return to the ocean (see: Alewife Restoration in Lake Wesserunsett). With the current lake level variability there is some concern that water levels are too low for the alewives to swim over the dam (Pottle, pers. comm.). However, there are plans to build upstream and downstream passages for anadromous fish (O'Donnell, pers. comm.). Dam regulation should be discussed with MDEP and DMR to determine the best practices for all parties concerned with the water level of Lake Wesserunsett.

OBJECTIVES OF THE STUDY

WATER QUALITY ASSESSMENT

Identification of Pollution Sources

One major aspect of water quality assessment is the identification of pollution sources. There are numerous sources of water pollution, including both natural and anthropogenic. These can be divided into two categories: point source pollution and nonpoint source pollution (Chiras 1994). Point sources of pollution are in specific locations and are easy to control. These include sewage pipes and factory outputs. Nonpoint sources are less distinct and harder to control. Farms, lawns, and roads, in which runoff may flush pollutants from the land into water bodies, are examples of nonpoint sources. These sources are often numerous and spread over a larger area, making them difficult to identify and regulate.

Lake Wesserunsett

The purpose of this study is to determine the current ecological health of Lake Wesserunessett, to identify possible pollution sources, and to suggest techniques for maintaining healthy water quality. Our assessment of Lake Wesserunessett includes physical and chemical tests for water quality conducted both in the field and in the Colby Environmental Analysis Laboratory. These tests were used to characterize the water quality and to identify changes over time when compared to MDEP and other available data. The information gathered from the assessment can be used to determine the effects of human activities on the health of Lake Wesserunessett, and to predict the magnitude of future impacts (Stednik 1991).

Preliminary spring and summer data collection by members of the Colby Environmental Assessment Team (CEAT) at selected sites on Lake Wesserunessett began in the spring of 2000. Extensive study continued in the fall of 2000. The lake analysis included comparisons with previously gathered data collected by the MDEP from 1970 to 2000. CEAT also surveyed the Lake Wesserunessett watershed in order to examine the potential effects of roads, shoreline and non-shore-

line residences, and summer camps, on water quality. In addition, CEAT assessed the effects of other land uses such as agriculture and forestry within the watershed on the health of Lake Wesserunsett. Water quality can be greatly affected by all of these activities in the watershed. It is crucial to assess these parameters to affirm healthy watershed management practices in order to minimize pollution and cultural eutrophication of Lake Wesserunsett.

Tributaries are defined as direct water flow from the watershed into the lake (Smith and Smith 2001). The monitoring of tributaries is essential because they can be a direct input of nutrients and pollution from the watershed. Lake Wesserunsett has one major tributary, Hayden Brook, and four minor tributaries that may not flow year round depending on precipitation levels. All of these tributaries flow into Lake Wesserunsett on the western and northeastern shore. The smaller tributaries flow into an extensive wetland in the northwestern corner of Lake Wesserunsett. Physical and chemical measurements were taken on these tributaries.

ANALYTICAL PROCEDURES AND RESULTS

WATERSHED ASSESSMENT

Land Use Assessment

Introduction and Relevance

Land use can significantly influence an area's contribution to nutrient loading in a watershed (see Background: Watershed Land Use). Different land use types typically have distinct types of vegetation cover which influence surface runoff by promoting or retarding erosion through runoff control, soil stabilization, and protection. For example, forested land provides excellent erosion control, while cleared land represents an erosion hazard due to its limited vegetative cover. Understanding the vegetative cover of the watershed and temporal trends in the corresponding land use types is critical to assessing the viability of the Lake Wesserunsett ecosystem. Developing this understanding is the main goal of the land use portion of this study.

History

The Lake Wesserunsett watershed has a long history of recreational use. For centuries, people have come to this lake to enjoy the placid lake shores and pastoral vistas (Kingsbury and Deyo 1892). In pre-colonial times, the Kennebec Indians used the shores of Lake Wesserunsett as a seasonal camp in the summer. In early colonial times settlers referred to the area now known as Lakewood as the Indian Camping Ground (Kingsbury and Deyo 1892).

In 1799, Jedediah Hayden settled on the shores of Lake Wesserunsett and cleared an area of land for a homestead in the Lakewood area (Clark et al. 1952). In 1802, Elisha Lincoln built a sawmill and gristmill on the outlet. Although both the sawmill and gristmill were probably quite small, this was the first recorded instance of industry in the watershed. The presence of a sawmill suggests that timber harvesting in the Lake Wesserunsett watershed has occurred for at least two hundred years. In 1885, an attempt at larger scale industry was made when the Wesserunsett Woolen Mill was established on the outlet. The venture was a failure and marked the last attempt at industry

of its type in the watershed (Clark et al. 1952).

By the 1880's, Madison residents had begun traveling to Lake Wesserunsett for recreational purposes (Clark et al. 1952). The school children and teachers of Madison went to Lake Wesserunsett at the beginning of the summer to enjoy picnic lunches, hayrides and the serenity of the lakeshore. Near the end of the 1880's, a small amusement park was built on the western shore of Lake Wesserunsett in the area presently known as Lakewood. Recreational opportunities at the amusement park included boating, swimming, croquet, and walking trails. A few cottages were built and a boathouse was converted into Lakewood's first hotel. In 1895, the construction of a railroad connecting Madison and Skowhegan began. The railroad line had a stop at Lakewood, which made Lake Wesserunsett more attractive for future development. It operated until it was decommissioned in 1928 (Clark et al. 1952).

Herbert Swett took over the management of the amusement park in 1901 and initiated plans to build a Broadway-like theater at Lakewood called "Broadway in Maine" (Cail 1968). The Lakewood amusement park had become run-down in the 1890's, but Swett immediately began renovations and opened his first theatrical production in June, 1901. Somerset Traction Company owned Lakewood Theater and as it gained in popularity, the company began to invest in improvements. Swett's improvements included a nine-hole golf course, horseback riding, cottages, tennis courts, an inn and a clubhouse (Cail 1968). The increase in recreational opportunities created a tourist boom, subsequently stimulating seasonal housing construction. By 1920, Lakewood Theater had truly become "Broadway in Maine." Off-Broadway plays soon frequented Lakewood, starring big name actors such as Humphrey Bogart. The Lakewood theater was the most successful industrial or recreational venture in the history of the Lake Wesserunsett watershed. In 1968, after its 842nd production, Lakewood Theater was pronounced the State Theater of Maine (Cail 1968).

Methods

Land use trends in the Lake Wesserunsett watershed were determined by the analysis and comparison of two sets of aerial photographs. Aerial photographs of the watershed taken in 1961

were compared with a similar set of aerial photographs taken in 2000 to assess changes in land use patterns over the past 39 years.

The 1961 aerial photographs were obtained from the Somerset County Soil and Water Conservation District (SWCD). CEAT contacted Nate Sylvester of the SWCD to obtain these images on CD-ROM. The scale of these black and white images is 1 inch : 660 ft.

The 2000 aerial photographs were contracted by Colby College and were flown by Aerial Survey and Photo Inc, of Norridgewock, Maine on 29-Sep-2000. The 2000 aerial photographs were received as 9"x 9" photographic prints. The scale of these black and white images is 1 inch : 1000 ft.

United States Geological Survey (USGS) 7.5 minute series topographical maps obtained from Colby College were used to trace the watershed boundary identified by the Maine Department of Environmental Protection (MDEP). The Solon, Madison East, and Skowhegan quadrangles encompass the entire watershed of Lake Wesserunsett. The standard scale for these maps is 1:24,000.

Digital Orthophoto Quadrangle (DOQ) images of the land use patterns within the Lake Wesserunsett watershed were purchased from USGS on CD-ROM. The DOQ's are black and white and each pixel in the image represents one square meter of land surface. These commercially available images are photographs which have been digitally manipulated to accurately depict the curved surface of the earth on a flat plane.

These images were crucial to the analysis because they contain georeferenced data which are necessary for the accurate calculation of distances and areas. An image is georeferenced if points in the digital images correspond to specific geographic points on the earth (see GIS Assessment: GIS Background). DOQ's provide the image characteristics of a photograph with the geometric qualities of a map (USGS 1998).

DOQ images are produced by the National Aerial Photography Program (NAPP). This program is overseen by the USGS in conjunction with other government agencies including the U.S. Forest Service, the Environmental Protection Agency, and the Natural Resources Conservation Service. NAPP currently updates its images archives of the entire continental United States every

five to six years (Light 1995). The most recent NAPP photos of the state of Maine were flown in 1996.

The land use component of this study differs from those done in previous years by CEAT because the entire analysis was completed using ArcView GIS v3.2 computer software. This component of the project was directed by Dr. Phillip Nyhus, an NSF/AIRE fellow in environmental science who worked to develop computer analysis techniques for CEAT. The hope is that these tools will generate a more sophisticated and accurate analysis of watershed land use patterns than was possible in previous years.

Before anything could be done in ArcView, topographic maps and the 2000 aerials had to be transferred to digital formats that ArcView could recognize and manipulate. Using Adobe PhotoShop v5.0 and a flatbed scanner, the maps and photographs were scanned and converted to digital JPEG images that were not georeferenced.

The individual aerial photos were pieced together in ArcView by importing JPEG aerial images and rectifying them to the DOQ's. Rectification is the process of adding a non-georeferenced data set, such as the topographic maps, to one with geographic information, such as the DOQ. Whenever possible, road intersections and permanent structures were chosen as the control points used to align the two maps because these points have changed little over the 39 year period. ArcView uses a complex algorithm to scale the whole aerial image to the DOQ beneath it, resulting in a composite digital image of watershed land use that is accurately georeferenced.

The first step in classification of watershed land use was to determine the correct watershed boundary and to create a digital file with this information. The MDEP in Augusta maintains an archive of USGS 7.5 minute series topographical maps delineated with the boundaries of all watersheds in the state. Using a light table, the correct watershed boundary was traced in pencil onto the three topographic maps that encompass the watershed. These maps were then scanned into the computer and rectified to the DOQ. The digital watershed boundary is important to our study because it defines the total area of the watershed. The watershed boundary was also used by the GIS team in their analysis.

When the 1961 image and watershed boundary were combined, it was discovered that there

were no aerial photos for the northwest portion of the watershed. A set of 1980 aerial photos depicting the missing portion of the watershed was available but the land use team chose not to use this set of photographs because the 1980 data cut the analysis period in half. In the final analysis the missing area of the 1961 image was excluded from the 2000 image for the purpose of comparison. This assured that only equal and identical land areas within the watershed were considered between 1961 and 2000.

Land cover types were identified by creating digital polygons and classifying them with a land use category according to what was interpreted from the aerial photos. ArcView has the ability to zoom in to the limit of the images' resolution, so divisions between cover types are easily identifiable. The entire watershed area of both the 1961 and 2000 images was classified into land use polygons. This information was then manipulated by Spatial Analyst, an ArcView extension used for modeling. Total area of each land cover type was calculated in square kilometers. In order to compare the 1961 and 2000 land use maps, the percent change of each land use over the 39 year period was calculated.

Two measures of percent change were developed to quantify how watershed land use has changed over the period of study. The first measure is the total percentage of area within the entire watershed of each land class, calculated for both 1961 and 2000. This percentage excludes the lake area.

The second measure of percent quantified how much change has occurred within each land class. For example, the percent increase in shoreline residential land was found by taking the 2000 area of shoreline residential land and subtracting the 1961 area, then dividing the difference by the 1961 area and multiplying by 100. This percentage shows how much the area of a specific land type has increased or decreased over the period of study.

The land use team built models within ArcView based on the land use data collected. The goal of the modeling analysis was to show specific conversions from one land type to another. CEAT identified specific land use changes and indicated both their locations in the watershed and potential impacts on water quality.

Some categories in the analysis were combined according to their potential impacts. To

facilitate modeling, shoreline residential and cleared land were grouped together and renamed cleared land because in terms of nutrient transport and runoff, they represent the greatest potential hazard to water quality. Forest and wetland were grouped together and renamed forest. These two land cover types represent the most natural state possible within the watershed and therefore have the most beneficial impact on water quality. Finally, disturbed forest and reverting land were grouped together and called disturbed forest as they represent an intermediate impact to water quality.

Land Use Classification

The land area within the 1961 and 2000 watershed composite aerial images was classified into one of six land cover types: cleared land, reverting land, disturbed forest, forest, wetlands, and shoreline residential. These six land uses are not the only cover types which exist in the watershed, but those which the land use team felt were most easily identifiable using aerial photos. Although it was not designated as a separate category, the Lake Wesserunsett watershed contains a small area of commercial property. In the land use analysis, roads were considered only as 2-dimensional lines that separated land cover types. The land use team obtained road area data from the GIS team. Roads and commercial property were evaluated separately because of their fractional area within the watershed.

Cleared land in the Lake Wesserunsett watershed was defined as any land which was not covered by trees or shrubs. This category included lands under agricultural tillage, grassy areas encompassing non shoreline residences, fallow fields, and the Lakewood golf course. These uses were grouped together because they transport nutrients and runoff at similar rates (see Background: Cleared Land).

Reverting land was defined as land that is in the process of succession. This category was selected in order to determine how much cleared land is presently being allowed to return to forest. Succession is the replacement of one vegetative community by another, which ultimately results in a mature and stable community referred to as a climax community (Smith and Smith 2001). Reverting

land was identified as “shrubby” fields lacking a distinct canopy on the aerial photos

Disturbed forest was defined as an intermediate category between cleared land and forest. It was identified on the aerial photos by large openings within an area of forest canopy, the presence of clear or selective cutting, logging roads, skidder trails and residential development in the understory.

Wetlands are defined as zones of transition between terrestrial and aquatic ecosystems (Weller 1994). In our study, the boundary of the wetland within the watershed was determined by a transition from short, dense emergent vegetation to a taller canopy of trees. Lake Wesserunsett has extensive wetlands in both the North and West portions of the lake. These wetlands have limited the development along the shore of the lake because the land is unsuitable for structures without significant mitigation. The amount of wetlands within any given watershed is critical because this land type is a major nutrient source and sink (see Background: Wetlands). Any pressure to develop wetlands for other uses will likely have negative impacts on lake water quality due to increased runoff, erosion, and decrease in natural buffering ability. Identification of wetland boundaries on the aerial photos proved challenging because of the resolution of the images. Wetlands were delimited by the presence of open mats of vegetation and areas of marsh or emergent plants. Wetlands beneath the canopy may be incorrectly classified as forest because we could not see below the trees on the aerial photos.

Forest was classified as areas which were clearly covered by a canopy of trees. The canopy had to be continuous, without identifiable breaks and clearings.

Shoreline residential land was classified to examine the impact of recreational development within the watershed. The land use team identified this category to show how recreational development along the shoreline has changed in the past 39 years. This category was delimited on the aerial photographs by the presence of camp roads and roofs. It is important to note that this evaluation was subjective. The land use classification of shoreline residential includes not only houses but all residential land in contact with the shoreline. Unlike the development groups assessment of shoreline residential area which multiplied the shoreline house count by the area of a 0.5 acre shoreline lot, the land use team quantified shoreline residential area from the shoreline inland to the first observable road on the aerial photos.

Results and Analysis

Land use was classified for the entire Lake Wesserunsett watershed using 1961 and 2000 aerial photographs. Land use maps for 1961, 2000 and areas of land use class change are shown in Figures 15 and 16.

Wetlands

In 1961, 2.00 percent of the watershed area was classified as wetlands. The area covered by wetlands within the watershed decreased to 1.83 percent by 2000 (Table 6). In 2000, the area of wetlands was 6.62 percent less than the area of wetlands in 1961 (Figure 17 and Table 6). Although the area of wetlands decreased, it represents only a 0.17 percent change in the total area of watershed

Table 6. Lake Wesserunsett watershed land use types and areas in km², change in percentage of total watershed area, and percentage change of each land use type area between 1961^a and 2000^b. Results are based on computer assisted analysis of aerial photographs from 1961 and 2000.

Land use type	Area in km ²			% Change	
	1961 ^a	2000 ^b	2000(total)	Watershed	Land use type
Forest	18.47	20.21	25.87	3.17	8.79
Disturbed forest	3.95	4.18	4.77	0.62	8.39
Reverting land	0.56	0.19	0.19	-0.98	-66.77
Cleared land	8.60	7.13	7.96 ^c	-4.21	-17.13
Wetlands	0.78	0.72	0.87	-0.17	-6.62
Shoreline residential	0.50	1.20	1.09	1.75	140.31
Commercial land	-	-	0.05	-	-
Roads	-	-	1.31	-	-
Total ^d	38.50	39.30	47.78	-	-

^a 1961 data are missing for 17.75 percent of the total watershed area (**Figure IV.A.1.d.6**).

^b 2000 data with missing 1961 area removed for accurate comparison with available 1961 data.

^c Cleared land includes a 0.51 km² golf course bordering Hayden Brook.

^d Total includes 5.67 km² of lake area.

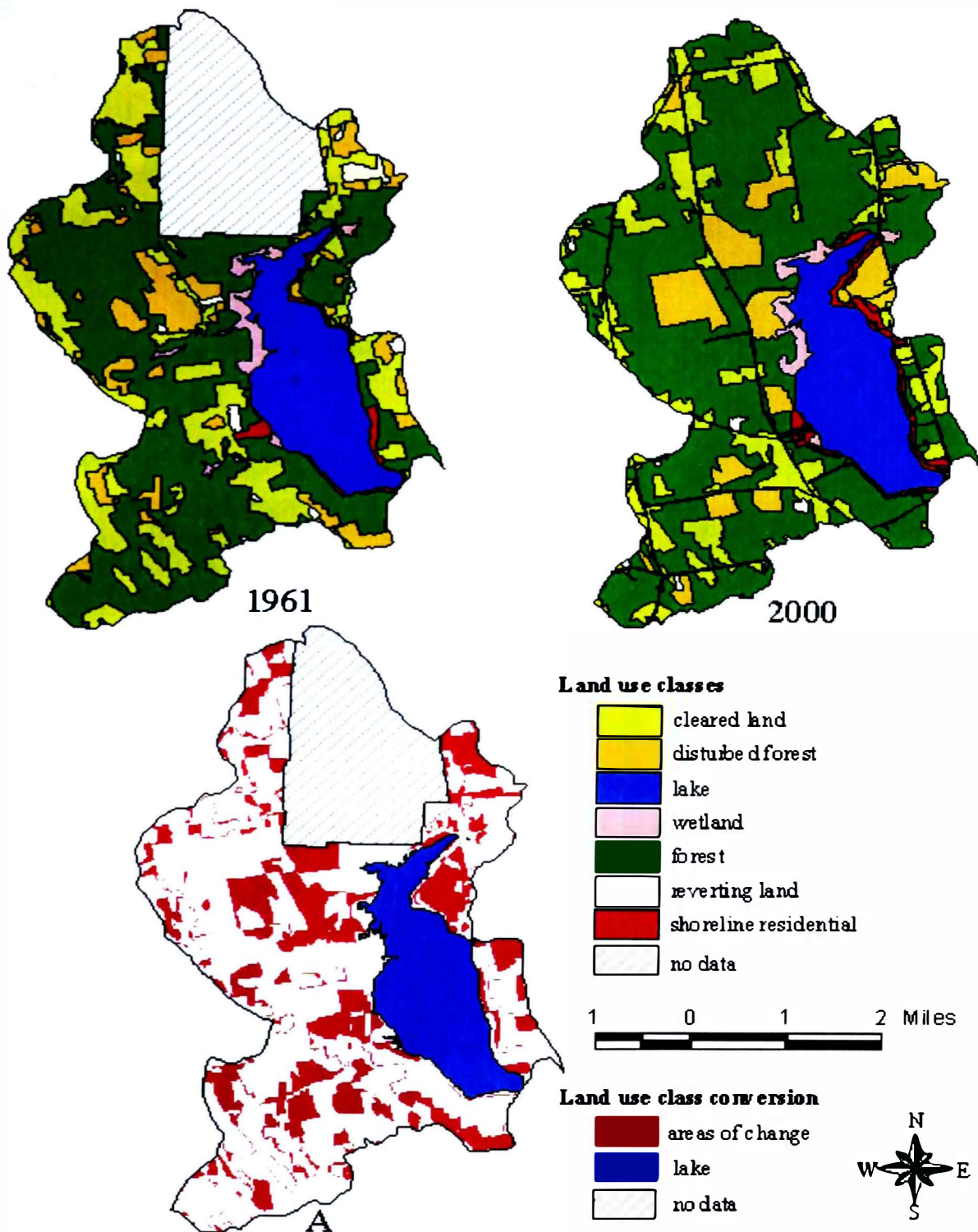


Figure 15. Land use classes in 1961 and 2000 for the Lake Wesserunsett watershed. Figure A shows all areas of change in land use class from 1961 to 2000. Aerial photographs were not available for the 1961 land use analysis of the northern portion of the watershed.

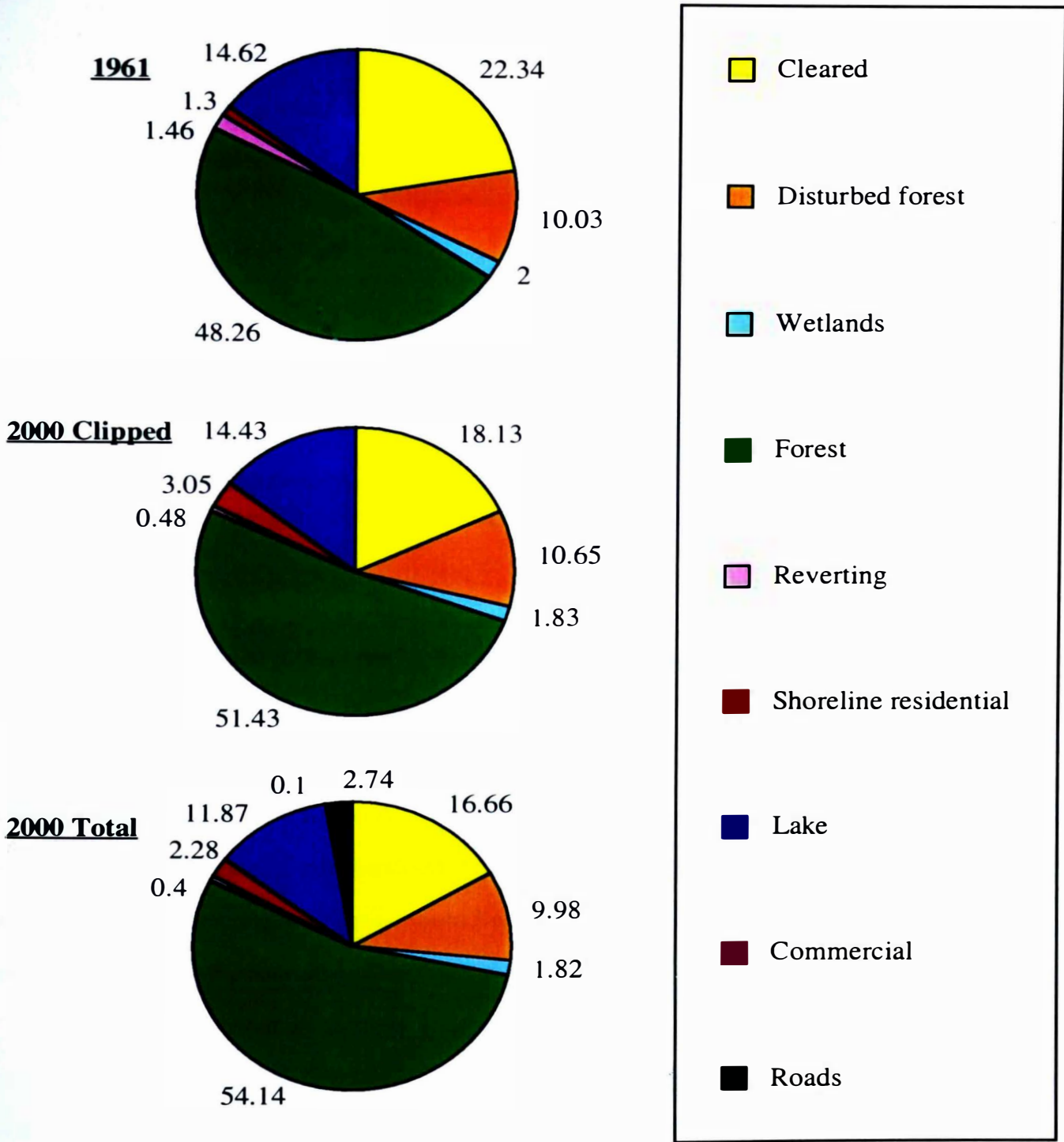


Figure 16. Percent of Lake Wesserunsett watershed area covered by each land use type. Year 2000 clipped data exclude the area missing from 1961 data. Year 2000 total data include the entire surface area of the watershed.

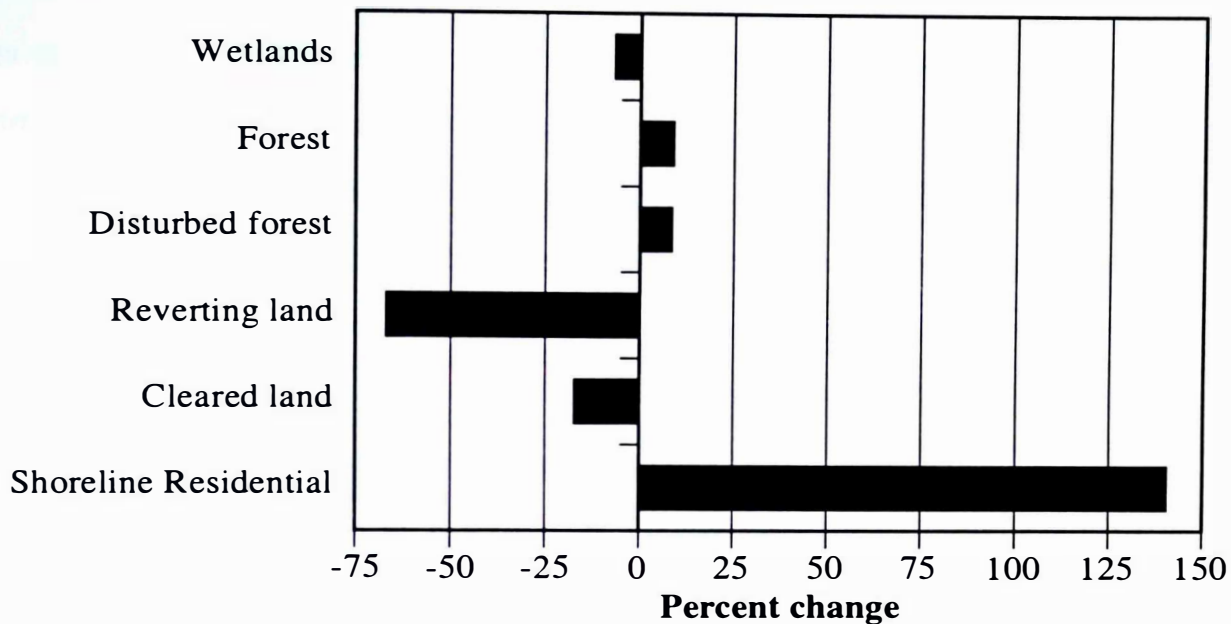


Figure 17. Percent change of individual land use types between 1961 and 2000. Missing 1961 area is excluded from 2000 data to facilitate comparison.

area. Due to difficulty in differentiating forested wetlands from forest during classification, these wetland figures may be low.

The water level of Lake Wesserunsett has fluctuated since 1961 due to changes in the management of the dam at the outlet (see Background: Lake Level Management). A change in water level can change the area of land suitable for wetlands, possibly accounting for the decrease in wetlands. A possible source of error could be due to the difficulty of properly identifying the smooth transition between wetlands and the surrounding land on the aerial photographs.

Wetlands can serve as nutrient sources or sinks depending on the type and location in the watershed (see Background: Wetlands). Wetlands that serve as sinks can improve the water quality in several ways. Water is slowed when it passes through wetland vegetation, allowing for the removal of sediment from the water column. Wetlands also have the ability to remove phosphorus from the water through uptake by aquatic plants (Patrick 1994). The decrease in wetlands in the watershed may increase the level of phosphorus in the lake because of fewer nutrient sinks.

Forest

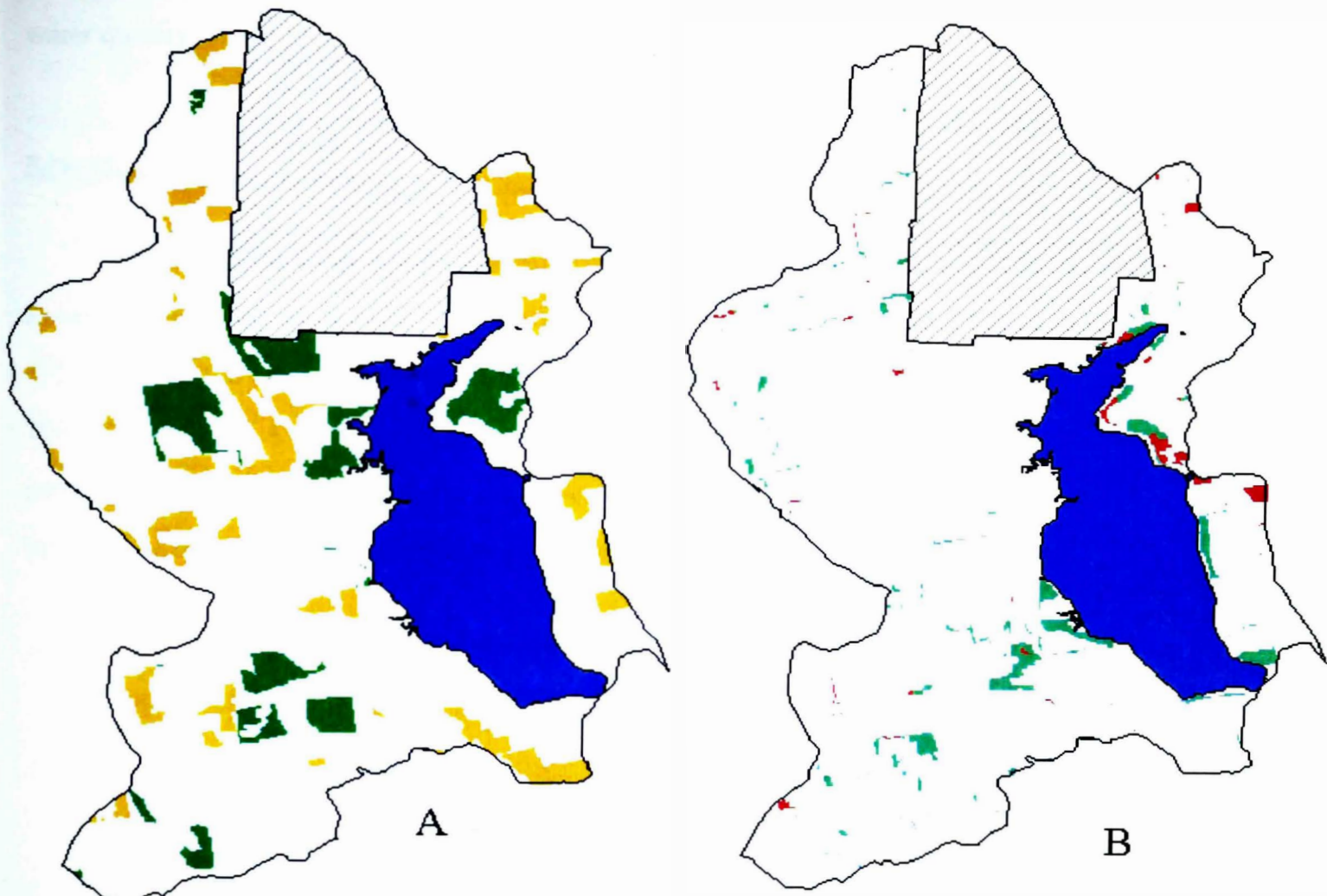
The area of forest in the Lake Wesserunsett watershed increased by 3.17 percent over the period from 1961 to 2000 (Table 6). Within the forest land use class, there was 8.79 percent more forested land in 2000 than in 1961 (Figure 17 and Table 6). Forests act as buffers, absorbing runoff from other land use types such as roads, cleared land and residential land (see Background: Land Use Types). The increase in forest area exerts a positive influence on the water quality of Lake Wesserunsett because forests have low erosion potential and contribute fewer nutrients to Lake Wesserunsett due to reduced surface runoff and increased nutrient absorption (Dennis 1986).

There are several possible explanations for the increase in forest cover in the Lake Wesserunsett watershed. A significant decrease in cleared land occurred between 1961 and 2000. Some areas that were cleared land in 1961 may have reverted to forest by 2000 (Figure 18). Other explanations for the increase in forest cover include the natural conversion from disturbed forest to forest (Figure 18). Several areas that changed from disturbed forest to forest likely experienced logging prior to 1961 and have since re-grown into mature forests.

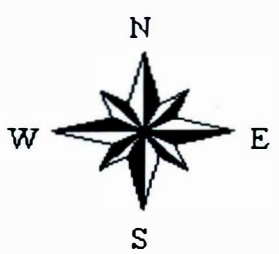
Disturbed Forest

The percent of disturbed forest has changed little over the period of analysis. The area of disturbed forest in the watershed increased 0.62 percent from 1961 to 2000 (Table 6). In 2000, the area of disturbed forest was 8.39 percent greater than the area of disturbed forest in 1961 (Figure 17 and Table 6). The increase in disturbed forest could be a result of increased logging in the Lake Wesserunsett watershed.

From the 2000 aerial photographs, it is apparent that logging has taken place in the east-central portion of the watershed. Many areas in the watershed experienced a conversion from forest to disturbed forest between 1961 and 2000 (Figure 18). These areas have likely experienced a recent timber harvest, but do not represent all logging operations since 1961. A timber harvest that occurred in the 1960's would be nearly indistinguishable from other areas of forest due to natural succession processes. Logging operations must cut roads and skidder trails, which cause erosion and



1 0 1 2 Miles



Land use class conversion

- disturbed forest to forest
- forest to disturbed forest
- lake
- no data

Land use class conversion

- cleared land to disturbed forest
- cleared land to forest
- lake
- no data

Figure 18. Key land use class conversions in the Lake Wesserunsett watershed from 1961 to 2000. Figure A shows areas of conversion of forest to disturbed forest and disturbed forest to forest. New areas of disturbed forest likely represent sites of recent logging. Figure B shows conversions of cleared land to forest and cleared land to disturbed forest.

increase the amount of runoff entering the lake (Williams 1992). The runoff associated with logging activity through increased erosion potential increases the lake's nutrient load and degrades overall water quality.

Reverting Land

Reverting land represents a small portion of the total Lake Wesserunsett watershed area. Reverting land constituted only 1.46 percent of total area in 1961 and 0.49 percent in 2000 (Figure 19). In 2000, the area of reverting land was 66.77 percent less than the area of reverting land in 1961 (Figure 17). Although there was a large decrease in reverting land, it represented only a 0.98 percent decrease in area relative to the entire Lake Wesserunsett watershed (Table 6). The decrease most likely represents the succession of reverting land to forest or disturbed forest.

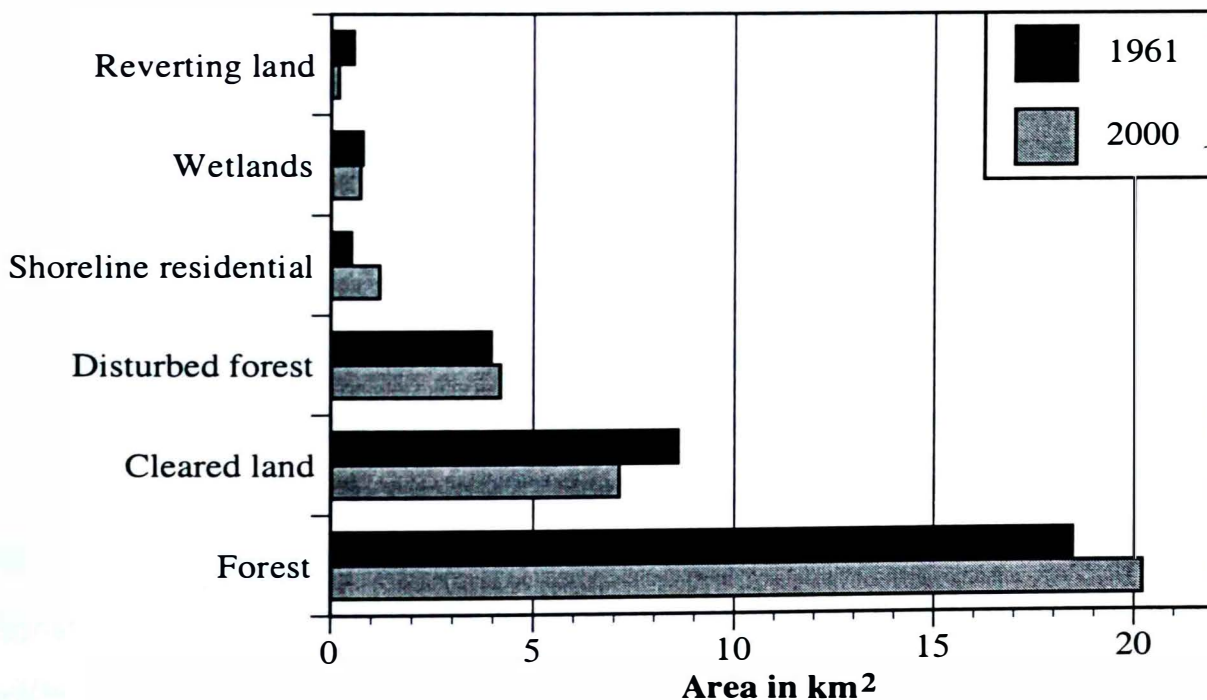


Figure 19. Land use type and area within the Lake Wesserunsett watershed in km². Area missing from 1961 data is clipped from the 2000 data to facilitate comparison.

Cleared Land

The area of cleared land in the Lake Wesserunsett watershed decreased by 4.21 percent from 1961 to 2000 (Table 6). Within the cleared land class, there was 17.13 percent less cleared land in 2000 than in 1961 (Figure 17 and Table 6). A decrease in cleared land generally benefits the water quality of Lake Wesserunsett because runoff from cleared land tends to contain more phosphorus than forested land (Lea et al. 1990). Most of the decrease in cleared land is due to a conversion from cleared land to disturbed forest (Figure 18). The largest areas of land that changed from cleared land to disturbed forest are located in close proximity to Lake Wesserunsett, especially on the eastern-shore and around Lakewood. Areas of conversion from cleared land to disturbed forest that border the lake reduce the amount of runoff entering the lake due the re-growth of adequate buffer vegetation (see Development Assessment: Buffer Zone Survey).

There are two specific land uses that are included in cleared land: a golf course and farmland. A golf course near Lakewood on the west side of Route 201 covers an area of 0.51 km² of the 7.13 km² of cleared land (Table 6). The golf course may exert a negative influence on the water quality of Lake Wesserunsett due to runoff containing fertilizers and pesticides. The use of pesticides by the Lakewood golf course may have a significant impact on water quality because Hayden Brook runs directly through the golf course. Pesticides with a relatively high water solubility tend to be washed away with runoff when applied to the short grass of turf greens. Pesticides used on golf courses may also have adverse effects on non-target species (Wan et al. 1996).

Very little cleared land in the Lake Wesserunsett watershed is devoted to agriculture. Agriculture can cause increased runoff which contributes to nutrient loading (see Background: Agriculture and Livestock), but the only farms in the watershed are a horse farm and a small dairy farm. Since there are only two small farms in the watershed and they are distant from the lakeshore, the effect of agriculture on the water quality of Lake Wesserunsett appears to be minimal.

Commercial Land

In 2000, the area of commercial land was 0.05 km², approximately 0.1 percent of the area of the Lake Wesserunsett watershed (Table 6). All ten commercial properties identified are small businesses including an antique shop and the office of a logging company. The largest concentration of commercial land is in the Lakewood area. Parking lots, such as in the Lakewood area, and large buildings are often present on commercial properties. These impervious surfaces do not absorb water and do increase runoff, erosion and nutrient loading. However, none of the commercial properties in the watershed have large parking lots or large industrial buildings. Since the area of commercial land makes up only one tenth of one percent of the watershed, this land use is not considered to have a large impact on the water quality of Lake Wesserunsett.

Shoreline Residential

Land use analysis suggests a large increase in shoreline residential land use. Shoreline residential land use constituted 1.30 percent of the area of the Lake Wesserunsett watershed in 1961 and 3.05 percent in 2000 (Table 6). This represents a 1.75 percent change in the area of shoreline residential land (Table 6). In 2000, the area of shoreline residential land was 140.31 percent greater than the area of shoreline residential land in 1961 (Figure 17).

Land conversion to shoreline residential use is a serious threat to the water quality of Lake Wesserunsett (see Background: Shoreline Residential Areas). The highest concentration of new shoreline residential land was on the eastern shore of Lake Wesserunsett. Most camp roads in this area run downhill directly to the lake. This increases runoff and causes higher levels of nutrient loading and sedimentation. Some houses on the eastern shore have poor buffer strips (see Development Assessment: Buffer Zone Survey), so runoff from roads and cleared land will likely enter the lake at a greater rate. If the development of new shoreline residences continues at a high rate, then runoff from shoreline residential land may become a more serious threat to the water quality of Lake Wesserunsett.

Table 7. Percent of watershed area covered by land use types and percent of shoreline covered by wetlands for Lake Wesserunsett, Messalonskee Lake, Long Pond- South Basin and North Basin, North Pond, Salmon Lake, and East Pond watersheds. Transitional land includes reverting and disturbed land. Developed land includes roads, residential, industrial, and commercial land. Data are obtained from CEAT studies performed in 1991, 1994, 1995, 1996, 1997, 1998, 1999, and 2000.

	Lake Wess.	Mess. Lake	Long Pond S.Basin	Long Pond N.Basin	North Pond	Salmon Lake	East Pond
Wetlands	2.1	13.5	8.3	4.2	7.0	1.0	3.0
Mature forest	61.4	58.5	58.0	68.0	75.0	83.0	77.0
Transitional land	11.8	4.0	27.0	14.5	2.0	3.0	2.0
Cleared land	18.9	13.9	4.8	3.0	10.0	9.0	2.0
Developed land	2.6	8.8	6.7	9.0	4.0	3.0	14.0
Roads	3.1	1.3	0.5	1.0	1.0	1.0	2.0
Shoreline wetland coverage	34.3	26.6	-	-	10.0	-	13.02

Watershed Comparisons

By looking at previous CEAT studies, comparisons can be made with other watersheds in central Maine (Table 7). Lake Wesserunsett has more cleared land than any other watershed studied previously by CEAT. Developed land occupies 2.9 percent of the watershed, the lowest of all CEAT studies. The lake has nearly the lowest percentage of wetlands, so runoff and sediment from increased development could impact Lake Wesserunsett more than it would in other lakes studied by CEAT. Despite the small area of wetlands, Lake Wesserunsett has a higher percent of shoreline covered by wetlands than any previous CEAT study site. This has a positive impact on Lake Wesserunsett's buffering capacity.

Development Assessment

Residences

House Survey

Introduction-Building Regulations

Residences built on lakefront property must follow specific development regulations designed to limit the nutrient loading into a lake. All principal and accessory structures must be set back at least 100 ft from the normal high water line of Lake Wesserunsett, and cannot exceed 35 ft in height. In addition, the total area of all new structures within the shoreline zone cannot exceed 20 percent of the footprint lot size previously developed (Madison 1995). These regulations must be followed in lakefront development because clearing land creates physical sediment disturbance that results in increased nutrient runoff.

Some lakefront development practices are more environmentally sound than others. During construction, low disturbance machinery and a thick buffer zone can limit soil runoff. The use of runoff diversions and sediment holding silt fences detours runoff into nearby highly vegetated areas. Shoreline development planning must account for the shoreline slope, the characteristics of the sediment, and specific shoreline elevations to limit nutrient runoff (Adams and Wernousky 1998). In addition, developers must consider the road location, condition and gradient, the type of soil and the available buffer strip in shoreline development.

Methods

All houses in the watershed were counted by two methods and categorized as seasonal or year-round. The first method was by boat during the buffer strip survey on 25-Sep-00. The second method was a house survey that was performed in conjunction with the road survey on 2-Oct-00 (Appendix B). The buffer strip analysis only provided information on the total number of houses along the shoreline, while the house survey analysis included information on the seasonal or year-round status of residences. In addition to the field data collected, tax maps and corresponding

reference cards were obtained from Madison Town Hall. By comparing the information on the reference cards with the corresponding tax map number, it was determined if the lot had single or multiple houses and which lots were undeveloped.

The changes in the seasonal and year-round house numbers over time were determined by comparing the analysis of seasonal or year-round house counts taken in 1971 by the Inventory of Existing Land Use from the North Kennebec Regional Planning Commission with present counts (NKRPC 1971). To determine change in the percent of shoreline residential areas in the watershed from 1961 to 2000, aerial photographs were digitized and analyzed using ArcView (see Land Use Assessment: Shoreline Residential). The area from the lakefront to the closest camp road was considered to be shoreline residential.

To determine if a house was a seasonal or year-round residence, particular features were noted. Seasonal houses may have an open foundation and boarded up or shutter-covered windows at survey time. Features suggesting year-round residency include an enclosed foundation, an external oil tank, a chimney, or a paved driveway.

Houses within the watershed were also classified as being either greater or less than 200 ft from the Lake Wesserunsett shoreline. Those within 200 ft of the water are considered shoreline residences with lot property leading to the lakefront (Madison 1995). Using the MDEP method for determining residential use area, shoreline houses are considered to occupy half an acre and non-shoreline houses occupy one acre.

Results and Discussion

Results from the house count indicate that of the 533 houses in the watershed, 55 percent (293 houses) are year-round and 45 percent (240 houses) are seasonal (Figure 20). The house count survey also found that along the shoreline of Lake Wesserunsett, 68 percent of the houses are seasonal (145 houses) and 32 percent are year-round residencies (68 houses), for a total of 213 houses. According to the reference cards for the tax maps from the Madison Town Hall (2000), 71 percent (149 houses) of shoreline residences are seasonal, while 29 percent (61 houses) are year-round, for a total of 210 houses. Current total residences on the shoreline from the house survey and tax map

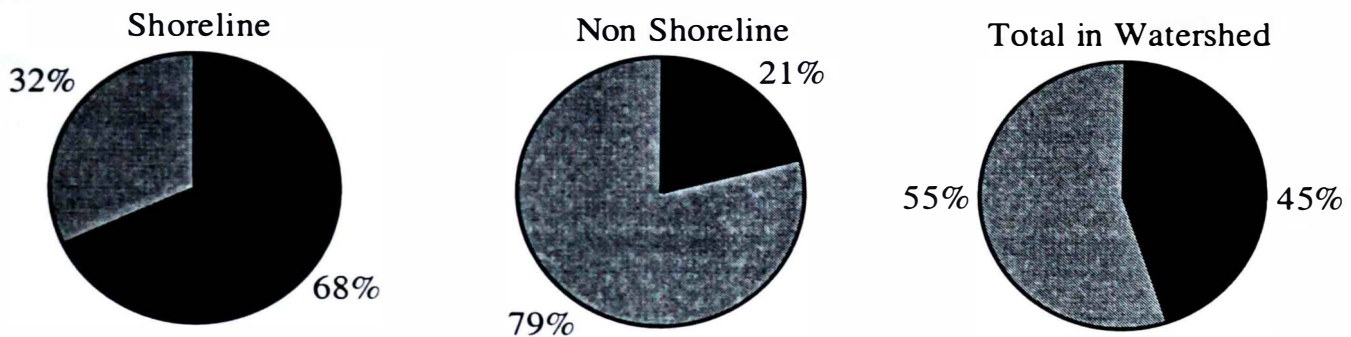


Figure 20. Percent of seasonal and year-round residences on shoreline and non shoreline areas of Lake Wesserunsett as determined from the road analysis survey on 2-Oct-00. The majority of shoreline residences are seasonal (68.1%) while the majority of residences off the shoreline are year-round (79.1%).

analysis are 213 and 210, respectively. The buffer strip analysis found 242 houses along the shoreline (Table 8). According to the tax maps, 51 lots along the shoreline are not developed.

Averaging the results from the different surveys can account for the variability in the multiple survey techniques. The percent of seasonal shoreline residences from the 2000 house count survey (68 percent) averaged with the 2000 Madison tax maps (71 percent) yields 69.5 percent of shoreline houses as seasonal and 30.5 percent as year-round. Averaging the number of shoreline residences from the 2000 House Count Survey (213 houses), the Madison Tax Maps (210 houses) and the Buffer Strip Survey (242 houses) yields 221 houses. The buffer strip survey yielded a higher number than the other surveys, likely due to counting structures from the boats that were not houses.

Discrepancies amongst the total number of houses along the shoreline range from 210 houses to 242, a difference of only 32 houses. This is a variation due to different data collection techniques and possible sources of error. For example, the road survey analysis may not have recorded all the shoreline houses due to long driveways, thick vegetation or avoidance of trespassing onto private property. Also, the buffer strip analysis may not detect all the shoreline residences from the boats due to thick vegetation or houses obscured by other property. In addition, data gathered by CEAT

Table 8. Total house counts and percent of seasonal and year-round residences along the Lake Wesserunsett shoreline. Data are from the 1971 House Count Survey, the 2000 House Count Survey and the 2000 Tax Map Analysis.

House Count Method	Total Seasonal (%)	Total Year-Round (%)	Total Count
1971 House Count	213 (96%)	9 (4%)	222
2000 House Count	145 (68%)	68 (32%)	213
2000 Tax Map Count	149 (71%)	61 (29%)	210

from the field may have misidentified buildings as houses, leading to variations in house count numbers.

The total number of houses along the shoreline has not changed significantly since 1971. The number of houses along the shoreline in 1971 was 222 (NKRPC 1971). Of these 222 houses, 96 percent (213 houses) were seasonal and 4 percent (9 houses) were year-round. Comparing this with the current average of 69.5 percent seasonal shoreline houses indicates a 26.5 percent decrease in seasonal houses and corresponding increase in year-round houses. Since the actual number of houses along the shoreline has not changed much over this time period, the decrease in seasonal houses may be due to conversions to year-round houses. These winterizing additions can have effects on Lake Wesserunsett in the form of the particulates emitted in fireplace usage, the release of byproducts from using oil and natural gas to heat the house, and an increase in runoff from driveways and lawns. An increased use of septic systems will be a result of year-round living. Construction on highly erodible soil can also lead to high levels of nutrient loading into Lake Wesserunsett (Cole, pers. comm.; see GISAssessment: Erosion Potential Model).

According to the MDEP method for land area allocation, shoreline residences are considered to occupy half an acre, while non-shoreline houses occupy one acre. Of the 533 houses in the watershed, 222 are along the shoreline and 311 houses are more than 200 ft from the shoreline. This indicates that 44.92 ha (111 acres) are occupied by shoreline residences and 125.85 ha (311 acres) are occupied by non-shoreline residences. While non-shoreline residences occupy more land, the close proximity of the shoreline residences to Lake Wesserunsett causes significant runoff from the shoreline houses. Land use analysis indicates a 140 percent increase in shoreline residential area

from 1961 to 2000 (see Land Use Assessment: Shoreline Residential). This increase in area does not account for new individual houses and instead indicates increased lot clearing for development. Because GIS information could not provide individual house number increases, the increase in the area cleared along the shoreline was considered land cleared for residential development. This increased lot clearing can be in the form of the removal of buffer strips for increased visibility directly down to the water, tree reduction along the shoreline for lake access or logging purposes or clearing for farming purposes. However, a portion of the increase in shoreline residential area is due the conversion of seasonal camps to year-round homes. While there is no available data concerning the land use changes within the watershed more than 200 ft from the shoreline, there has been a 14 percent population increase in Madison since 1970, which could indicate an increase in development within the watershed as a whole (see: Population Information).

Seasonal and year-round houses have different features in their construction, use and maintenance that will affect nutrient loading differently for each type of house. While there has been increased development of year-round residencies, all the surveys performed indicate that the majority of shoreline houses are seasonal. Due to their close proximity to the lake, shoreline houses will have more direct runoff than houses greater than 200 ft from the shore.

Population Information

Introduction

Population increase over time can indicate the rise in development within an area. Where population density increases are highest, development occurs at the fastest rates. Shoreline residential percent change over time can also indicate increased development along the shoreline (see Land Use Assessment: Shoreline Residential). Comparison of the population change in Madison from 1970 to 1999 indicates a population growth trend. In comparison to the population density concentration along the shoreline, areas within the watershed that have potential problems for nutrient runoff can be identified based on the density of houses.

Methods

Population change from 1970 to 1999 was obtained from the Kennebec Valley Council of Governments (KVCG 2000). Watershed population density data were obtained from the 1990 Census Topologically Integrated Geographic Encoding and Referencing (TIGER) database (TIGER 2000). Using these data, the population concentration around the shoreline was determined and compared with areas of high house concentrations. These densely populated areas are believed to cause high levels of runoff and result in more phosphorous loading to the lake than less populated areas.

Results and Discussion

The population in Madison grew from 4,278 in 1970 to an estimated 4,895 in 1999 (KVCG 2000). The 1990 TIGER population density analysis indicated that the majority of the population of the Lake Wesserunsett watershed is located on or within 200 ft from the shoreline. The most populated areas are on the western side of the lake. There is also a significant population with a relatively even distribution of people from Abnaki Campground in the northeastern section of Lake Wesserunsett down to the seaplane chartering company in the southeast corner (Figure 21).

The correlation between areas of high population density and the type of houses that dominate that area could have effects on the seasonal variation in nutrient runoff. Population density is highest along the shoreline with seasonal houses accounting for 68 percent of these shoreline residences (Figure 20). There is an increase in population during the seasonal months. Assuming that each residence has 2 to 3 people, a broad approximation of the summer population increase results in an additional 444 to 666 people living in the 222 seasonal houses along the shoreline. Chemical analysis indicates that the phosphorus levels are highest during the summer months (see Water Quality Assessment: Total Phosphorus). While these high phosphorus levels are possibly caused by the natural seasonal changes in lake features, some of the increase in nutrient loading may be due to the increased number of seasonal residents in the summer. Seasonal phosphorus increases in Lake Wesserunsett may also be due to improvements made to seasonal houses in the warmer months,

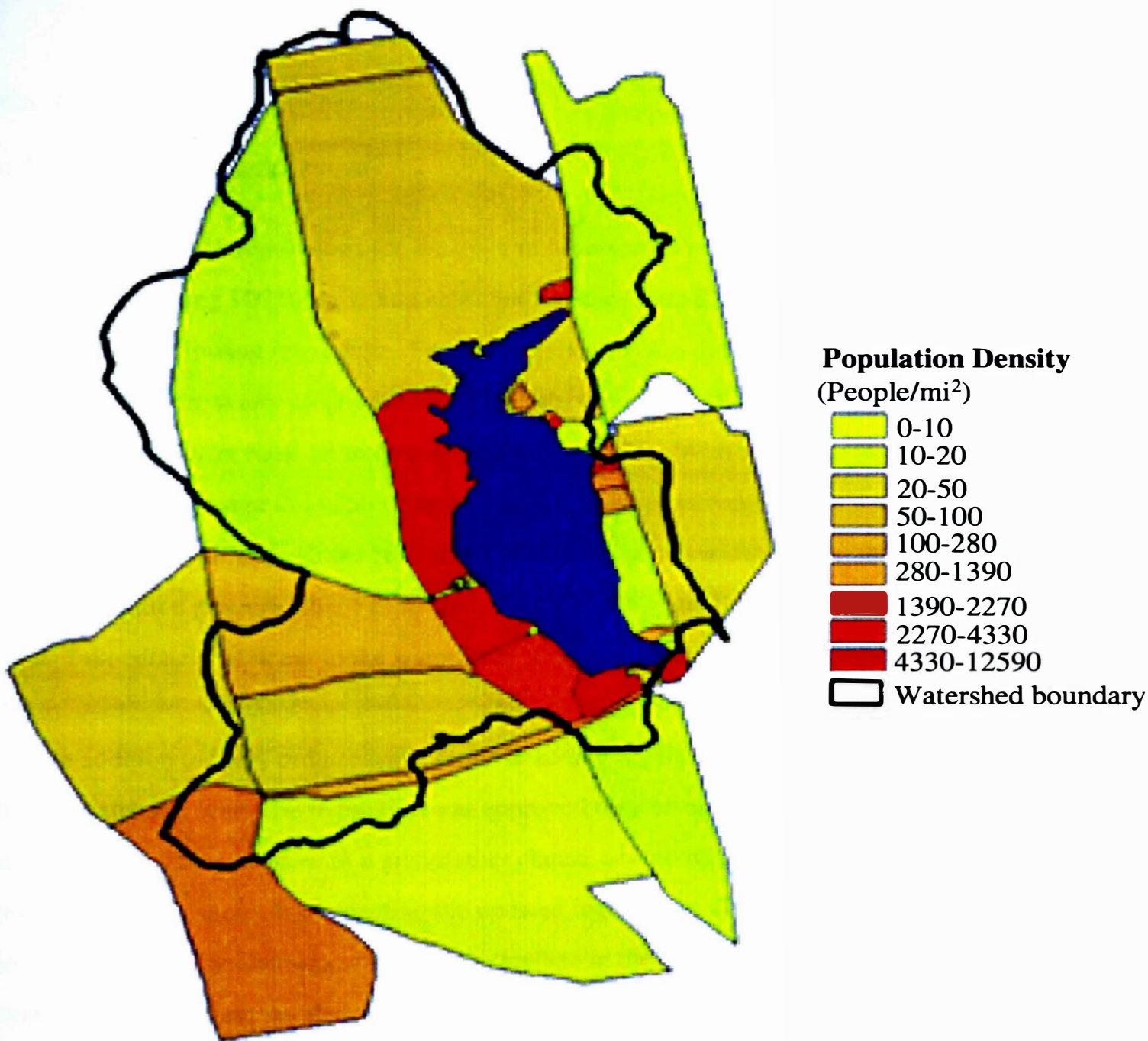


Figure 21. Population density (people/square mile) within the Lake Wesserunsett watershed. Data were omitted when a census block was located primarily outside the watershed. Data adapted from 1990 TIGER census data (TIGER 2000).

increased runoff in the summer due to the use of fertilizers for lawn care, or the increased use of septic systems with seasonal population influx.

Buffer Zone Survey

Introduction-Shoreline Regulations

Current setback regulations for the town of Madison do not permit development within a strip of land extending 100 ft horizontal shoreline distance inland, perpendicular to the shoreline of a lake or a tributary flowing into a lake. Setback regulations also define a zone of 75 ft horizontal shoreline distance from any other water body, tributary stream, or the upland edge of a wetland in which the natural buffer must be maintained (Madison 1995). With respect to this area, there can be no cleared opening greater than 250 ft² in the forest canopy as measured from the outer limits of the tree crown. A footpath through the buffer, not to exceed 10 ft in width as measured between tree trunks, is permitted provided that a clear line of sight to the water through the buffer strip is not created. Immediately adjacent to the water body, the width of a footpath is limited to 6 ft (Madison 1995).

In addition to these ordinances, a separate zoning regulation states that cleared openings already in existence when the regulation was approved may be maintained, but shall not be enlarged (Madison 1995). This is known as a grandfather clause, and permits much of the shoreline residential development to be exempt from meeting the updated regulations. This clause is significant to the watershed, as a large percentage of property examined in the shoreline survey does not meet the current standards of these regulations due to this legal exemption.

Methods

In order to assess buffering on Lake Wesserunsett, the shoreline was divided into five equal sections (Figure 22). Each section of the lake shoreline was assessed via boat on 25-Sep-00 using standardized buffer strip evaluations. Buffer strip evaluations were based on percent coverage, depth

back from shoreline, slope, composition (tree, shrub, ground cover, and duff layers) and riprap (present or absent). All evaluations were recorded and tallied on the Buffer Strip Survey Form (Appendix C). CEAT determined that buffer depth and slope had the greatest impact on buffer quality, followed by percent of shorefront coverage and composition.

An index was developed based on the totals obtained from the survey forms to assess the quality of individual buffer strips. Buffer strips were partitioned into three major categories: adequate, at risk, and at high-risk, based upon their score totals from the individual surveys. High-risk buffers received a buffer strip score ranging from 0 to 9, and contained buffer strips that were less than 25 ft in depth and less than 25 percent coverage of the property's shorefront. At risk properties received scores ranging from 10 to 16, and included residences with less than 75 ft of buffer, but more than 25 ft buffer depth, and an intermediate level of lake shore coverage. An intermediate level of coverage is defined as property that retains between 25 percent and 50 percent of a naturally vegetated buffer. Adequately buffered properties received scores of 17 and over. Using the evaluation form, the highest possible total for a buffer strip rating was 31, based on percent cover, depth back from shore, and composition. The highest score recorded in our survey was 25.

Results and Discussion

A total of 242 shoreline properties were examined to evaluate buffer strip quality. Of all properties surveyed, only 35 percent were found to have adequate buffer strips. The at risk buffer strips constituted the largest category observed on the lake, with a total of 45 percent. In addition, 20 percent of buffer strips that were determined to be in the high-risk category (Figure 23).

In Section 1, located in the northwest corner of Lake Wesserunsett, 44 percent of the buffer strips are adequate. Section 1 contains 12 percent at risk buffer strips, and an additional 44 percent of high-risk category buffer strips. The potential benefit of the 44 percent of adequate buffers in this section of Lake Wesserunsett is offset by the additional 44 percent of high-risk buffer strips (Figure 23).

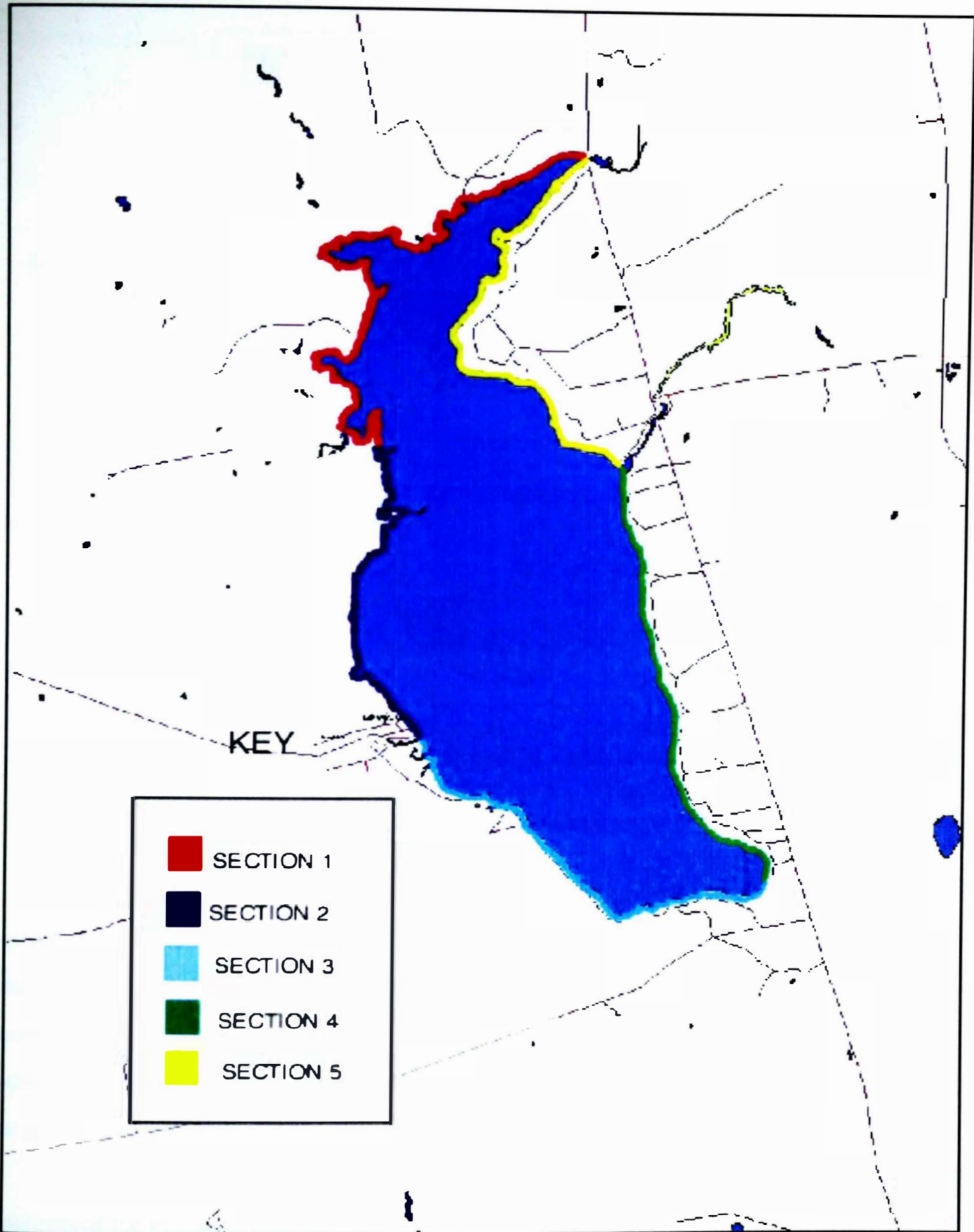


Figure 22. Breakdown map of lake sections.

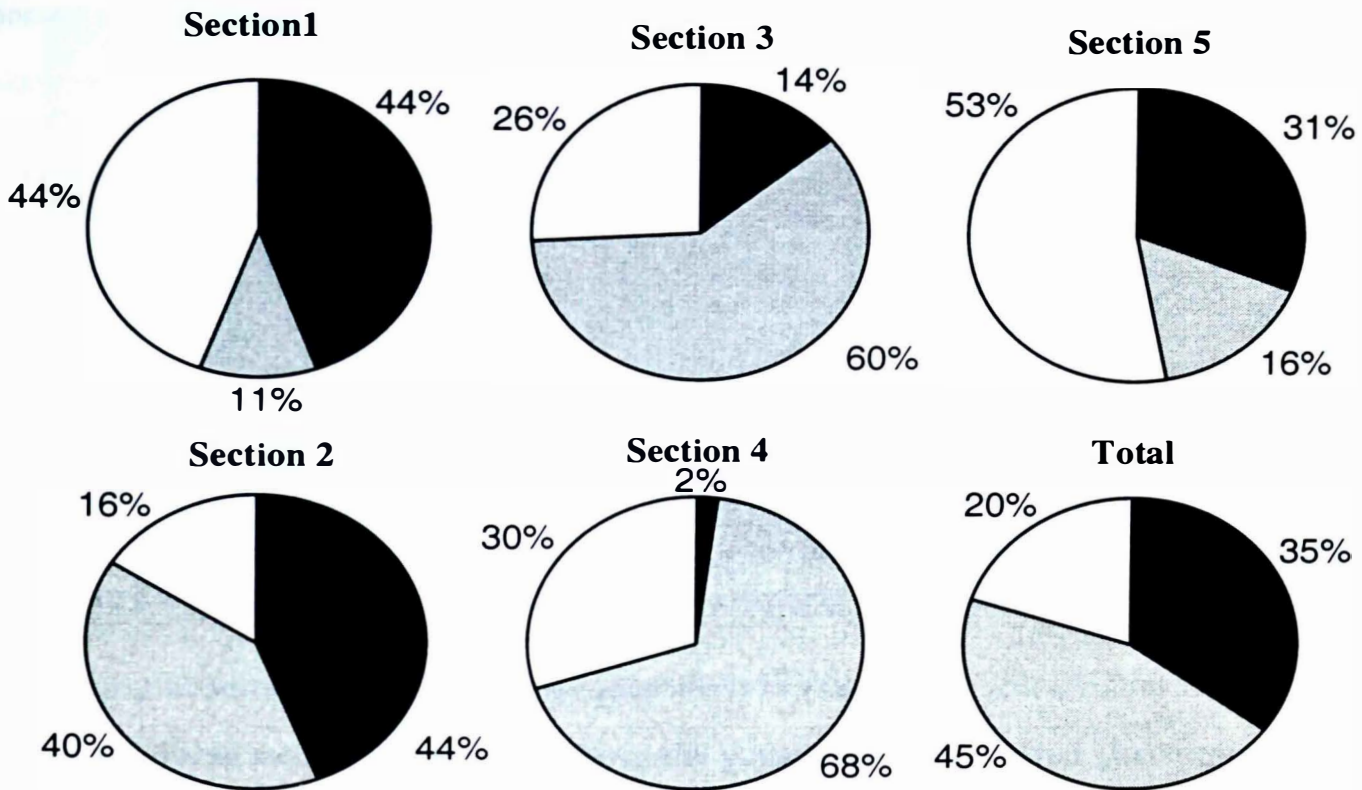


Figure 23. Risk potential of buffer strips for nutrient loading on Lake Wesserunsett during Fall 2000, divided into lake section based on geography of the lake (see section map for shoreline survey, Figure 22). Risk potential of buffer strips for total shorefront of Lake Wesserunsett.

In Section 2, spanning the western edge of Lake Wesserunsett, 44 percent of the residences surveyed are adequately buffered. However, another 40 percent of buffer strips surveyed are in the at risk category. In addition, 16 percent of buffer strips are high-risk. There is a heightened amount of traffic and activity in this part of the Lake Wesserunsett shoreline because of the Lakewood development. The presence of good or adequate buffers in this section of Lake Wesserunsett is especially important (Figure 23).

In Section 3, which runs along the southwestern edge and southern tip of Lake Wesserunsett, 14 percent of the properties surveyed contain adequate buffers. The remaining properties have 60 percent at risk buffer strips and 26 percent high-risk buffer strips. While this section of Lake Wesserunsett is inadequately buffered, it is still not as poorly buffered as Section 4 (Figure 23).

Section 4 runs along the southeastern border of Lake Wesserunsett, one of the most developed areas of the watershed. It contains 2 percent of adequate buffer strips along its properties. Over 68 percent of the properties surveyed in Sections 4 (58 houses) have at risk buffer strips, and an additional 30 percent (26 houses) contain high-risk buffers (Figure 23). The shoreline of Section 4 can be subject to heavy wave action due to the prevailing northwesterly winds which blow across Lake Wesserunsett (see Background: Lake Wesserunsett Characteristics). Erosion is a more significant threat along the shorefront of this section of the lake and the condition is compounded by the already poor buffering capacity of Section 4 (see Background: Buffer Strips).

Section 5, in the northeast corner of Lake Wesserunsett, contains 31 percent of adequately buffered properties. Sixteen percent of the properties surveyed have at risk category buffer strips, and 53 percent of the properties surveyed in Section 5 contain high-risk category buffer strips (Figure 23).

These data indicate that the majority of residences surrounding the shoreline of Lake Wesserunsett are poorly buffered. Compounding this problem, some of the most developed and densely populated areas of Lake Wesserunsett appear to need the most improvement. This is likely due to the grandfather clause that allows many residences to be exempt from the updated development regulations. Figures 24 and 25 represent two extreme examples of buffer strips that were observed in the study. Note the contrast in composition and percent coverage in the two examples.

One way to improve the current buffer strip condition is to plant native trees and shrubs to help encourage the regrowth of a naturally vegetated buffer zone (MDEP 1990). Abundant literature is available on native species which thrive in particular locations and environments (Hardesty and Kuhns 1998). Residential landscaping is a popular activity that not only increases the beauty, aesthetic value, and economic value of a property, but can also help to maintain the buffering capacity of the land itself. In addition to causing harm to Lake Wesserunsett, inadequately buffered lots risk severe damage due to erosion (Figure 26). It is important to note that investment in buffer strip enhancement can potentially save money and land in the future by decreasing erosion (MDEP 1990).



Figure 24. An example of a well buffered property on Lake Wessernsett, Fall 2000.

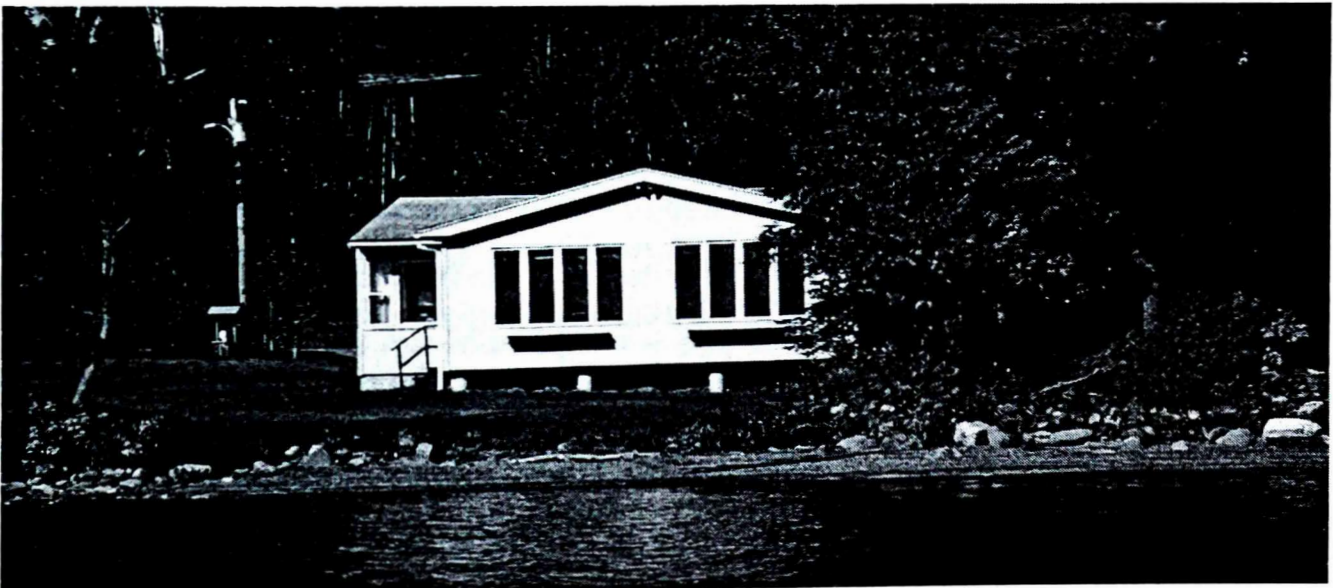


Figure 25. An example of a poorly buffered property on Lake Wesserunsett, Fall 2000.



Figure 26. An example of severe erosion on the bank of shorefront property of Lake Wesserunsett, Fall 2000.

Septic Systems

Introduction-Plumbing Regulations for Madison

The town of Madison adheres to plumbing regulations adopted by the state of Maine. These regulations are found in the Maine Subsurface Wastewater Disposal Rules, which are published by the Maine Department of Human Services (MDHS). The version of regulations that was obtained by the Colby Environmental Assessment Team (CEAT) became effective on 1-June-00 (MDHS 2000).

These regulations contain rules that specifically apply to administration and enforcement of wastewater disposal. All wastewater must be handled in one of three ways: on-site disposal, public sewer, or licensed disposal (MDHS 2000). Septic systems and disposal fields are forms of on-site wastewater disposal (See Background: Sewage Disposal Systems). In order for any type of disposal system to be installed, repaired, or removed, permits first must be obtained from both the MDHS and

from the town's plumbing inspector. It is important to ensure that all systems are in accordance with current regulations because the use of an inappropriate disposal system could be hazardous to both human and environmental health. Grandfather clauses often allow older systems to continue being used after the new regulations are in place (Cole, pers. comm.). According to MDHS, the grandfather clause that allows a system to continue to be used if it accurately complies with codes in place upon its installment, is currently used for the purpose previously intended, and is currently functioning properly (MDHS 2000).

Prior to the installation of a disposal system, such as a septic system or disposal field, a detailed site evaluation must be conducted to determine the proper location and the type of system that is most suitable (MDHS 2000). A proper site evaluation includes: assessment of soil suitability, setback requirements, soil profile and conditions, proposed system location, slope, surface runoff and existing subsurface groundwater drains. Madison's current setback regulations require that septic systems are set back 100 ft from any major or minor water course or potable water source. Disposal fields must be 300 ft from any public water supply and 100 to 300 ft from any major watercourse or well, depending on the size of the septic system in gallons per day (MDHS 2000).

Specific regulations for use of septic systems are outlined in the ordinances published by the MDHS. The regulations for septic systems include: the use of approved construction materials, tank dimensions, inlet and outlet connections, access to openings, liquid capacity, installation and maintenance of tanks, and sludge disposal (MDHS 2000). One of the most important regulations is the liquid capacity of the tank. For residential systems, one tank may service 1 to 3 homes simultaneously, as long as it meets the minimum size requirement. A 750 gallon tank is required for one or two bedrooms, 1,000 gallons for three or four bedrooms, 1,250 gallons for five bedrooms and 250 additional gallons for each bedroom over five. Installation codes include regulations against surrounding a tank with improper fill, flotation of empty tanks and leakage of surface water into tanks. In addition, regulations exist that pertain to the proper installation of systems under driveways or parking lots, and the orientation of the tank in the ground (MDHS 2000).

Madison and the MDHS require a disposal field with all types of septic systems (MDHS 2000), and a specific set of regulations controls the installation and operation such disposal fields.

The two most important factors in determining the specifics of a disposal field are the soil profile of the proposed site and the volume and quality of the waste. There are several types of disposal fields, but all work by percolating wastewater through the ground to remove impurities. The proper size of a disposal field is determined using an equation that considers the minimum hydraulic loading rate, the design flow for the type of structure and an adjustment factor based on the five-day biochemical oxygen demand and the total suspended solids of the wastewater (MDHS 2000).

Problems with Improper Septic Treatment

Septic systems are built to store and treat the waste from residences and businesses (MDHS 2000). Chemicals used in residences and businesses are often improperly treated in the septic system or disposal field, and subsequently accumulate in nearby lakes and streams. Chemicals in septic tanks can also kill the bacteria needed for proper septic function (MDHS 2000). Phosphorus from both residential and commercial septic systems can contribute to the total phosphorus in a lake and accelerate lake eutrophication (Mason 1996).

In order to assess the impacts of improperly operating septic systems on Lake Wesserunsett, the quantity and quality of septic pollution must be determined. The number of improved shoreline lots can be used to quantify the impact septic systems have on lake water quality. In this study the numbers of seasonal residences and improved lots on the shoreline were determined using tax maps provided by the town of Madison and a summary of property cards.

The map in Figure 22 represents the five sections of the lake delineated for use in the buffer strip survey (see Buffer Zone Survey). Table 9 depicts the number of lots, number of developed lots, and number of seasonal residences for each section of Lake Wesserunsett. Sections 1 and 2 have fewer lots than Sections 3, 4 and 5. Sections 2 and 3 have the greatest percentage of lots with seasonal development: 100 percent for Section 2, and 84 percent in Section 3. Sections 4 and 5 both have 69 percent with seasonal residences, the lowest percent on Lake Wesserunsett. Section 1 has only 33 percent seasonal residences and Sections 4 and 5 are the most densely populated shoreline areas based on the number of developed lots, with 84 and 91 percent, respectively. Section 1 has 60

Table 9. Comparison of lot characteristics for Lake Wesserrunset shoreline properties, based on tax maps provided by the Town of Madison. The lake sections are based on those delineated in Figure 22.

Lake Section	Total # of Lots	# Improved Lots		# Not Improved
		Seasonal	Year-round	
Section 1	9	2	3	4
Section 2	13	9	4	0
Section 3	69	37	6	26
Section 4	80	51	25	4
Section 5	90	50	23	17
Lake Total	261	149	61	51

percent developed lots, the lowest on the shoreline.

In order to determine the impact of septic systems in the highly developed seasonal areas of Lake Wesserrunsett, phosphorus concentrations were considered. Characterization Sites 2 and 3, and Spot Sites 7 and 9 are the closest sample sites to Sections 4 and 5 on the shoreline. The phosphorus concentrations for these sites vary greatly (see Water Quality Assessment: Total Phosphorus).

By following the regulations instituted by the Town of Madison, possible negative impacts of septic systems on Lake Wesserrunsett can be mitigated. Further investigation of physical indicators is necessary to identify the degree of compliance with regulations within the shoreline community.

Road Survey

Introduction

Roads have the potential to contribute significantly to the runoff entering a lake. The building of roads strips the land of vegetation and may cause a channeling effect, allowing soil particles and chemicals contained in runoff to enter a lake and affect water quality. Water enters the road from surrounding areas and is able to flow quickly down the surface of the road where there is no vegetation for dispersal and absorption. Runoff is especially a problem for the transportation of phosphorus, the limiting nutrient in Maine lakes. Phosphorus attaches to sediment and is carried quickly to the water body. Due to this ability to transport phosphorus, camp roads are typically the

greatest threat to the health of lake watersheds in this area (Michaud 1992).

Paved roads, although generally farther from the water, also pose a risk to lake water quality. Sand and salt used on these roads in the winter increases the sediment that can be carried into the lake. Because of the impervious surface of paved roads, those located in close proximity to tributaries or the lakeshore pose an even greater threat to water quality. Although not included in this survey, driveways, especially those of shoreline residences, also have a high potential for nutrient loading.

Methods

All dirt roads within the watershed were surveyed using the Detailed Road Survey Form (Appendix D). This survey was provided by MDEP and modified by CEAT. Six survey teams evaluated the camp roads on 25-Sep-00. To obtain road area, CEAT measured the road length using an automobile odometer and the width using a meter tape. Five factors were considered to assess roads: surface, ditching, culverts, water diversions, and erosion potential. Scores were based on characteristics within each of the five areas that are described below. High scores reflect road characteristics in poor condition.

The overall surface score was based on a series of scores pertaining to the condition of the road's crown, surface material, edge, base, seasonal or year-round usage, and overall surface condition. Crown height was measured using a string, a line level, and meter stick. The string was extended from the center of the road to the edge. A line level on the string ensured that it was horizontal. The distance of the string off the ground at the edge of the road measured the crown height. An ideal road needs at least 0.5 to 0.75 inches of crown for every foot of width (Michaud 1992).

Ditching is necessary to drain runoff into buffer zones where nutrients can be absorbed by vegetation. The total ditching score was based on our assessment of a road's need for ditches and the condition of existing ditches. CEAT determined that ditching was needed if any obstruction, such as berm, prevented water from running off the roads sides or if the water from the road directly entered the lake or a lawn of a shoreline house. The condition of ditches was determined by considering

depth, width, shape, vegetation, and sediment depth. An ideal ditch, depending on road size, would be about 2 feet deep, fairly wide, parabolic in shape, and lined with vegetation or rip rap. It is better to have sediment in the ditch where it can be cleaned out than to have it pass through a ditch into a lake.

Culverts are installed beneath roads to prevent water from running over the roads causing excess sediment to be carried down to the lake.. To calculate the total culvert score, CEAT looked for signs of erosion, such as road washouts, as well as the condition of existing culverts. The condition of existing culverts was determined by considering the wear and size of the pipe, the amount of sediment inside, and the depth below the road surface. A meter stick was used to measure the dimensions of existing ditches and culverts. An ideal culvert would be sized large enough to handle the runoff at peak flow periods for the particular road, be clear of sediment, and free from rust with at least one foot of covering material.

Diversions channel water away from the road surface, and therefore decrease the amount of runoff coming directly from roads into a lake. The total water diversion score was calculated by determining where the diversions were needed and where diverted water was channeled. The total road score for camp roads was then calculated by summing the total surface, ditching, culvert and water diversion scores. An ideal water diversion should be located where road washouts have previously occurred or are likely to occur.

Erosion potential quantifies the likely contribution of a particular road to sediment runoff. The product of the road slope and the length of the road determined the erosion potential for a segment. Percent slope was determined using a clinometer. Segment length was measured using a measuring wheel. The road total erosion potential was determined by summing the product of percent slope and length for all segments. The segment averages for erosion potential were determined using a scoring grid on the Detailed Road Survey Form (Appendix D). The grid assigns sediment loading potentials that help quantify the impact of a particular road on sediment runoff.

After all detailed surveys were taken, the scores were separated into quartiles to facilitate comparison among the roads in the watershed. To accomplish this, the scores for road total, total erosion potential, and segment averages of erosion potential were placed in numerical order from

lowest to highest. The data were then divided into four sections from the best 25 percent to the worst 25 percent (Appendix E).

Roads were then divided into three categories based on the risk they pose to lake water quality: acceptable, risk, and high risk (Table 10). To rank each road relative to the others, the road total score received priority. For example, if a road had a high road total score (in the worst 25 percent quartile), it was placed in the high-risk category. For further categorization, both the erosion potential total score and the segment average were considered. Roads in the acceptable range have low phosphorus loading potential, while roads in the high risk range had high phosphorus loading potential.

Paved roads were surveyed by CEAT on 2-Oct-00. Each paved road was surveyed by measuring the length using an automobile's odometer, and the width using a meter tape. The paved roads were not surveyed in terms of their quality like the detailed surveyed roads because the goal of this survey was simply to calculate the total area of paved roads in the watershed.

Results and Discussion

CEAT surveyed 27 gravel roads and 11 paved roads. The total area of gravel roads surveyed was 11.39 hectares (28.15 acres). The total area of paved roads surveyed was 32.09 hectares (79.3 acres) (Appendix F). Though there are fewer paved roads, they cover a larger area of the watershed. Paved roads carry less sediment in runoff and are usually in better condition than gravel roads. However, regular maintenance is required to maintain the road surface and prevent excess phosphorus loading caused by improper runoff..

Total road scores for gravel roads ranged from 26.0 to 422.5 (Appendix G). The lowest score possible for a road assessed by this survey is 15.0 and the highest possible score is 935.0. Erosion potential scores do not have a minimum possible score or a maximum possible score; they can be of any value. The scores for this particular survey ranged from 12,000.0 to 20,300.0 for erosion potential total scores, and 7.3 to 20.8 for the segment averages, which is the average erosion potential score for a portion of the road. A longer road will generally have a higher erosion potential score

Table 10. Individual rankings of detail survey roads. See Appendix E for derivation of the grayscale-ranking breakdown into quartiles.

Road Name	Surface Total	Ditching Total	Culvert Total	Water Diversion Total	Road Total	<u>Erosion Potential</u>	
						Total Score	Segment Average
Acceptable:							
Sierra Rd.	18.0	2.0	2.0	4.0	26.0	-	-
Bass Rd.	42.5	1.0	1.0	3.0	47.5	-	-
FR #1 (upper)	30.0	34.0	1.0	2.0	67.0	-	-
Grange Rd.	80.0	1.0	1.0	2.0	84.0	2900.0	7.3
Olive Rd.	24.0	1.0	1.0	35.0	61.0	1200.0	12.0
Hayden Rd.	20.0	8.0	18.0	12.0	58.0	3600.0	12.9
FR #13 (Heron Rd.)	23.0	39.0	6.0	1.0	64.0	4900.0	9.8
Foss Rd.	50.0	21.3	17.0	1.0	89.3	2400.0	12.0
Davis Rd.	70.0	16.0	1.0	2.0	89.0	3700.0	9.3
Risk:							
FR#9 (Drake Rd.)	63.8	9.5	13.5	3.0	89.8	10700.0	7.6
FR#6 (Teal Rd.)	90.0	5.0	1.0	3.0	99.0	3700.0	9.3
FR#8 (Loon Rd.)	120.0	8.0	1.0	2.0	131.0	5400.0	13.5
Bagley Rd.	90.0	26.7	1.0	2.0	119.7	4600.0	
Theater Rd.	135.0	75.0	0.0	35.0	245.0	2900.0	
FR#17	130.0	49.5	18.0	9.0	206.5	7900.0	7.9
Laney Rd.	67.5	110.0	16.0	35.0	228.5		10.0

Table 10. (continued)

Road Name	Surface Total	Ditching Total	Culvert Total	Water Diversion Total	Road Total	<u>Erosion Potential</u>	
						Total Score	Segment Average
High Risk:							
Kincaid Rd.	146.0	59.9	28.7	6.7	241.2	10400.0	
FR#11 (Wesserunsett Rd.)	125.0	46.5	26.4	16.0	213.9		
FR#12 (Merganser Rd.)	55.5	86.0	52.0	2.0	195.5		
Naomi Ave.	135.0	75.0	30.0	12.0	252.0	7400.0	
Hunnewell Rd.	127.5	48.1	49.5	32.0			12.9
FR #1 (lower)	220.0	57.0	1.0	2.0		-	-
FR#3 (Whittier Farm Rd.)	150.0	115.0	24.0	29.3		8000.0	8.9
FR#4 (Mallard Rd.)	210.0	60.0	39.0	2.0		7200.0	10.3
Beach Rd.	280.0	100.0	0.0	42.5		7100.0	10.1
FR#18	225.0	98.7	39.5	32.0			10.8
FR#10 (Merrill Rd.)	180.0	145.0	47.5	50.0			12.7

^a Grayscale Ranking: Best 25%, Second 25%, **Third 25%**, 

than a shorter road, but the segment averages are comparable as they show the condition of the road. A high risk road lacks sufficient ditching and water diversions, needs culvert maintenance or construction, and has loose surface material. An acceptable road has more stable surface material and sufficient culverts, ditches, and diversions. Overall, nine roads were deemed acceptable, seven at risk, and eleven at high risk (Table 10 and Figure 27).

While maintenance is necessary for all roads, it is most important for those with high erosion potential. The ratings of the roads in the Lake Wesserunsett watershed can be used to prioritize the order in which road repair should occur to protect and improve lake water quality. Although not included in our ranking, roads that lead directly to areas of the shoreline or tributaries should be addressed first.

High Risk Roads

Kincaid Road

- High segment average for erosion potential.
- More ditching is needed.
- Most sections need more of a crown to sufficiently move water off of the road.

FR #11 (Wesserunsett Road)

- Road total score better than most high risk roads.
- Could use work rebuilding the crown and clearing the ditches and culverts of sediment.
- Particularly high total erosion potential and segment average, therefore, regular maintenance of road conditions is of greater importance.

FR #12 (Merganser Road)

- Crown must be reestablished and ruts filled in.
- Needs more compact sediment material to prevent excess runoff.
- Because this road has high erosion potential scores, maintenance is necessary.

Naomi Avenue

- Needs construction of ditching.
- At least one of the culverts in place is not working due to sediment blockage and
- Needs more covering material.
- Crown must be rebuilt.

Hunnewell Road

- High road total score and erosion potential total score.
- Maintenance of culverts is needed. Some may need to be enlarged to prevent flow over road surface.
- Ditching must be established where it is now absent and berms must be eliminated..
- Present ditching must be lined with more vegetation to slow and absorb runoff.
- Water diversions needed to prevent runoff from entering a gully.

FR #1 (lower)

- Fire Road #1 was not evaluated in terms of erosion potential, but had a significantly high road total score.
- A crown must be built in most places along the lower section of the road.

FR #3 (Whittier Farm Road)

- Had a high road total, but the segment average for erosion potential within the best 25%.
- Maintenance of this road can significantly reduce the negative impact it has on lake water quality.
- A crown and more ditching must be established and berm removed.
- Culverts should be larger and cleaned out.
- Because this road leads directly into a lawn that enters the lake in certain places, road work is necessary.

FR #4 (Mallard Road)

- Not at high risk because of erosion potential, but because of the conditions of the road.
- Berm needs to be eliminated and the crown needs to be rebuilt.
- Some of the culverts are not working due to large logs and sticks blocking water passage.

Beach Road

- Shares the highest road total score with one other road, Fire Road #10.
- A crown must be rebuilt and the berm eliminated.
- More compact sediment material and ditching is needed.
- Water diversions to vegetated areas are necessary in many places.

FR #18

- Has both a road total score and erosion potential total score in the worst 25%.
- One of the culverts is aging and filled with sediment. Water diversions are also needed.
- A proper crown should be rebuilt and berm eliminated from the edge of the road.

Road Quality






-  Acceptable
-  Risk
-  High Risk
-  Not Sampled/Paved
-  Lake Wesserunsett



Figure 27. Condition of detailed surveyed roads in the Lake Wesserunsett watershed based on road ranking data from Table 10. High risk roads in close proximity to the lake should receive priority in maintenance to prevent adverse water quality effects.

FR #10 (Merrill Road)

- Has both the highest road total score (with Beach Road) and erosion potential score.
- Is in close proximity to the shoreline, so is of immediate concern for maintenance.
- Ditching is needed on much of the road, and berm must be eliminated,
- Condition of the culvert in place is good, but more culverts are needed.
- Water diversions also are badly needed to divert runoff into a vegetated area.

Risk and Acceptable Roads

For most of the seven roads categorized as risk (Table 10 and Figure 27), poor surface conditions contributed to much of the road total score. Each could benefit from a more prominent crown and removal of berm. Ditching is also a prevalent problem among the risk roads, and must be established or maintained along many of the roads. Water diversions are badly needed on Theater Road and Laney Road. Culverts were in fairly good condition on most of these roads, but still require regular maintenance and repair.

While the nine acceptable roads are not an immediate threat to the health of the lake, consistent road management is necessary (Table 10 and Figure 27). By their very nature, each road within the Lake Wesserunsett watershed has a potential to load nutrients into the lake. Constant upkeep and repair can help decrease their negative impact on lake water quality.

GIS Assessment

GIS Background

Introduction

A Geographic Information System (GIS) is a computer system that allows a user to map, analyze and manipulate geographically referenced data. GIS is used for an enormous range of applications worldwide, from endangered species conservation in national parks to exploration for fossil fuels by multi-national corporations (Lang 1998). Although GIS outputs superficially resemble paper maps, they are fundamentally different approaches to representing and thinking about

the earth. On a paper map, features such as bodies of water, contour lines and towns are inseparably represented on the map's surface, and the map user's view is static and predetermined (Burrough and McDonnell 1998). In contrast, a GIS is a dynamic combination of data that are based upon a separate map for each type of feature represented in the GIS. These individual maps, usually known as themes, may be layered on top of one another to create a multi-featured map while retaining their integrity. This gives the users a great deal of license in determining the appearance of maps, and more importantly, it allows for the manipulation of data for analytical purposes (Mitchell 1999).

An important feature of all GIS is that the data they contain are geographically referenced. These types of data are known as spatial data, which means that each data point represents a specific location on the earth's surface (Hutchinson and Daniel 2000). The GIS is designed to recognize the location that the data represents, and display the data in its correct geographical location relative to the rest of the earth. This allows for the representation of a complex, real-world environment within a computer system.

There are two basic formats used to represent spatial data within a GIS: vector and raster. Vector data may be comprised of zero, one and two-dimensional objects known as points, lines, and polygons, respectively. Points have a specific zero-dimensional location in space, lines have only length and are spatially referenced by their endpoints, and polygons have two dimensions with the vertices serving as spatial references (Clarke 1999). In contrast, raster data are based on a grid-cell format in which each cell has an assigned value and the intersections between gridlines serve as the spatial references (DeMers 2000). Each data type is useful in different situations, and most GIS computer software can handle both formats.

The computer program used to develop the GIS for this study is ArcView GIS 3.2, a product of Environmental Systems Research Institute (ESRI) in Redlands, California. ArcView is designed to work with data sets known as themes, and can handle data in both vector and raster formats. ArcView was chosen for this study because of its relatively user-friendly analytical capabilities, extensive support structures, and manageable learning curve. There is also an abundance of data available that can be imported directly into ArcView without additional formatting.

GIS Research Goals

The primary goal of using GIS in this study is to provide useful and relevant geographic information to stakeholders in the Lake Wesserunsett watershed. To achieve that goal, it is necessary to gather the best possible information, combine it in a way that is readily understandable, and analyze it such that we can make well-supported recommendations on issues affecting the watershed. We identified three main products that our GIS team should produce in order to provide useful information to Lake Wesserunsett stakeholders.

The first product is a base map of the watershed area. The components of this map are very similar to what one would find on a paper map produced by the United States Geological Survey (USGS). Roads, elevation contours, streams, lakes and rivers are included as they would appear on a USGS quadrangle. The map is further enhanced by the addition of soils data for the watershed.

The second product is an erosion hazard model for the watershed. A model of this type combines information on soil type, land slope and land use to make predictions about the potential for soil erosion in different areas. Erosion is one of the principal routes of nutrient movement within watersheds, and identifying erosion problem areas is critical to understanding and managing lake water quality (Mason 1996).

The third product is a septic suitability model for the watershed. The United States Department of Agriculture (USDA) has found that soil type and land slope are two important factors in determining whether a given septic system will deal effectively with human waste (USDA Soil Potential Ratings). The water quality consequences of ineffective waste control may include eutrophication and the introduction of pathogenic fecal coliform bacteria into water sources (Mason 1996). Therefore, a septic suitability map may be useful in identifying problem areas within the watershed and recommending strategies for future development.

Methods

Base Map

Data Collection and Base Map Construction

The data used in developing our basemap were provided by the Maine Office of GIS through their website (MOGIS 2000). Data were partitioned by USGS 7.5 minute quadrangle, as well as by thematic content. The Lake Wesserunsett watershed overlaps three quadrangles: Madison East, Skowhegan and Solon. For each of these quadrangles, data were downloaded for streams, rivers, lakes, roads and elevation contours as compressed ArcInfo export coverages. All data were decompressed using WinZip and imported into ArcView shapefile format using the Import71 utility. All MOGIS data were already projected in Universal Transverse Mercator (UTM) North American Datum of 1983 (NAD83) Zone 19 before they were downloaded, and this projection was maintained in all maps created from the data. Using ArcView's Geoprocessing Wizard, the feature themes from each quadrangle were merged with themes from all other quadrangles to create one feature theme for the entire watershed. For example, the three separate road maps (one for each quadrangle) were merged to form one overall road map for the entire watershed. The combination of data for roads, streams, contours, lakes and rivers resulted in a single basemap containing the foundational data necessary for the study (Figure 28).

Soil Map Generation

With this foundation in place, the next step was to add data to the basemap that would be useful in performing analysis. Our goal of developing predictive models for erosion hazard and septic suitability required the addition of soils data to our basemap. We found the best source of detailed soils data for the watershed to be the Soil Survey Maps published by the USDA Soil Conservation Service (USDA and VMAES 1972). These maps were scanned into the computer using a flatbed scanner. The scanned soil maps were aligned with each other within Adobe Photoshop 5.0 to create a single, computerized image of the soils within the watershed. This image was then imported

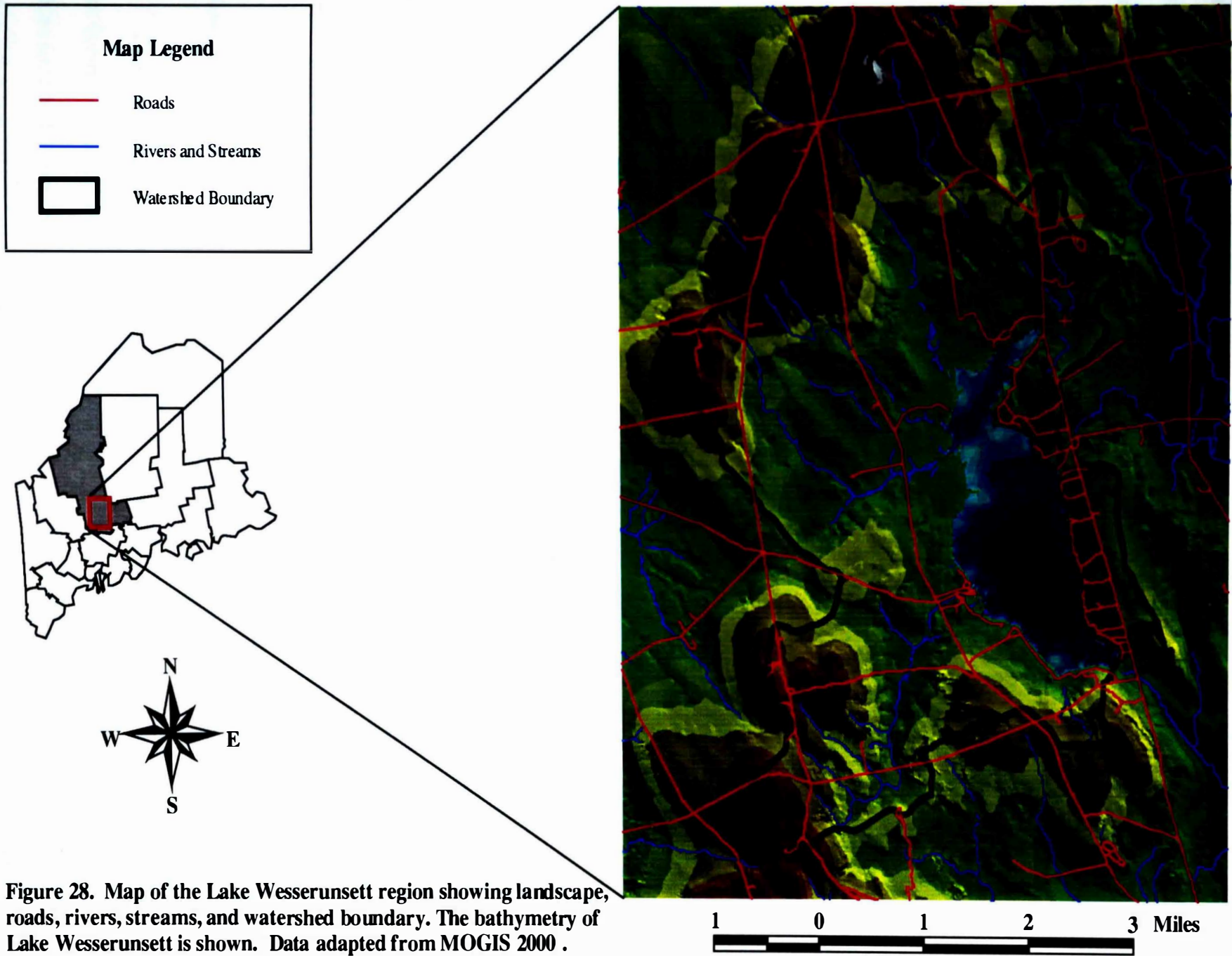


Figure 28. Map of the Lake Wesserunsett region showing landscape, roads, rivers, streams, and watershed boundary. The bathymetry of Lake Wesserunsett is shown. Data adapted from MOGIS 2000 .

into ArcView and aligned with the existing basemap in a process known as rectification. We then digitally traced the lines of this rectified image to convert the scanned soils image into a digital, georeferenced soils map made up of polygons. Once this was completed, the scanned soils image was removed from the background, and what remained was a digitized soils map for the Lake Wesserunsett watershed (Figure 29).

Erosion Potential Model

Introduction

The Lake Wesserunsett watershed includes a variety of soil types, slopes and vegetation cover. The seventeen different soil types and their corresponding K-factor ratings, the percent slope of the landscape, and the type of vegetation cover all play an important role in determining the degree of erodibility in a given area of the watershed (USDA Soil Potential Ratings). To combine all three factors and produce an erosion potential model that visually demonstrates the erosion potential of a given area within the watershed, the GIS team used a program within ArcView called Model Builder (ESRI 2000).

Model Builder has the capability to integrate vector data and raster data in a variety of analyses, and to create a spatial model of a given geographic area. This spatial model is the result of a variety of sophisticated processes, involving programs such as scripts (directions for a particular process), extensions (such as Image Analyst), and weighted overlays (processes that weigh different factors within a data set) (ESRI 2000).

Methods

Digitized soil and land use data from the Maine Office of GIS website were obtained in vector format (MOGIS 2000). Each vector data set was converted to a grid (a type of raster format) in order for Model Builder to read the data (ESRI 2000). The percent slope was derived from a Triangulated Irregular Network (TIN), which is a form of elevation data comprised of interlocking

triangles. This TIN represented elevation data derived from the contour themes obtained for the Lake Wesserunsett watershed from the Maine Office of GIS website (MOGIS 2000). Percent slope data were calculated from the contour TIN and converted into a grid format.

The soil grid, land use grid, and percent slope grids were then combined in a model. Since each grid had a different set of value scales, K-factor for soils, area for landuse, and percent slope for slope, all grids had to be converted into a common evaluation scale of erosion potential. A scale of 1 through 9 was used for all three grids; 1 represented the least erosion potential and 9 represented the greatest erosion potential.















Another aspect of the weighted overlay process involved assigning values to the percent influence field (ESRI 2000). The value for percentage of influence was assigned based on each factor's erosion potential as it related to the other factors involved. Slope was assigned a 50 percent weighting and both soil and land use were assigned a 25 percent weighting, summing 100 percent altogether. The slope was assigned the highest percentage because regardless of land use or soil type, a steeper slope implies increased erosion potential (ESRI 2000).

Soil

The distinguishing feature in each soil type that was considered for the erosion potential model was the K-factor. The K-factor is the degree of susceptibility of soil particle detachment and transport by water (Somerset County Soil and Water Conservation District, unpublished data). The factors that affect the K-factor value include: particle size, texture, water content, composition, and presence or absence of a protective vegetative layer. The values assigned for the K-factor are between 0 and 1; 0 is non-erodible soil, and 1 is highly erodible soil (Table 11). All information pertaining to K-factors was obtained from the Somerset County Soil and Water Conservation District.

Since the soil K-factors for Somerset County fell within 0.1 and 0.5 (Table 11), they were not an appropriate fit for the 1 through 9 integer scale. Each K-factor was multiplied by 20 and rounded

Soil Types

- Adams
-  Bangor
-  Berkshire
-  Dixmont
-  Dune Land
-  Leicester
- Lyman
-  Madawaska
-  Mixed Alluvial Land
-  Monarda
-  Peat and Muck
- Peru
- Rock Land
- Skowhegan
-  Stetson
-  Thorndike
-  Walpole
-  Streams
-  Roads

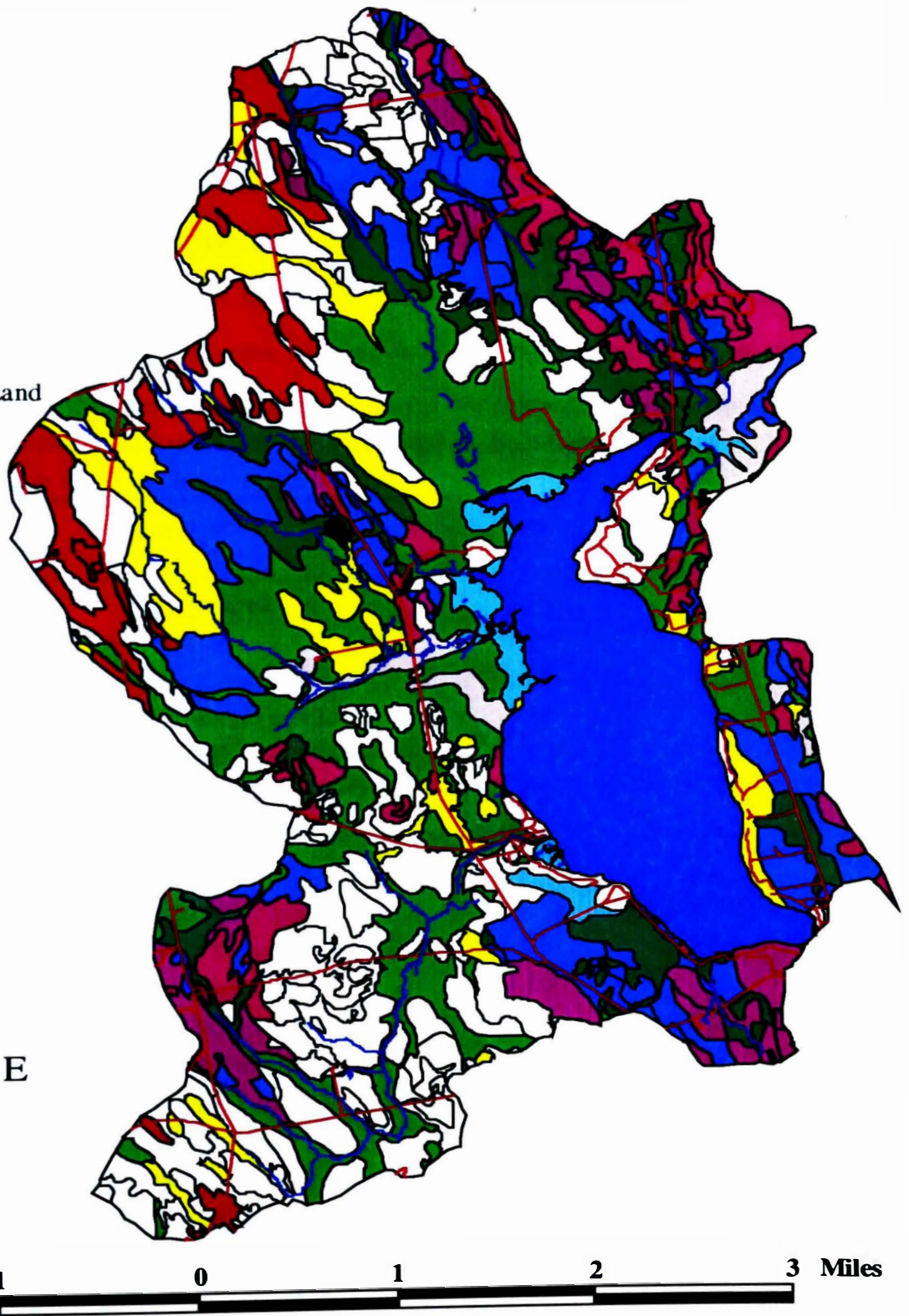


Figure 29. Soils map of the Lake Wesserunsett watershed with roads and streams included for geographic reference. Soils data adapted from USDA Soil Survey maps for Somerset County (USDA 1972).

to the nearest integer value. For example, the Skowhegan soil type has a K-factor of 0.17, so its corresponding integer value for the model is 3 (3.4 rounded to 3).

Land use

Land use classes were also assigned values based on their erosion potential. Shoreline residential was assigned a value of 9 due to the inadequate buffer strips and impervious surfaces, the close proximity to the lake, and the steep slope leading directly into the water source. Cleared land was assigned a value of 8 due to its lack of diverse vegetation and its consequent inability to protect

Table 11. Soil types of Lake Wesserunsett watershed and corresponding description (Soil Survey; Somerset County, Maine Southern Part, USDA Soil Conservation Service 1972), and K-Factor (USDA, unpublished data).

Soil	Description	K Factor	Reclassified K Factor
Adams	loamy sand	0.21	4
Bangor	silt loam/very stony silt loam	0.35	7
Berkshire	loam/very stony loam	0.26	5
Dixmont	silt loam/very stony silt loam	0.24	5
Dune Land	sand	0.13	3
Leicester	very stony loam	0.32	6
Lyman	loam/rocky loam	0.26	5
Madawaska	fine sandy loam	0.14	3
Mixed Alluvial Land	silty and sandy material	-	Restricted
Monarda	silt loam/very stony silt loam	0.26	5
Peat and Muck	decaying organic matter	<0.10	1
Peru	loam/very stony loam	0.26	5
Rock Land	outcrops of bedrock	0.41	8
Skowhegan	loamy fine sand	0.17	3
Stetson	fine sandy loam	0.14	3
Thorndike	loam/silt loam	0.17	3
Walpole	fine sandy loam	0.24	5

soil from erosion. Reverting land was assigned a value of 6 due to the low density of new growth and lack of trees. Disturbed forest was assigned a value of 4 due to the existence of breaks in the canopy and dense understory. Finally, forest was assigned a value of 1 because it represented an

undisturbed and healthy ecosystem in which erosion was very low due to the large amount of ground cover and presence of canopy and understory. Any wetland areas were labeled as “restricted” because of their positive buffering capabilities and water composition. The “restricted” rating in Model Builder indicates a body of water or any factor that is not involved in the erosion potential (ESRI 2000).

Slope

The percent slope grid values were grouped in 2 degree increments (i.e., 0 to 2 percent, 2 to 4 percent, etc.). A 100% slope would be at an angle of 45 degrees. These were assigned increasing integer values as slope increased; the steeper the slope, the more erodible the land. For example, a slope range of 0 to 2 percent was assigned a value of 1 and a slope range of 22 to 24 percent was assigned a value of 9.

Results

After all grid values had been weighted accordingly, the model was run and the final output grid was produced (Figure 30). The areas in light pink indicate the least erosion potential. These sections include level land, wetlands, and forested areas. The portions in dark red indicate the highest erosion potential. These include all shoreline residential land and all cleared land, particularly that which is on a steeper slope.

Septic Suitability within the Watershed

Introduction

The septic suitability of soil, or its ability to properly handle human waste, is determined by a combination of several factors. These include the percent slope, rate of percolation, depth to bedrock, restrictive layer, water table and the hazard of flooding (USDA Soil Potential Ratings).

If the rate of percolation is too great, nutrients and microbes may reach groundwater (USDA Soil Potential Ratings). If the rate is too slow, waste will run off horizontally rather than being absorbed by the soil. A high percent slope will also cause increased runoff. If the depth to either the bedrock, a restrictive layer, or the water table is too shallow, percolation and nutrient absorption will be adversely affected. Soils with the above characteristics, when used as a basis for a septic system, have the potential to increase the quantity of nutrients draining into the lake, subsequently contributing to eutrophication and algal blooms. (see Development Assessment: Septic Systems.)

Based on the above criteria, the USDA places each soil type into one of three categories of septic suitability: slight, moderate, and severe. Those with a rating of slight are most appropriate for septic system use; those rated severe are inappropriate. In addition, new systems are restricted from areas with slopes greater than 20 percent and in shoreland zones where the bedrock, restrictive layer, or water table level is consistently less than 15 in. from the surface (Department of Human Services 2000). In non-shoreland zones, the bedrock, restrictive layer, or water table level must not be less than 12 in. from the surface. Septic suitability ratings were obtained from the Soil Interpretations Records, courtesy of the Somerset County Soil and Water Conservation District (unpublished data).

Methods

A septic suitability model for the Lake Wesserunsett watershed was created by CEAT using ArcView's Model Builder (ESRI 2000). Two factors were considered in the construction of the model: slope and septic suitability ranking. The percent slope was derived from the TIN (see Erosion Potential Model). Percent slopes were then grouped into categories based on 10 percent slope: 0 to 10 percent, 10 to 20 percent, 20 to 30 percent slope, etc. Each slope category was assigned a value ranging from 1 to 9; lower percent slope categories were assigned lower values. All categories with slopes greater than 80 were assigned a value of 9.

Each soil type was also assigned a value based on its septic suitability rating. Soils with a severe rating were assigned a value of 9, moderate soils received a value of 5, and slight soils were assigned a 1. Model Builder then evaluated each factor to produce a map of septic suitability for the

watershed. Each factor was not considered equally, however; in the erosion hazard model, percent slope was weighted more heavily (66 percent) than soil type (34 percent).

Results

The septic suitability model, Figure 31, displays the areas best suited for septic system installation in pink and those that are most poorly suited in dark red. In general, the Wesserunsett watershed is of moderate septic suitability. Notice that the northeast corner of the lake, a highly developed area, is particularly well suited for human waste disposal.

In some cases, soils in the severe category may still be acceptable for waste disposal if the proper precautions are taken. An example would be using fill to increase the distance from soil to bedrock. It should be noted, however, that these measures impart additional and potentially high costs (USDA Soil Potential Ratings). Alternatively, if septic systems are installed in areas of poor septic suitability without taking these protective measures, the result will be accelerated eutrophication of Lake Wesserunsett.

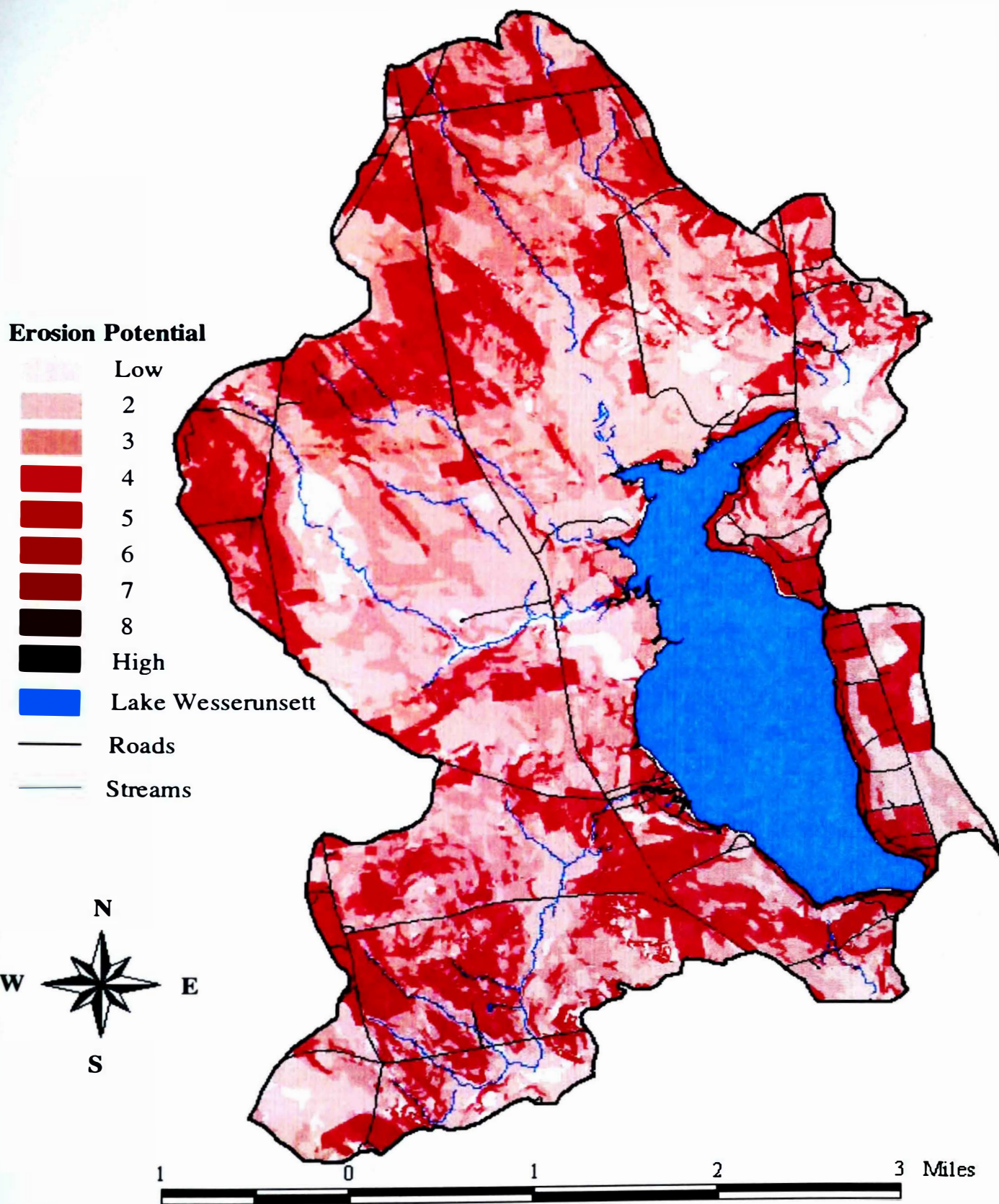


Figure 30. Erosion potential of the Lake Wesserunsett watershed with roads and streams for geographic reference. Data adapted from USDA Soil Survey Maps for Somerset County (USDA and UMAES 1972) and Maine Office of GIS website (MOGIS 2000).

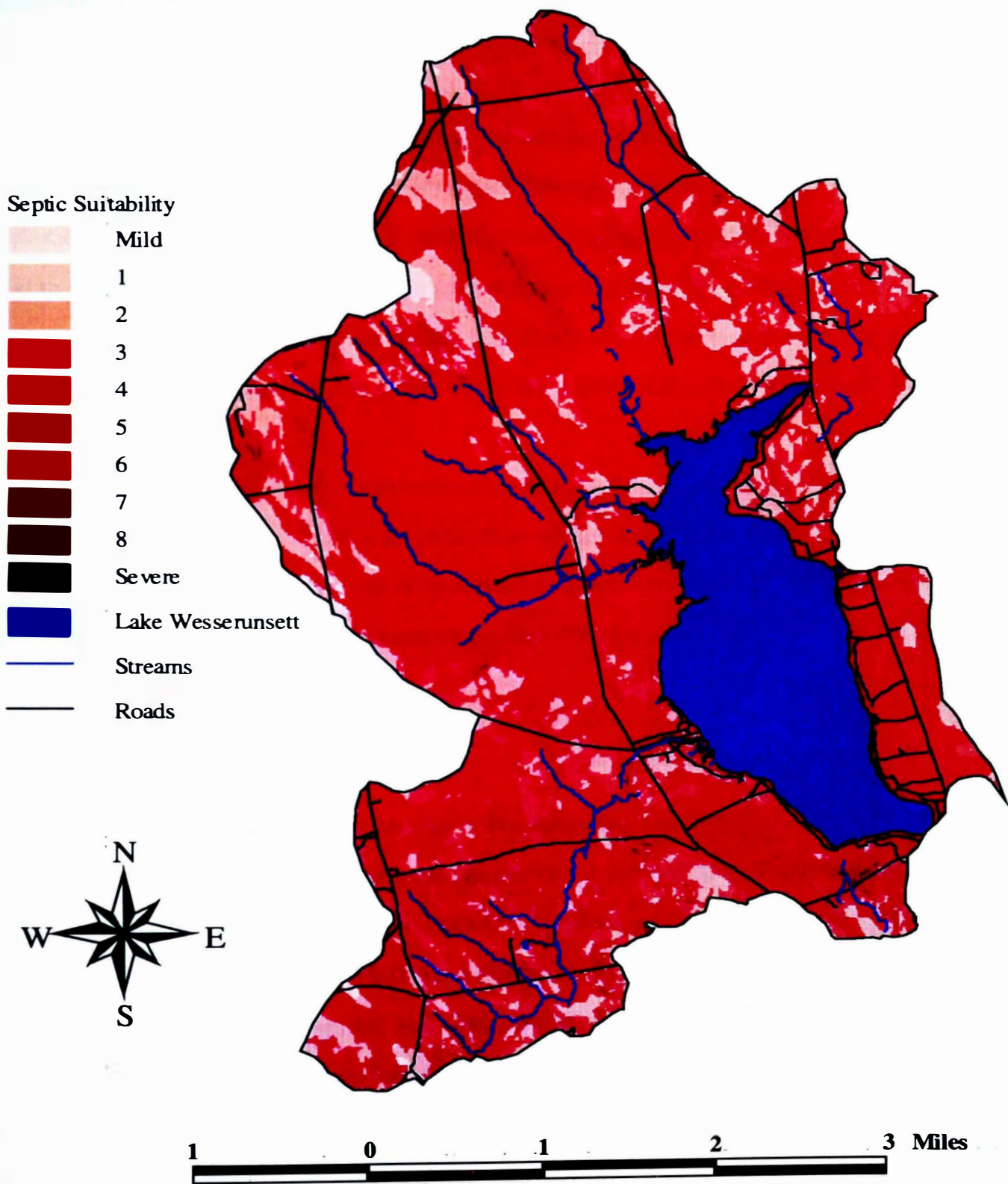


Figure 31. Septic suitability map for the Lake Wesserunsett watershed with roads and streams shown for geographic reference.

WATER QUALITY ASSESSMENT

Water Budget Assessment

Introduction

Water is cycled through a lake via rivers, tributaries, groundwater, precipitation, outlets, and evaporation (Chapman 1996). The hydrologic cycle contains a fixed volume of water. By defining total volume of inputs and outputs, CEAT created a water budget for Lake Wesserunsett. This is essential to determine the water quality of a lake and to generate nutrient loading models. The addition and distribution of water influence the deposition of pollutants as well as their circulation. Understanding this process can help to locate the sources and routes of pollution and nutrients in a lake.

The water budget ultimately determines the flushing rate, a measure of how many times per year a lake replaces its volume. This is an indication of how quickly water flows through a lake (Chapman 1996). This rate is important in understanding the water cycling patterns of the lake and developing proper assessment, management plans, and directly correlates to nutrient flushing.

Methods

The net amount of water going into Lake Wesserunsett was determined to help create a water budget. Information on average precipitation per year for a ten year period was obtained from the National Oceanic Atmospheric Association (NOAA) for the town of Madison from 1990 to 1999. Data from the years 1991, 1992, and 1997 were absent for Madison and were supplemented with NOAA data for Waterville and Augusta, ME. The data for 1991 and 1997 were supplemented with Waterville data and Augusta was used for 1992. The runoff rate for Lake Wesserunsett was determined by a ten-year mean runoff rate recorded in the Kennebec River Basin from 1958 to 1967 (North Kennebec Regional Planning Commission, unpublished data). The evaporation rate was obtained from a study conducted in the Lower Kennebec River Basin (Prescott 1969). Land area, lake area and average depth were obtained from our GIS analysis and MDEP data (see Land Use

Assessment: Methods). The net volume of water entering the lake (I_{net}) was determined from precipitation, runoff, evaporation, lake and land area using the formula below:

$$I_{net} = (\text{runoff} * \text{watershed area}) + (\text{precipitation} * \text{lake area}) - (\text{evaporation} * \text{lake area})$$

To determine the flushing rate, the I_{net} was divided by the volume of the lake;

$$\text{Flushing Rate} = I_{net} / (\text{Mean Depth} * \text{Area})$$

Results and Discussion

Watershed area, lake volume, groundwater, and surface water inputs all influence the flushing rate of a lake. Watershed area expansion increases the amount of runoff that flows into a body of water and in turn adds to the flushing rate. Inputs from tributaries and streams increase the water movement in a lake. Water movement and volume are opposing factors that strike a balance in determining the number of flushes a lake has per year.

Lake Wesserunsett has a flushing rate of 1.09 flushes/yr. In one year's time, the water in Lake Wesserunsett will be completely replaced slightly more than once. Lake Wesserunsett has a flushing rate that is in the range of other area lakes (Table 12). This rate is slower than the South

Table 12. Comparison of flushing rates for area lakes. Data obtained from lake watershed studies by Biology 493 classes from 1994-1999.

Lakes	Flushing Rate (Flushes/Yr)	Volume (M ³)	Watershed Area (M ²)
Lake Wesserunsett	1.09	22,888,673	42,110,000
Great Pond	0.52	209,160,000	83,122,431
North Pond	1.36	37,148,856	30,917,983
Salmon Lake	0.59	28,410,750	23,123,738
Messalonskee Lake	1.59	33,450,000	12,508,4285
East Pond	0.29	33,848,120	10,949,000
Long Pond			
North Basin	2.80	46,267,529	24,163,780
South Basin	3.55	47,032,200	38,918,618

Basin of Long Pond, which flushes 3.55 times per year, but Lake Wesserunsett's flushing rate is greater than that of East Pond, which flushes at a rate of 0.30 flushes/yr. The lake has a shallow basin and few surface water inputs (See Background: General Characteristics of Lake Wesserunsett). Shallow lakes tend to have faster rates, but since Lake Wesserunsett has few surface water inputs, its rate is reduced.

The flushing rate reported by MDEP was 0.89 flushes/year (MDEP 2000a). The volume of Lake Wesserunsett reported by MDEP was 22,888,613 cubic meters, and the volume obtained by CEAT was 25,9000,000 cubic meters. Due to the smaller volume, the MDEP would be expected to report a higher flushing rate. The values reported by MDEP for lake area and mean depth were entered into the CEAT model, and a flushing rate of 1.24 flushes/year was obtained. This suggests that the differences between the two models must be due to other data. When all other variables are held constant, the flushing rate is higher than reported by MDEP. The disparity between the models lies in precipitation data, the evaporation constant, or the runoff constant. However, these data and sources were not reported by MDEP. This is conservative estimate since no data is available for water inputs from springs in the lake. However, our experience also indicates that the lake is slightly deeper than the only bathymetric data available, which would decrease flushing rate slightly.

Study Sites

There are three types of sample sites included in the Colby Environmental Assessment Team (CEAT) study: Characterization, Spot, and Tributary. Characterization Sites were used to determine values for physical and chemical parameters of Lake Wesserunsett. Spot Sites were used to test areas of Lake Wesserunsett where CEAT hypothesized that a high threat of non-point source nutrient loading or pollution might exist. Tributary Sites were located in inlets or outlets in order to assess the amount that the tributary was contributing as a point source. The locations of all the sample sites are described in the text below and illustrated on the site map (Figure 32).

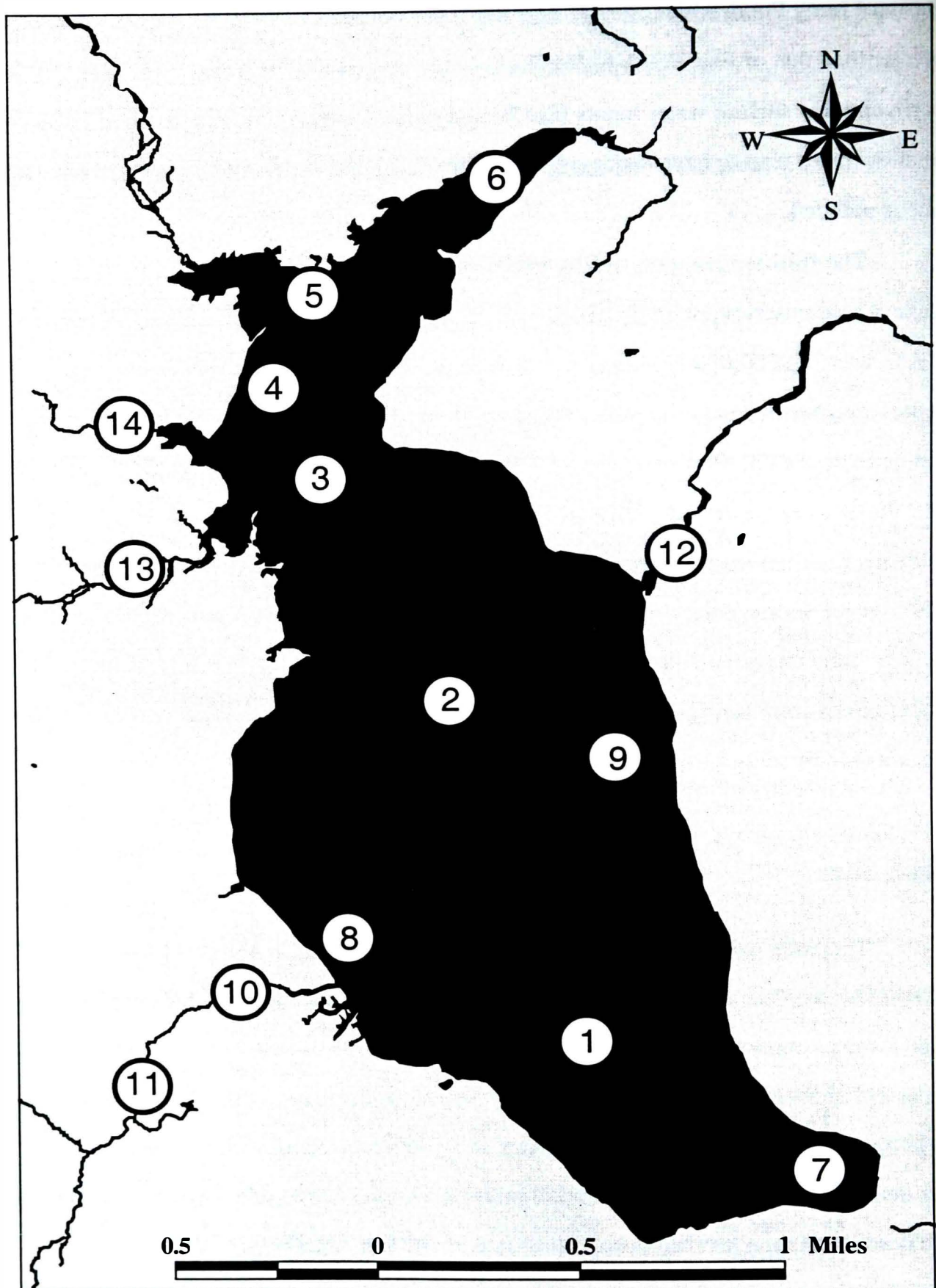


Figure 32. Map sampling sites tested in water quality analysis by CEAT during Fall 2000 Lake Wesserunsett watershed assessment. Sites 1-3 are characterization sites, sites 4-9 are spot sites, and sites 10-14 are tributary sites.

Characterization Sites

- **Site 1:** Maine Department of Environmental Protection (MDEP) Site (Depth: 22 ft). Site 1 is in the south central area of Lake Wesserunsett, where the depth is greatest, at the midpoint of the landmarks of Hubbard Road and Fire Road # 10. This site was chosen because it is the deepest section of the lake and it has been tested annually by MDEP for the last 30 years. This site was also the location of the Volunteer Lake Monitoring Program sampling.
- **Site 2:** Central Lake Site (Depth: 18 ft). Site 2 is located in the center of Lake Wesserunsett between Black Point and the public boat ramp. This site was chosen to characterize the central region of Lake Wesserunsett. A MDEP volunteer and members of CEAT previously sampled at this site during the summer of 2000.
- **Site 3:** North Lake Site (Depth: 14 ft). Site 3 is approximately 0.3 km southeast of Thompson's Point in the middle of Lake Wesserunsett. This site was chosen to characterize the northern part of Lake Wesserunsett and was tested during the previous summer by members of CEAT.

Spot Sites

- **Site 4:** Sandy Beach Campground Site. Site 4 is located due west of Thompson's Point, 75 ft off of the west shore, near the Sandy Beach Campground (not to be confused with Sandy Beach at the Art School at the southern end of Lake Wesserunsett). This site was chosen to evaluate any possible effects of the campground in that section with respect to non-point source pollution.
- **Site 5:** Northwest Marsh/Horse Farm Site. Site 5 is located northwest of Thompson's Point, at the mouth of the marshy cove, 75 ft off of the western shore. This site was chosen to see the filtering effects of the marsh, before runoff enters from the upland fields and forest into Lake Wesserunsett.
- **Site 6:** Northeast Marsh and East Madison Road Site. Site 6 is located on the far northeastern tip of Lake Wesserunsett near the marsh and lakeside of East Madison Road. This site was chosen to examine the effects of a major road near Lake Wesserunsett and the filtering effects of the marsh.

- Site 7: Seaplane Terminal Site. Site 7 is located at the far southeastern end of Lake Wesserunsett, approximately 75 ft off the shore of the commercial float plane area. This site was chosen in order to test the potential impact of the floatplane terminal in the watershed.
- Site 8: Lakewood Theater Site. Site 8 is located 75 ft offshore of the Lakewood Theater and Resort, at the end of Lakewood Road directly off the beach. This site was chosen to test the effects of the Lakewood Theater and the road running by the former boat launch.
- Site 9: Fire Road # 8 Site. Site 9 is located in the central part of Lake Wesserunsett, 75 ft off the Eastern Shore where Fire Road # 8 comes directly down to the shoreline. This site was chosen to determine the effects of this and other camp roads that possibly channel water and other materials straight down to Lake Wesserunsett.

Tributary Sites

- Site 10: Hayden Brook Downstream Site. Site 10 is located 50 ft upstream in Hayden Brook, which is adjacent to the Lakewood Theater and Resort on the southwestern side of Lake Wesserunsett. This site was chosen to test the potential impact of the golf course and the densely populated residential area upstream, as well as the flow of the tributary.
- Site 11: Hayden Brook Upstream Site. Site 11 is located upstream of the golf course in Hayden Brook. This site was chosen to determine the flow and act as a water quality comparison before it flows through the golf course and the camps in Lakewood.
- Site 12: Outlet Site. This site is located next to the outlet, near the boat ramp. Site 12 was tested to determine the quality of water flowing over the dam into the western branch of Wesserunsett Stream.
- Site 13: South Site. Site 13 is located just north of Black Point, 50 ft above the beaver dam and just below a fork in the stream. This site was chosen to test the flow of the tributary and potential nutrient contribution from this point source to Lake Wesserunsett.

- **Site 14: North Site.** Site 14 is located 50 ft upstream in the tributary due west of Thompson's Point and just north of the Site 13 Tributary. This site was tested to measure the flow and the potential contribution from this point source into Lake Wesserunsett.

Water Quality Methods

Water quality assessment of the Lake Wesserunsett watershed was conducted both in the field and in the Colby Environmental Analysis Laboratory (CEAL). CEAT conducted water quality field measurements and collected water samples for Lake Wesserunsett on 13-Sep-00. Open water sites were sampled by boat and tributary sites were reached either by canoe, car, or wading to the test site.

Physical measurements taken in the field included depth, dissolved oxygen, turbidity, temperature and tributary flow. At some sites, measurements were taken with a Hydrolab Surveyor equipped with a 4A Data Sonde, which measures depth, dissolved oxygen, turbidity, temperature, pH and conductivity throughout the water column (Hydrolab Corporation 1997). Depth was measured at other deep-water sites using a Hondex PS-7 Depth Finder with a LCD Digital Sounder. At tributary sites depth was measured using a meter stick. Dissolved oxygen and temperature profiles were obtained using an ORION Dissolved Oxygen/Temperature meter (Orion Research Inc. 1997). Turbidity was measured on site or in the laboratory with a HACH Turbidimeter. Transparency was measured with a Secchi disk and Aqua Scope. Tributary flow was measured in the center of each stream with a Flo-mate flow meter (Marsh-McBirney, Inc 1990). Chemical measurements of pH were taken in the field using a HORIBA Twin pH meter. All pH meters were calibrated in the field before testing (Appendix H).

Physical measurements performed in the lab included true color, conductivity and turbidity. Chemical tests included nitrates, phosphorus, hardness and alkalinity. The analyses were performed according to the processes outlined in the Lake Wesserunsett Water Quality Measurements and Analysis section of this report.

For sample collection, an appropriately sized and labeled sampling bottle was given to the groups for each test. All bottles used for phosphorus testing were rinsed three times with both 1:1

hydrochloric acid and E-pure water. All other bottles used for tests were rinsed three times with RO pure water before sampling.

Surface grabs were taken at all sites, while epicore, mid-depth and bottom samples were taken only when the depth was sufficient. Epicore samples were taken using 1/2-inch flexible clear plastic tubing. The tube was rinsed three times in the lake water before sampling. In order to obtain samples, the tube was lowered into the water column to approximately 1 m above the bottom, crimped, and brought up. This was done three times and water was combined in a 1 liter Nalgene bottle (Appendix H). Mid-depth and bottom samples were taken with a Wildco water sampler. Bottom samples were taken at approximately 1 m above the bottom of the lake.

Samples collected were chilled on ice in a cooler until they could be refrigerated in the CEAL. They remained refrigerated until chemical tests were performed. Samples collected for the hardness test were lowered to a pH of less than 2 by adding nitric acid in a drop wise manner. Sulfuric acid was added to nitrate samples in order to lower the pH to less than 2. All laboratory tests were performed within 24-48 hours of collection or within the proper time limit for the specific analysis.

Sampling quality was ensured by strict adherence to the Quality Assurance protocol (Appendix H). In the field measurements, three random repeats were done for every ten tests performed to ensure accuracy in sampling methods. In samples taken for laboratory tests, a split sample and a duplicate sample were taken for every ten samples to test accuracy in laboratory techniques and in collecting, respectively. To obtain a split, one sample bottle was used for water collection and then the water was split into two bottles for testing. For duplicate samples, two sample bottles were collected and tested separately. Spikes were also used in phosphorus testing. To perform a spike, a sample is split in two parts and a known amount of phosphorus is added to one. This was done in order to assure accuracy in phosphorus testing techniques

Lake Wesserunsett Water Quality Measurements and Analysis

Physical Parameters

Introduction

Physical parameters influence a broad range of biological and chemical processes within a lake that help shape the composition of its biological community and potential for human use (Chapman 1996). In Lake Wesserunsett, the following physical parameters were measured and analyzed: dissolved oxygen (DC), temperature, transparency, turbidity, color, and conductivity.

Dissolved Oxygen and Temperature

DO and temperature measure the concentration of oxygen and heat in the lake water column, respectively (MDEP 2000a). An inverse relationship exists between DO and water temperature; both parameters have wide ranging biological and chemical effects (Reid 1961). Low DO levels and high temperatures can reduce reproduction and increase mortality rates among many fish species, leading to an overall reduction in diversity (MDEP 2000a). DO varies both daily and seasonally. It is positively affected by photosynthetic activity and wave action and negatively affected by aerobic decomposition, respiration, and temperature increase (Chapman 1996). DO and temperature are important parameters to study in evaluating the overall health of a lake (Chapman 1996).

Methods

DO and temperature measurements were completed on 13-Sep-00 by CEAT using an ORION DO/Oxygen Meter and a Hydrolab sonde. Lake measurements were made at Sites 1, 2, and 3. Tributary Sites 10, 13, and 14 were also assessed (Figure 32). Measurements were made along vertical profiles from surface to lake bottom at one meter intervals. DO and temperature were measured in parts per million (ppm) and in degrees Celsius, respectively. DO and temperature

readings for past years were acquired from the Maine Department of Environmental Protection (MDEP 2000a).

Results and Discussion

DO profiles and temperature readings on 13-Sep-00 for Sites 1, 2, and 3 were essentially uniform. Among these sites, DO measurements ranged from 7.8 ppm to 8.8 ppm, with a mean value of 8.3 ± 0.1 ppm ($n = 16$, Figure 33). Temperature ranged from 19.8°C to 20.4°C , with a mean value of $20.2 \pm 0.03^\circ \text{C}$ ($n = 25$). Tributary Sites 10, 13, and 14 had surface DO and temperature readings of 7.4 ppm and 18.3°C , 10.3 ppm ($n = 2$) and 20.5°C ($n = 2$), and 6.9 ppm and 17.3°C , respectively.

Past MDEP data for Lake Wesserunsett also demonstrate a uniform DO pattern along a vertical profile. DO levels from May through October of 1978 to 1997 ranged from 6.0 ppm to 8.9

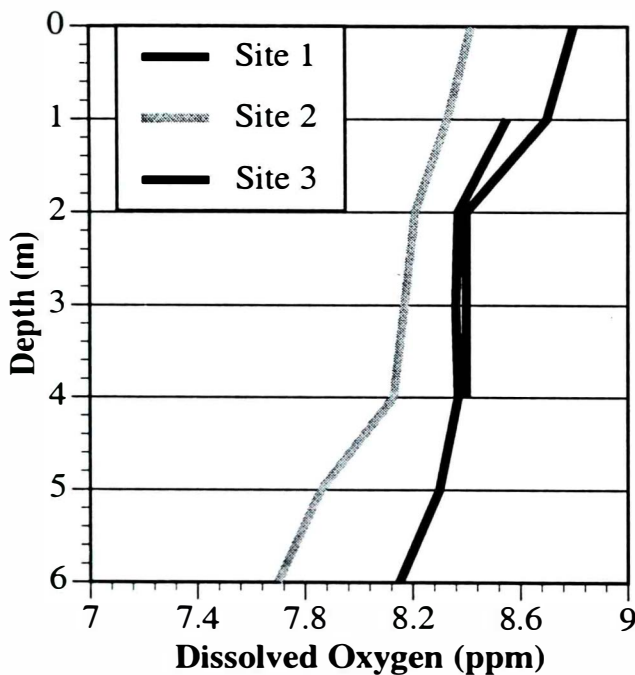


Figure 33. Dissolved oxygen (ppm) of Lake Wesserunsett plotted against depth (m) at Sites 1, 2, and 3 on 13-Sep-00. See site map for locations (Figure 32).

ppm (Figure 34). Measurements from the current study fall into the higher section of this range. These results suggest that Lake Wesserunsett is well mixed throughout the year and typically lacks a thermocline. The uniform distribution of DO and temperature is most likely attributable to mixing due to the shallowness of the lake. Stratification is typical only in lakes deeper than 7.5 m (Chapman 1996). The depth of Lake Wesserunsett does not exceed that depth.

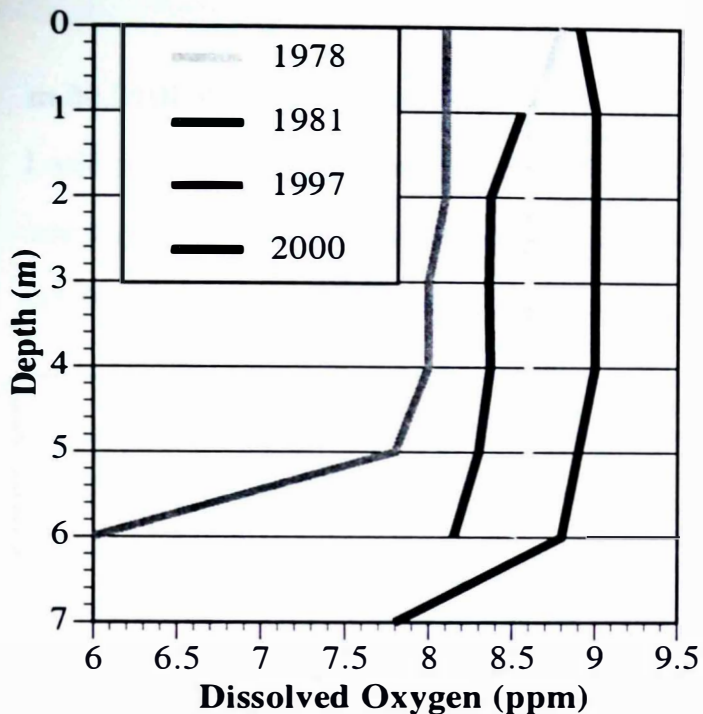


Figure 34. Dissolved oxygen (ppm) of Lake Wesserunsett plotted against depth (m) at Site 1 for 1978, 1981, 1997, and 2000 (MDEP MIDAS data 2000). See site map for location (Figure 32).

Transparency

Transparency is the measure of water clarity and is determined by the concentration of dissolved and particulate matter in the water column (Wetzel and Likens 1995). Transparency is typically reduced by the presence of dissolved vegetative matter, silt, and algae. Since algae frequently constitute a large percentage of suspended matter, transparency also can provide a measure of productivity (Pearsall 1993). Transparency varies seasonally and yearly due to changes in weather, suspended sediment, and algae concentrations (Pearsall 1993). Eutrophication status can also be measured by transparency

readings due to the direct correlation between nutrient and algal concentrations and transparency levels (Harper 1992).

Methods

Transparency was measured by CEAT members using a Secchi disk and Aqua-Scope® at Sites 1, 2, and 3 on 13-Sep-00 (Figure 32). Each individual reading was obtained by first lowering the Secchi disk vertically in the water column until it was no longer visible through the Aqua-Scope.® The Secchi disk was then lowered further and brought back towards the surface until it was again visible. Transparency was calculated as an average of these two depths, measured in meters. Transparency levels for past years were acquired from the MDEP (MDEP 2000a).

Results and Discussion

Transparency ranged from 5.13 to 5.75 m on 13-Sep-00 with a mean value of 5.40 ± 0.06 m ($n=9$; Figure 35). For years sampled since 1970, a range of 4.07 to 6.83 m was observed for Site 1 (MDEP 2000a) (Figure 35). Water quality problems related to algal blooms are indicated by transparency readings of less than 2 m (Pearsall 1993). All mean Secchi values measured since 1970 in

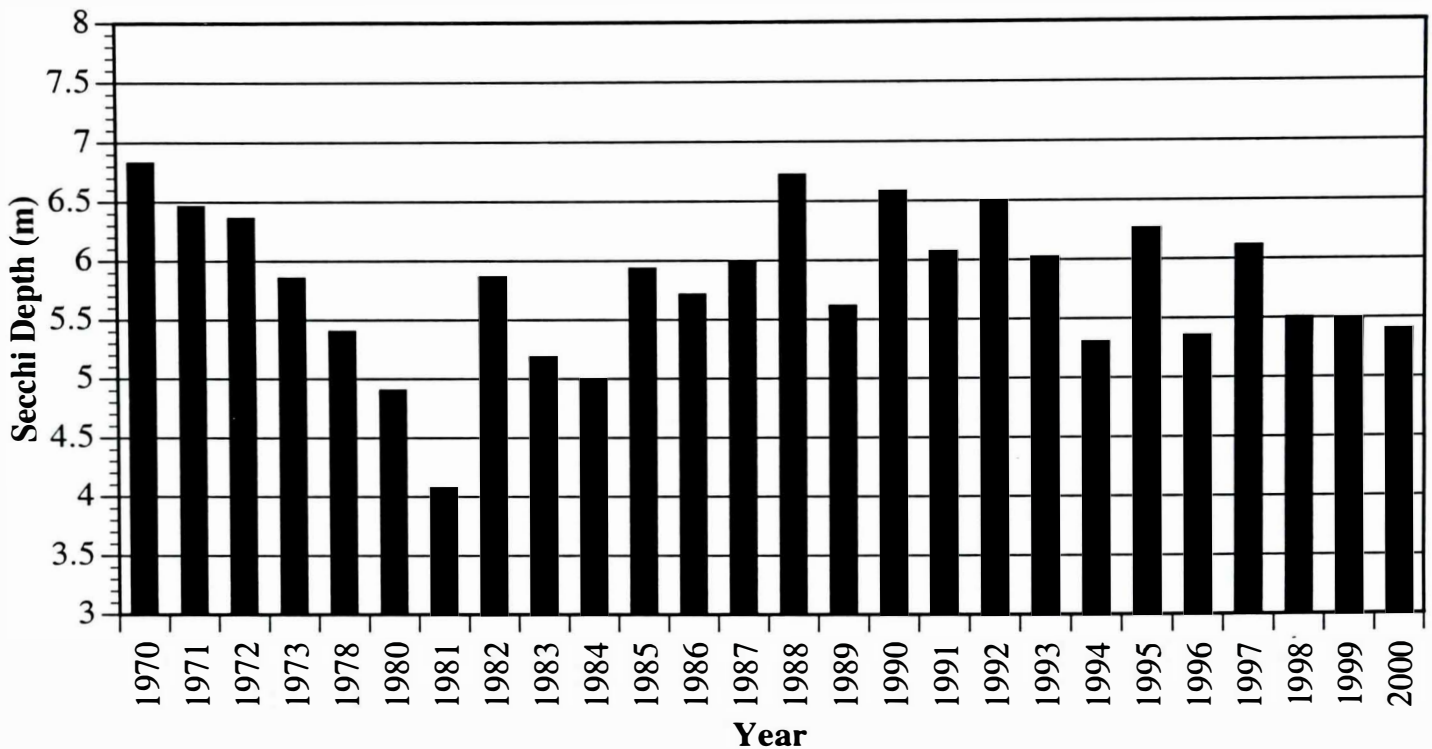


Figure 35. Average Secchi disk transparency levels for Lake Wesserunsett Site 1 for selected years between 1970 and 2000 (MDEP MIDAS data 2000). See site map for location (Figure 32).

Lake Wesserunsett are at least twice as high as this threshold level. Light penetration does not appear to be critically limited and large algal blooms have most likely not occurred during these sampling periods. In relating average Secchi disk readings to productivity, the transparency range observed in the current study (5 to 6 m) and over time (4 to 7 m) falls within the moderately productive designation, an intermediate productivity between productive (less than or equal to 4 m) and unproductive conditions (greater than or equal to 7 m) (Pearsall 1993). Mean transparency results from past research conducted on lakes in the region ranged from 2.88 ± 0.38 m at Salmon Lake to 6.90 m at the Long Pond South Basin. Lake Wesserunsett falls in the higher range with a transparency reading of 5.40 ± 0.06 m (Table 13).

Table 13. Comparison of mean (\pm SE) lake water quality values for physical tests at sites in the Belgrade Lakes and Lake Wesserunsett. Data collected from lake watershed studies by the Colby Environmental Assessment Team (CEAT) in 1991 and 1994-2000.

Lake	Transparency (m)	Turbidity (NTU)	Color (SPU)	Conductivity (μ MHOs/cm)
Lake Wesserunsett	5.40 \pm 0.06	0.97 \pm 0.09	10 \pm 2.7	39.8 \pm 0.8
Great Pond	5.91 \pm 0.21	4.34 \pm 1.84	14 \pm 2	32.2 \pm 1.0
Messalonskee Lake	4.60 \pm 0.40	5.00 \pm 2.00	50 \pm 12	36.0 \pm 3.0
North Pond	3.50 \pm 0.20	2.79 \pm 0.28	17 \pm 2	27.3 \pm 1.8
East Pond	3.25	4.70	17	27.5
Long Pond – North Basin	6.90	3.40	12	31.7
Long Pond – South Basin	6.50 \pm 0.003	2.31 \pm 0.35	8 \pm 1	34.5 \pm 0.2
Salmon Lake	2.88 \pm 0.38	2.23 \pm 0.17	13 \pm 2	69.8 \pm 11.9

Turbidity

Turbidity is a measure of the reduction of light penetration in the water column by suspended particulate matter. Substances such as silt, humus, organic detritus, and plankton can all contribute to turbidity levels (Reid 1961). Turbidity can vary daily and seasonally under the influence of factors such as rainfall, surface runoff and biological activity (Chapman 1996). Combined with color, turbidity determines the depth of light penetration, and consequently the water volume available for primary production. In this manner, turbidity affects phytoplankton, algae, and macrophyte abundance that in turn influence the overall lake community (Chapman 1996).

Methods

Samples were collected from the surface, mid-depth, bottom and by epicore sample. Samples were analyzed by CEAT members either in the field or in the Colby Environmental Analysis Laboratory during a 24 hour period after sampling on 13-Sep-00. Samples tested in the Colby Environmental Analysis Laboratory were kept at 4° C prior to analysis. Samples were analyzed using a HACH 2100P Turbidimeter, with values measured in Nephelometric Turbidity Units (NTU).

Results and Discussion

Turbidity levels ranged from 0.59 NTU to 1.57 NTU, with a mean level of 0.97 ± 0.09 NTU ($n=11$) for all of the lake samples tested. Among the three tributary sites sampled, Tributary Site 10 had a turbidity level of 0.99 NTU, while Tributary Sites 11 and 13 both had higher turbidity levels than the lake samples with readings of 2.03 and 8.27 NTU, respectively (Appendix L). These higher readings are most likely a result of higher water flow and consequent sediment resuspension. Low turbidity levels suggest high light penetration, resulting in a greater depth that is available for photosynthesis. In comparison to past research conducted on lakes in the area, Lake Wesserunsett had the lowest mean turbidity reading. Other values ranged from 2.23 ± 0.17 NTU at Salmon Lake to 5.00 ± 2.00 NTU at Messalonskee Lake (Table 13). Low turbidity levels in Lake Wesserunsett can be

attributed to low levels of erosion and runoff from tributaries and shoreline areas when the samples were collected as well as the absence of algal blooms.

Color

True color refers to the concentration of natural dissolved organic material in the water column. Apparent color measures the effects of both dissolved and suspended material, providing a measurement comparable to turbidity. True color is typically the result of vegetative decomposition products like tannins and lignins (McKee and Wolf 1963). True color and turbidity, which represent dissolved and solid matter in the water column respectively, combine to determine light penetration and primary productivity (Chapman 1996).

Methods

Surface, mid-depth and bottom samples were collected on 13-Sep-00 by CEAT members. Samples were kept at 4° C and analyzed in the CEAL within 48 hours of collection. All samples were filtered to remove suspended particulate matter prior to testing and analyzed using a HACH 4000 DR Spectrophotometer, with values measured in Standard Platinum Units (SPU) (HACH 1997).

Results and Discussion

Color ranged from 4.0 to 25.0 SPU, with a mean value of 10.0 ± 2.7 SPU (n=8) among lake sites tested (Appendix I). Among the four tributary sites tested, Tributary Sites 10 and 12 had color readings of 14.0 and 7.0 SPU, respectively. Tributary Sites 13 and 14 had significantly higher color readings of 56.0 SPU (Site 13) and 58.0 and 70.0 SPU (Site 14). These higher color readings are most likely attributable to dense aggregations of bordering wetlands and other forms of vegetation that would contribute proportionately greater concentrations of decayed material. Lake Wesserunsett

mean color readings by the MDEP for years sampled from 1978 to 1998 ranged from 14.0 SPU to 25.0 SPU (MDEP 2000a).

The current study had the lowest mean color reading among years tested at 8.2 SPU. (Figure 36). This decline in lake color levels may be due to variation in land use patterns in the Lake Wesserunsett watershed, analysis techniques, or temporal variation. Increased shoreline develop-

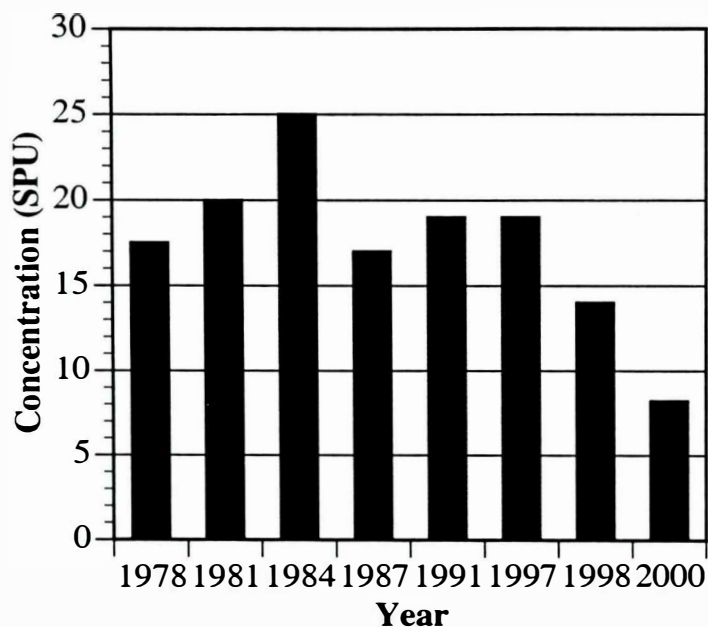


Figure 36. Mean color concentrations (SPU) for Lake Wesserunsett Site 1 for years sampled from 1978 to 2000 (MDEP MIDAS data 2000). See site map for location (Figure 32).

ment may actually decrease color concentrations, since forests and naturally vegetated areas would typically contribute more decayed vegetative material than cleared land or even lawns. While the CEAT study measured true color by filtration and removal of all suspended materials from samples prior to testing, some past MDEP studies may have measured apparent color. MDEP studies would produce higher readings since apparent color includes both dissolved and particulate matter.

Seasonal variation in vegetative production may also influence color levels.

Lower readings for the current study may be attributable to sampling time. Samples have been collected in June, August, and September, and this temporal variation may contribute to color level differences. The average lake color concentration in Maine is 27.0 SPU. Lakes with color concentrations exceeding 30.0 SPU are considered to be colored (MDEP 2000a). Since all mean Site 1 values taken over the past thirty years and the current study mean are below this threshold level, color levels do not appear to limit light penetration in Lake Wesserunsett.

Conductivity

Conductivity measures the ability of water to conduct an electrical current, which is a direct result of the dissolved solids present in the water, especially Ca^{2+} , Mg^{2+} , K^{+} , and Na^{+} salts (Chapman 1996). The degree of dissociation of these solids, ion mobility, ion charge, and solution temperature all affect conductivity, which is measured in micromhos per centimeter ($\mu\text{MHOs/cm}$). Conductivity can be an approximate measure of the mineral content of water and is useful in establishing zones where point pollution sources such as drainpipes enter the lake (Chapman 1996). Conductivity increases when ions leach in from underlying bedrock, or when pollutants and runoff increase. Maine lakes have an average conductivity between 20 and 40 $\mu\text{MHOs/cm}$ (Pearsall 1993).

Methods

Samples measured for conductivity were taken on 13-Sep-00 from the surface at Sites 1 and 2, and at the surface, mid-depth and bottom of Site 3. Tributary Sites 10, 13, and 14 were also sampled. Duplicate samples were taken at Site 2 and Tributary Site 14. Samples were kept at 4° C and analyzed in the CEAL within 24 hours of collection using a YSI Model 31A Conductance Bridge.

Results and Discussion

The conductivity of the water at Site 1 was 41.0 $\mu\text{MHOs/cm}$, and at Site 2 the mean for the sample and duplicate was 41.5 $\mu\text{MHOs/cm}$. The surface of Site 3 had a conductivity of 37.0 $\mu\text{MHOs/cm}$, the mid-depth, 38.0 $\mu\text{MHOs/cm}$, and the bottom, 40.0 $\mu\text{MHOs/cm}$ (Appendix I). Conductivity increased with depth, suggesting the amount of dissolved solids increases with proximity to the bottom and these dissolved solids are being released by the sediments. These sites were at the upper threshold of the Maine lake average, 44.0 $\mu\text{MHOs/cm}$ (MDEP 2000a), indicating that Lake Wesserunsett has a high amount of dissolved solids.

The tributary readings further suggest a high dissolved solid content in Lake Wesserunsett.

Tributary Site 10 had a conductivity of 96.0 $\mu\text{MHOS/cm}$, Tributary Site 13 had 55.0 $\mu\text{MHOS/cm}$, and the sample and duplicate of Site 14 had a conductivity of 79.0 $\mu\text{MHOS/cm}$ (Appendix I). The moving water in the tributaries stirs up sediments from the bottom, which increases the amount of dissolved solids present in the sample. This also supports the argument that the tributaries may be a major source of dissolved particles in Lake Wesserunsett. However, the tributaries had low flow at the time of measurement, and may not be a consistent source of dissolved solids.

The MDEP monitored the conductivity of Lake Wesserunsett for a number of years between 1978 and 1998 (MDEP 2000a). The mean conductivity during this time period was 57.8 ± 3.0 $\mu\text{MHOS/cm}$ ($n=6$), with the values ranging from 48.0 to 66.0 $\mu\text{MHOS/cm}$ (Appendix J). The mean conductivity for Lake Wesserunsett as tested by CEAT on 13-Sep-00 was 39.8 ± 0.8 $\mu\text{MHOS/cm}$ ($n=6$) for the lake sites, and 77.25 ± 8.43 $\mu\text{MHOS/cm}$ ($n=4$) for the tributary sites. The data obtained by CEAT are consistent with the range of data obtained by MDEP. Both sets of conductivity data suggest that there is a high concentration of dissolved solids in Lake Wesserunsett. This may be due to the shallowness of Lake Wesserunsett, which makes it more susceptible to sediment re-suspension caused by wave action. Other sources of dissolved solids are surface runoff and pollutants.

Ion Concentrations and Buffering

Introduction

Ion concentrations play a major role in the water quality of lakes (Chapman 1996). Hydrogen ions affect pH, calcium and magnesium affect hardness, phosphorus and nitrates affect nutrient levels, and carbonates affect the buffering capacity. These ions are found in variable concentrations in surface and groundwater due to geologic and climatic conditions, as well as the level of development of the surrounding area (Chapman 1996).

Positive Ions

pH

The pH of a solution is the measure of how acidic or basic it is. pH measures the concentra-

tion of hydrogen ions on a logarithmic scale ranging from 0 to 14 (Chapman 1996). The solution is considered acidic if the pH is less than 7, basic if it is greater than 7, and neutral when pH is equivalent to 7. A change of one unit of pH is equivalent to a ten-fold change in acidity or basicity. A normal pH for most lakes is between 6 and 9 (Goldman and Home 1983).

The pH of a lake is important because it influences many biological and chemical processes that occur in the water (Chapman 1996). For example, enzyme functions are inhibited when the pH of the environment changes significantly. The pH of a lake can be reduced when excessive amounts of acid rain are deposited. A decrease in pH below a level of 4 or 5 can result in the reduction of species diversity (Chapman 1996). In some regions of the Eastern United States, acidic water has been responsible for the disappearance of certain plants and animals (Goldman and Home 1983). The concentration of hydrogen ions in a lake can also influence the availability of other important nutrients such as phosphate, ammonia, iron and trace metals (Goldman and Home 1983). Most Maine lakes are in the pH range of 6.5 to 7.5 and few have seen significant effects from acid rain.

Methods

The pH of Lake Wesserunsett was taken from the surface by CEAT using a calibrated HORIBA twin pH meter. Samples were analyzed in the field for all sites indicated on 13-Sep-00. Historical pH data were obtained from the MDEP (MDEP 2000a).

Results and Discussion

The mean pH of the sites tested on 13-Sep-00 was 7.08 ± 0.0 ; (n=20; Appendix K). This mean falls within the range of healthy lakes (Goldman and Home 1983). The average pH for Maine lakes is 6.76 (MDEP 2000a). Lake Wesserunsett is slightly more basic than most Maine lakes.

Historically, Lake Wesserunsett has had a mean pH of 7.18 ± 0.11 (n=7), with samples being taken sporadically between 1978 and 1998. These data are consistent with the results obtained by CEAT, indicating that Lake Wesserunsett's pH has been stable over time, and suggest that Lake

Wesserunsett is closer to neutral than other area lakes, which may be related to the underlying geology of the watershed.

Hardness

Introduction

Hardness is a measure of the concentration of magnesium (Mg^{2+}) and calcium (Ca^{2+}) ions in the water column (USGS 1989). These ions are usually found in the form of calcium and magnesium salts, and are measured in mg/L. This value often represents mg/L of calcium carbonate ($CaCO_3$), the predominant calcium source in most lakes. The United States Geological Survey (USGS) considers water with less than 60 mg/L of $CaCO_3$ to be soft, water with 61 to 120 mg/L moderately soft, 121 to 180 mg/L hard, and water with over 180 mg/L $CaCO_3$ to be very hard (USGS 1989). Water with less than 80 mg/L is considered to be ideal, and any water with a hardness of greater than 100 mg/L to be unsafe for human use.

Methods

Hardness was tested at Sites 1, 2, and 3 on 13-Sep-00. A duplicate was collected at Site 3 for quality control. The water was sampled from the surface, acidified to a pH of 2 and kept at 4° C. Before analysis of the samples, pH was adjusted to between 3 and 8 using 5.0 N sodium hydroxide (NaOH). The sample was then tested in the CEAL using the calmagite colorimetric method for detecting Ca^{2+} and Mg^{2+} and the HACH DR/4000 Spectrophotometer (HACH 1997).

Results and Discussion

The mean hardness for Lake Wesserunsett was 3.24 ± 0.03 mg/L ($n=4$). Site 1 had a hardness of 3.25 mg/L. Site 2 had a value of 3.23 mg/L. Site 3 had a value of 3.17 mg/L and the duplicate from site 3 had a value of 3.30 mg/L (Appendix K). These data indicate that Lake Wesserunsett is

very soft by USGS standards.

Research conducted on other lakes in the Belgrade area show that the region as a whole has soft water. The hardness in other area lakes ranged from 3.00 ± 0.03 mg/L in Great Pond to 25.38 ± 0.77 mg/L in the South Basin of Long Pond (Table 14). The lack of hardness may be due to the granite composition of the bedrock that underlies the region (see Background: Geological and Hydrological Characteristics). Granite is deficient in calcium carbonate, so the water running into the lake will not have as many calcium ions to contribute to the hardness of the water. Water deficient in calcium may cause problems in the physiological systems of organisms living in that environment (Danner 2000), although Maine lakes have not reached that level of deficiency. Additionally, the soft quality of the water in Lake Wesserunsett makes it more susceptible to algal blooms and phosphorus loading.

Negative Ions

Total Phosphorus

Introduction

Phosphorus (PO_4)³⁻ is often the limiting nutrient for algal blooms in freshwater environments. Total phosphorus, which includes both dissolved phosphorus and particulate phosphorus, is measured to predict the chance of a bloom (See Background: Phosphorus and Nitrates). In the dissolved form, phosphorus can be assimilated by algae and is necessary for the production of ATP and DNA (Goldman and Home 1983). Therefore, it is essential to control and monitor the total phosphorus that enters freshwater ecosystems from anthropogenic and natural sources.

In late spring, summer and early fall much of the total phosphorus is present within either living or dead biota (Goldman and Home 1983). Algae are the primary consumers of dissolved phosphorus due to its abundance and rapid growth (Chapman 1996). Since the algal population is proportional to phosphorus levels, a bloom can occur when phosphorus levels rise above a threshold level for the lake. The typical threshold level for a Maine lake is about 15 parts per billion (ppb)

Table 14. Comparison of mean (\pm SE) lake water quality values for chemical tests at sites in the Belgrade Lakes and Lake Wesserunsett. Data collected from lake watershed studies by the Colby Environmental Assessment Team (CEAT) in 1991 and 1994-2000.

Lake	pH	Hardness (mg/l)	Nitrates (ppm)	Alkalinity (μ eq/l)
Lake Wesserunsett	7.08 \pm 0.09	3.24 \pm 0.03	0.04	280
Great Pond	6.98 \pm 0.09	3.00 \pm 0.03	a	180 \pm 20
Messalonskee Lake	6.98 \pm 0.11	14.79 \pm 0.30	0.10 \pm 0.00	360 \pm 20
North Pond	7.07 \pm 0.05	10.11 \pm 0.40	0.05 \pm 0.01	240 \pm 0.4
East Pond	7.06	3.90	0.04	224 \pm 14.4
Long Pond – North Basin	6.80	13.00	0.04	180
Long Pond – South Basin	6.59 \pm 0.01	3.42 \pm 0.42	0.04 \pm 0.003	180 \pm 0.6
Salmon Lake	7.78 \pm 0.13	25.38 \pm 0.77	a	-

^a Below the limit of detection

(Pearsall 1993). The MDEP has used a range between 12 to 15 ppb as a signal that a lake is capable of an algal bloom (Bouchard, pers. comm.).

Maine lakes are classified based on phosphorus levels by the MDEP. A lake with total phosphorus concentration below 4.5 ppb is classified as oligotrophic; lakes between 4.5 ppb and 20 ppb are classified as mesotrophic. When levels are above 20 ppb the lake is considered eutrophic (MDEP 1996).

Methods

CEAT sampled nine sites on Lake Wesserunsett, three tributaries, and the outlet of the lake. Sites 1 through 14 were sampled on 13-Sep-00, while Characterization Sites 1 and 2 were also sampled on 26-May-00 and Characterization Sites 1 through 3 were also sampled on 9-Aug-00. At Characterization Sites 1 through 3, CEAT obtained measurements from the surface, mid-depth, bottom and epicore. Samples collected on 13-Sept-00 of Sites 4 through 14 were obtained from the surface of the water column. Tributary Sites 10, 11, 13, and 14 are inlets of the lake and Site 12 is the outlet of the lake (Figure 32).

The samples were chilled to 4° C and brought to the CEAL where they could be refrigerated. All samples were separated into two containers. One container held 50 ml of sample for concentration readings. The other container was a safety precaution in case of error. To ensure accuracy, duplicates and splits were made for 10 percent of all samples. Standards of known phosphorus concentrations were made in order to calibrate the spectrophotometer. The 50 ml samples and standards were digested by first treating with 1.0 ml of 11 normal (N) sulfuric acid and 1.0 ml of 1.75 N ammonium peroxydisulfate, then placing into an autoclave at 15 pounds per square inch at 120° C for 30 minutes. This digestion process sterilized the samples and released the organic phosphate into a dissolved form. To obtain concentration readings, the pH level of the samples was raised to approximately 8.2. They were treated with a combination of 5.0 N sulfuric acid, potassium antimonyl tartrate, ammonium molybdate, and ascorbic acid. The samples then stood for ten minutes and the concentration of phosphate was obtained using a HACH DR/4000 spectrophotometer.

The methods for total phosphorus analysis were outlined by Eaton, Clesceri and Greenberg (1995), with modifications by G. Hunt and C. Elvin from the MDEP and CEAT.

Results and Discussion

Characterization Site History

The MDEP began monitoring phosphorus concentrations in Lake Wesserunsett during the summer of 1972. They have continued sampling every few years up to the present (MDEP 2000a).

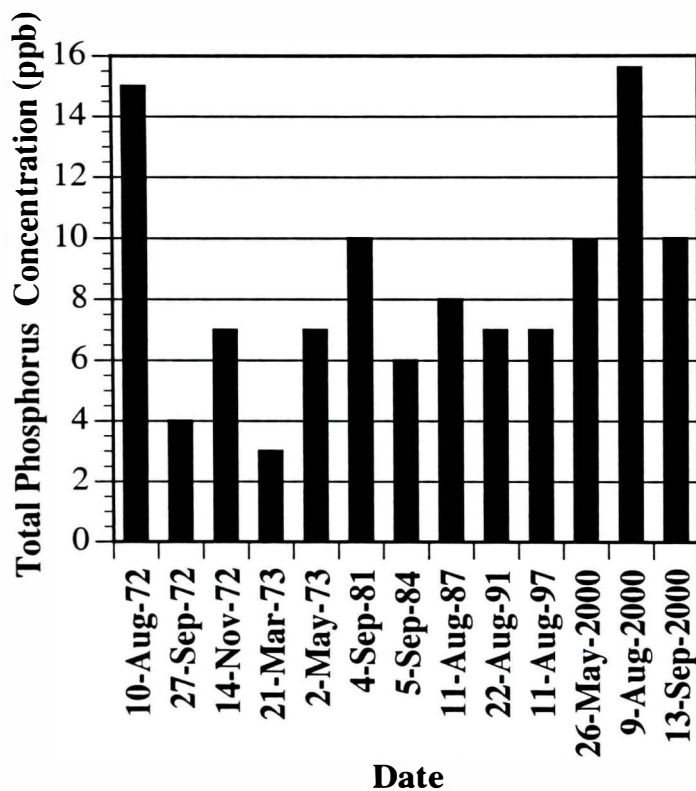


Figure 37. Total phosphorus levels for Lake Wesserunsett sampled at Site 1 over an 18 year period from 1972 to 2000 (MDEP MIDAS data 2000). See site map for location (Figure 32).

The average total phosphate level in the lake during past years was 7.4 ± 1.0 ppb; ($n=10$; Figure 37). The mean level in the 1970's was 7.2 ± 2.1 ppb ($n=5$). During the 1980's the mean level increased to 8.0 ± 1.2 ppb; ($n=3$). In the 1990's, the average concentration fell to 7.0 ± 0.0 ppb; ($n=2$; Figure 37). These averages are well below the threshold for algal blooms. CEAT determined there has not been an algal bloom reported in Lake Wesserunsett during the last three decades, although high algal levels have been observed in several years by residents. (Reid, pers. comm.).

Spring Characterization Sites

The spring sampling of phosphate on 26-May-00 was taken from the surface, mid-depth, bottom, and epicore of Site 1 and the epicore of Site 2. Similar concentrations of phosphorous at the surface and bottom of Lake Wesserunsett would be expected because no thermocline or stratification

exists which prevents mixing from occurring at any time of year. The results indicate that there was some stratification of phosphate in the lake at the time of sampling. In some years, there is evidence of thermal stratification starting just above the bottom of site 1. Surface concentrations were lower than readings taken from the bottom. This observed stratification may be due to the release of dissolved phosphorus from organisms that reside in the sediments (Wetzel and Likens 1991). The average phosphate concentration during this sampling was 10.0 ± 1.1 ppb; (n=7; Appendix L).

Summer Characterization Sites

The summer sampling was performed on 9-Aug-00 from Lake Wesserunsett at Characterization Sites 1, 2 and 3. Surface, mid-depth, bottom and epicore samples were taken at each of these sites. Sampling results demonstrated that the stratification of phosphate observed during the spring had reversed; the surface of the lake had a higher concentration than the bottom. The average concentration from this collection period was 15.6 ± 0.8 ppb; (n=12; Appendix L). This average excludes samples that were spiked with phosphorus and epicore readings that greatly exceeded the lake profile readings taken at that site, during the same sampling period. The epicore samples may have elevated readings if there was contamination from the sediment of the lake. The mean total phosphate level of characterization sites surpassed the threshold limit of 15 ppb during the summer of 2000. This indicates that Lake Wesserunsett may be capable of blooming during the summer months.

One explanation for the observed phosphate loading between sampling periods may be increased runoff due to high precipitation during the current year. Also, the influx of residents on the lake during the summer months, whose daily activities also contribute to phosphate loading, could be part of the observed trend (See Development: Septic Systems). A third factor that may contribute to elevated surface readings was an increased level of precipitation falling in the Lake Wesserunsett watershed as CEAT sampled on 9-Aug-00. Despite the fact that wave action did not increase significantly during sampling, the precipitation may have added some phosphorus to the surface of the lake as fallout.

Fall Characterization Sites

The results from the CEAT sampling on 13-Sep-00 show that the mean phosphate level in Lake Wesserunsett dropped back below the threshold level 10.1 ± 0.8 ppb; (n=15) (Appendix M). The

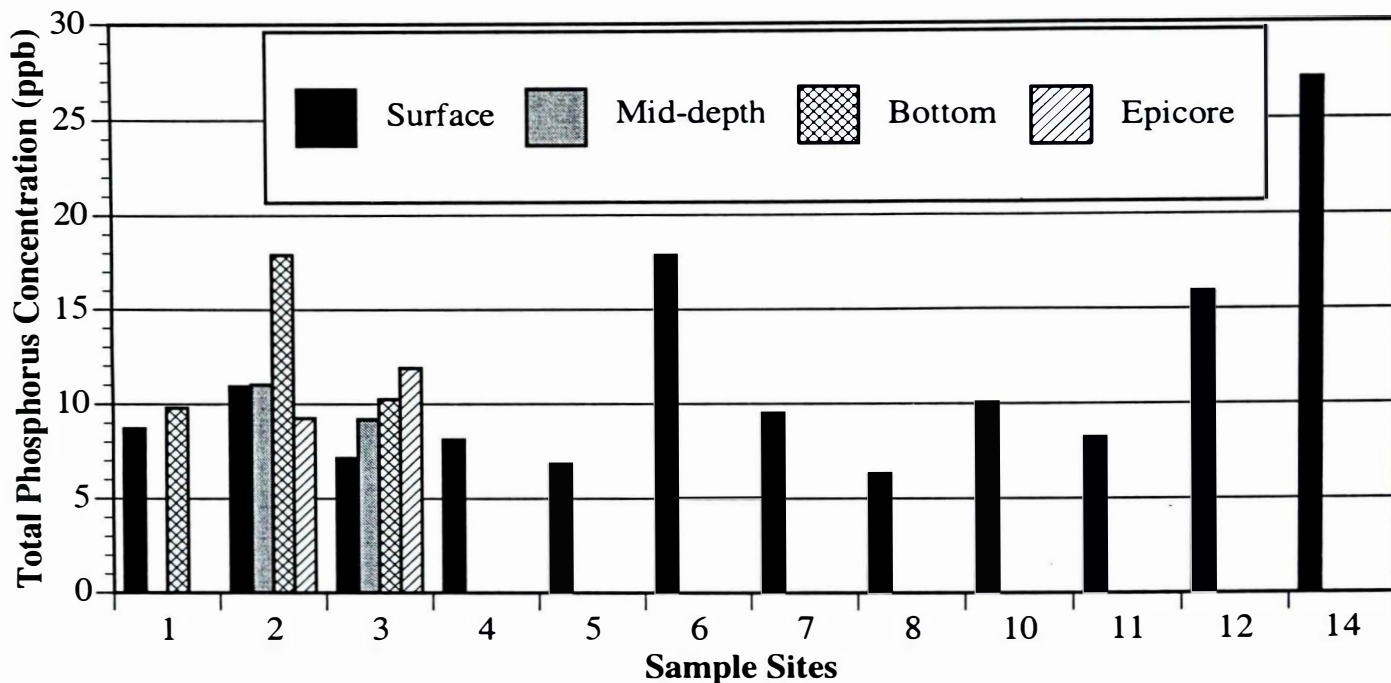


Figure 38. Total phosphorus levels for 12 sample sites on Lake Wesserunsett. Samples were taken at the surface, mid-depth, bottom or as an epicore on 13-Sep-00. Site 2 surface, 3 surface, 3 epicore, 7 surface and 10 surface each had duplicate samples taken. Data shown are an average value of the sample and duplicate sample. See site map for locations (Figure 32).

phosphorus stratification also returned to the pattern observed in the spring sampling period, with the lowest concentrations on the surface and the highest concentrations near the bottom (Figure 38).

Characterization site readings during spring, summer and fall 2000 show that Lake Wesserunsett is considered mesotrophic by MDEP standards (MDEP 1996). The average phosphorus levels at characterization sites through the three seasons of 2000 was 12.0 ± 0.7 ppb (n=34). Lake Wesserunsett has not been tested for consecutive seasons since 1972 through 1973. The average phosphorus concentration during the summer and fall of 1972 and spring of 1973 was 9.7 ± 3.2 ppb

(n=3, Figure 37). No significant difference can be drawn from these data because the standard error for the 1972 to 1973 sampling period lies within the range of the 2000 data.

Fall Spot Sites

All spot sites were sampled on 13-Sep-00. The average phosphorus level at Sites 4 through 9 was 8.8 ± 1.6 ppb (n=7) (Appendix M). Most spot sites were at or below average for the fall sampling period with the exception of Site 6, which was 17.8 ppb (Figure 38). This may have been a result of direct runoff of water and nutrients from East Madison Road into Lake Wesserunsett since Site 6 was in close proximity to the road. Overall, the sites that CEAT chose as possible sources of phosphorus had averages below the mean total phosphorus for the lake.

Fall Tributary Sites

Four Tributary Sites and one Outlet Site were measured on 13-Sep-00. The mean of the four tributaries was 22.8 ± 5.6 ppb (n=8; Appendix M). The relatively large standard error demonstrates that the tributaries had highly variable concentrations. Upper Hayden Brook, Tributary Site 11, measured 8.2 ppb, while lower Hayden Brook, Tributary Site 10, contained 10.0 ppb total phosphorus. This level is close to the average phosphate concentration in Lake Wesserunsett, therefore Hayden Brook could not be cited as a source of nutrient loading during our study. Monitoring this throughout the year is important. The stream at Tributary Site 13 had an average phosphorus concentration of 42.2 ppb, while Tributary Site 14 contained 27.1 ppb. Due to the lack of flow at Tributary Site 14, it was considered at the time not to be a substantial source of total phosphorus. It is possible that these tributaries contribute a significant amount of phosphorus during spring snow melt or heavy rains. The outlet, Tributary Site 12, had a phosphorus level of 15.8 ppb, higher than most other levels measured in the lake (Figure 38). One possible explanation is that phosphorus is exiting the lake incorporated in biomass. Another possibility is that the outlet is located in a shallow area of Lake Wesserunsett, which allows phosphorus to recycle quickly between dissolved and

particulate form. There also could be pollution in the outlet area as well. This location is also the site of public boat launch for Lake Wesserunsett and motor boat engines may stir up the sediment around the outlet.

Nitrates

Introduction

Nitrogen is essential to cells because it is incorporated into the building blocks for both proteins and the genetic material DNA and RNA (Cooper 1997). Nitrogen enters a lake system through both naturally occurring inputs and anthropogenic sources (Harper 1992). Because nitrate is the most abundant and important form of nitrogen to organisms, nitrogen levels in most lakes are found by measuring the concentration of nitrates (NO_3^-) in the water column. In many freshwater environments, including Maine, nitrate is not the limiting nutrient for algal blooms (Firmage, pers. comm.). When nitrate levels exceed 5.0 ppm, the lake is considered to be polluted (Chapman 1996). Nitrate concentrations can remain relatively high in a lake without inducing an algal bloom. Blooms are only a threat when high phosphorus and nitrogen levels occur simultaneously (Chapman 1996).

Methods

The samples for nitrate testing were taken from Characterization Sites 1, 2 and 3, Spot Sites 4, 5 and 6, and Tributary Sites 10, 11, 13 and 14. Only Characterization Site 1 was measured at the surface, mid-depth, bottom, and epicore; the other two characterization sites were measured only through an epicore. Surface grab samples were used for the Spot and Tributary Sites. After a sample was obtained from the lake, the pH of the water was immediately dropped to less than 2, then the sample was kept at 4° C. These samples were analyzed within 48 hours using the Hach DR/4000 spectrophotometer. The low range cadmium reduction nitrate test program was used to obtain nitrate levels for Lake Wesserunsett (HACH 1997).

Results and Discussion

The average nitrate level for Lake Wesserunsett was 0.037 ± 0.004 ppm ($n=12$), while the Tributary Sites averaged 0.042 ± 0.005 ppm ($n=5$; Appendix N). These levels are consistent with past findings on Lake Wesserunsett and are far below the level of a polluted lake (Chapman 1996). Nitrate levels in Lake Wesserunsett are currently stable, healthy, and do not indicate a nitrogen loading problem. Site 6 was the only site with a relatively high level of nitrates, recording 0.07 ppm. This site is located off the shore of the Sandy Beach Campground and may receive an influx of nitrates due to improper waste disposal by campers. All other sites had low variability with concentrations close to the average. When compared to the Belgrade Lakes chain, Lake Wesserunsett has nitrate levels similar to those found in North Pond, East Pond and the North and South Basins of Long Pond (Table 14).

Buffering and Alkalinity

Introduction

Alkalinity measures a body of water's ability to buffer against an influx of either acidic or basic substances. The revised definition states that alkalinity represents the acid neutralizing capacity (ANC) of water. It measures the equivalence or capacity of carbonate (CO_3)⁻², bicarbonate (HCO_3)⁻, hydroxide (OH)⁻ and many other basic compounds in solution (Wetzel and Likens 1991). If the alkalinity level is high, the lake can buffer against a sudden increase in acid and keep pH levels fairly constant. According to Adirondack Lakes Survey Corporation (1999), when a lake's ANC drops below 40 $\mu\text{eq/l}$, the lake is considered to be extremely sensitive to further acidification. Chapman (1996) states that buffering capacity is low if the concentration falls below 480 $\mu\text{eq/l}$. Maine lakes generally range from 80 $\mu\text{eq/l}$ to 400 $\mu\text{eq/l}$, with an average ANC of 200 $\mu\text{eq/l}$ (Davis et al. 1978; Pearsall 1993).

Methods

CEAT obtained surface grab samples from Site 2 on 13-Sept-00. The samples were kept at 4° C and analyzed within 24 hours of acquisition. A titration using 0.02 N H₂SO₄ was performed on the samples and the final results of the titration were entered into a formula to obtain the quantity of calcium carbonate CaCO₃ in parts per million (ppm). This concentration was then converted to µeq/l to measure the ANC (1 ppm ≈ 20 µeq/l) (Wetzel and Likens 1991).

Results and Discussion

The mean alkalinity of Site 2 on 13-Sept-00 was 280±7 µeq/l (n=2; Appendix K). This level suggests that Lake Wesserunsett has some buffering capabilities against acid rain, but it may not have high buffering ability during chronic exposures to precipitation with a low pH.

When compared to lakes in the Belgrade Region, Lake Wesserunsett has a relatively high buffering capacity, exceeded only by Messalonskee Lake with 360±20 µeq/l. Alkalinity ranged from 180 µeq/l to 360 µeq/l, with the average of the lakes at 227±29 µeq/l (n=6; Table 14). Examining the average pH of the lake is one way of verifying the lake's buffering capacity. The pH of Lake Wesserunsett is 7.04 (Appendix K), just slightly above neutral, demonstrating that carbonate and other buffers are neutralizing any acid rain that enters the Lake Wesserunsett watershed.

PHOSPHORUS LOADING

Introduction

The Phosphorus Loading Model is used to calculate the total amount of phosphorus that enters into a body of water over the period of a year. This calculation can then be manipulated to estimate the total phosphate concentration of a body of water. The model adapted from Reckhow and Chapra (1983) considers the phosphorus inputs from various land uses, septic systems, as well as atmospheric inputs. Another useful purpose of the Phosphorus Loading Model is to predict the phosphorus level for a body of water in the future, should a change in land use or development occur within the watershed.

Methods

The first step towards estimating the total phosphorus concentrations in Lake Wesserunsett is to obtain the total phosphorus that enters the lake in a given year. The equation used for this calculation contains constants and coefficients signifying the total amount of phosphorus released from a land use type in a given year, over a certain area of space. The equation is as follows:

$$W = (Ec_a * A_s) + (Ec_f * Area_f) + (Ec_l * Area_l) + (Ec_d * Area_d) + (Ec_w * Area_w) + (Ec_c * Area_c) + (Ec_m * Area_m) + (Ec_r * Area_r) + (Ec_s * Area_s) + (Ec_n * Area_n) + (Ec_v * Area_v) + [(Ec_{ss} * \# \text{ Capita years}_1 * (1 - SR_1)) + (Ec_{ns} * \# \text{ Capita years}_2 * (1 - SR_2))] \quad (1)$$

The value (W) represents the total phosphorus that enters Lake Wesserunsett in kilograms per year (kg yr⁻¹). The term Ec represents the export coefficient for a source input in kilograms of total phosphorus per hectare per year (kg ha⁻¹ yr⁻¹). The subscript for the export coefficient represents inputs from: the atmosphere (a), forested land (f), logged land (l), disturbed forest (d), wetlands (w), cleared land (c), commercial land (m), roads (r), shoreline development (s), non-shoreline development (n), reverted land (v), shoreline septic system (ss), non-shoreline septic system (ns) and inputs from summer camps (# capita years). The constant SR1 represents the shoreline soil retention capacity, while SR2 is non-shoreline soil retention capacity (Appendix O). The soil retention signi-

fies the percent of phosphorus that a particular soil is able to retain, reducing the amount flowing to Lake Wesserunsett. The constant A_s represents the surface area of Lake Wesserunsett, while Area represents the total area in the watershed for that respective land use type.

The export coefficients were assigned a high, low and best estimate for each source. The values were based on multiple sources from the New England Area (Reckhow and Chapra 1983, BI 493 1991, 1996, 1997, 1998 and 1999). The original model by Reckhow and Chapra (1983) on Higgins Lake, Michigan, standardized the setup of a Phosphorus Loading Model. They created a range between high and low values so that uncertainty for each source can be accounted for. The best estimate was determined by CEAT to give a more accurate estimate of the phosphorus loading from each source. It took into account the distinct details of the Lake Wesserunsett watershed and possible impact of each land use and developed area (Table 6). Digitized aerial photographs of Lake Wesserunsett's watershed determined the area for the lake and various land use types.

The total phosphorus load for a given area of Lake Wesserunsett was calculated using the equation:

$$L = W / A_s \quad (2)$$

The variable (L) represents the total kilograms per square meter over a year ($\text{kg m}^{-2} \text{yr}^{-1}$), derived from dividing the annual rate of phosphorus inflow (W), obtained in equation (1), by the total surface area of the lake (A_s) (Appendix P).

The annual atmospheric water loading to Lake Wesserunsett was calculated using the following equation:

$$q_s = Q_{\text{total}} / A_s \quad (3)$$

The expression (q_s) is indicative of total water loading in meters per year (m yr^{-1}) entering Lake Wesserunsett. The total volume of inflow (Q_{total}) expressed in cubic meters per year ($\text{m}^3 \text{yr}^{-1}$) is divided by the total surface area of the lake (See Water Budget).

The predicted phosphorus concentrations for low, high and best estimate were determined in parts per billion (ppb). The quotients (L) and (q_s) of equations (2) and (3) were then entered into the formula:

$$P = L / (11.6 + 1.2 q_s) \quad (4)$$

The expression $(11.6 + 1.2 q_s)$ represents the settling velocity of phosphorus in lakes. The export coefficients were adjusted to best fit the Lake Wesserunsett watershed area.

Results and Discussion

The Phosphorus Loading Model generated a range of phosphorus concentrations from 7.5 ppb to 22.0 ppb, with a best estimate of 12.4 ppb for Lake Wesserunsett. The mean phosphorus concentration generated by MDEP and CEAT sampling and analysis for spring, summer, and fall of 2000 was 12.0 ppb. This value is within the phosphorus range generated by the Phosphorus Loading Model and is only slightly below the best estimate, supporting the accuracy of this model as an indicator of phosphorus loading.

Based on the Phosphorus Loading Model, the total mass phosphorus loading for Lake Wesserunsett ranged from 771.8 kg/yr to 2,283.3 kg/yr, with the best estimate of 1,289.1 kg/yr falling in the middle of these low and high values (Appendix P). Among land use categories for the Lake Wesserunsett watershed, cleared land and roads contributed the highest percentages of phosphorus loading, representing 30.9 and 22.3 percent of total phosphorus loading, respectively, based upon best estimates (Figure 39). According to these estimates, cleared land and roads accounted for approximately one-fifth of total watershed area (21.7 percent) and more than half of all phosphorus loading to Lake Wesserunsett. Other land use categories, particularly forests, comprised greater land area (Table 6) but accounted for lower percentages of phosphorus loading. These Phosphorus Loading Model results suggest that roads and cleared land contributed disproportionately high levels of phosphorus to Lake Wesserunsett. This may be due to increased erosion related to destabilized surfaces lacking vegetation and poorly maintained roads.

According to best estimates, the second largest source of phosphorus loading was forests, which contributed 16.0 percent (Figure 39). Forests also constituted over 60.0 percent of the watershed area (Table 6), indicating that this contribution is related to forest's large area rather than concentrated phosphorus loading.

Disturbed forest and shoreline septic systems constituted the third largest source of phospho-

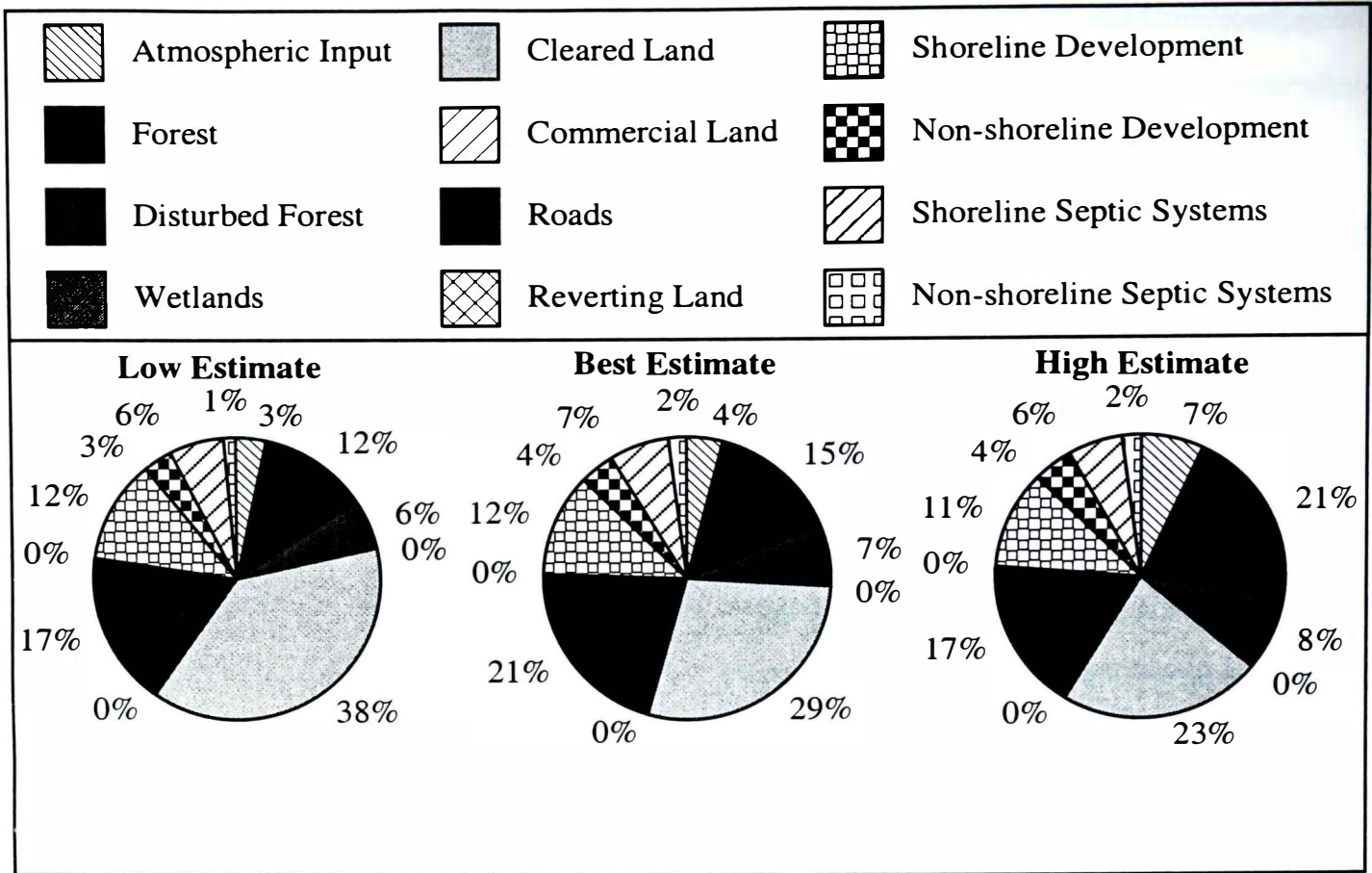


Figure 39. Low, high and best estimates of yearly percent contribution of watershed land use types to phosphorus loading in Lake Wesserunsett in 2000. Percentages based upon phosphorus loading for each land use category from the Phosphorus Loading Model.

rus contribution, adding 7.4 and 7.3 percent, respectively, according to best estimates. Disturbed forest contributed higher amounts of phosphorus due to reduced vegetative cover while shoreline septic systems had a greater impact as a result of proximity to Lake Wesserunsett and consequent reduced buffering.

Shoreline development, atmospheric input, and non-shoreline development contributed 4.9, 4.4, and 4.1 percent, respectively. Among these values, loading resulting from shoreline development presents a greater threat since it results more from erosion, removal of vegetation, and other anthropogenic contributions to phosphorus loading than from greater area. Shoreline residential land constituted less than 1.0 percent of the watershed area (Table 6). Non-shoreline development represented a low phosphorus percentage due to buffering provided by soil and vegetation between areas of development and Lake Wesserunsett, despite constituting 3.1 percent of the watershed area.

Atmospheric phosphorus does not contribute significantly to loading in this area of Maine (Firmage, pers. comm.).

Finally, non-shoreline septic, reverting land, commercial land, and wetlands represented the lowest sources of phosphorus, contributing 2.2, 0.3, 0.3, and 0.2 percent, respectively, according to best estimates (Figure 39). Non-shoreline septic contributions were minimized due to buffering provided by soil and vegetation between areas of development and Lake Wesserunsett. Reverting land contributed minimal amounts because this land area is vegetated and consequently buffered. Commercial land contributed high levels of phosphorus but also represented a very small area of the Lake Wesserunsett watershed. Wetlands do not typically contribute high amounts of phosphorus and instead function as phosphorus sinks (see Background: Wetlands). (Table 6).

FUTURE TRENDS

The Phosphorus Loading Model allows future predictions to be made based upon land use trends. Land use categories that represent large land areas or high phosphorus inputs should be examined. Specifically, shoreline development must be monitored because it contributes significantly to phosphorus loading and has a high potential for increase. Forest represents a lower source of phosphorus but a large percent of the watershed area and should be valued for its phosphorus retention capabilities.

Future development represents a risk to Lake Wesserunsett water quality. Fifty-one undeveloped shoreline lots currently remain around Lake Wesserunsett (Table 9). Potential phosphorus loading resulting from future development of these lots was estimated using the Phosphorus Loading Model. Values were based upon both changes in the total number of developed shoreline lots and more specifically, the relative numbers of seasonal and year-round houses surrounding Lake Wesserunsett from 1971 to 2000 (Table 8). Phosphorus loading effects were assessed by replicating these historical seasonal and year-round house percentages and adding the remaining 51 undeveloped shoreline lots to the total shoreline residential count and residential land area accordingly. Based upon these manipulations, the best estimate of Lake Wesserunsett phosphorus concentrations

is 13.0 ppb. Although remaining undeveloped lots represent less than one-fourth of the current shoreline residences, further development could pose a serious threat to Lake Wesserunsett phosphorus levels.

Any shoreline housing development will be accompanied by related development, such as road construction, which will further increase phosphorus levels. A 15 percent increase in road area combined with projected shoreline development produces a best estimate of 13.4 ppb for Lake Wesserunsett phosphorus concentrations. This development raises phosphorus levels by approximately 1 ppb, a potentially significant increase considering that phosphorus levels in Lake Wesserunsett are already within the MDEP threshold range at which algal blooms can occur, 12-15 ppb.

In addition to development, removal or disruption of natural watershed ecosystems can also contribute to phosphorus loading. Forest currently constitutes the majority of watershed land area (Table 6). This stable, unaltered land contributes significantly less phosphorus in comparison to developed areas. Increased logging practices could significantly impact phosphorus loading by removing this natural buffer. These effects would be further compounded due to the large land area that mature forest represents. Since forest constitutes the majority of Lake Wesserunsett watershed area and represents a minor source of phosphorus loading overall, any future development, logging or other forms of disturbance to this area will increase total phosphorus input. For example, logging of 20 percent of current forest would increase phosphorus concentrations to 13.1 ppb. Finally, if logging impact is combined with projected increases in roads and shoreline development, the Phosphorus Loading Model generates a phosphorus concentration of 14.0 ppb. This level could possibly induce regular algal blooms.

Current phosphorus levels in Lake Wesserunsett are precariously close to threshold levels required for algal blooms (see Water Quality Assessment: Phosphorus). Future development and land use alteration within the watershed should be carefully monitored and regulated to prevent an increase beyond current levels. While Phosphorus Loading Model predictions do not link significant phosphorus increases to any single projected land use alteration, when looked at collectively, these changes can increase phosphorus levels beyond the threshold level required for algal blooms.

SUMMARY

The future water quality of Lake Wesserunsett is uncertain. Water quality has reached the threshold at which ecologically detrimental algal blooms can occur. Phosphorus concentration in the water is the single most important factor in the health of the Lake Wesserunsett ecosystem. Average concentration of total phosphorus in Lake Wesserunsett for the spring, summer and fall of 2000 was 12.0 ± 0.7 parts per billion (ppb). This number has increased 25% from the 1972 MDEP measurement of 9.6 ± 3.2 ppb. The MDEP threshold at which total phosphorus concentration can potentially cause algal blooms in lakes is between 12 and 15 ppb. Consequently, it is crucial to the future health of the watershed that actions are taken to reduce the total phosphorus concentration in the water. Phosphorus levels in the water are dependent on a number of land uses that occur in the watershed. The goal of our analysis was to identify these land use patterns and their impact on water quality, and give recommendations to help preserve the future quality of the watershed.

The use of Geographic Information Systems (GIS) was of significant importance to our analysis. GIS allowed CEAT to compare aerial photographs of the watershed taken in 1961 and in 2000. In 2000, there was 140 percent more shoreline residential land than in 1961. This increase in shoreline residential land includes the clearing of land for houses, camp roads, and open spaces such as lawns. In addition, there has been a 28 percent increase in shoreline year-round houses. Year-round houses have the potential to contribute greater amounts of total phosphorus than seasonal homes. This significant increase in residential land, compounded by the increase in year-round houses in the watershed, may have contributed to the phosphorus level observed in Lake Wesserunsett.

GIS was also instrumental in composing the erosion potential map for the watershed. Careful planning is necessary for construction in areas of the watershed that have moderate to high erosion potential. To prevent additional phosphorus loading, measures should be taken to reduce existing erosion and prevent further erosion from occurring in the future.

Summer populations in the Lake Wesserunsett watershed and especially along the shoreline increase significantly because it is a popular area for summer recreation. This rise in seasonal population may be associated with the observed rise in phosphorus levels. Total phosphorus levels

for the years 1972 and 2000 both reached their peak during the summer months. This trend indicates that algal blooms will be more likely to occur in the future during summer months.

An important factor in reducing the amount of nutrient loading is the presence of adequate buffer strips. Based on our analysis, only 35 percent of shoreline property was adequately buffered. In addition, 45 percent was determined to have at risk potential, and 20 percent was considered to be at high risk. The southeastern shore of Lake Wesserunset was the most poorly buffered area of the shoreline, containing only two percent of adequately buffered homes. This section of Lake Wesserunsett is particularly susceptible to erosion due to its combination of high seasonal development, poor shoreline buffering, and high wave action from the prevailing northwesterly winds.

Increased residential activity in the watershed creates other potentially significant development implications. Poorly maintained roads can ultimately be large contributors to nutrient loading in a watershed. Because of their impervious surfaces, without proper crowning, diversion and ditching, runoff can travel quickly along these surfaces, eventually depositing high amounts of sediment in a body of water. Our analysis indicated that close to 30 percent of camp roads in the Lake Wesserunsett watershed are in a high risk category for causing nutrient loading. An additional 28 percent of roads were found to be at risk. Proper maintenance of these roads is necessary to help minimize the contribution to nutrient loading.

The specific type of land use in a given area can have a variety of different effects on nutrient loading. Wetland areas constitute about two percent of the total area within the watershed, but comprise 34 percent of the total shoreline area. The majority of inlets that enter Lake Wesserunsett flow through these wetland areas, absorbing much of the phosphorus prior to entering the lake. In the past thirty years, forested area within the watershed has increased, while the total area of cleared land has decreased, primarily through the natural process of succession. This greatly decreases the amount of phosphorus entering the lake. Our analysis indicates that the large area of shoreline wetland, combined with the increase in forested area of the watershed have a positive effect on buffering the amount of phosphorus that is entering Lake Wesserunsett.

A phosphorus model was developed by CEAT that allowed the projection of current and future total phosphorus concentrations in Lake Wesserunsett. Current projections match the results

of our analyses. This model, which considers relative importance of various land uses to phosphorus loading, predicts that algal blooms will pose an increasing threat to Lake Wesserunsett if proper actions are not taken to mitigate the negative impact of nutrient loading in the watershed.

Species of invasive plants have caused significant damage to New England lakes. These species are easily spread between lakes by human activity. While not currently a problem, the introduction of these species can potentially affect the quality of the Lake Wesserunsett ecosystem. Rapid decline in the health of the lake ecosystem will in turn affect the economic and recreational resources affiliated with the area such as fishing and boating.

Lake Wesserunsett is at a critical stage in the eutrophication process. Many human and natural processes are currently influencing the overall nutrient loading occurring in Lake Wesserunsett. Current development within the watershed poses an immediate threat to the balance of the lake ecosystem. Education, awareness, and community action will be instrumental in preserving and improving the health of the Lake Wesserunsett ecosystem.

RECOMMENDATIONS

High levels of phosphorus are a threat to the water quality of Lake Wesserunsett because phosphorus is the nutrient most responsible for algal blooms. Our study shows that the concentration of phosphorus in Lake Wesserunsett is approaching the level at which algal blooms can occur. Preventative steps must be taken to reduce the amount of phosphorus entering Lake Wesserunsett, such as improving buffer strips, septic systems, and camp roads, as well as careful control of development in areas with high erosion risk.

The following recommendations are based on our semester-long study. We believe that precautionary steps to reduce runoff and phosphorus loading will help to maintain the water quality of Lake Wesserunsett in the future.

PHOSPHORUS CONTROL

Buffer Strips and Erosion

- Careful planning to minimize potential nutrient loading is important when developing or logging a site in high erosion potential areas. Refer to the erosion potential map to identify these areas.
- Steps must be taken to improve the conditions of buffer strips on most shoreline residential land by planting native shrubs, trees, and groundcover to reduce runoff into the lake.
- Buffer strips on shoreline residential land on the southeastern shore of Lake Wesserunsett need immediate improvements due to a high erosion risk and disturbance from prevailing wind-driven waves.

Roads

- A volunteer road survey program and a road association should be developed to monitor camp roads within the watershed for erosion problems and lobby for maintenance
- DEP certified contractors should be employed in all road work.

- Roads at high risk in close proximity to the lake should receive first priority for repair and maintenance.
- Generally, road repair priorities should be in the following order: crown, ditching, water diversions and culverts, and lastly surface composition.

Septic Systems

- The town of Madison should apply for state grant money or use property tax revenues to identify and improve grandfathered septic systems that may be contributing heavily to nutrient loading.
- Encourage property owners to update grandfathered systems to the level of 2000 regulations.
- Regular septic system maintenance and inspection will benefit the long term health of the lake.

Land Use

- Residents within this watershed should be aware of potential logging within the region. This watershed has a high percentage of forested land and the community should promote awareness on forestry issues among its members so that the remaining forested land can be properly managed and will continue to enhance the water quality of the lake.
- Approximately 2/3 of Lake Wesserunsett's shoreline consists of residential land. Since the remaining 1/3 of the shoreline is covered by wetlands, which have poor septic suitability and high erosion potential, there is little suitable land left for future development. Management of the present level of development requires proper adherence to zoning and building codes.

Other Measures

- Consistent monitoring of phosphorus levels and transparency in the spring, summer, and fall is necessary. Phosphorus monitoring is particularly crucial because current total phosphorus concentrations are approaching the range in which algal blooms can occur.
- Limit the amount of phosphorus entering Lake Wesserunsett through the use of low phosphorus

lawn and garden fertilizers and low phosphate soaps and detergents. To limit the amount of runoff, which carries phosphorus to the lake, proper construction and maintenance of roads and buffer strips are necessary.

- Protect existing wetlands against human encroachment to maintain their capacity as a phosphorus sink for incoming nutrients.

INVASIVE SPECIES

- Clean all boating and fishing equipment of all plant material when travelling between lakes to avoid the introduction of invasive species which threaten lake water quality. Be sure to properly dispose of all plant material in upland areas. Post signs near the boat ramp in East Madison to inform boaters of the laws and regulations to help prevent the introduction of these species.

FISH POPULATIONS

- Fish populations in Lake Wesserunsett should continue to be monitored as their abundance and health are indicative of water quality. They are also an important resource for residents and tourists in the Lake Wesserunsett watershed.

AWARENESS

- The community should work with the DEP, VLMP, and the Lake Association to create awareness programs using information sessions, pamphlets, and signs for all watershed stakeholders and general users of the lake.
- A pamphlet on the importance of buffer strips and methods to create effective buffer strips should be made available at the Madison Town Office and promoted at Lake Association meetings.

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APPENDIX A. NUMBER, SIZE AND WEIGHT OF FISH STOCKED IN LAKE WESSERUNSETT BASED ON DIVISION OF FISHERIES AND WILDLIFE FISH STOCKING HISTORY

Date	Brown Trout	Brook Trout	Rainbow Trout	White Perch	Size (inches)	Weight (lbs)
Nov-46	-	-	200	-	-	-
May-47	1500	-	-	-	-	-
Nov-47	2000	-	-	-	-	-
Oct-48	1000	-	-	-	-	-
Sep-49	1000	-	-	-	-	-
Aug-50	40	-	-	-	-	-
Oct-50	1000	-	-	-	-	-
Aug-51	5000	-	-	-	2-4	-
Aug-51	1000	-	-	-	-	-
Jun-52	-	-	-	2500	2-4	-
Oct-52	1500	-	-	-	-	-
Jun-54	27000	-	-	-	Fry	-
Jul-54	1500	-	-	-	-	-
Jun-63	-	750	-	-	6-8	-
Jun-64	-	5000	-	-	6-8	-
Jun-66	-	800	-	-	6-8	-
May-67	-	1000	-	-	6-8	-
May-71	-	5000	-	-	6-8	-
Oct-74	3000	-	-	-	6-8	1111
Oct-75	5000	-	-	-	8-10	1351
Oct-76	5000	-	-	-	8-10	930
Nov-77	2500	-	-	-	8-10	1000
Oct-78	5000	-	-	-	8-10	1400
Oct-79	2500	-	-	-	8-10	925
Oct-80	3500	-	-	-	10-12	2058
Nov-80	-	100	-	-	16-18	300
Sep-81	3600	-	-	-	8-10	1423
Nov-81	50	-	-	-	16-18	150
Sep-82	3600	-	-	-	10-12	1895
Sep-83	3600	-	-	-	10-12	2255

APPENDIX A. CONTINUED

Date	Brown Trout	Brook Trout	Rainbow Trout	White Perch	Size (inches)	Weight (lbs)
Oct-84	3600	-	-	-	10-12	2572
Nov-85	3000	-	-	-	8-10	1250
Nov-85	-	100	-	-	16-18	300
Sep-86	3600	-	-	-	10-12	2250
Sep-87	3600	-	-	-	10-12	2059
Nov-87	-	250	-	-	16-18	1000
Oct-88	50	-	-	-	16-18	325
Oct-88	3960	-	-	-	8-10	1210
Nov-88	-	100	-	-	-	300
Oct-89	3600	-	-	-	8-10	1413
Oct-90	3600	-	-	-	10-12	2250
Oct-91	3964	-	-	-	10-12	2851
Oct-92	3600	-	-	-	10-12	3000
Nov-92	-	83	-	-	18-20	340
Oct-93	3600	-	-	-	10-12	2000
Oct-94	3600	-	-	-	12-14	2499
Nov-94	-	53	-	-	16-18	265
Sep-95	2600	-	-	-	12-14	2000
Apr-96	3600	-	-	-	10-12	1636
Oct-96	1000	-	-	-	6-8	87
Oct-97	3600	-	-	-	14-16	2560
Oct-97	360	-	-	-	14-16	257
Apr-98	3600	-	-	-	8-10	1280
Oct-98	-	300	-	-	12-14	215
May-99	3600	-	-	-	8-10	1714
May-00	3600	-	-	-	10-12	1714

APPENDIX C. BUFFER STRIP SURVEY FORM

Date: _____ Surveyors: _____ Section: _____

House #:	0	1 - 25	26 - 50	51 - 75	> 75	Score:
Lakeshore coverage (%)	0	1	2	3	4	
Buffer depth from shore(ft.)	0	1	2	3	4	
Slope b/w shore & house: 100 % equals 45° slope	> 50	50 - 26	25 - 1	0		
	0	1	2	3		
Composition:	100%	75%	50%	25%	0%	
Trees	4	3	2	1	0	
Shrubs/Flowers	10	8	6	4	0	
Riprap needed:	YES-0	NO-2				
Lot Shoreline distance	0-60'	60-120	120-180	>180'		
Total:						
House #:	0	1 - 25	26 - 50	51 - 75	> 75	Score:
Lakeshore coverage (%)	0	1	2	3	4	
Buffer depth from shore(ft.)	0	1	2	3	4	
Slope b/w shore & house: 100 % equals 45° slope	> 50	50 - 26	25 - 1	0		
	0	1	2	3		
Composition:	100%	75%	50%	25%	0%	
Trees	4	3	2	1	0	
Shrubs/Flowers	10	8	6	4	0	
Riprap needed:	YES-0	NO-2				
Lot Shoreline distance	0-60'	60-120	120-180	>180'		
Total:						
Lot Shoreline distance	0-60'	60-120	120-180	>180'		
Total:						

Slope: 50%=22.5°; 25%=11.25°

APPENDIX D. (CONTINUED)

DATE: _____

SURVEYOR'S NAME(S): _____

ROAD NAME/NUMBER: _____

DESCRIPTION OF ROAD DITCHING						
Score the quality of ditches 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] _____
_____ [e]	X	_____ [f]	=	_____ [g]		
DITCHES		CONDITION		DITCH TOTAL		

APPENDIX D. (CONTINUED)

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. 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).

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	()	()	()	()	()	_____
N	Length	50	100	200	500	1000	_____
	% Grade	()	()	()	()	()	_____
O	Length	50	100	200	500	1000	_____
	% Grade	()	()	()	()	()	_____

ROAD SEGMENT TOTAL _____

% Grade	Segment Length (feet)				
	50	100	200	500	1000
0-5%	____(4)	____(5)	____(8)	____(12)	____(17)
Total	_____	_____	_____	_____	_____
6-10%	____(10)	____(14)	____(19)	____(31)	____(43)
Total	_____	_____	_____	_____	_____
11-15%	____(16)	____(23)	____(33)	____(51)	____(73)
Total	_____	_____	_____	_____	_____
16-20%	____(29)	____(41)	____(58)	____(91)	____(129)
Total	_____	_____	_____	_____	_____

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 _____

APPENDIX D. (CONTINUED)

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	Ave. 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)	____(2)	____(3)	____(4)	____(5)	[i] ____
	100%good, or none needed	75%good	50%good	25%good	0%good, no culvert present but needed	____ ____ ____
	_____ X		_____ =		_____	
	CULVERTS [h]		CONDITION [i]		CULVERT TOTAL [j]	

APPENDIX D. (CONTINUED)

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 (1)	∅∅∅∅∅∅	∅∅∅∅∅∅	∅∅∅∅∅∅	badly needed (5)	_____
Where does diverted water go?	woods (1)	field or lawn (2)	gully in woods (3)	Stream (4)	Lake (5)	_____
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] _____
$\text{WATER DIVERSIONS [k]} \times \text{CONDITION [l]} = \text{WATER DIVERSIONS TOTAL [m]}$						

FINAL EVALUATION OF THE ROAD								
_____	+	_____	+	_____	+	_____	=	_____
[d]		[g]		[j]		[m]		
SURFACE		DITCHES		CULVERTS		WATER DIVERSIONS		ROAD TOTAL
<p>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. <u>As a rule, if any item checked was worth more than two points, it should be given priority when developing a road maintenance plan.</u></p>								
ROAD SEGMENT TOTAL = _____								
ROAD SEGMENT AVERAGE = _____								

APPENDIX E. BREAKDOWN OF ROAD QUARTILES

Classification of road total scores and erosion potential scores into quartiles.

	Minimum	Maximum	Mean±SE
<u>Best 25%</u>			
Road Total	26.0	84.0	58.2±6.8
Erosion Potential- Total Score	1200.0	3600.0	2650.0±329.4
Erosion Potential- Segment Average	7.3	9.3	8.4±0.4
<u>Second 25%</u>			
Road Total	89.0	131.0	99.8±5.4
Erosion Potential - Total Score	3700.0	7100.0	4900.0±518.3
Erosion Potential - Segment Average	9.8	10.8	10.2±0.4
<u>Third 25%</u>			
Road Total	195.5	252.0	226.1±8.0
Erosion Potential- Total Score	7200.0	10700.0	8600.0±629.8
Erosion Potential- Segment Average	12.0	13.5	12.7±0.2
<u>Worst 25%</u>			
Road Total	257.2	422.5	343.8±25.97
Erosion Potential- Total Score	11900.0	20300.0	16316.7±1442.1
Erosion Potential- Segment Average	14.5	20.8	16.6±0.9

APPENDIX F. LENGTH, WIDTH, AND AREA OF ROADS

Summary of length, width, and area for all roads surveyed.

Road Name	Length (miles)	Length (feet)	Width (feet)	Area (acres)
<u>Paved Surface</u>				
Golf Course Rd./Lakewood Rd.	1.10	5,808.0	20.5	2.73
Thurston Hill Rd.	5.00	26,400.0	29.7	18.00
Blackwell Hill Rd.	1.50	7,920.0	23.7	4.31
Route 148	3.30	17,424.0	34.0	13.60
East Madison Rd.	4.70	24,816.0	22.8	12.99
Horsetail Hill Rd.	0.70	3,696.0	22.5	1.91
Route 201	6.00	31,680.0	28.0	20.36
School House Rd.	1.10	5,808.0	21.5	2.87
Orchard Hill Rd.	0.42	2,217.6	20.0	1.02
Eames Hill Rd.	0.39	2,059.2	20.0	0.95
Boardman Rd.	0.20	1,056.0	23.0	0.56
<u>Dirt/Gravel Surface</u>				
Bagley Rd.	1.40	7,392.0	23.0	3.90
Bass Rd.	0.01	52.8	13.0	0.02
Beach Rd.	0.40	2,112.0	18.5	0.90
Davis Rd.	0.30	1,584.0	20.0	0.73
FR #1 (lower)	0.60	3,168.0	29.5	1.12
FR #1 (upper)	0.60	3,168.0	19.0	1.38
FR #3 (Whittier Farm Rd.)	1.00	5,280.0	15.0	1.82
FR #4 (Mallard Rd.)	0.50	2,640.0	14.0	0.85
FR #6 (Teal Rd.)	0.20	1,056.0	8.0	0.19
FR #8 (Loon Rd.)	0.10	528.0	12.0	0.15
FR #9 (Drake Rd.)	0.50	2,640.0	14.0	0.85
FR #10 (Merrill Rd.)	0.45	2,376.0	9.5	0.52
FR #11 (Wesserunset Rd.)	0.50	2,640.0	17.5	1.06
FR #12 (Merganser Rd.)	0.40	2,112.0	10.5	0.51
FR #13 (Heron Rd.)	0.20	1,056.0	10.0	0.24
FR #17	0.50	2,640.0	12.0	0.73

APPENDIX F. CONTINUED

Road Name	Length (miles)	Length (feet)	Width (feet)	Area (acres)
FR #18	0.40	2,112.0	12.0	0.58
Foss Rd.	0.50	2,640.0	22.0	1.33
Grange Rd. (boat launch)	0.15	792.0	20.0	0.36
Hayden Rd.	0.30	1,584.0	16.0	0.58
Hunnewell Rd. (FR #19)	2.00	10,560.0	13.0	3.15
Kincaid Rd.	1.90	10,032.0	15.0	3.45
Laney Rd.	0.65	3,432.0	17.0	1.34
Naomi Ave.	0.40	2,112.0	11.5	0.56
Olive Rd.	0.15	792.0	9.0	0.16
Sierra Rd.	0.15	792.0	19.0	0.35
Theater Rd.	0.30	1,584.0	18.0	0.65
Upper Beach Rd.	0.30	1,584.0	18.5	0.67
Totals	39.27	207,345.6	-	107.45

APPENDIX G. RESULTS OF DETAILED SURVEYED ROADS

Summary of road survey data for detail surveyed roads. See Appendix C for survey form

Road Name	Surface	Ditching	Culvert	Water	Road	Erosion Potential	
	Total	Total	Total	Diversion Total	Total	Total Score	Segment Average
Bagley Rd.	90.0	26.7	1.0	2.0	119.7	4600.0	15.3
Bass Rd.	42.5	1.0	1.0	3.0	47.5	-	-
Beach Rd.	280.0	100.0	0.0	42.5	422.5	7100.0	10.1
Davis Rd.	70.0	16.0	1.0	2.0	89.0	3700.0	9.3
FR #1 (upper)	30.0	34.0	1.0	2.0	67.0	-	-
FR #1 (lower)	220.0	57.0	1.0	2.0	280.0	-	-
FR#3 (Whittier Farm Rd.)	150.0	115.0	24.0	29.3	318.3	8000.0	8.9
FR#4 (Mallard Rd.)	210.0	60.0	39.0	2.0	311.0	7200.0	10.3
FR #5	-	-	-	-	-	-	-
FR#6 (Teal Rd.)	90.0	5.0	1.0	3.0	99.0	3700.0	9.3
FR#8 (Loon Rd.)	120.0	8.0	1.0	2.0	131.0	5400.0	13.5
FR#9 (Drake Rd.)	63.8	9.5	13.5	3.0	89.8	10700.0	7.6
FR#10 (Merrill Rd.)	180.0	145.0	47.5	50.0	422.5	20300.0	12.7
FR#11 (Wesserunsett Rd.)	125.0	46.5	26.4	16.0	213.9	18800.0	18.8
FR#12 (Merganser Rd.)	55.5	86.0	52.0	2.0	195.5	12100.0	17.3
FR #13 (Heron Rd.)	23.0	39.0	6.0	1.0	64.0	4900.0	9.8
FR#14 (Snipe Rd.)	-	-	-	-	-	-	-
FR#17	130.0	49.5	18.0	9.0	206.5	7900.0	7.9
FR#18	225.0	98.7	39.5	32.0	395.2	11900.0	10.8

APPENDIX G. (CONTINUED)

Road Name	Surface	Ditching	Culvert	Water	Road	Erosion Potential	
	Total	Total	Total	Diversion Total	Total	Total Score	Segment Average
Foss. Rd.	50.0	21.3	17.0	1.0	89.3	2400.0	12.0
Grange Rd.	80.0	1.0	1.0	2.0	84.0	2900.0	7.3
Hayden Rd.	20.0	8.0	18.0	12.0	58.0	3600.0	12.9
Hunnewell Rd.	127.5	48.1	49.5	32.0	257.2	16800.0	12.9
Kincaid Rd.	146.0	59.9	28.7	6.7	241.2	10400.0	20.8
Laney Rd.	67.5	110.0	16.0	35.0	228.5	18000.0	10.0
Naomi Ave.	135.0	75.0	30.0	12.0	252.0	7400.0	14.8
Olive Rd.	24.0	1.0	1.0	35.0	61.0	1200.0	12.0
Sandpiper Rd.	-	-	-	-	-	-	-
Scotter Rd.	-	-	-	-	-	-	-
Sierra Rd.	18.0	2.0	2.0	4.0	26.0	-	-
Theater Rd.	135.0	75.0	0.0	35.0	245.0	2900.0	14.5
Upper Beach Rd.	10.0	32.0	20.0	50.0	112.0	2900.0	14.5

APPENDIX H. QUALITY ASSURANCE

The Lake Wesserunsett study followed a quality assurance plan that standardized the procedures of CEAT. The following document was modified from BI493 (1998).

Bottle Preparation

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

Approaching Site

1. When approaching the test site, speed up first, then kill the engine and coast to the sampling site.
2. Always sample from the bow of the boat, into the wind.

Surface Sampling

1. Remove cap from sample bottle without touching lip of bottle or edge of cap.
2. Invert and immerse bottle to approximately 0.5 m down. Turn bottle on its side and move it through the water away from the boat.
3. Tilt bottle upright, remove from water, and cap. Place bottle in cooler.

Secchi Disk

1. Duplicate reading on every 10th sample.
2. Use Aqua-scope to view the disk.
3. Lower until the disk is out of sight, then record the depth.
4. Lower the disk an extra meter, then bring it back into sight and record the depth.
5. Bring the disk back to the surface and repeat the process two more times.

Measuring Depth

A. LCD Digital Sounder (Depth Finder)

1. Put the lanyard of the depth finder around your wrist.
2. Put the depth finder in the water and push the switch towards the bottom of the lake (in the direction of the arrow). Hold for 3 seconds.

APPENDIX H. CONTINUED

3. The depth finder must be pointed straight down. Record this depth.
4. Repeat this process one time.

B. Drop line/Measuring Tape

1. Drop the depth line into the water quickly and vertically until you feel slack, then gently pull the slack out of the line, bringing it through the muck and being careful not to lift the sinker off the bottom. Record this depth by counting the black tick marks on the line. Each black tick is 1 m.
2. Repeat this process one time.

Conductivity

1. Use the 250 mL Nalgene bottle labeled for conductivity test.
2. Follow surface sampling procedure.
3. Place water sample on ice in cooler.

Turbidity

1. Use the 250 mL Nalgene bottle labeled for turbidity test.
2. Follow surface sampling procedure.
3. Put water sample on ice in cooler.

Acidification of Hardness Samples

1. Rinse bottle lids with distilled water and add a small amount of the sample to the lid.
2. Test the water's pH in the sample bottle lid. If it is lower than 2, discard, rinse the lid, and cap the bottle. If the pH is greater than 2, add concentrated nitric acid (HNO_3) to your sample drop by drop until it is below 2.
3. The same number of drops of acid should be added to all the other bottles of the same size and same test.

Acidification of Nitrate Samples

1. Rinse bottle lids with distilled water, and add a small amount of the sample to the lid.
2. Test the water's pH in the sample bottle lid. If it is lower than 2, discard, rinse the lid, and cap the bottle. If the pH is greater than 2, add concentrated sulfuric acid (H_2SO_4) to your nitrate test sample drop by drop until it is below 2.
3. The same number of drops of acid should be added to all the other bottles of the same size and same test.

APPENDIX H. CONTINUED

Using pH Meter

A. Proper calibration method. (Before any testing is done, the pH meter must be calibrated using a 2-point calibration method at 7, and 4. This should be done only once during the testing day, as long as the meter's calibration is not accidentally deleted).

1. Press the POWER button. The pH meter automatically enters the measurement.
2. Apply the pH 7 solution by opening the sensor guard and wetting the entire probe well.
3. Press the CAL button one. The sensor guard will display 7.0 and a CAL symbol will appear at the bottom right hand corner followed by a smiley face indicating it is done.
4. After calibration, rinse the sensor well with E-pure (highly filtered and de-ionized water).
5. Repeat calibration for pH 4.
6. Check that probe is working properly by measuring aerated de-ionized water. The meter should return to a value of 5.65.
7. Take care to rinse probe with distilled water prior to and following each measurement.

B. Measurement

1. Lift the lid to the probe well and immerse the pH meter 0.5m to 1.0 m below the surface.
2. Close the lid. Bring the meter to the surface and record the reading after the smiley face has appeared in the bottom right hand corner.

C. Quality Assurance

1. Take the pH reading twice at each site to assure accuracy.

Dissolved Oxygen (DO) Meter

1. Lower DO/Temperature meter into water, shaking it to make sure there are no bubbles around the probe.
2. Immerse probe until covered. Record DO and temperature readings.
3. Lower probe 1 m at a time. Record DO and temperature for every meter until the bottom is reached.

APPENDIX H. CONTINUED

Mid-Depth and Bottom Sample

1. Pull rubber stoppers out of the ends of the bottom sampler.
2. Hook metal cables to the two small pegs located at the top of the sampler.
3. After taking depth reading, lower sampler to mid-depth sample depth.
4. Release sliding weight to close water sampler.
5. Pull out water sampler. Open air valve and open black tap by pushing outside ring of tap in. Drain tap for a few seconds.
6. Fill sample bottle to bottom of neck and cap. Place bottle in cooler.
7. Empty water sampler. Repeat sampling procedure for Bottom sample.
8. Take bottom sample 1 m above bottom.

Epicore

1. Rinse the tube three times by lowering it down into the lake water and pulling it back out.
2. For sites with great depth lower the tube down to 1 m below the thermocline (measured in the DO profile).
3. For shallow sites (all other sites) lower the epicore 1 m from the bottom.
4. The tape marks indicate 1 m.
5. Crimp the tubing just above the water (this is best done by bending it tightly and then holding it in your hand).
6. Pull the tubing up making sure that the excess tubing goes into the water. Be careful not to touch the end at which the water comes out.
7. Allow the water to drain into the large bottle being careful not to touch the inside of the bottle or the cap or the end of the tube.
8. Make sure to keep the non-pouring end of the tube up so the water does not drain out of it and that it does not take up surface water.
9. Hold up the crimped area and undo the crimp. Continue raising the tubing and move towards the draining end.
10. Repeat process three times, draining all of the water into the epicore mixing bottle.
11. Pour about 125 ml of this water into two Erlenmeyer flasks (fill to just below the neck). Again be careful not to contaminate the bottles by touching the inside of the bottle or the inside of the bottle cap.
12. Discard the remaining water and rinse the mixer with E-Pure water. Place all samples into the cooler.

APPENDIX H. CONTINUED

Flo-Mate

1. Turn the meter on. Place the black sensor entirely underwater, with the bulb facing upstream.
2. The meter will read the flow in either ft/s or m/s. Press the on/c and off keys at the same time to switch between the two.
3. Fixed Point Average (FPA) will take more accurate readings (hold up and down arrows at the same time). A time bar will move across the screen. When it reaches the far side, a new average velocity will be displayed.
4. Divide the topography of the stream into equal sections and measure the flow in each segment.

Global Positioning System (GPS)

1. Record three objects to triangulate your position. Concentrate on the distance from shore, try to approximate these distances.
2. Turn on the GPS.
3. When the unit says PRESS POS WHEN READY, press POS. It will say WAITING FOR FIX. Make sure there are six numbers at the bottom of the screen.
4. At the desired location press "enter". This stores your waypoint, labeling it W001 or W002, etc. After pressing enter, record the coordinates and name/number of the site.

Flagging tape

1. After locating tributary site, mark location using flagging tape.
2. Tie the tape in a locatable, yet discrete spot. This will avoid complaints and removal of tape.

Quality Control Sampling

1. E-pure samples were spiked (in groups of ten) with a known amount of 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 percent 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 procedure.

Total Phosphorus

1. For every ten samples, splits and duplicates were collected or made.

APPENDIX H. CONTINUED

2. Known concentrations of phosphorus in E-pure water were made on every run to test lab precision.
3. Reagent blanks were used to make a standard curve to determine the concentration of phosphorus studied. The standard curve should have a minimum of 6 points.
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.

Hardness

1. For every ten samples, splits and duplicates were collected or made.
2. The water samples were preserved for the analysis of hardness by adding nitric acid in the field until the pH was less than 2.
3. A HACH titration method, adapted 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 ppm CaCO₃. The range of the test is 0.03 ppm to 4.00 ppm CaCO₃.
5. Analysis was conducted within 14 days of sampling date.

Alkalinity

1. One duplicate sample was taken for every ten 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 was taken for every ten 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 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 units to 500 units.
6. Analysis was conducted within 48 hours of sampling date.

Conductivity

1. One duplicate sample was taken for every ten samples.
2. Results should not vary more than 1 $\mu\text{mhos}/\text{cm}^2$.
3. De-ionized water should read less than 1 $\mu\text{mhos}/\text{cm}^2$.
4. The water sampler was used at the desired stratification.
5. The water sample was poured into its specified conductivity bottle.
6. A Model 31A YSI Conductance Bridge was used to measure conductivity in the Colby Environmental Laboratory.
7. Analysis was conducted within 28 days of sampling date.

Turbidity

1. For every ten samples, splits and duplicates were collected or made.
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 sampling date.

Nitrates

1. For every ten samples, splits and duplicates were collected or made.
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 ppm $\text{NO}_3\text{-N}$. The range for the test is 0.0 ppm to 10.2 ppm $\text{NO}_3\text{-N}$.
4. Analysis was conducted within 48 hours of sampling date.

APPENDIX I. CONDUCTIVITY, COLOR, AND TURBIDITY FOR LAKE WESSERUNSETT.

Samples taken on 13-Sep-00 by the Colby Environmental Assessment Team. See site map for locations (Figure 32).

Site	Location	Conductivity (μ MHOs/cm)	Color (SPU)	Turbidity (NTU)
Lake		-		
1	surface	41	5	-
2	surface	42	4	1.21
2	surface	41 ^a	5 ^a	-
2	middle	-	-	0.80
2	bottom	-	-	0.94
2	epicore	-	-	0.90
3	surface	37	9	0.61
3	middle	38	8	-
3	bottom	40	18	0.75
3	epicore	-	-	0.84
4	surface	-	-	0.59
5	surface	-	25	-
6	surface	-	6	1.21
8	surface	-	-	1.57
9	surface	-	-	1.20
Tributaries				
10	surface	96	14	0.99
11 -	surface	-	-	2.03
12	surface	-	7	-
13	surface	55	56	8.27
14	surface	79	58	-
14	surface	79 ^a	70 ^a	-

^a duplicate

**APPENDIX J. CONDUCTIVITY FOR LAKE WESSERUNSETT
TAKEN BETWEEN 1978 AND 1998 (MDEP MIDAS DATA 2000).**

Date	Conductivity (μ MHOs/cm)
Aug-78	63
Aug-78	60
Sep-81	48
Aug-87	50
Aug-91	60
Jun-98	66

APPENDIX K. FALL ANALYSIS OF pH, ALKALINITY (μ EQ/L), AND HARDNESS (MG/L) LEVELS FOR LAKE WESSERUNSETT
Samples taken from the surface of the lake by the Colby Environmental Assessment Team on 13-Sep-00. See site map for locations (Figure 32).

Site	pH	Alkalinity (μ eq/l)	Hardness (mg/l)
Lake			
1	6.76 ^a	-	3.25
2	7.35	266	3.23
2	7.35 ^b	280 ^b	-
3	7.27	-	3.17
3	7.36	-	3.30 ^b
4	6.91	-	-
5	7.53	-	-
6	7.54	-	-
7	7.27	-	-
7	7.35 ^b	-	-
8	7.18	-	-
8	7.09 ^b	-	-
9	7.27	-	-
9	7.63 ^b	-	-
Tributaries			
10	6.55	-	-
10	6.67 ^b	-	-
13	6.20	-	-
13	6.37 ^b	-	-
14	6.92	-	-
14	7.01 ^b	-	-

^a Average of 6 values taken using Hydrolab sonde, values recorded for each meter of depth

^b Duplicate

APPENDIX L. TOTAL PHOSPHORUS OF SITES 1, 2, AND 3 FOR LAKE WESSERUNSETT (PPB).

Samples taken between 26-May-00 and 9-Aug-00 by the Colby Environmental Assessment Team. See site map for sampling locations (Figure 32).

Date	Site	Location	Concentration
26-May-00	1	surface	16.38 ^a
26-May-00	1	surface	6.89
26-May-00	1	middle	11.32
26-May-00	1	middle	8.78 ^b
26-May-00	1	bottom	11.38
26-May-00	1	epicore	46.66
26-May-00	2	epicore	12.96
26-May-00	2	epicore	12.10 ^b
9-Aug-00	1	surface	16.25
9-Aug-00	1	middle	16.51
9-Aug-00	1	bottom	9.87
9-Aug-00	1	epicore	41.25 ^c
9-Aug-00	1	epicore	53.33 ^{a, c}
9-Aug-00	2	surface	16.13
9-Aug-00	2	bottom	13.77
9-Aug-00	2	epicore	17.30
9-Aug-00	3	surface	16.32
9-Aug-00	3	surface	31.39 ^a
9-Aug-00	3	middle	14.40
9-Aug-00	3	middle	16.83 ^b
9-Aug-00	3	bottom	11.92
9-Aug-00	3	epicore	16.53

^a spike- 10 ppb added to split sample

^b duplicate

^c Values excluded from sample average due to bottom sediment contamination

APPENDIX M. TOTAL PHOSPHORUS (PPB)

Measured by Colby Environmental Assessment Team (CEAT) for Lake Wesserunsett samples taken on 13-Sep-00. See site map for locations (Figure 32).

Site	Location	Concentration
Lake		
1	surface	8.73
1	middle	3.67
1	bottom	9.82
2	surface	9.35
2	surface	12.84
2	surface	10.62 ^a
2	middle	11.02
2	bottom	17.91
2	epicore	9.25
3	surface	8.32
3	surface	5.97 ^a
3	middle	9.21
3	bottom	10.26
3	epicore	13.49
3	epicore	10.32 ^a
4	surface	8.13
5	surface	6.81
6	surface	17.83
7	surface	10.36
7	surface	8.57 ^a
8	surface	6.25
9	surface	3.97
Tributaries		
10	surface	8.71
10	surface	11.31 ^a
11	surface	8.15
12	surface	15.84
13	surface	55.12
13	surface	39.42 ^b
14	surface	22.49
14	surface	31.69

^a Duplicate

^b Spike- added 10 ppb of phosphorus

APPENDIX N. FALL ANALYSIS OF NITRATE CONCENTRATIONS (MG/L) FOR LAKE WESSERUNSETT.

Samples taken on 13-Sep-00 by the Colby Environmental Assessment Team. See site map for sampling locations (Figure 32).

Site	Location	Concentration
Lake		
1	surface	0.03
1	surface	0.03 ^a
1	middle	0.02
1	bottom	0.03
1	epicore	0.03
2	epicore	0.06
3	epicore	0.03
3	epicore	0.02 ^a
4	surface	0.07
4	surface	0.04 ^a
5	surface	0.04
6	surface	0.04
Tributaries		
10	surface	0.04
11	surface	0.06
13	surface	0.04
13	surface	0.03 ^a
14	surface	0.04

^aDuplicate

APPENDIX O. PHOSPHORUS BUDGET EQUATION

The following equation was used to calculate the total phosphorus that enters Lake Wesserunsett annually (W). The equation utilizes the watershed's land use, soil retention, land area, population and residential development as sources that contribute phosphorus to Lake Wesserunsett.

$$W = (Ec_a * A_a) + (Ec_f * Area_f) + (Ec_l * Area_l) + (Ec_d * Area_d) + (Ec_w * Area_w) + (Ec_c * Area_c) + (Ec_m * Area_m) + (Ec_r * Area_r) + (Ec_s * Area_s) + (Ec_n * Area_n) + (Ec_v * Area_v) + [(Ec_{ss} * \# \text{ Capita years}_1 * (1 - SR_1)) + (Ec_{ns} * \# \text{ Capita years}_2 * (1 - SR_2))]$$

Ec_a = export coefficient for atmospheric input (kilograms per hectare per year) (kg/ha/yr)

Estimated Range (ER) = 0.05 to 0.30

Best Estimate (BE) = 0.10

This coefficient was modified from the coefficient used in studies of lakes in the Belgrade Lakes Region of Maine. It is based on the very low amount of industrial activity in the Lake Wesserunsett watershed. With the absence of local point sources, airborne particulate phosphorus needs to travel from distant locations before deposition in Lake Wesserunsett. This decreases overall atmospheric deposition due to dispersion

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

ER = 0.04 to 0.20

BE = 0.08

The export coefficient reported by Reckow and Chapra (1983) was 0.10 to 0.30 for the forested land in the watershed of Higgins Lake in Michigan. Their coefficient is based on the coniferous forests present in the watershed. The coefficient for Lake Wesserunsett is based on the mixed coniferous/deciduous forest found in the lake's watershed. The export coefficient for Lake Wesserunsett is lower due to the large percentage of wetlands that cover the shoreline, 34 percent, filtering phosphorus from runoff (see Land Use Assessment: Watershed Assessments).

E_{c_1} = export coefficient for logged land (kg/ha/yr)

ER = 0.00 to 0.00

BE = 0.00

The Lake Wesserunsett watershed contains no logged areas so this land use does not contribute any phosphorus to the lake. These values will change if any logging occurs within the watershed.

E_{c_d} = export coefficient for disturbed lands (kg/ha/yr)

ER = 0.10 to 0.40

BE = 0.20

The disturbed land in the Lake Wesserunsett watershed represents areas of broken canopy in the forest. This is due to houses, partially logged land, or other forms of

development. This type of land use has a higher export coefficient than forested lands due to increased phosphorus runoff.

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

ER = 0.00 to 0.10

BE = 0.02

The export coefficient for wetlands is very low because wetlands can act as a sink for phosphorus as opposed to being a source. The wetlands in the Lake Wesserunsett watershed may act as a large sink for phosphorus since many inlets in the northern and western parts of the watershed run into wetlands before entering the lake.

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

ER = 0.40 to 0.70

BE = 0.50

The cleared land in the Lake Wesserunsett watershed represents grazing lands, mowed fields, agricultural fields and open lots surrounding houses. A high percentage of cleared lands in Lake Wesserunsett's watershed is thick, grassy pastures, which can retain a higher percentage of phosphorus than cleared land without vegetation. This allows Lake Wesserunsett's export coefficient to be relatively low for cleared land.

Ec_m = export coefficient for commercial lands (kg/ha/yr)

ER = 0.40 to 0.70

$$BE = 0.60$$

The export coefficient for commercial lands within Lake Wesserunsett's watershed is based upon the businesses found around the lake. Businesses have a higher export coefficient than non-shoreline development due to parking lots and other impervious surfaces. Impervious surfaces will increase runoff from the land, therefore increasing phosphorus loading into the lake.

E_{c_r} = export coefficient for roads (kg/ha/yr)

$$ER = 1.10 \text{ to } 3.20$$

$$BE = 2.20$$

The export coefficient for roads was relatively high due to poor conditions of camp roads in the Lake Wesserunsett watershed. Poor ditching, berms, and lack of water diversions are just some factors that lead to increased phosphorus input into Lake Wesserunsett, especially along camp roads.

E_{c_s} = export coefficient for shoreline development (kg/ha/yr)

$$ER = 0.90 \text{ to } 2.50$$

$$BE = 1.50$$

The high variability of buffer strip quality along Lake Wesserunsett's shoreline prompted a wide range for this export coefficient. Unless a sufficient buffer strip is in

place, phosphorus can be deposited directly into Lake Wesserunsett due to shoreline development.

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

$$ER = 0.20 \text{ to } 0.80$$

$$BE = 0.40$$

Non-shoreline development in Lake Wesserunsett's watershed usually can not directly deposit phosphorus into the lake, consequently a lower export coefficient is assigned. Usually some buffer exists between the non-shoreline development and Lake Wesserunsett acting as a sink for phosphorus runoff.

Ec_v = export coefficient for reverting lands (kg/ha/yr)

$$ER = 0.09 \text{ to } 0.30$$

$$BE = 0.13$$

The export coefficient for reverting lands is lower than disturbed lands but greater than forested lands. Reverting lands represents areas of land currently in succession between open fields and forest. The thick shrub and ground cover prevents phosphorus from being exported with sediment.

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

$$ER = 0.40 \text{ to } 0.80$$

$$BE = 0.60$$

The conditions for septic systems along Lake Wesserunsett's shoreline are generally poor. Updated regulations have taken this into account, but many house's septic systems do not need to abide by these regulations (see Development: Septic Systems). A majority of the houses along Lake Wesserunsett's shoreline are seasonal so their septic systems contribute less than if they were all year-round. These two factors result in a moderate export coefficient for shoreline septic systems.

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

$$ER = 0.30 \text{ to } 0.70$$

$$BE = 0.50$$

Non-shoreline septic systems are in equally poor soil conditions as shoreline but their distance from Lake Wesserunsett lowers the export coefficient. The majority of non-shoreline houses are year-round, so they contribute more phosphorus than seasonal houses. The combination of these two factors allowed the export coefficient to be relatively close to the shoreline septic system export coefficient.

Capita years _{1 and 2} = capita years for shoreline and non-shoreline development

$$\text{Capita years } _1 = 284.18$$

$$\text{Capita years } _2 = 376.33$$

This term accounts for the number of people potentially contributing waste to the shoreline and non-shoreline septic systems. It is calculated using the following equation:

Capita years = Average number of persons per unit * (Days in use / 365) * Total number of units

Seasonal and non-seasonal residence was estimated to be 89 and 355 days, respectively. The average number of persons per household was estimated to be 2.8 for both shoreline and non-shoreline development.

$SR_{1 \text{ and } 2}$ = soil retention constants for shoreline and non-shoreline development

Shoreline

Non-shoreline

$ER_1 = 0.55$ to 0.35

$ER_2 = 0.90$ to 0.80

$BE_1 = 0.45$

$BE_2 = 0.85$

Soil retention measures the ability of soil to hold onto phosphorus and prevent runoff into Lake Wesserunsett. It is based on the percent phosphorus that the soil retains. Soils with high values prevent phosphorus loading more than soils with lower values. Since shoreline soils have in general much less buffering than non-shoreline soils, the values for shoreline soils are much lower.

Areas for Land Use components:

A_s = area of Lake Wesserunsett = 567.18 hectares (ha)

A_f = area of forest lands = 2580.56 ha

A_l = area of logged lands = 0 ha

A_d = area of disturbed lands = 477.10 ha

A_w = area of wetlands = 93.57 ha

A_c = area of cleared lands = 795.64 ha

A_m = area of commercial lands = 5.27 ha

A_r = area of roads = 130.56 ha

A_s = area of shoreline development = 44.29 ha

A_n = area of non-shoreline development = 125.86 ha

A_v = area of reverting lands = 18.51 ha

APPENDIX P. PREDICTIONS FOR ANNUAL MASS RATE OF PHOSPHORUS INFLOW

The phosphorus loading model used by the Colby Environmental Assessment Team (CEAT) presents the annual total phosphorus input as a loading per unit lake surface area, measured in kilograms per hectare. The annual total phosphorus input was calculated by dividing Lake Wesserunsett surface area (A_s) by the total phosphorus inflow (W) (Reckhow and Chapra 1983):

$$L = W/A_s$$

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

Atmospheric water loading was calculated by dividing the total inflow water volume by the Lake Wesserunsett surface area (A_s) (Reckhow and Chapra 1983):

$$q_s = Q_{\text{total}}/A_s$$

- q_s = areal water loading (m/yr)
 Q_{total} = total inflow water volume (m³/yr)

Low and high estimates of the total phosphorus concentration were then calculated by dividing the total atmospheric phosphorus loading by the approximation of the phosphorus settling velocity in Lake Wesserunsett (Reckhow and Chapra 1983):

$$P = L/(11.6 + 1.2q_s)$$

P = total phosphorus concentration (kg/m³)

Constants for low and high predictions for Lake Wesserunsett:

- A_s = 567.18 ha
 Q_{total} = 5,671,813 m³
 q_s = 5.56 m/yr

Low Prediction:

$W = 772.41$ kg/yr
 $L = 1.36 \times 10^{-1}$ kg/ha-yr
 $P = 7.46$ ppb

Best Estimate:

$W = 1,289.86$ kg/yr
 $L = 2.27 \times 10^{-1}$ kg/ha-yr
 $P = 12.45$ ppb

High Prediction:

$W = 2,283.90$ kg/yr
 $L = 4.03 \times 10^{-1}$ kg/ha-yr
 $P = 22.05$ ppb