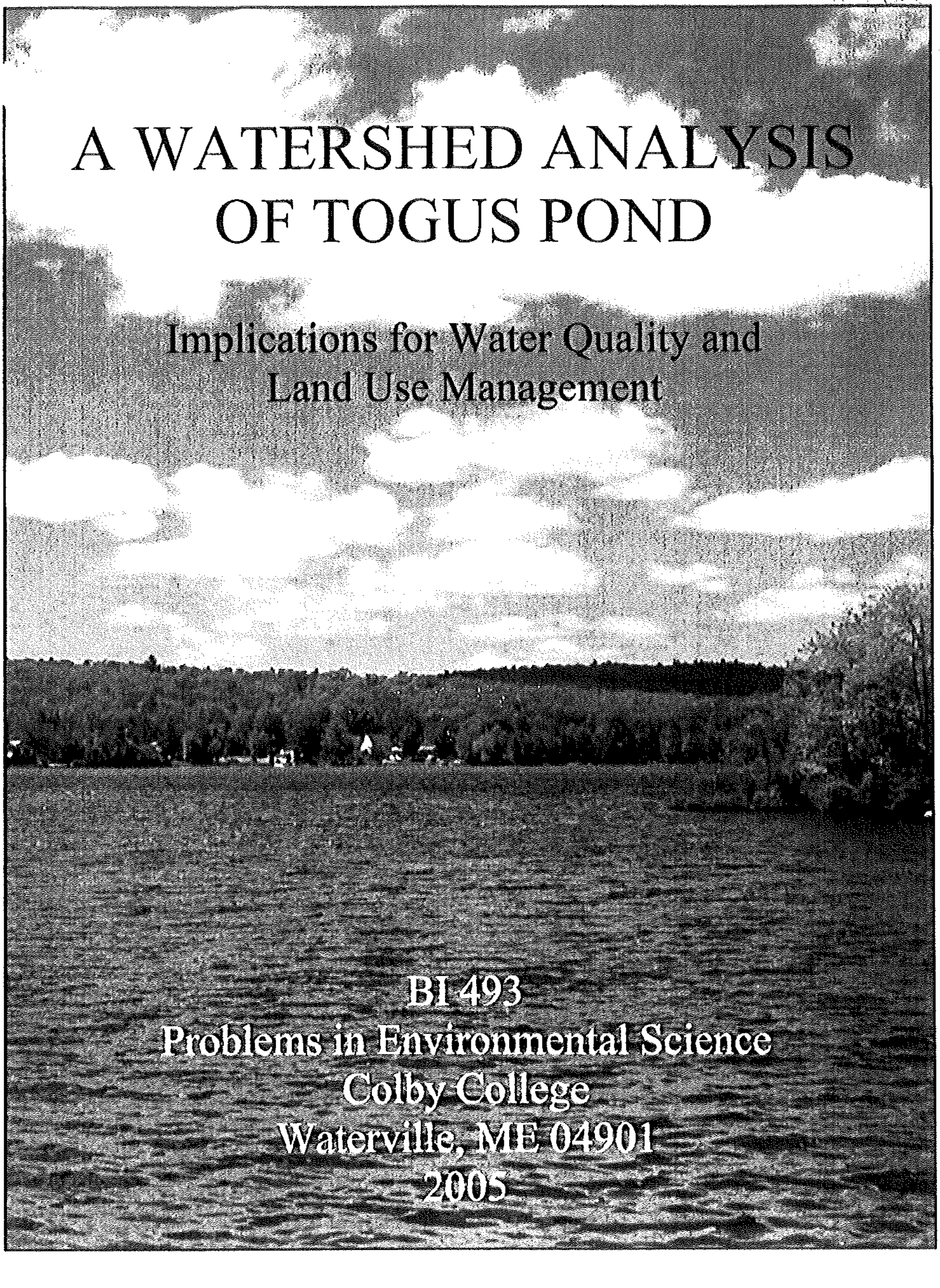
A WATERSHED ANALYSIS OF TOGUS POND

Implications for Water Quality and Land Use Management



BI 493
Problems in Environmental Science
Colby College
Waterville, ME 04901
2005

DATE: April 22. 2005

TO: **Report recipients**

FROM: **Professors Russell Cole and David Firmage**

RE: **Class report on Togus Pond**

We have very much enjoyed working with the people concerned with the water quality of Togus Pond 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.

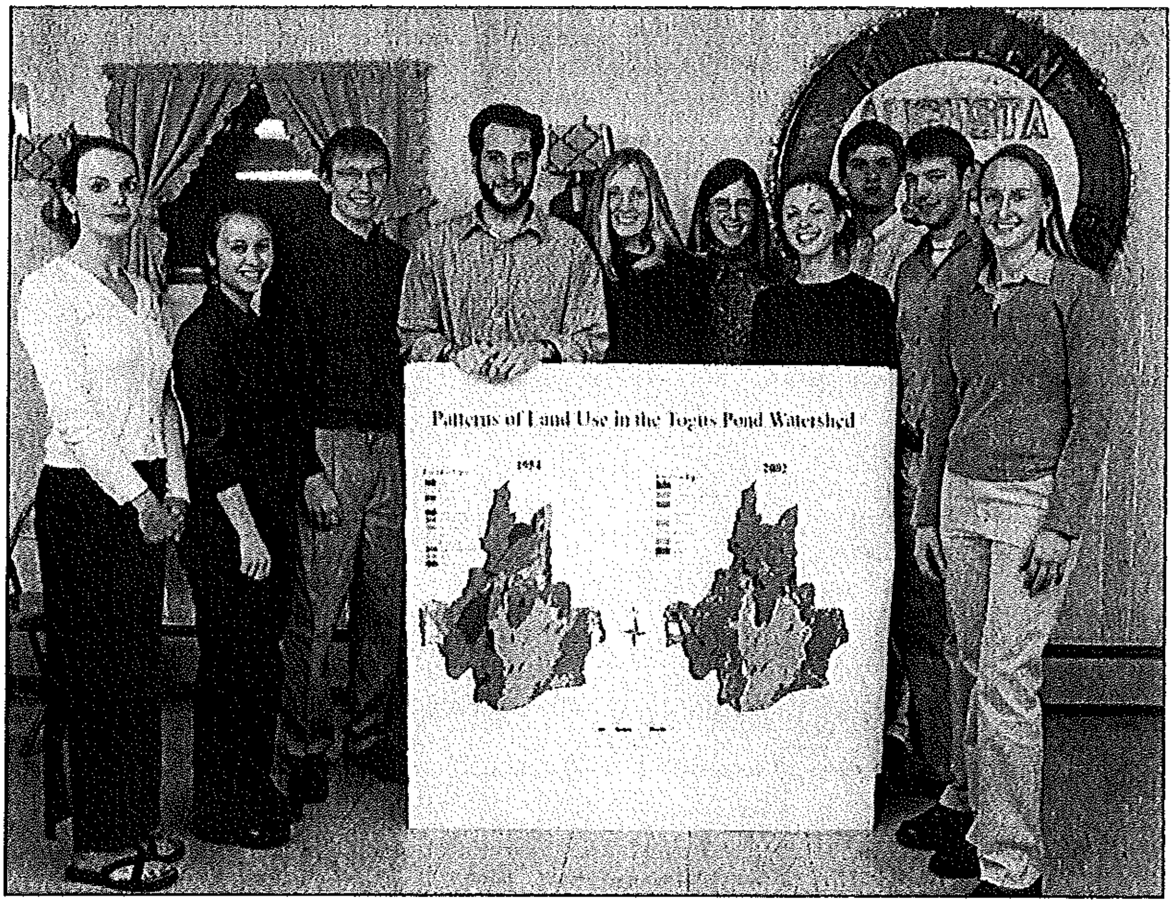
This report is the work of students enrolled in the Problems in Environmental Science course (Biology 493) taught at Colby College during the fall semester of 2004. The course is taken by seniors majoring in Biology, most having a concentration in Environmental Science, as well as by Environmental Science majors. 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 work plan, 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 Togus Pond watershed was conducted by the students of Biology 493: Problems in Environmental Science class at Colby College, Waterville, Maine.



Left to right: Alice Torbert, Lauren Wolpin, Mike Misencik, Andrew Drummond, Wendy Sicard, Carolyn Hunt, Kara Lanahan, Rob Mehlich, Tim Lancaster, and Natalie Maida.

The advisors for this study were Professors F. Russell Cole and David H. Firmage.

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calculated to assess the flow rate of nutrients through the lake. The results of the various tests and measurements were used to develop a phosphorus model, which allowed the calculation of present and prediction of future phosphorus loading.

The findings from the lake and watershed analysis can be used to make recommendations regarding the health and future remediation of Togus Pond. The water quality and land use assessments in this study were conducted by CEAT during the summer and fall of 2004.

WATERSHED ASSESSMENT INTRODUCTION

GENERAL NATURE OF STUDY

Lakes and their surrounding watershed provide important habitats for a wide variety of aquatic and terrestrial wildlife. Community members and businesses also benefit from lakes, enjoying them for their beauty and using them for recreational purposes. However, human activity has the potential to drastically alter the natural processes within a lake.

Lakes age through the process of eutrophication (Chapman 1996). A young lake is nutrient poor, but as it matures, nutrients accumulate from various sources, such as decaying organic matter and bedrock erosion. This influx of nutrients promotes plant growth, increasing the productivity of the lake. Human activities in the lake watershed tend to increase the amount of nutrients entering the water, accelerating the aging process (Dodson 2004). In Maine, phosphorus is the limiting nutrient for plant and algal growth in most aquatic ecosystems. Excessive phosphorus levels can increase growth and primary productivity in the watershed, resulting in ecologically harmful algal blooms and rendering lakes aesthetically unappealing. In turn, algal blooms can lead to a decrease in dissolved oxygen levels, which may result in fish kills and decreased biodiversity in the lake (Chapman 1996).

The 2004 Colby Environmental Assessment Team (CEAT) chose to study the Togus Pond watershed, located in Augusta, Maine. Togus Pond is a popular site for recreation and is home to a wide range of flora and fauna. Like all other lakes in Maine, it is a geologically young lake. However, intensive human activity in the watershed has caused accelerated aging of Togus Pond, also known as cultural eutrophication. This activity contributes to substantial nutrient-loading in the lake, and as a result, Togus Pond has had an extensive history of summer algal blooms (Sowles 1983).

The purpose of this study was to assess the impact of land use and development on the water quality of Togus Pond. Physical and chemical parameters of the lake were evaluated in order to determine both the current water conditions and trends in water quality. Recent land use patterns were examined and categorized with respect to their effect on water quality. Also, land use changes over the past 50 years were analyzed. A Geographic Information System (GIS) was used to generate models of septic suitability and erosion potential in the Togus Pond watershed. These models were used to predict where future impacts of human activities on water quality might occur. Development within the watershed was evaluated through the counting of residences, assessment of septic systems, and evaluation of roads. Economic correlations between water quality and the local economy were investigated for lakes in Maine. The water budget and flushing rate (cleansing potential) for Togus Pond were

EXECUTIVE SUMMARY

The Colby Environmental Assessment Team (CEAT) investigated the water quality and factors affecting water quality in the surrounding watershed of Togus Pond in Augusta, Maine from June to September 2004. CEAT analyzed several physical, chemical and biological water quality parameters, land use patterns in the watershed, and the impact of residential and commercial development on water quality. Data collected were used to produce models of the watershed that enabled CEAT to identify possible sources of degradation to the current and future water quality of Togus Pond. To obtain a historical perspective, all data collected this summer were compared to data collected in previous years by the Maine Department of Environmental Protection. Lake water quality is most affected by the accumulation of external nutrients, particularly phosphorus, resulting from surface runoff and land erosion. Internal nutrient loading is an important factor to consider since a large amount of the phosphorus in the lake from internal sediment loading. When concentrations of phosphorus approach threshold levels (15 ppb), a lake may experience algal blooms that decrease the aesthetic, recreational, ecological, and economic value of the lake and land areas surround the lake.

- Dissolved oxygen and mean transparency (3 m) readings for Togus Pond were consistent with other lakes in the surrounding area. The dissolved oxygen level during the mid-summer months was 0 ppm at 8 m and below, giving a volume of approximately 485 million gallons for the anoxic water in the lake.

- The conductivity measurement was 58 μMHOs/cm, which is well above the averages for other lakes in the area, suggesting that runoff is contributing particulate matter to Togus Pond.

- Mean hardness (22.2 mg/L) is an important factor to consider about Togus Pond since the level was very high compared to surrounding lakes in the area due to a high amount of dissolution of limestone.

- A phosphorus loading model was used to assess the inputs and outputs of phosphorus in the Togus Pond watershed in 2004. The budget is based on the amount of phosphorus entering the lake from the different land use types in the watershed. It also takes into account internal recycling of phosphorus. According to the model, the Togus Pond watershed contributes 466 kg/yr of phosphorus, while 358 kg/yr of phosphorus came from sediment release within the lake. The mean phosphorus concentration was 19 ppb, which was similar to water quality data analyzed by CEAT.

- The average septic suitability of the watershed was 5.0 on a scale of 1-9, with 9 being the most suitable for septic systems and 1 being the least suitable. The maximum value was 9, for areas where new septic systems should be developed with care and old ones should be cited for repairs.

- Roads within the watershed disproportionately contribute to the phosphorus loading of Togus Pond. Paved state and municipal roads contribute approximately four percent of the total phosphorus, and camp roads contribute five percent of the total phosphorus. This is a substantial amount for a relatively small percent of the watershed area (1.5%). Because road area is relatively small, road improvement is an easy way to decrease the total phosphorus to help improve water quality.

- CEAT found that 43% of the buffer strips on developed residential lots are inadequate. The majority of buffer strips need to be enhanced to provide proper erosion control. Many of the older homes do not meet current setback requirements, but septic systems do not appear to be a major problem within the watershed.

- CEAT found a total of 283 houses in the Togus Pond watershed. 184 of these houses (65%) are considered shoreline (within 200 feet of the lake) and 99 houses (35%) are non-shoreline. There are 221 year-round residences (78% of the houses) and 62 seasonal residences (22%) in the Togus Pond watershed.

- CEAT used ArcGIS™ 9.0 to analyze past and present land use patterns in the watershed. Maps were created showing the land use patterns in 1954 and 2002, as well as a map showing where land use changed in the intervening time period. Forested land remained the dominant land use type, covering over 60% of the total watershed area. Residential and commercial land both increased in area, while the area of agricultural land decreased.

- On a scale of 1-9, the average value of erosion potential (the likelihood that soil will be moved by wind or water) was 3.2, which means that the watershed has a moderate amount of erosion that affects lake water quality by carrying nutrients into the lake. Most of the areas that are currently residential land did not have very high erosion potential values.

- Small commercial developments exist in the Togus Pond watershed, particularly along Route 3 and Route 105. The proposed expansion of the golf course on Bolton Hill Road is a potential hazard to lake water quality. Clustering of shoreline residences occur frequently, especially along the southern shores of the lake, eliminating any major future increase in residences along the shore. In the future, the Togus Pond watershed may see an increase in population outside the shoreline zone. Septic systems within the watershed are generally in good condition.

- The four remediation methods deemed most applicable to Togus Pond are: alum treatment (to reduce the concentration of phosphorus in the water column by sealing it in the bottom sediment); fish stock manipulation (to encourage the zooplankton populations that control unsightly phytoplankton); drawdown (to remove nutrient-rich water from the lake); and vegetative mats (to trap phosphorus in aquatic plant biomass and remove it from the lake).

The Colby Environmental Assessment Team presentation is available online at: http://www.colby.edu/biology/BI493/ClassPres04.html.

BACKGROUND

This section provides the reader with background information relating to lake eutrophication. The information is intended to help the reader better understand the findings of this study and the discussion of those findings in the Analytical Procedures and Results section of the report.

LAKE CHARACTERISTICS

Distinction Between Lakes and Ponds

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 greater depth than ponds (Smith and Smith 2001). Lakes generally develop both vertical stratification and horizontal zonation while ponds do not. Horizontal zonation in a lake divides the lake into zones based on sunlight penetration and the growth of vegetation. The littoral zone, or shallow-water zone, is the area in which sunlight can penetrate to the bottom, allowing vegetation to grow from the substrate. The deep-water area is divided into the upper limnetic and lower profundal zones where rooted plants are unable 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 stratification found in a lake depends on density differences do to water temperature. Deep lakes will stratify with the densest (colder) water on the bottom and the least dense (warmer) water toward the surface. Ponds and shallow lakes do not stratify because disturbance by wind and waves causes constant mixing and temperature circulation.

General Characteristics of Maine Lakes

Lakes are a vital natural resource in Maine (Davis et al. 1978). They provide fresh water for swimming, fishing, drinking, livestock, and agriculture. The beauty of Maine lakes draws many tourists throughout the years. Lakes also serve as important habitats for wildlife.

The majority of Maine lakes were formed during the Wisconsonian 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 infertile. 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, plays 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 which will ultimately influence water quality.

Annual Lake Cycles

Stratification is a vital factor in lake ecosystem function, created by the different densities of water layers 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 in 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. This thermocline separates the epilimnion from the hypolimnion, the lowest stratum of a lake. The hypolimnion, only found in deeper lakes, is beyond the depth to which sufficient light can penetrate in order to facilitate effective photosynthesis (Figure 1). It is in the substrate below 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, re-oxygenates 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). A lake that has two turnover events per year is classified as dimictic, whereas

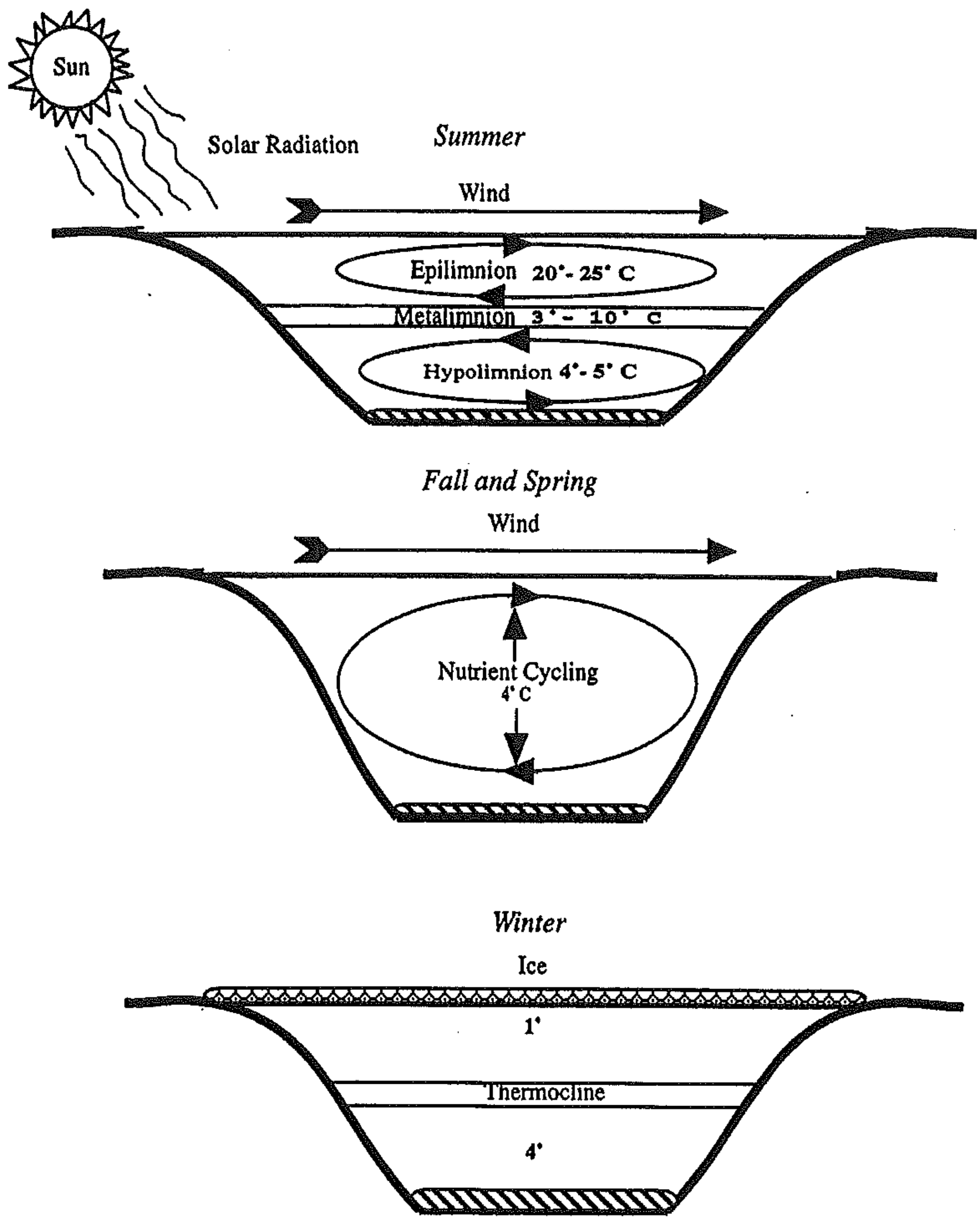

Figure 1. Mixing by means of lake turnover in dimictic lakes. During the summer, lakes are stratified into three layers (epilimnion, metalimnion, and hypolimnion). During the fall and spring, the isothermal temperature and density facilitate the lake turnover and redistribution of nutrients. In the winter,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

shallow lakes that may turn over at anytime of the year are known as polymictic

In winter, lakes in Maine are covered with ice for 4-5 months. The stratification is reversed as the coldest water (ice) is on the surface and the warmest water (roughly 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 fish kills because ice prevents diffusion of oxygen into the water and photosynthetic activity decreases, reducing oxygen production from phytoplankton. (Smith and Smith 2001).

In the spring after the ice has melted, solar radiation warms the upper stratum of the lake. The freshly melted water sinks and this process continues until the water column is uniform in temperature. Once this happens, oxygen and nutrients are again mixed throughout the water column. As late spring approaches, solar radiation increases, stratification becomes evident, and temperature (density) profiles return to that of summer in dimictic lakes, preventing water column mixing from occurring (Smith and Smith 2001).

Trophic Status of Lakes

One biological classification of lakes, called eutrophic state, 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). Oligotrophic lakes tend to be deep and oxygen rich with deep-sided basins, creating a low surface to volume ratio. They are low in suspended solids such as nitrates and more importantly 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 compared to oligotrophic lakes (Maitland 1990). These lakes have a large phytoplankton population that is supported by the increased availability of dissolved nutrients. Low dissolved oxygen levels at the bottom of a eutrophic lake are the result of decomposers using up oxygen. Anoxic (oxygen deficient) conditions lead to the release of phosphorus and other nutrients from the bottom sediments, resulting in their eventual recycling through the water column (Chapman 1996). This phosphorus release and recirculation stimulates even further growth of phytoplankton populations (Smith and Smith 2001). Eutrophic lakes tend to be shallow and bowl shaped due to sediment loading over the years, which allows for the establishment of rooted plants particularly in the shallow areas.

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 inva-

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

sion of rooted aquatic macrophytes chokes the habitat with plant growth. This leads to the filling in of the basin, developing a terrestrial ecosystem.

Eutrophication is a natural process- lakes begin as oligotrophic and eventually become terrestrial landscapes as they age (Niering 1985). This process is greatly accelerated by anthropogenic activities, that increase nutrient loading. The United States Environmental Protection Agency (EPA) characterizes the process of eutrophication by the following criteria:

- Decreasing hypolimnetic dissolved oxygen concentrations
- Increasing nutrient concentrations in the water column
- Increasing suspended solids, especially organic material
- Progression from a diatom population to a population dominated by cyanobacteria and/or green algae
- Decreasing light penetration (e.g., increasing turbidity)
- Increasing phosphorus concentrations in the sediments (Henderson-Sellers and Markland 1987)

Lakes may receive mineral nutrients from streams, groundwater, and runoff as well as precipitation. As a lake ages, it fills with dead organic matter and sediment that settle to the bottom. The increase in nutrient availability, particularly phosphorus, promotes algal growth.

Phosphorus and Nitrogen Cycles

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 the limiting nutrient for plant growth in freshwater systems, and is considered the most important nutrient in lakes (Maitland 1990). Phosphorus naturally occurs in lakes in minute quantities measured in parts per billion (ppb). However, due to the high efficiency with which plants can assimilate phosphorus, these concentrations are sufficient for plant growth (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 (Figure 2; 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). DP is an inorganic form that 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 that 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, resulting in byproducts

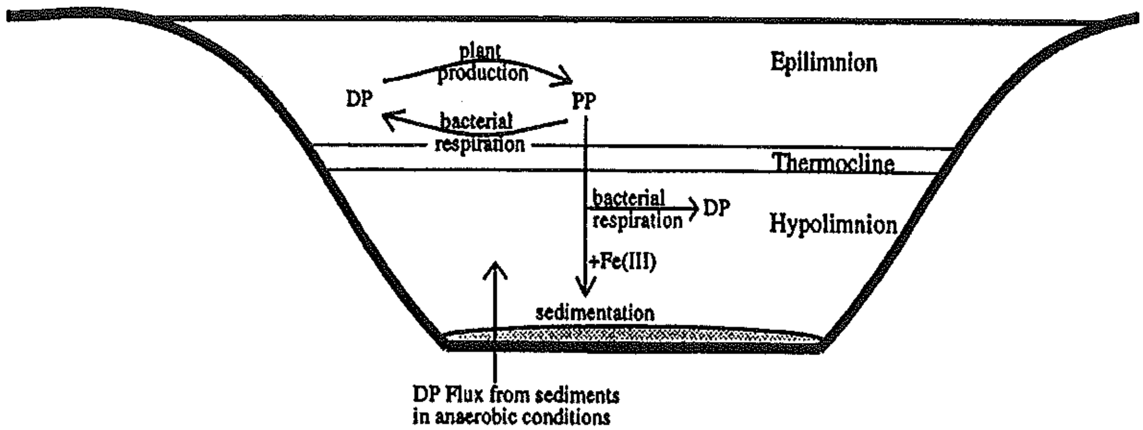

Figure 2. A model of the cycle of the major forms of phosphorus, dissolved (DP) and particulate (PP), within a lake ecosystem. The sedimentation of DP through complexation with Fe (III) contributes to the build-up of DP in the sediments. Note the production of DP in the hypolimnion due to bacterial decomposition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

such as hydrogen sulfide, a toxin to fish (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 anoxic sediments. The sediments of a lake can have phosphorus concentrations of 50 to 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. Nutrients are mostly inhibited from mixing into the epilimnion by stratification during the summer, and as a result, DP concentrations build up in the lower hypolimnion until fall turnover.

During fall turnover water temperatures become more uniform and wind mixes the water, resulting in a large flux of nutrients moving from the bottom of the lake to the upper layers, creating the potential for algal blooms. Algal blooms can occur when phosphorus levels rise above 12.0 ppb to 15.0 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 concentrations 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) (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. In aerobic conditions, nitrate-forming bacteria convert nitrites to nitrates. Ammonia enters the lake ecosystem as a product of the decomposition of plant and animal tissues and their waste products, and is processed in one of three ways. Macrophytes can assimilate ammonia directly into their tissues. Alternatively, under oxygen-rich conditions, aerobic bacteria will convert the ammonia directly to nitrates, the more usable form of nitrogen. Finally, anaerobic decomposition, a characteristic of the sediments of stratified lakes, can reduce nitrates 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

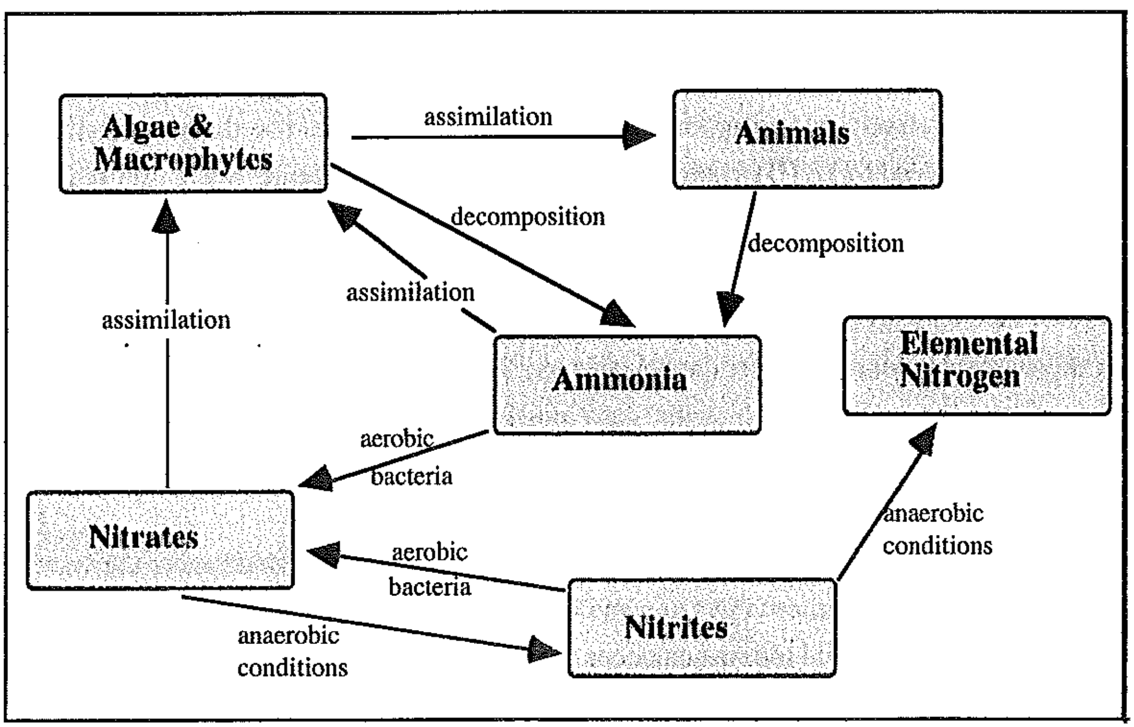

Figure 3. A diagram of the various forms of nitrogen that occur in the nitrogen cycle within a lake ecosystem. It is important to note that in aerobic conditions both ammonia and nitrites are converted to nitrates which are available for use by plants.

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).

Once nutrients have built up in a lake, eliminating them is a challenging task. The ideal method for controlling nutrients in a lake is to regulate and monitor the input sources before they become problematic. 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. Wetland soil is periodically or perpetually saturated and, because wetlands usually have a water table at or above the level of the land, they contain non-mineral substrates such as peat. Growing in this partially submerged habitat is hydrophytic vegetation that is adapted for life in saturated and anaerobic soils (Chiras 2001). Wetlands are beneficial to lakes for a number of reasons. For one, they support a wide range of biotic species (Table 2; MLURC 1976). Wetlands also help to maintain lower nutrient levels in an aquatic ecosystem because of the efficiency in nutrient uptake by their vegetation (Niering 1985, Smith and Smith 2001). Finally, wetlands have the potential to absorb heavy metals and nutrients from various sources including mine drainage, sewage, and industrial wastes (Chiras 2001).

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 (EPA 1990a). Due to their influence on erosion and runoff, different types of land use have different effects on nutrient loading in lakes. Assessment of land use within a watershed is 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

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

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. 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, and impervious surfaces such as driveways, parking spaces, or roof-tops that reduce percolation and 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 its 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, phosphorus, other plant nutrients and miscellaneous chemicals. It should be noted that more environmentally friendly soaps and detergents that have low phosphorus levels are now available (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 (EPA 1980). Proper treatment and disposal of nutrient-rich human waste is essential in maintaining high lake water quality.

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% of active and 20% of inactive logging sites selected (MDC 1983). Skidder trails may pose a problem when they run adjacent to, or through, streams. Shoreline zoning ordinances have established that a 75 ft strip of vegetation must be maintained between a skidder trail and the

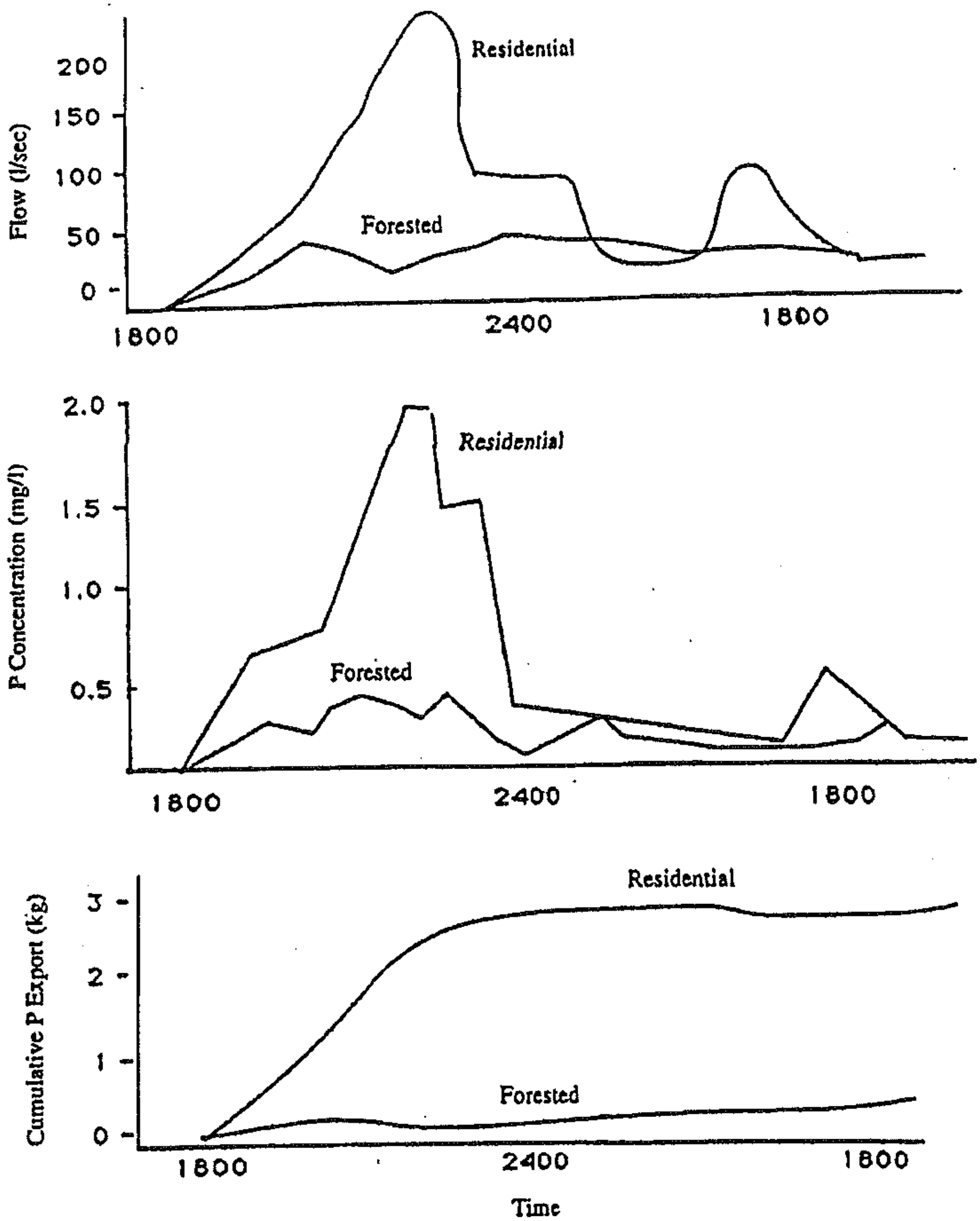

Figure 4. Comparisons of runoff after an April rain storm in two neighboring watersheds near Augusta, ME. Top: volume of immediate runoff over a 12 hour period; Middle: phosphorus concentration in the runoff; Bottom: total amount of phosphorus exported into local streams and lakes from the storm (Dennis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

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, 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). Suggested buffer strip widths are dependent on, but not limited to, steepness of slope, soil type and exposure, pond watersheds, floodways, and areas designated critical for wildlife (City of Augusta 1998).

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 ideally buffered home should have a winding path down to the shoreline so that runoff is diverted into the woods where it can be absorbed in the forest litter rather than channeled into the lake (Figure 5). The house itself should be set back at least 100 ft from the shoreline and have a dense buffer strip between it and the water. The buffer is composed of a combination of canopy trees, understory shrubs, and groundcover. To effectively deter runoff, the driveway should be curved rather than steep, straight, paved, and leading directly toward the water. Slopes within a buffer strip that are less than 2% 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

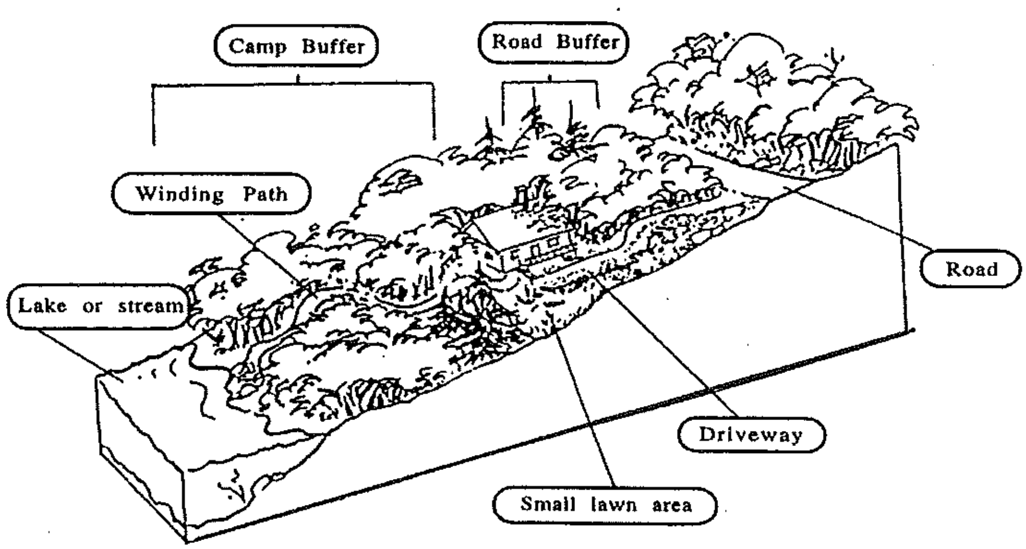

Figure 5. Diagram of an ideally buffered home.

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 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 assumptions determines the accuracy of the predictions (EPA 1990a).

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) that 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 1978). 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 (MDEP 1998). 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 ft 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 sponges for the nutrients flowing from residential areas to the lake (Woodard 1989). These buffer strips consist of areas of natural vegetation growing between a building and the body of water in question.

Residences that have lawns leading directly down to the shore have no barriers 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. Phosphorus export from these areas is likely to increase during periods of heavy use. The location and condition of septic systems also affects the nutrient loading from these plots (see Sewage Disposal Systems).

Non-shoreline Residential Areas

Non-shoreline residential areas (greater than 200 ft 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 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 (e.g., driveways) to the lake. Although non-shoreline 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 non-buffered, non-shoreline residences 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. Similar restrictions and regulations as those for shoreline residences apply to non-shoreline 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 devices and associated piping including treatment tanks, disposal areas, holding tanks, alternative toilets which function as a unit to dispose 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 and 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 1,500 gallons. These must be pumped or else they could back up into the structure or leak into the ground, causing contamination. Although purchasing a holding tank is less expensive than installing a septic system, 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 connect to a pump (Figure 6). The pump enables the effluent to be moved uphill from the shoreline to a more suitable leach field location (MDHS 1983). 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. 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 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, more 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). As the physical, chemical, and biological breakdowns occur, scum and sludge are separated from the effluent (Figure 7). 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 microor-

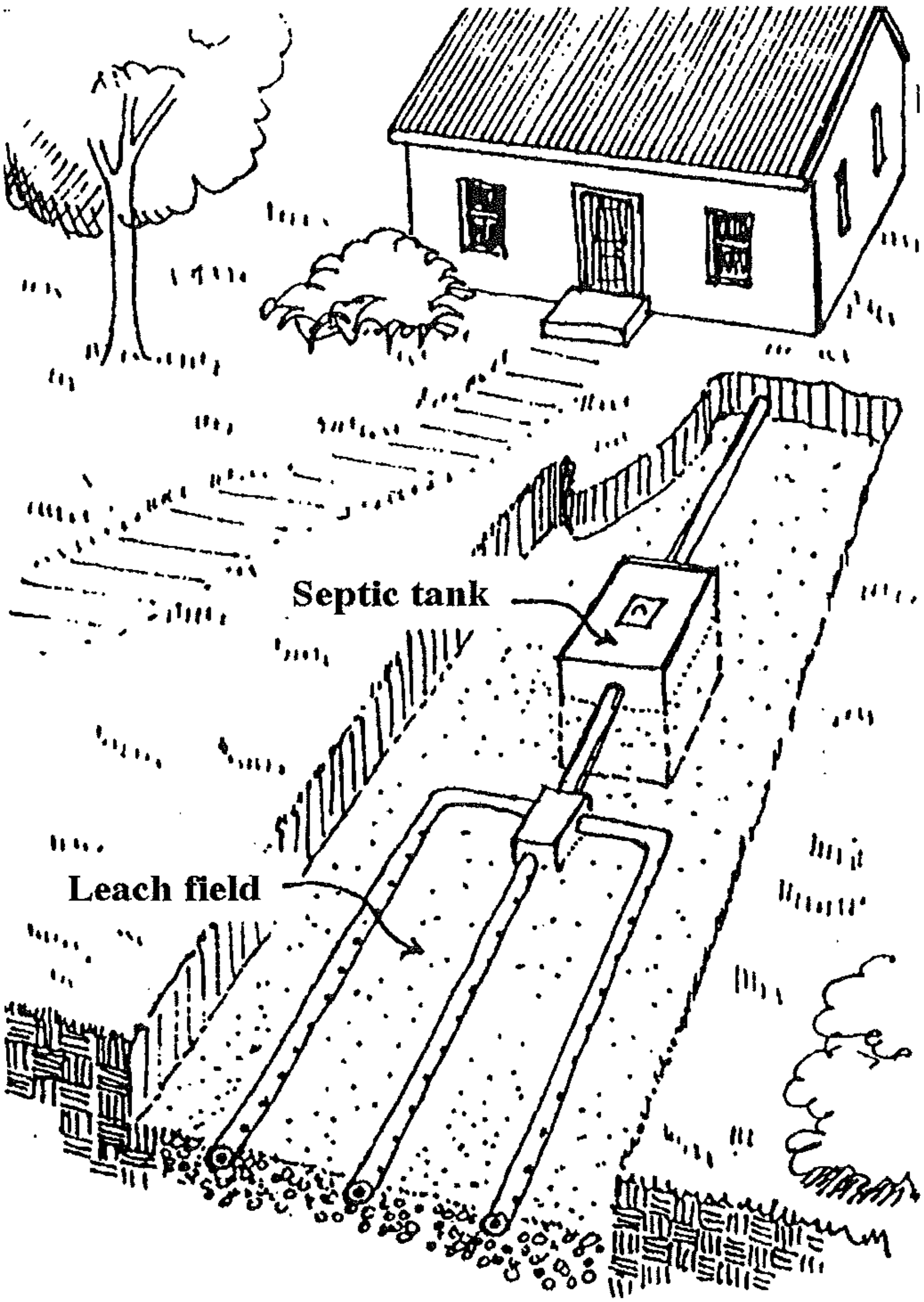

Figure 6. The layout of a typical septic system (Williams 1992).

ganisms 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 effluent threats to lakes include organic particulates, nutrient loading, and water contamination through the addition of viruses and bacteria (MDHS 1983). Organic particulates also

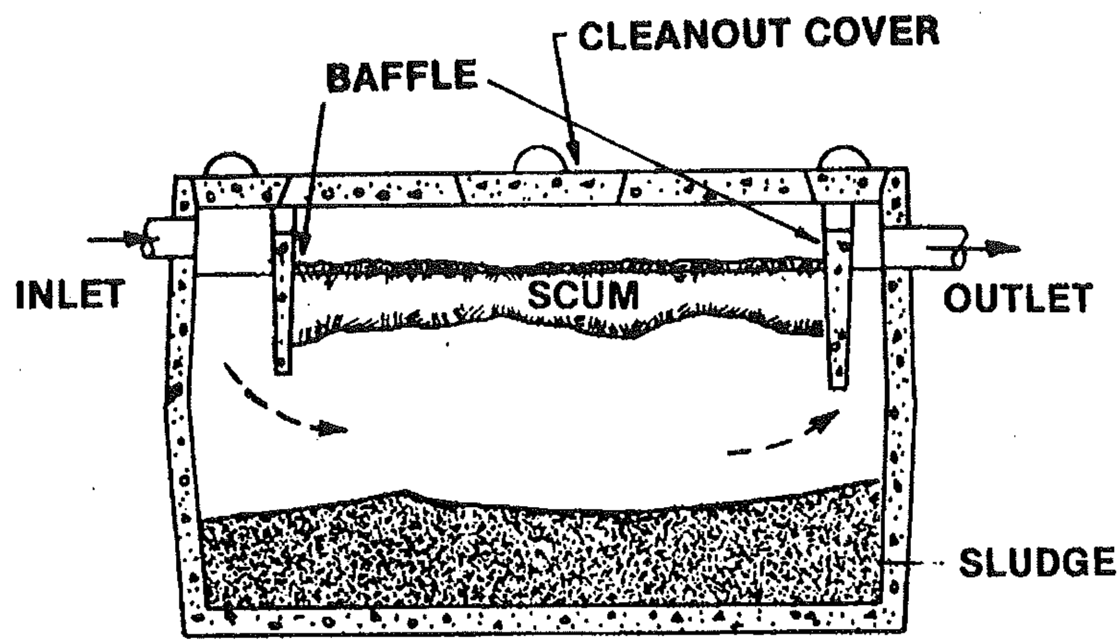

Figure 7. The cross-section of a typical treatment tank showing the movement of effluent through the tank as well as the separation of the scum and sludge (MDHS 1983).

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 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, containing black or gray water, 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 is 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%) that allows for gravitational pull is often 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 should not 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 (MLURC 1976). 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% 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 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 (KCSWCD 2000). 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: to 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 to 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 beginning construction 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 that includes maintenance concerns 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 et al. 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. Sand and gravel are typically used for roads in low traffic areas or seasonal use areas. Both types of roads need proper maintenance. 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. This crown should have a slope of 1/8 inch to 1/4 inch per ft of width for asphalt and 1/2 inch to 3/4 inch per ft of width for gravel roads (Michaud 1992). This slope allows the surface water to run off the road on either side as opposed to remaining on the road surface and 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 off 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 to areas where it can be absorbed. They are ideally u-shaped, deep enough to gather water, 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 riprapped or constructed of soil that will not be easily eroded by the water flowing through them.

Culverts are 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 (KCSWCD 2000). 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 to 4% (Michaud 1992). A proper crown above the culvert is necessary to avoid creating a low center point and damaging the culvert. The standard criteria for covering a culvert is to have 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 by infiltration before it reaches the lake (Michaud 1992). Efficient installation and spacing of diversions can also reduce the use of culverts.

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 may result in relatively high levels of erosion and decreased water quality (MDEP 1990). Plowing with the contour lines (across as opposed to up and down a slope), and strip cropping both serve to 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 if areas are over-fertilized. 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. This prohibition is legislated by the Nutrient Management Act. The town may provide subsidies as an incentive if the problem is large enough. These solutions do not address the problem of livestock that defecate close to bodies of water. One solution for this problem may be to put up fences to keep the animals away from the edge of the lake or pond.

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 may also have negative impacts on water quality. Alternative methods of pest control may be appropriate, including biological controls such as integrated pest management and intercropping, 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 address 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 ft^2 in the forest canopy, and if they exceed 500 ft^2, they have to be at least

100 ft apart. These regulations are intended to minimize erosion (MDEP 1990). In order for these laws to be effective they have to be enforced. This may be a difficult task for most towns since they do not have the budgets necessary to hire staff to regulate these areas. Illegal forestry practices may occur and negatively impact lake water quality.

Transitional Land

Before any form of development occurred in the Togus Pond 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 almost all 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 transitional 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 (old field). Intermediate and later successional stages involve the growth of larger, more mature tree species. The canopy of this forest is more developed, allowing less light to reach the forest floor. A developed canopy also slows down rainfall, reducing its erosion potential. This land use type, in which a forest is nearing maturity and contains over 50% tree cover, is referred to as transitional forest. Mature forest is defined as areas of closed canopy that predominantly contain climax species.

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 and buffers against heavy rainfall. 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. Agricultural land is a type of cleared land where the natural vegetation is removed and the land is used for cropland, pastureland, or as a hayfield. Large grassy areas such as lawns and parks are included with residential areas, not cleared land.

The MDEP (1990) has established specific guidelines for cleared land. There can be no cleared openings greater than 250 ft^2 in the forest canopy within 100 ft of a lake or river. Where there are cleared lands, some solutions to minimize erosion are construction of terraces and plowing parallel to the contour lines. Both guidelines decrease the flow of storm water down a slope, allowing the nutrients to settle out before they get to the lake and they reduce erosion by breaking up large areas of tilled soil.

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 bladder-wort. 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 (Washington State Department of Ecology 1998). 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. Wetland 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 illegal development (Nebel 1987). A decrease in wetlands will most likely have negative effects on the water quality of a lake due to increased runoff, erosion, and decreased natural buffering.

TOGUS POND CHARACTERISTICS

WATERSHED DESCRIPTION

The Togus Pond watershed is located in Kennebec County, Maine, and is contained entirely within the limits of the City of Augusta (Figure 8). The lake is classified by the Maine Information Display Analysis System (MIDAS) as MIDAS #9931. This system assigns unique four-digit codes to identify all lakes and ponds in Maine. Togus Pond is situated at 44.32° W, 69.66° N and an elevation of 181 ft (PEARL 2004c). This single basin lake covers a surface area of 687 acres and has a flushing rate of 0.72 flushes per year (see Water Budget). It has an average depth of 17 feet and a maximum depth of 51 feet (see GIS: Bathymetry). Togus Pond is dimictic, experiencing thermal stratification in the summer, with turnovers occurring each spring and fall. Algal blooms have been reported since the late 1920's (Sowles 1983), and the Maine Department of Environmental Protection currently describes Togus Pond as a "frequently blooming" lake that commonly experiences late summer and early fall reductions in water transparency (MDEP 2004a).

The Togus Pond watershed boundary used in this study was obtained from the Maine Office of

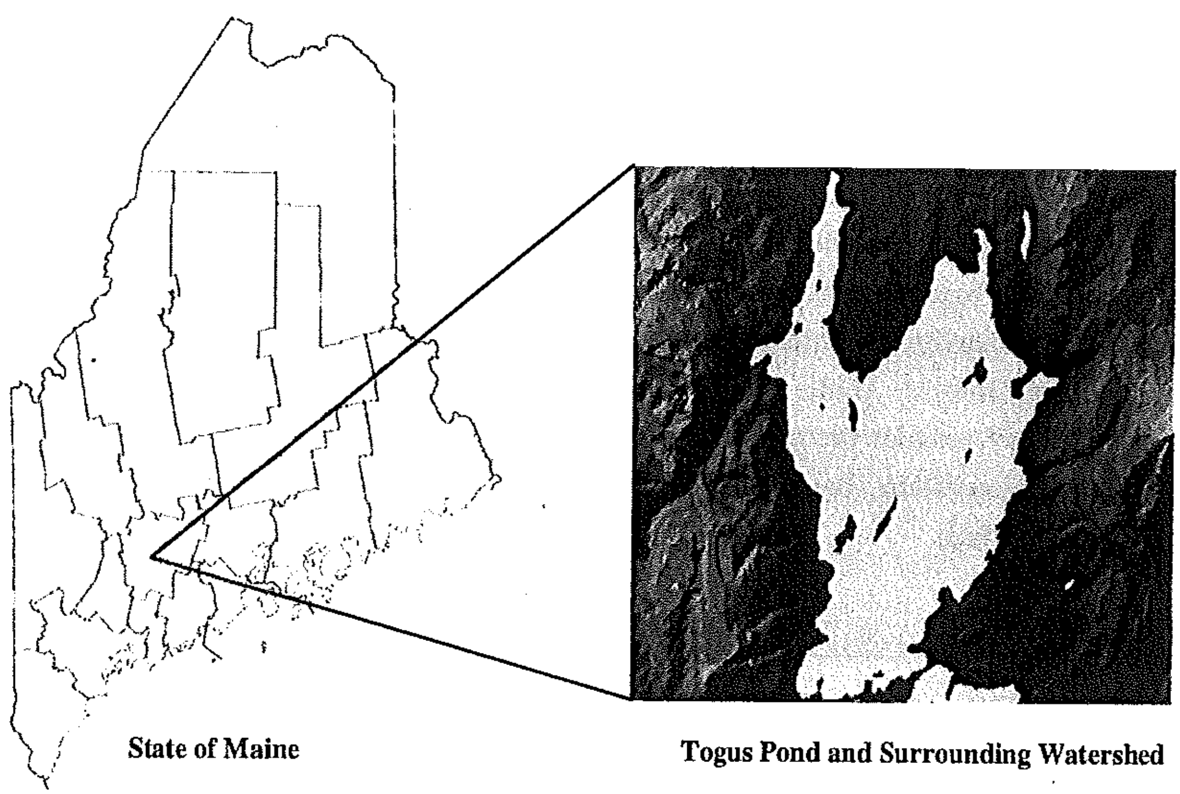

Figure 8. Togus Pond locator map. Shows the location of the Togus Pond watershed within Kennebec County in the State of Maine. The Togus Pond watershed was created from digital elevation maps from the Maine Office of GIS.

GIS, and includes the direct drainage area of Togus Pond and two small sub-watersheds that feed into Togus Pond (MEGIS 2004). The direct drainage area of the Togus Pond watershed, defined as the area around the lake into which water drains without first entering another lake or pond, covers an area of 3.41 square miles. With the inclusion of the two sub-watersheds, which comprise the northern and westernmost sections of the Togus Pond watershed, the total drainage area covers 4.76 square miles (PEARL 2004c). Togus Pond is a naturally formed, glacial-basin lake that has been enlarged throughout the past two centuries by several instances of damming (Norton pers. comm.). During the 1800's, the brook that currently flows into the northwestern cove of Togus Pond was dammed in sections as a part of logging operations in the area. Three separate dams were built during this time period, the first occurring near the present location of Rt. 3, and the later two occurring further south in the direction of the lake, creating and deepening the present cove as they were constructed. Evidence of this logging and damming cycle still exists, as stump fields and gravel paths are visible well below the water surface. Most recently, a dam built on Togus Stream in the early 1900's created Lower Togus Pond and raised the level of Togus Pond three to four feet, bringing the lake to its current size and depth (Figure 9; Sowles 1983). The water flow out of Togus Pond is currently constrained by a culvert under Rt. 105 that empties into Lower Togus Pond.

The majority of the water input to Togus Pond comes from small, mostly spring-fed tributaries that enter from the relatively steep northwestern and northeastern areas of the lakeshore. These include Hayden's Brook, which enters into Hayden's Cove, and three unnamed streams entering into Spring Cove, Barrow's Cove and the large, unnamed cove in the northwest corner of the lake. However, no tributaries of Togus Pond were observed to be actively flowing during the time of this study. There is also evidence for water input from springs within the lake, as coldwater fish are found to gather around these inputs during the warm months of summer (Norton pers. comm.). The waters of Togus Pond flow north to south, and Togus Stream, via Lower Togus Pond to the southeast of the lake, is the only outlet for Togus Pond. Togus Stream ultimately empties into the lower Kennebec River (Sowles 1983, PEARL 2004c; see Water Budget). Little Togus Pond, located directly south of Togus Pond, is a distinctly separate water body and does not input water to or receive water from Togus Pond. There are several small islands located within Togus Pond, most notably Fisherman's Island, White's Island, Coon Island, and Poor's Island.

GEOLOGICAL AND HYDROLOGICAL PERSPECTIVE

During the Pleistocene Epoch (25,000 to 20,000 years ago), Maine was covered completely by the Laurentide Ice Sheet, which extended from Eastern Canada through New England, reaching its southernmost point near Long Island, New York at the height of glaciation (Marvinney and Thompson 2000).

The ice sheet moved in a south-southeastern direction and spread beyond the present coast of Maine and onto the continental shelf. The motion of the ice shaped the landscape of Maine as sedi-

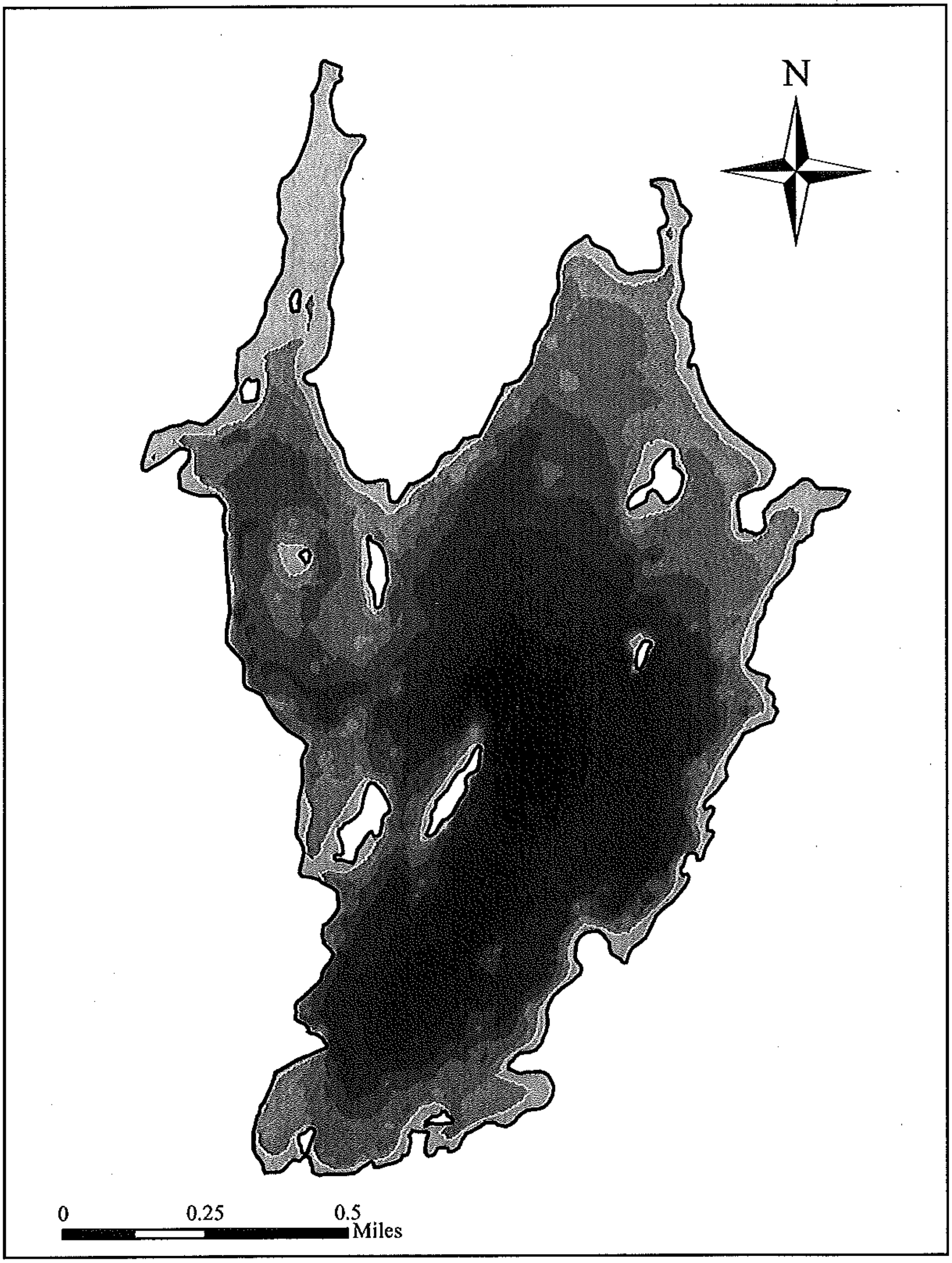

Figure 9. Blue indicates the hypothetical area of Togus Pond in the late 1800's, before damming of Togus Stream increased the water level by about 4 ft. Areas that were submerged after the dam was built are indicated in orange.

ments were lifted and deposited, previous waterways were destroyed, and the beginnings of hundreds of new lakes and ponds were left in their place (Marvinney and Thompson 2000).

About 21,000 years ago, the warming climate began to cause melting of the ice sheet, which nearly completely receded from Maine by 10,000 years ago (Marvinney and Thompson 2000). Melting of the glacier caused further deposition of sediments, leaving a substrate throughout Maine that consists of glaciomarine clay-silt over glacial till and bedrock. This substrate now characterizes the typical lake basin in the state, most of which have a southeasterly orientation due to the direction of glacial movement down the coast (Davis et al. 1978). These lakes are considered young by geologic terms, being formed less than 10,000 years ago, and are naturally nutrient poor because of their characteristic substrate. This combination of young age and naturally low nutrient levels would predict most Maine lakes to be oligotrophic, but in fact a large number are eutrophic due to the acceleration of natural evolution by human activity (Davis et al. 1978; see Togus Pond Characteristics: Biological Perspective: Trophic Status).

The geologic history of Maine is well reflected in the geology of Togus Pond, as the lake basin exhibits a southeasterly orientation and an expected stratification of underlying sediments. The bedrock of the Togus Pond area is composed primarily of Devonian biotite and biotite muscovite granite with some quartzite monzonite, all overlain by a mantle of marine clay (Sowles 1983). Sand and fine gravel karnes are found above the marine deposits (Leavitt and Perkins 1934). The dominant soil type in the watershed is a shallow Paxton-Charlton fine sandy loam with slopes between 3 and 15 % (USDA 1978).

HISTORICAL PERSPECTIVE

Regional Land Use Trends

Throughout modern history, agriculture has been the most significant source of land use change in Maine. In 1600, Maine was nearly entirely forested, with forest covering 92.1% of the total land area of the state (Irland 1998). By the late 1870's, roughly five million acres of this forest area had been lost, primarily because of conversion to agricultural uses. The area of forested land in Maine reached a historical low in 1872, at 53.2% of total land area. Since the turn of the 20th century, however, land use in the state has reflected the predominant trend that has occurred throughout New England, featuring a decline in agricultural use accompanied by increasing residential and reverting forest lands (Irland 1998). Since the 1950's, and primarily during the 1950's and 1960's, the area of cropland in Maine decreased by 713,000 acres, and pastureland decreased by 174,000 acres (Plantinga et al. 1999). A large portion of the lost forest lands have been regained due to land use changes in the past century, as forest cover has risen from about 70% of total land area in 1900 to almost 90% in 1995 (Irland 1998). The remainder of Maine's land area is currently divided between agriculture (3%), urban uses (2%), and other uses such as suburban housing, transportation uses, and wetlands (5%) (Plantinga et al.

1999).

The land use history of the Togus Pond watershed, and the Augusta area in general, parallel that experienced by the State of Maine. According to the City of Augusta (2004), European settlers from the short-lived Popham Colony began exploration of the lower Kennebec River area, as early as 1607. Representatives of the Plymouth Colony built a trading post, which came to be known as Cushnoc, on the east shore of the river in 1628, near what is now the City of Augusta. The post was abandoned in the 1670's, and was followed by years of conflict involving the French, English, and Native Americans. In 1754, Fort Western was constructed near the Cushnoc site by the Kennebec Proprietors, which served as a supply point for Fort Halifax further upstream, and efforts were initiated to settle the surrounding regions. The village at Fort Western was incorporated as the Town of Hallowell in 1771, and the legislature approved the separation of Augusta from Hallowell in 1797. In 1827, Augusta was designated as the capital of Maine. This period of colonialism and early development saw the establishment of urban areas in Augusta, accompanied by settlement of the surrounding regions and conversion of forest to farmlands (City of Augusta 2004).

Throughout the past two centuries, Kennebec County has experienced some of the most severe agricultural and urban development in Maine. In the 1880's, at the height of the agricultural period in Maine, Kennebec County was among the three most fully deforested counties in the state (along with York and Waldo counties), having only 40% of its land area covered in forest (Irland 1998). Between 1880 and 1995, Kennebec County showed a 150% increase in forested land area (the second highest increase in Maine behind only Waldo County). Despite this significant increase, Kennebec was still among the three least forested counties in the state in 1995 (now along with Androscoggin and Knox counties). While agriculture has decreased in the county, increasing development now accounts for a large amount of deforested land.

Augusta has traditionally been described as a usual Maine mix of central urban village surrounded by rural fringe, which is made up of forest, farmland, and seasonal lakefront cottages (City of Oakland 2004). However, recent development pressures along the I-95 corridor have brought about the conversion of "fringe" to individual, year-round house lots and road-front commercial enterprises. This trend has been demonstrated in the Togus Pond watershed, as the number of lakeshore dwellings has increased from 55 mostly seasonal cottages in the mid-1930's to 179 shoreline houses today, 124 of which are year-round homes (Sowles 1983; see Watershed Development: Residential Survey). Population growth has been fueled by the attractiveness of small town lake areas and by the strengthening of non-farm job markets in the Augusta area (City of Oakland 2004).

The Togus Pond watershed has seen a predictable progression of land use change characteristic of Maine lake communities. The land area became significantly deforested during the 1800's with the expansion of agriculture, but forest area has made substantial recoveries since the decline of agriculture in the mid 20th century. Development pressures are now a more significant source of land use change, as residential and commercial enterprises increase in the area.

Water Quality

The most prominent and visible water quality issues in Maine lakes come as a result of algal blooms. Often produced by increased phosphorus in lakes, blooms are commonly exhibited by undesirable symptoms such as green-colored and bad-tasting water, reduced transparency, unsightly scum, and foul odors (Smith and Witherill 1999). Repeated algal blooms can also result in fish kills and loss of the coldwater fishery. Water quality has become a relevant factor in the consideration of lakes by visitors and homeowners, and produces a significant influence on the economy and population of lake communities (see Watershed Development: Economic Impact of Blooms).

Long time residents of the Togus Pond area have reported that summer algal blooms commonly occurred in the lake as early as the late 1920's and early 1930's, and frequent blooming has continued throughout the past several decades (Sowles 1983). The water quality of Togus Pond has been investigated several times throughout this period, initially by Cooper (1942) in 1941 for fishery management purposes. Temperature and dissolved oxygen profiles, collected in August 1941, indicated an anoxic hypolimnion (less than 1 mg/L dissolved oxygen) that produced water quality unsuitable for trout and salmon (Cooper 1942). Further work done in 1971, as part of a hypolimnetic aeration-destratification demonstration, revealed similar temperature and dissolved oxygen conditions as those described in 1941 (Cortell Associates 1973). Another study conducted in 1976 also reported oxygen depletion in the hypolimnion (Cobbossee Watershed District 1977). The most comprehensive study to date, a MDEP diagnostic on cultural eutrophication in Togus Pond, was conducted by Sowles (1983) and covered the period from 1979 to 1981. This study indicated severe oxygen deficits in the summer hypolimnion for each of these three years, and confirmed the status of Togus Pond as a eutrophic lake in which regular algal blooms occur. MDEP is currently conducting a Total Maximum Daily Load (TMDL) study on Togus Pond, which investigates phosphorus loading in the lake and is scheduled for completion in 2005.

In response to the frequent algal blooms experienced by Togus Pond, various remediation techniques have been attempted since the late 1930's. Around 1937, annual springtime drag bag applications of copper sulfate, an algicide that increases water transparency by killing bloom-causing algae, were begun by residents of the Togus Pond area (Sowles 1983). The practice was continued until 1979 with varying success. Copper sulfate application is not a long lasting treatment for water quality because it simply kills off excess algae and does not address the causal problem of increased phosphorus loading in the lake (see Background: Lake Characteristics: Phosphorus and Nitrogen Cycles; see Lake Remediation Techniques). Currently, the Maine Department of Inland Fisheries and Wildlife only considers copper sulfate treatments in cases of severe algae blooms, due to its short-term success, cost, and adverse effects on fisheries (MDIFW 2003a). CEAT does not recommend copper sulfate treatments as an applicable remediation technique for Togus Pond (see Lake Remediation Techniques: Techniques Not Applicable for Togus Pond: Chemical Manipulation Techniques: Algicides).

A demonstration of hypolimnetic aeration-destratification was undertaken in Togus Pond by Jason

Cortell and Associates, of Waltham, Massachusetts, during the late summer of 1971, under contract by the Maine State Planning Office (Cortell Associates 1973). This process involves the summertime addition of air into the water column, in an attempt to prevent anoxia in the hypolimnion and reduce phosphorus release from the lake sediments. In lakes with an already established anoxic hypolimnion, aeration may also be used to induce turnover before the onset of late summer algal blooms and the resulting reduction in water transparency (see Lake Remediation Techniques). The 51-day hypolimnetic aeration, which began 6-Aug-71, was concluded by Cortell to produce destratification and was cited as the reason for the absence of an algal bloom in 1971. These findings were disputed by Sowles (1983), however, as the "induced" turnover coincided with the natural fall turnover in the lake, and the absence of an algal bloom in this year was credited to the unpredictability of phytoplankton community dynamics.

During the summers of 1977 and 1978, hypolimnetic aeration was repeated in Togus Pond by the Worromontogus Fish and Game Association (Sowles 1983). It was concluded, however, that aeration did not improve water quality. Hypolimnetic aeration is also not recommended by CEAT as an applicable remediation technique for Togus Pond (see Lake Remediation Techniques: Techniques Not Applicable for Togus Pond: Physical Treatments: Hypolimnetic Aeration).

Togus Pond has experienced documented algal blooms (transparency < 2.0 m) in four of the past five years, with the exception being 2002. One of the most severe recent algal blooms occurred in the summer of 1999 (MDEP 2004b). Togus Pond is included on MDEP's list of 38 Maine lakes that commonly bloom; 13 of these lakes are located in Kennebec County. The lake is also listed as one of the "most at risk" lakes in Maine in terms of potential development, and is considered a Non-Point Source (NPS) Priority Watershed by the Maine Land & Water Resources Council for its susceptibility to NPS pollution (MDEP 2004c).

To date, there have been no long-term successes in the remediation treatments applied to Togus Pond. Sedimentation, phosphorus loading, and internal phosphorus recycling currently contribute to water quality problems in the lake, and have been a cause of the low success rate of past remediation attempts. Improvements in water quality could have far reaching benefits for many aspects of Togus Pond, such as higher property values, greater success of stocked and native fisheries, and increased late summer use of the lake.

BIOLOGICAL PERSPECTIVE

Introduction

The Togus Pond watershed encompasses a broad range of habitats that allow for significant biodiversity, including lake, wetland, ephemeral tributary, riparian, and forested habitats. The biological diversity found in this watershed is important not only for people who enjoy its aesthetic value, but also to the health of the ecosystem.

Human activities adversely affect the biology of Togus Pond. Since Togus Pond is a eutrophic lake with a heavily developed shoreline, it is likely that there is a considerable amount of non-point source pollution from high-nutrient runoff such as fertilizers. High inputs of phosphorus and nitrates may cause an overgrowth of algae and aquatic macrophytes, leading to depletion of dissolved oxygen through the process of plant respiration near surface and in shallow areas and microbial decomposition on basin substrate (see Background: Lake Characteristics: Phosphorus and Nitrogen Cycles).

Biodiversity is a key measurement of environmental quality in lake ecosystems because it provides a baseline by which the influence of human activity can be measured (Sayer et al. 1999). Human causes of reduced biodiversity include over-hunting, introduction of non-native species, pollution, and reduction of habitat through fragmentation, degradation, and destruction (Ellsworth 2002). To prevent further loss of biodiversity in the Togus Pond watershed, the influences of human activity must be limited and controlled.

Native Aquatic Flora/Fauna

Aquatic plants are vital to lake ecosystems. They provide food and habitat for aquatic organisms, oxygenate the water column through photosynthesis, and reduce shoreline erosion by anchoring shoreline sediment (see Background: Lake Characteristics: Freshwater Wetlands). In addition, aquatic plants tie up nutrients (such as phosphorus) required for algal growth, reducing the occurrence of blooms in the lake. Excessive growth of macrophytes (large plants) can indicate pollution, as they often occur where runoff carries sediment into the lake (Firmage pers. comm.). Plants can absorb nutrients in the short-run, but excess growth can increase nutrient levels as plants die and decompose.

Togus Pond supports a diverse community of submergent, floating, and emergent macrophytes. These plants inhabit the shallow coves of the lake where they are protected from winds and exposed to sunlight. Common macrophytes found in Togus Pond include Pickerel Weed (*Ponterderia cordata*), Arrowhead (*Sagittaria spp.*), Watershield (*Brasnia schreberi*), Yellow Pond Lily (*Nuphar variegatum*), Scented Pond Lily (*Nymphaea odorata*), Coontail (*Ceratophyllum spp.*), Pipewort (*Eriocaulon aquaticum*), and Elodea (*Elodea canadensis*) (MDIFW 2004a).

Invasive Plants

Organisms that move from their native habitat and establish a population in a new environment are referred to as non-native species. A new environment can be the next county, state, or water body. Non-native species are considered invasive if they possess ecological characteristics that make them good competitors in new habitats. These plants can seriously degrade their new environment, outcompeting native species, reducing economic values, or harming human health (MDEP 2004d). Invasive species are primarily spread from one body of water to another through human activities, especially boating. Plant fragments may be carried on boats, motors, trailers, and fishing gear from an infested water body and can survive out of the water for days. There is no known method for successfully eradicating invasive aquatic plants once they have become established in Maine lakes (MDIFW 2004a).

There are many invasive species that pose a serious threat to Maine water bodies (Table 3). Currently, two of these plants are in Maine: Variable-leaf Milfoil and Hydrilla (MDEP 2003d). While few lakes in Maine suffer from the presence of these aggressive species, several lakes near Togus Pond have had invasions in recent years. Variable-leaf Milfoil infestations have been documented in Messalonskee Lake, located in Oakland, and in Cobbossee Stream, which flows into Horseshoe Pond in West Gardiner (MDEP 2003e). Hydrilla, an even more aggressive species, was found during the fall of 2002 in Pickerel Pond in Limerick, Maine (Varney 2003). Since Togus Pond does not have a public boat ramp, it is less susceptible to the introduction of invasive species by recreational boaters than are other lakes that do have public boat ramps. This, however, does not mean that protective measures can be overlooked. Currently, Togus Pond does not contain any invasive species, but residents should be educated about precautionary measures that could prevent the spreading of invasive species to their lake.

Table 3. Invasive Aquatic plant species that are a threat to Maine's lakes, ponds, rivers, and streams (MDIFW 2004a).

Common Name	Species Name
Eurasian Water Milfoil	*Myriophyllum spicatum*
Variable-leaf Water Milfoil	*Myriophyllum heterophyllum*
Parrot Feather	*Myriophyllum aquaticum*
Water Chestnut	*Trapa natans*
Hydrilla	*Hydrilla verticillata*
Fanwort	*Cabomba caroliniana*
Curly-Leaf Pondweed	*Potamogeton crispus*
European Naiad	*Najas minor*
Brazilian Elodea	*Egeria densa*
Frogbit	*Hydrocharis morsus-ranae*
Yellow Floating Heart	*Nymphoides peltata*

Fish Species

Togus Pond is considered a warm water fishery, containing 12 naturally reproducing species (Table 4). Most of these fish species inhabit the open water or shoreline of the lake, while the brown bullhead is a bottom dweller. Bass, pickerel, and pumpkinseeds prefer shoreline habitat as adults. Brook trout and sunfish spend their adulthood in open water. American eels are migratory, but are unable to bypass the Lower Togus dam. Smallmouth bass prefer shallow, rocky areas found along the majority of Togus Pond shoreline. Largemouth bass inhabit, but are not limited to, shallow, weedy areas. Sunfish, perch, pickerel, bass, and brown trout are piscivorous (fish-eating) and bullheads are omnivorous. While coldwater fish generally spawn in the fall between October and November, warm water fish species spawn in the spring from May to late July, either along the lakeshore or in the tributaries of Togus Pond (Woodward pers. comm.).

The Togus Pond fish population is dominated by white perch and large mouth bass. It has been speculated that the current population of large mouth bass is too high, causing these fish to stunt in growth. White perch have also been identified in large numbers from past fish netting by MDIFW (2004b).

Table 4. Fish present in Togus Pond based on data from the Maine Department of Fisheries and Wildlife Lake inventory (MDIFW 2004b).

Fishes Present	Scientific Name
American Eel	*Anguilla rostrata*
Banded Killifish	*Fundus diaphanus*
Brown Bullhead	*Ictalurus nebulosus*
Brook Trout[ab]	*Salvelinus fontinalis*
Brown Trout[ab]	*Salmo trutta*
Chain Pickerel[a]	*Esos niger*
Golden Shiner	*Notemigonus crysoleucas*
Largemouth Bass[a]	*Micropterus salmoides*
Pumpkinseed Sunfish	*Lepomis gibbosus*
Rainbow Smelt	*Osmerus mordax*
Smallmouth Bass[a]	*Micropterus dolomieui*
White Perch	*Morone americana*
White Sucker	*Catostomus commersoni*
Yellow Perch[a]	*Perca flavescens*

[a]Anadromous: living in oceans and spawning in lakes and rivers
[b]Principal fishery

Fish Stocking

The Maine Department of Inland Fisheries and Wildlife is responsible for maintaining wild, self-sustaining populations of native fish, while developing fisheries to provide diverse and rewarding angling opportunities (Van-Riper pers. comm.). This is accomplished though the stocking of more than 42 lakes and rivers in Kennebec county alone. Because of the department's stocking efforts, anglers are able to fish year-round at a variety of locations. In 2002, Maine voters approved a seven million dollar bond package to improve the state's hatcheries, allowing MDIFW to raise and stock more fish in waters throughout the state. Last year a total of 1,408,879 fish were stocked in Maine inland waters made possible by the funding from this bond package and this year, more fish are likely to be stocked (MDIFW 2003b).

In addition to the 12 naturally reproducing fish species, two coldwater fish are stocked for recreational angling: the brown trout (*Salmo trutta*) and the brook trout (*Salvelinus fontinalis*). Since Togus Pond is an enclosed water body with no significant tributaries, coldwater fish are unable to successfully reproduce and must be restocked every year. The number of fish stocked each year is determined by the Maine Department of Inland Fisheries and Wildlife (MDIFW). Fish counts are conducted to generate a snapshot of the current fish populations. Nets are placed in multiple locations on the lake and the catch is counted the following day. These counts are good indicators of whether a fish population is being over or under-fished. Fish counts are used in conjunction with angler surveys (also referred to as creel surveys), which are a fishery management technique used to determine game fish harvest in recreational fisheries. During these surveys, creel survey technicians ask anglers about their fishing trip. Questions focus on determining the angler's catch of each species and the fishing time required to catch the fish. When statistically combined with periodic counts of angler numbers, this information can be used to estimate total angler participation, catch rate, and total sport harvest of important species (ADFG 2004).

Togus Pond has been stocked with brown trout since the 1920's. However, regularly documented fish stocking reports were not produced until 1978 (MDIFW 2004b). Over the past 25 years, the primary stocked fish has been the brown trout (Figure 10). The brown trout, introduced from Europe in the 1880's, is a hearty fish species that competes well in Maine lakes (Woodward pers. comm.). In 1999, 25 brook trout were stocked in Togus Pond at the request of anglers. Brook trout, a native fish to Maine, tends to be easier to catch than brown trout but has a lower survivorship in landlocked water bodies because they are easily out-competed for space and food by other fish species (Van-Riper pers. comm.).

In comparison to the numbers of fish stocked in nearby lakes, Togus Pond received a greater ratio of fish per acre than both Webber Pond and Threemile Pond in 2004 (Table 5). This year, MDIFW stocked 700 brook trout and 250 brown trout in Togus Pond as a result of the angling pressure from the previous year. Webber Pond received very few stocked fish this year from MDIFW. This was a result of the high success rate of the 1,200 brook trout stocked the previous year. Overstocking can have serious effects on all fish in the lake; heavy depletion of food resources results in the crashing of fish populations, requiring a long period to recover.

Fishing pressure during the winter months is about equal to open water fishing during the rest of the year (Van-Riper pers. comm.). Access to the lake in the winter is facilitated though multiple access points including snowmobile trails and Route 105. Although there is no public boat ramp, fishing during the summer months is facilitated by shoreline residents (providing access for friends and family). Access to Togus Pond is also available at the Worromontogus Lake Association boat landing and from shore along Route 105.

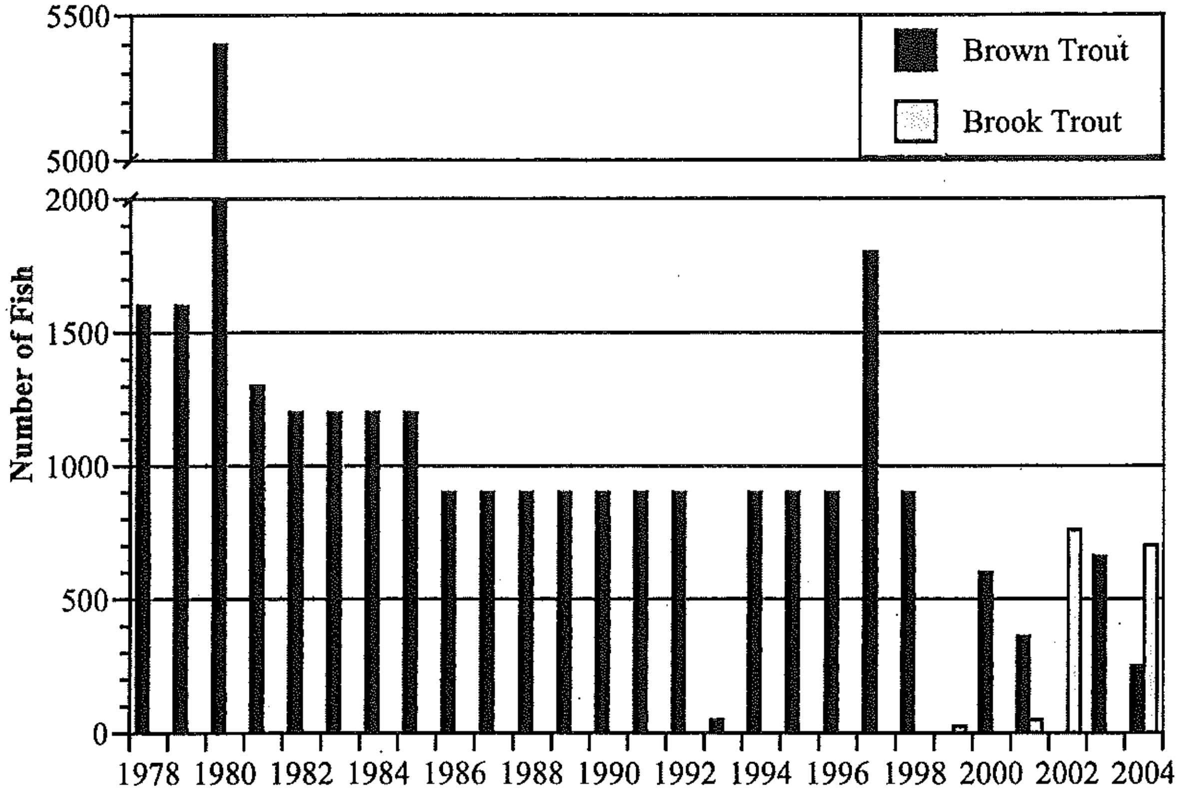

Figure 10. Species of fish stocked in Togus Pond between the years 1978 and 2004 (MDIFW 2004b).

Table 5. Number of Trout stocked per km^2 surface area in Togus Pond and other local lakes in 2004 (MEDIFW 2004b).

Body of Water	No. Trout Stocked	Lake Surface Area (km^2)	Trout Stocked/km^2
Togus Pond	950	2.67	335.8
Threemile Pond	600	5.72	104.9
Webber Pond	100	9.12	11.0
China Lake	5400	15.56	347.4

Loons

The common loon (*Gavia immer*) is found statewide in Maine with a population estimate of 4,300 adults (Maine Audubon 2001). Their extensive range, at one point, extended as far south as Pennsylvania, Connecticut, and Rhode Island, but competition with humans for habitat has narrowed their southern limits to Maine, New Hampshire, and some parts of Massachusetts and Vermont. Loons require shoreline habitat for their nests and typically defend a territory of 20 to 200 acres of water surface. Water clarity is important to the survival of loons because they rely on their eyesight to capture small fish.

There are many human influences that affect loons. On lakes where dams cause fluctuation of water levels, loon nests can be either flooded or stranded above the water's edge, making them more vulnerable to predators. Wave disturbance from human traffic is common on most lakes, but is preventable around nesting sites by placing buoys or other markers that warn the public. Loons may become entangled in fishing lines and small lead sinkers can poison loons, if ingested. Mercury accumulation in Maine lakes has also become a concern for loon populations because early research indicates that mercury is having an impact on reproductive success; loons with high levels of mercury spend less time incubating their eggs and feeding their chicks, and subsequently have lower reproductive success (Maine Audubon 2001).

The loon population of Togus Pond has remained steady over the past five years (PEARL 2004c). With the shoreline of the lake already extensively developed, residents should take extreme care near loon nesting sites to ensure this habitat is preserved. There are many ways to get involved to help protect loon populations. For more information contact the Maine Audubon or visit their website (http://www.maineaudubon.org).

Trophic Status

In a lake ecosystem, the trophic status indicates the efficiency of nutrient use (Chapman 1992). The trophic status specifically measures the total biomass production at the primary producer level, which is comprised of aquatic plants and algae. Lakes of a low trophic status have an abundance of consumer species, including zooplankton and fish, that are capable of minimizing the biomass of primary producers. When dissolved nutrient availability increases, phytoplankton and macrophyte levels increase to a level that can no longer be effectively managed by the consumer population. This surplus of nutrients in the lake results in the buildup of dead algae and aquatic plant biomass. Consumers cannot absorb the nutrients, especially phosphorus, in decomposing plants, and these nutrients are instead recycled back into the lake ecosystem for primary producers to reuse (Chapman 1992).

Phytoplankton biomass resulting from high nutrient availability can alter species composition, physical qualities, and chemical characteristics in a lake (Chapman 1992). Fish populations change as lakes become more eutrophic and herbivores such as minnows become more dominant. Decomposing bacteria exhaust oxygen levels in the deeper sections of the lake, resulting in anoxia (Chapman 1992). Anoxia may result in mass deaths of coldwater fish species that rely on cold, oxygenated water. Making matters worse, dissolved oxygen levels below one ppm can release phosphorus trapped in bottom sediments, feeding the algal bloom (see Background: Lake Characteristics: Phosphorus and Nitrogen Cycles).

There are four trophic status characterizations for Maine lakes: oligotrophic, mesotrophic, eutrophic, and dystrophic (see Background: Lake Characteristics: Trophic Status of Lakes). Trophic status changes in lakes and ponds as they acquire sediments over time through a process called eutrophication. Secchi disk transparency, chlorophyll-*a* (Chl-*a*), and total phosphorus, are often used to define the degree of eutrophication, or trophic status, of a lake. The concept of trophic status is based on the changes in nutrient levels (measured by total phosphorus) that cause changes in algal biomass (measured by chlorophyll-*a*), which in turn cause changes in lake clarity (measured by Secchi disk transparency) (EPA 2003). Biologists and volunteers can calculate the trophic status of a lake by using transparency, total phosphorus, or chlorophyll-*a* readings taken over a period of at least five months (MDEP 1986).

A trophic state index is a convenient way to quantify the relationship among transparency, phosphorus, and chlorophyll-*a*. One popular index was developed by Dr. Robert Carlson of Kent State University (EPA 2003). His index uses a log transformation of Secchi disk values as a measure of algal biomass. An oligotrophic lake is characterized by above average transparency (> 8 m Secchi disk transparency), deficient phosphorus levels (< 6 ppb total phosphorus), and low productivity (< 1.00 ppb Chl-*a*). A mesotrophic lake has average transparency (2 to 4 m SDT), moderate phosphorus levels (12 to 24 ppb TP), and moderate productivity (2.6 to 7.3 ppb Chl-*a*). A eutrophic lake has below average transparency (< 2 m SDT), high phosphorus levels (> 24 ppb TP), and high productivity (> 7.3 ppb Chl-*a*). The hypolimnia of shallower lakes may become anoxic at Secchi disk readings below 4 meters (Carlson and Simpson 1996). In the most severe cases, a lake is considered dystrophic when the internal generation of organic matter is extremely high, water use becomes severely impaired, and anoxia occurs often in the hypolimnion during summer stratification (Chapman 1992).

The Maine Department of Environmental Protection classifies a lake as threatened by assessing the vulnerability of lake water quality to future impacts from changing land use. A lake that is classified as impaired already shows signs of water quality degradation, including increased algae growth and blooms resulting from human activity (MDEP 1996). Lakes high in nutrients are eutrophic by definition and continued degradation increases the chance that eutrophic lakes will become unsuitable for both aquatic species and human recreation (see Background: Lake Characteristics: Trophic Status of Lakes). In general, eutrophic lakes have large populations of a few dominant phytoplankton species, high oxygenation at the surface and low oxygenation at the bottom, many fish species, and high levels of suspended solids (Chapman 1992).

Togus Pond has had a long history of algal blooms and it continued to display its eutrophic status this year as it maintained a summer algal bloom into October. The current trophic status of Togus Pond is showing strong signs of water quality impairment as blooms are becoming longer-lasting and more severe. This status is not ideal for the native wildlife. As previously mentioned, birds such as loons depend on the clarity of the water to capture fish, and fish depend on sufficient oxygen levels to survive. It is evident that further impairment of water quality will negatively affect the native wildlife.

STUDY OBJECTIVES

WATER QUALITY ASSESSMENT

The primary purpose of this study is to determine the ecological health of Togus Pond: its trophic state, capacity to support wildlife, ability to support the current level of development or future growth in development, and its suitability for safe recreational use by nearby residents and visitors. Pollution of the lake by chemicals or sediments lowers water quality, affecting all of these factors. The Togus Pond watershed contains few if any point sources of pollution (such as effluent pipes discharging directly into the water); the vast majority of water pollution in the area is from non-point sources like lawns and roads.

The best indicator of the pollution load from non-point sources, as well as the best indicator of the ecological condition of the lake, is its general water quality. In this study, CEAT analyzed multiple physical, chemical, and biological water quality parameters. Testing began in the early summer of 2004 and continued into the early fall; in the fall of 2004 testing was continued at an expanded number of sites. Our findings were compared to water quality analyses performed by the MDEP during the summer of 2004 and in previous years to inform us of the effect of human activity on the trophic status of Togus Pond.

LAND USE ASSESSMENT

Land use patterns in a watershed have a significant impact on the health of an associated water body. Different land uses produce different types and amounts of both man-made and natural pollutants. Forested land, for example, is highly desirable in the vicinity of a water body because it traps sediments that would otherwise contribute to nutrient loading. In contrast, a commercial property located near a water body could generate many pollutants and also constitutes a large area of impervious surface, potentially inducing high levels of surface runoff and sedimentation. Sediments carry nutrients (most importantly phosphorus) that accelerate lake eutrophication.

Using aerial photography and ArcGIS™ 9.0 software, CEAT identified and quantified the current patterns of land use in the Togus Pond watershed. A road survey was conducted identify specific locations in the roads where improvements could ameliorate runoff problems. CEAT used a house count survey to estimate the area of highly developed land. A shoreline buffer survey of the watershed was also conducted to identify areas along the shore where landscaping changes could protect the lake from sedimentation. This information was combined with soil maps and slope maps obtained from the Maine Office of GIS to produce an erosion potential model and a septic suitability model (see GIS: Erosion Potential Model and Septic Suitability Model), as well as a phosphorus budget (see Phosphorus Budget) (MEGIS 2004). These models help to project the impact of future development in various parts of the watershed.

FUTURE TRENDS

One purpose of monitoring water quality is to allow informed planning for future development and protection of the lake. CEAT developed a Phosphorus Loading Model that was used to predict the effects of further development on nutrient loading in Togus Pond (see Phosphorus Budget). The comparison of land use patterns in 1954 and 2002 aerial photographs and the analysis of demographic statistics for the area give a general sense of the possible future of land use in the watershed, allowing us to predict its impact on the lake.

REMEDIATION TECHNIQUES

Having identified the most important issues of lake quality and land use, the next step is to learn how to improve them. CEAT presents a variety of commonly used techniques in this report for improving lakes with poor water quality. While many of these may be inappropriate for use in Togus Pond for various ecological and economic reasons (see Lake Remediation Techniques), there are several approaches which may be useful to residents of the Togus Pond watershed interested in improving the quality of their lake. These approaches include both in-lake treatments and improvements in watershed management.

ANALYTICAL PROCEDURES AND RESULTS

WATER QUALITY STUDY SITES

A total of nine study sites were chosen for water quality testing on Togus Pond (Figure 11). During the summer months of June to August 2004, sampling was performed by the Colby Environmental Assessment Team (CEAT) at the characterization sites and at Sites 4, 5, and 9. Sampling was also performed on 20-Sep-04 at all sites, with the exception of some hardness and coliform tests conducted later. Multiple physical tests (dissolved oxygen, temperature, transparency, turbidity, color, and conductivity) were performed at various sites on the lake. Many chemical tests (pH, hardness, alkalinity, nitrates, ammonium, and total phosphorus) were also performed. The two biological tests performed were for fecal coliform and chlorophyll-*a*. All of these parameters were measured to obtain an accurate view of the water quality in Togus Pond and to identify potential problem areas.

Sites 1 (the site used by MDEP to perform Togus Pond water quality tests), Site 2, and Site 3 are characterization sites, at which almost all tests were performed in order to obtain a complete understanding of water quality at a few representative points on the lake. Water profiles were performed at the characterization sites to obtain an accurate view of water quality, dissolved oxygen concentrations, and temperature at all depths. Sites 4-9 (culvert) are spot sites, where a limited number of tests were performed. Spot sites were chosen to study potential differences in water quality and to investigate potential problem areas that were close to roads or near clusters of houses. No tributaries were observed running into Togus Pond during our testing period, so no tests were performed at tributary sites.

The study site map (Figure 11) was created by taking GPS points at each of the sampling sites and then adding those coordinates onto the map using GIS (see GIS: Introduction). The most common coordinate system for taking GPS points, UTM (Universal Transverse Mercator), was used to plot our sample site locations. GPS points were recorded as Northing (the number of meters North of the equator) and Easting (the number of meters East of the Prime Meridian) coordinates for each site. This map shows roads that are near the lake as well as showing gradations indicating the relative depth of the lake at the sample sites.

CHARACTERIZATION SITES

Site 1: Northing: 4908075 Easting: 0447481 Depth: 15.5 m

Site 1, which is also referred to as the deep hole, was chosen because it is the deepest part of the lake and previous tests have been performed by MDEP at that location.

Site 2: Northing: 4908703 Easting: 0447734 Depth: 5.5 m

Site 2 was chosen because of its depth, which was suitable for taking profiles, and because of its location north of Site 1, which is representative of the northern part of the lake.

Site 3: Northing: 4907383 Easting: 0447531 Depth: 7.5 m

Site 3 was chosen because of its depth, which was suitable for taking profiles, and because of its location south of Site 1, which is representative of the southern part of the lake.

SPOT SITES

Site 4: Northing: 4909396 Easting: 0447942 Depth: 1.3 m

Site 4 was chosen to test water quality at a shallow site in the northern part of the lake and to test the water quality coming from the northwest basin.

Site 5: Northing: 4909229 Easting: 0446924 Depth: 1.6 m

Site 5 was chosen to test water quality at a shallow location in the northwestern part of the lake.

Site 6: Northing: 4908637 Easting: 0446822 Depth: 5.1 m

Site 6 was chosen to compare water quality test from Site 5 and because it was deep enough to perform a profile of the lake.

Site 7: Northing: 4907622 Easting: 0446934 Depth: 1.7 m

Site 7 was chosen to test for septic impact on the lake due to the abundance of houses near the water and to test the water quality on the west side of the lake.

Site 8: Northing: 4909066 Easting: 0447819 Depth: <1 m

Site 8 was chosen to test the water quality at the most southwestern location of the lake.

Site 9: Northing: 4906939 Easting: 0447570 Depth: <1 m

Site 9 was chosen because there is a culvert nearby, which is the only outlet from Togus Pond, and it is important to know the water quality of the water as it leaves the lake.

TRIBUTARIES

All identified tributaries were explored on foot, but no significant water flow was observed during our data collection in the summer and fall. No tributary sampling was conducted because of the lack of water flowing into the lake from tributaries.

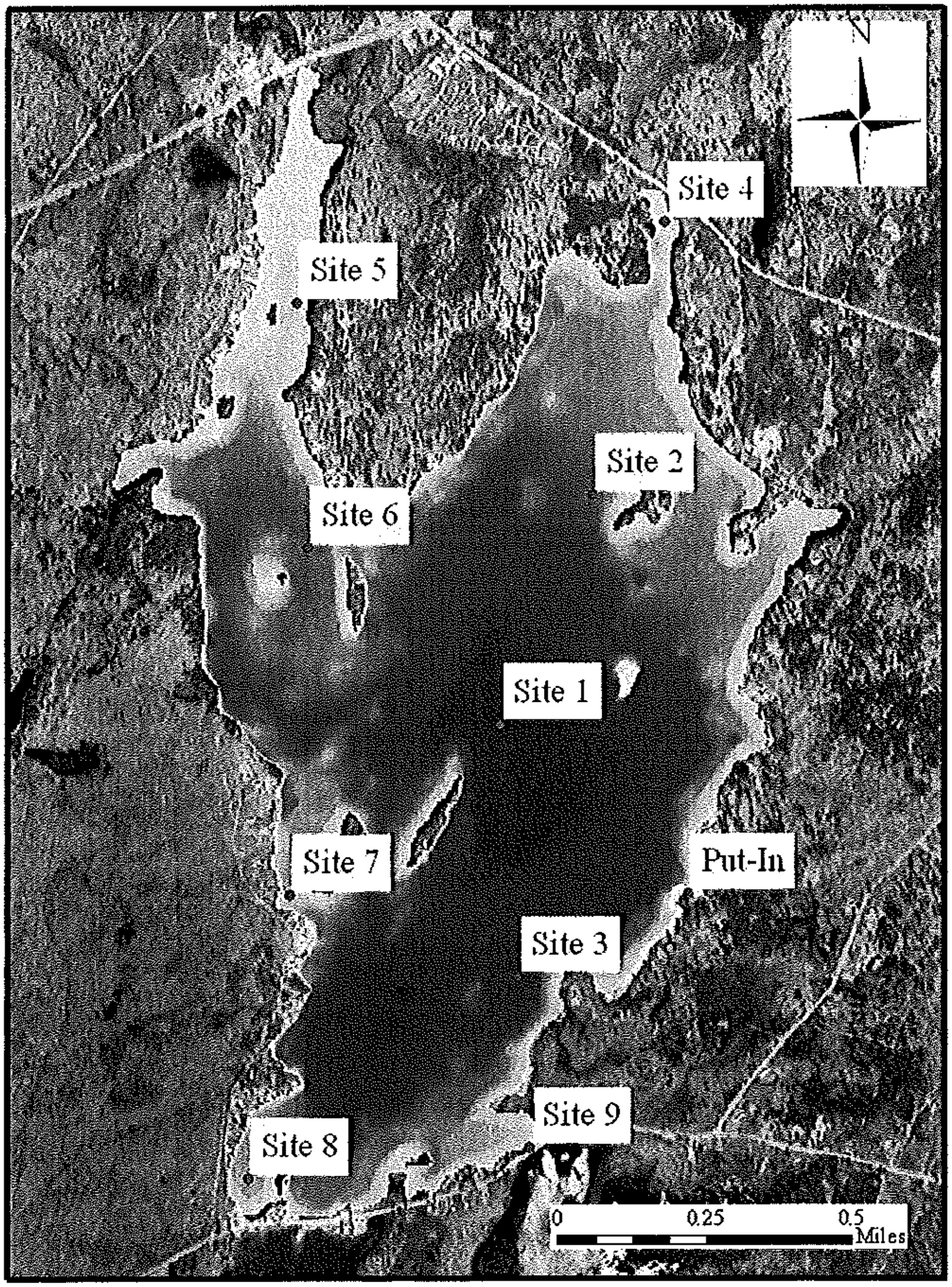

Figure 11. Sites for water samples taken at Togus Pond during the summer and fall by CEAT. Sites 1-3 are characterization sites, Sites 4-9 are spot sites. For an explanation of these sites see: Water Quality Study Sites.

WATER QUALITY

PHYSICAL MEASUREMENTS

Dissolved Oxygen and Temperature

Introduction

Dissolved oxygen (DO) is a measure of the concentration of oxygen present in water (PEARL 2004b). All living organisms depend on oxygen for their survival; too little oxygen can reduce the diversity of aquatic life in a water body. Water that has less than one ppm of oxygen is called anoxic, while water with less than five ppm oxygen is life-threatening to most coldwater fish (PEARL 2004b). Anoxic waters create a chemical change in the sediments of the water body, leading to a phosphorus release that can be detrimental to the lake by causing algal blooms and harm to the fish population (Henderson-Sellers 1987; see Background).

Oxygen is dissolved in water when there is diffusion of oxygen from the atmosphere to the water body. Dissolved oxygen concentration varies with salinity, temperature, turbulence, and photosynthetic activity of algae and plants present in the water body (Chapman 1996). Decomposition of organic matter, microbial activity, and biological respiration lead to decreased oxygen levels within the lake, particularly at depth and in the sediments (Chapman 1996). The release of phosphorus from the sediments, due to anoxic conditions, leads to an increase in algal blooms and the rate of eutrophication of the lake. As temperature and salinity increase, DO decreases due to the inverse relationship between temperature and DO and between salinity and DO (Stednick 1991).

Temperature is a measure of the average energy of the molecular motion in a body or substance at a certain point (Horton 2001). Increased temperature decreases the solubility of gases in water, such as oxygen (Chapman 1992). The metabolic rate of aquatic organisms is affected by water temperature; in warm waters, respiration rates increase, leading to increased oxygen consumption and increased decomposition of organic matter. Warmer temperatures also lead to increased growth rates of bacteria and phytoplankton, which increase water turbidity and the probability of algal blooms (Chapman 1992).

Togus Pond is a dimictic lake, which means its water column is not stratified for a period of time twice per year. During spring and fall turnover, the dissolved oxygen in the lake is redistributed and deep anoxic water moves to the surface and becomes more saturated with oxygen. Turnover prevents deep water, which tends to become anoxic, from continually being anoxic and causing the release of phosphorus from the sediments into the lake. Turnover also prevents the loss of fish and other aquatic animals by recharging the DO levels at depth in the lake.

Methods

On 20-Sep-04, CEAT measured dissolved oxygen and temperature at Sites 1, 2, 3, 5, 6, 7, and 8. DO was also measured throughout the summer months at Sites 1, 2, 3, 4, 5, and 9. DO values were measured with a YSI 650 MSD Sonde or a YSI 550 A DO meter. Measurements were taken at the surface at all sites, and at most characterization sites measurements were taken at one meter intervals from the surface to within one meter of the bottom of the lake. DO is measured in parts per million (ppm) and temperature was measured in degrees Celsius (°C). Please refer to the water quality assurance plan (see Appendix B) for details regarding sampling and testing procedures. Our historical data for dissolved oxygen and temperature, along with all other past water quality data collected before 2004, came from the Maine Department of Environmental Protection (PEARL 2004c).

Results and Discussion

The dissolved oxygen profile at Site 1 during the summer months ranged from 10.48 ppm at the surface to 0.1 ppm at the bottom (Figure 12). DO levels show that the water column was stratified during the summer months of July and August, while the stratification was not as strong in the months of June and September due to the effects of spring and fall turnover. During June and September the DO levels did not drop below 1 ppm (the concentration at which the water is considered anoxic) until a depth of about 12 m, whereas July and August show a drop in DO below one ppm at a depth of eight meters and below. In the early and late summer the lake is not very stratified, which leads to higher DO levels at depth and a smaller volume of anoxic water. The anoxic areas of the lake, due to the DO dropping below one ppm at eight meters, represents 12.38% of the lake volume or 1,835,812 m^3 is anoxic (Figure 13).

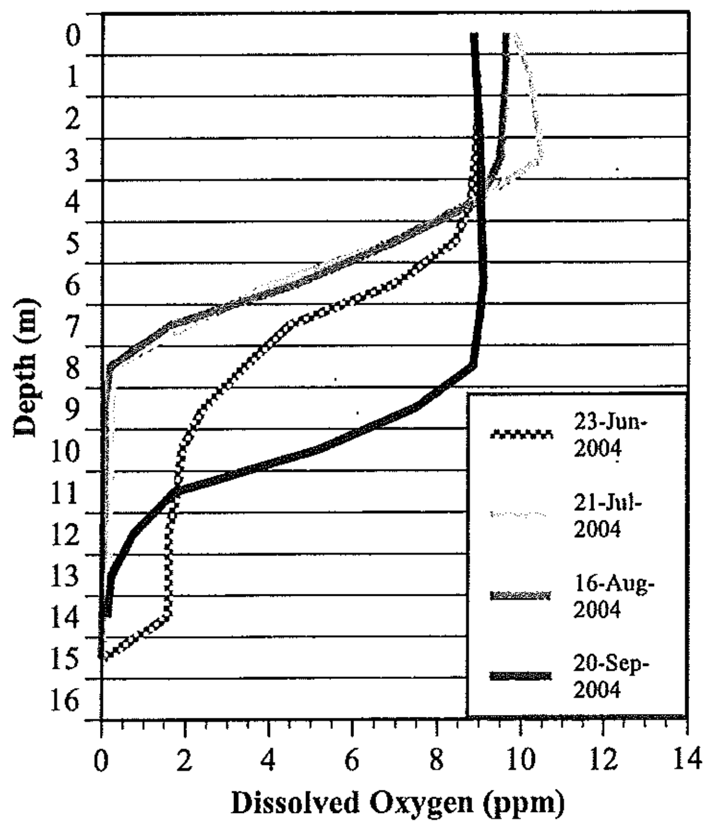

Figure 12. Togus Pond dissolved oxygen vs. depth for the summer of 2004 at Site 1. See Togus Pond sample site map for sample locations (Figure 11).

Past DO data show similar trends to data obtained by CEAT. The DO measurements taken for example in August of 1977, 1987, and 1998 show a stratified lake with surface DO levels reaching 8.8 ppm and dropping to as low as 0.1 ppm at a depth of 15 meters (Figure 14). The DO levels dropped below

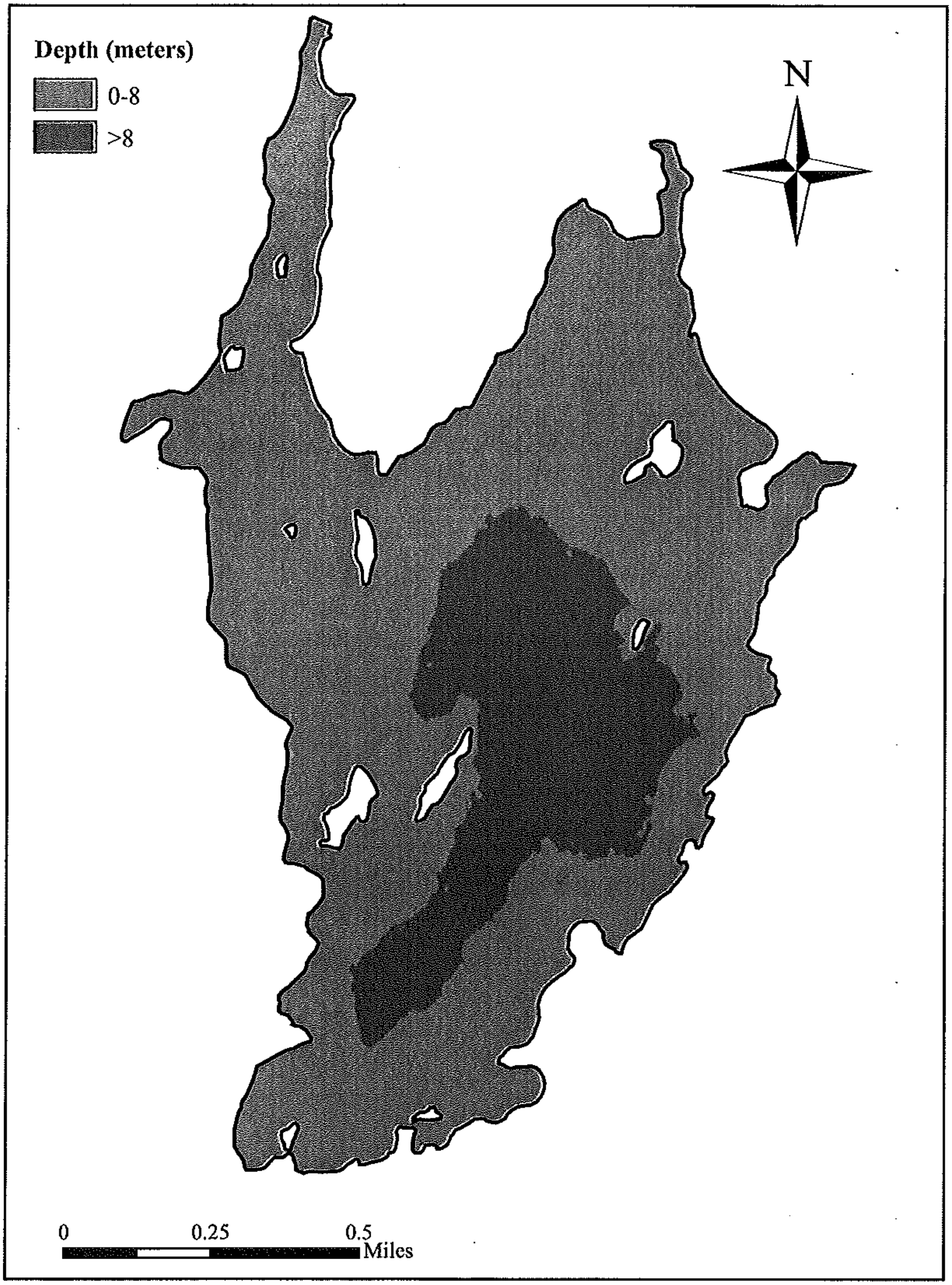

Figure 13. Potential anoxic areas of Togus Pond. Green areas show depths greater than 8 meters, where water typically becomes anoxic during summer stratification.

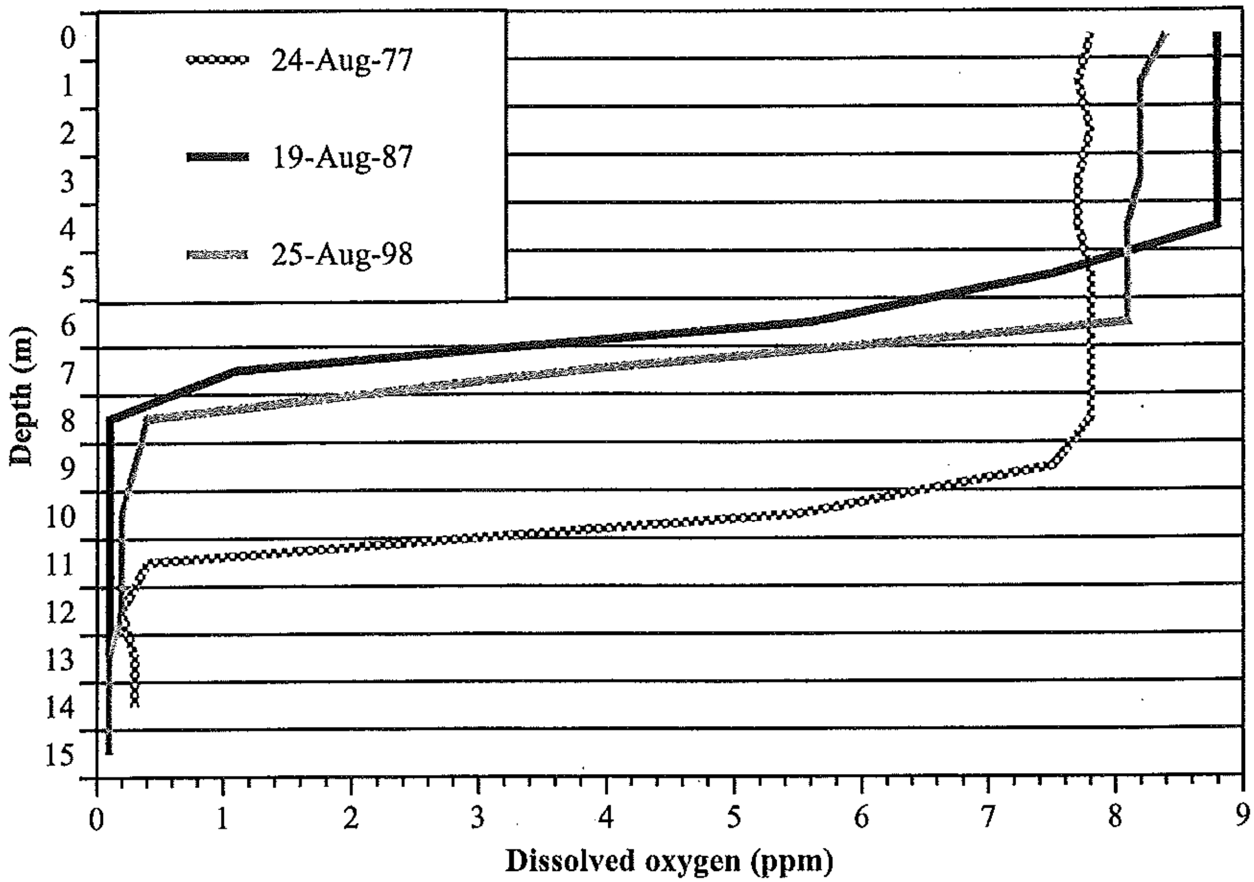

Figure 14. Togus Pond historical dissolved oxygen vs. depth at Site 1 (PEARL 2004c). See Togus Pond sample site map for sample locations (Figure 11).

one ppm in the historical data at about eight meters in depth with the exception of August 1977, where DO did not drop below one ppm until a depth of about 11 m (PEARL 2004c). The depth at which the lake becomes anoxic has not changed significantly over the years, which means that there is no trend towards a greater volume of water becoming anoxic over time. Internal loading of phosphorus is an important aspect to consider in Togus Pond due to the anoxic conditions observed by CEAT.

Temperatures at Site 1 from the months of June to September ranged from 25.4° C at the surface to 11.8° C at a depth of 15 m (Figure 15). Temperature data from the months of July and August showed more stratification of the water column than in the months of June and September. Less stratification in early and late summer is due to lake turnover, which causes water of different temperatures to mix in the water column.

Transparency

Introduction

Transparency is the measure of visibility in the water column, which is a result of suspended

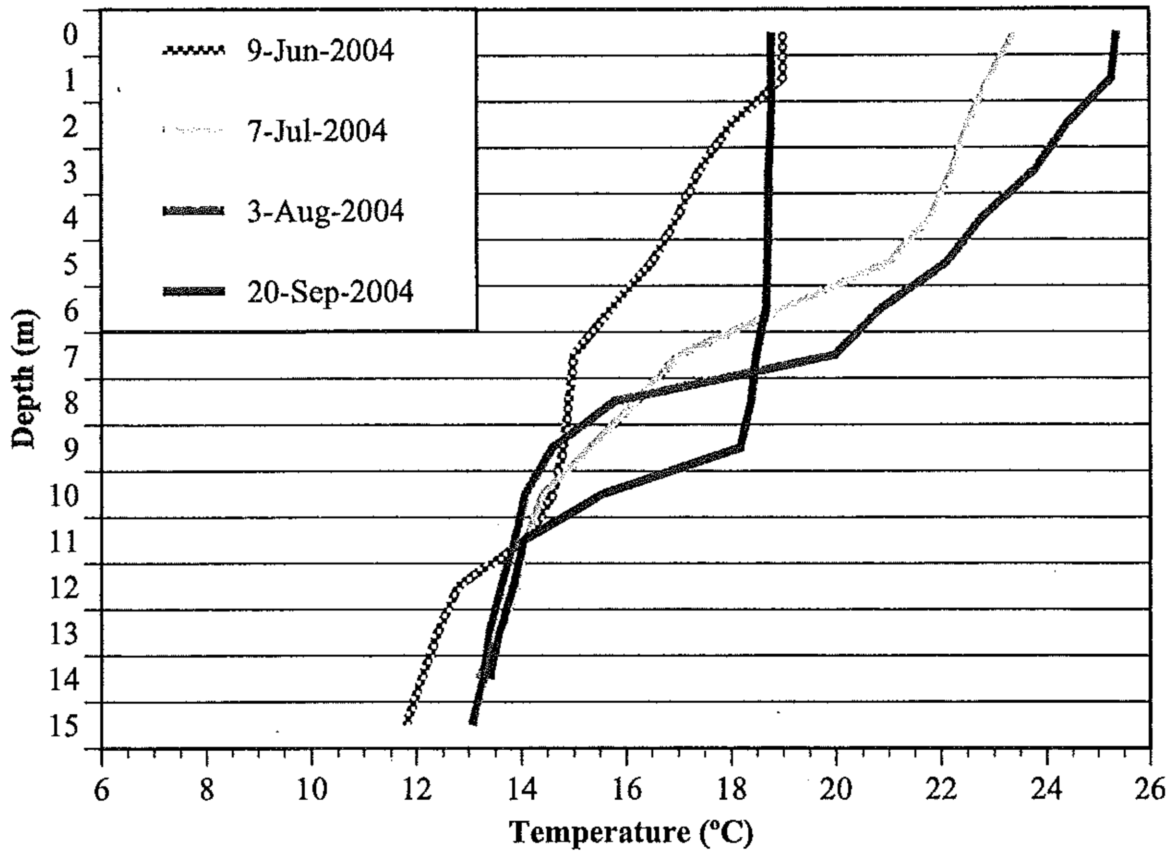

Figure 15. Togus Pond temperature vs. depth for the summer of 2004 at Site 1. See Togus Pond sample site map for sample locations (Figure 11).

matter in the water (Chapman 1996). Transparency measurements are a simple way to approximate the water quality and trophic state of any lake. Low transparency depth correlates with water containing high amounts of suspended matter (organic and/or inorganic matter, silt, clay, or plankton), which act to limit the light penetration of the water column. Transparency can change daily and is most affected by large inputs of water into the water body, such as spring runoff or rain, but can be changed drastically due to algal blooms. Low transparency normally means the lake has low water quality and is most likely a eutrophic lake. Lakes with average summer transparency depths less than two meters for three of more years out of a 10-year period and with color less than 25 SPU are considered eutrophic (PEARL 2004c). During high levels of productivity in the late summer, the lake will have low transparency, which can lead to limits in photosynthetic activity below surface levels and oxygen depletion (Stanicoff 1996).

Methods

Transparency was measured at Sites 1, 2, 3, and 6 on 20-Sep-04 by CEAT with a Secchi disk and also measured during the summer months at Sites 1, 2, 3, and 6 (see Appendix C). Other sites were not measured because the depth was too shallow. Please refer to the Water Quality Assurance Plan to read more about the procedure (see Appendix B). MDEP has used the same method in the past to do their water quality measurements and our historical data were obtained from MDEP (PEARL 2004c).

Results and Discussion

Transparency was measured a several times each month from June to September, and was observed to decrease steadily over the duration of the summer (Figure 16). The transparency was about 2 m on 21-Jul-04, which is an approximate date of when the algal bloom began. Lake transparency decreased as the algal bloom became more severe in the late summer. The mean Secchi disk transparency from Sites 1, 2, 3, and 6 ranged from 5.6 m in June to 1.8 m in September, with a mean (±SE) of 3.0 ± 0.5 m. Historical data from 1976 to the present day show peaks of increased transparency followed by years of slightly decreased transparency depths (Figure 17). Current Secchi disk transparency is not at its highest when compared to past data, which ranged from a high of 5.9 m in 1990 to a low of 2.5 m in 1978. There seems to be a reoccurring pattern of increased transparency followed by decreased transparency with a periodicity of about 10 years (Figure 18). Togus Pond is currently at a point in the cycle where transparency is low in comparison to previous years. The trends may be due to weather patterns over the past few decades or may be to due to some other unknown external factor (Bouchard pers. comm.). Togus Pond has a relatively deep transparency level in comparison to other lakes in the area tested by CEAT and MDEP (Table 6).

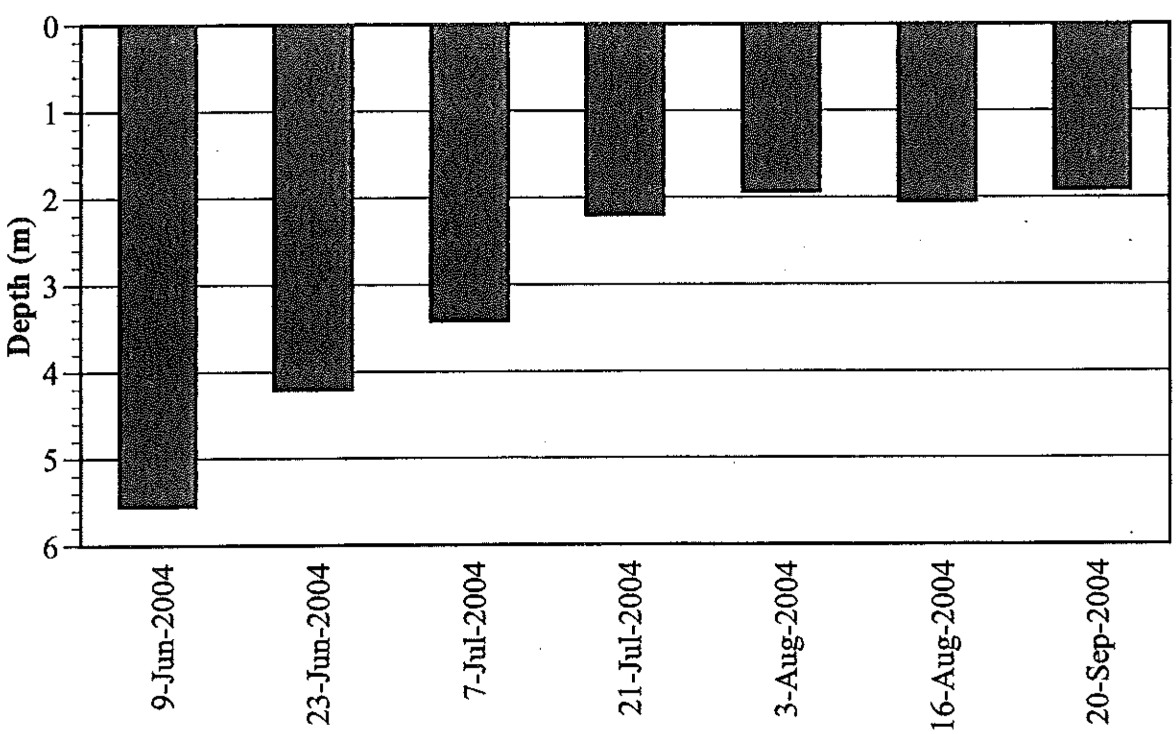

Figure 16. Togus Pond tranparency vs. depth for the summer of 2004 from the mean data taken from Sites 1, 2, 3, and 6. The line at two meters corresponds to the transparency depth below which water is considered eutrophic. See Togus Pond sample site map for sample locations (Figure 11).

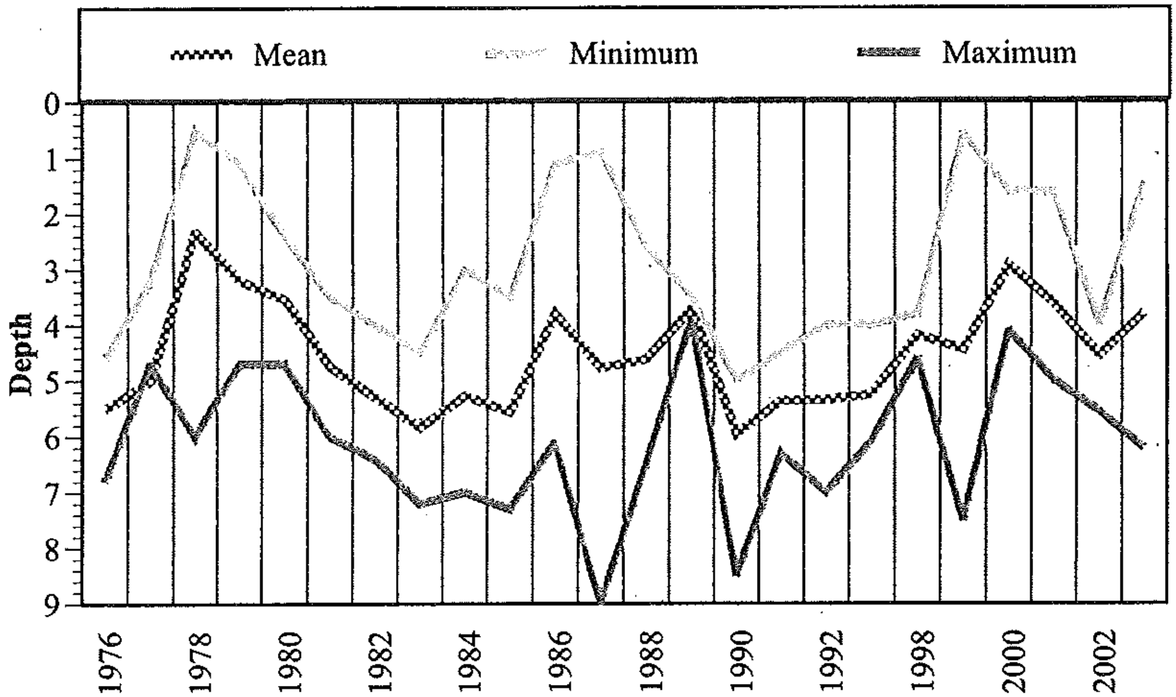

Figure 17. Togus Pond mean, minimum, and maximum tranparency vs. depth from 1976-2004 taken at Site 1 (PEARL 2004c). See Togus Pond sample site map for sample locations (Figure 11).

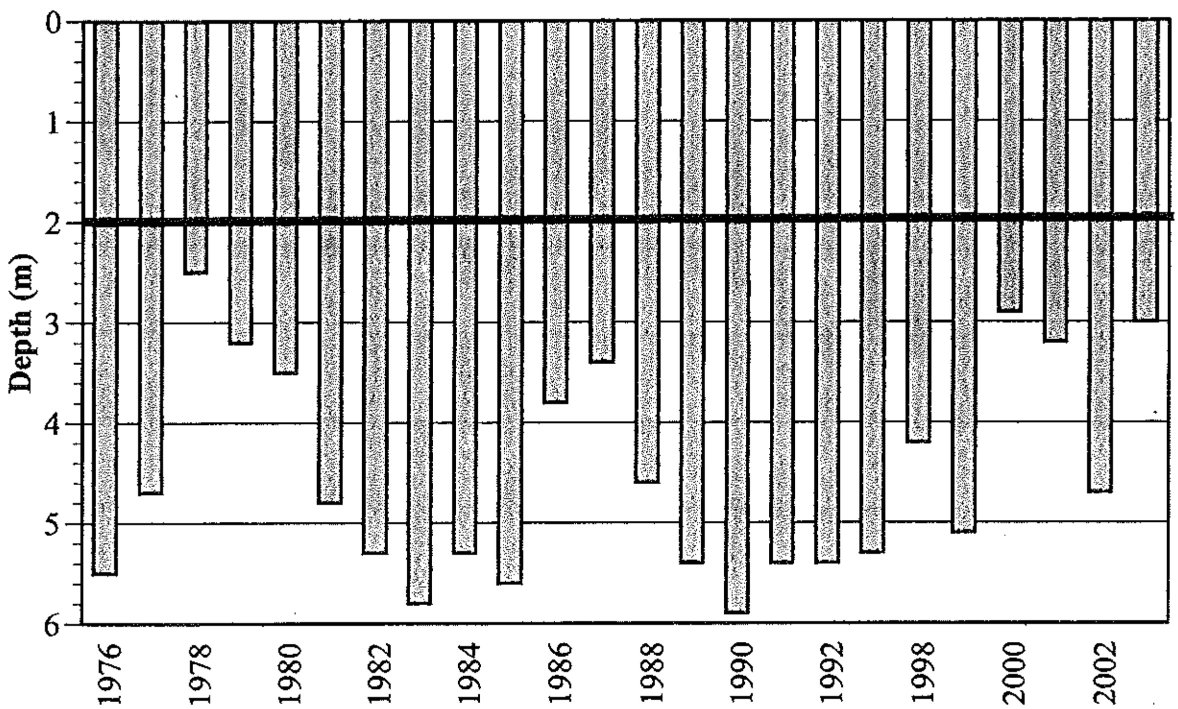

Figure 18. Togus Pond mean tranparency vs. depth from 1976-2004 at Site 1 (PEARL 2004c). A line at two meters corresponds to the transparency depth below which water is considered eutrophic. See Togus Pond site sample map for sample locations (Figure 11).

Table 6. Comparison of Togus Pond water quality parameters (mean ± SE) of three nearby lakes. Data are from past reports on nearby lakes (CEAT 1999, 2003, 2004).

	Togus Pond 2004	Threemile Pond 2004	Webber Pond 2003	East Pond 1999
Physical parameters				
Dissolved Oxygen	0 - 9	0.2 - 9.5	0.05 - 7.4	2 - 11
Color (SPU)	44 ± 16.1	14 ± 8.5	19 ± 3.6	17
Conductivity (µmhos/cm)	58 ± 2.03	48 ± 5.8	39 ± 1.0	28
Turbidity (NTU)	7.2 ± 1.33	1.6 ± 0.81	5.9 ± 2.7	8.0
Transparency (m)	3.0 ± 0.53	2.9 ± 0.04	1.3 ± 0.1	3.3
Chemical parameters				
pH	7.6 ± 0.25	7.1 ± 0.33	7.1 ± 0.31	7.4 ± 0.23
Nitrates (ppm)	0.95 ± 0.16	0.06 ± 0.02	0.07 ± 0.02	0.04
Alkalinity (mg/L)	18.3 ± 1.35	42.3 ± 4.75	37.0 ± 22.4	11.2 ± 0.72
Hardness (mg/L)	22.2 ± 4.5	4.04 ± 1.04	2.9 ± 0.09	3.9
Phosphorus (ppb)	28 ± 1.89	30	28 ± 1.28	20.8 ± 1.31

Turbidity

Introduction

Turbidity is similar to transparency in that it is affected by the suspended matter in the water column. However, turbidity results from the scattering and absorption of light. Turbidity, like transparency, can change daily and is primarily affected by large inputs of water into the water body such as spring runoff or rain. Low turbidity occurs when there is suspended organic and/or inorganic matter, silt, clay or plankton in the water column. Low turbidity indicates low light penetration and low rates of photosynthesis in the lake (Chapman 1996).

Methods

Turbidity was tested at the surface, mid-depth, and bottom at Site 1 using a Hach™ 2100P Turbidimeter on 20-Sep-04 and during the summer by CEAT. At Sites 2, 3, 5, 6, 7, and 8 turbidity was measured at the surface only. Turbidity was measured in Nephalometric Turbidity Units (NTU). In general, turbidity can range from 1-1000 NTU, but most samples are less than 50 NTU (Boyd 2000). Please refer to the Water Quality Assurance Plan (see Appendix B) for further procedural details.

Results and Discussion

Surface turbidity ranged from 3.6 NTU at Site 5 to 14.7 NTU at Site 8. The mean (±SE) was 7.2 ± 1.3 NTU for the samples taken from Togus Pond on 20-Sep-04 by CEAT (Table 6). Summer data collected from June to September reveals an increase in mean surface turbidity from 1.1 NTU on 23-Jun-04 to 6.3 NTU on 20-Sep-04. Increasing turbidity is a result of more suspended matter in the water, most likely due to the algal bloom. Turbidity of Togus Pond is problematic and comparable to ponds with similar turbidity measurements located in the same area (Table 6).

Color

Introduction

Color, like turbidity, helps to define the depth to which light can penetrate (Chapman 1996). There are two measurements for color: true and apparent. True color is measured after the water has been filtered, and apparent color is measured without filtration of water to determine the effect of suspended matter refraction and reflection of light. Color varies from 0 to 300 SPU, with the mean in Maine lakes being 28 SPU (PEARL 2004a). Dark colored water leads to low light penetration, low photosynthetic activity, and a lake with eventually decreasing productivity (Chapman 1996).

Methods

Color was measured on the surface at all sites by collecting water samples on 20-Sep-04 and performing the color measurements in the Colby Environmental Analysis Center. Samples were collected in appropriately sized bottles and kept on ice until returned to the laboratory, where they were refrigerated. Within 24 hours of sampling, the water was tested for true color using a HACH™ DR/4000 Spectrophotometer. Please refer to the Water Quality Assurance Plan (see Appendix B) for further procedural details.

Results and Discussion

True color for Togus Pond ranged from 2 SPU to 292 SPU on 20-Sep-04 with a mean (±SE) of 44 ± 16 SPU (Table 6). Color values normally range from 5 SPU in clear water to 300 SPU in peaty water (Chapman 1996). The water color of Togus Pond is high compared to other lakes in the same area, most likely due to the algal bloom in progress when measurements were taken (Table 6). Past color data for Togus Pond from 1977 to the present, obtained from the MDEP, give an average value of 17 SPU.

Conductivity

Introduction

Conductivity measures the ability of water to conduct an electric current, and is altered by mineral salts present in the water and by the degree to which those salts dissociate into ions (Chapman 1996). Conductivity is measured in mMHOs/cm and normally ranges from 10-888 mMHOs/cm in most water samples, with most Maine lakes ranging from 20-40 mMHOs/cm (MDEP 2002). As a reference point, pure water has a very low conductivity (Boyd 2000). Lakes near Togus Pond have conductivity values slightly lower than Togus Pond (Table 6).

Methods

A conductivity profile was performed by CEAT on 20-Sep-04 at Sites 1 and 3 using a YSI 650 MDS Sonde to take the conductivity measurements. During the summer months the YSI Model 31A Conductance Bridge was used. Please refer to the Water Quality Assurance Plan (see Appendix B) for further procedural details.

Results and Discussion

Conductivity measures the ability of water to conduct an electric current, and is altered by mineral salts present in the water and by the degree to which those salts dissociate into ions (Chapman 1996). Conductivity is measured in mMHOs/cm and normally ranges from 10-888 mMHOs/cm in most water samples, with most Maine lakes ranging from 20-40 mMHOs/cm (MDEP 2002). As a reference point, pure water has a very low conductivity (Boyd 2000). Lakes near Togus Pond have conductivity values slightly lower than Togus Pond (Table 6).

CHEMICAL ANALYSES

pH

Introduction

The pH of a body of water is defined as the negative logarithm (base 10) of the concentration of hydrogen ions present in the water (Chapman 1996). A one unit change in pH is representative of a 10 fold change in the acidity or alkalinity of the water. High pH corresponds to a low concentration of hydrogen ions (more alkaline), while a low pH represents a high concentration of hydrogen ions (more acidic). A pH of 7 is neutral, a pH of 14 is the most basic, and a pH of 0 is the most acidic. Most natural waters have a pH between 6 and 8.5, with eutrophic lakes having a higher pH than 8.5 (Chapman 1992). The pH of Togus Pond and lakes nearby ranges from 7.0 to 7.6 (Table 6).

Methods

The pH of surface water was measured on 20-Sep-04 at all sites but Site 8 by CEAT using the YSI 650 MDS Sonde or standardized EXTECK ExStik pH meter. pH was measured by CEAT during July and August using the same equipment. Both instruments were calibrated before measurements were taken. Please see the Water Quality Assurance Plan (see Appendix B) for more procedural details.

Results and Discussion

The range of surface pH from all tested sites on 20-Sep-04 was 6.36 to 8.29 with a mean (±SE) surface pH of 7.23 ± 0.25 (Figure 19). The summer data show that pH was high at the surface and decreased with depth at the beginning of the summer, but the difference in pH between shallow and deep water diminished as the summer continued (Figure 19). The pH of Togus Pond is comparable to other Maine lakes, and is not problematic for water quality (Table 6). Historical pH are very hard to find, but the MDEP has some results that indicate a rising trend in pH beginning in the 1970's (PEARL 2004c; Figure 20). The pH of lakes tends to rise as they become eutrophic, and the tests performed by CEAT along with past MDEP data exhibit this trend in Togus Pond (Chapman 1996). A problem when lake pH rises above 8.5 is the release of phosphorus from the sediments (James 1996). Although the pH at depth has not reached 8.5, the rising trend in pH observed may mean that the pH should be closely monitored in the future to prevent excess release of phosphorus from the sediments.

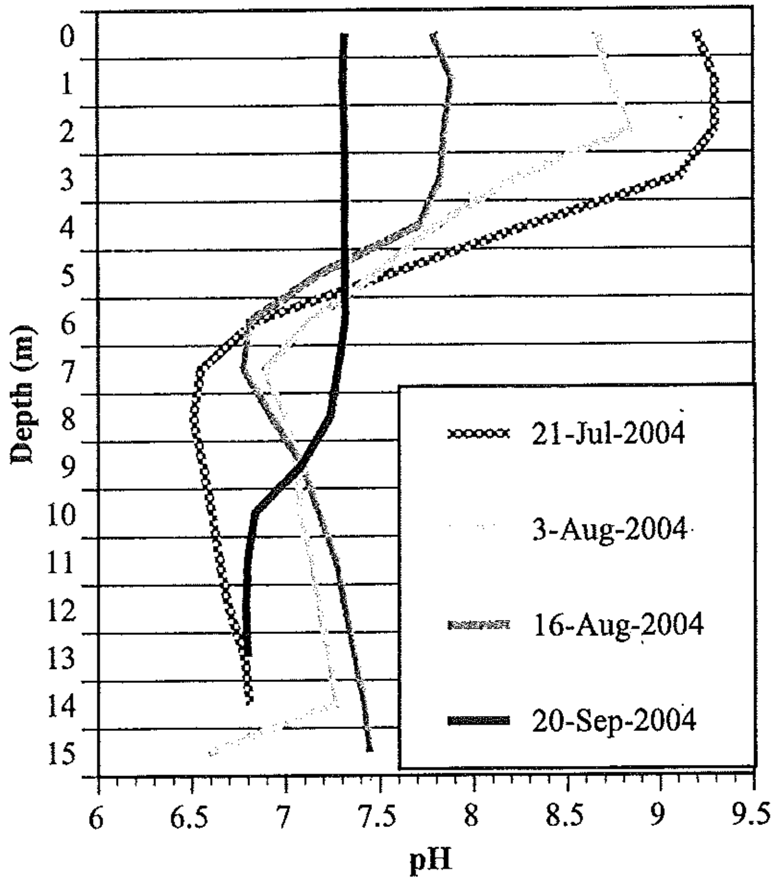

Figure 19. Togus Pond pH vs. depth for the summer of 2004 at Site 1. See Togus Pond sample site map for sample locations (Figure 11).

Hardness

Introduction

Hardness is determined by the concentration of calcium (Ca^{2+}) and magnesium (Mg^{2+}) salts in a water body (Chapman 1996). Summing the calcium and magnesium concentrations gives a general hardness value, which consists mostly of calcium. Calcium and magnesium come primarily from the

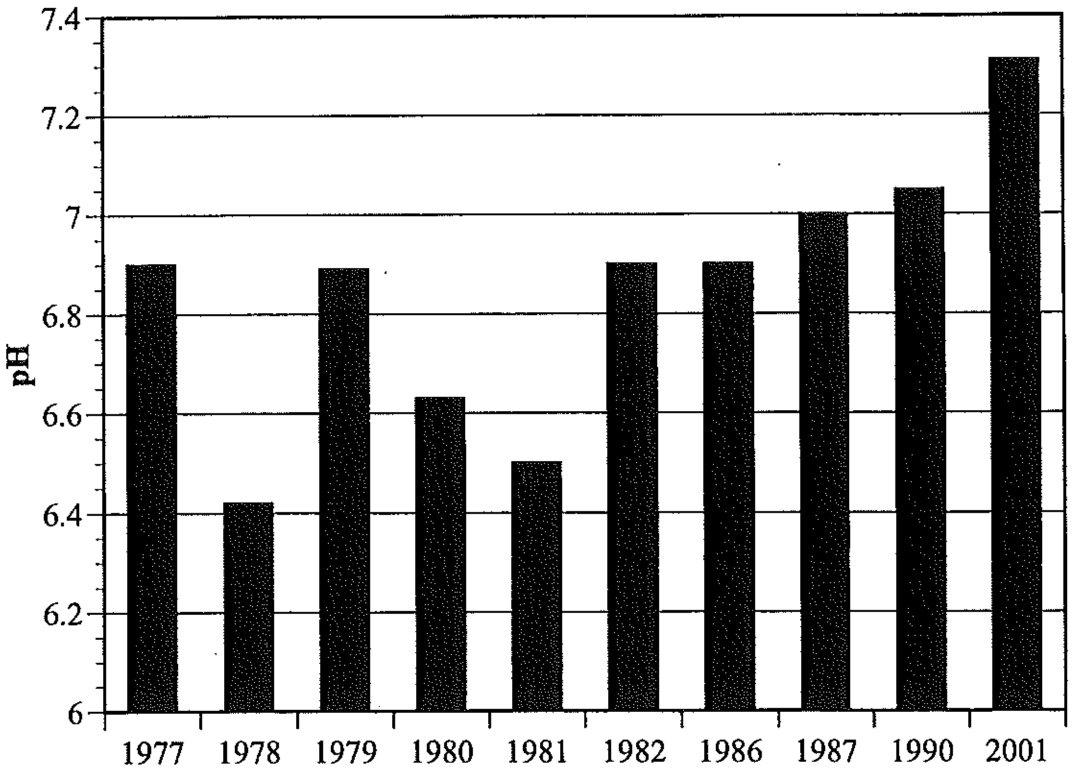

Figure 20. Historic mean pH values from Site 1 at Togus Pond (PEARL 2004c). See Togus Pond sample site map for sample locations (Figure 11).

dissolution of limestone, which is accelerated by carbon dioxide in rainwater (Boyd 2000). Calcium and magnesium are found nearly in chemical equivalence to the concentration of bicarbonate and carbonate (Boyd 2000). As defined by the USGS, soft water ranges from 0 to 60 mg/L in hardness, moderately hard water ranges from 61 to 120 mg/L, hard water ranges from 121 to 180 mg/L, and very hard water measures more than 180 mg/L (USGS 2004a). Soft water is more prone to algal blooms than hard water (Pearsall 1993).

Methods

Hardness was tested at sites 1, 2, 3, and 7 on 20-Sep-04 by CEAT by collecting surface water samples. The water samples were acidified to a pH of less than 2 and kept on ice until they were transferred to the refrigerator in the Colby Environmental Analysis Center. The samples were tested within 28 days of collection, using the HACH titration method (HACH 1997; see Appendix B). Some samples were also sent to Northeast Laboratory in order to confirm accuracy in our testing. Please refer to the Water Quality Assurance Plan (see Appendix B) for further procedural details.

Results and Discussion

The water hardness in Togus Pond on 20-Sep-04 ranged between 2.2 mg/L and 40.5 mg/L with a

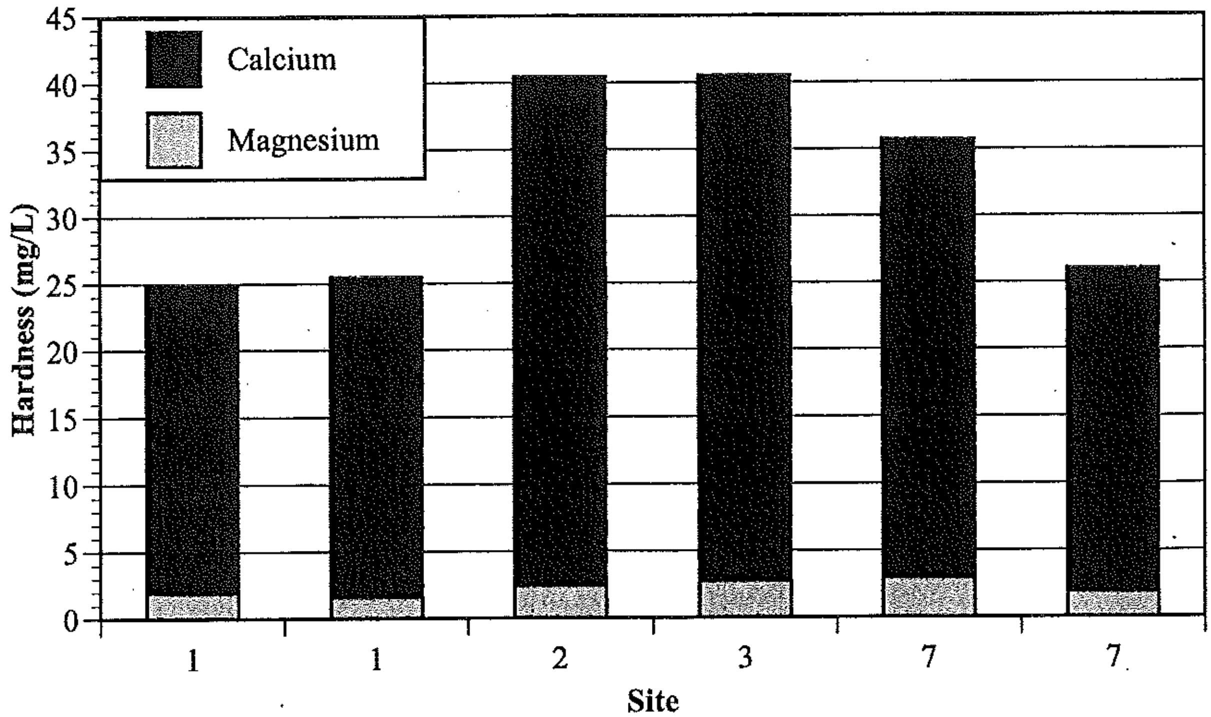

Figure 21. Total hardness (Ca and Mg combined) for selected study sites on Togus Pond. Data for Site 9 and a randomly selected adjacent site were obtained from analyses conducted by Northeast Laboratories, Winslow, ME. The total hardness at these sites was 10 mg/L and 17 mg/L, respectively. See Togus Pond Site map for location of sites (Figure 11).

mean (±SE) value of 20.6 ± 4.5 mg/L (Figure 21). Togus Pond has harder water than any of the surrounding lakes tested by CEAT in the past, but the water is still considered soft by USGS standards (Table 6). The occurrence of algal blooms in Togus Pond supports the observation that lakes with soft water are more prone to algal blooms.

Alkalinity

Introduction

Alkalinity is a measure of the buffering capacity of a water body (Chapman 1996). In natural freshwaters, alkalinity is based on the calcium carbonate concentration in the water because carbonates and bicarbonates are the predominant buffers in these ecosystems (Eaton et al. 1995). The mean range for alkalinity in Maine lakes is 4 to 20 ppm (Pearsall 1993). Past studies have found other Central Maine lakes to fall in the high end of this range, with a mean alkalinity of 11.2 mg/L in East Pond and 42.3 mg/L for Threemile Pond (Table 6; CEAT 2000, 2004). Lakes in Maine typically exhibit higher alkalinity than similar freshwater ecosystems in the Northeast, which means they are more resistant to changes in pH and acidification. A resistant water body has an alkalinity of 10 ppm or higher (Pearsall 1993).

Methods

Alkalinity data were collected by CEAT on six separate occasions between June and September of 2004. Alkalinity was determined for surface and/or epicore samples at all the characterization sites (1, 2, and 3). Epicore samples were collected in July and August, while only surface samples were collected in June and September. Immediately after collection, samples were placed on ice and transported to the laboratory. Analysis was conducted promptly after returning from the field. Alkalinity values were measured in milligrams of $CaCO_3$ by titration with 0.02 N sulfuric acid.

Results and Discussion

The mean (±SE) of alkalinity was 18.25 ± 1.35 ppm. Alkalinity ranged from 5.33 ppm at Site 2 to 22.95 ppm at Site 1, and there did not appear to be any significant variation between surface and epicore samples. These results are typical of Maine lakes and the relatively high alkalinity indicates that Togus Pond is not immediately susceptible to acidification (Table 6). This buffering capacity is important because most living organisms can only function within a narrow range of neutral pH conditions, which can be adversely affected by acidification.

Nitrates

Introduction

Along with phosphorus, nitrates are the primary nutrients essential for plant growth. Nitrates are found naturally in limited amounts in freshwater systems; concentrations greater than 0.2 ppm can stimulate algal growth in lakes (Chapman 1996). Elevated levels in freshwater lakes (5 ppm or higher) often indicate the presence of effluent from wastewater treatment plants, fertilizers, or other anthropogenic sources of nitrogen (Chapman 1996). In the freshwater ecosystems of Maine, nitrates are present in sufficient amounts to accommodate algal growth so they are not typically the limiting nutrients responsible for blooms (Firmage pers. comm.).

Methods

Data were collected by CEAT on 21-Jul-04 and 3-Aug-04 at all characterization sites and select spot sites (4, 5, 9) using the YSI 650 MDS Sonde. Values were taken at one-meter increments from the surface to the deepest point of the lake at the characterization sites, and two readings were taken near the surface at the shallower spot sites.

Results and Discussion

The mean (±SE) concentration of nitrates was 0.95 ± 0.16 ppm. At Site 1, nitrate levels increased with depth, although this trend did not persist across all sites (Figure 22). Both the lowest and highest levels occurred at Site 1: 0.17 ppm at 7 m in depth and 5.9 ppm at 15 m. The significantly higher levels

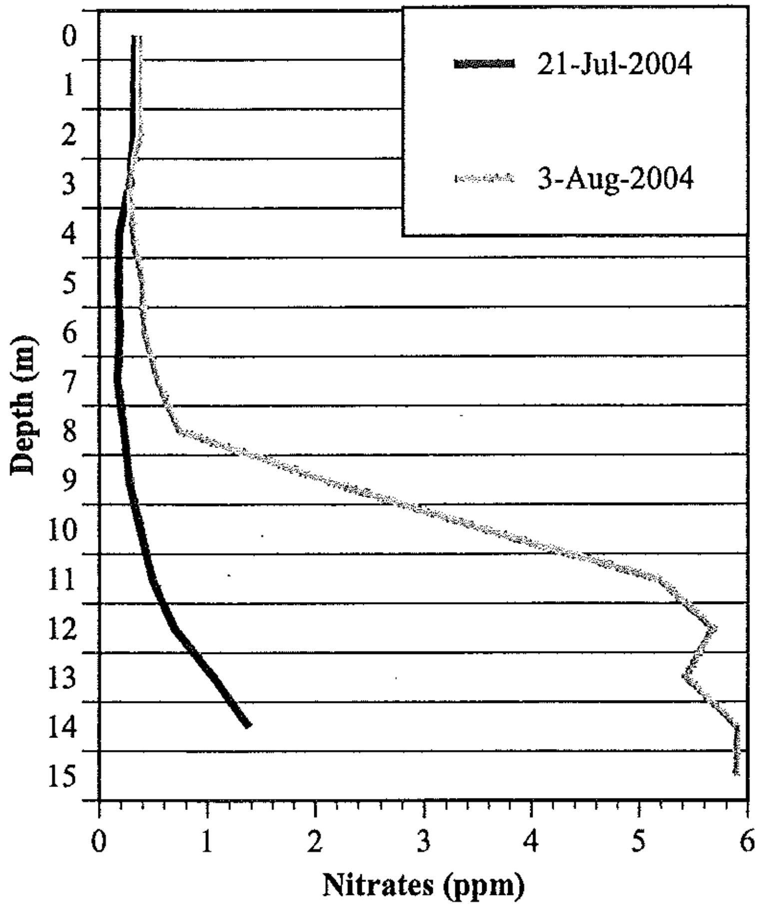

Figure 22. Togus Pond nitrate concentration vs. depth for the summer of 2004 at Site 1. See Togus Pond sample site map for sample locations (Figure 11).

of nitrates found at Site 1 in August versus July might be explained by increased stratification during the progression of the summer, which allows for the buildup of nutrients in the hypolimnion (Figure 22). There is a rapid increase in August nitrate levels at 9 m, which peaked at almost 6 ppm at 15 m. Although nitrate levels in excess of 5 ppm are considered evidence of organic pollution, high nitrate concentration might also be explained by significant organic decomposition on the lake bottom. High levels of decomposition deplete oxygen at depth and produce nitrogenous waste products.

Ammonium

Introduction

Pristine waters naturally contain small amounts of ammonia and ammonia compounds; higher amounts can indicate organic pollution such as domestic sewage, fertilizer, or industrial waste (Chapman 1996). Ammonia levels can fluctuate over time as phytoplankton and bacteria die and decay. Higher concentrations of ammonia can be found in anoxic waters. Ammonium is the reduction product of ammonia and can be readily taken up by freshwater plants for growth (Firmage pers. comm.).

Methods

Ammonium data were collected by CEAT on 21-Jul-04, 3-Aug-04, and 16-Aug-04 at all characterization sites and select spot sites (4, 5, 9, and Lower Togus Dam) using the YSI 650 MDS Sonde. Values were taken at one-meter increments from the surface to the deepest point of the lake at characterization sites, and two readings were taken near the surface at spot sites.

Results and Discussion

Ammonium was higher in July than in August and levels increased with depth at characterization Site 1 on all days sampled (Figure 23). This increase with depth is probably associated with the strong

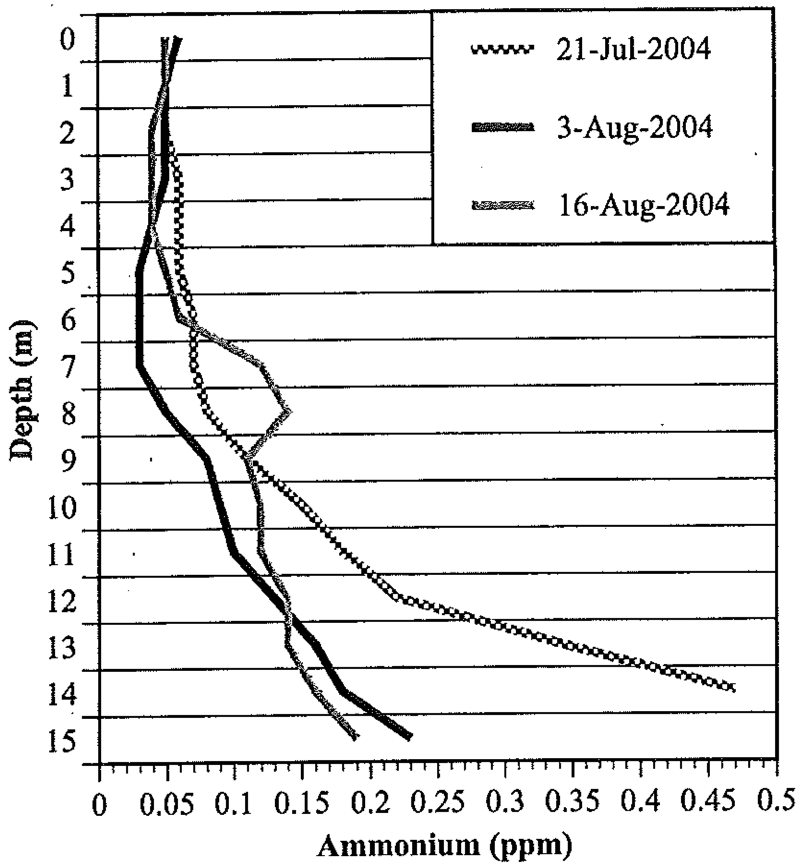

Figure 23. Togus Pond ammonium concentration vs. depth for the summer of 2004 at Site 1. See Togus Pond sample site map for sample locations (Figure 11).

stratification of the lake in the summer months; waste products are likely to become concentrated in the hypolimnion because mixing and dilution are not occurring. It is unclear why levels were higher in July, although there are limited data (only three sample dates) for making this kind of determination.

Total Phosphorus

Introduction

Phosphorus is the limiting nutrient for aquatic plant growth in lake ecosystems and the main determinant of algal blooms (see Background: Lake Characteristics: Nitrogen and Phosphorus Cycles). Since phosphorus levels drive algal production, phosphorus concentration is the most important component in the determination of the trophic state of the lake. This is particularly important in Maine lakes, where the natural phosphorus levels are quite low, usually between 6 and 12 ppb (Pearsall 1993). A minimal increase in the seasonal average to 15 ppb is sufficient to promote nuisance algal blooms (Pearsall 1993). According to the MDEP, a lake experiencing algal blooms two years in a row or more is considered "impaired" and eutrophic (Halliwell pers. comm.).

Algal blooms pose numerous problems for freshwater resources. The algae can give a foul smell and poor taste to drinking water, while also significantly reducing recreational access to the water by making swimming and other activities unpleasant or even difficult. As the algae die, they sink to the bottom of the lake where they are decomposed by bacteria. These bacteria consume oxygen at depth, depleting the oxygen dissolved in the water column, and degrading habitat for coldwater fish and other organisms (Cole pers. comm.). These anoxic conditions stimulate internal phosphorus recycling, releasing additional phosphorus from the sediments into the water column (Chapman 1996).

Phosphorus occurs naturally in sediments, decomposing leaf litter, and other organics in lake ecosystems, so some phosphorus in the ecosystem is inevitable. However, when runoff contains detergents, fertilizers, and other anthropogenic sources of phosphorus. The increase in phosphorus can lead to algal blooms and decreased water quality (Pearsall 1993; see Background: Watershed Land Use: Nutrient Loading).

Methods

Phosphorus data were collected every other week from 9-Jun-04 to 16-Aug-04 and again by CEAT on 20-Sep-04. In the summer, data were collected at the three characterization sites in addition to Sites 4, 5, and 9. To give a more comprehensive picture of the nutrient status and to assess potential problem sites, fall sampling was conducted at all summer sites in addition to Sites 6, 7, and 8. Samples were collected in 125 mL PMP flasks that were triple-acid-rinsed to prevent contamination. At characterization sites, samples were taken at the surface, mid-depth, and bottom, in addition to epicore sampling. Samples from bottom and mid-depth were collected using a water sampler (see Appendix B). Surface samples were taken at all other sites. To ensure accuracy in field techniques, duplicates were taken (two samples at the same sampling location/depth). In addition, splits (two samples taken from the same bottle) were performed to determine the level of accuracy in laboratory testing. In total, these quality assurance measures accounted for more than 10% of all samples collected (see Appendix B). All samples were put on ice promptly after collection to retain accurate phosphorus levels.

Immediately upon returning from the field, all samples were digested using 1 mL of 1.75 N ammonium peroxysulfate and 1.0 mL 11 N sulfuric acid in a 15 lbs/in^2 autoclave at 120° Celsius for 30 minutes. The digestion process converts all organic phosphorus bound up in phytoplankton, algae, or other organisms into its inorganic form in order to measure total phosphorus. Following digestion, samples were brought to a more neutral pH of 6 and a combined reagent was added for analysis (see Appendix B). This reagent produced a range of color corresponding to the phosphorus concentration present, with clear samples having less phosphorus and blue samples containing more phosphorus. Standards ranging from 0 ppb to 100 ppb of phosphorus were made to calibrate the spectrophotometer and create a linear equation of absorbance. Following a 10-minute development period, the samples were poured into 10 cm sample cells and analyzed with a Milton Roy Thermospectronic Aquamate Spectrophotometer.

Results and Discussion

Historic Phosphorus Levels

Phosphorus levels in Togus Pond have been high historically. Algal blooms have been documented in the lake as early as the 1920's and 1930's, which is unusual for the great ponds of Kennebec County, since most other lakes in the area did not experience algal blooms during this time (Sowles 1983). Phosphorus data have been collected since 1978 by MDEP, although there are some gaps in these data and the quantity of data points collected varies from year to year. There is a history of widely fluctuating phosphorus levels in Togus Pond, with peaks in 1979 and 1980, and a gradual decrease in overall levels through the 1990's to the present (Figure 24). In almost every year for which there are

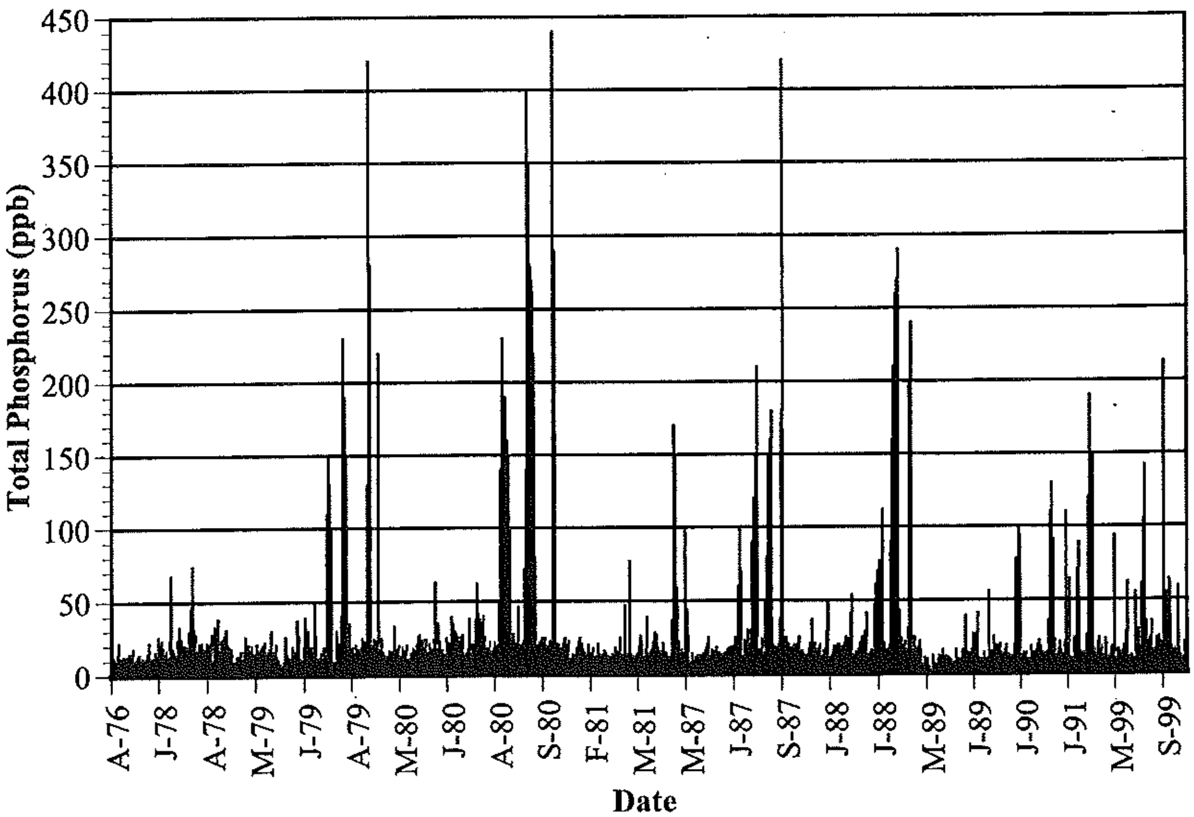

Figure 24. Togus Pond historical total phosphorus values taken at various sites and depths with highest values occuring in the deep areas of the lake (PEARL 2004c).

data available, fall phosphorus levels were higher than those reported for the summer (Figure 25). This might be explained by the release of additional phosphorus into the water column following fall turnover. This turnover allows for phosphorus to be released during the anoxic period to be mixed throughout the water column.

Unfortunately, the historical data available from the MDEP are incomplete. Data represented in Figure 24, for example, are not directly comparable across years because this representation includes grab samples (bottom samples) and epicore samples. Since there is not adequate historical data to represent each year with an epicore value, it is more difficult to assess the historical nutrient levels of the lake. Historical data do, however, provide strong evidence for a history of unnaturally high phosphorus levels in Togus Pond (Sowles 1983). More data are necessary to accurately determine the long-term trends of phosphorus.

Current Nutrient Status

Phosphorus levels increased in bottom samples throughout most of the summer and into the fall, when the highest concentration, 401 ppb, was recorded at Site 1 (Figure 26). The maximum phosphorus concentration was found at this characterization site because it was the deepest site sampled, making it the most susceptible to anoxic conditions and phosphorus release from the sediment. Historical

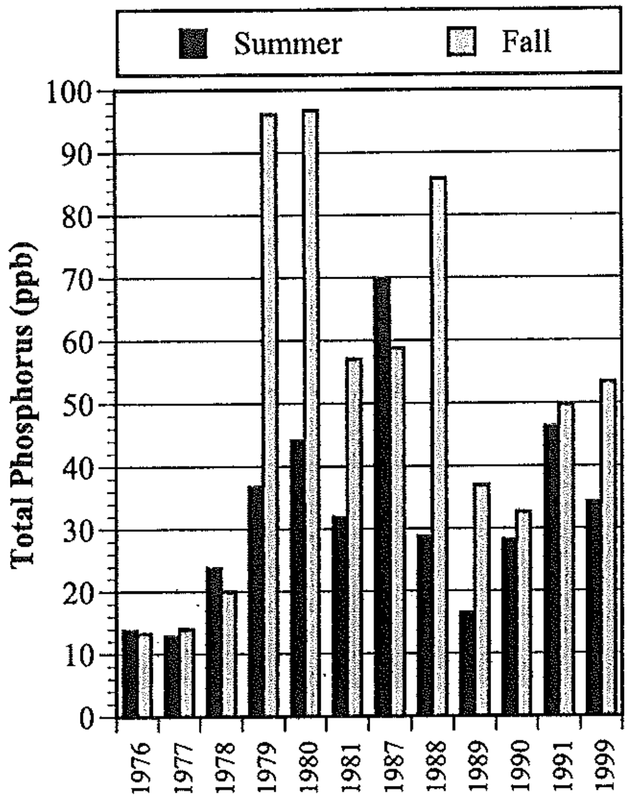

Figure 25. Historic mean total phosphorus in the summer (June, July, August) and fall (September) for Togus Pond (PEARL 2004c).

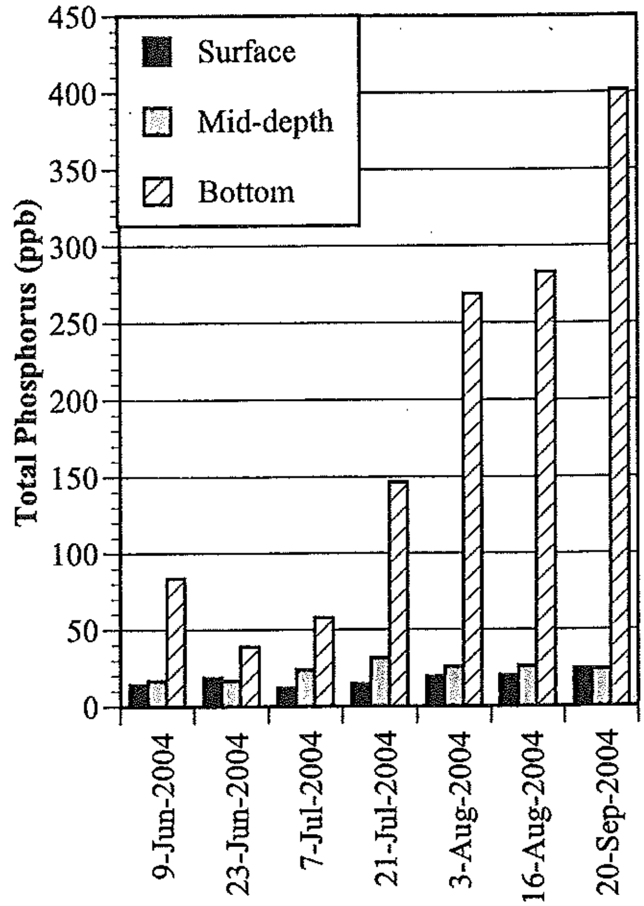

Figure 26. Distribution of total phosphorus at Site 1 by depth. Site 1 has a depth of 14.7 m. See Togus Pond Site map for location of Site 1 (Figure 11).

levels for bottom grabs have approached this level, reaching the 440 ppb in 1980 and 420 ppb in 1987, at depths of 14 and 13 m respectively (Figure 24). (Depth and other details were taken from MDEP (PEARL 2004c) data and are not presented in this figure.)

Although the high levels found by CEAT and those from the past are well above the 15 ppb required for algal blooms, these samples were collected from the bottom layer of the lake. This phosphorus is trapped in the bottom layer of the lake for the majority of the summer because of stratification and is not directly available for plant growth. It is important to look at the phosphorus concentration of epicore and epilimnion samples, taken where sunlight is readily available for photosynthesis. Mean phosphorus concentration of all epicore samples collected was 28.0 ± 1.9 ppb. Mean epicore levels from all sites were consistently above 15 ppb from June to September (Figure 27). The total phosphorus value for Togus Pond was similar to that for nearby lakes in Central Maine, especially Webber and Threemile Ponds (Figure 28).

Phosphorus was also consistently higher than 15 ppb in surface samples (Figure 29). Epicore and surface data indicate that phosphorus levels were similar among all sites sampled in terms of overall phosphorus concentration and the concentration of phosphorus in the epilimnion. However, there was not an even distribution of phosphorus at other depths and locations. The highest level of phosphorus

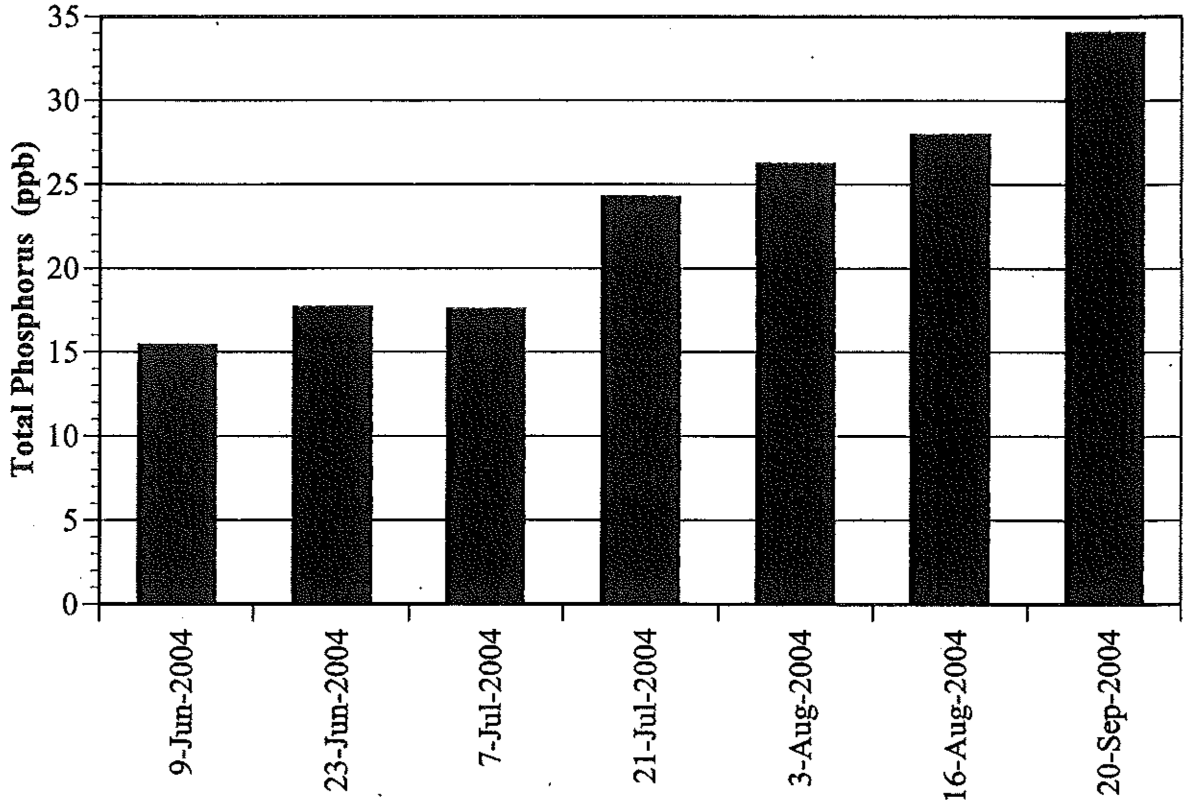

Figure 27. Total phosphorus from epicore samples at Site 1 during the summer of 2004. Data for June 9 and 23 represent the mean for surface and mid-depth values. See site map for location of Site 1 (Figure 11).

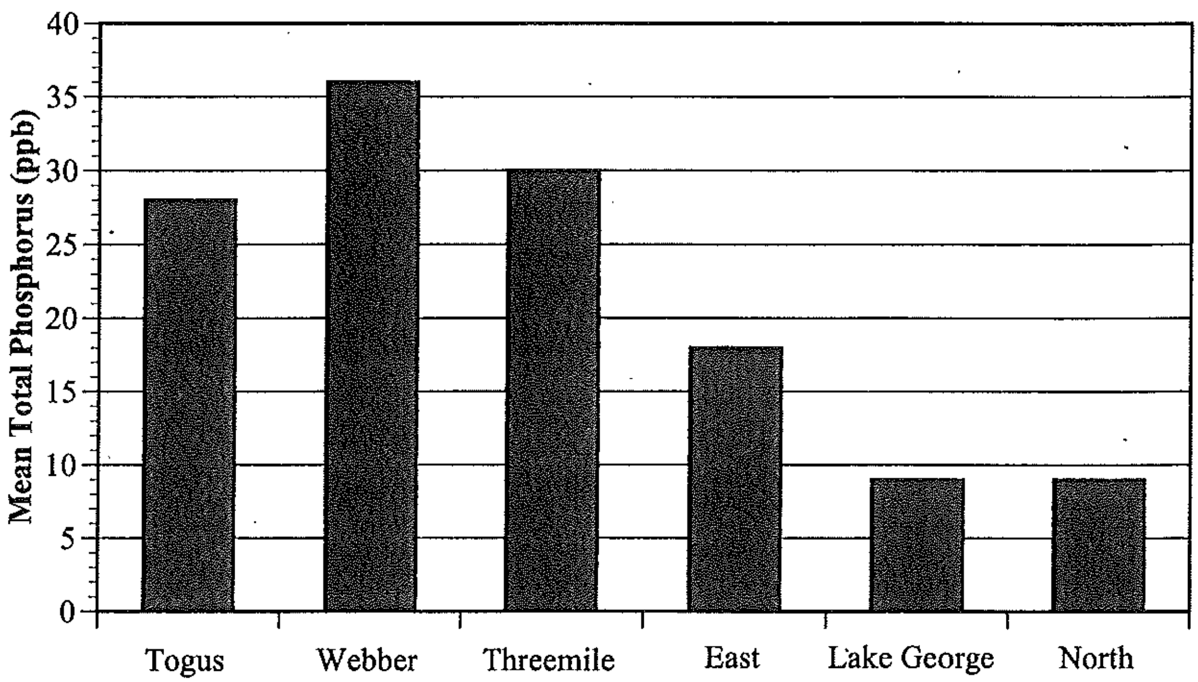

Figure 28. Mean total phosphorus for several Maine lakes taken from past years of CEAT data for Webber Pond (CEAT 2003), Threemile Pond (CEAT 2004), East Pond (CEAT 2001), Lake George (CEAT 2002) and North Pond (CEAT 1998).

in a bottom sample occurred at Site 1, although bottom samples did not represent the highest samples collected at Site 2, another characterization site, where the highest phosphorus concentration was found in the epicore sample. This finding is not typical and is probably due to sampling error; some phosphorus-rich sediment might have been collected in the epicore tube during collection. Overall, data collected during the summer and fall of 2004 indicate high levels of available phosphorus distributed relatively evenly among all sites, particularly in the epilimnion, where photosynthesis and algal blooms occur, which explains the decreased clarity and green appearance of the lake during sampling.

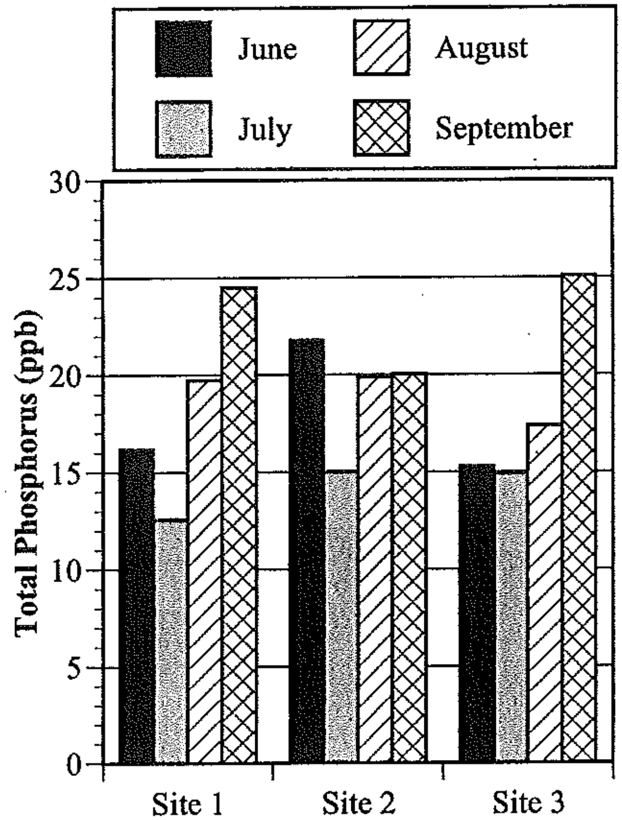

Figure 29. Total phosphorus in the epilimnion. Data were collected from sites 1, 2, and 3 during the summer and fall of 2004. See Togus Pond Site map for location of these sites (Figure 11).

Trophic Status

The Maine State Trophic Index (MDEP 1986; Bouchard pers. comm.) is an assessment of the lake's trophic state, which can be determined using chlorophyll-*a*, Secchi disk transparency, or total phosphorus. It is important because it provides a means for comparing water quality and trophic state across different lakes in Maine. CEAT calculated the Trophic State Index for Togus Pond using total phosphorus data because this was the only parameter for which five consecutive months of data were available, a stipulation that is required for the TSI per MDEP guidelines. Using data collected by CEAT for June - September 2004 and data for the month of May collected by MDEP (Halliwell pers. comm.), the TSI for Togus Pond was determined using the following equation:

$$\mathbf{TSI_p = 70\ log(0.33 \times mean\ total\ phosphorus + 0.70)}$$

The TSI for total phosphorus was 65.7. According to MDEP, a lake indexed at 70 should have Secchi disk transparency of about 3.4 m, and total phosphorus levels of 28.2 ppb. CEAT data were quite close to these predictions, with 3.0 m transparency, and 28 ppb mean phosphorus in epicore samples. However, Secchi disk transparency did drop to 2 m and lower during the course of the summer, when the algal bloom was most severe. Together, these data indicate that Togus Pond is a eutrophic lake.

BIOTIC MEASUREMENTS

Fecal Coliform

Introduction

Coliform bacteria are found in the feces of humans and other mammals (Chapman 1996). Total coliform is the sum of all bacteria present from both mammals and humans, whereas fecal coliform is a measure of bacteria from human feces only. Since these bacteria are associated with human and animal wastes, they can enter the water through runoff, leaky septic systems, and improperly controlled point sources. Some level of coliform bacteria is common naturally from organisms living in and around the water. Public health regulations for drinking water allow for up to 10 coliform colonies per 100 mL of water, as long as this includes no fecal coliform bacteria (Boyd 2000).

Methods

Samples were collected by CEAT on 20-Sep-04 at Site 7 and again on 14-Oct-04 at Site 7 and two other randomly chosen sites. Samples were collected in 250 mL e-pure-rinsed bottles. The collected water was then poured into sterile specimen bottles obtained from Northeast Laboratories. All samples were immediately taken to Northeast Laboratories for analysis.

Results and Discussion

The initial test result for total coliform was 1 colony per 100 mL. In order to determine whether the coliform bacteria present were fecal (from humans) or if they were from other mammals, another sample was taken from the same site and two other randomly selected sites nearby. These results came back negative for fecal coliform, 0 colonies/100 mL. The results from these later samples indicate that the bacteria present are from other mammals in the watershed, not from human waste. The water in Togus Pond meets general public regulations as stated by Boyd (2000). However, since this is a frequently used recreational spot, continued testing for this biotic measure is necessary to ensure that the water is safe for recreational use. In addition, sampling should be conducted in the warmer summer months when there is a greater likelihood of finding coliform bacteria.

Chlorophyll-*a*

Introduction

Chlorophyll-*a* is present in photosynthesizing organisms and is used to transform light energy into a food source. Measuring chlorophyll-*a* is an indirect determination of algal biomass and the trophic status of freshwater lakes (Chapman 1996). Since the growth of planktonic algae is affected by changes in temperature, light, and nutrient levels, chlorophyll-*a* can fluctuate daily, seasonally and with depth and weather conditions (Chapman 1996). Measuring chlorophyll-*a* is important because it adds to the data available for the determination of the trophic status of the lake.

Methods

Chlorophyll-*a* was measured through fluorescence using the YSI 650 MDS Sonde at all characterization sites (1, 2, 3) and Sites 4, 5, 9 and Lower Togus Dam. Fluorescence does not directly measure chlorophyll-*a*; it is a relative measure that determines the chlorophyll-*a* at different locations by comparing them with a calibrated 0 standard (E-pure or deionized water was used for this purpose). At the characterization sites, measurements were taken every meter from the surface to the deepest point. At all other sites, two measurements were taken at the surface. Data were collected on four occasions between July and September. In September, chlorophyll-*a* was only recorded at characterization sites.

Results and Discussion

Chlorophyll-*a* peaked between two and three meters of depth, at three out of four sites sampled, declining after that point until a depth of approximately nine m, when values began to rise again (Figure 30). This initial peak at 2-3 m can be explained by maximum photosynthesis occurring at this depth, where there are appropriate conditions for algal production, such as moderated sunlight. Chlorophyll-*a* levels are lower in the first meter of water, in part because algal growth can be inhibited by direct sunlight (Firmage pers. comm.). The rising levels of chlorophyll-*a* deeper in the water column can be attributed to the algae that are sinking to the lake bottom. These levels are too deep for adequate sunlight to penetrate, so no photosynthesis is occurring, although sinking algae will still fluoresce, explaining the presence of chlorophyll-*a* at these depths. The level of chlorophyll-*a* jumped significantly in August (Figure 30).

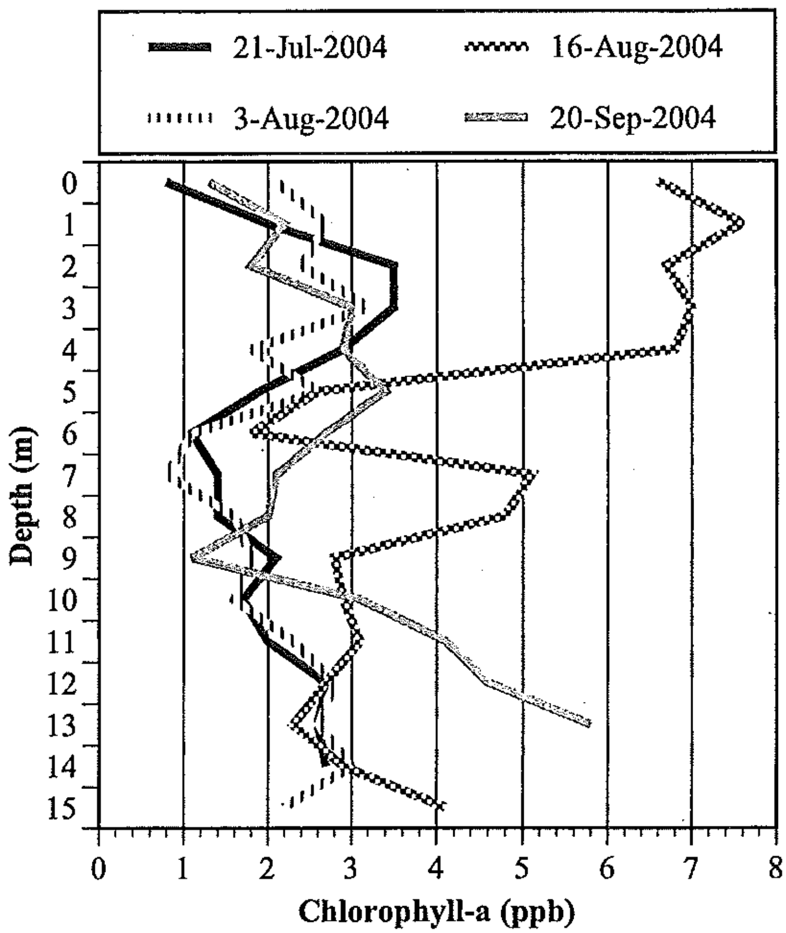

Figure 30. Distribution of chlorophyll-*a* with depth at Site 1. See Togus Pond Site map for Site 1 location (Figure 11).

Levels of chlorophyll-*a* were inversely related to transparency, confirming that algal blooms decreased clarity of the water (Figure 31). Although chlorophyll-*a* varied directly with transparency, it did not appear to be as closely correlated with phosphorus (Figure 32). Chlorophyll-*a* and total phosphorus peaked simultaneously in 1991 and 2000 but a major peak in chlorophyll-*a* in 1978 was not accompanied by a peak in phosphorus, which also corresponded with very low transparency (Figure 31). A peak did occur two years later, however, in 1980 (Figure 32).

It is difficult to determine the relationship between phosphorus and chlorophyll-*a* because there is a gap in the historical data. In addition, although the data available indicate that enough phosphorus was present in the lake for algal blooms to occur (more than 15 ppb), they did not always appear, and the peaks for production (chlorophyll-*a*) did not always coincide with the peaks in total phosphorus. This uncertainty indicates that some other natural factor such as weather might be influencing when and to what degree available phosphorus drives algal blooms (Bouchard pers. comm.).

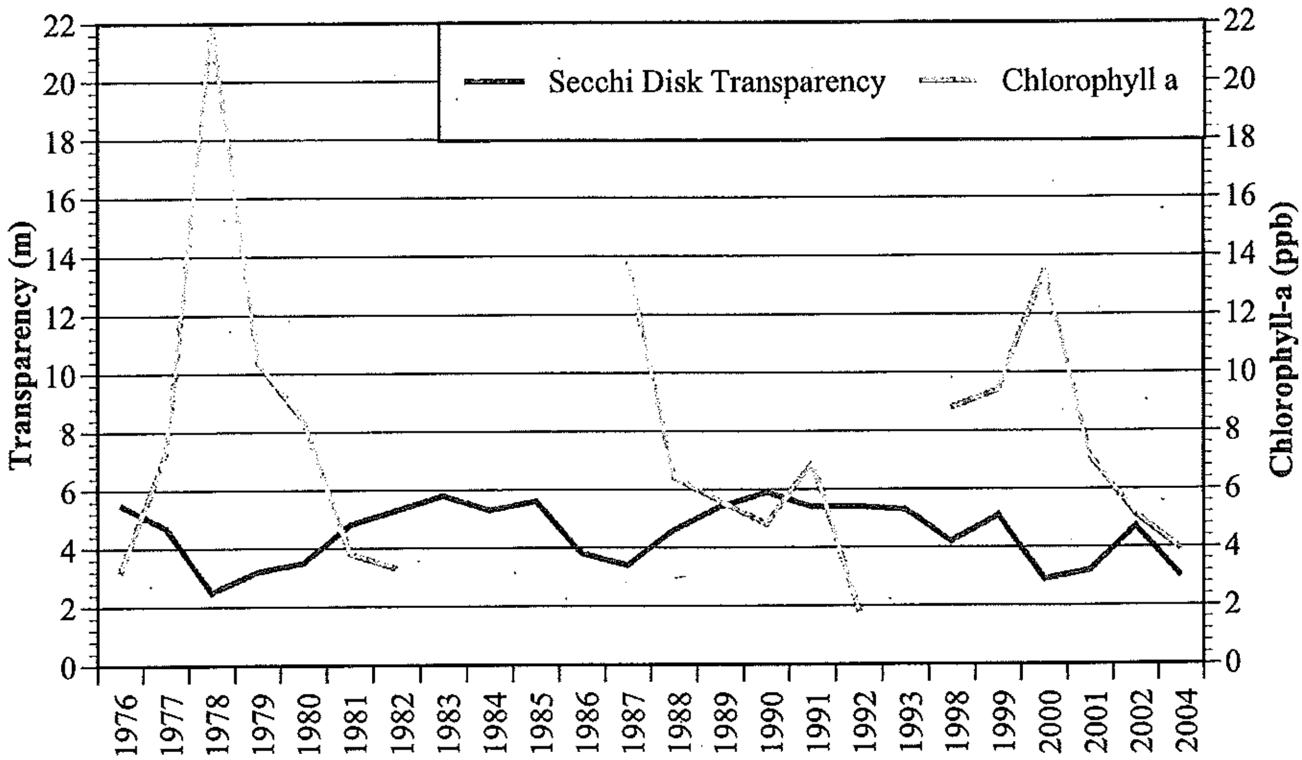

Figure 31. Historical relationship between chlorophyll-*a* and secchi disk transparency Site 1. The values represent the annual mean for both variables (PEARL 2004c). See Togus Pond Site map for the location of Site 1 (Figure 11).

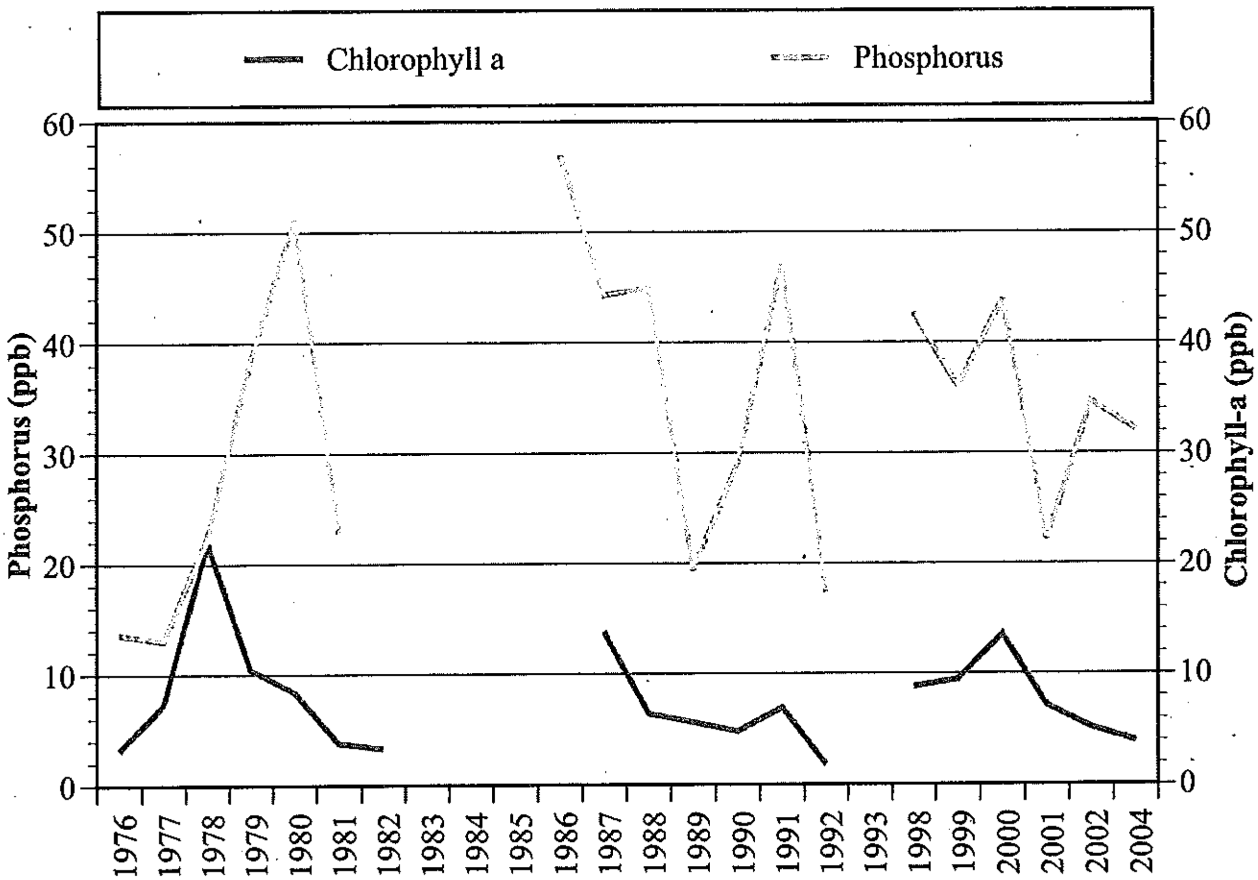

Figure 32. Historical relationship between mean total phosphorus and chlorophyll-*a* levels at characterization Site 1. Values represent the annual mean for both variables (PEARL 2004c). See Togus Pond Site map for the location of Site 1 (Figure 11).

WATERSHED LAND USE PATTERNS

INTRODUCTION

An investigation of the land use patterns in the Togus Pond watershed, based on 2002 aerial photos, was conducted by CEAT to complement water quality and development analyses. Such a survey is critical to conducting an analysis of watershed health, because each land use type has unique potential effects on water quality. Each type of land use in the watershed contributes differently to the overall level of nutrient inputs reaching a body of water, because each type experiences erosion of phosphorus-carrying sediments at different rates. For example, forested lands serve to control soil erosion and absorb runoff from rainwater, and are expected to have a beneficial effect on water quality by reducing nutrient loading in the lake. In contrast, residential land generally has a large amount of impervious surfaces, such as driveways and rooftops, which promote runoff into the lake and have a detrimental effect on water quality.

An examination of historical land use change within the Togus Pond watershed between 1954 and 2002 has also contributed to a better understanding of the current status of Togus Pond. The Augusta area and the Togus Pond watershed in particular have undergone significant economic and population changes during this 48-year time period, which are visible in the evolving composition of land use types in the watershed (see Togus Pond Characteristics: Historical Perspective: Regional Land Use Trends). The investigation of historic land use trends is an important component of understanding how the watershed has arrived at its present condition. For example, if large-scale agriculture or commercial uses increased over time in a watershed, it would be reasonable to anticipate an increase in nutrient loading over the same time period.

METHODS

A Geographic Information System (GIS), which allows the electronic manipulation of geographic layers to help analyze land use types, was used to map land use patterns of the Togus Pond watershed for 1954 and 2002 (Figures 33 and 34). The GIS work was conducted using ArcGIS™ 9.0 software, which enables the user to portray a variety of geographical characteristics (such as slope, soils, or land use types) and to combine them with other layers (see GIS: Introduction). Aerial photography of the Togus Pond watershed was used as the basis for the land use maps. For the 1954 land use map, nine black and white aerial photographs (1inch:1000 ft scale) were purchased from the J.W. Sewell Company in Old Town, Maine. For the development of the 2002 land use map, 14 color aerial photographs with considerably greater resolution (1inch:750 ft scale) were obtained from the J.W. Sewell Company. For each of the two years, the individual photographs were aligned to produce an image displaying the entire expanse of the watershed. A 1954 photographic image could not be obtained for a small area in the southeast of the watershed, so there is no data available for this area in the 1954 land use map.

For both land use maps, it was necessary to first georeference, or assign coordinate values to, the aerial photographs before they could be used in GIS. Layers in a GIS exist in a coordinate space defined by easting and northing coordinates. Because the aerial photographs were simple digital images and were not defined by a coordinate system, it was necessary to assign coordinates to the images so that land use designations could be interpreted through GIS. Georeferencing was accomplished by matching each photograph to existing data layers of the roads and the water bodies in the Togus Pond watershed. This was done by assigning control points (points marking identical locations on the photograph and the existing layers) at obvious road intersections or shoreline features, which fit the photograph to the appropriate coordinate system.

The watershed boundary, roads layer, and ponds layer of the Togus Pond watershed were downloaded from the Maine Office of GIS (MEGIS) and imported into ArcGIS™ 9.0 for use in georeferencing the photographs and constructing the land use maps (MEGIS 2004). For development of the land use map, a new layer was created that classifies the entire area of the watershed into ten unique land use types. Each area of visibly different land use in the photographs was outlined with drawn polygons, which were color-coded to distinguish among land use characterizations.

The land use classifications and descriptions were slightly modified from those used by CEAT in the Threemile Pond study (CEAT 2004). The ten classifications used in the land use maps are wetlands, mature forest, transitional forest, old field, cleared land, cropland, hayland, pasture, commercial/municipal, and residential. The definitions of the land use categories are as follows:

Wetlands: transitional zones between terrestrial and aquatic ecosystems, including all forms of freshwater wetlands.

Mature forest: forest habitat having a distinctly closed, continuous tree canopy with no identifiable patches or breaks.

Transitional forest: forest habitat with at least 50% tree cover, consisting of a mixture of shrubs, young trees, and old trees, which results in a patchy, uneven canopy.

Old field: land that is no longer under cultivation and is undergoing the process of succession from agricultural land to mature forest. Old fields are characterized as dry land with less than 50% tree cover, and often retain the shape of the previously agricultural field.

Cleared land: cleared patches of forest that are often associated with logging operations, and that may or may not contain logging roads and trails from skidders. Cleared land was distinguishable from agricultural land since it is typically surrounded by forest and is not commonly found in association with houses or barns.

Cropland: plowed areas exhibiting even rows that indicate a planting pattern.

Hayland: grasslands exhibiting row patterns from planting or mowing.

Pasture: cleared land without crop rows. Pasture was distinguished from land cleared for forestry by its association with animal agriculture and its proximity to cropland, roads, and nearby houses, barns, and storage buildings.

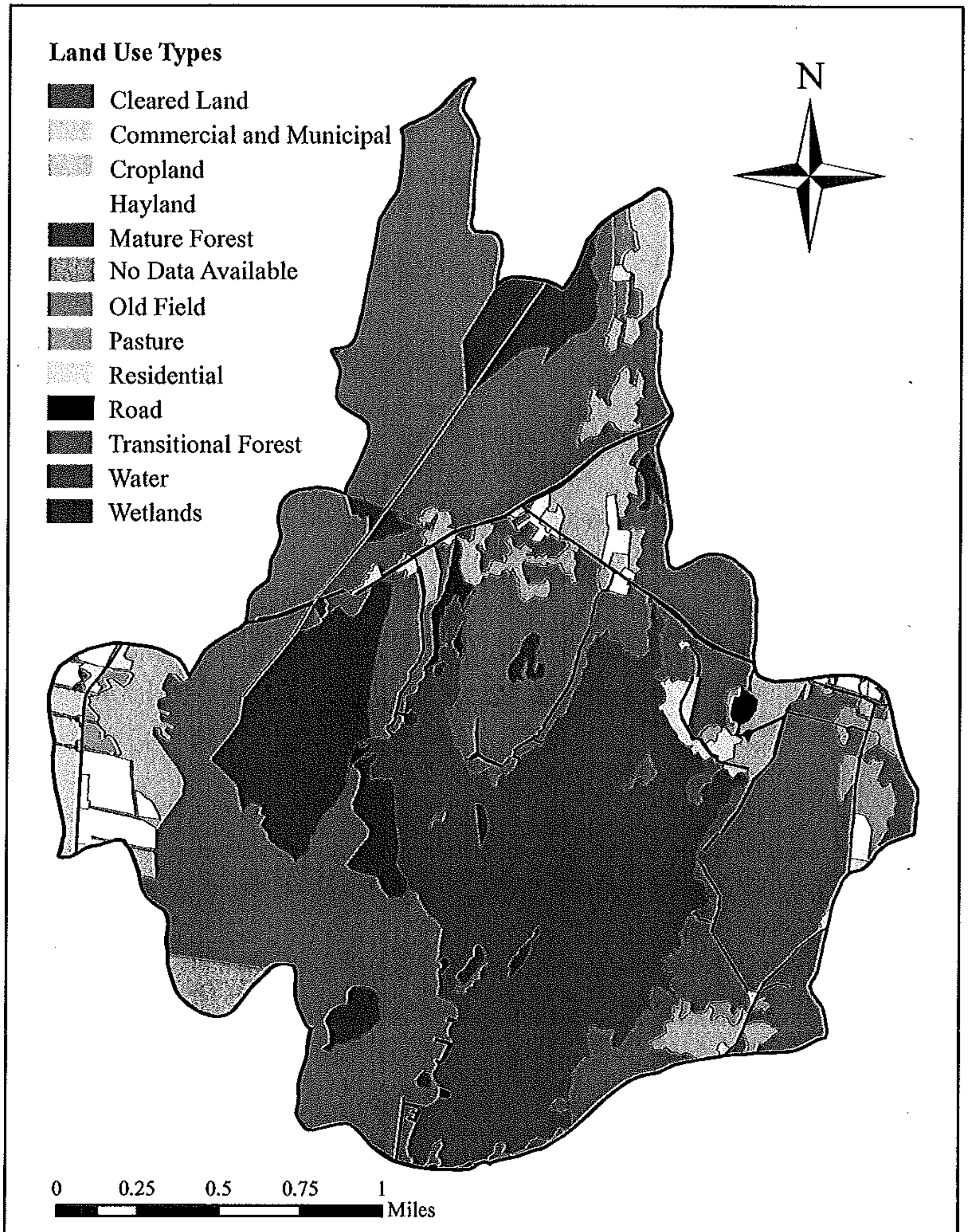

Figure 33. Land use patterns for the Togus Pond watershed in 1954. Each color on the map represents a different land use type, as indicated in the legend. Land use types were determined using aerial photographs at a scale of 1 inch to 750 ft, using methods defined in the text (see Watershed Land Use Patterns).

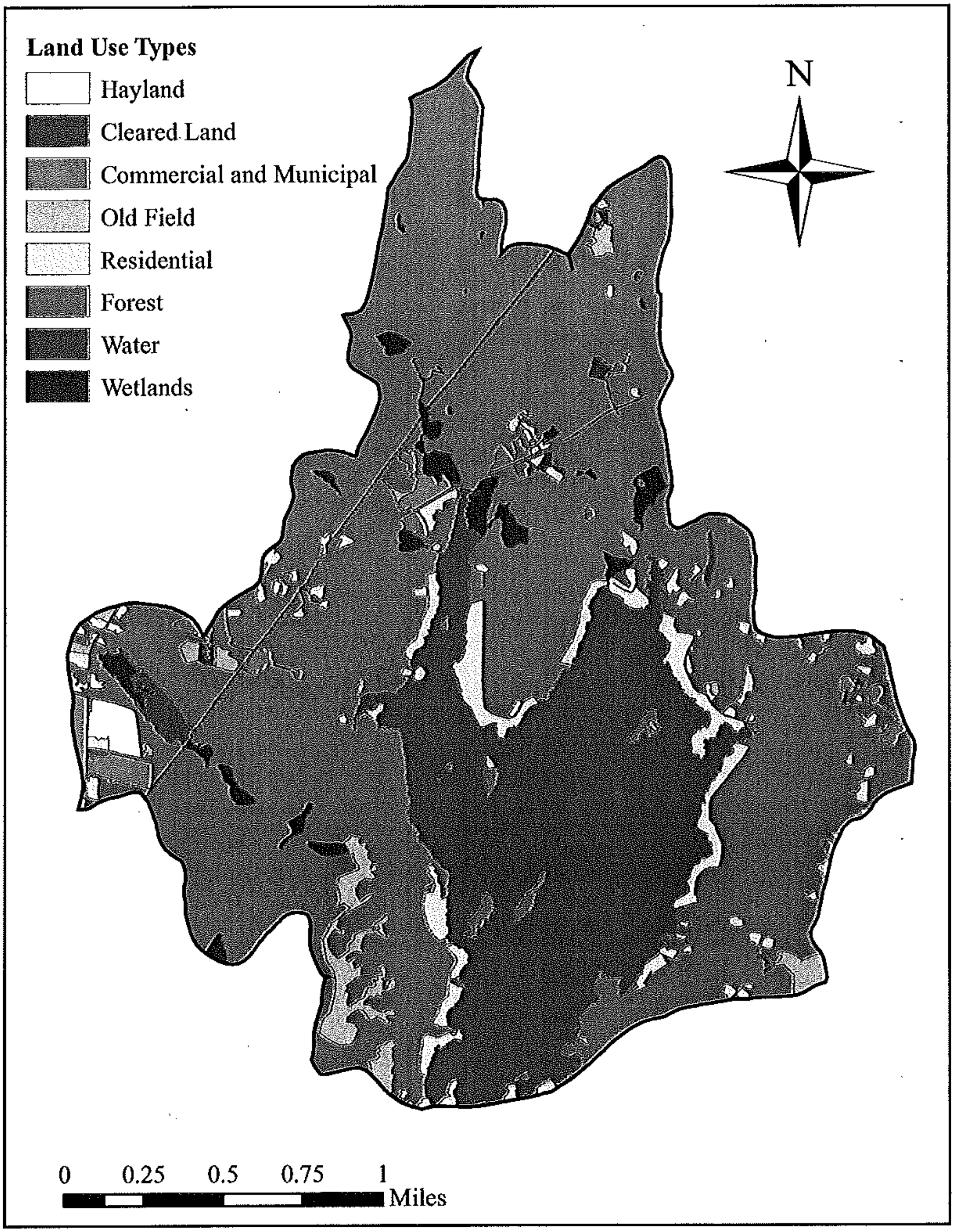

Figure 34. Land use patterns for the Togus Pond watershed in 2002. Each color represents a distinct land use type as defined in the text. Land use types were determined using aerial photographs at a scale of 1 inch to 750 feet, using methods defined in the text (see Watershed Land Use Patterns:Methodology).

Commercial and municipal: all businesses and public facilities, such as shops and schools. Land use areas of this type were designated as the smallest area containing buildings, parking lots, and other impervious surfaces. Large cleared or wooded areas contained within commercial/ municipal property boundaries were not included in this designation, but rather were classified individually, as they better represent their own separate land use types in their effect on lake water quality.

Residential: privately owned land with one residential unit and associated buildings such as a garage or shed. The residential land use area was designated as the smallest area containing the house, associated buildings, small lawns, and gardens. As in the commercial/municipal classification, large cleared or wooded areas within the residential property boundaries were classified as separate land use types, rather than being included in the residential designation.

Modifications of the descriptions used by CEAT in the Threemile Pond study (CEAT 2004) include the reclassification of "reverting land" to "old field", and the addition of "hayland", which was previously grouped together with the "cropland" classification. Reverting land was renamed as old field to better describe the appearance of this land use type in aerial photography and to better describe its impact as a contributor to water quality. Hayland was distinguished from cropland because of the significant differences in the effects of these two land use types on water quality (see Watershed Land Use Patterns: Agriculture).

All ten land use classifications were used in the construction of the 1954 land use map, however only nine were used in the 2002 land use map, for which transitional and mature forest were grouped together to provide the more general category of forest. The aerial photographs depicting the 2002 Togus Pond watershed were taken in April, at which time the deciduous trees, which comprise the majority of the forest cover in the watershed, were still entirely bare of leaves. This lack of foliage made it nearly impossible to determine the evenness of the tree canopy, and we were unable to accurately classify the 2002 forest areas as either mature or transitional. In contrast, the 1954 aerial photography was taken during the growing season, and the foliated tree cover clearly depicted the evenness of the canopy. The distinction between mature and transitional forest was kept in the 1954 land use map because of our ability to distinguish the two types of forest and because of the additional insight the distinction provides.

The roads of the Togus Pond watershed were not investigated through the GIS characterization of land use for 2002, due to the inability of the aerial photographs to clearly display the full extent of the roads. Because some of the smaller roads may not have been visible due to resolution limitations, and because some areas of the roads may have been obscured by the tree canopy, a GIS analysis was not the most accurate method available for assessing the land area dedicated to roads. Instead, the total road area of the 2002 watershed was more accurately calculated by conducting a field survey of the length and width of all roads (see Watershed Development: Road Survey). In constructing the 2002 land use map with GIS, all visible roads were included in the forest land use classification, and the total road area calculated from the field survey was then subtracted from the forest area. For the 1954 land use map, it was not possible to obtain a more accurate field-measured calculation of the road area, because the roads found in the watershed today are not identical to those that were present in 1954. The only option for calculating the road area of the 1954 watershed was by using GIS to digitize the roads visible in the aerial photographs. This distinction explains the presence of the road polygon in the 1954 land use map (Figure 33) and its absence in the 2002 land use map (Figure 34).

After the watershed for each year was categorized and digitized by drawing polygons, the 1954 and 2002 land use maps were finalized by merging the polygons to create a single polygon for each land use type in the watershed (Figures 33 and 34). From these maps, the total area dedicated to each land use type was calculated for 1954 and 2002 (Figure 35).

Additionally, a land use change map was created using the data layers from the 1954 and 2002 land use maps (Figure 36). The 1954 and 2002 land use layers were projected over each other, and the intersection function of ArcGIS™ 9.0 was used to display the areas that have undergone changes in land use over the time period. These areas of change were imported into a new data layer, from which the areas that did not change were excluded. Each unique type of change was characterized by its 1954 and 2002 land use classifications, and each area of change was color-coded according to these characterizations. The remaining area of the watershed, which did not change in land use type, was colored gray in the map.

To enable the land use comparison between the 1954 and 2002 land use maps, the two systems of forest classification were equated by summing the mature and transitional forest areas of the 1954 map to match the broader 2002 category of forest. Similarly, other land use classifications were grouped into broader categories for both years in the land use change map, in order to simplify the land use change characterizations: the classifications of cropland, hayland, and pasture were grouped into the broader category of agriculture; old field and cleared land were grouped into the category of disturbed forest; and commercial/municipal and residential were grouped into the category of developed land. Wetlands were not included in the land use change map because we were unable to determine whether changes in wetland area were real, or whether they were products of the differences in resolution between the 1954 and 2002 photographs (see Watershed Land Use Patterns: Wetlands). This ability to group the specific land use classifications into broader categories will also prove useful when conducting future comparisons of the Togus Pond watershed with other watersheds that have been investigated in past CEAT studies, as these studies have all used slightly different land use classifications.

WETLANDS

Introduction

Wetlands are defined as areas that have waterlogged soils for the entire year, or for extended periods during the year, including the growing season (EPA 2004). Wetlands represent transitional zones between aquatic and terrestrial ecosystems, and serve important functions for both people and

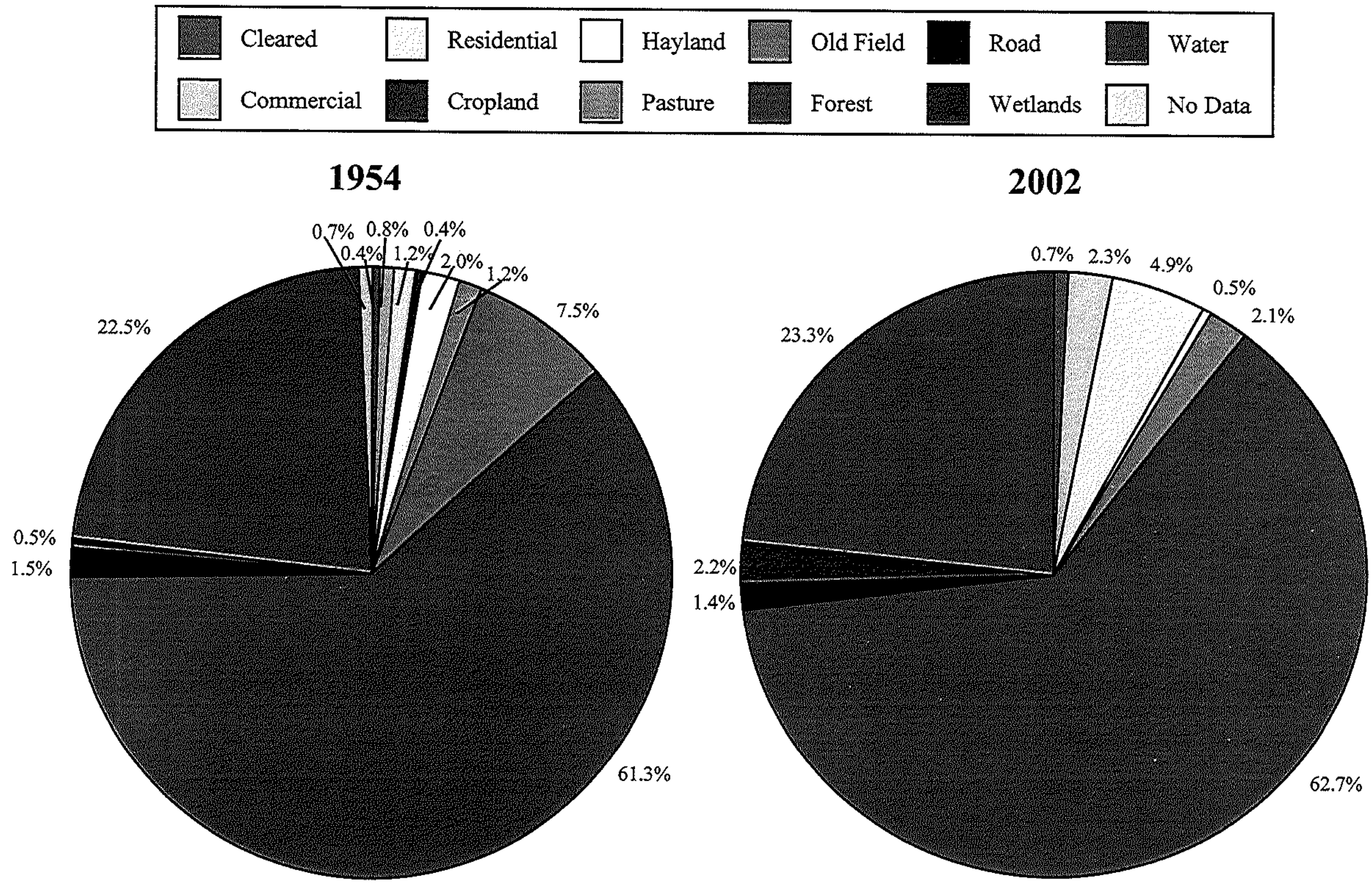

Figure 35: Percent of the Togus Pond watershed covered by each land use type for 1954 and 2002. See Watershed Land Use Patterns: Methods for land use definitions.

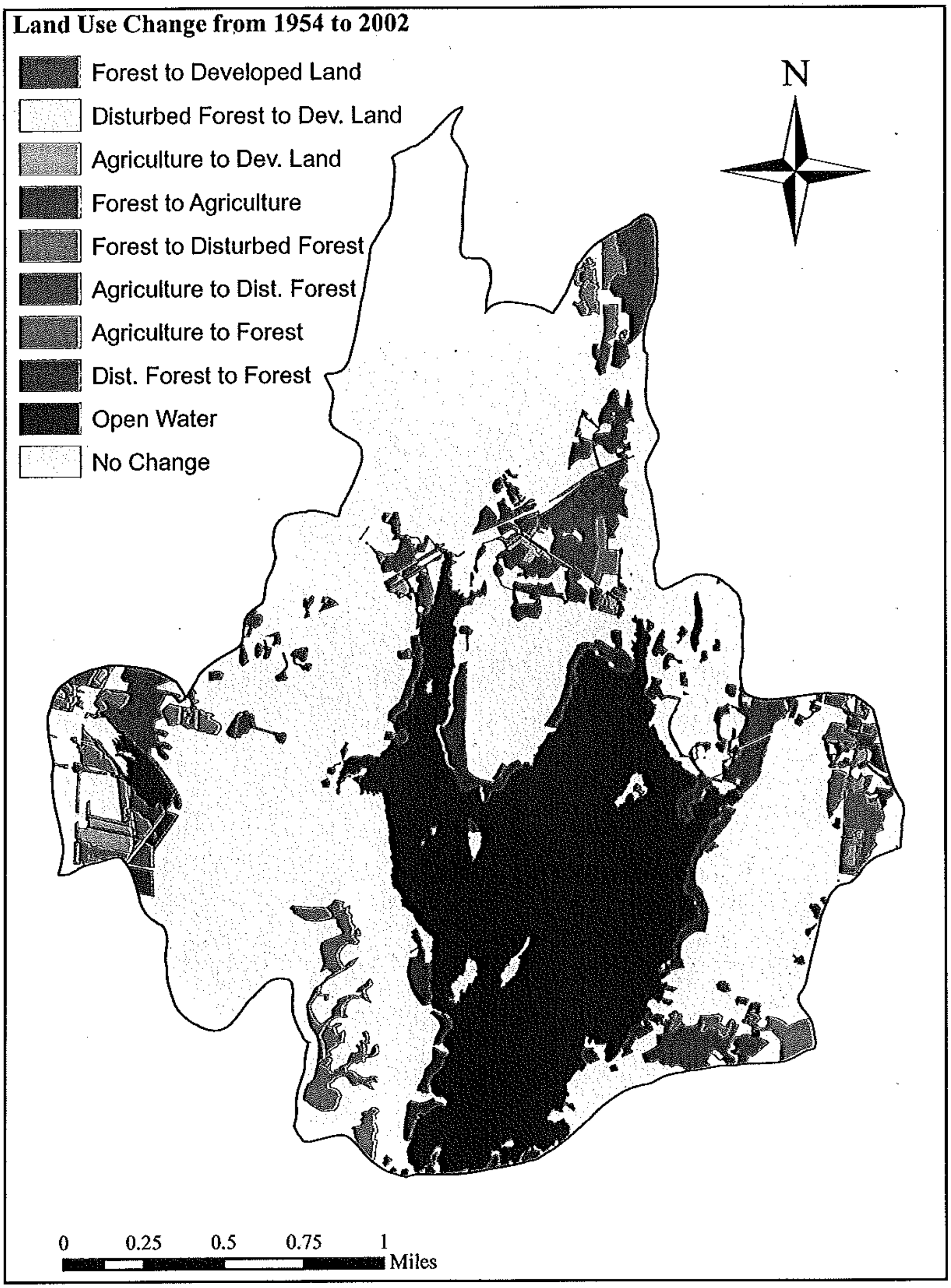

Figure 36. Land use change of Togus Pond watershed between 1954 and 2002. Please see text for definitions of land use categories.

wildlife. The shallow water, high productivity, and abundant nutrients in wetland areas provide valuable habitat for numerous species. Wetlands also help protect lakes from harmful pollutants, sedimentation, and runoff. Acting as a filter, the wetland slows runoff and removes sediments and pollutants that would otherwise reach the lake. Plant roots and microorganisms in the soil absorb nutrients, while other pollutants are bound to soil particles (EPA 2004). In addition, wetlands act as nutrient sinks, naturally reducing anthropogenic inputs of phosphorus before they enter lakes and streams (Keenan and Lowe 2001).

The wetland land use characterization included all types of freshwater wetlands contained within the Togus Pond watershed, which were identifiable in the aerial photography as dark areas indicating waterlogged soils.

Results and Discussion

In 1954, wetlands composed only 14 acres of the Togus Pond watershed, or 0.5% of the total watershed area (Figures 33 and 35). Wetlands covered an area of 65 acres in 2002, or 2.2% of the total watershed area (Figures 34 and 35). These data show an increase of 41 acres of wetland area between 1954 and 2002. It is not likely, however, that these results reflect an actual increase in the acreage of wetlands over this time period. It is more likely that these data are a construct of the relatively poor resolution of the 1954 aerial photography, in which it was very difficult to discern wetland from forest areas. The only wetland areas that were visible in the 1954 aerial photographs were those directly bordering the lake, most notably surrounding Hayden's Cove and the northwest cove. The majority of these wetlands were still present in 2002, and the additional wetland areas that appear in the 2002 photographs were located among forest areas at greater distances from the lake. It is probable that these areas were indeed wetland in 1954, but that their location made them appear identical to the surrounding forest in the black and white 1954 aerial photographs.

While the indicated increase in wetland area may not be real, it is promising that these data do not indicate a decline in wetland acreage in the Togus Pond watershed. National trends have reflected the opposite to be true throughout the country, with wetland areas decreasing ever since the era of colonial America. From the 1780's to the 1980's, the United States lost 53% of its original wetlands (Dahl 1990). The Department of the Interior Fish and Wildlife Service reports that between 1986 and 1997 there was a net loss of 644,000 acres of wetlands in the nation (USFWS 1998). Data collected by previous CEAT studies indicate a decline in wetlands in the Lake George and Oaks Pond watersheds and in the Lake Wesserunsett watershed in the Skowhegan area. The Togus Pond watershed, however, does not appear to exhibit these local and national trends of wetland loss. The maintenance of wetlands in the Togus Pond watershed may be a result of Augusta ordinances regulating development on and around wetland areas.

FOREST TYPES

Introduction

Forested land is highly desirable in a watershed because it helps to prevent nutrient loading of water bodies. The vegetative cover provided by trees, shrubs, undergrowth, and naturally occurring detritus serves as a physical barrier to runoff, reducing the chance that sediments will reach the lake. Once the sediments are stabilized, vegetation provides a sink for the nutrients that the sediments carry, especially nitrogen and phosphorus. Both the roots and the aboveground portions of the trees tend to absorb rainwater instead of allowing it to flow over the ground as runoff; by reducing the velocity of rain before it hits the ground (which lowers the erosion potential by softening the impact) and by protecting the ground from wind, the forest also reduces the amount of soil carried away by any water that does run off (Gottle et al. 1997).

For the purposes of our study, any area with a tree cover of greater than 50% was considered forested. For reasons previously mentioned (see Watershed Land Use Patterns: Methods) forests were categorized as mature or transitional for the 1954 land use map (Figure 33), but were considered a single category for the 2002 land use map (Figure 34).

Results and Discussion

In 1954, forests covered 61% of the Togus Pond Watershed. The greatest part of this forest, and the dominant land use category for the watershed at this time, was transitional forest. Transitional forests accounted for 52% of the watershed area and 84% of the forested land in the watershed (Figures 33 and 35). These areas were probably regenerating from former agricultural use (see Togus Pond Characteristics: Historical Perspective). Some mature forest was also present in the western and northern parts of the watershed, accounting for 16% of the forested land and 9.6% of the watershed area.

In 2002, the forested area had increased slightly to 64% of the Togus Pond watershed, but due to the nature of the photographs it was impossible to distinguish different successional stages. It is probable that many areas of forest that were transitional in 1954 and that still stood in 2002 had reached successional maturity.

CLEARED LAND

Introduction

The clearing of forested land negates its beneficial influence on a watershed. When trees are removed, they can no longer act as a nutrient sink, absorb rainwater, or inhibit runoff. Under natural conditions, trees continually shed small quantities of bark, twigs, and leaves as these tissues die. In most logging or other clearing operations, large amounts of such debris are left on the site, where they decompose all at once and contribute a surge of nutrients to the system (Institute of Water Research 1997). When heavy equipment is used for the clearing operation, it compacts the soil, creating a less permeable surface and further encouraging runoff (Institute of Water Research 1997). Poor logging techniques, such as removing more than 50% of the trees in a given area, causing massive surface disturbance, or leaving inadequate buffers between clearings and water bodies, can have a huge impact on water bodies. Under these conditions, the amount of sediment reaching the water body from the forest may be as much as four thousand times higher than under undisturbed conditions (Kreutzweiser and Capell 2001). In the aerial photography used in this study, areas of cleared land were identifiable as light-colored areas surrounded by forest.

Results and Discussion

In 1954, the total area of cleared land was only 11 acres, or 0.4% of the watershed (Figures 33 and 35). By 2002, this area had increased to 21 acres, or 0.7% of the watershed. Although this represents almost a doubling in the amount of cleared land, the areas involved are not significantly large and are generally located in areas that were already disturbed by residential development. It is probable that these areas were cleared for building along existing roads. However, road survey data from the fall of 2004 indicate that since 2002 a large area in the vicinity of the Pipeline Road has been newly cleared; this area is within view of the water and on a downward slope, so it may have an effect on the lake.

AGRICULTURE

Introduction

Most forms of agriculture contribute to the nutrient loading of lakes in two ways: by disturbing the soil (increasing the chance of erosion) and by adding varying quantities of nitrogen and phosphorus in the form of fertilizer to soil that might be washed into the lake as runoff.

Cropland (usually silage corn or potatoes in Maine) creates runoff with a high ratio of nitrogen to phosphorus (Arbuckle and Downing 2001). Because the soil is plowed every year, some runoff of sediments is very likely. Cropland also receives annual applications of water-soluble fertilizers. Cropland is the most frequent recipient of pesticide applications as well, which may also wash off and contaminate nearby water bodies. In the aerial photographs, cropland had three distinguishing characteristics: visible row patterns created by plows or tillage tools, a small border of unplowed land surrounding the plowed areas, and a lack of hedgerows dividing the fields into "lands".

Hayfields are usually only plowed once every five to ten years, so the runoff of sediments is on average less than in the case of cropland. Many, but not all, hayfields receive annual applications of fertilizer, but applications of pesticides are very rare. Hayfields were identifiable in the aerial photographs because the mower swaths were visible, because the "rows" created by the mower swaths abutted the edges of the fields, and because in most cases a series of hayfields was divided into lands by hedgerows.

Pastures are, in most cases, never plowed, but disturbance of the turf by animal traffic may lead to areas of bare or compacted soil that contribute to the runoff of sediment. Pastures do not receive fertilizer applications, but the animals grazing them drop manure. Animal manure is rich source of leachable nitrogen and phosphorus. Animal agriculture results in runoff with a high ratio of phosphorus to nitrogen, which is associated with algal blooms (see Background: Phosphorus and Nitrogen Cycles; Arbuckle and Downing 2001). Pastures, unlike cropland, do not receive pesticide applications. Identifiable features of pastures in the aerial photographs were a lack of row patterns from tillage tools or mower swaths, fewer shrubs and less variation in vegetation than in old fields, and sometimes meandering tracks beaten down by animal traffic or visible fence lines.

Results and Discussion

Agriculture was not as prevalent in the Togus Pond watershed as in nearby watersheds in the 1950's, and by 2002 it had almost disappeared (CEAT 2001, 2004). In 1954, the watershed contained 10 acres of cropland, 59 acres of hayfields, and 35 acres of pasture (0.3%, 2%, and 1.2% of the watershed area respectively; Figures 33 and 35). In 2002, the watershed contained no cropland, and no pasture, and only 13.6 acres of hayfields, comprising a mere 0.4% of the watershed area. These hayfields are located on the western boundary of the watershed and are unlikely to contribute appreciably to the nutrient loading of the lake.

COMMERCIAL AND MUNICIPAL

Introduction

Commercial land is used for businesses, such as stores, gas stations, or restaurants. Municipal land consists of areas used by the city, such as schools, fire stations, or road maintenance facilities. Often, parking lots or other impervious surfaces are found within commercial and municipal areas. Parking lots contain a high concentration of pollutants associated with automobiles, such as gasoline, oil, and lead. Parking lots, along with other impervious surfaces, do not allow water to penetrate the soil column and cause increased water runoff, which can lead to erosion. This runoff, along with the particles it carries, moves downhill and can eventually be deposited in Togus Pond.

During our land use analysis, commercial and municipal land was defined as having a parking lot present or an obvious business of some kind (such as the golf course and the junkyard). During the road survey on 4-Oct-04, CEAT noted locations of commercial lots, which further increased the accuracy of the land use map.

Results and Discussion

In 1954, the total area of commercial and municipal land was 22 acres (0.75% of the watershed), which increased to 67 acres (2.28%) by 2002. This represents a three-fold increase in the last 50 years. Throughout this time period, the major contributor to this category was the Western View Golf Club on Bolton Hill Road. Although the golf course has remained the same size, other commercial land development, especially along Route 3, has increased the total area of commercial land. All of the commercial and municipal land is located at a significant distance from the lake and this helps to reduce its effect on the water quality of Togus Pond. Its small overall area and Department of Environmental Protection permit requirements also limit the effects of the commercial and municipal lands in the watershed. In the future, commercial land is sure to increase, as the golf course plans to construct a nine-hole expansion on the watershed side of Bolton Hill Road (Connolly pers. comm.) The growing population of the area may also initiate further development of commercial and municipal land, so this land use type is definitely a nutrient loading concern for the future.

RESIDENTIAL

Introduction

Résidential land was defined in this study as an area containing a house, any surrounding lawns and gardens, the driveway, and any smaller buildings (such as sheds or separate garages). Areas adjacent to houses but with tree cover or old fields (non-manicured lawns) were classified separately, and were not included as residential land.

Since the watershed is heavily forested, some houses may have been obscured under the canopy and missed. This is especially true for the 1954 land use map, but it may also have occurred with the 2002 map as well. In order to account for this, CEAT surveyed the number of houses along the shoreline on 16-Sep-04, and performed a house count along all the roads in the watershed during the road survey of 4-Oct-04. These numbers were used to calculate the approximate impacted area around the residence by assuming that the average shoreline plot encompassed half an acre, and the plots away from the shoreline encompassed a full acre. These areas do not represent the average residential lot sizes, but rather the average area that is likely to contribute to nutrient loading in Togus Pond. These standards were suggested by the Maine Department of Environmental Protection (Bouchard pers. comm.) and have been verified by CEAT in previous years.

Results and Discussion

The amount of residential land in the Togus Pond watershed has increased dramatically since 1954. In 1954 this land use type composed only a small area (33 acres, or 1.12% of the watershed, as determined through the 1954 aerial photographs), and development along the shoreline was limited to a small area along the eastern shore. It is possible that there was slightly more residential land, however, since houses could be obscured under the forest canopy. In contrast, by 2002 there was an increase in residential development along most of the lake shoreline, which now includes 179 shoreline residences. The only exception was the forested section on the western shore, and near the wetland in the northwestern inlet. The total area of residential land in 2002 was 144 acres (4.89%), more than quadruple the 1954 area of 33 acres. The overall population of Augusta decreased during this time, from 20,913 in 1950 to 18,560 in 2000 (Raymond H. Fogler Library 2001). These results may demonstrate a movement away from the developed center of the city and into the more rural surrounding area, which includes the Togus Pond watershed.

The effects of residential land on water quality can be significant, depending on the location of the lot in the watershed and how the individual homeowner maintains it. Buffer strips help to decrease the amount of runoff reaching the lake, but artificial lawn fertilizers and other nutrients or pollutants may still enter the lake and lead to eutrophication. A homeowner can reduce these impacts by using phosphorous-free fertilizers and by maintaining a properly functioning septic system.

GIS

INTRODUCTION

A Geographic Information System (GIS) is a computer application that allows for the manipulation, analysis, and presentation of data that have spatial coordinates (GIS.com 2004). Spatial coordinates allow information to be displayed according to a coordinate system, such as the one used on United States Geological Survey maps, the Universal Transverse Mercator (UTM) projection (USGS 2004b). Although GIS is often confused with maps, they are two different entities. While maps and globes have been used to study the world in the past, they lack the analytical capabilities of GIS (Ormsby et al. 2001). With GIS, users are able to determine relationships between data sets, such as adjacency (what they are next to), containment (how much area they contain), and proximity (how close they are). By combining the many abilities of GIS, various analyses can be performed. It is estimated that 80% of all data have a spatial component (GIS.com 2004), enabling numerous applications for the software, including watershed analysis.

Data inputs for GIS are referenced to coordinates showing a position on the Earth. Many different types of data inputs can be utilized by GIS, including: aerial photographs, Global Positioning System (GPS), online databases, and field sampling of attributes. Much of the data for our study was obtained from the Maine Office of GIS, which provides technical support for GIS data concerning the State of Maine (MEGIS 2004). Each data set or layer illustrates a different topic. For example, layers can show the location of roads, bodies of water, types of soil, or elevation (Figure 37). Each of these individual layers can be added to or removed from the GIS program, allowing for the specific display of only information relevant to the study. The products are not cluttered by extraneous information and the results can be clearly shown, making it easy to visualize and interpret.

Two types of data are commonly shown in GIS format: vector and raster data (Ormsby et al. 2001). Vector data are shown in either point, line, or polygon format. Polygons are used to represent objects that have areas, such as a body of water. If a feature is too narrow to be represented by a polygon, a line is used, such as for a road. If an area is too small to be represented by a polygon, a point is used, such as for a house. Raster data, on the other hand, are a continuous

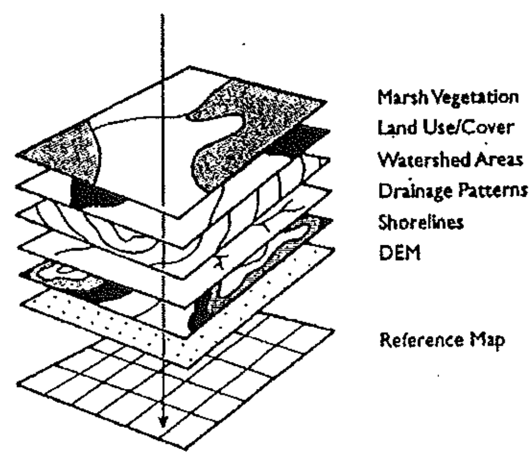

Figure 37. A Geographic Information System allows users to add layers such as roads, vegetation, and watershed boundaries to present specific data without extraneous information (Food and Agriculture Organization of the United Nations 2004).

data set. Instead of representing only certain areas of a map, the raster form contains data for an entire surface. An area is divided up into equal-sized cells, and each cell in the grid is given a value for that location. For example, an elevation raster dataset can be divided into cells of a hundred square meters, and each cell would contain the average elevation for that area. In this study CEAT used ArcGIS™ 9.0 software, which allows for data to be converted into both vector and raster formats depending on its intended use.

CEAT utilized many of the ArcGIS capabilities during our survey of Togus Pond. We produced a bathymetry map, soil map, septic suitability model, and an erosion potential model. All of these were made using ArcGIS™ 9.0, the newest of the ESRI GIS line of products. The GIS models allowed us to analyze the possible impact of factors that may be affecting the water quality of Togus Pond such as slope, soil types, and land use.

BATHYMETRY

Introduction

A bathymetry map shows the overall shape and depth of a waterbody, with darker regions representing the deepest area of the lake and lighter regions representing the shallower areas. Since anoxic areas of the lake are usually found below a specific depth during summer stratification, bathymetry maps make it possible to calculate the volume percent of anoxic lake water. This information is crucial for evaluating the condition of the lake ecosystem, as anoxic conditions can be detrimental to many organisms, including fish (see Water Quality: Physical Measurements: Dissolved Oxygen and Temperature). In addition to affecting the fauna of a lake, anoxic conditions can do further harm by causing excess phosphorus loading, which contributes to algal blooms (see Phosphorus Budget).

Methods

To make the bathymetry map, thousands of depth points with corresponding Geographic Positioning System (GPS) coordinates were gathered on Togus Pond using the LowranceÆ LCX-15MT sonar and GPS receiver on the Colby Department of Biology boat. These points were uploaded to a computer and imported into the GIS software in the Geographic Information Systems lab. They were then converted into a raster data set consisting of 5 m by 5 m cells. Each cell displays the corresponding depth of the area.

The bathymetry map is extremely accurate compared to normal boating charts because of the method in which it was created. Boating charts have limited data points, whereas the Togus Pond map was created with thousands of points to determine the lake bottom shape with greater accuracy. These points were obtained by patrolling Togus Pond in a grid fashion while the system took a depth reading every two seconds. Adding to the accuracy of the map is the fact that the lake bottom may have changed since the boating chart was made. Togus Pond may have filled in a little, or land levels may have changed. The bathymetry map CEAT created corrects these inaccuracies.

By classifying these data into only two categories, the water above and below the thermal water layer at eight meters, it was possible to display the anoxic portions of the lake as discussed in the dissolved oxygen section (see Water Quality: Physical Measurements: Dissolved Oxygen and Temperature).

Results and Discussion

The average depth of Togus Pond is 17.8 feet. The deepest point in the lake is 51.4 feet, but only 24.5% of the lake is deeper than 25 feet. The majority of Togus Pond, 75.5%, is shallower than 25 feet. Most of the shallow areas are located near shore, especially in the northern part of the lake (Figure 38). The deepest parts of the lake are located in the large basin in the middle of Togus Pond This leaves less than a quarter of the lake vulnerable to anoxic conditions, which occur below 8 meters (26.2 feet) (see Water Quality: Physical Measurements: Dissolved Oxygen and Temperature).

Another factor threatening all Maine lakes is the introduction of invasive aquatic plant species (see Background: Togus Pond Characteristics: Biological Perspective: Invasive Plants). Some of these species include Eurasian Watermilfoil (*Myriophyllum spicatum*), Variable Watermilfoil (*Myriophyllum heterophyllum*), and Water Chestnut (*Trapa natans*). None of these species can survive in water deeper than 16 ft (Bunganut Lake Association 2004). This means that about 50% of Togus Pond is exposed to potential invasion, mostly towards the north end of the lake. Boaters must be extremely cautious to ensure that exotic plants are not introduced into Togus Pond.

EROSION POTENTIAL MODEL

Introduction

Soil erosion and runoff causes nutrients, such as phosphorus, and anthropogenic contaminants to enter Togus Pond. When water moves over surfaces that are highly erodible, it carries large amounts of soil particles, which hold nutrients, herbicides, and pesticides. The probable risk of erosion in different areas of the watershed can be displayed graphically on a model, created using GIS.

One of the most powerful uses of GIS is that of making models. Models are maps that combine several input factors weighted to show how these factors might interact. The Erosion Potential Model for Togus Pond consists of the characteristics of the watershed that contribute most to erosion. These characteristics are slope, soil type, proximity to the lake, and land use types. Each of these was weighted by the extent to which it is likely to cause erosion that impacts the lake. CEAT used the raster calculator feature of ArcGIS™ 9.0 to create the Erosion Potential Model, which allowed us to draw conclusions about the effect that erosion throughout the watershed has on the lake and enabled us to pinpoint areas of concern for remediation.

Methods

Soils

A soil classification layer was downloaded from the Maine Office of GIS (MEGIS 2004). These data are the most detailed soil geographic data that have been developed by the National Cooperative Soil Survey. The erosion potential factor (k) provided by the Soil and Water Conservation District was added to the data in the soil type layer (USDA 1978). These values were divided into nine even classes, which represent different levels of erosion potential. For example, clay soils and soils commonly found in bogs and wetlands are less likely to erode than sandy and silty soils (Figure 39; USDA 1978).

Slope

To create a map of slopes in the Togus Pond watershed, the Digital Elevation Model (DEM) of the watershed was downloaded (MEGIS 2004). A DEM is a set of evenly-spaced coordinate points with corresponding elevations. Using the spatial analyst tool, CEAT created a map of percent slope from the DEM. The slope map shows the percent difference in height from one point to neighboring points within the watershed. Slope has major implications for erosion and for the state of the lake in general. Areas with higher slopes are more likely to erode than those with lower slopes. Most of the shoreline of Togus Pond has between 0-2% slope, with a few isolated areas on the west shore of the pond that are steeper. This steeper portion is the shoreline area that has not been developed for residential use. The range of slopes throughout the watershed, 0-55%, was divided into nine equal intervals of about 6% each (Figure 40). These intervals were given scores of 1-9, 1 being the smallest slope, 9 being the largest slope.

Land Use

Each land use from the 2002 land use map was weighted by erosion risk (Figure 34). Mature forest was given an erosion risk factor of one. Phosphorus and other contaminants are held tightly by the complex root systems of mature forests. Furthermore, rainfall does not disrupt the soil in mature forests because thick canopies of trees prevent water from hitting the soil surface directly at a high velocity. Wetlands were also considered to have a low erosion risk designated with a factor of 1 because the high water table in wetlands inhibits erosion. Transitional forest was classified with an erosion risk factor of 3 because of the relatively open canopy and the presence of spaces that lack large tree root systems to hold soil. Old field sites were given an erosion risk factor of 4. In an old field, which is characterized by a mix of grasses, shrubs, and small trees, rain is more likely to reach loose soil than in a transitional or mature forest. Pasture was given a higher risk factor of 7, because of the minimal cover provided by grasses. Residential land, cleared land, cropland, municipal land, and

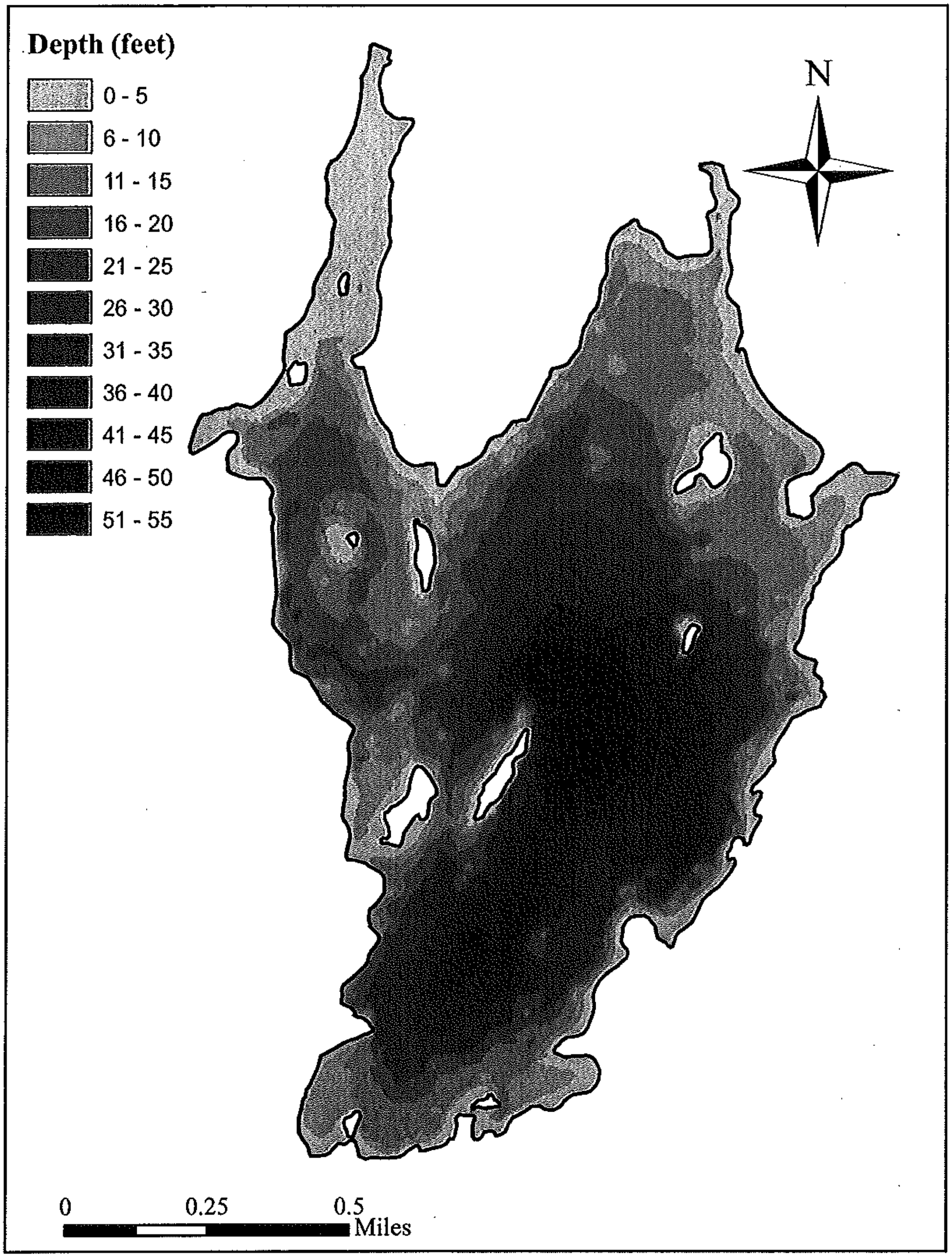

Figure 38. Bathymetry map for Togus Pond with depth measurements in feet. Depth points were acquired using a Lowrance® LCX-15MT, which consists of a boat-mounted sonar device and a GPS unit.

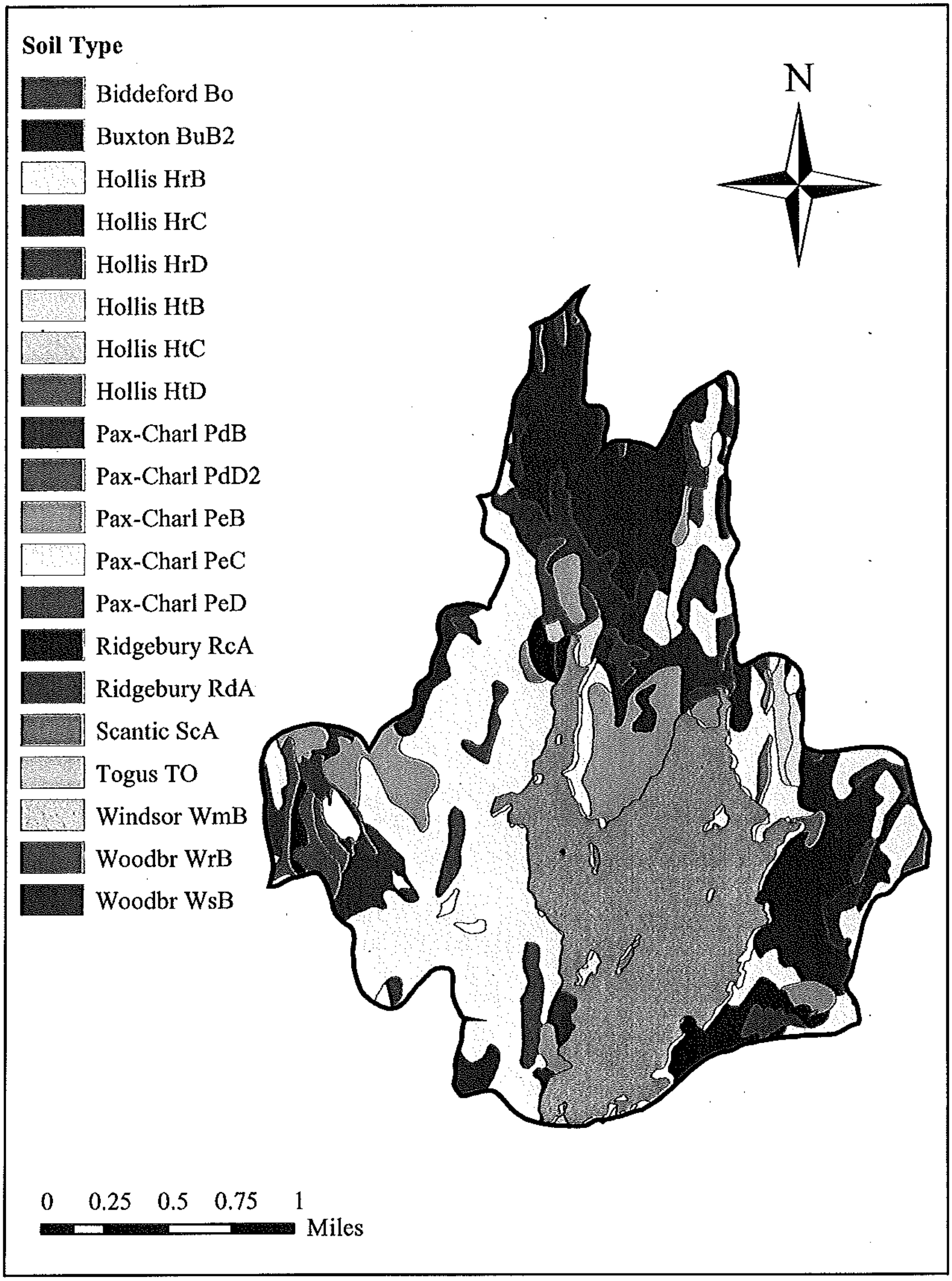

Figure 39. Soil types found in the Togus Pond watershed, obtained from the Maine Office of GIS (2004).

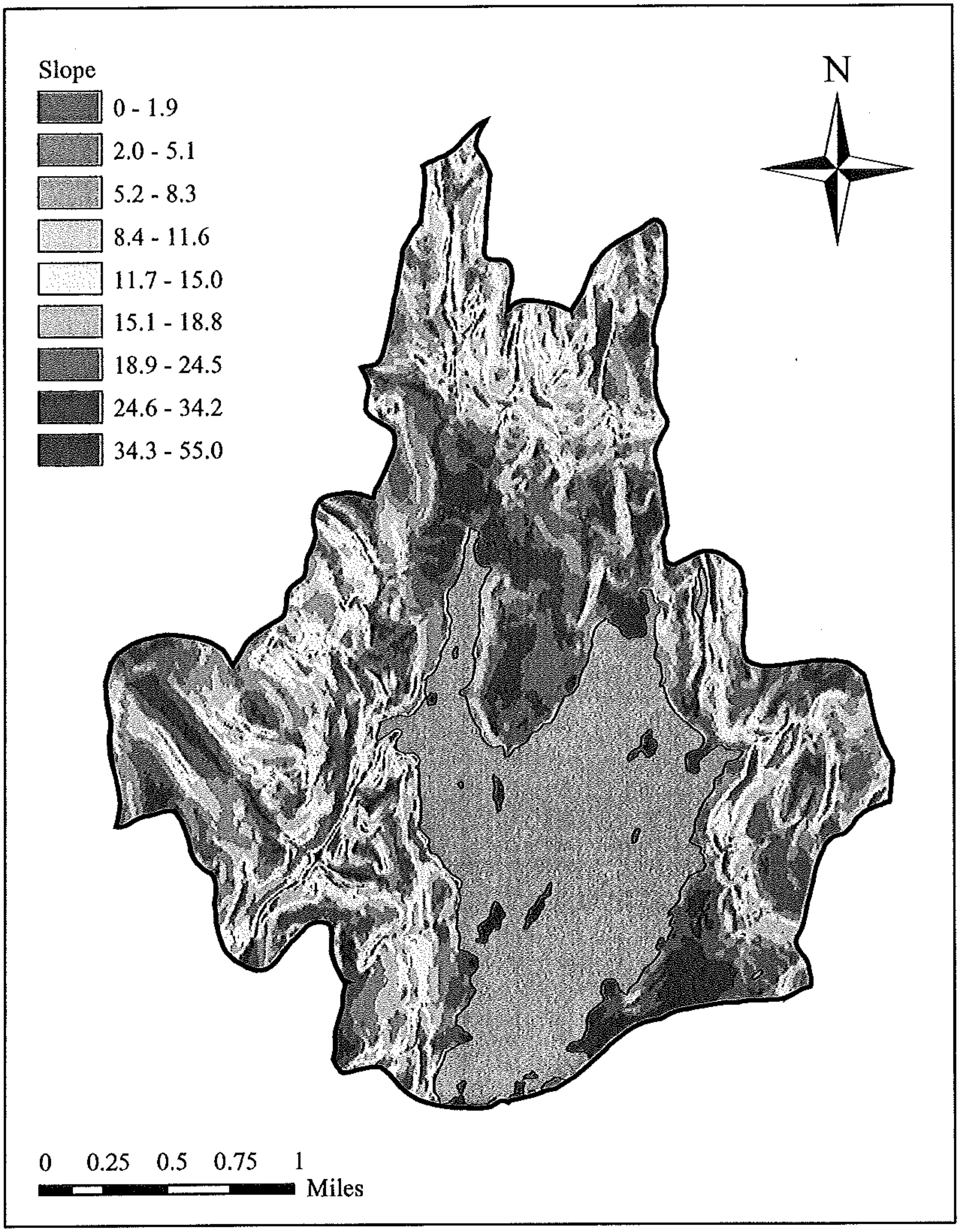

Figure 40. Slope of the land in the Togus Pond watershed as interpolated from the 10 meter Digital Elevation Model, obtained from the Maine State Office of GIS (2004).

roads were each given a maximum erosion risk factor of 9 because open soil and exposed impervious surfaces lead to high amounts of erosion.

Proximity to Lake

Soil erosion near water is a more important factor in influencing the water quality of Togus Pond than that of soil erosion farther away. In ArcGIS™ 9.0, a polygon was created for the shoreline zone of the watershed, including all places that were 200 ft or less from a water body in the watershed. The rest of the area in the watershed was divided into eight polygons, called "buffers", and each buffer had a width of about 850 ft. These polygons were reclassified with values from 1-9, 9 being the 0-200 ft shoreline buffer, which has the most potential impact on water quality and 1 being the buffer that is farthest from the lake.

Weighted Overlay

The weighted overlay combines all four input raster maps, soil, slope, land use, and proximity (Figure 41). The common scale of values (1-9) is applied to all of these inputs. The weighted overlay allows us to measure the relative contribution of each of these inputs to the overall erosion potential of

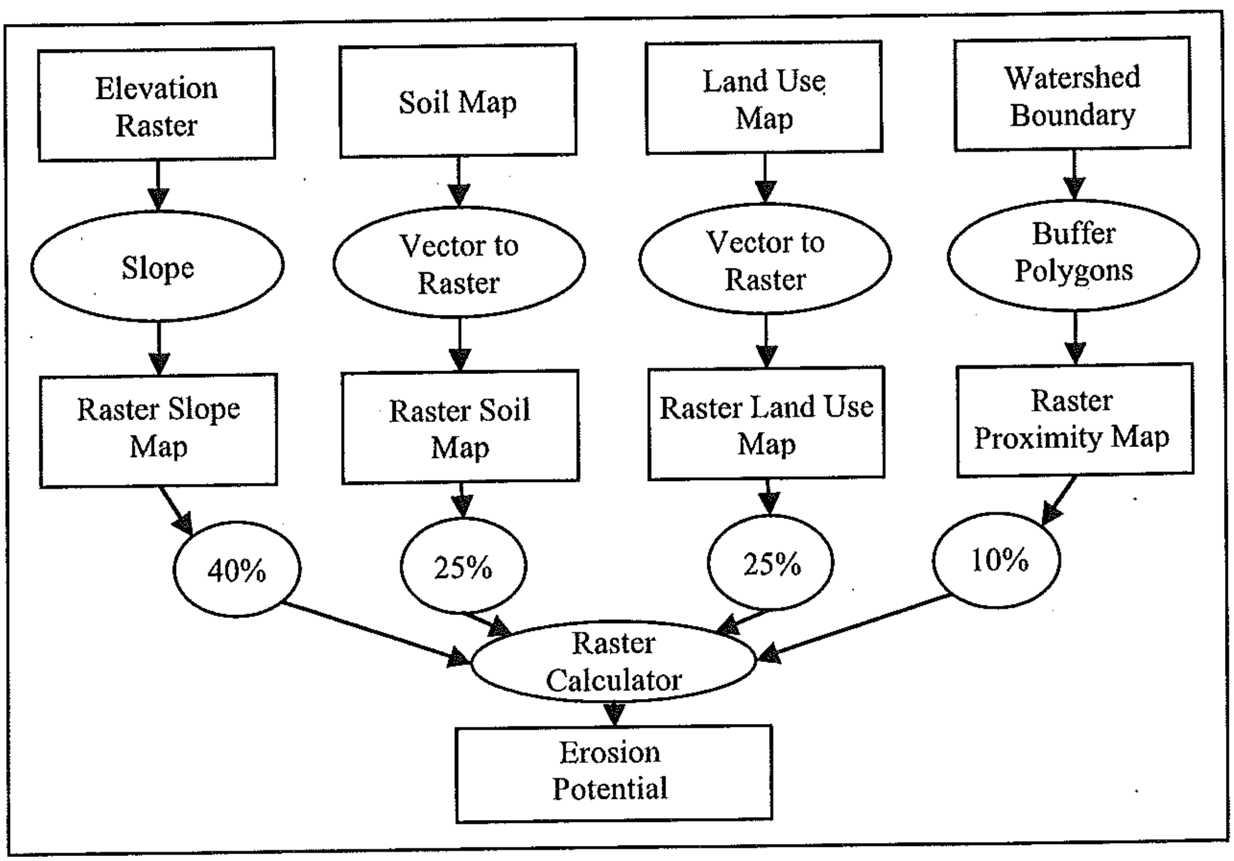

Figure 41. Flow chart showing the inputs and relative weights assigned to the factors that contribute to the erosion potential model. Rasters are arrays of equally spaced cells that together form a geographical image in which each cell is assigned a value, in this case, from 1 to 9.

the watershed. Slope is the most heavily weighted input (40%) because it has the greatest effect on erosion of soil. 25% of the model was weighted on soil, and 25% on land use. 10% of the model was weighted on proximity to the lake.

Results and Discussion

On a scale of one to nine, the Togus Pond watershed had a maximum erosion potential value of 7.75. The average value was 3.20, which means that the watershed, overall, has a moderate amount of erosion potential. Most of the areas that are currently used as residential land did not have extremely high erosion potential. The areas of greatest concern were those having erosion levels between 7.1 and 7.75. These areas were predominantly located on the eastern shore of the lake, which does not have extensive residential development, a land use that has a high erosion potential. The green-colored areas on the map have low levels of erosion potential and are characterized by low slopes, forest or wetland land uses, and soils that are not easily eroded (Figure 42). Because this model accounted for proximity, areas closer to the lake have a higher erosion potential than those that are farther away. This allowed us to consider the impact of erosion on lake water quality, not just erosion alone (Figure 42).

High erosion potential can be mitigated through the use of erosion barriers and land use planning. Development in an area with high erosion potential should be done in a way that controls erosion and limits the impacts on the lake. This model could serve as a tool when planning future developments or erosion control measures. Focusing erosion control efforts on areas with high erosion potential will lead to more efficient prevention of runoff. New housing should be built only in areas with low erosion potential or in areas with high levels of erosion potential only when erosion is properly mitigated since clearing forest and building houses can result in large amounts of erosion.

SEPTIC SUITABILITY MODEL

Introduction

Septic systems of homes in the Togus Pond watershed have a significant potential impact on the nutrient loading of the lake. When the installation of new septic systems or leach fields is being considered, the soil type and slope should be analyzed before construction. This model, much like the erosion potential model, combines two weighted factors, soil septic limitations and slope, into one geographical image that shows how they interact in the overall septic suitability of the watershed. Through the use of this model, areas where septic systems might become a major problem for the water quality of the lake can be easily identified and septic limitations can be properly mitigated.

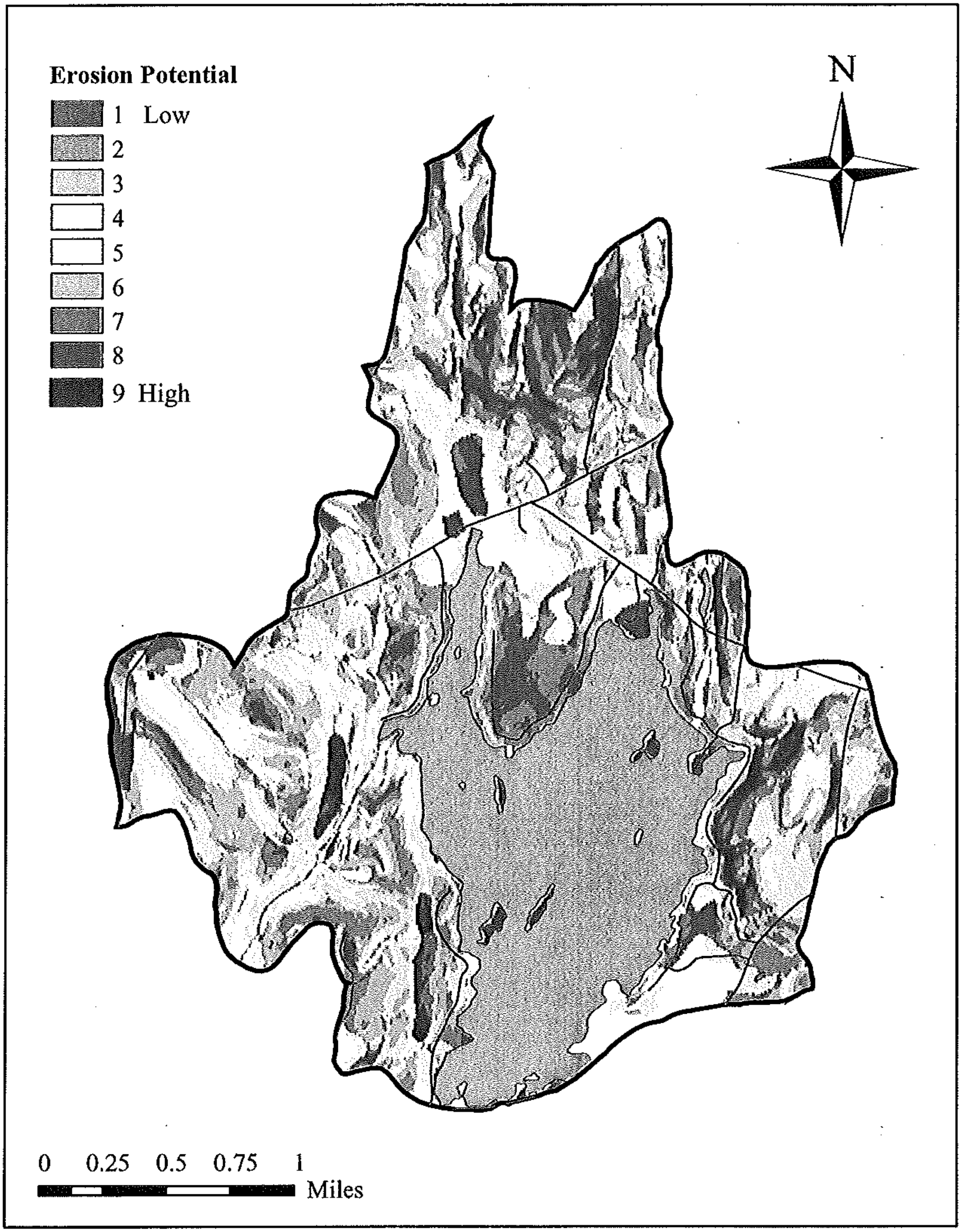

Figure 42. A model showing erosion potential of the Togus Pond watershed which combines slope, proximity, land use, and soil erosion factors into a score of 1-9, where 1 represents areas with low levels of potential erosion and 9 represents areas with high potential erosion that could be detrimental to lake water quality.

Methods

Soils

Soil type is a contributing factor to septic suitability. Soils that drain too quickly do not allow nutrients to permeate out of the leach field, and those that are too dense cause backups in septic systems and leakage. In a USDA (1978) study of Kennebec County soils, septic limitations were assigned to soil types based on permeability and the depth to bedrock or the water table. These septic limitation data were added to the soil type layer, obtained from the Maine Office of GIS (MEGIS 2004). Soils with slight limitations were weighted with the lowest value of one. Those with severe limitations were given a rank of nine.

Slope

As with erosion, slope is a major factor to be considered in septic suitability. Septic systems that are constructed on ground that is too steep drain before nutrients have leached out of the effluent. Those on flat ground leach slowly, causing leakage and overfilling. In this model, areas were assigned a weighted value for slope from 1-9 based on percent slope.

Results and Discussion

Soil septic limitation scores made up 50% and slope made up 50% of the model in the weighted analysis (Figure 43). The average septic suitability of the watershed was 5 on a scale of 1-9, with 9 being the most suitable for septic systems. In the model, areas that are suitable for septic systems are indicated in green, and those that are less suitable are red (Figure 44). The maximum value was 9, for areas where new septic systems should be developed with care and old ones should be cited for repairs. These areas are characterized by high slopes and soil types that drain too quickly to leach out nutrients. Areas that have low slopes and soils that hold water for excessively long periods of time were also likely to have low septic suitability. Poor septic suitability can be mitigated before septic systems are installed.

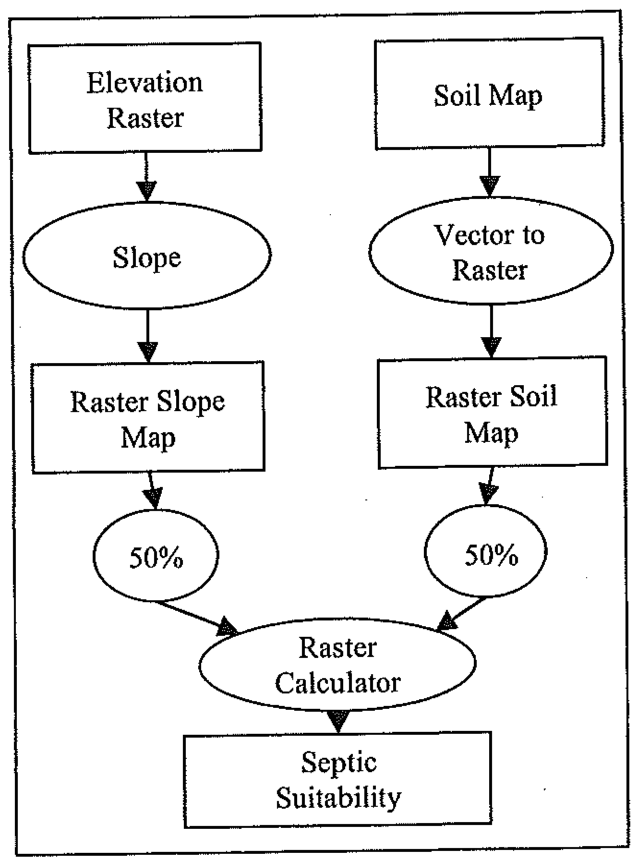

Figure 43. Flow chart showing the inputs and relative weights assigned to the factors that contribute to the septic suitability model.

The Septic Suitability Model can be used when planning the construction of new septic systems. It may also be helpful in focusing efforts for monitoring septic system efficiency for those systems already in place.

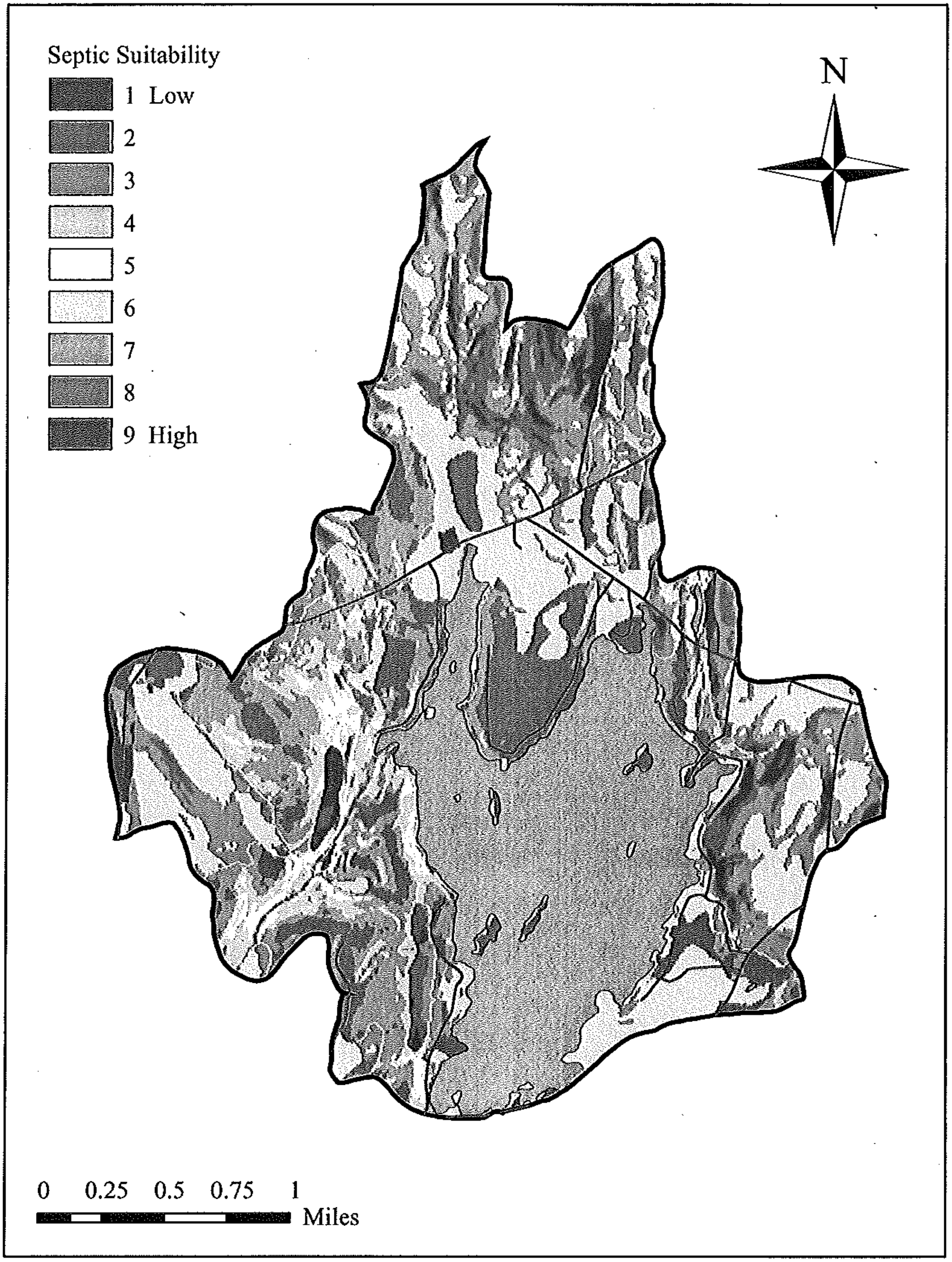

Figure 44. A model showing septic suitability of the Togus Pond watershed which combines soil septic limitations and slope into a score of 1-9, areas with low septic suitability are in red.

WATERSHED DEVELOPMENT

RESIDENTIAL SURVEY

Shoreline Zoning

Regulations

Development within the immediate area of a water body can have negative effects on water quality. Increased soil erosion, road runoff, and septic contaminants are all results of shoreline development that increase the nutrient and sediment loading of the body of water. In 1971, the Mandatory Shoreland Zoning Act was enacted by the Maine State legislature with the intent of protecting water quality, animal habitat, and the natural beauty associated with lakes, ponds, rivers, streams, and wetlands (MDEP 2003a). The creation of the Mandatory Shoreland Zoning Act was established with the help of the Maine Department of Environmental Protection (MDEP). The act requires all municipalities to adopt and enforce ordinances regulating land use within 250 ft of the high water mark of great ponds, rivers, freshwater wetlands, and within 75 ft of the high water mark of streams (MDEP 2003a). According to the act, municipalities containing the water types described above must adopt shoreland-zoning ordinances of equal or greater standards than the minimum guidelines described in the Mandatory Shoreland Zoning Act. Municipalities have the authority to strengthen the regulations of the ordinances when deemed necessary.

Within individual municipalities, it is the responsibility of the planning board and code enforcement officers to regulate and enforce the adopted ordinances. The City of Augusta has several code enforcement officers to implement the ordinances, as well as a permitting process for any new development that must meet acceptance by the Planning Board. Augusta has made a packet available to the public that includes the zoning ordinance regulations for the entire city. The creation of this packet, called Land Use Ordinance for the City of Augusta, was a recommendation made in the 1988 Growth Management Plan published by the City of Augusta and is available at the City Hall (City of Augusta 1988).

The Land Use Ordinance set forth by the city of Augusta has established the following regulations in accordance with the Mandatory Shoreland Zoning Act (City of Augusta 2002):

- A horizontal distance of 100 ft from the high water mark of the shoreline is the minimum required set back for structures.
- A height of 35 ft, measured from the downhill side of the building, is the maximum allowed for structures.
- A minimum shore frontage of 200 ft is required for individual lots.
- A minimum lot size of 40,000 sq. ft is required for new developments.

• A lot must be made up of no more than 20% impervious surfaces.

The entire Togus Pond watershed falls under an area designated as a Rural Pond District (City of Augusta 2002). Rural Pond Districts are characterized as having some of the following: shallow and highly erodible soils, steep slopes, wetlands, deer yards, shoreland areas, and State of Maine wildlife management areas. New development in these areas must follow the regulations stated above, as well as many more involving the placement of driveways, septic systems, and buffer strips. These regulations are an effort to control the amount of erosion along the shoreline in an attempt to minimize additional nutrient and phosphorus loading into Togus Pond effectively.

Non-conformance is a major problem within the Togus Pond watershed. A structure that is non-conforming is one that does not meet one or more of the regulations set forth by the City of Augusta Land Use Ordinance described above. However, many of these structures may remain because they were in lawful existence before the enactment of the ordinance. People commonly refer to these structures as "grandfathered". Non-conforming structures may be maintained and improved, but, any new additions, expansions, or relocations require permitting with restrictions similar to that of new developments. After January 1, 1989, the City of Augusta altered their policies to meet the MDEP guidelines regarding non-conformities; structures not within the required setback may not be expanded any more than 30% during the lifetime of that structure and may not be expanded towards the shoreline (City of Augusta 2002).

Discussion

Residents who wish to expand, change, or develop new property within the Togus Pond watershed must apply for a permit and present their proposed projects to the Planning Board of the City of Augusta. Through our various visual surveys of the Togus Pond watershed (see Watershed Development: House Count and Buffer Strips), CEAT noticed many properties located within the shoreline area that do not meet current regulations set forth by the City of Augusta Land Use Ordinance especially in regards to setbacks. A large portion of these properties must be non-conforming, indicating that they were built before the enactment of the 1971 Mandatory Shoreland Zoning Act. There are numerous houses located close to the shoreline, which increase the probability of nutrient loading from septic systems and erosion. Ideally, the number of non-conforming properties should be decreased over time by increasing the stringency of when they should be corrected and the regulations pertaining to non-conformities. The eventual increase in the number of houses setback at the proper distance from the water would help decrease the erosion potential from each property, hopefully increasing the water quality of Togus Pond. This action would only be possible if current properties were redeveloped in a proper fashion, which would most likely be a costly endeavor. Togus Pond is already one of the most intensely developed lakes in Central Maine (City of Augusta 1988). It is questionable whether there can be future development along the shoreline because of spatial constraints; energy should be focused upon improving the current properties in respect to impervious surfaces, driveways, and buffer strips. An estimate formulated by looking at the current tax maps indicates the possibility of five more houses along the shoreline, further emphasizing the fact that there are spatial constraints along the Togus Pond shoreline.

Subsurface Disposal Systems

Introduction

Wastewater disposal around Maine lakes can be an important factor influencing water quality. Often, rural areas are not connected to municipal sewer systems and disposal must occur onsite. Three basic options exist for disposal: holding tanks, pit privies, and septic systems (see Background: Watershed Land Use: Sewage Disposal Systems). Septic systems are the most commonly found option in the Togus Pond watershed, and are the only option available for new construction. When properly installed and maintained, septic systems can have a limited impact on water quality.

In a septic system, wastewater is collected in an underground tank where solids settle and are processed by anaerobic bacteria. The liquid is diverted to an absorption field to filter slowly into the soil where more bacteria purify the waste (Jemison 2004a). A septic system may have a high initial cost, but if properly installed and maintained it can last up to 20 years. Compared to pit privies and holding tanks, which must be constantly monitored, a septic system tank only needs to be pumped every two to three years (Green 2004).

Shoreline property owners face special challenges for waste disposal. Septic systems in these areas are often too close to both surface water and the water table, and can potentially contaminate the body of water and the homeowner's well. Contamination can happen when absorption fields become saturated due to the level of surrounding waters. Shoreline erosion also has a negative effect by decreasing the setback of a system from the shoreline and increasing the likelihood of horizontal movement of unprocessed waste into the body of water. The input of wastewater that has not been properly treated increases the phosphorus loading to a lake, consequently increasing aquatic plant and algal growth. Bacteria and viruses that cause infectious diseases may also enter the water body, closing lakes for use as a drinking supply and for swimming (Jemison 2004b). The University of Maine Cooperative Extension Program recommends several ways to prevent problems with septic systems:

- Regular pumping of septic tanks.
- Water conservation within the home.
- Drainage of surface water away from the absorption field.
- Planting of a vegetated buffer between the absorption field and shoreline.
- Consolidation of private systems into a community system, if possible.
- Replacement of old systems.
- Construction of new systems as far away from the shoreline as possible (Jemison 2004b).

Results and Discussion

Maine regulates septic systems with the Maine Subsurface Waste Water Disposal Rules (144A CMR 241) (MDHS 1988). It is the responsibility of the municipalities to enforce these state regulations and to implement stronger regulations if they so choose. Augusta does not have any additional regulations. According to these rules, failing systems must be replaced because of their potential harm to surrounding water bodies. Richard Dolby, Director of Code Enforcement for Augusta, informed CEAT that failing systems are not a particularly serious problem around Togus Pond (Dolby pers. comm.). However, code enforcement would only become aware of the situation if a homeowner or neighbor reports it. Septic systems in Augusta must be replaced when they fail, if a home is expanded, or if a seasonal property is changed to a permanent residence. Regulations have lagged behind installation of updated systems and many old systems still exist. However, Augusta's septic system records only date back seven years and CEAT was unable to determine the number of remaining systems installed before the current regulations (Dolby pers. comm.).

During the road survey, we noticed one temporary portable toilet. The Augusta Code Enforcement Office is currently unaware of any permanent pit privies in use around Togus Pond (Dolby pers. comm.). Holding tanks are also uncommon and are no longer permitted in new construction in Augusta.

Septic systems do not appear to be a big concern to the Augusta Code Enforcement Office, despite the fact that the potential for serious problems exists. CEAT learned of a case on Hayes Road where one homeowner's septic system was regularly flooded in the spring, when an inadequate culvert failed to divert water away from his yard (Connolly pers. comm.). This problem was under remediation in early October 2004 by replacement of the culvert with a larger one. However, since culverts are one of the largest problem concerning watershed roads, seasonal flooding of septic systems may occur elsewhere (see Watershed Development: Road Survey).

Another issue concerning septic systems in the watershed is the Togus Pond total coliform water test that came back positive for contamination (see Water Quality: Biotic Measurements: Fecal Coliform). Although the fecal coliform tests were negative and this appears to be an isolated incident, contamination may be occurring intermittently, and faulty septic systems are likely the cause. CEAT conducted our water quality tests at the end of the summer, when septic systems are not at their peak use. More problems may be apparent during heavy-use time. Water quality must be monitored, but to eliminate the problem these systems must be identified and corrected.

House Count

Introduction

CEAT conducted a road and a shoreline survey of the houses in the Togus Pond watershed. The main objective of these surveys was to determine the extent of development within the watershed.

Development along the shoreline has a major impact on the water quality of Togus Pond because of potential chemical and sediment runoff associated with this shoreline development. The house count data gave us insight into the quantity of septic systems located within the watershed, which have significant potential to contribute additional phosphorus to the lake. All houses within the watershed were counted, because even houses that are not located along the shoreline may contribute to erosion and produce chemical and nutrient runoff into Togus Pond. Another important aspect of our survey was determining whether shoreline houses were seasonal or a year-round residence. This was significant because a non-seasonal house will generally contribute more nutrients to the lake than a seasonal house. Assuming the septic systems between the seasonal and year-round residences were equivalent, a permanent residence will contribute more septic contaminants because the number of uses over the course of a year will be higher.

Methods

CEAT used two methods to count the number of houses within the Togus Pond watershed. The shoreline houses (within 200 ft of the normal high water mark of the lake) were counted by boat during the buffer strip survey conducted on 16-Sep-04 (Appendix H). This 200 ft shoreline zone is consistent with previous studies performed by CEAT because it is a depth easily visible from the boats and will have a greater impact on water quality. In addition, a house count of the entire watershed was conducted in conjunction with the road survey on 4-Oct-04 (Appendix G). Classification of the seasonality of houses was based on several characteristics. Features contributing to the classification of a year-round residence included: the presence of a firewood pile, an enclosed foundation, an oil tank, a paved driveway, storm windows, and a brick or stone chimney. These features generally tend to indicate that the residence is winter-ready. Features that may indicate a seasonal residence are an open foundation, dirt driveway, and the absence of a chimney. This study was fairly subjective because we were unable to ask the residents about the seasonality of their homes and relied on external factors for this classification. When CEAT was in doubt about the classification of a residence, it was classified as year round because of the added containments associated with this type of residence. It is also important to note that many seasonal residents may reside in their seasonal residence late into the fall months. We also noted any commercial building or lots that were present while conducting our surveys because of possible contamination associated with their businesses.

Results and Discussion

Within the Togus Pond watershed, CEAT found that there were a total of 283 houses (Figure 45). Of these residences, 179 were classified as shoreline (63% of the total houses). The shoreline count did not include the five houses located on islands (2% of the total houses), but the island houses are classified as shoreline. CEAT classified 99 houses as non-shoreline (35% of the total houses). Of the shoreline residences (including the islands), 129 were classified as permanent (70%) while 55 were classified as seasonal (30%). Within the Togus Pond watershed, a total of 221 houses were considered

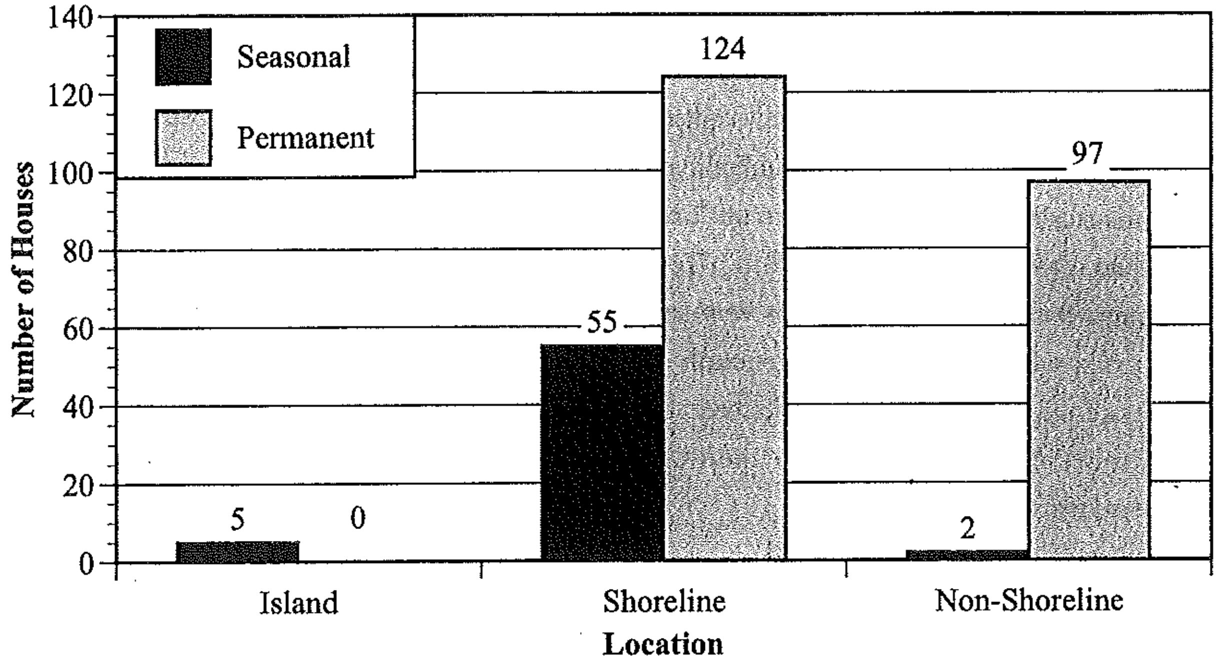

Figure 45. Total house counts for the Togus Pond watershed. Data were collected during the buffer strip survey conducted on 16-Sep-04 and during the road survey conducted on 4-Oct-04 and 7-Oct-04 by the Colby Environmental Assessment Team.

permanent (78% of the total houses) and a total of 62 houses were considered seasonal (22% of the total houses). The house counts conducted during the buffer strip survey and the road survey were consistent; both surveys yielded the same number of houses. Within the watershed we found several commercial lots and a few possible residential lots under early stages of development. Pipeline Road and Gerabro Acre Road, located off Route 3, both had areas of significant clearing. We were unable to establish the intended purpose of the land. However, the clearings are most likely for the purpose of future residential expansion because of the direct view of the lake. Commercial properties located along Route 3 are of significant importance for our study because of their potential for leaching contaminants into the Togus Pond watershed. Some of the properties worth noting are a gas station, junkyard, golf course, a barn with a large dirt parking lot, a motorcycle dealership, and several smaller stores.

CEAT found that the majority of the houses within the Togus Pond watershed are shoreline houses, many of which are in high-density clusters and not in conformance with current zoning regulations. The greater part of the lake shoreline is intensely developed with little area remaining as natural vegetation. A great deal of the untouched natural area is unlikely to be developed in the future because it is low lying and swampy, meaning it is unpopular with the general public for development. Zoning regulations also restrict the development in this area because of its wetland status (Soucy pers. comm.). This intense lakeside development, as seen in the shoreline zoning maps provided by the City of Augusta, indicates that the Togus Pond shoreline has most likely seen its maximum capacity for house building. Development is hard to predict and potentially problematic in areas that are not within the shoreline limits because the watershed area beyond the shoreline limits has significant area for future commercial and residential development and may adversely effect water quality.

With the vast majority of the houses within the watershed being considered permanent (78%), a tremendous year-round nutrient load from septic systems and road usage is present in the Togus Pond watershed. Seasonality is an issue with shoreline residences. With 30% of the residences being considered seasonal, Togus Pond will see an increase in the septic and road system usage along the shore during significant vacation times, particularly the summer months, due to the increase in residency. These summer months are also when the lake is most susceptible to algal blooms. Off overall concern is the conversion of seasonal houses to year-round because of the added load they will bare on the watershed.

Buffer Strips

Introduction

The proximity of a house to the shoreline directly impacts water quality. Impervious surfaces and landscaping associated with lakeshore residences produce increased runoff and erosion potential, leading to an increased probability of phosphorus loading to the lake.

One method of limiting the impact of these houses on water quality is through the use of a buffer strip to help stop the erosion of soils and the leaching of contaminants from the residence into the water. This is both a practical and economical method to limit erosion and phosphorus input. It is an easy way to beautify yards and produce privacy while helping to protect water quality (see Background: Buffer Strips).

An ideal buffer should consist of varying native plant species, especially shrubs and forbs. MDEP has established guidelines regarding buffer strips, which unfortunately only apply to new developments. Buffer strips are now mandated to extend a horizontal distance of 75 ft from the high water mark of the lake. In addition, the guidelines mandate limited cutting in the buffer strip area. Any plants removed should be replaced with a counter part of equal size, preferably native species (MDEP 2003b). Impervious surfaces should also be mitigated to aid in erosion control.

It is easy for homeowners to create a buffer strip by simply not mowing the edge of the lawn. While this does not produce a fully effective buffer immediately, it is the start of one that may be adequate in the future. MDEP has established a set of guidelines to aid residents in the construction and maintenance of buffer strips. This set can be found on their website at (http://www.maine.gov/dep/blwq/docwatershed/bufa.htm). Establishing these guidelines is a positive step in the right direction for the State of Maine to help control the water quality of many lakes that are threatened by phosphorus loading.

Not directly related to buffer strips, but also found along shorelines as a method to control erosion and subsequent nutrient runoff, is the use of rip rap. Rip rap is a layering of gravel along the waterline of the shore that minimizes the amount of unprotected bare soil and mitigates wave erosion of the shoreline.

Methods

CEAT conducted a buffer strip survey on 16-Sep-04 to assess the quality of the buffer strips for shoreline properties along Togus Pond. Boats were used to perform the survey, allowing CEAT to perform a thorough analysis of the lake perimeter. The survey form used for the study was revised from previous CEAT studies to produce a clearer and more concise form for the surveyors to fill out (Appendix H). Each property was located using a GarminÆ GPS unit, enabling the survey data to be easily used in the GIS studies. The survey categories included; percent lake shore coverage by buffer strip, depth of the buffer strip from the shore, slope rating from the water to the residence, seasonality of the residence, composition of the buffer strip (percentage of trees and shrubs), and the need for riprap. Although riprap and seasonality are not directly related to buffer strips, they are important because they are indicators of the amount of erosion and contaminants that each residence potentially emits into the lake.

Buffer strips were graded on the basis of their individual components. The independent scores were tallied, scoring from 0 to 30. The lowest possible score was zero, indicating the total absence of a buffer strip, and nothing to stop erosion and potential phosphorus loading. The highest score possible was 30, demonstrating an exceptional buffer strip that could significantly reduce runoff and erosion into Togus Pond.

To receive a grade of "good", a residence must have received a combined grade of at least 25 points out of the possible 30 on the buffer strip survey. "Good" indicates that the buffer strip has significant lakeshore coverage, buffer depth, and area coverage by shrubs and trees. A grade of "fair" represents scoring between 20 and 24 points on the survey. In this case, a buffer strip may have coverage all the way across the lot and be composed 100% of trees and shrubs but have inadequate depth. Buffer strips that earned a grade of "poor" on the survey, are those that received a combined score between 15 and 19 points. A "poor" buffer strip would have mid to low-range depth, coverage and foliage. A failing grade on the survey was any score that is less than 15 points, because a score less than this would contribute significant erosion and phosphorus loading to the lake. A "failing" score would be missing several of the key components such as percent coverage and shrubbery or there may not be a buffer strip present.

Results and Discussion

In the buffer strip survey, a total of 184 shoreline residences were surveyed for buffer strip adequacy. Of this total, 11 were classified as good, 44 were fair, 50 were poor, and 79 failed (Figure 46). These numbers were quite startling, with 43% of the lakeshore residences receiving a failing grade from the buffer strip survey.

A representative example of a buffer strip that failed the CEAT survey can be seen in Figure 47. It is evident in this photograph is that there is no buffer strip present. What may have previously been a buffer strip has been clear-cut, leaving bare dirt directly next to the waters edge with nothing to stop run-off. There is also very little rip rap. Although rip rap is a separate issue from the buffer strip, it is still a significant erosion-stopping agent, especially wave erosion, that CEAT deemed important to include in the buffer strip survey. Figure 48 depicts a residence that is adequately buffered. While this example may not receive a rating of "good", it is certainly a major improvement upon Figure 47. The homeowner has made an effort at stopping erosion by adding rip rap and planting shrubs around the shoreline. However, improvements can be made to this buffer strip, such as greater depth and density of vegetation and inclusion of larger species that prevent rain water from directly hitting the ground and roots systems that maintain ground stability.

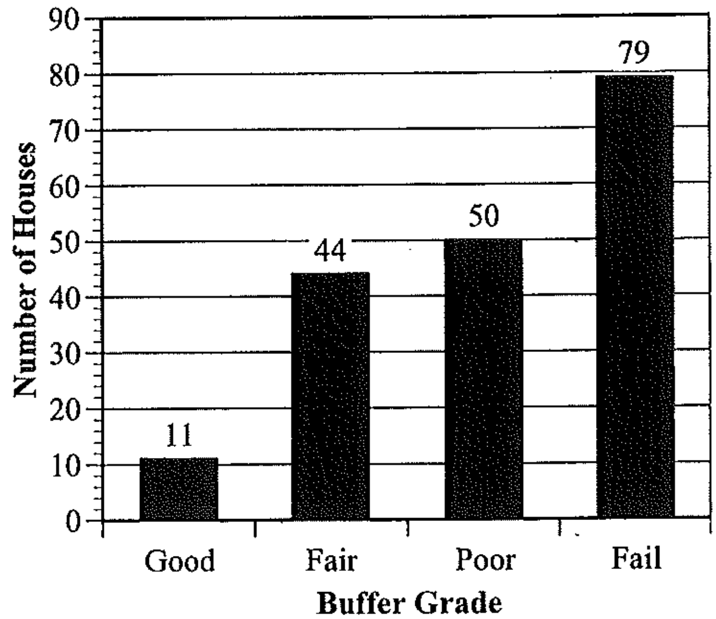

Figure 46. Buffer strip scores for shoreline properties within the Togus Pond watershed. Survey conducted 16-Sep-04 by CEAT. For information on scoring see Appendix H and Watershed Development: Buffer strips.

A GIS buffer strip survey map was created using the information collected by CEAT during the buffer strip survey (Figure 49). The GPS coordinates of the individual residences were matched with their respective scores. This allowed sections of Togus Pond to be identified as problem areas for buffer strip inadequacies. This identification was based on the assumption that lower scores would be associated with more developed areas. The buffer strip survey map showed that there are clustered areas of failing buffer strips. Most notably, these areas are found in the northeast and northwest corners of the Togus Pond shoreline, specifically around areas of high density development. It is evident through our analysis that work must be done on the Togus Pond shoreline to improve the quality of the residential buffer strips.

ROAD SURVEY

Introduction

The condition of roads in the Togus Pond watershed is an important factor influencing water quality. Soil erosion can be the single largest cause of pollution in Maine lakes and ponds, and roads

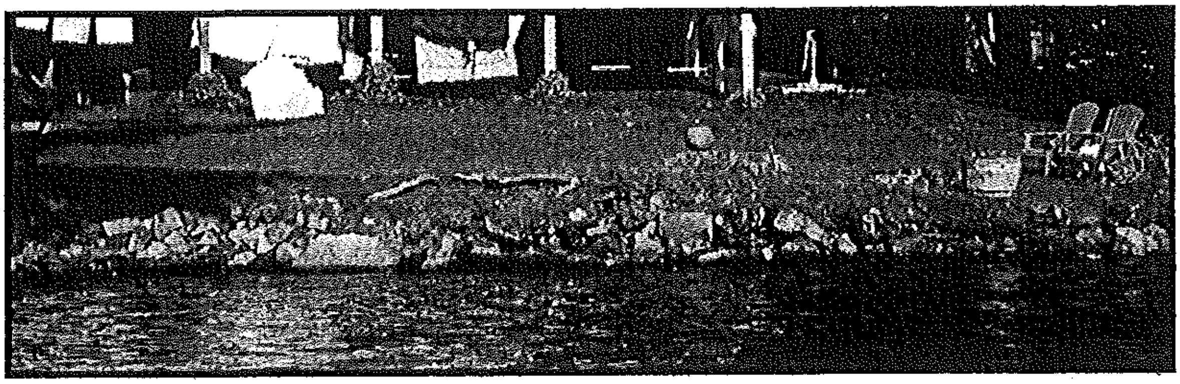

Figure 47. Photo of a poorly buffered home receiving a failing score on the buffer strip survey. The buffer strip has been cut down, exposing bare dirt to the elements. There is no buffer depth or coverage along the shoreline, in addition, there is no plant life along the shore. There is also very little rip rap. Overall, this shoreline is very susceptible to erosion.

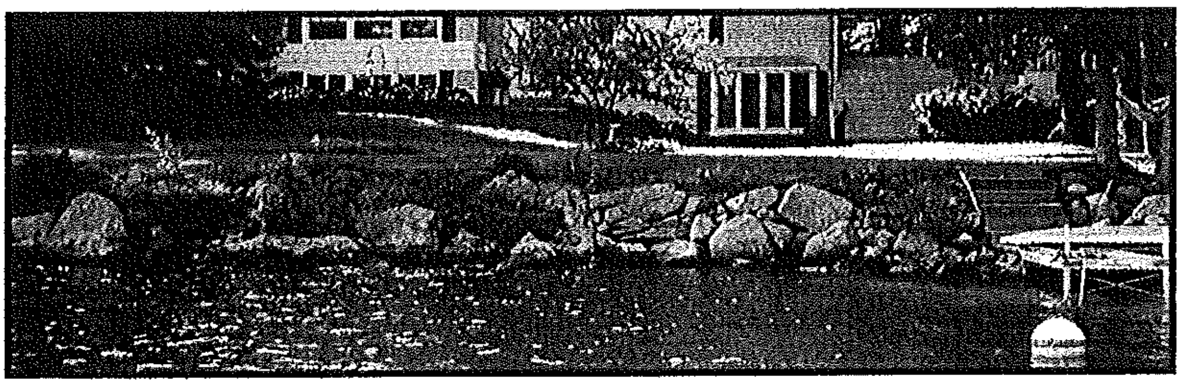

Figure 48. Photo of a "fair" buffer strip. Some attempt has been made to create a buffer with the use of low lying shrubs and proper shoreline coverage. However, the buffer strip should have a greater depth. The lawn is very contoured, providing resistance from direct runoff into the lake.

can be a source of up to 85% of all erosion and sedimentation problems (KCSWCD 2000). Sediments that make their way into the lake can turn the water brown, cause sedimentation, irritate fish gills, increase phosphorus loading and the potential for algal blooms, and decrease property values. Road surfaces, which may be either paved, or gravel and sand, are an important factor for erosion potential. Paved roads are usually maintained on a regular basis by the state or town, and are of less concern than the unpaved, usually private, camp roads (KCSWCD 2000). Although the town maintains most camp roads in the Togus Pond watershed, these roads are still a concern due to their proximity to the lake (Halsted 2004; see Background: Watershed Land Use: Roads).

Maine has several laws in place to regulate erosion around lakes. The Erosion and Sedimentation Control Law protects water from the discharge of any pollutant and unnatural soil erosion (KCSWCD 2000). Erosion control is mandated during the construction of camp roads or any other disturbance to the soil. Once a road is in place, this law requires erosion control during maintenance, like grading. No

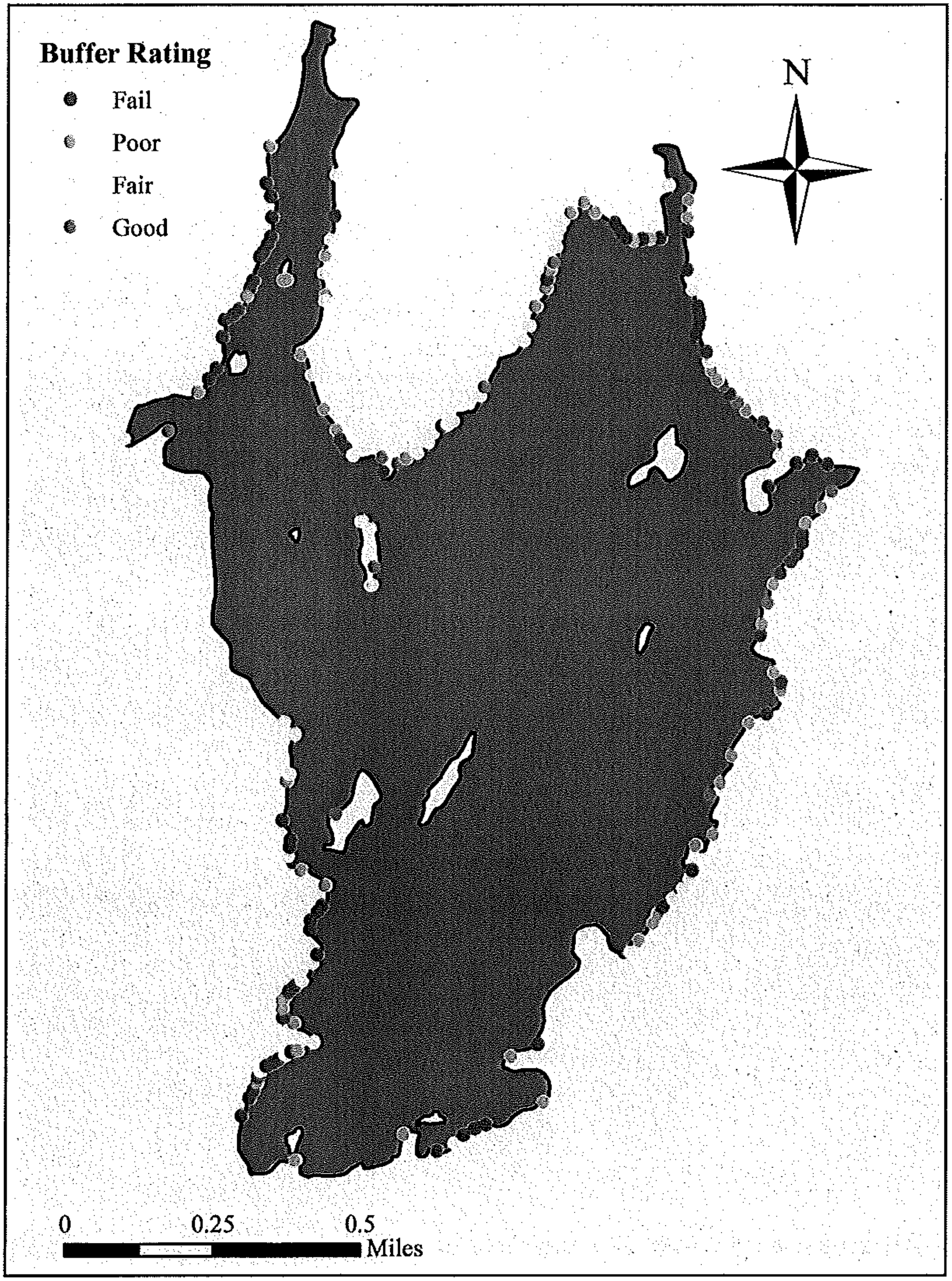

Figure 49. Buffer evaluation map for Togus Pond. Buffer evaluation determined by buffer survey on 16-Sep-04. Points correspond to developed house lots.

permits are needed but the Maine DEP or local code enforcement officers enforce these requirements. However, without a permitting process, it is difficult to ensure that new projects comply with the law (KCSWCD 2000).

Another regulation is the Natural Resources Protection Act (KCSWCD 2000). This act regulates and grants permits for any activity disturbing soil, rocks, or vegetation within 100 feet of a water body. The first type of permit is a permit-by-rule. The applicant must file notice for any roadwork, and then follow state standards such as those issued by the Maine Land Use Regulation Commission (MLURC 2000). This is most commonly the case with camp road maintenance, including replacement of culverts and bridges. The second type is a full permit that requires a formal review by MDEP and takes about five months to process. This process is used for major projects like the alteration of a wetland (KCSWCD 2000).

Both of these regulations are applicable to camp roads around Togus Pond, yet the roads continue to be a major nonpoint pollution source. A survey conducted by the Kennebec County Soil and Water Conservation District (KCSWCD) in 2003 identified 144 sites in the Togus Pond watershed contributing to nonpoint source pollution (Halsted 2004). Of these sites, 93% were problems on roads, the remaining were erosion problems on residential, commercial, or recreational properties. Town-maintained camp roads make up the majority of roads in the watershed and had the largest number of problems. Culvert issues were the most common problem (Halsted 2004). Relevant problems identified in the KCSWCD survey were reassessed in the survey conducted by CEAT for this report.

Methods

CEAT conducted a survey of all roads in the Togus Pond watershed on 4-Oct-04 and 7-Oct-04. Each road was rated using qualitative assessments of the crown, ditch conditions, road surface conditions, and specific problems with diversions and culverts (see Background: Watershed Land Use: Roads). Problem sites were marked using GPS units and noted on the Road Survey Data Sheet for Problem Areas (see Appendix F). The problem sites from the KCSWCD survey were compared to those found by CEAT (KCSWCD 2000).

For the general road survey conducted on 4-Oct-04, the length of each road or portion within the watershed was measured using car odometers and GIS (see GIS: Introduction). Several road widths were measured using a tape measure and an average width was calculated for each road. These data were used to calculate the area of each road. An estimate was made of the general slope of each road using clinometers. The numbers of culverts and water diversions were noted, as well as any areas in need of either one. Culverts were identified and evaluated for their condition and capacity (Figure 50). Water diversions were considered to be any man-made alteration to the road designed to divert runoff (Figure 51). Areas lacking diversions were identified as areas where water had flowed along the edge of the road causing erosion. The crown was evaluated as present or absent; in some cases, measurements of the crown height were made using a string, meter stick, and level. Acceptable ditch condi-

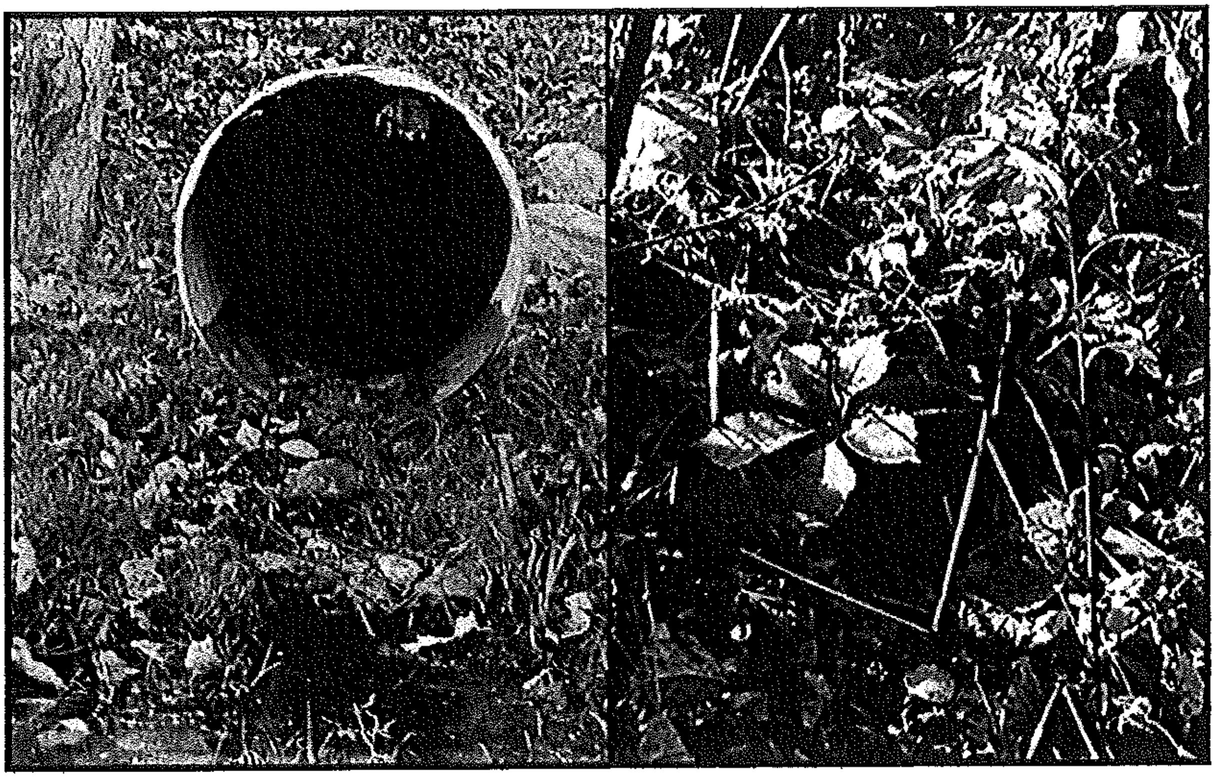

Figure 50. On the left, a properly maintained culvert. The culvert is free of debris and is large enough to accommodate excess volumes of water during storms. On the right, an improperly maintained culvert. This culvert is completely overgrown and filled with debris. There is no way for water to move in or out, which can cause water to back up and flood over roads into lawns.

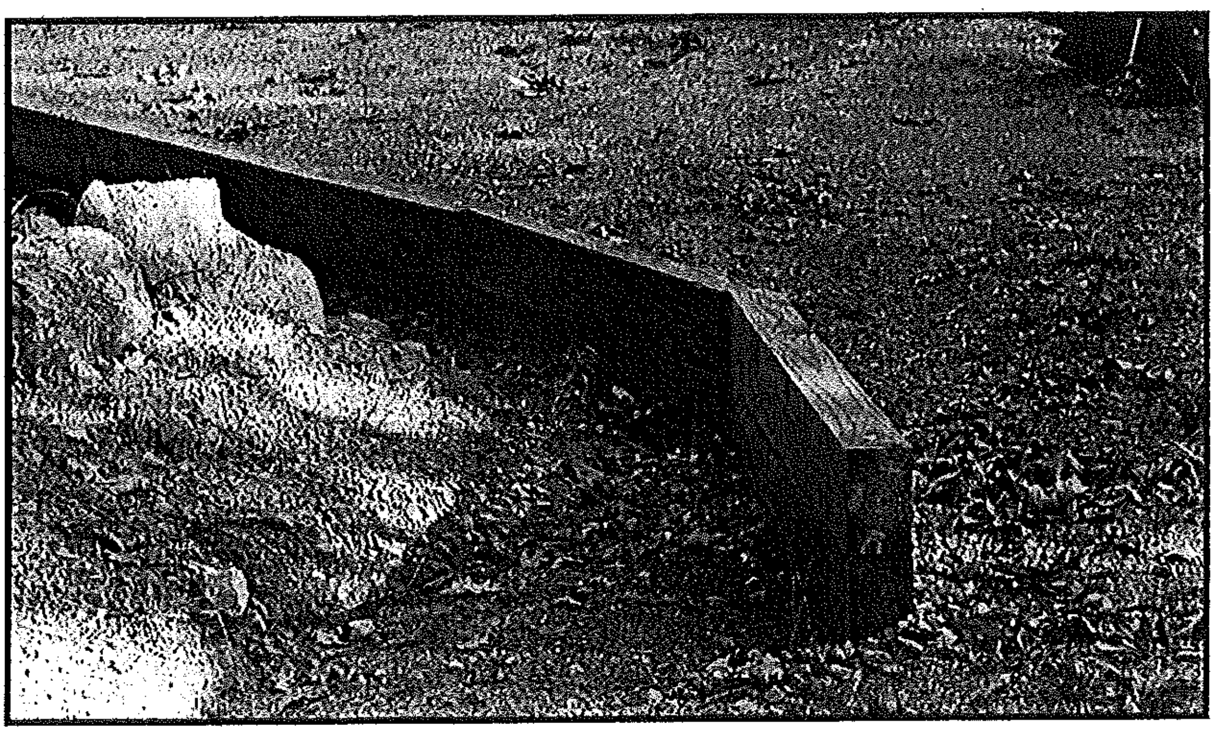

Figure 51. Example of a diversion built on a lot to divert runoff away from the lake. Diversions are an effective remedy for steep driveways.

tions were identified by the presence of a parabolic or u-shape and rip rap. The road surface condition was also assessed. The surface material was identified as either pavement, sand, gravel, or other, the amount of packing was noted, and potholes and washboard were taken into consideration when evaluating road quality. Other variables considered were areas of obvious erosion, the slope of the road at its edges, the level of the road bed compared to the surrounding area, and the presence of berms, all of which influence sediment drainage (see Background: Watershed Land Use: Roads).

A follow up survey was conducted on 7-Oct-04 of Hayes Road, which was being graded on the initial survey day, and to identify areas with steep driveways that could possibly use improvement.

Results and Discussion

The road survey found 12.31 miles of roads in the watershed totaling 39.76 acres. Unpaved camp roads make up 39% of this area. Of the total road mileage in the watershed, 55% are from camp roads. Camp roads are either maintained by the town or privately. It is hard to break this down exactly because parts of the same road may or may not be private, but the majority of camp roads were maintained by the town (Figures 52, 53; Halsted 2004). All paved roads were given one of the two highest ratings, either good or acceptable, and were not a cause for concern. The majority of camp roads were rated as fair (Figure 54).

Although most of the roads in the watershed were rated good or acceptable, camp roads have plenty of room for improvement. All of the rated poor roads were located in the northwest corner of the watershed, some of it most likely due to the new development in the area (see Watershed Development: Residential Survey: House Count). CEAT used GPS devices to mark specific problem spots (Figure 55). The most problems were found on Young Road, while some roads had no identifiable problems. Poor culverts and evidence of erosion were the most common problems. Berms were also common and occurred where the road was too close to trees, causing sand and gravel to build up during grading or plowing (Figure 56).

Culverts are a substantial problem in the Togus Pond watershed. CEAT found many that were either perched above the waterline, or clogged, leaving no path for water to flow in or out. In these areas, streams were backing up and creating wetlands that risk flooding over the road in the springtime, washing more phosphorus into the lake and flooding septic systems. Problem culverts that are too small or perched above the water level should be replaced. Other culverts require regular maintenance to keep them clear of debris.

Erosion is a more serious problem and was found on roads lacking adequate ditches and crowns. These roads were often below the level of the surrounding land, leaving nowhere for water to go besides into the road, causing gullies and ruts to form in the soft sediments (Figure 57). Erosion was also common on the sides of roads where diversions for stormwater runoff were absent. Erosion further exacerbated problems with culverts by eroding the banks of roads, leaving culverts perched.

During this survey, CEAT looked for the problem sites identified by KCSWCD (Halsted 2004) and found some sites but not all, making it difficult to draw comparisons. However, in both surveys the same types of problems were found: culverts and erosion being the most common. KCSWCD found the most problems on Young Road, as did CEAT. These problems were designated high or medium priority for remediation by KCSWCD, yet were still present after the summer work season. CEAT believes that this road needs the most work.

On 7-Oct-04, CEAT identified areas in the watershed with steep, problematic driveways (Figure 55). There are many driveways that lead straight towards the lake and have erosion problems. The highest number of steep driveways were identified on Tasker Road and Hayes Road, with four and three respectively. This is partly due to the slope of the land, but driveways in these areas could be constructed to minimize their potential harm to the lake. Redirecting driveways to include multiple curves prevents runoff from flowing straight down-slope into the lake. For driveways that cannot be changed, diversions and water bars can be installed just as they would be used on a road to direct runoff into wooded areas to settle (see Background: Watershed Land Use: Roads). These improvements can reduce annual maintenance and potential nutrient loading, and are recommended for any steep driveway in the Togus Pond watershed.

Problems found by CEAT on selected roads are detailed below. Specific problem sites are noted in Figure 55. Recommendations have been made to aid in future remediation of the camp roads in the watershed. The road survey was completed by CEAT on 07-Sep-04.

Hayes Road (Landing)

Problems: Inadequate and collapsing culverts, culvert emptying into yard, potholes and washboard despite recent grading.

Remediation: Replace with larger culverts, redirect remaining culverts. Grade road to remove pot holes and washboard. Finer road surface material may be needed.

Tasker Road

Problems: Berms and erosion in many places along road length.

Remediation: Remove berms, build ditches, and add diversions.

Buck and Doe Trail

Problems: Berms, potholes, erosion in some areas.

Remediation: Remove berms and build ditches with diversions. Grade road regularly and maintain crown to prevent potholes.

Albee Road

Problems: Overgrown, clogged, and rusting culverts, erosion around culverts, steep and eroding ditches, lack of diversions causes water to turn out into driveways and erosion along road edge.

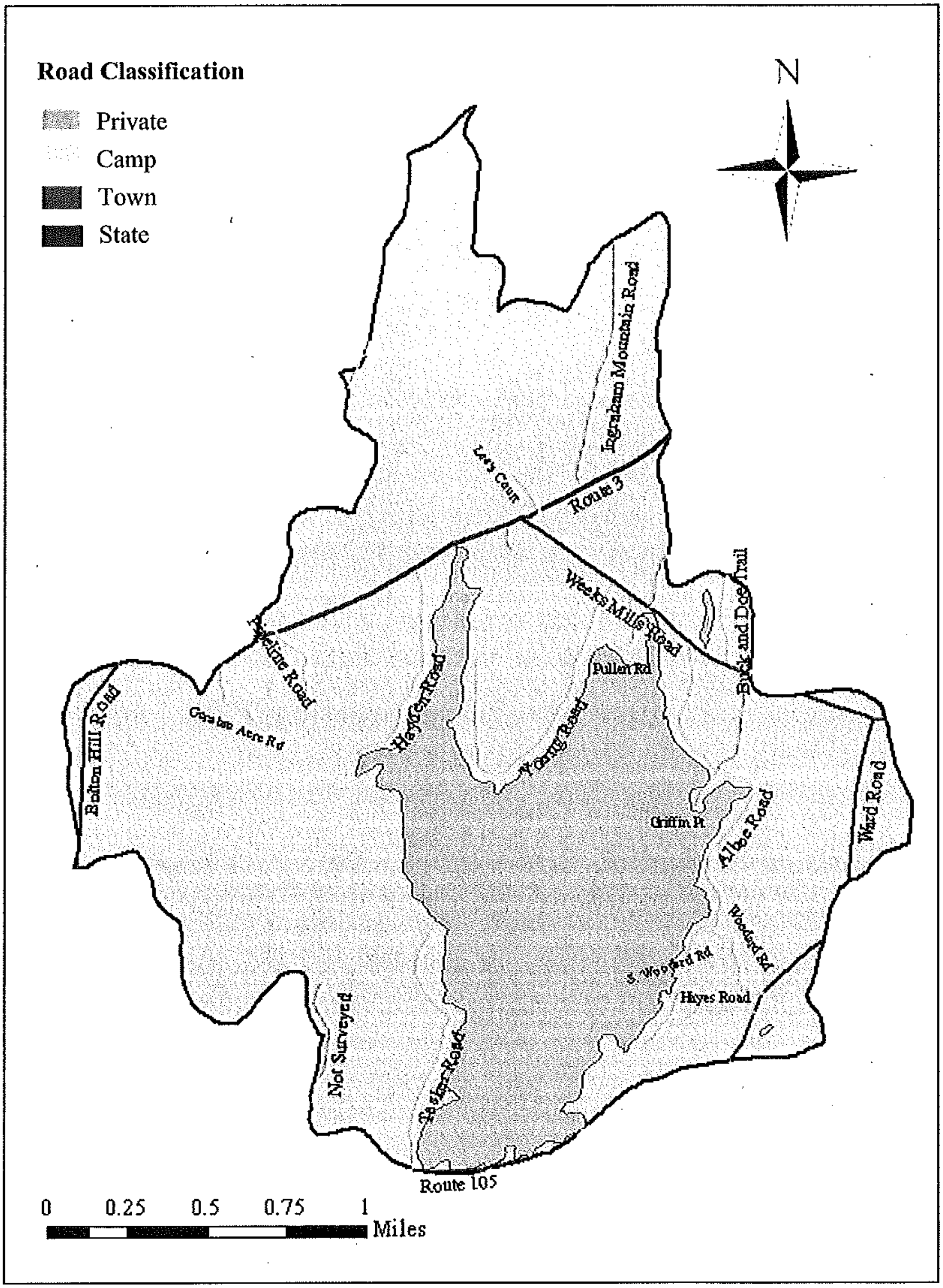

Figure 52. Classification of the roads in the Togus Pond watershed. Each road is colored According to who is responsible for its upkeep.

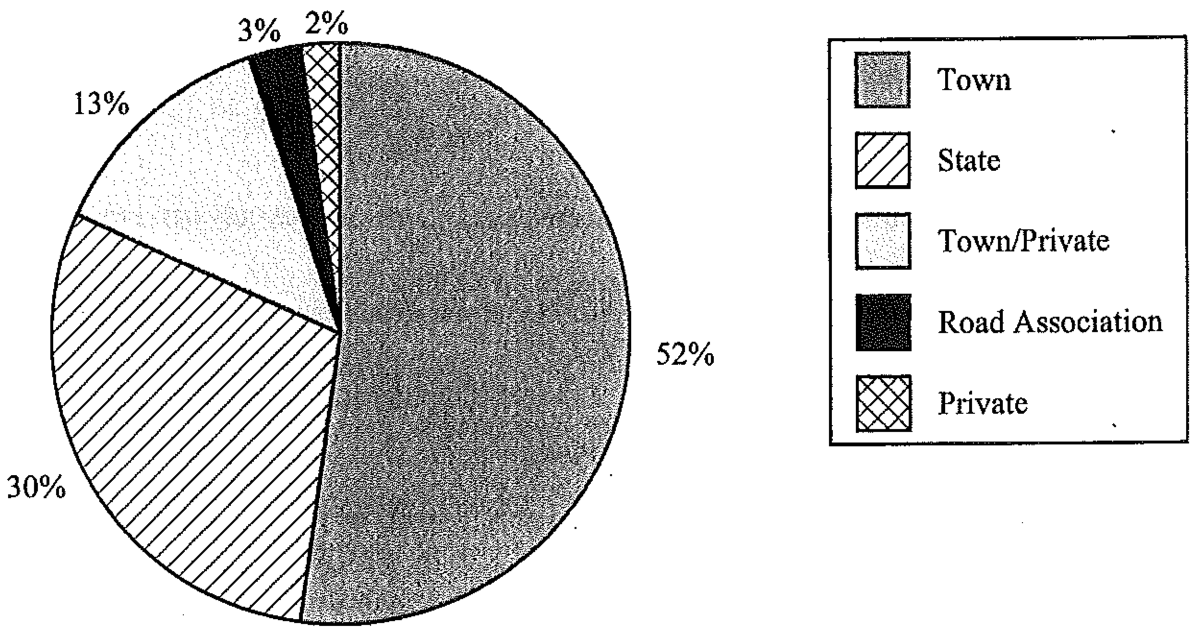

Figure 53. Maintenance responsibility for roads in the Togus Pond watershed as a percentage of total road acreage. Town/Private represents town-maintained roads with privately-maintained sections. Based on KCSWCD Nonpoint Source Pollution Survey (Halsted 2004).

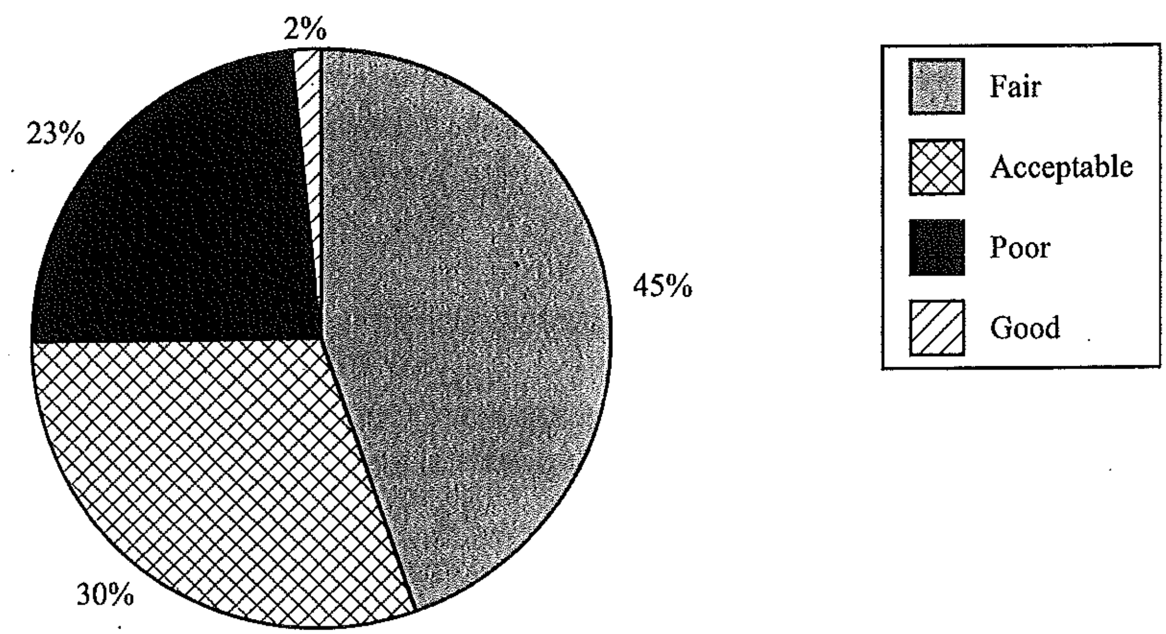

Figure 54. Conditions of camp roads in the Togus Pond watershed represented as percentage of total road acreage based on road survey data taken on 4-Oct-04 and 7-Oct-04 by the Colby Environmental Assessment Team.

Remediation: Replace inadequate culverts, regularly maintain clogged culverts. Line ditches with rip rap and add diversions.

Hayden Road

Problems: Berms in some areas, defunct water bar, erosion around culverts, erosion of road edge, some potholes.

Remediation: Remove berms, maintain water bar, expand ditches and apply riprap, grade potholes and maintain crown.

Gerabro Acres

Problem: Culvert with insufficient road material cover, steep ditches with exposed soil, potholes and ruts, erosion of roadbed.

Remediation: Replace culvert deeper in roadbed, widen ditch to parabolic shape and fully line with riprap or vegetation, grade crown into road.

Ingraham Mountain Road

Problem: Clogged culvert, berms, steep road banks, potholes, and erosion.

Remediation: Clear culvert of leaves, remove berms, build ditches and diversions, grade crown into road and maintain.

Pullen Road

Problems: Berms, insufficient crown, steep eroding banks, ruts, and erosion of roadbed.

Remediation: Remove berms and add diversions into forested areas, grade crown into road, rip rap banks to prevent further erosion.

Young Road

Problems: Berms, several clogged and inadequate culverts, erosion along road bank and bed, fine sediment build up on road surface.

Remediation: Remove berms, remove trees too close to the road, replace and maintain culverts, build ditches and diversions to direct runoff away from lake.

Pipeline Road

Problem: Possibly unfinished road, berms, erosion of roadbed, potholes, gullies.

Remediation: Grade and finish road, build ditches and diversions, assess current traffic on road, and adjust maintenance schedule accordingly.

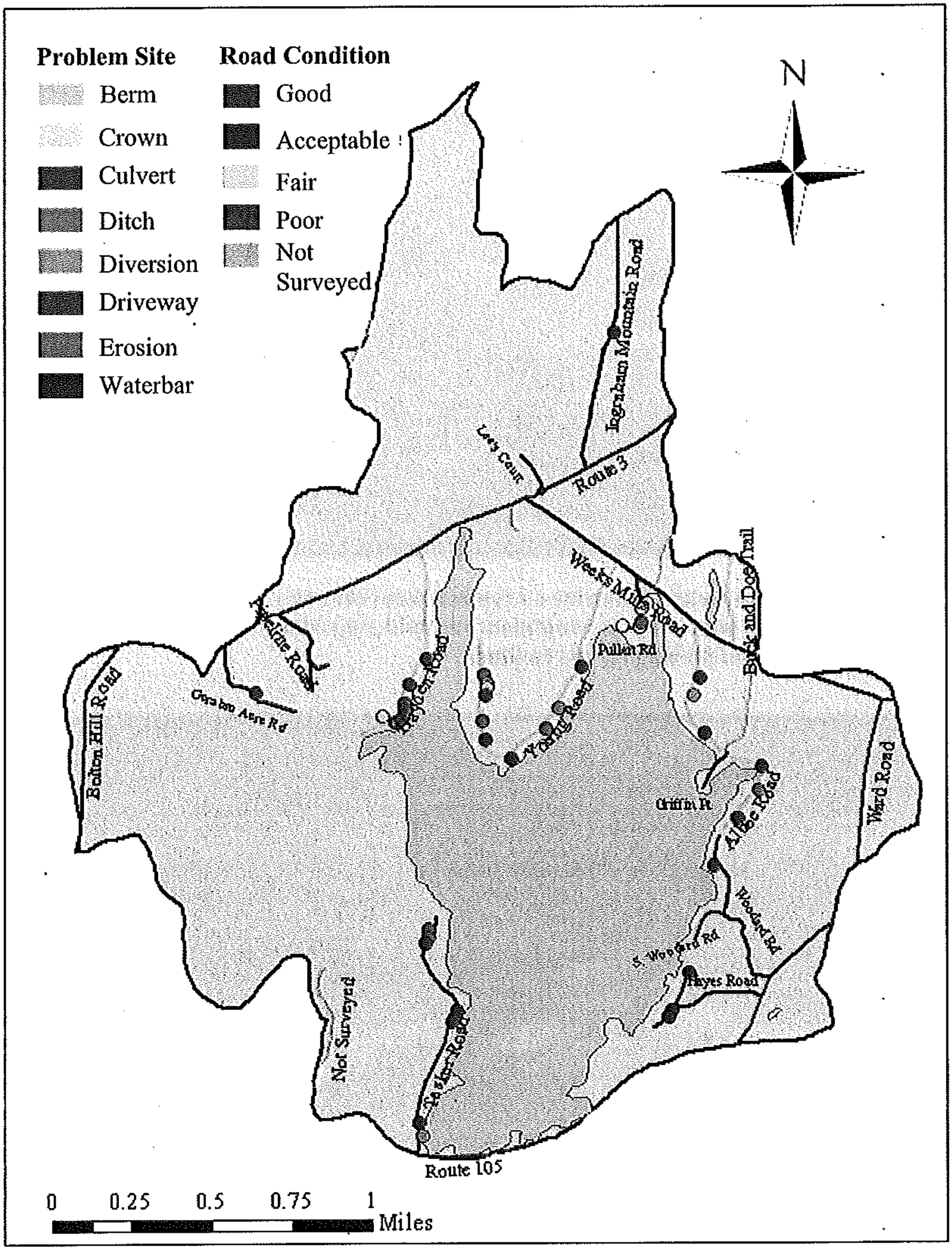

Figure 55. Quality classes and problem sites for roads in the Togus pond watershed. Roads were classed according to their ability to prevent runoff from entering the lake. Problem sites were locations in the road in need of a specific improvement as designated in the legend.

Figure 56. This photograph illustrates a typical berm that can result when grading or snowplowing in the winter causes sediments to build up along the edge of the road, preventing water from flowing off the roadbed.

Figure 57. Erosion of roadbed. Ruts and gullies form when roads are soft in the spring and are over used. Damage can last until grading occurs.

ECONOMIC IMPACT OF BLOOMS

Water quality is a relevant factor that visitors and homeowners often consider when choosing a lake, and consequently water quality affects the economy and population of communities living near water bodies (Bouchard 2000). Several key studies were completed in Maine between 1996 and 2000, linking water clarity to property values and recreational activity (EPA 2000). The results of these studies quantify the economic costs of lake water quality degradation and the benefits to the state in maintaining and improving water quality.

Increased phosphorus input to lakes often results in algal blooms that turn lakes green and leave unsightly scum, foul odors and bad tasting water (Smith and Witherill 1999). In some lakes, repeated algal blooms can result in fish kills or loss of the coldwater fishery (see Togus Pond Characteristics: Biological Perspective: Fish Stocking). All of these factors reduce property values in lake communities and diminish Maine's appeal to visitors (Schuetz et al. 2001). A one meter reduction of summertime minimum water clarity (Secchi disk transparency) resulted in a reduction of 3 to 5% of the expected market price for lakefront property (EPA 2000). On 164 monitored low quality lakes defined by a minimum clarity of three meters, aggregate property value loss ranged between $200 and $400 million (EPA 2000). As much as 15% of the value of properties on China Lake were dependent on water quality (MDEP 2004e). Schuetz et. al. (2001) found that visitors also place value on the water quality of lakes and demonstrate their willingness to pay for water quality programs.

The annual economic value of Maine's lakes is about seven billion dollars (Bouchard 2000). In 2000, the cost to administer all water-related programs in Maine was $11.1 million (EPA 2000). This cost included licensing, compliance, enforcement, technical assistance, pollution prevention, wastewater engineering, environmental assessment, lake restoration, nonpoint source controls, and ground water protection. More than a quarter of Maine's adults (greater than 200,000 people) use Maine lakes for short, daylong access each year, spending approximately $100 million and generating over 50,000 jobs (EPA 2000). It was estimated that these access-users would be willing to pay a minimum of $3.87 per person each year to prevent a half-meter decline in average water clarity and $13.01 per person each year to prevent a one and a half meter decline (Schuetz et al. 2001). Consumer surplus, the economic value derived in excess of what is actually paid for the recreational experience, estimated at $7.5 billion for lakes in Maine, would decline by one to two billion dollars with measurable declines in water quality (EPA 2000). This relationship between water quality and economic well-being shows that improving the ecological health of lakes increases lake use and value.

These surveys in the State of Maine indicate that further reductions in the water quality of Togus Pond could have substantial economic impacts. The clarity of Togus Pond appears to be variable (see Water Quality: Physical Measurements: Transparency), meaning that property values could be unstable depending upon the presence or absence of a bloom each summer. Property values are the most important economic consideration due to the limited amount of access-use on Togus Pond. These survey results indicate that Maine residents place a high value on programs that address water clarity and are willing to put money into them. CEAT encourages residents of the Togus Pond watershed to develop community-based programs to improve properties and surrounding roads in ways that will not only improve lake water quality, but also the economic value of the lake (see Recommendations: Watershed Management: Roads).

WATER BUDGET

INTRODUCTION

A water budget is broadly defined by the inputs and outputs of a lake, and is particularly important in understanding the flow rate of nutrients through the lake. The flushing rate that is calculated from the water budget is a perceivable measurement conceptualizing the rate at which a lake replenishes its water over the course of a year. The flushing rate can also provide some indication of recovery or self-purification rate of lakes (Chapman 1992). The flushing rate is inversely proportional to residence time, which is an indication of the length of time water remains in a lake before it is replaced with new water. A higher flushing rate corresponds with a lower residence time.

The water budget is an important place to start when assessing the physical and chemical features of a lake. Higher concentrations of substances in a lake may relate to a lower flushing rate. These dissolved substances affect the aquatic species and alter species composition in the lake. Lakes have lower flushing rates than streams and rivers, making them more vulnerable to the accumulation of pollutants in the water column and to bioaccumulation of pollutants in aquatic organisms (Chapman 1992). Low flushing rates can compound nutrient loading problems and accelerate eutrophication because the water is not replenished often enough to prevent the accumulation nutrients on the lake bottom or in the water column.

METHODS

The water budget calculation for Togus Pond measures the total water inputs entering the lake and subtracts the total water outputs from the lake. The equations used to calculate a water budget and flushing rate are:

I_{net} (cubic meters/year) = (runoff x land area) + (precipitation x lake area) – (evaporation x lake area)

Flushing rate (flushes/year) = (I_{net} Togus Pond + I_{net}Dam Pond)/(mean depth x lake area)

For the purpose of this water budget, we may assume that the amount of water entering the lake is equal to the amount of water leaving the lake at any given time over the course of the year, even though the water level fluctuates regularly from droughts and rain events (MDEP). I_{net} values were calculated for Togus Pond and Dam Pond. Dam Pond was included in the water budget as an indirect watershed because its outlet stream is entirely located in the Togus Pond watershed (Figure 58). I_{net} values for Togus Pond and Dam Pond were summed and divided by the Togus Pond volume to find the annual flushing rate.

Parameters for the water budget were obtained from various sources. Others were calculated by CEAT. Constants exist for runoff (0.62 m/yr), as defined by the Northern Kennebec Regional Planning Commission in unpublished data, and for evaporation (0.56 m/yr) (Prescott 1969). The average precipitation for was derived from a 10-year average (1.012 m/yr, 1994-2003) given by the National Oceanic & Atmospheric Administration (NOAA 2004) from the Augusta State Airport meteorological station. The average depth for Togus Pond is 17.8 feet, calculated by CEAT (see GIS: Bathymetry map).

Watershed land area and lake surface area for Togus Pond were calculated using ArcGIS™ 9.0 with layers downloaded from the Maine Office of GIS (MEGIS 2004). Lake volume and flushing rate for Dam Pond was obtained from the PEARL (2004c) website.

RESULTS AND DISCUSSION

The majority of water entering Togus Pond is from spring runoff, seasonal tributary runoff, storm events, and inflow from other watersheds (see Background: Watershed Description). Tributaries were not active when observed this past summer/fall, indicating that this year may have been a low rainfall year, or that the tributaries observed are ephemeral. Hayden Brook, a significant water source for Togus Pond, is spring fed and modified by a beaver dam (Norton pers. comm.). Another water source for Togus Pond is a wetland area north of Route 3 that feeds into a culvert under Route 3 and into the northwest cove of the lake. This culvert could not be located by CEAT (possibly because of dense vegetation) but was confirmed by a local resident. Other possible sources of water input are various streams around the northeastern shore and springs within the lake. Springs are not accounted for in the water budget but they are commonly observed by anglers in the summertime as they attract coldwater fish (Norton pers. comm.).

Water exiting Togus Pond leaves through a culvert under Route 105 at the southern end of the lake and empties into Lower Togus Pond. The water then flows through a dam at Route 17 into Togus Stream where it flows 7.4 miles to its confluence with the Kennebec River (Miller 2003). Evaporation is another source of water output in the Togus Pond water budget.

CEAT calculated the water budget for Togus Pond to be 0.81 flushes/year. Conceptually, this means that 81% of the water in Togus Pond is replaced each year. This rate is in the middle range in comparison to other lakes in the county (Table 7), and is lower than the average flushing rate of 1 to 1.5 flushes/year for Maine lakes (MDEP 1996). A local resident stated that the outflow from Dam Pond is blocked by a ridge and does not enter the Togus Pond watershed. If this were true, then the recalculated water budget for Togus Pond would be 0.46 flushes/year, drastically lower than our original calculation. This flushing rate would indicate an impaired cleansing potential (the ability to flush out nutrients) for Togus Pond.

The CEAT calculated water budget agrees with the PEARL (2004c) water budget, which included

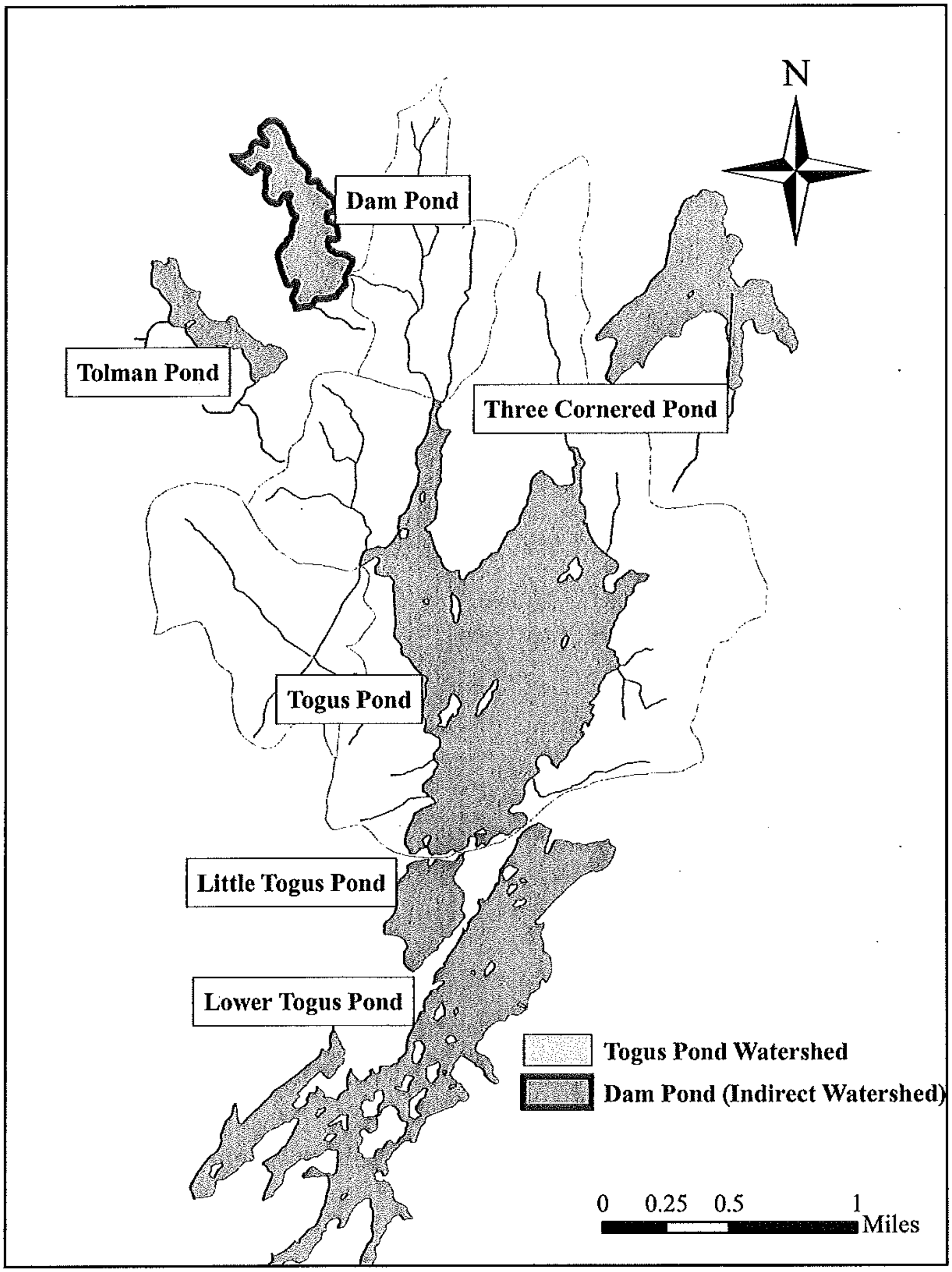

Figure 58. Map of the Togus Pond water budget watershed. The I_{net} of Dam Pond was included as an indirect watershed because it flows directly into the Togus Pond watershed.

Table 7. Flushing Rate of Togus Pond and other lakes in Kennebec County (China Lake Data from PEARL 2004)

Lake	Flushes/Year	Volume (m^3)	Watershed Area (m^2)
China Lakes Region			
Togus Pond	0.81	13,909,671	11,690,801
Threemile Pond[a]	1.10	25,120,168	24,813,955
Webber Pond[b]	1.77	27,048,136	20,598,125
Skowhegan Region			
Lake Wesserunsett[c]	1.09	22,888,673	42,110,000
Belgrade Lakes Region			
Salmon Lake/McGrath Pond[d]	0.58	28,410,750	23,126,300
East Pond[e]	0.29	33,848,120	10,598,777
North Pond[f]	1.36	37,148,856	30,920,000
China Lake	0.43	240,649,445	214,710,000

[a]CEAT 2004, [b]CEAT 2003, [c]CEAT 2001, [d]CEAT 1995, [e]CEAT 2000, [f]CEAT 1997.

the same indirect and direct watersheds. However, our average depth differed from theirs (0.67 m less) which means that the CEAT calculated surface area was probably higher than the one used by PEARL. This makes sense considering that the water level of Togus Pond has risen over the past century as a result of various dammings (see Watershed Description). It is also likely that our shallower depth calculation was a result of the natural filling in of the lake basin.

Togus Pond has a water budget most similar to China Lake and Salmon Pond (Table 7). By comparing flushing rates and past Secchi readings, it is clear that flushing rate is not an accurate representation of lake water quality. For example, North Pond has a flushing rate of 1.36 flushes/year (CEAT 1997), but has a mean Secchi disk reading of 3.8 ± 0.3 m compared to that of Togus 3.0 ± 0.5 m. This suggests that other factors such internal phosphorous recycling and watershed development may be more likely to influence a lake's health than its water budget.

Togus Pond is already an impaired water system and, unfortunately, does not have the benefit of a high flushing rate. The flushing rate of Togus Pond is unlikely to experience future changes which means that nutrients, such as phosphorus, are going to have longer residence times than most other Maine lakes. It is very important that nutrient sources into the lake are limited and controlled.

PHOSPHORUS BUDGET

INTRODUCTION

A phosphorus loading model was used to assess the inputs and outputs of phosphorus in Togus Pond watershed in 2004. This model is of critical importance in determining the movement of phosphorus within the watershed. The model is also a tool for determining the future input of phosphorus to the lake as a result of land use change and population growth.

METHODS

The model used for Togus Pond was adapted from Reckhow and Chapra (1983) and past studies on similar central Maine lakes (CEAT 2003, 2004). The amount of phosphorus entering the watershed from various sources was determined using the following equation:

$$\mathbf{W = (Ec_a \times As) + (Ec_{of} \times Area_{of}) + (Ec_f \times Area_f) + (Ec_w \times Area_w) + (Ec_c \times Area_c) + (Ec_{com} \times Area_{com}) + (Ec_{cr} \times Area_{cr}) + (Ec_{sr} \times Area_{sr}) + (Ec_h \times Area_h) + (Ec_s \times Area_s) + (Ec_n \times Area_n) + [(Ec_{ss} \times \#capita\ years \times (1\text{-}SR_1)) + (Ec_{ns} \times \#capita\ years_n \times (1\text{-}SR_2))] + (Sd_{cs} \times Area_{cs}) + PSI}$$

W represents the total phosphorus entering the lake in kg/year. The Ec terms all represent the export coefficients for the various land use types, measured in kg/hectare/year. The export coefficient is determined by the degree to which that land use type contributes phosphorus to the lake. These coefficients are further explained in Appendix E. Phosphorus inputs included in this model are as follows: atmosphere (a), old field (of), forest (f), wetlands (w), cleared land (c), commercial land (com), state roads (sr), hay fields (h), shoreline development (s), non-shoreline development (n), shoreline septic systems (ss), non-shoreline septic systems (ns), and sediment release (cs). Sd represents the amount of phosphorus released from sediments at the lake bottom. SR_1 and SR_2 are measures of the soil retention capacity for phosphorus of shoreline and non-shoreline soils. The coefficients were multiplied by their corresponding land area. A_s is the surface area of Togus Pond. The area for all other land uses was determined using ArcGIS™ 9.0 and digital orthophotoquads of the Togus Pond watershed from 2002 (see Watershed Land Use Patterns: Methodology). PSI stands for point source inputs from tributaries or industrial sources.

To determine the input of phosphorus from septic systems, the export coefficients for shoreline and non-shoreline septic systems were multiplied by the number of capita years and by one minus the coefficient values for soil retention. The value for capita years is based on the average occupancy of each residence and the average family size in the watershed. Average family size was based on past reports on similar watersheds (CEAT 1999). The value used for seasonal residences was less than that used for permanent residences because of the lower occupancy rates. Full-time residences were estimated to be occupied 355 days per year, while seasonal residences were estimated at 36 days annually.

Total phosphorus loading was determined using high, low, and best estimates. This range of values was used to account for uncertainty from human error and natural sources affecting phosphorus loading. The best estimate represents our estimate of the most accurate depiction of phosphorus inputs within that range. The phosphorus load for Togus Pond was calculated using the export coefficients and data from the water budget (see Appendix D). Please see Appendix E for the equations used and the calculations of annual phosphorus loading.

RESULTS AND DISCUSSION

The Phosphorus Loading Model predicted a range of 227.7 kg/yr to 814.2 kg/yr of phosphorus, with a best estimate of 466.0 kg/yr of phosphorus. The best estimate for total phosphorus concentration was calculated to be 19.1 ppb, with a range from 9.4 ppb to 28.1 ppb. These values include phosphorus release from the sediment, an important component of the total phosphorus load in Togus Pond. The best estimate is in line with spring values for total phosphorus concentration collected by MDEP, which ranged from 18 ppb to 21 ppb. The high range value corresponds well with CEAT data from the summer and early fall, which had a mean value of 28 ppb. The increase over the course of the summer can be explained by increasing phosphorus released from the sediment and internal recycling of phosphorus within Togus Pond. The predicted values for total phosphorus concentration are accurate because they are similar to actual data collected in the field (see the Phosphorus section of Water Quality Analysis). Both the high and best estimates are above the 15 ppb required to produce algal blooms, which explains the algal blooms that affected Togus Pond in 2004.

Based on our model, the highest contributor of phosphorus to Togus Pond is sediment release, which contributes 357.5 kg phosphorus/ha/yr to the lake. This phosphorus is released into the water column from the sediments during internal recycling that is caused by anoxic conditions (see Phosphorus section of Water Quality section). The rest of the phosphorus in Togus Pond comes from the surrounding watershed. Forest, which supplies 25% of the total phosphorus load or 106.8 kg phosphorus/yr (Table 8) is the largest land use contributor. Shoreline septic tanks came next, contributing 23% of the total load, or 96 kg phosphorus/yr.

The predominance of these sources of phosphorus can be explained by several factors. Togus Pond has a relatively low flushing rate of 0.81 flushes/yr, or 0.41 flushes/yr when excluding Dam Pond (see Appendix D). This indicates that the water within the lake is not moving in or out at a high rate. In addition, the Togus Pond watershed is relatively small in comparison to nearby lakes such as Threemile and Webber Ponds. Each input is likely to have a higher percentage contribution into the lake, causing a reduced dilution ability for nutrient inputs.

In terms of land area, the Togus Pond watershed is mostly forested. Although this land use type contributes relatively little phosphorus to the system in comparison with other land uses, the large area

Table 8. Percent contribution of phosphorus for all land use types. This percent was determined by the different export coefficients used for low, best and high estimates. Values reflect the amount of phosphorus input for each land use under different estimates, relative to the total phosphorus load.

Landuse type	Low estimate	Best estimate	High estimate
Atmospheric input	16.22	11.54	9.17
Old field	3.65	2.44	2.97
Forest	26.71	26.07	16.11
Wetlands	0.30	0.25	0.27
Cleared land	0.79	1.32	0.95
Commercial	7.88	8.57	10.69
Camp roads	1.56	4.95	5.51
State roads	2.60	3.63	7.85
Hay field	0.53	0.59	0.48
Shoreline development	10.86	13.63	14.74
Non-shoreline development	4.67	2.93	7.93
Shoreline septic systems	23.77	23.44	22.46
Non-shoreline septic systems	0.46	0.65	0.87

(763 ha) counteracts the smaller export coefficient. In other words, since most of the watershed is forested, it represents a significant amount of the nutrient load entering the lake, even though forest is not a major contributor of phosphorus.

Septic system contribution is affected by several other factors in addition to those already addressed. Compared with Threemile Pond, which was studied in 2004 (CEAT 2004), there are twice as many year round homes on the Togus Pond shoreline, which means that the capita years factor is significantly higher, increasing the impact of the septic systems of these homes. Many of the septic systems around Togus Pond, which was developed earlier than Threemile Pond, are quite close to the water because they are not subject to the most recent regulations for septic tank setback near lakeshores. This further increases the potential for phosphorus leakage into the lake. Finally, the soil retention surrounding Togus Pond is relatively poor, which means that any phosphorus leeched into the soil is more likely to be flushed out into the nearby water during times of heavy precipitation or by groundwater movement over time.

Other significant contributors of phosphorus included shoreline development (14% or 55.9 kg/yr), atmospheric input (12% or 47.3 kg/yr), and commercial sources (9% or 65.1 kg/yr). All other sources including wetlands, hayfield, non-shoreline development, roads, and cleared land, exported 5% or less, of the total phosphorus load. (Table 8).

Shoreline development contributes phosphorus to the lake through runoff, carrying nutrients and phosphorus-laden sediment produced through erosion. This process is exacerbated by inadequate buffers between the shore and the lake (see Watershed Land Use: Buffer Strips).

The export rate of the atmosphere is due to close proximity to Augusta and the development there, since phosphorus can be released to the atmosphere and later deposited into the lake through industrial processes and wood-burning stoves (Reckhow and Chapra 1983).

The main contributor of phosphorus for nearby Webber and Threemile Ponds was also sediment release. The main land use exporting phosphorus to these ponds was reverting land, whereas forest was the largest source in Togus Pond. Threemile and Webber Pond have significant phosphorus input from agricultural lands, and a golf course in the case of Webber Pond (CEAT 2003). Together, agriculture and the golf course contributed almost 40% of the phosphorus load to Webber Pond, while mature and transitional forests comprised two-thirds of the land area but only exported 14 % of the phosphorus load. The absence of nutrient-intensive land use, such as agriculture, underscores the importance of the internal recycling and sediment release in the phosphorus budget of Togus Pond. This also explains the higher contribution of forest in the Togus Pond watershed, where there are no major contributors such as farms or golf courses (the golf course nearby is just outside the Togus Pond watershed).

Using our phosphorus model, we determined that a phosphorus concentration of 1 ppb was equivalent to a phosphorus load of 41.7 kg/yr. In other words, an increase in the phosphorus load by approximately 42 kg annually would raise the mean phosphorus concentration of the lake by about 1 ppb. This value was calculated by dividing the best estimate for annual total phosphorus load (kg/yr) by the best estimate for total phosphorus concentration (ppb) (Appendix E). In order to decrease the likelihood of algal blooms, the mean phosphorus concentration needs to be decreased to 15 ppb or lower. This would necessitate a reduction of 4 ppb, or a cut in the annual load by approximately 167 kg phosphorus/yr.

The first step in achieving this reduction should be to decrease external phosphorus loading to Togus Pond from the surrounding watershed. The primary target among the external sources would be shoreline septic systems, which contribute 96 kg/yr. Total elimination of this phosphorus source is unlikely if not impossible, however, so reduction also needs to take place elsewhere. Although forest contributes more phosphorus than septic tanks to the total external load (106.8 kg/yr), this is a variable that cannot be controlled. Another large contributor of phosphorus, shoreline development, is also difficult because much of the Togus shoreline has already been developed. There is not much room for significantly reducing phosphorus loading from shoreline development, although an increase in development in the watershed would lead to greater phosphorus loading (see Future Projections: Phosphorus Budget Projections).

The algal blooms in Togus Pond are not likely to be eradicated by reducing the external load alone, because of the inability to control the major contributors and because sediment release is still the largest source of phosphorus. The internal cycling of phosphorus is an important component of Togus Pond's algal blooms and needs to be addressed to improve the health of the lake. There are several options for dealing with internal phosphorus loading which are discussed in the next section (Lake Remediation Techniques).

LAKE REMEDIATION TECHNIQUES

INTRODUCTION

The CEAT analysis of Togus Pond has led to the identification of the principle contributors to poor lake quality. To improve the health of the lake and preserve its natural, residential, and recreational value, remediation techniques must be explored and implemented.

The first step in restoring or improving the quality of eutrophic lakes is to remove or treat direct inputs of nutrients through wastewater, stormwater, or both. Unless such external inputs are reduced, any long-term benefits from in-lake nutrient reduction treatments are likely to be insignificant. In many cases, reduction of external inputs is sufficient to restore the health of the water body, but in other cases, where internal loading of nutrients is significant, in-lake treatments may be necessary to achieve the desired reduction (Cooke et al. 1993). Road evaluation and maintenance, septic system regulations, and proper shoreline buffers have been addressed previously in this report (see Background: Watershed Land Use and Watershed Development) and recommendations for their application are made in the summary.

The remediation techniques that are discussed in this section are separated into Techniques Deemed Most Applicable to Togus Pond and Commonly Used Techniques Inapplicable to Togus Pond (see Appendix J and Appendix K). Techniques that could be applicable to Togus Pond include alum treatment, manipulation of fish stocks, water drawdown, and vegetative mats. All of these techniques would be most effective (ordered by what we perceive to be the most effective to least effective) if used in combination with the land and road recommendations. The combination of two or more techniques has also been shown to be more effective than only one, as long as they complement each other and their effects are carefully studied (Cooke et al. 1993). The inapplicable techniques are included to give a comprehensive background on all the possibilities of water quality improvement and to explain why we believe that they are not possible for Togus Pond. This section is further separated into two major groups: Chemical and Physical mitigation techniques. Chemical manipulation techniques deemed non-applicable include calcium additives, ferrous additives, algicides, and herbicides. Physical treatments deemed non-applicable include dilution and flushing, dredging, hypolimnetic aeration, hypolimnetic withdrawal, and aquatic plant harvesting.

TECHNIQUES MOST APPLICABLE TO TOGUS POND

Alum Treatment

Aluminum sulphate ($Al_2(SO_4)_3$), or alum, has been used for decades to precipitate and increase the sorption (uptake and holding) capacity of phosphorus (P) and to remove it from internal cycling in ponds and lakes (Sondergaard et al. 2002). Aluminum complexes and polymers have the advantage over iron by requiring a low redox potential for the reduction of insoluble Al^{3+} to soluble Al^{2+}, meaning that adsorbed P will not be released from the sediment during periods of anoxia. When added to water, alum forms an aluminum hydroxide complex ($Al(OH)_3$), which has a cotton-like appearance called 'floc' (Sondergaard et al. 2002):

$$Al^{3+} + H_2O \rightarrow Al(OH)^{2+} + H^+ + 2\,H_2O \rightarrow Al(OH)_3 + 3H^+$$

P adsorbs to the floc and sinks to the lake bottom where it can be permanently removed from the P cycle, fixed, and buried in the sediment. If alum treatment is capable of transforming loosely-sorbed and iron-bound P to aluminum-bound P, it may reduce the internal P loading caused by anoxia in the hypolimnion. The floc also tends to physically entrap algae and other particulate matter (Sondergaard et al. 2002). Alum is usually applied in concentrated liquid form, which is dispersed from the back of a small boat, modified harvester, or pontoon barge (Cooke et al. 1993). For maximum effectiveness and to ensure complete coverage, it can also be injected at prescribed depths into different parts of the lake (Welch and Cooke 1999). Alum is normally added as a one-time treatment based on the current water and sediment P content, implying that the capacity to adsorb further P will eventually cease and not have long-term effectiveness (Sondergaard et al. 2002).

In most cases, the treatment has been reported to last for about ten years, fluctuating between one and 20 years (Welch and Cooke 1999). Treatments have had greater longevity and have been more successful in stratified rather than unstratified lakes (Welch and Cooke 1999). Typical lake responses to alum treatment include: sharply lowered P concentrations; greatly increased transparency and improved conditions for weeds; and algal blooms of much reduced intensity and duration (EPA 1990a). In a study by Welch and Cooke (1999) on 21 lakes across the U.S., internal P loading decreased by an average of 67% for the six successful cases and lasted an average of eight years. Annabessacook Lake, Maine (574 hectares), is the largest lake cited by Cooke et al. (1986) to be treated with alum. The lake had experienced blue-green algal blooms over the previous 40 years, particularly at the end of summer stratification. Sewage diversion and land management improvements reduced external P from entering the lake, but blooms continued, supported by internal P loading. A 1:1.6 mixture of aluminum sulfate to sodium aluminate, determined empirically in the laboratory as a ratio that would keep pH in the 6-7 range, was applied to the top of the hypolimnion (121 hectares) over an 18-day period in the summer of 1978 (Cooke et al. 1986). A significant lake improvement followed. In the summer before treatment, 1800 kg of P was added to the water column through internal loading, while in the summer of 1979, one year after treatment, only 625 kg of P (a 65% reduction) was added with no autumnal blue-green algae bloom (Cooke et al. 1986). This example demonstrates that an adequate dose of alum can be determined for soft-water lakes without adverse effects (Cooke et al. 1986).

Acidification of alum-treated lakes to below pH 6 may result in increased aluminum concentrations and adverse toxic effects associated with enhanced metal solubility (Cooke et al. 1993). Aluminum can be a toxic metal in lakes, particularly in acidic water. It has been found to be toxic to fish at concentrations as low as 0.1 to 0.2 mg Al per liter at a pH of 4.5 to 5.5. However, in the few studies on effects of an alum treatment on lake biota, there were no massive biotic changes, such as fish kills (Cooke et al. 1993). Dense macrophyte beds may decrease the effectiveness of the treatment because they can cause uneven floc distribution or sediment P recycling from below the floc layer through plant accumulation and decay. A lack of light before treatment can lead to alum treatments facilitating a drastic increase in macrophyte biomass in shallow, eutrophic lakes with low clarity and few macrophytes. High iron content in the sediment can cause redox and release phosphorus. Aluminum hydroxide can block the iron redox mechanism so that high pH caused by algae photosynthesis will not occur, and sediment P will remain inactivated (Welch and Cooke 1999).

P inactivation with alum is fairly expensive, but costs have decreased dramatically since the 1970s (Cooke et al. 1993). With the use of barges, modified harvesters, and computerized dose and navigation systems (like that used at Threemile Pond in 1988) it takes less time for the treatment to be applied, resulting in fewer worker days per hectare. The cost to treat Threemile Pond in 1988 was $640 per hectare with the high speed system, whereas the cost of treating Medical Lake, WA, with similar acreage and a lower dosage, was $1101 per hectare using an old barge system (Cooke et al. 1993). The current cost of application is dependent on the form of alum used (liquid alum has been used for large applications), dosage rate, area treated, equipment used, and labor, and ranges from $280/acre to $700/acre ($450 is the approximate average) (WDNR 2003).

Alum treatment is a strong possibility for remediation of Togus Pond. Tests should be done to determine how the water would react, and careful measurements and monitoring would be necessary to ensure that toxicity does not become a problem. Studies on the proper placement in regard to water depth and correct quantities should be carried out to ensure the treatment works to its full potential. Depending on the amount of funding available for remediation, cost could also be an issue, but this method is highly recommended for Togus Pond.

Fish Stock Manipulations

A biological control that has some promise for Togus Pond is manipulation of the fish stock. Biological approaches to the improvement of lakes might eventually reduce the use of common chemical and mechanical techniques, although they are more precise. The abatement of external nutrient loading, combined with food web management or fish removal, may offer the best opportunity for long-term control of algal biomass. This method attempts to enhance top-down control of phytoplankton either by removing the planktivorous fish that eat the zooplankton, adding piscivorous fish to eat the planktivorous fish, or both (Cooke et al. 1993). Hurlbert et al. (1972) demonstrated that planktivorous fish can severely reduce or eliminate the most efficient grazers of planktonic algae, large-bodied *Daphnia*. A high abundance of piscivorous fish, such as largemouth bass, trout, and pumpkinseed, could reduce the abundance of planktivorous fish (Cooke et al. 1993). Planktivorous fish, such as the alewife, minnows, and yearly-young of many species, graze selectively on the largest species of zooplankton, like *Daphnia*. It has been shown that these larger zooplankton, being eliminated or populations reduced by size-selective predation, have the highest grazing rates and also ingest the largest particles of algae (Cooke et al. 1993). Harvesting planktivorous fish species and further reducing their numbers by increasing populations of piscivorous fish could have a dramatic effect on decreasing the phytoplankton in the lake.

Success of reconstructing fish communities depends first on reducing the planktivorous fish prior to restocking piscivores (Cooke et al. 1993). Success is also related to maintenance of stocked fish densities so that about 30 to 40% of the fish community is made up of piscivores. After the restocking of the lake, one strategy to help maintain the biomass of piscivores is to establish length limits on fish which can be removed. A common plan is to establish a "slot length limit" so that, for example, largemouth bass of 12 to 16 inches long can be removed from the lake, but large individuals with the greatest mouth gapes are returned so they can inflict more predation on planktivores. This strategy can result in cleaner water, improved game fishing, and, at the same time, protection of herbivores such as *Daphnia* that will continue to eliminate phytoplankton from the water column for greater future effects of remediation (Cooke et al. 1993). A study on the commercial removal of planktivorous species, mostly white and yellow perch, is currently being conducted by MDEP at East Pond (Halliwell pers. comm.), and may offer suggestive data in the future. East Pond received a $50,000 EPA 319 grant to support a graduate student from the University of Maine, Orono, in the two-year assessment phase of the project, and after this the implementation process is expected to last a further two years. It may not be possible to determine if the treatment is effective in improving water quality until 2010, at which time MDEP will investigate the use of this technique on lakes with similar problems, such as Togus Pond. Rough estimates predict that the entire project will cost several hundred thousand dollars.

Togus Pond is already stocked on a yearly basis with piscivorous species, so this method would be fairly inexpensive (see Background: Biological Perspective: Fish Stocking). There are, however, many species of planktivorous species in the lake as well, such as minnows and white perch. A reduction of planktivorous fish would be required to attain maximum effectiveness of the remediation method. A limit on fishing certain species may also be necessary to ensure that a stable population of introduced species takes hold. Piscivorous fish will require restocking yearly because many of them do not reproduce outside of coldwater fisheries.

Drawdown

Water level drawdown occurs when a dam is altered to allow the lake to drain a significant amount. This technique is used primarily for reservoirs and small ponds and used to control certain aquatic plants, manage fish populations, repair structures such as dams or docks, and facilitate other improvement procedures such as dredging (Cooke et al. 1993). The expulsion of nutrient-rich water from the lake is also a benefit of drawdown, as long as nutrient reduction precautions are being applied to watershed inputs concurrently. This is the benefit that would be most applicable to Togus Pond. Of the other benefits, the primary use is to control macrophytes by exposing plants, especially their root systems, to dry conditions for a period of time sufficient to kill them. Winter drawdowns seem to be more effective for this purpose, but this also depends on the type of plant because not all aquatic plants respond the same way to drawdown (Cooke et al. 1993). Changes in the water level may also influence lakes directly, by affecting fish recruitment (Jeppesen and Sammalkorpi 2002). Shifting water levels may reduce the survival of planktivorous fish by entangling them in the exposed weeds and suffocating them. This enhances zooplankton populations that feed on phytoplankton, and improves water clarity. Short-term partial drawdown has been used to improve game fishing because it enhances the size and weight of predatory fish at the expense of planktivorous and benthivorous fish. This may be because the lower water table increases the predation risk or dries the planktivores' fertilized eggs in their early development from embryo to adult (Jeppesen and Sammalkorpi 2002). Drawdown is currently being utilized as a water quality remediation technique at Webber Pond.

Togus Pond cannot currently implement this remediation strategy because Route 105, the road that separates it from Lower Togus Pond, does not have an easily manipulated dam. Instead, a culvert runs under the road into Lower Togus, which is dammed at the southern end. Even if the dam at the south end of Lower Togus were lowered, Togus Pond would not respond significantly because the water level is only several inches above the lower lip of the culvert. This would only enable the lake to drain a few inches, which would not be enough to have an effective drawdown effect. However, if the culvert area was altered in order to allow a greater depth of water to pass through, resulting in a water level reduction of several feet, drawdown would be an effective technique for Togus Pond.

Vegetative Mats

The addition of nutrient absorbing plants is sometimes used as a remediation technique to take available phosphorus (P) out of the water column and make it less available to algae. The mats could also provide cover for the zooplankton which eat phytoplankton. Introduced plants can be a tool for absorbing nutrients, but they must be able to grow well during the growing season but not survive and reproduce over the winter. Once the plant biomass has trapped nutrients, it can be harvested at the end of the growing season, composted, and put on gardens or disposed of away from the lake.

A potential exotic plant for Togus Pond is the water hyacinth (*Eichhornia crassipes*) because it flourishes in the summer and is killed by cold weather due to its origins in South America. Mats of water hyacinth could be raised and harvested to remove P. The mats would prevent plants from becoming a nuisance to recreation by containing them within specific areas. Water hyacinth has not been used in Maine due to state regulations involving introduced species (Bouchard pers. comm.). This plant has caused significant problems in southern regions, where the winter is not cold enough to stop it from spreading, so this plant should be used with caution (Bouchard pers. comm.).

Native aquatic plants can also be used in floating vegetative mats. However, because they are adapted to the climate, they would have to be carefully harvested at the end of the growing season to ensure they do not grow out of control. This technique is labor intensive because it requires harvesting the wet biomass and finding a proper disposal site or composting site. Floating mats are designed for small and relatively shallow bodies of water. Togus Pond has areas of shallow shoreline where these floating mats have the potential to do well, but homeowners might consider them to decrease lake aesthetics. Because Togus Pond is a large lake, the effectiveness of this method is uncertain. This method would be best if used in combination with other techniques. The use of exotic plants instead of native species would also need to be approved by the MDEP.

TECHNIQUES NOT APPLICABLE FOR TOGUS POND

Chemical Manipulation Techniques

Calcium Additives

The goal of calcium additives is to inactivate phosphorus (P) by binding P in lake sediments and causing bottom settlement. Lime treatments of ponds with algal blooms are an inexpensive procedure with a smaller likelihood of toxicity problems than with the use of alum (Cooke et al. 1993). Slaked (chemically combined with water or air) lime (calcium hydroxide ($Ca(OH)_2$)) has been added to eutrophic lakes to diminish P availability by the formation of calcite (calcium carbonate, $CaCO_3$) into insoluble $Ca_{10}PO_4$ complexes (hydroxyapatite) (Sondergaard et al. 2002).

Unlike $Fe(OH)_3$ and $Al(OH)_3$, hydroxyapatite has its lowest solubility at pH > 9.5, and P binds strongly to it at high pH (Cooke et al. 1993). If a proper deep water pH is not maintained, P absorption can be lost and P will be released from the sediment back into the water column (Cooke et al. 1993).

This form of remediation is not a safe option for Togus Pond because a pH higher than 9 is recommended, and the mean pH of Togus Pond is 7.62. In addition, calcium additives are best used in lakes with hard water, and Togus Pond has fairly soft water. Other problems normally associated with this method are: increased short-term turbidity following the treatment; the possibility of the precipitate dissolving and releasing the P; and the subsequent pH shock, which may last for a year or more after treatment, having a negative impact on the macroinvertebrate community and other animals (Sondergaard et al. 2002). The extent of pH increase after the addition depends on the buffering capacity of the lake and the dosage applied, but in soft-water lakes, like Togus Pond, pH may increase to above 11, causing severe danger to most organisms (Sondergaard et al. 2002).

Ferrous Additives

Iron addition is used to increase the iron buffer within the sediment and is often used in combination with nitrate (Sondergaard et al. 2002). The objectives of iron treatment are: precipitation of phosphorus (P) from the water body; increase of the sediment's P-binding capacity; and decontamination or precipitation of surplus hydrogen sulfide, which can play a substantial role in the oxidation of organic substances (Sondergaard et al. 2002).

Without net photosynthesis or periodic aeration by mixing of hypolimnetic waters impermeable to light, pH and dissolved oxygen concentrations in the benthic sediment declines so that iron changes to its reduced, soluble state (Fe^{2+}) and iron-bound P is released back into the water column (Cooke et al. 1993). At the time of their publication, Cooke et al. (1993) had found no demonstration of long lasting control of sediment P with iron, because every published test had reported failures.

The stratification of Togus Pond would cause dissolved oxygen in the hypolimnion to be too low for this treatment, causing potential for the P to dissolve back into the water column. In addition, the pH of Togus Pond (7.62) is too high for the recommended levels of 5 to 7.

Algicides

The most widely used chemical to kill algae is copper sulfate ($CuSO_4$). Unfortunately, it has some major negative impacts on non-target organisms, and significant contamination of sediments with copper is possible (Cooke et al. 1993). It inhibits algal photosynthesis, cell division, and alters nitrogen metabolism. Copper is applied by towing a burlap bag filled with granules of $CuSO_4$ (which dissolve in water) behind a boat. In alkaline waters, or in waters high in organic matter, copper can be quickly lost from solution and is rendered ineffective (EPA 1990a). In these cases, a liquid, chelated form is often used in order to maintain it in solution long enough to produce the desired effect (Cooke et al. 1993).

Negative impacts include toxicity to fish and dissolved oxygen depletions when large areas are treated within a short period of time (EPA 1990a). Copper kills algae but does not reduce phosphorus (P), so it is not an ideal lake management technique. Copper sulfate may be associated with the development of resistance in target algae, so subsequent uses of the chemical would have no positive effect (Cooke et al. 1993). Both the chelated and nonchelated forms of $CuSO_4$ are highly toxic to species of *Daphnia*, one of the larger zooplankton species that is extremely effective in phytoplankton grazing (Cooke et al. 1993). In other words, it kills not only the algae, but also the natural consumer of the algae.

In 1953, a study was done by the State of Maine that determined that Togus Pond would need 3,505 pounds of copper sulfate to treat at 1 ppm, or 1,052 pounds to treat at the recommended amount of 0.3 ppm (Bond 1953). For more on the historical use of copper sulfate in Togus Pond, see Togus Pond Characteristics: Historical Perspective: Water Quality. CEAT recommends that copper sulfate should not be used as a remediation technique because of the potential negative effects.

Physical Treatments

Dilution and Flushing

Dilution and flushing can improve water quality in two ways: the concentration of phosphorus (P) and other nutrients can be reduced (dilution); and the water exchange (flushing) rate of the entire lake is increased. Both processes can reduce the biomass of plankton algae (Cooke et al. 1999). The addition of low-nutrient water both increases the expulsion of phytoplankton and algae cells, dead and alive, from the lake, and also dilutes the concentration of nutrient rich inflow water. Flushing, using water of the same nutrient level as the lake, achieves only the first of these objectives (Cooke et al. 1986). Dilution is usually feasible only when large quantities of low-nutrient water are available. Low-nutrient water has been obtained in several ways in past case studies, such as adding city water to Green Lake in Seattle, WA in the 1960s and diverting the Columbia River into Moses Lake, WA on a regular basis since 1977 (Cooke et al. 1993).

In the case of Togus Pond, no low-nutrient water source is readily available, and there is no guarantee that wells drilled specifically for this purpose would have a low enough nutrient content. The high concentration of houses around the lake, combined with the large amount of water necessary for dilution, could draw too heavily on the area's water source and necessitate the end of the project, even if treatment was restricted to the summer months. In addition, the increased volume released downstream could have negative effects on ecosystems of surrounding water bodies (EPA 1990a).

Hypolimnetic Withdrawal

Hypolimnetic withdrawal involves the removal of water from the deepest parts of the lake, so that the most anoxic water is expelled. Hypolimnetic withdrawal is applicable to stratified lakes in which anaerobic hypolimnia restrict the habitat for fish and promote the release of P, toxic metals, ammonia, and hydrogen sulfide from sediments (Cooke et al. 1993). This technique is accomplished by installing a pipe that travels from near the deepest point in the lake along the lake bottom to the outlet. Destratification, which could increase the transport of hypolimnetic nutrients and water without dissolved oxygen to the epilimnion, will not occur as long as the transport of hypolimnetic water from the lake is not too great. Selectively removing hypolimnetic water should decrease the period of anoxia and increase the depth of the anoxia boundary, resulting in a decrease in internal P loading (Cooke et al. 1993). Withdrawal can be an inexpensive remediation tool if the lake has an easily manipulated dam, but because the outlet culvert of Togus Pond runs under a fixed land bar with Route 105 on it, the alternative pumps required would be somewhat expensive. As with dilution and flushing, a major problem with hypolimnion withdrawal is finding a location to pump the water. Pumping it into the nearby ponds or watersheds would compound the problems there because they are too small to effectively handle the nutrient-rich input.

Hypolimnetic Aeration

Depletion of oxygen in the hypolimnion is one of the first signs of eutrophication in lakes. If lake enrichment becomes severe enough for all or most of the oxygen in deep levels to become depleted before autumn destratification occurs, anoxia will result (Cooke et al. 1993). Anoxia can accelerate internal recycling of nutrients, cause undesirable metals to become soluble, and limit cold water species in fisheries. Aeration of the hypolimnion is a lake remediation technique designed to counteract hypolimnion anoxia. There are three objectives: raise the oxygen content of the hypolimnion without destratifying the water column or warming the hypolimnion; provide increased habitat and food supply for cold-water fish species; and decrease the internal loading of P by establishing aerobic conditions at the sediment-water interface (Cooke et al. 1986). Aeration is accomplished by various methods, grouped into three categories by Cooke et al. (1993): mechanical agitation, which involves removal, treatment, and return of the hypolimnetic water; injection of pure oxygen; and injection of air, either through a full or partial air-lift design or through a down-flow injection design. The air-lift design is one of the most popular, where oxygen-depleted bottom water is brought to the surface via a full-lift aerator where it is aerated and returned to the bottom (Jeppesen and Sammalkorpi 2002).

Problems associated with hypolimnetic aeration are that it reduces the internal P loading but not the overall P levels present in the watershed. Methods that use rotating aeration blades can kill fish, and supersaturation of hypolimnetic water with N_2 was suggested as a possible problem that might lead to gas bubble disease in fish (Cooke et al. 1993). The large amounts of circulating water can stir up sediments and increase turbidity and P levels. Cooke et al. (1993) mention a case in which nutrients that diffused into the hypolimnion during aeration doubled the phytoplankton biomass, which was composed of mostly blue-green algae. The equipment for this method is also fairly expensive. There was an attempt in 1971 to use aeration for remediation, in the Togus Pond Aeration Project (Anderson 1972). It was reviewed by biologists as having no real effects. The results did not indicate any significant overall improvement in water quality other than enlarging the aerobic zone, and Togus Pond did not become any less eutrophic (Ritzi 1972). For a more complete history of hypolimnetic aeration on Togus Pond, see Togus Pond Characteristics: Water Quality: Historical Perspective. Due to the cost and potential hazards of hypolimnion aeration with unreliable results, this technique is not recommended for Togus Pond.

Dredging

When properly conducted, dredging (sediment removal) is effective as a lake management tool. Shallow eutrophic lakes are frequently susceptible to nutrient release from the sediment, and in cases where a significant amount of nutrient loading from sediments can be detected, dredging could reduce the rate of internal nutrient recycling and improve the overall lake water quality conditions. Dredging removes the most enriched layers of sediment from the lake bottom to decrease the problems caused by nutrients released from the sediment (EPA 1990a).

A major environmental concern of dredging is the resuspension of P-containing sediment during removal (Cooke et al. 1993). A possibly dangerous problem is the release of heavy metals contained in the sediment and their effect on fish and humans (EPA 1990a). If the lake basin is dredged completely, it may take two to three years to reestablish the benthic fauna, whereas if portions of the bottom are left undredged, reestablishment may take place immediately or in one to two years (Cooke et al. 1993). Dredging and all it involves can be a very expensive process. This is not a feasible remediation technique for Togus Pond because of its cost.

FUTURE PROJECTIONS

POPULATION TRENDS

HISTORIC

The population of Augusta has shown a steady increase throughout most of the city's history, with the exception of a couple of short declines (Figure 59). The population doubled in less than a decade after Augusta became the first town in Kennebec County in 1799 (City of Augusta 2004). Since this doubling, the population continued to gradually increase (Raymond H. Folger Library 2001). After Augusta was named the new capital of Maine in 1827, the city's growth rate increased further and the city continued to grow until the mid-nineteenth century (City of Augusta 2004). The growth was due to the tremendous economic growth experienced after Maine became a state, as many industries prospered, including mining, manufacturing, and lumbering (State of Maine 2004). There was a slight depression in the population between 1850 and 1860, but it climbed steadily until the 1920's, when it again began to grow more quickly. By 1980 the population had peaked at 21,945, and it remained steady for next decade before falling to 18,560 in the year 2000.

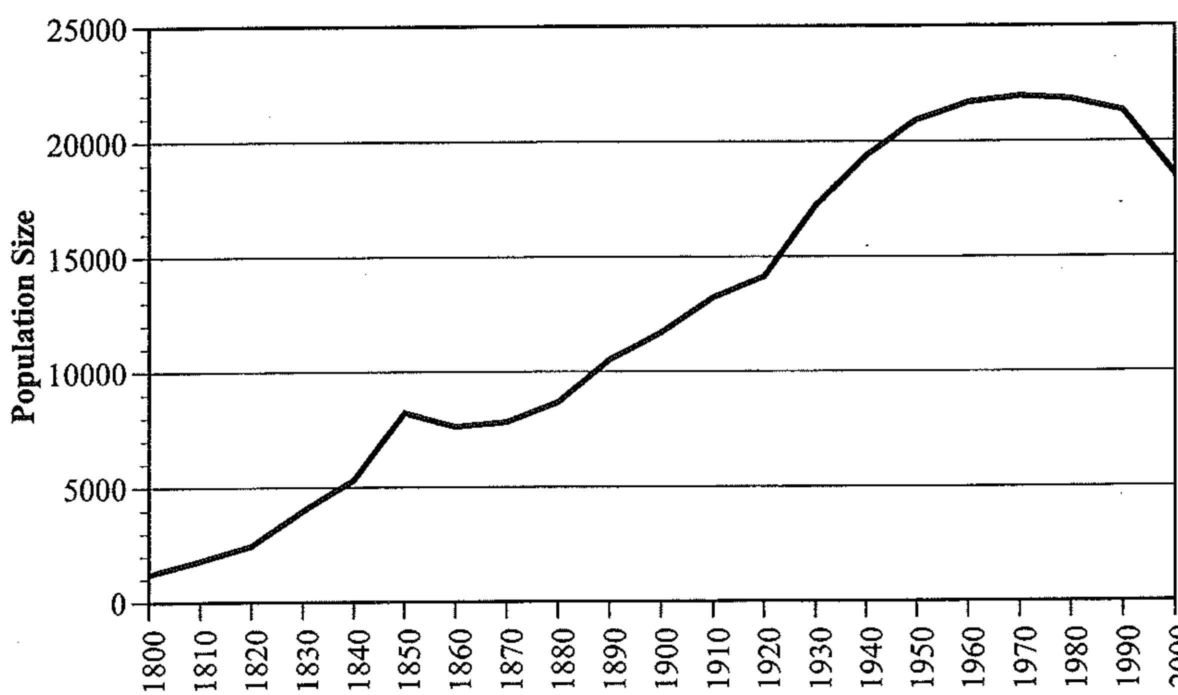

Figure 59. Population trends for the City of Augusta from 1800 to 2000. Data were obtained from the Maine census data (Raymond H. Fogler Library 2001).

FUTURE

The population of Augusta leveled off in the 1980s before beginning to decline over the last 15 years. According to the Maine State Planning Office, the population is predicted to decline in the near future, before beginning to recover. Based on local demographics and economic factors, the Maine State Planning Office has made population projections for 2005, 2010, and 2015 (MSPO 2002). The city of Augusta's population is projected to decrease to 17,441 in 2005, and 16,875 in 2010, before slightly increasing to 17,020 in 2015 (MSPO 2001). In surrounding towns, such as Windsor, Sidney, Vassalboro, and Hallowell, the population is expected to increase by 2015. Only Gardiner's population is expected to decrease by 2015.

These numbers seem to imply that although the population of Augusta is declining, people may be moving into the area surrounding the urban center rather than moving away entirely. This suggests that rural areas around Augusta, such as the Togus Pond watershed, may experience a population increase in the near future.

PHOSPHORUS BUDGET PREDICTIONS

METHODS

The Phosphorus Loading Model was used to predict the total phosphorus level of Togus Pond in 2030. A 25-year period was chosen to allow sufficient time for changes in the watershed to occur without seeming too distant in the future. The 25-year projection of the phosphorus budget was calculated by making educated predictions based on the future population trends projections (see Future Projections: Population Trends). CEAT predicts a population increase in the Togus Pond watershed of the same proportions as the City of Augusta. Augusta's population has been declining but is expected to increase very slightly by 2015 (MSPO 2001). CEAT projects the population of the Togus Pond watershed will increase until 2030 at an annual rate of 0.17 percent as people settle permanently in the area. The Phosphorus Loading Model uses an average of 2.3 people per residence in the calculations (CEAT 1999). Using this figure for the Togus Pond watershed, CEAT estimates a current population of 651 people in the 283 permanent and seasonal houses (see Watershed Development: Residential Survey: House Count). As the population grows by 0.17 percent annually, this number will increase to 679 people and 12 new residences by 2030. CEAT predicts these residences to be permanent based on the current conversion of many seasonal homes. Review of Augusta tax maps indicated that five of these new residences could be on shoreline lots. Areas of potential shoreline development include the Northern part of Togus Pond along Young Road. These new residences would be built on land that is currently forest.

The remaining seven residences would be on non-shoreline lots. These developments could be located in many places throughout the watershed. During the road survey, CEAT noted recently cleared land in the vicinity of Gerabro Acres Road and along the non-shoreline side of Young Road. Based on the population estimates, CEAT projects that a minimum of nine acres could be developed in the next 25 years. This number is low because the area is already heavily developed and little acreage exists growth.

CEAT also predicts a continued increase in commercial and municipal land in the watershed at the same historical rate between 1954 and 2002 with an increase of 37 acres by 2030. This is a high estimate based on the low population projections, but available land exists along Route 3 and the West View Golf Club has plans to expand. CEAT used the same phosphorus budget coefficients in the projection as in the current Phosphorus Loading Model.

RESULTS AND DISCUSSION

Using the predicted changes in land use types and new development, the Phosphorus Loading Model predicted a total phosphorus concentration range in 2030 of 9.6 ppb to 29.4 ppb with a best estimate of 19.6 ppb. The best estimate for 2030 (19.6 ppb) is only 0.5 ppb higher than the best estimate for 2004 (19.1 ppb), but is still well over the MDEP acceptable limit of 15 ppb (pers. comm. Halliwell). The model predicts a significant amount of phosphorus released from bottom sediments within Togus Pond (see Phosphorus Budget). In-lake reductions as well as reductions of cultural sources will be required to lower the phosphorus concentration and any further inputs will hinder remediation efforts.

The 2030 projection predicts forest, shoreline septic systems, and shoreline development to contribute the highest percentage of phosphorus based on the best estimates for land use contributions in the watershed (Table 9). Shoreline septic systems are the largest cultural source of phosphorus and are the second largest source overall. While forests, the largest overall source of phosphorus, are non-cultural and cannot be controlled, septic systems can be regulated. Replacement of septic systems to meet current setback rules would change the coefficients in the model, reducing the projected total phosphorus loading. Shoreline development is also a large contributor of phosphorus and new development could be limited in the future.

Table 9. Projected 2030 estimates of percent contribution of phosphorus for all landuse types. This percent was determined by the different export coefficients used for low, best and high estimates. Values reflect the amount of phosphorus input for each landuse under different estimates, relative to the total phosphorus load.

Landuse type	Low estimate	Best estimate	High estimate
Atmospheric input	15.41	10.92	8.54
Old field	3.46	2.31	2.76
Forest	24.74	24.07	14.62
Wetlands	0.29	0.24	0.26
Cleared land	0.75	1.25	0.88
Commercial	11.64	12.62	15.48
Camp roads	1.49	4.68	5.13
State roads	2.47	3.44	7.31
Hay field	0.50	0.55	0.44
Shoreline development	6.72	13.26	14.09
Non-shoreline development	4.75	2.97	7.91
Shoreline septic systems	23.45	23.04	21.66
Non-shoreline septic systems	0.47	0.65	0.86

RECOMMENDATIONS

WATERSHED MANAGEMENT

ROADS

- Regular maintenance of camp roads, especially those near streams and shoreline.
- Remediation of specific problem sites identified by CEAT.
- Limited and monitored construction of any new roads in the watershed. No new roads within shoreline zone.
- Regular enforcement of the Sedimentation Control Law during new road construction and grading by DEP and code enforcement officers.
- Homeowner education on driveway improvement.

SEPTIC SYSTEMS

- Identification and replacement of old septic systems to meet current shoreline setback require ments.
- Regular maintenance of septic systems.
- Upgrading of septic systems in response to home expansions and winterization.

BUFFER STRIPS/EROSION

- Development in the watershed should:
  - Limit the amount of impervious surfaces to meet or exceed MDEP guidelines.
  - Repair driveways to limit runoff into the lake.
- There are many inadequate buffer strips along Togus Pond and the following steps should be followed to minimize erosion and nutrient loading:
  - Increase shore coverage of native forbs, shrubs, and trees.
  - Increase the horizontal buffer depth to MDEP regulations where possible.
  - Implement riprap where needed to prevent the shore from eroding.
  - Limit the cutting of vegetation within the buffer zone.
  - Keep necessary paths narrow and winding to limit runoff of nutrients and other contaminants.

IN-LAKE MANAGEMENT

- In-lake remediation techniques may be expensive and labor intensive, but the status of Togus Pond may demand such mitigation in addition to other monitoring, regulations, and awareness.
- Alum treatment can effectively reduce the amount of phosphorus available in the water column and sediment release if used with proper management and proper application.
- Fish stock manipulation establishes top-down control of phytoplankton in order to control algal blooms by reducing the number of planktivorous fish or stocking piscivorous fish.
- Drawdown can easily expel nutrient-rich water from the lake with dam and culvert modifications.
- Vegetative mats allow contained absorption of available nutrients and provide a protective cover for valuable zooplankton.
- Some of these methods can also be combined as long as they enhance or complement each other.
- All remediation action should be carefully studied and monitored before implementation.

MONITORING AND REGULATIONS

- Implement consistent monitoring of phosphorus levels and transparency in the spring, summer, and fall. Continue participation in the Maine Volunteer Lake Monitoring Program.
- Continued promotion of the Worromontogus Lake Association to promote awareness of the problems effecting the lake to the residences.
- Limit the amount of phosphorus entering Togus Pond by not using fertilizer in shoreline areas. Shoreline residents should also consider using low-phosphate soaps and detergents.
- Maintain wetlands protection because of their function as a natural buffer and wildlife habitat refuge.
- Continue strict enforcement of regulations for new developments and expansion of old developments.

COMMUNITY AWARENESS AND EDUCATION

PESTICIDES

Low-phosphorus fertilizers and pesticides are available for purchase at stores near Togus Pond. The lake association should provide information about safer pesticide use and organic gardening techniques for the residents of the Togus Pond watershed in order to improve overall lake water quality. Publications, such as fact sheets or brochures, could be distributed to households and commercial landowners. The choice of what kind of pesticide to use, if any, lies with the residents of Togus Pond. Informed decisions would lead to a reduction in the amount of nutrients that enter the lake from excessive pesticide use and other factors contributing to phosphorus loading. The lake association could sponsor a fertilizer poster that would rate the phosphorus content of different brands of fertilizers, highlighting the use of phosphorus-free fertilizers. Workshops could be held in organic gardening and lawn care to minimize pesticide use.

HOUSEHOLD DETERGENTS

Low-phosphorus detergents are available and can cut phosphorus input of septic systems by as much as 50% (Williams et al. 1997). The residents of Togus Pond should be informed about consumer choices in detergents. The lake association could provide brochures or fact sheets could be distributed about various detergents that are better for lake quality and for input into septic systems. They could obtain this information from national organizations, such as the Environmental Protection Agency, or the Maine Department of Environmental Protection. Samples could be offered for trials in households. Label reading practices can be highlighted by the lake association, since producers of detergents list how much phosphorus and other nutrients they contain.

GRANTS AND FUNDING

- There are many sources of possible funding for the restoration of Togus Pond.
- The Maine Department of Environmental Protection is a good source for information on a variety of grants and loans. This information can be accessed at their website: http://www.maine.gov/dep/blwq/grants.htm
    - Some of the information includes:

        Nonpoint Source Water Pollution Control Grants, the Small Community Grant Program and other non-DEP affiliated programs, such as Nutrient Management Loans and Environmental Protection Agency programs.

- The Maine Department of Transportation (MDOT) runs the Surface Water Quality Protection Program (SWQPP). It is a cooperative effort between local, state, and federal organizations to reduce the effect of polluted storm water runoff from state highways and other MDOT transpor tation facilities.

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APPENDIX A. TOGUS POND WATER QUALITY MEASUREMENTS AND TESTS

Measurement or Test	Sample Date	Sample Site
Physical Measurements		
DO/Temperature	20-Sep-04	1, 2, 3, 5, 6, 7, 8
Transparency	20-Sep-04	1, 2, 3, 6
Turbidity	20-Sep-04	1, 2, 3, 5, 6, 7, 8
Color	20-Sep-04	1, 2, 3, 4, 5, 6, 7, 8, 9
Conductivity	20-Sep-04	1, 3
Chemical Analyses		
pH	20-Sep-04	1, 2, 3, 4, 5, 6, 7, 9
Hardness[1]	20-Sep-04	1, 2, 3, 8
Alkalinity	20-Sep-04	1, 2, 3
Nitrates	Jul-04 and Aug-04	1, 2, 3, 4, 5, 9
Ammonium	Jul-04 and Aug-04	1, 2, 3, 4, 5, 9
Total Phosphorus	20-Sep-04	1, 2, 3, 4, 5, 6, 7, 8, 9
Biological Analyses		
Fecal Coliform[1]	20-Sep-04	7
Chlorophyll-*a*	Jul-04 and Aug-04	1, 2, 3, 4, 5, 9

[1] Samples analyzed by Northeast Laboratories, Winslow, Maine.

APPENDIX B. QUALITY ASSURANCE

The Togus Pond study followed a quality assurance plan developed by CEAT to standardize the procedures used. The following document was modified from CEAT (2003).

Bottle Preparation

1. All samples for total phosphorus analysis were triple-acid-rinsed with 1:1 HCL:E-pure water before use to avoid contamination of 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 before sampling and E-pure-rinsed after sampling was completed.

Approaching Site

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

Surface Sampling

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

Secchi Disk

1. Use Aqua-Scope to view the disk.
2. Lower until the disk is out of sight, then record the depth. Lower the disk an extra meter, then bring it back into sight and record the depth. Average the two depths and record Secchi reading.
3. Bring the disk back to the surface and repeat the process two more times.

Measuring Depth

Speedtech Depth Finder

1. Use LCD Digital Sounder (Depth Finder)
2. Put the lanyard of the depth finder around your wrist.
3. 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.
4. The depth finder must be pointed straight down. Record this depth.
5. Repeat process once.

Lowrance LCX 15MT

1. Power on the device.
2. Mark waypoint.
3. Download data to computer file.

Conductivity

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

Turbidity

1. Use the cleaned sample cells included with the portable turbidimeter.
2. Follow surface sampling procedure.
3. Place water sample on ice. Done on site using a 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 sample drop by drop until it is below 2.
3. The same amount of acid should be added to all other bottles of the same size and 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 sample drop by drop until it is below 2.
4. The same amount of acid should be added to all other bottles of the same size and test.

Using pH Meter

A. Calibration (Before any testing is done, the pH meter must be calibrated using a 2-point calibration method at pH 4 and pH 7. This should be done during the testing day, as long as the meter's calibration is not accidentally deleted).
   1. Press the ON button. The pH meter automatically enters the measurement.
   2. Press the ON button. The pH meter automatically enters the measurement.
   3. Place the electrode into the pH 7 buffer solution by taking the cap of and submerging the entire sensor. Press the CAL button—The ExStik™ automatically recognizes the solution and calibrates itself to that value (the circled number on the LCD will match the solutions).

4. During calibration, 'CAL' appears on the lower display and the pH reading flashes on the main display. When calibration is complete, the ExStik™ automatically displays 'END' and returns to normal operation mode.
5. Repeat calibration for pH 4.
6. Check that the probe is working properly by measuring aerated deionized water. The meter should give a value of 5.65.
7. Be sure to rinse the probe with distilled water prior to and following each measurement.

B. Measurement.

1. Immerse the sensor in the sample water. Wait until the reading balances out. Record the reading and replace cap.

C. Quality Assurance.

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

<u>Dissolved Oxygen (DO) Meter</u>

1. Lower DO/temperature meter into the water, shaking it to make sure there are no bubbles around the probe.
2. Immerse probe until covered. Record DO and temperature readings every meter.

<u>Mid-depth and Bottom Sample</u>

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 and place it in the cooler.
7. Empty water sampler. Repeat sampling procedure for bottom sample.
8. Take bottom sample 1 m above bottom to avoid sediment contamination.

<u>Epicore Samples</u>

1. Rinse the tube three times by lowering it down into the lake water and pulling it back out.
2. For sites with sufficient depth lower the tube 1 m below the thermocline (determined from the DO/temperature profile).
3. For shallow depths lower the tube to 1 m from the bottom.
4. The tape marks indicate 1 m.
5. Crimp the tubing just above the water (best done by bending it tightly and then holding it in one's hand).

6. Pull the tubing up, making sure that the excess tubing goes into the water. Be careful not to touch the end through which the water comes out.
7. Allow the water to drain into the labeled epicore mixing bottle, being careful not to touch the inside of the tube, the cap, or the end of the tube.
8. Be sure to keep the non-pouring end of the tube up so the water does not drain out of it and so 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). Be careful not to contaminate the samples by touching the inside of the bottles or the inside of the caps.
12. Discard the remaining water from the mixing bottle and rinse it with E-pure water. Place all samples into the cooler.

Global Positioning System (GPS)

1. Turn on the GPS.
2. Wait for the screen to display position coordinates.
3. Record the coordinates or press ENTER to store the waypoint.

Quality Control Sampling

1. E-pure samples were spiked 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.
2. Standard solutions of known concentrations were made with every testing to ensure 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 six points.
4. The accuracy of the Absorbic Acid method used for total phosphorus analysis had a detection point less than 1 ppb.
5. Water samples were preserved for analysis by being digested 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 persevered for analysis 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 $CaCO_3$. The range of the test is 0.03 ppm to 4.00 ppm $CaCO_3$.
5. Analysis was conducted within six months 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 et al. 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 24 hours of sampling date.

Conductivity

1. One duplicate sample was taken for every ten samples.
2. Results should not vary more than 1 μmhos/cm^2.
3. Deionized water should read less than 1 μmhos/cm^2.
4. The water sampler was used at the desired depth.
5. The water sample was poured into the appropriately labeled conductivity bottle.
6. A Model 31A YSI Conductance Bridge was used to measure conductivity.
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 the 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 No3-N. The range for the test is 0.0 ppm to 10.2 pm NO_3-N.
4. Analysis was conducted within 48 hours of sampling date.

YSI 650 MDS (Multiparameter Display System) Sonde

The YSI MDS sonde was calibrated and used as directed in the YSI 6-series operating manual (YSI 2002). This sonde was used to measure the following parameters in the field: Chlorophyll-*a*, Conductivity, Nitrates, Ammonium, pH, Temperature, Dissolved Oxygen, and Depth.

APPENDIX C. PHYSICAL MEASUREMENTS, CHEMICAL AND BIOLOGICAL ANALYSES OF TOGUS POND WATER QUALITY

Physical Tests: Temperature (° C), Dissolved Oxygen (ppm), Conductivity (µmhos)

	6/9/04		6/23/04		7/7/04	
Depth (m)	Temperature	D.O.	Temperature	D.O.	Temperature	D.O.
Site 1						
0	19	10.2	23.55		23.4	8.6
1	19	10.3	20.5	8.95	22.9	8.75
2	18	10.3	20.4	8.96	22.5	8.8
3	17.4	10.4	20.4	8.9	22.2	8.8
4	17	10.4	20.3	8.8	21.8	9
5	16.5	9.7	19.9	8.4	21	8.1
6	15.7	9	17.9	7	19	4.9
7	15	8	16.1	4.5	17	1.5
8	14.9	8	15.1	3.4	16.2	1.55
9	14.8	7.8	14.2	2.4	15.3	0.7
10	14.6	7.2	13.9	1.9	14.4	0.07
11	14.1	6	13.8	1.8	14.1	0.05
12	12.8	2.8	13.7	1.6	13.9	0.05
13	12.4	1.9	13.6	1.6	13.6	0.04
14	12.1	0.95	12.8	0.05	13.2	0.04
15	11.8	0.6				
Site 2						
0	20	10.1	21.9	9	22.9	9.6
1	19.5	10.3	21	9	22.4	9.78
2	19	10.5	20.9	9.1	22.09	9.65
3	17.7	10.4	20.7	9.1	22.02	9.52
4	17.1	10.2	19.8	8.2	21.83	9.34
5	16.7	10.3	19.1	7.5	20.23	8.05
Site 3						
0	19.8	10	22.1	8.5	23.2	7.71
1	19	10.2	21.4	8.9	22.8	7.68
2	18.5	10.3	21	9	22.37	7.59
3	17.3	10.4	21	9.1	22.3	7.49
4	16.6	10.2	20.8	9.1	22.2	7.4
5	16.1	9.7	20.6	9	21.2	7.19
6	15.2	7.7	18.8	7.6	19.6	5.92
7	14.7	7	17.3	5.6	16.9	3.56

Physical Tests: Temperature (° C), Dissolved Oxygen (ppm), Conductivity (µmhos)

	7/21/04			8/3/04		
Depth (m)	Temperature	D.O.	Conductivity	Temperature	D.O.	Conductivity
Site 1						
0	25.47	9.81	63	25.36	8.65	60
1	24.21	10.21	61	25.27	8.73	60
2	23.64	10.34	60	24.40	8.88	59
3	22.43	10.48	58	23.77	8.49	58
4	21.81	8.93	56	22.80	7.37	58
5	21.19	6.93	55	22.11	6.17	57
6	20.00	4.11	55	20.84	4.30	56
7	17.68	2.04	53	19.97	1.36	55
8	15.90	0.28	54	15.78	0.37	59
9	14.52	0.23	55	14.59	0.14	60
10	13.99	0.21	55	14.08	0.11	59
11	13.77	0.19	56	13.88	0.09	58
12	13.53	0.18	57	13.62	0.09	62
13	13.23	0.17	60	13.39	0.07	62
14	13.08	0.16	64	13.28	0.07	65
15				13.07	0.06	69
Site 2						
0	25.63	9.96	63	25.69	8.80	58
1	24.09	10.41	62	25.54	8.65	61
2	23.56	10.28	60	25.14	8.76	60
3	22.09	9.51	57	24.50	8.65	59
4	21.69	8.50	56	22.93	7.00	58
5	21.41	7.46	56	22.34	5.89	58
Site 3						
0	25.52	10.37	63	25.15	8.91	60
1	24.26	10.71	62	25.02	8.91	60
2	23.64	10.82	61	24.21	8.84	56
3	22.92	10.84	60	23.63	8.31	56
4	22.29	10.65	58	23.05	7.46	58
5	21.61	8.16	56	22.57	6.53	58
6	19.48	3.53	54	20.01	2.30	55
7	17.34	0.52	53	18.38	0.63	57
Site 4						
	25.66	9.68	62	24.79	6.76	63
	24.86	9.37	60	26.14	7.19	62
Site 5						
	24.89	9.49	60	25.91	11.48	61
	24.95	9.42	57	25.69	7.99	62
Site 9						
	28.62	9.14	46	25.74	7.45	61
				26.05	8.77	61
				26.09	8.67	
Dam						
	26.01	8.06	62	25.74	7.76	46

Physical Tests: Temperature (° C), Dissolved Oxygen (ppm), Conductivity (μmhos)

	8/16/04			9/20/04		
Depth (m)	Temperature	D.O.	Conductivity	Temperature	D.O.	Conductivity
Site 1						
0	23.23	9.62	58	18.79	8.86	52
1	23.21	9.62	58	18.79	8.92	52
2	23.16	9.55	58	18.78	8.99	52
3	23.15	9.49	58	18.73	9.03	52
4	23.14	9.02	58	18.73	9.03	52
5	22.82	6.99	58	18.71	9.07	52
6	22.31	4.68	57	18.68	9.10	52
7	18.66	1.64	65	18.49	8.98	52
8	16.26	0.19	64	18.39	8.85	52
9	15.04	0.06	63	18.18	7.47	52
10	14.46	0.08	64	15.55	5.15	52
11	14.04	0.06	65	14.05	1.73	78
12	13.69	0.05	66	13.85	0.76	74
13	13.57	0.04	67	13.58	0.23	74
14	13.53	0.02	69	13.40	0.13	
15	13.31	0.01	72			
Site 2						
0	23.31	9.91	58	18.80	8.88	
1	23.15	9.86	58	18.90	8.90	
2	23.09	9.87	58	18.80	8.83	
3	23.05	9.63	58	18.80	8.80	
4	23.02	9.43	58	18.80	8.64	
5	23.02	9.49	56			
Site 3						
0	24.04	10.34	59	18.85	10.21	78
1	23.48	10.64	59	18.86	10.09	52
2	23.34	10.43	58	18.84	10.03	52
3	23.23	9.96	58	18.84	10.05	52
4	23.14	9.88	58	18.82	10.02	52
5	22.65	6.82	55	18.76	9.96	52
6	22.24	5.26	57	18.76	10.00	52
7	19.22	1.69	65	18.55	9.89	52
Site 4						
				19.5		
Site 5						
				17.8	8.73	
Site 6						
0				19	8.88	
1				18.9	8.97	
2				18.7	9.08	
3				18.6	9.08	
4				18.6	8.94	
5				18.5	8.84	
Site 7						
				19	9.41	
Site 8						
				20.2	9.04	

Physical Tests: Secchi Disk (meters), Turbidity (NTU), and True Color (SPU)

	6/9/04	6/23/04	7/7/04	7/21/04	8/3/04	8/16/04	9/20/04
	19 ° C	23.5 ° C	22.7° C	25° C	25.3° C	23.3°C	
Cloud Cover	5-10%	< 5%	5-10%	5-10%	0%	50%	
Wind speed	5-10 mph	17 mph	10 mph	None	11 mph	0-5mph	
Wind Direction	From SW	NW	NE	None	SW	N-NW	
Previous Weather		Rain	Cloudy, Drizzling	T-storms	Hot, Humid	Rainy	Rain 48 hrs before
Site 1							
Sample Depths (m)							
Epicore	7	7	8	9	8	7	10
Middle	7.5	7	7.5	7.5	7.5	7.5	
Bottom	14.7	13.5	14.5	15	15	15	
Secchi Disk	5.5	4.12	3.25	2.2	2.2	1.75	2
Turbidity							
Epicore			3.31	3.62			
Surface		1.11	1.64		4.68		6.34
Middle			2.36	2.89	2.46		2.9
Bottom		2.55	2.97	1.5	1.91		4.67
Color (SPU)							19
Site 2							
Sample Depths (m)							
Epicore	3	5	5	5			5
Middle	3	2.75	2.5	2.8	2.5	2.5	
Bottom	5	5	5.5	5	5	5	
Secchi Disk		4.1	3.25	2.2	1.8	2.25	1.75
Turbidity							
Epicore		1.38		5.9			
Surface		1.08			3.77	2.53	5.25
Middle				6.69	3.46		
Bottom				5.71	4.38	2.48	
Color (SPU)							30
Site 3							
Sample Depths (m)							
Epicore	3	6	7	7	7	7	7
Middle	3.5	3.5	3.5	3.5	3.5	3.5	3.75
Bottom	7	7	7.2	7	7	7	7
Secchi Disk	5.6	4.4	3.75	2.2	1.8	2.15	1.9
Turbidity							
Epicore				4.46			
Surface		1.75			3.55	2.37	6.63
Middle				5.62	3.96	2.42	
Bottom		2.21		2.87	1.8	2.07	
Color (SPU)							22
Site 4							
Turbidity (NTU)			1.6				
Color (SPU)							24
Site 5							
Turbidity (NTU)			1.22				3.62
Color (SPU)							10
							25
Site 6							
Secchi Disk (m)							2
Turbidity (NTU)							6.84
Color (SPU)							2
							170
							30
Site 7							
Turbidity (NTU)							6.77
Color (SPU)							7
							34
Site 8							
Turbidity (NTU)							14.7
Color (SPU)							60
							21
Site 9							
Color (SPU)							5
							292
							33

Chemical Tests: Alkalinity (mg/L), Ammonium (ppm), Nitrates (ppm), pH, and Hardness (mg/L CaCO3)

	6/23/04		7/7/04		7/21/04			
Depth (m)	Alkalinity	pH	Alkalinity	pH	Alkalinity	Ammonium	Nitrates	pH
Site 1								
0		7.52		7.19		0.05	0.34	9.20
1						0.05	0.33	9.30
2						0.05	0.33	9.30
3						0.06	0.29	9.11
4						0.06	0.19	8.31
5						0.06	0.18	7.57
6						0.07	0.19	6.84
7						0.07	0.17	6.55
8						0.08	0.23	6.51
9						0.11	0.28	6.56
10						0.15	0.38	6.61
11						0.18	0.49	6.65
12						0.22	0.69	6.70
13						0.34	1.06	6.78
14						0.47	1.38	6.81
15								
Epicore					22.95			
Site 2								
0		7.35		7.85		0.05	0.36	9.18
1						0.05	0.40	9.36
2						0.05	0.38	9.23
3						0.05	0.23	8.47
4						0.05	0.20	7.99
5						0.05	0.20	7.54
Epicore					22.04			
Site 3								
0	19.3	7.32		7.99		0.06	0.33	9.22
1						0.05	0.36	9.37
2						0.05	0.40	9.39
3						0.05	0.42	9.36
4						0.05	0.38	9.03
5						0.05	0.22	7.98
6						0.06	0.18	6.86
7						0.06	0.20	6.44
Epicore			20.5		18.54			
Site 4								
				7.53		0.06	0.23	8.49
						0.06	0.27	8.25
Site 5								
				7.41		0.06	0.24	7.75
						0.06	0.27	7.84
Site 9								
						0.05		7.48
Dam						0.04		7.06

	8/3/04				8/16/04			9/20/04		
Depth (m)	Alkalinity	Ammonium	Nitrates	pH	Alkalinity	Ammonium	pH	Alkalinity	pH	Hardness
Site 1										
0		0.06	0.38	8.66		0.05	7.79	16.30	7.32	24.94
1		0.05	0.37	8.73		0.05	7.89		7.31	
2		0.05	0.38	8.86		0.04	7.85		7.32	
3		0.05	0.28	8.24		0.04	7.83		7.32	
4		0.04	0.32	7.81		0.04	7.72		7.32	
5		0.03	0.40	7.49		0.05	7.19		7.32	
6		0.03	0.42	7.13		0.06	6.81		7.32	
7		0.03	0.54	6.89		0.12	6.78		7.28	
8		0.05	0.73	7.00		0.14	6.93		7.24	
9		0.08	2.08	7.06		0.11	7.09		7.09	
10		0.09	3.55	7.08		0.12	7.18		6.84	
11		0.10	5.18	7.14		0.12	7.27		6.80	
12		0.13	5.68	7.18		0.14	7.32		6.79	
13		0.16	5.43	7.23		0.14	7.37		6.80	
14		0.18	5.91	7.27		0.16	7.42			
15		0.23	5.90	6.59		0.19	7.45			
Epicore	22									
Site 2										
0		0.06	0.48	8.51		0.05	7.78	5.33	7.42	40.44
1		0.05	0.49	8.62		0.04	7.84			
2		0.05	0.49	8.74		0.04	7.87			
3		0.05	0.45	8.57		0.04	7.76			
4		0.06	0.28	7.58		0.04	7.65			
5		0.06	0.29	7.05		0.04	7.65			
Epicore										
Site 3										
0		0.05	0.78	8.71	19.70	0.05	8.42	15.00	7.53	40.50
1		0.05	0.79	8.71		0.04	8.82		7.45	
2		0.05	0.73	8.52		0.04	8.64		7.43	
3		0.05	0.64	7.96		0.04	8.29		7.42	
4		0.06	0.58	7.53		0.04	8.09		7.40	
5		0.06	0.59	7.15		0.04	7.32		7.38	
6		0.06	0.55	6.62		0.05	6.89		7.34	
7		0.08	0.57	6.57		0.10	6.76		7.32	
Epicore	18.60									
Site 4										
		0.06	0.69	6.96					7.19	
		0.06	0.57	7.15						
Site 5										
		0.06	0.45	7.69					8.29	
		0.06	0.56	7.41						
Site 6										
									6.36	
Site 7										35.71
									6.51	
Site 9		0.04	1.64	7.75						
		0.06	1.68	7.73						
		0.05								
Dam		0.04	1.98	7.17						
			2.40	7.00						

Total Phosphorus (ppb)

	6/9/04	6/23/04	7/7/04	7/21/04	8/3/04	8/16/04	9/20/04
Site 1							
Surface	14.20	18.75	11.90	14.82	19.40	20.05	24.49
Mid	16.59	16.57	23.74	31.29	25.84	26.10	24.09
Bottom	83.64	38.71	57.75	146.38	268.82	282.88	401.44
Epicore	35.49	36.53	17.55	24.24	26.20	27.94	34.02
Site 2							
Surface	31.30	23.29	13.61	14.72	17.81	20.19	20.90
Mid	15.70	15.84	15.57	26.07	21.10	20.22	29.89
Bottom	20.70	20.93	29.24	24.85	21.11	25.48	20.07
Epicore	18.27	17.66	15.65	33.93			57.37
Site 3							
Surface A	14.79	13.67	13.83	16.01	14.17	20.58	25.08
Surface B	12.73	14.21	10.80	17.53	14.72		
Mid	16.82	18.57	15.43	24.31	17.68	27.70	22.01
Bottom	21.20	22.92	17.22	30.02	24.55	33.90	23.68
Epicore	51.32	25.83	16.10	23.66	18.10	29.35	29.76
Site 4							
Surface	18.98	15.30	20.51	98.69	17.41		25.10
Site 5							
Surface	16.61	13.67	12.43	16.22	16.24		21.32
Site 6							
Surface							22.22
Mid							24.68
Bottom							21.23
Site 7							
Surface							17.60
Site 8							
Surface					36.50		23.54
Site 9							
Surface		15.48	14.48	32.65	14.57		23.78
Lower Togus Dam							
Surface		22.20	26.81	18.00	13.39		23.78

Biological Tests: Chlorophyll-*a* (ppb), Total and Fecal coliform (CFU)

	7/21/04	8/3/04	8/16/04	9/20/04		
Depth (m)	Chlorophyll-*a*	Chlorophyll-*a*	Chlorophyll-*a*	Chlorophyll-*a*	Total Coliform	Fecal Coliform
Site 1						
0	0.8	2.1	6.6	1.3		0
1	2.0	2.7	7.6	2.2		
2	3.5	2.4	6.7	1.8		
3	3.5	3.2	7.0	3.0		
4	2.9	1.8	6.8	2.9		
5	1.9	2.6	2.6	3.4		
6	1.1	1.1	1.8	2.7		
7	1.4	0.8	5.1	2.1		
8	1.4	1.6	4.8	2.0		
9	2.1	1.8	2.8	1.1		
10	1.7	1.6	2.9	3.1		
11	2.0	2.3	3.1	4.1		
12	2.7	2.8	2.7	4.6		
13	2.6	2.6	2.3	5.8		
14	2.7	3.0	2.9			
15		2.2	4.1			
Site 2						
0	2.3	1.9	6.0			0
1	3.6	1.6	9.0			
2	3.3	2.6	8.3			
3	4.8	3.2	7.4			
4	3.3	2.4	7.5			
5	2.0	1.8	6.8			
Site 3						
0	0.8	1.6	4.5	1.5		
1	2.2	1.9	8.4	2.8		
2	3.1	3.0	8.9	2.6		
3	3.3	3.0	6.3	2.5		
4	3.7	2.4	6.3	1.5		
5	2.1	1.2	2.2	3.0		
6	1.5	1.5	1.8	2.6		
7	1.9	2.2	4.9	2.4		
Site 4						
	4.0	3.8				
	3.0	3.1				
Site 5						
	2.7	3.0				
	2.5	2.3				
Site 7						
				9.41	1	0
Site 8						
				9.04		
Site 9	7.7	2.6				
		2.1				
Dam	6.6	4.8				
		5.2				

APPENDIX D. WATER BUDGET VALUES AND CALCULATION FOR TOGUS POND

Parameters	Values	Units
Runoff[a]	0.622	meters/year
Evaporation[b]	0.56	meters/year
Precipitation[c]	1.012	meters/year
Land Area[d]	8,961,452	square meters
Lake Area[d]	2,729,350	square meters
Average Depth[e]	5.43	meters
I_{net} Togus Pond[f]	6,809,108	cubic meters/year
Q Togus Pond[g]	8,337,544	cubic meters/year
Q Total[h]	13,458,533	cubic meters/year
I_{net} Dam Pond	5,120,988	cubic meters/year
Sum: I_{net} Togus + I_{net} Dam Pond	11,690,800	cubic meters/year
Flushing Rate[i]	0.81	flushes/year

[a] North Kennebec Regional Planning Commission. Unpublished Report.
[b] Prescott 1969.
[c] Ten year precipitation average (1994-2003) NOAA 2004.
[d] MEGIS. 2004.
[e] PEARL. 2004.
[f] I_{net} = (Runoff x Land Area) + (Precipitation x Lake Area) – (Evaporation x Lake Area).
[g] Q Togus Pond = I_{net} Togus Pond + (Evaporation x Lake Area).
[h] Q Total = Q Togus Pond + I_{net} Dam Pond .
[i] Flushing Rate = (I_{net} Togus Pond + I_{net} Dam Pond) / (Average Depth x Lake Area).

APPENDIX E. PHOSPHORUS MODEL COEFFICIENTS & CALCULATIONS

The following coefficients are based on past studies of Central Maine Lakes (CEAT 1999, 2000, 2001, 2002, 2003, 2004), in addition to other sources that are specifically cited in the following section These export coefficients were estimated using several factors regarding the movement of phosphorus into Togus Pond, including: land use patterns, soil type and quality, land area, population, and residential development.

Ec_a = export coefficient for atmospheric input

Estimated Range = 0.10-0.25 Best Estimate = 0.17

This coefficient was based on past studies done on Central Maine Lakes. Togus Pond is not located near any significant industrial sources of air pollution. However, it is in closer to downtown Augusta than either Threemile or Webber Ponds (CEAT 2002, CEAT 2003) so the best estimate was elevated slightly to account for the potentially higher phosphorus input.

Ec_{tf} = export coefficient for forest

Estimated Range = 0.06-0.16 Best Estimate = 0.14

This category includes all transitional and mature forest in the watershed. The 2002 photo used to determine land use types was taken in the spring, so it was impossible to differentiate between transitional and mature forest because no canopy was present. Therefore, the coefficient for this land use type falls between the export value for mature and transitional forest. Compared with mature forest, transitional forest has more open, unforested land, and thus contributes more phosphorus to a watershed than mature forest. In addition, most of the forest present in the watershed is deciduous forest, with small patches of coniferous or pine forest. Deciduous forests contribute more phosphorus to the system because of annual leaf shed than coniferous forests, which do not shed leaves every year. This was also taken into account when determining the coefficient of transitional forest.

Ec_w = export coefficient for wetlands

Estimated Range = 0.02-0.08 Best Estimate = 0.04

The export coefficient for wetlands is very low because this vegetation type absorbs phosphorus when there is active plant growth during the summer, when algal blooms typically occur. Some phosphorus may be released from wetlands during spring runoff. For the most part, wetlands act as sponges, soaking up runoff, and the nutrients carried in it.

Ec_{of} = export coefficient for old field or reverting land

Estimated Range = 0.25-0.90 Best Estimate = 0.40

Old field is land that was cleared of its forest and lies fallow, allowing for slow regeneration of forest. There is much less tree coverage, because less than 50% is canopy cover, although there is groundcover (grasses and shrubs), which help mediate phosphorus runoff from the soil. The coefficient for phosphorus loading is higher than for transitional forest.

Ec_c = export coefficient for cleared land

Estimated Range = 0.15-0.80 Best Estimate = 0.60

Cleared land contributes more phosphorus to the watershed because there is significantly less ground cover, which is less efficient in preventing erosion. However, since most of the area remains undeveloped, the coefficient for this land use is greater than the coefficient used for old field.

Ec_h = export coefficient for hay field

Estimated Range = 0.35-1.35 Best Estimate = 0.50

The range for hay field phosphorus export was taken from a TMDL study for nearby Threemile Pond (MDEP 2003c). Hay field contributes less phosphorus than cleared land, but more than reverting land or old field.

Ec_{com} = export coefficient for commercial land

Estimated Range = 0.50-3.00 Best Estimate = 1.30

Commercially developed land contributes more phosphorus to the watershed than undeveloped, natural areas because of the increased runoff from impervious surfaces such as buildings and parking lots.

Ec_s = export coefficient for shoreline development

Estimated Range = 0.50-3.00 Best Estimate = 1.50

Development within 200 feet of the shoreline has a potentially high impact on water quality, because water runs directly off the lawns, roofs, and other exposed surfaces into the lake. Togus Pond is also a highly developed lake with numerous residences directly on the shoreline or very close to the water, increasing the probability that phosphorus will enter the lake via runoff. To account for this, the coefficient is correspondingly high.

Ec_n = export coefficient for non-shoreline development

Estimated Range = 0.20-1.50 Best Estimate = 0.30

The impact of non-shoreline residences is significantly lower because runoff from this development has more time to absorb into the soil and there is a wider buffer between these homes and the lake.

Ec_{ns} = export coefficient for non-shoreline septic systems

Estimated Range = 0.30-1.00 Best Estimate = 0.50

Ec_{ss} = export coefficient for shoreline septic systems

Estimated Range = 0.40-0.90 Best Estimate = 0.60

Many of the septic systems for Togus Pond residencies were built before the implementation of current standards for these systems. There are many septic systems that are located close to the water's edge, allowing for potential leakage problems. The problem may be exacerbated by high water tables, which are common in the soils around Togus Pond (USDA 1978) Although there do not to appear to be any major problems with septic tanks leaking into the lake, the coefficient for shoreline residences is high because of the potential for these systems to export phosphorus into the lake. The coefficient for non-shoreline residencies is lower for similar reasons to those explained above in the non-shoreline development section.

Ec_{sr} = export coefficient for state roads

Estimated Range = 0.45-6.00 Best Estimate = 1.50

Ec_{cr} = export coefficient for camp roads

Estimated Range = 0.45-8.00 Best Estimate = 3.40

Roads are a major source of phosphorus to the watershed because they represent a significant percentage of the impervious surface. Camp roads were given a higher coefficient because they are unpaved, not as well-maintained as state roads, and closer to the water's edge, making them more susceptible to erosion.

SR_1 = soil retention coefficient for shoreline residences

Estimated Range = 0.65-0.35 Best Estimate = 0.45

SR_2 = soil retention coefficient for non-shoreline residences

Estimated Range = 0.90-0.75 Best Estimate = 0.80

The characteristics of the soil in the watershed are important in determining the export of phosphorus to the lake, particularly the retention of the soil around the shoreline and in close vicinity to the lake itself. Again, the soil retention of the shoreline has a much greater impact than the soil farther away from the water. The dominant soil type of the Togus Pond watershed has very low to moderate permeability and moderate to severe limitations for septic suitability. In addition, portions of the soil around the lake are excessively drained. It is possible that material entering septic tanks around Togus Pond does not percolate down into the soil, but is trapped where it can then be flushed out in a heavy rain or storm event. This makes for a moderate to high probability of leakage, or poor retention from septics, which explains the relatively low coefficient for shoreline residences.

Calculations for Total Phosphorus Loading

The total phosphorus loaded into Togus Pond from the watershed per hectare per year (**L**) was calculated by dividing the annual inflow by the surface area of the lake:

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

W = annual phosphorus inflow in kg/yr (includes sediment release)

$\mathbf{A_s}$ = surface area of the lake

Togus surface area = 2,729,350 kg/yr

Annual atmospheric water loading was calculated by dividing the total volume of water inflow by the surface area of Togus Pond:

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

$\mathbf{Q_{total}}$ = total volume of water inflow in m^3/yr

Togus inflow = 8,337,544 m^3/yr

The predicted ranges of phosphorus concentration were calculated by dividing annual phosphorus loading by the settling velocity of phosphorus and the areal water loading in a lake:

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

L = phosphorus loading (m/yr)

$\mathbf{(11.6 + 1.2q_s)}$ = settling velocity of phosphorus and areal water loading in a lake

q_s for Togus = 3.05 m/yr

<u>Low estimate</u>:

W = 227.74 kg/yr

L = 0.834 kg/ha/yr

P = 9.04 ppb

<u>Best estimate</u>:

W = 466.04 kg/yr

L = 1.71 kg/ha/yr

P = 19.05 ppb

<u>High estimate</u>:

W = 814.18 kg/yr

L = 2.98 kg/ha/yr

P = 28.06 ppb

APPENDIX F. ROAD SURVEY FORM USED TO NOTE CHARACTERISTICS OF ALL ROADS SURROUNDING TOGUS POND

ROAD SURVEY DATA SHEET

DATE:	SURVEYORS:	ROAD NAME:	
		ROAD TYPE:	state road
GPS at start of road:			camp road
			other:

ROAD LENGTH (MILES):	
AVERAGE WIDTH (FEET):	
OVERALL SLOPE general estimate	0-5% 6-10% 11-15% 16-20% 21%+
TOTAL # OF WATER DIVERSIONS:	
TOTAL # OF MISSING WATER DIVERSIONS:	
TOTAL # OF CULVERTS:	
TOTAL # OF MISSING CULVERTS:	

DESCRIBE CROWN:
DESCRIBE DITCH CONDITION:
DESCRIBE ROAD SURFACE CONDITION: surface material:
BASIC SUMMARY:
OVERALL GRADE: GOOD ACCEPTABLE FAIR POOR

APPENDIX F (CONT.). ROAD SURVEY DATA SHEET FOR PROBLEM AREAS

Please address these issues for the following problem areas:

- Crown- height, surface when wet and dry, edge
- Ditch- depth and width, vegetation, sediments, shape.
- Diversion- where does water runoff go?
- Culvert- wear, diameter, inside, covering material

Problem #
GPS reading
Miles
Problem area crown ditch diversion culvert
Summary (address issues above):
What needs to be done?

Problem #
GPS reading
Miles
Problem area crown ditch diversion culvert
Summary (address issues above):
What needs to be done?

Problem #
GPS reading
Miles
Problem area crown ditch diversion culvert
Summary (address issues above):
What needs to be done?

APPENDIX G. RESIDENTIAL SURVEY FORM

Suvey Group:

Date:

	Residences within 200 ft of water		Residences beyond 200 ft of water	
Road Name	# Seasonal	# Permanent	# Seasonal	# Permanent

Other buildings of note (agricultural, construction, commercial, etc.):

APPENDIX H. BUFFER STRIP SURVEY FORM

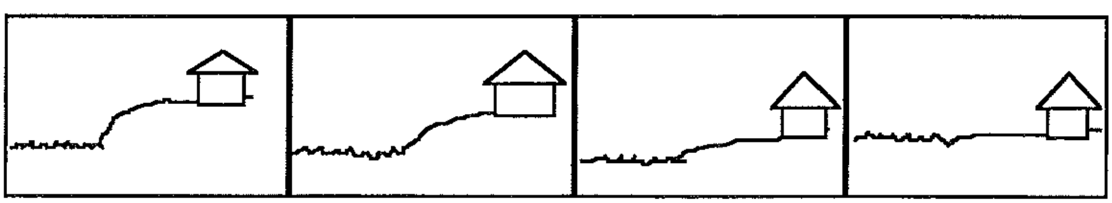
Date: Group:
General Description of first house:

General Description of last house:

House # (on island?): GPS Coordinates:						
Lakeshore Coverage%	0	1 - 25	26 - 50	51 - 75	> 75	
	0	1	2	3	4	
Buffer depth from shore(ft)	0	1 -10	11 - 35	36 - 65	> 65	
	0	1	2	3	4	
Slope rating		Steep	Moderately Steep	Small Incline	Flat	
		1	2	3	4	
Seasonal	YES 2	NO 0				
Buffer 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				
					Total:	
Lot Shoreline distance (ft)	0-60	60-120	120-180	>180		
Noticeable outdoor septic	YES	NO				

Slope Diagrams: Steep – Flat

Steep Moderately Steep Small Incline Flat



APPENDIX I. PERSONAL COMMUNICATION

Roy Bouchard	Coordinator, Maine Lakes Assessment and Invasive Species Department, Maine Department of Environmental Protection
Russell Cole	Professor of Biology, Colby College
Paul Connolly	Resident of Hayes Landing, Togus Pond
Richard Dolby	Director, Code Enforcement Bureau, Augusta, Maine
David Firmage	Professor of Biology, Colby College
David Halliwell	Director of TMDL Studies, Maine Department of Environmental Pro tection
Jeff Norton	Employee of Elma's Tackle and Hunting Supply Store
George Soucy	City of Augusta Code Enforcement Officer
Bobby Van-Riper	Field Biologist, Maine Department of Inland Fisheries and Wildlife
Bill Woodward	Field Biologist, Maine Department of Inland Fisheries and Wildlife

APPENDIX J. REMEDIATION TECHNIQUES DEEMED MOST APPLICABLE TO TOGUS POND

Remediation Technique	Focus of Technique	Ideal Usage Requirements
Alum Treatment[1]	Phosphorus (P) in water column and in sediment[1]	Depth > 3 m; prior control of P influx[1]
Manipulation of Fish Stocks	Food web manipulation to obtain favorable levels of phytoplankton[2]	Lake must accommodate added species
Water Drawdown	Removal of nutrient-rich water	Dam; discharge area
Vegetative Mats	Trapping and removing P, protection for zooplankton	Lake must accommodate added species; harvesting and disposal; plants must remove substantial P

[1]Bouchard pers. comm.
[2]Cooke et al. (1993)
Techniques are listed from most effective to least effective.

APPENDIX K. COMMONLY USED REMEDIATION TECHNIQUES NOT APPLICABLE TO TOGUS POND

Remediation Technique	Focus of Technique	Costs and disadvantages
Chemical Treatments		
Calcium Additives	P in water column and in sediment	Togus Pond does not have high enough pH for absorption; has softwater
Ferrous Additives	P in water column and in sediment	Relatively expensive; dissolves under anoxic conditions[1]
Algicides	Algal cell growth	Temporary; environmentally detrimental
Physical Treatments		
Dilution	Replaces nutrient-rich water with lower nutrient water	No dam, expensive pumps; outflow to Lower Togus; no clean inflow source
Flushing	Expels nutrient-rich water with similar water	No dam, expensive pumps; outflow to Lower Togus; no inflow source
Hypolimnion Withdrawal	Removal of nutrient-rich hypolimnetic water	Dam or pump; discharge area
Hypolimnetic Aeration	Aerates hypolimnion to prevent anaerobic activity	Relatively expensive; does not remove P; potential risk to fish[1]
Dredging	Removal of accumulated nutrient-rich sediment	Very expensive; disposal site for sediment

[1]Cooke et al. 1993