A WATERSHED ANALYSIS OF LONG POND NORTH

Implications for Water Quality and Land-Use Management

BI 493
Problems in Environmental Science
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WATERSHED ASSESSMENT INTRODUCTION

EXECUTIVE SUMMARY

The Colby Environmental Assessment Team (CEAT) investigated the water quality of Long Pond North, located in the Belgrade Lakes region of Maine, from June through December 2006. CEAT analyzed several physical, chemical, and biological water quality parameters to determine the current health of the lake. Attributes of the watershed such as land-use patterns and residential and commercial development were also studied to determine their impact 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 Long Pond. To examine historic water quality trends, all data collected this summer were compared to data collected in previous years by CEAT and the Maine Department of Environmental Protection.

The trends observed show a decrease in mean Secchi depth, a measurement of transparency that is an important indicator of water quality. CEAT also observed an increasing trend in mean phosphorus levels. Phosphorus is a limiting nutrient for aquatic plant species, and higher phosphorus levels in the lake can result in algal blooms that decrease the aesthetic and recreational value of the lake. Although the phosphorus levels of Long Pond North are not at the level to produce algal blooms, the increasing phosphorus level is a cause for concern.

Following is a brief summary of findings from CEAT's study of Long Pond North and its watershed:

- Using a water budget, CEAT calculated the flushing rate at 3.79 flushes per year. The relatively large water input from Great Pond (77 percent) contributes to the high flushing rate.
- The dissolved oxygen level in Long Pond North has decreased substantially in the past 30 years. Anoxic waters were measured at depths below 10 meters by mid August. As a result, bottom total phosphorus increased over the summer at this site. Low oxygen levels also limit the available habitat for cold-water fish species.
- There is an historic trend in decreasing mean Secchi depth, indicating that water clarity is decreasing. The trophic state index, which is based on Secchi depth, was calculated to be 38, classifying Long Pond North as oligotrophic, although close to mesotrophic status.

- *Gloeotrichia*, a cyanobacteria, occurs in Long Pond North. There are no health risks associated with this species, but its presence in the water column may detract from recreational enjoyment of the lake. Further studies on the life history and phosphorus sequestration of this species are being conducted.
- Roads found within the watershed can contribute disproportionately high amounts of phosphorus to the lake. The best estimate for state and municipal roads indicates a contribution of 18.00 kg/yr and 82.50 kg/yr for camp roads. Camp roads not only contribute more phosphorus to the lake but are also of greater concern because of their proximity to the shoreline. Many camp roads are in need of specific improvements such as grading, crowning, ditching, and the placement of diversions to limit erosion and nutrient runoff.
- The residential survey found 479 residences in the watershed. Of these, 286 (59.7%) were year-round and 193 (40.3%) were seasonal. Conversion of seasonal homes to year-round residences is common and increases septic system use, which can increase the amount of phosphorus entering the lake.
- Two hundred and sixty seven (55.7%) of the residences are shoreline. Residential density along the shoreline is low (17.5 houses/shoreline mi), but this is because there remains some large sections of undeveloped shoreline. Density is much higher in the developed areas, and parts of the remaining forested areas may be developed in the future, placing more pressure on the lake.
- Seventy-four percent of shoreline homes have buffers in good or excellent condition. The greatest concerns for homes with poor buffers are lack of buffer depth and the absence of canopy species.
- There are 66 lots still undeveloped along the shoreline and hundreds of non-shoreline lots that are close to the lake. Development of these lots will bring increased pressure to the lake.

The water quality of Long Pond North and trends within its watershed should continue to be monitored, and steps should be taken to reduce external nutrient loading. Maintaining roads, improving buffer strips, and limiting development within the watershed will help reduce the quantity of nutrients entering the lake. Collaboration is necessary among watershed residents, as well as with the residents of the Great Pond watershed, to minimize current threats to water quality and protect the future of Long Pond North.

BACKGROUND

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). Lake and ponds differ in their size and depth profiles: lakes have greater surface area and depth than ponds (Smith and Smith 2001), and generally develop both vertical stratification and horizontal zonation while ponds do not. Horizontal zonation divides lakes into zones based on sunlight penetration and the growth of vegetation. The littoral 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. Ponds do not have this zonation and are shallow enough that vegetation can be rooted throughout (Smith and Smith 2001). The vertical stratification found in lakes depends on water density differences that occur as a result of temperature. Deep lakes will stratify with the densest (colder) water on the bottom until a threshold of 4° C and the least dense (warmer) water toward the surface. Ponds and shallow lakes do not stratify because disturbance from 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), providing fresh water for swimming, fishing, drinking, livestock, agriculture, and native mammals. In addition to the native appeal of Maine lakes draws tourists to the state throughout the year. Lakes also serve as important habitats for wildlife.

The majority of Maine lakes were formed during the Wisconsonian glaciation of the Pleistocene Epoch (Davis et al. 1978). Glacial activity in Maine has left most lake basins comprised of glacial till, bedrock, and glaciomarine clay-silt.   These deposits and the underlying granite bedrock are infertile and as a result, most of Maine's lakes are relatively nutrient poor. The movement of glaciers in Maine was predominantly to the southeast, carving out Maine lakes in a northwest to southeast direction (Davis et al. 1978). This orientation, along with lake surface area and shape, plays a fundamental role in the effect of wind on the water body, which is an important factor for 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 forests are potentially threatened by logging by 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 not 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, including depth and surface area can affect temperature and turnover in the lake, which will ultimately influence water quality.

Annual Lake Cycles

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

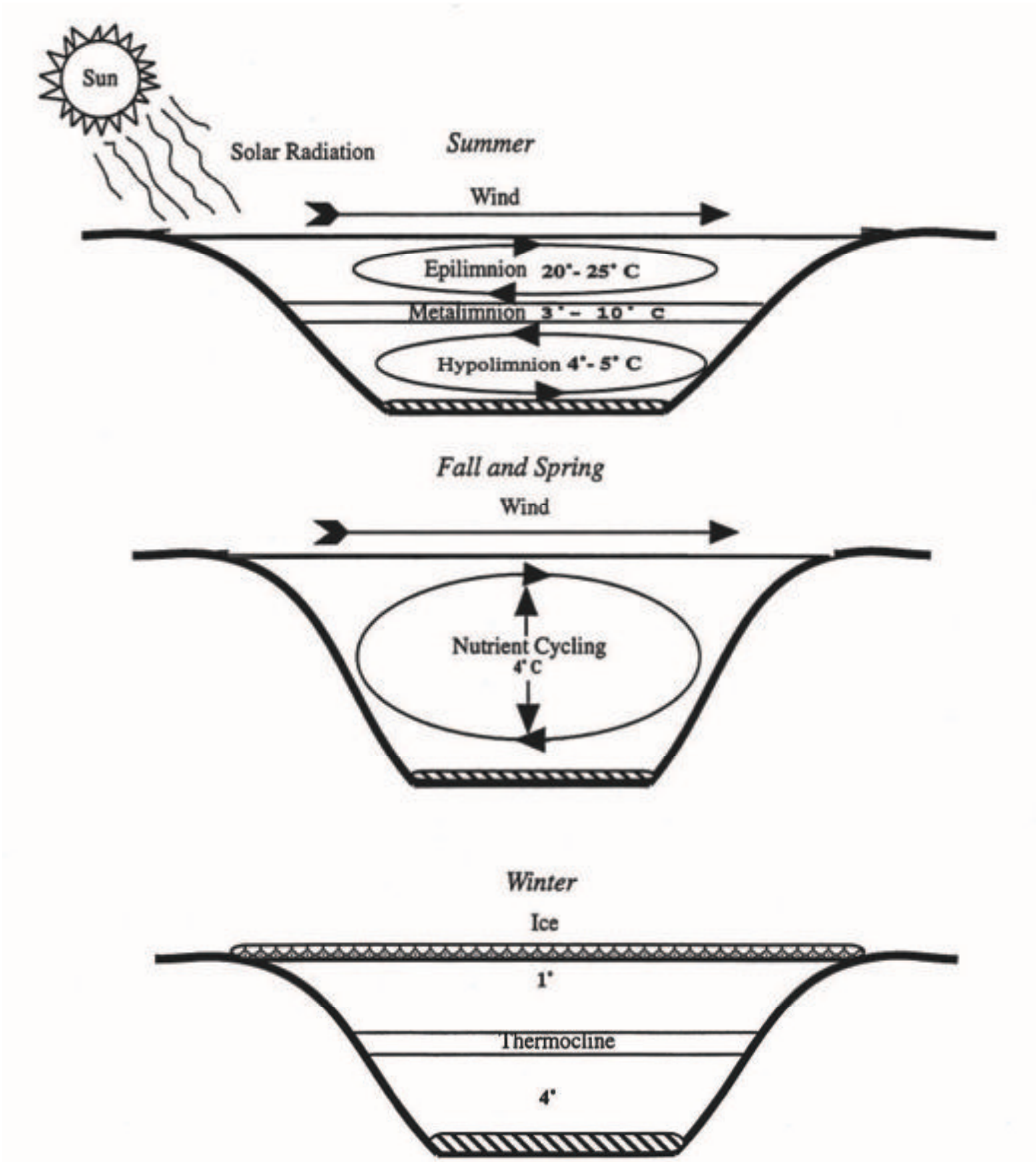

Figure 1. Mixing by means of lake turnover in dimictic lakes. During the summer, lakes are stratified into three layers (epilimnion, metalimnion, and hypolimnion). During the fall and spring, the isothermal temperature and density facilitate the lake turnover and redistribution of nutrients. In the winter,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

bacteria break down organic matter more quickly than anaerobic bacteria (not requiring oxygen), they also significantly deplete the oxygen at these depths (Davis et al. 1978).

As the weather 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 of the lake 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 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, wherein the stratification is reversed as the coldest water and ice are on the surface and the warmest water (roughly 4° C) extends to the bottom because water is densest at 4° C. Significant snow cover on the ice may affect the photosynthetic processes under the ice by blocking some of the incoming solar radiation. Ice prevents diffusion of oxygen into the water and photosynthetic activity decreases, reducing oxygen production from phytoplankton resulting in dissolved oxygen levels depleted enough to cause significant fish kills (Smith and Smith 2001).

After the ice has melted in the spring, 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 and oxygen and nutrients are mixed throughout the water column. As late spring approaches, solar radiation increases, stratification occurs, and temperature profiles return to that of summer in dimictic lakes, preventing water column mixing (Smith and Smith 2001).

Trophic Status of Lakes

The biological classification of lakes by their eutrophic state is based on nutrient levels in the water (Maitland 1990). Lakes are divided into four major trophic states: 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 steep-sided basins, creating a low surface to volume ratio. They are low in suspended solids such

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

Character	Oligotropic	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 characteristics	Many species, especially minnows	Extremely few species, often none

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 little shallow margin for attachment.

Eutrophic lakes are nutrient-rich and have a relatively high surface to volume ratio compared to oligotrophic lakes (Maitland 1990, Chapman 1996). 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 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 further growth of phytoplankton populations (Smith and Smith 2001). Eutrophic lakes tend to be shallow and bowl-shaped as a result of sediment loading, allowing for the establishment of rooted plants in shallow areas.

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

Eutrophication is a natural process—lakes begin as oligotrophic, and after a long period of aging, eventually become terrestrial landscapes (Niering 1985). This process, which is called eutrophication 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, runoff, and precipitation. As a lake ages, it fills with dead organic matter and sediment that settles 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), and it is necessary to understand these cycles to devise better techniques to control high nutrient levels.

Phosphorus is the most important limiting nutrient for plant growth in freshwater systems (Maitland 1990). Phosphorus naturally occurs in lakes in minute quantities measured in parts per billion (ppb). However, due to the high efficiency with which plants can assimilate phosphorus, normal phosphorus concentrations are sufficient for plant growth (Maitland 1990). There are multiple external sources of phosphorus (Williams 1992), but a large quantity 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 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 such as hydrogen sulfide, which is toxic to fish (Lerman 1978).

An important reaction occurs in oxygenated water between 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.

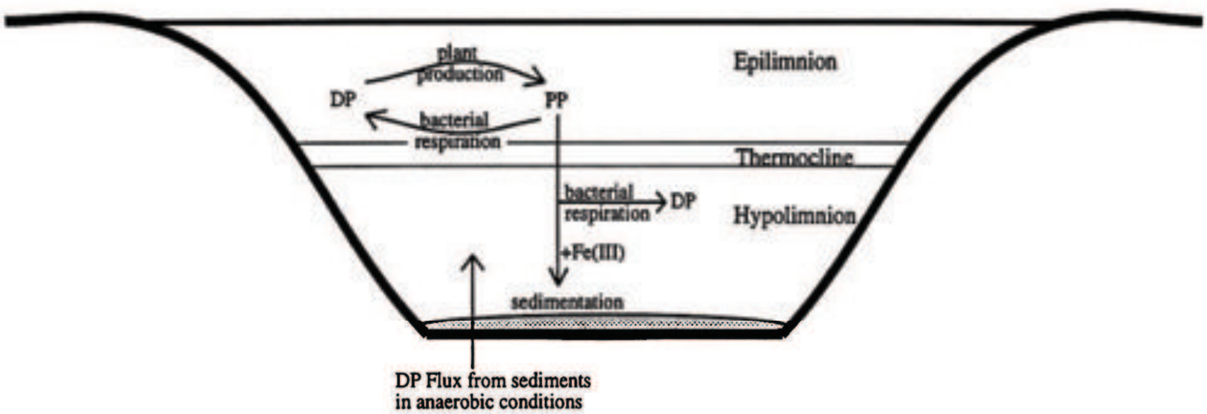

Figure 2. A model of the cycle of the major forms of phosphorus, dissolved (DP) and particulate (PP), within a lake ecosystem. The sedimentation of DP through complexation with Fe (III) contributes to the build-up of DP in the sediments. Note the production of DP in the hypolimnion due to bacterial decomposition 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 DP to accumulate in bottom waters (adapted from Lerman 1978).

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 generally 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 ppb to 15 ppb. If an algal bloom does occur, DP is converted to PP in the form of algal tissues. The algae die as winter approaches and the dead organic matter settles to the bottom where PP is converted back to DP and builds up again, allowing for another large nutrient input to surface waters during spring turnover (Bouchard, pers. comm.).

Nitrogen, the other major plant nutrient, is usually not the limiting factor for plant growth in a lake (Chapman 1996), but 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).

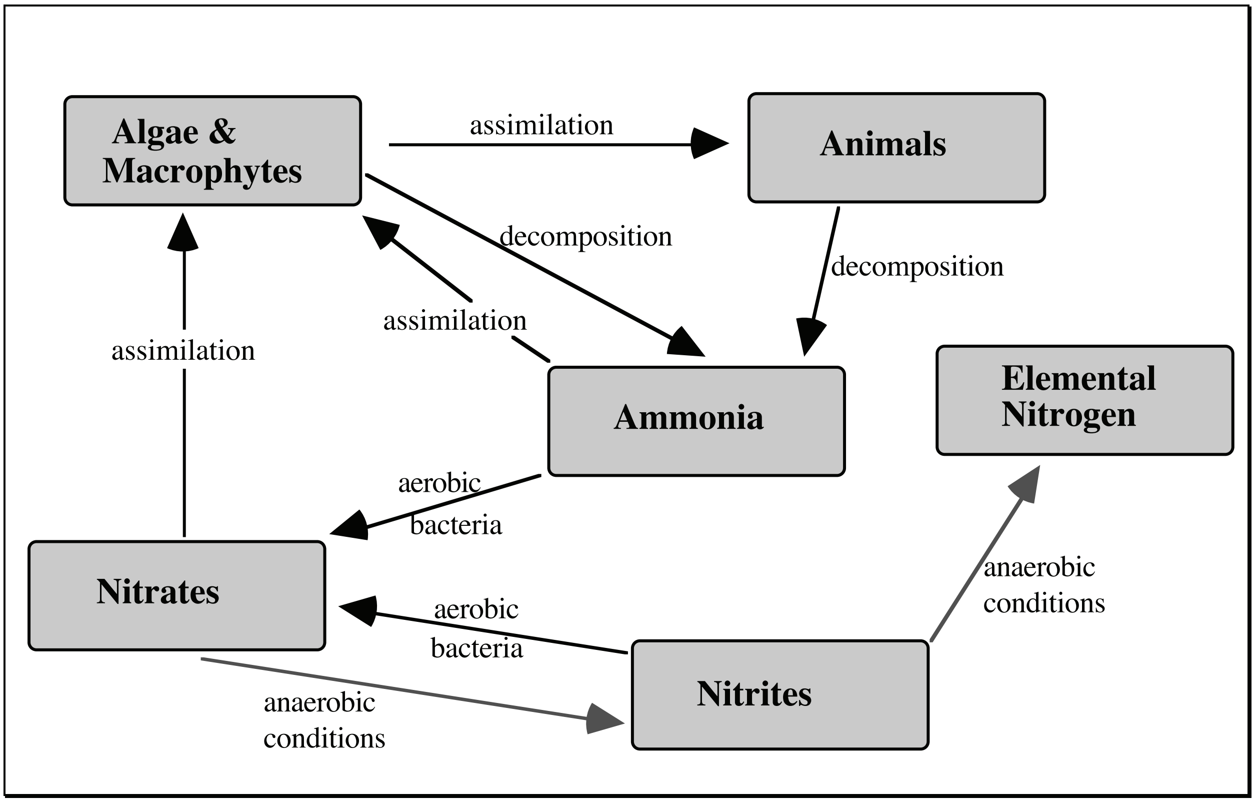

Figure 3. A diagram of the various forms of nitrogen that occur in the nitrogen cycle within a lake ecosystem. It is important to note that in aerobic conditions both ammonia and nitrites are converted to nitrates, which are available for use by plants.

The majority of free nitrogen in a lake exists in the form of nitrates (Maitland 1990), a form that 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). Plants, however, cannot use nitrites. 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, 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, 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 eventually become available for plant use. The various forms of nitrogen, as well as the oxygen concentrations (aerobic and anaerobic conditions) in the water, must be considered to understand the availability of this nutrient for plant growth. Several in-lake mitigation techniques exist to deal with the problem of excessive nutrients. (Henderson-Sellers and Markland 1987). None of these techniques are without disadvantages, but for lakes with serious algal growth problems they may become 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. The natural processes of nutrient cycling and uptake by flora and fauna to compensate for nutrient inputs without further accelerating eutrophication of the lake.

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 naturally 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). Different types of land use have different effects on nutrient loading in lakes because of varying influences on erosion and runoff. 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 nutrients than a naturally vegetated area such as forested land (Dennis 1986). The combination of vegetation removal and soil compaction involved in the clearing of land results in a significant increase in surface runoff, amplifying the erosion of sediments carrying nutrients and anthropogenic pollutants.

Naturally vegetated areas offer protection against soil erosion and surface runoff. The forest canopy reduces erosion by diminishing the force of impact of rain on soil. The root systems of trees and shrubs reduce soil erosion by decreasing the rate of runoff by holding water in place, 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. As a result, 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. 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.

Forests cover much of Maine, and the development or expansion of residential areas 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 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 areas 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. 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. It should be noted that more environmentally friendly soaps and detergents containing low phosphorus levels are now available and recommended (MDEP 1992a).

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 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 nutrient loading problems are caused by only 20% of culverts or crossings. 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.

Nutrient Loading

Nutrient loading into a lake is affected by natural and anthropogenic processes (Hem 1970). Human activity usually accelerates the loading of nutrients and sediments into a lake, and water quality can be adversely affected in a short period of time. Clearing 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 in phosphorus and nitrogen in the water column from these sources can lead to a decrease in lake water quality and eventual eutrophication.

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Total phosphorus loading to a lake can be determined using a phosphorus loading model. This model takes into account the various aspects upon which the phosphorus concentration in the lake basin is dependent, such as lake size, volume, flushing rate, and land-use patterns within the watershed (Cooke et al. 1986). The model allows for the projection of the impact that various factors may have on phosphorus loading and generates predictions of lake responses to changes in land use. The accuracy of the 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. The physical characteristics of soil (permeability, depth, particle size, organic content, and the presence of an impermeable layer or "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 1992). Soils that do not meet these criteria should be considered carefully before implementing a development, forestry, or agricultural plan.

Zoning and Development

The purpose of shoreline zoning and development ordinances is to control water pollution, protect wildlife and freshwater wetlands, monitor development and land use, conserve wilderness, and anticipate the impacts of development (MDEP 1998). Shoreline zoning ordinances regulate development along the shore 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.

Buffer Strips

Buffer strips play an important role in absorbing runoff by 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 width of a buffer strip is 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). Native vegetation forms the most effective buffer. Trees and their canopy layer provide the first defense against erosion by reducing 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 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 by 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 composed of a combination of canopy trees, understory shrubs, and groundcover, between it and the water. To divert runoff effectively, the driveway should be curved rather than straight, and not leading directly toward the water. Slopes within a buffer strip that are less than 2 percent steep are most effective at slowing down the surface flow and increasing absorption of runoff (MDEP 1998a). Steep slopes are susceptible to heavy erosion and will render buffer strips ineffective.

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

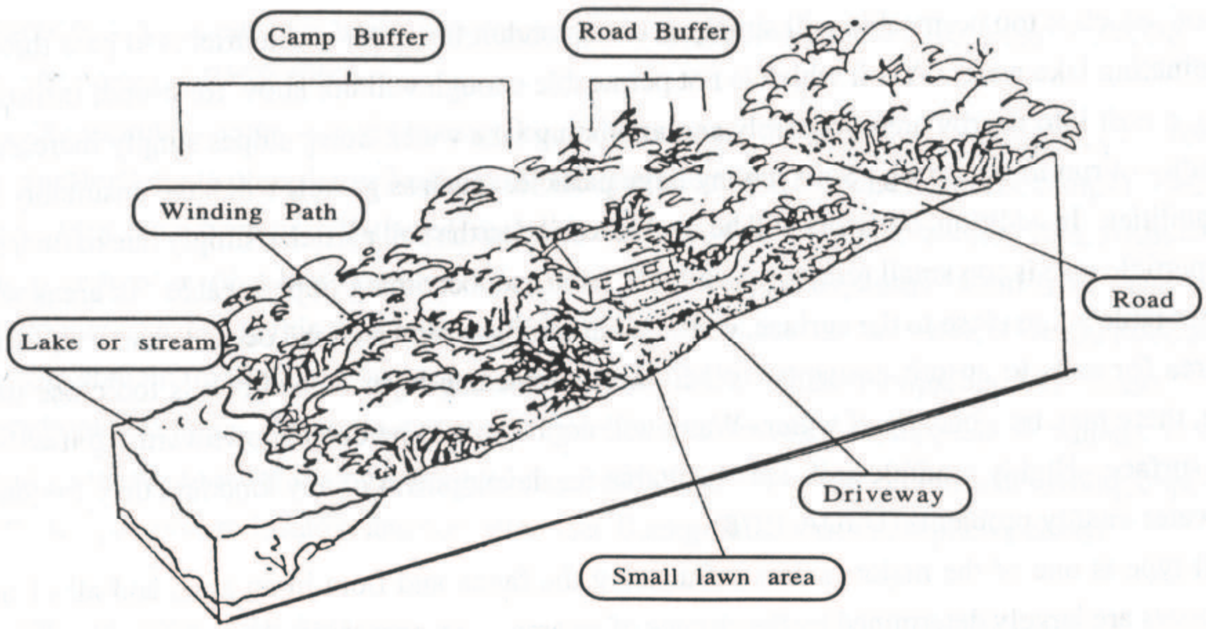

Figure 5. Diagram of an ideally buffered home.

Shoreline Residential Areas

Shoreline residential areas are of critical importance to water quality because of 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).

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 were built before shoreline zoning laws were passed and are legally non-conforming. Although seasonal, they may accommodate large numbers of people in season. 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. In these cases, phosphorus has the opportunity to be absorbed into the soils and vegetation, the majority will not reach the lake, but will enter the forest nutrient cycle.

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. 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.

Subsurface Wastewater 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 2002). These systems are generally found in areas with no municipal disposal systems, such as sewers. Examples of these subsurface disposal systems include pit privies, holding tanks and septic systems.

Pit Privy

Pit privies are also known as outhouses and are mostly 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 2002). The minimum capacity for a holding tank is 1,500 gallons. These must be pumped or 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 is connected to a pump (Figure 6). The pump enables 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, septic systems that are not installed or located properly 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, 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).

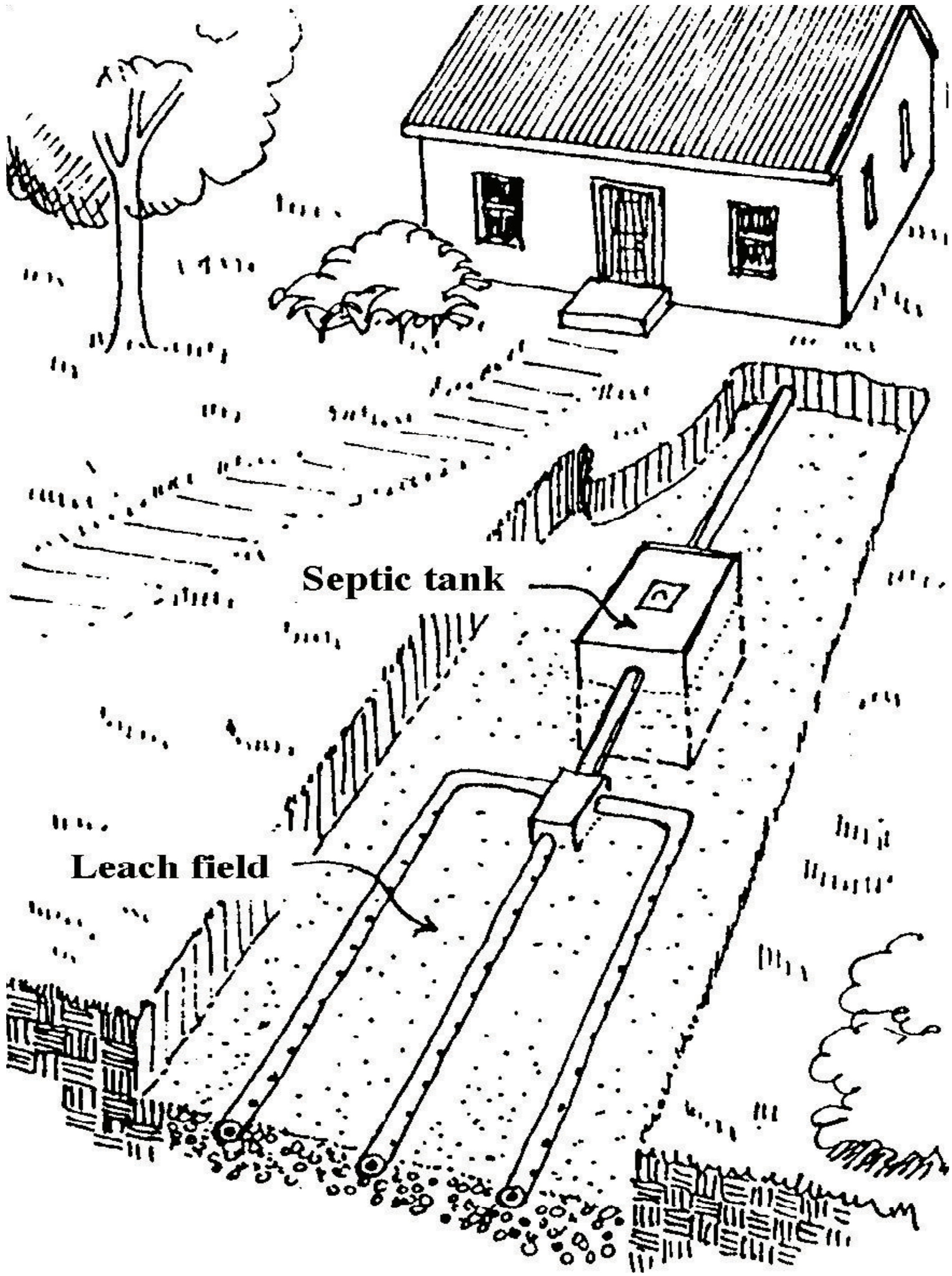

Figure 6. The layout of a typical septic system (Williams 1992).

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. 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. Baffles trap scum 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.

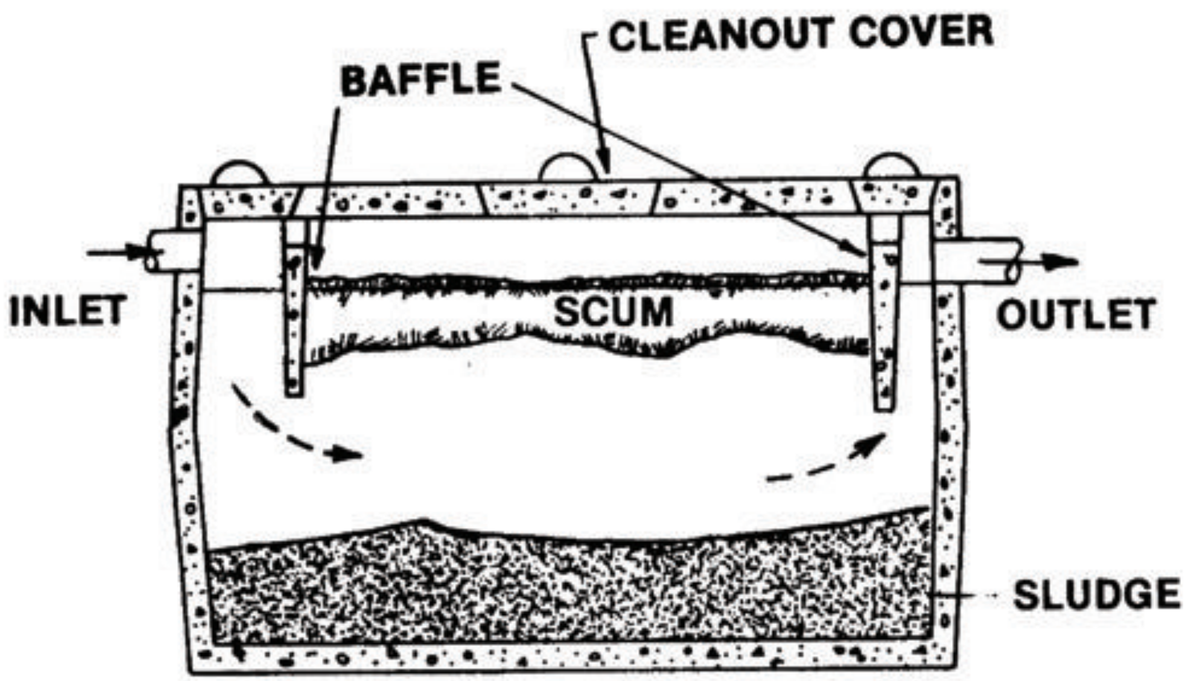

Figure 7. The cross-section of a typical treatment tank showing the movement of effluent through the tank as well as the separation of the scum and sludge (MDHS 1983).

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

BOD is the oxygen demanded by decomposers to break down organic waste in water. Organic matter will increase if there is contamination from human and animal wastes and as the amount of organic material increases, BOD increases. If the BOD depletes dissolved oxygen, species within a lake may begin to die. If the 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 contributes nitrogen, toilet wastes, and microorganisms, while 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 three to five years, or when the sludge level fills half the tank (MDEP 2003d). 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, 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 to determine the best location. An area with a gradual slope (10 to 20 percent) that allows for gravitational pull is often necessary for proper sewage treatment (MDHS 2002). A slope that is too gradual causes stagnation. A slope that is too steep drains the soil too quickly cutting treatment time short and preventing water from being treated properly. Adding or removing soils to change the slope is one solution to this problem.

Soil containing loam, sand, and gravel allow the proper amount of time for runoff and purification (MDHS 1983). Soils should not be too porous or water runs through them 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, causing wastewater to run along the soil surface untreated. Adding loam and sand to clay containing soils can 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 2,000 gallons per day (MDHS 2002). Also, 20 percent is the maximum slope of the original land that can support a septic system. These regulations are in place for the safety of people living in the 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 (KCSWCD 2000). Roads may allow easy access for runoff of nutrients and organic pollutants into the lake via improperly constructed culverts and ditches. Improper road construction and maintenance can increase the nutrient load entering the lake.

Proper drainage of roads is very important when trying to control phosphorus loading within a watershed. Construction materials such as pavement, dirt, or gravel, may influence the amount and rate of runoff (Woodard 1989). The inevitable erosion of these building materials due to road traffic causes deterioration of the road surface. Storms increase road deterioration by dislodging particles from the road surface; nutrients attached to these particles are transported to the lake by runoff from the roads (Michaud 1992).

Road construction should try to achieve the following long-term goals: minimize the surface area covered by the road, minimize runoff and erosion with proper drainage and the placement of catch basins (as well as culverts and ditches), and maximize the lifetime and durability of the road (MDEP 1990). A well-constructed road should divert surface waters into a vegetated area to prevent excessive amounts of surface runoff, phosphorus, and other nutrients from entering the lake. Items that 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 1991b).

Designing a road with future use in mind is very important. A road should be constructed no longer than is absolutely necessary, and 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 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 the road will slope downward from the middle, towards the outer edges. This crown should have a slope of 0.13 to 0.25 inches per foot of width for asphalt and 0.50 to 0.75 inches per foot 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. 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 constructed of riprap or 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 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 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 percent (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 working condition, as well as to prevent it from causing problems for a lake. Over time, roads deteriorate, and problems will only become worse if ignored and will cost more money in the long run to repair. Roads should be periodically graded, ditches and culverts should be cleaned and regularly inspected to assess any problems that may develop. Furthermore, any buildup of sediment on the sides of the road (especially berms) that 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 (Williams 1992) and 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. 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. 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. A prohibition legislated by the Nutrient Management Act. The town may provide subsidies as an incentive if the problem is large enough but 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, planting alternating rows of different crops in the same field.

Forestry

Forestry is another type factor 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). There are state and municipal shoreline zoning ordinances in place to address these specific problems. 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). Clear-cutting within 75 ft of the shoreline of a lake or a river running to the lake is prohibited. 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 must be at least 100 ft apart. These regulations are intended to minimize erosion (MDEP 1990), but 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 forestry. Illegal practices may occur and negatively impact lake water quality.

Transitional Land

Before any form of development occurred in the Long Pond North 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, agriculture has decreased and much of the land previously used for this purpose 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. 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 rainfall, reducing its erosion potential. This land type, in which a forest is nearing maturity and contains over 50 percent tree cover, is referred to as transitional forest. Mature forest is defined as areas of closed canopy that predominantly contain climax species.

Wetlands

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

The type of wetland and its location in a watershed are important factors when determining whether the wetland either prevents nutrients from going into a lake or contributes nutrients to a lake, a nutrient sink or source (Washington State Department of Ecology 1998). It is important to note that one wetland may be both a source and a sink for different nutrients and may vary with the season, depending on the amount of input to the wetland. Vegetation diversity 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.

Wetlands are important transitional areas between lake and terrestrial ecosystems. Wetland soil is periodically or perpetually saturated, because wetlands usually have a water table at or above the level of the land, contains 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 support a wide range of biotic species (MLURC 1976; Table 2). 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).

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 prevent development within 250 ft of the wetland. Due to their location, wetlands along the shoreline may be prone to illegal development (Nebel 1987). A decrease in wetlands will have negative effects on the water quality of a lake due to increased runoff, erosion, and decreased natural buffering.

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

Wetland 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

LONG POND CHARACTERISTICS

WATERSHED DESCRIPTION

Long Pond is located in the Belgrade lakes region of Kennebec County, Maine and is characterized by two separate water basins, the North and the South. Long Pond North, on which this study concentrates, has shoreline lots located in the towns of Belgrade and Rome (Figure 8). Belgrade Village is located in the center of the eastern side of the lake at Longitude 69:50:56 and Latitude 44:29:17. The two highest elevations of the watershed include Blueberry Hill, which is located on the western side of the lake and The Mountain, located between Long Pond North and Great Pond on the northeastern part of the lake. Long Pond North has a total volume of 34,922,160.4 m_, a surface area of 1,275 acres, a mean depth of 10 m, and a maximum depth of 20 m (PEARL 2006a). Furthermore, Long Pond North is considered a dimictic lake because of its spring and fall turnovers and its stratification during the summer months.

Long Pond is the second to last lake in the chain of the Belgrade Lakes. Great Pond, located to the east, flows into Long Pond as its major input. Water flows from the North Basin to the South Basin of Long Pond, eventually draining into Messalonskee Lake to the southeast before entering the Kennebec River by way of Messalonskee Stream. Because of the large amount of water flowing into Long Pond from Great Pond, the water quality of Great Pond has a great effect on that of Long Pond. Overall, Long Pond is considered a relatively healthy lake but has come under recent attention because of declining trends in deep water dissolved oxygen levels and an increased presence of *Gloeotrichia echinulata*, an invasive bacterium, which has become a more severe and persistent problem in Great Pond. In addition to the main input of water from Great Pond, there are several small and two prominent tributaries located in the northwest finger and along the west side of the lake.

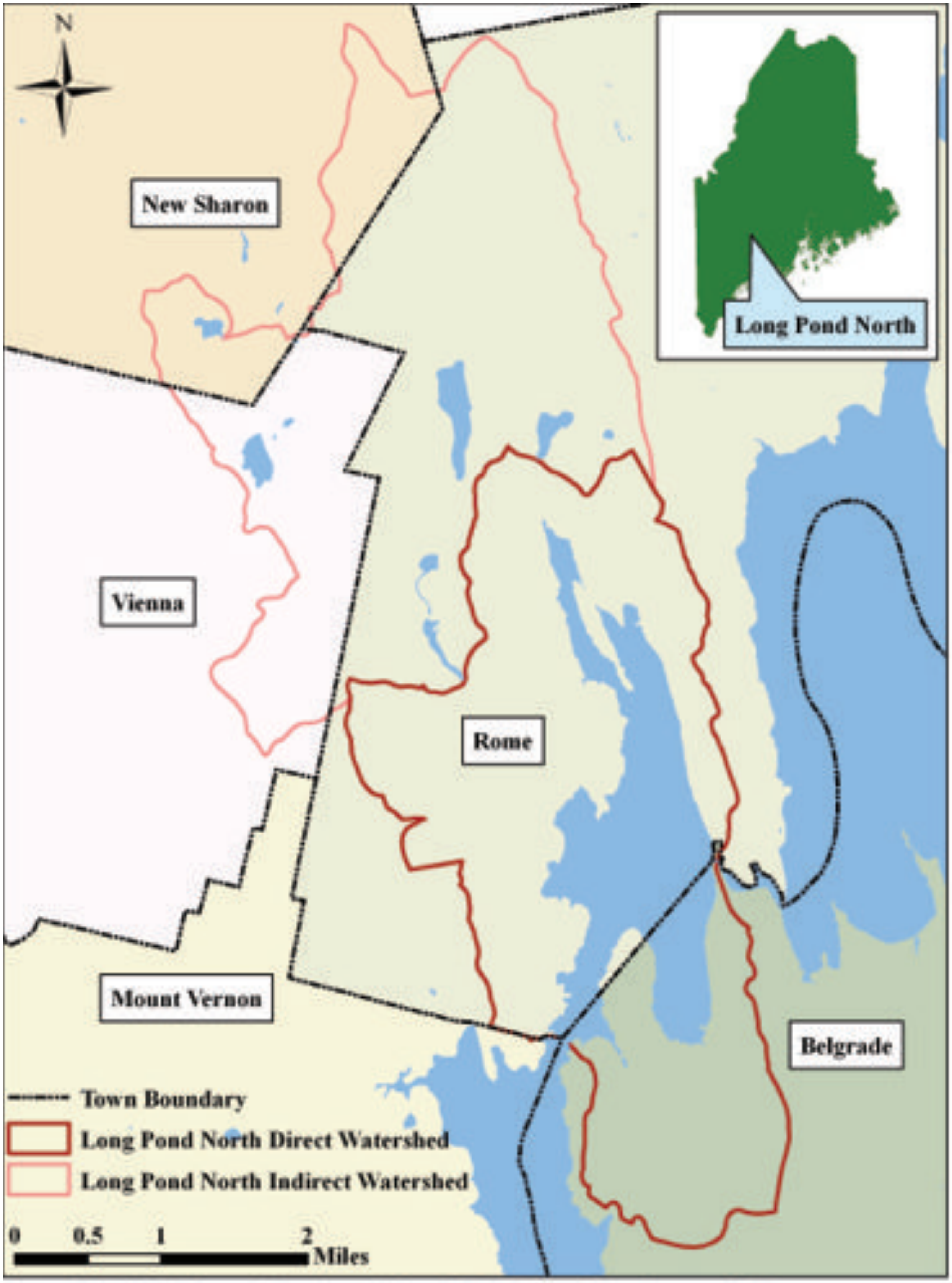

Figure 8. Political boundaries that divide the Long Pond North watershed.

HISTORICAL PERSPECTIVE

Water Quality

General Chemistry

Water-quality surveys performed by Gerald P. Cooper on Long Pond North exist dating back to 1939 (Strunk & Wallace 1973). The Maine Department of Inland Fisheries and Wildlife (Maine DIFW), Fishery Division began comprehensive studies in various Maine lakes including Long Pond in 1972. Maine DIFW annually surveys depth, Secchi transparency, temperature, conductivity, outlet discharge, dissolved oxygen, pH, and alkalinity. Until recently, Long Pond had consistently displayed high water quality since the onset of the assessment. For more information on water-quality parameters, see Analytical Procedures and Results: Water Quality.

The trophic status of a lake is based on primary production and can be estimated by transparency measured with a Secchi disk. The transparency derived Trophic State Index (TSI) values in Maine lakes range from 8 to 119, with a mean of 42 (MDEP 1996). Recent trophic status for Long Pond North has been determined in response to new Secchi transparency data and confirmed by variables such as chlorophyll-*a* and phosphorus concentrations. Long Pond North has a historic TSI value of 33 (Davis et al. 1978) and a current TSI value of 38 (see Water Quality: Transparency). This indicates that Long Pond North has remained an oligotrophic lake with a trend toward mesotrophy (see Background: Trophic Status of Lakes).

Phosphorus is the limiting nutrient in most aquatic systems (Wetzel 2000). As residents seek to prevent algal blooms, minimizing phosphorus concentration is always a primary target. Fortunately, Long Pond North has historically had relatively low phosphorus concentrations. The fact that current nutrient levels have stayed relatively stable and low, despite a rise in development, can be attributed in part to the Belgrade Regional Conservation Corps (BRCC). To reduce phosphorus loading, the BRCC has installed riprap on the shoreline to prevent erosion and planted larger buffers to reduce runoff from the land.

Past studies have reported low dissolved oxygen levels at bottom depths in Long Pond North (CEAT 1994). Until a short time ago, the values have remained sufficiently high to support cold-water fisheries, and the lake never experienced complete dissolved oxygen depletion (Davis et al. 1978). In 1994, CEAT reported anoxic waters at site 1 by mid August and the cold-water fishery was presumed to be in jeopardy (see Figure 28). Landlocked salmon (*Salmo salar sebago*) and brook trout (*Salvelinus fontinalis*) both favor colder waters and dissolved oxygen levels above 5 ppm (PEARL 2006b). In Long Pond North this colder, deeper water is poorly oxygenated by the end of the summer, thus limiting the available habitat of these species that are annually stocked by Maine DIFW. In addition, low oxygen levels accelerate the release of phosphorus from ferric compounds on the lake's bottom. This annual trend toward anoxic water is cited as the reason the Maine Department of Environmental Protection (Maine DEP) placed Long Pond on the impaired waters list in 2006 (Roy Bouchard pers. comm.).

The acidity of a lake is measured by pH. Increased acidity is implicated in limited egg viability of aquatic organisms and in localized extinctions (Pearsall 1991). Acidic pH values below 6 harm snails and crustaceans. Lower pH levels are also harmful to salmon, whitefish (*Coregonus clupeaformis*), perch (*Morone americana*), pike (*Esox spp.*), eel (*Anguilla rostrata*), and brook trout (Bunce 1990). The mean pH in Maine lakes is 6.7 (n = 453) (PEARL, 2006j). Historically in Long Pond North, pH was reported at 6.7, posing no threat to aquatic life (Davis et al. 1978). Additionally, this pH falls within the range of maximum phosphorus retention by soil sediments (pH values 5 to 7) (Cooke et al. 1993). However, since 1976, CEAT has observed pH values exceeding 7 where more phosphorus is released from iron complexes.

Gloeotrichia

Landowners on Long Pond and Great Pond are becoming concerned with an increasing abundance of *Gloeotrichia echinulata* (King 2005). *G. enchinulata* is a nitrogen-fixing cyanobacteria that is commonly associated with cultural eutrophication. This blue-green algae's first life stage occurs in the benthos (the lake bottom), where internal carbon dioxide production increases buoyancy, causing migration into the water column. Able to store phosphorus above normal concentrations for later growth and reproduction in surface waters, *G. echinulata* has the potential to proliferate exponentially. Dr. Whitney King and Dr. David Firmage of Colby College are currently investigating this organism's proliferation and lifecycle.

Regional Land-use Trends

Most Maine lake watersheds are heavily forested. Urbanization within a watershed results in pollution that ultimately degrades lake water quality. Large-scale point-source pollution is now relatively rare in Maine lake watersheds (Firmage, D., pers. comm.). Non-point source pollution, such as residential and agricultural land-use practices, is more common. The resulting runoff from these land-use types, as well as from septic systems within residential areas, can significantly contribute to lake nutrient loading. Thus, evaluating the changing patterns of different land-use types can be helpful when estimating nutrient loading in a watershed (Davis et al. 1978).

Land-use patterns in the Belgrade Lakes region have changed dramatically over the past 70 years (Plantinga et al. 1999). In the 1930s, the Belgrade Lakes region was inhabited primarily by year-round residents who were both isolated and self-sufficient. Many of these year-round residents found employment in agricultural practices. In order to meet water needs for irrigation purposes, a majority of farmlands were located on lake shorelines. However, during World War II, many young men left farms to contribute to the war effort (Bacon, pers. comm.). These men learned new trades and skills while they were away from the Belgrade region. Armed with a greater skill-base upon their return, the appeal of a predictable wage and fewer working hours led these men to explore employment opportunities not tied to agriculture (Bacon, pers. comm.). As development increased and job opportunities expanded, much of the agricultural and pasture lands were abandoned and left fallow. In time, early successional forest reclaimed the numerous abandoned farms in the Long Pond North watershed.

In the 1960s, the towns surrounding Long Pond agreed that the construction of camp roads and the subdivision of large shoreline farm plots would increase residential development and be profitable and beneficial for commercial and municipal growth (Bacon, pers. comm.). As a result, farmed land moved farther from shore, but was still common. Many seasonal residents relocated to the Belgrade region after buying the smaller, sub-divided residential plots.

The most important regional land-use trend affecting aquatic nutrient loading has been the decline in agricultural practices. Farming and timber harvesting reached their peak in 1872, when forested land reached an all time low, covering only 53.2 percent of the total land area in Maine (Plantinga et al. 1999). Since 1872, agricultural and timber harvesting have declined in Maine, particularly in the twentieth century (Plantinga et al. 1999). Between 1950 and 1999, cropland and pasture area declined by 713,000 acres (288,544 ha) and by 174,000 acres (70,416 ha) respectively, while forested area in Maine increased by 400,000 acres (172,000 ha) (Plantinga et al. 1999). This increase in forested lands can be attributed to the transition away from agricultural activity (Plantinga et al. 1999). Currently, agriculture is more common in southern Maine and Aroostook County than in regions of higher relief such as the Long Pond North watershed, where agricultural practices have diminished (Fuller pers. comm.).

In lake watersheds lacking notable agricultural land use, residential development is the predominant cause of anthropogenic nutrient loading (Davis et al. 1978). The seasonal and year-round residences frequently surrounding Maine lakes tend to account for much of the nutrient loading. Road maintenance and construction, forest clearance, building construction, and sewage disposal are examples of nutrient-loading activities that are commonly associated with residential development.

BIOLOGICAL PERSPECTIVE

Introduction

Included within the Long Pond North watershed are a variety of habitats, which support diverse flora and fauna. The watershed encompasses wetlands, coniferous and deciduous forests, small ponds, and riparian habitat. These ecosystems are complexly interconnected and greatly affect lake health. Human developments and practices within the direct watershed have the capacity to profoundly alter the landscape and impact regional ecological health. Residential, commercial, and agricultural development, in addition to other human activities, can transform the lake ecosystem through a process known as cultural eutrophication. While eutrophication refers to the natural aging process of lakes occurring in the absence of anthropogenic forces, it can be exacerbated by anthropogenic influence (Hem 1970). Eutrophication may lead to undesired conditions such as oxygen depletion, habitat loss for cold-water fish species, and unpleasing aesthetics associated with algal blooms.

Native Aquatic Flora

Aquatic plants play an integral role in the Long Pond North ecosystem. They oxygenate the water column, provide food and shelter for aquatic organisms, and sequester phosphorus. By tying up this limiting nutrient, aquatic plants may significantly reduce the risk of algal blooms. Excessive growth of macrophytes, or large plants, may indicate increased nutrient levels resulting from pollution (EPA 2006a).

Fish Stocking

The stocking of fish falls under the jurisdiction of the Maine Department of Inland Fisheries and Wildlife (MDIFW). Stocking is administered to create self-sustaining populations of native fish, and to improve recreational angling opportunities. The approval in 2002 of a seven million dollar bond package aimed at improving state hatcheries greatly strengthened MDIFW's stocking program. In 2005, MDIFW stocked 1,058,491 fish in state waters. More specifically, MDIFW stocked 2,350 brook trout and 3,500 landlocked salmon into both basins of Long Pond between May and November of that year (MDIFW 2005). Inadequate spawning and nursery areas in Long Pond necessitate the periodic stocking of salmon. The stocking of brook trout and landlocked salmon in Long Pond has been ongoing since 1989. Populations of warm-water fishes in Long Pond are self-sustaining and do not require stocking (MDIFG 1967).

Long Pond contains 19 species of fish and harbors many recreational fishes including salmon, brook trout, brown trout, smallmouth bass, largemouth bass, smelt, pickerel, northern pike, and white perch (Table 3) (MDIFG 1967). Findings indicate that deeper areas in the water column experience low levels of dissolved oxygen (DO), which poses a problem for salmonid species like salmon and trout. Salmonids prefer dissolved oxygen levels above six ppm and are susceptible to reduced DO levels arising from increased decomposition of organic matter in the benthos (Firmage pers. comm.).

Table 3. Fish species currently found in Long Pond (MDIFG 1967).

Common Name	Scientific Name
American eel	*Anguilla rostrata*
Black crappie	*Pomoxis nigromaculatus*
Brook trout	*Salvelinus fontinalis*
Brown bullhead	*Ameiurus nebulosus*
Brown trout	*Salmo trutta*
Chain pickerel	*Esox niger*
Golden shiner	*Notemigonus crysoleucas*
Landlocked salmon	*Salmo salar sebago*
Largemouth bass	*Micropterus salmoides*
Northern pike	*Esox lucius*
Pumpkinseed	*Lepomis gibbosus*
Rainbow smelt	*Osmerus mordax*
Redbreast sunfish	*Lepomis auritus*
Slimy sculpin	*Cottus cognatus*
Smallmouth bass	*Micropterus dolomieu*
Walleye	*Sander vitreus*
White perch	*Morone americana*
White sucker	*Catostomus commersoni*
Yellow perch	*Perca flavescens*

Invasive Plants

The introduction of non-native, invasive aquatic plant species can be detrimental to lake ecosystems. Because these plants have not co-evolved within the specific lake community to which they have been introduced, they are often not susceptible to competition and disease and thus have an advantage over native species (MDIFW 2006). Invasive species can quickly increase their population and effectively dominate an entire ecosystem. Invasive aquatic plants are introduced to lakes in large part through boating. The Maine Volunteer Lake Monitoring Program (VLMP) is currently promoting public awareness of the invasive plant issue in Maine and endeavors to successfully prevent introduction of any of the 11 species (Table 4) considered imminent threats to Long Pond North (VLMP 2006). Thus far, investigations have not discovered any invasive aquatic species in Long Pond North.

Table 4. Invasive aquatic plants threatening Maine's inland waters (MDIFW 2005).

Common Name	Scientific Name
Eurasian water milfoil	*Myriophyllum spicatum*
Variable-leaf water milfoil	*Myriophyllum heterophyllum*
Parrot feather	*Myriophyllum aquaticum*
Water chestnut	*Trapa natans*
Hydrilla	*Hydrilla veticillata*
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*

Trophic Status

A lake's trophic status is a measurement of the total biomass production occurring at the primary producer level (Chapman 1996). Primary production results from photosynthesis of aquatic plants and algae and is measured in terms of biomass. Healthy lakes are composed of consumer species that minimize the biomass of primary producers. When this biomass exceeds the amount that consumers can assimilate, the nutrients leached from decomposing plants become available for reuse by primary producers. High nutrient availability leads to an inefficient use of phytoplankton biomass because of rapid growth. This inefficiency can affect species composition, as well as a lake's physical and chemical characteristics (Chapman 1996).

Secchi disk readings, phosphorus levels, and chlorophyll-*a* counts are measures of primary productivity and reflect a lake's trophic status. A lake can progress through the four principal trophic status categories by acquiring nutrients. Oligotrophic lakes are relatively unproductive and have a Secchi disk transparency above 8 m, low concentrations of phosphorus (less than 6 ppb), and low chlorophyll-*a* (less than 1 ppb). Mesotrophic lakes have moderate productivity (2.6 to 7.3 ppb chlorophyll-*a*), a Secchi disk transparency between 2 and 4 m, and moderate phosphorus levels (typically between 12 and 24 ppb) (Carlson and Simpson 1996). Eutrophic lakes exhibit below average transparency of less than 2 m, high phosphorus levels (greater than 24 ppb), and high productivity (greater than 7.3 ppb chlorophyll-*a*). Lakes that generate large quantities of organic matter and experience anoxia in the hypolimnion during summer stratification are thus limited in their recreational usage and are considered dystrophic (Chapman 1996). Based on these criteria, Long Pond North is currently considered oligotrophic, but is approaching mesotrophic status. Historically, Long Pond North has not experienced algal blooms, but current trends suggest that they could be a concern in the future.

GEOLOGICAL AND HYDROLOGICAL PERSPECTIVE

The geologic features in Maine can be attributed to glacial activity in the region that occurred during the Pleistocene Epoch. During this time of geologic activity, several glacial sheets advanced over the land depositing soil, eroding existing mountains, and fragmenting rock (MGS 2005a). In Maine, the most recent glacial activity began 35,000 years ago when the Laurentide Ice Sheet extended across the state. The ice sheet eventually grew to a thickness of several thousand feet and caused a depression in the land covering much of the southern, eastern, and central regions of Maine (MGS 2005a). As the weather warmed and the glacier receded north, it deposited large rocks and varying sediments. The absence of the glacier also allowed the depressed land, now known as the Presumpscot Formation, to be flooded by sediment rich sea water (MGS 2005b).

The glacier's behavior, north-south orientation, and progression created many of the lakes and geological features in the Belgrade region. Eskers are characteristic of this area and were formed by the deposition of stream sediments underneath the glacier. Additionally, kettlehole bogs are common in this area and resulted from the deposition of sediment around a large block of ice that eventually melted. The soil composition in Maine is a direct product of the glacial deposits during the Pleistocene Epoch. Generally, the most common type of soil found in Maine and this region is glacial till (Caswell 1974).

In addition to creating geological formations and affecting soil types, glaciers also had a profound impact on the current drainage system found throughout the Belgrade region. Long Pond is the second to last lake in a water flow chain of seven lakes. Long Pond receives inputs from Great Pond and releases its outputs into Messalonskee Lake by way of Messalonskee Stream.

Long Pond is a long lake running north-south. It is comprised of two basins though this report will only consider the north basin. Long Pond is a lake that experiences seasonal stratification and is considered to be dimictic. The stratification of dimictic lakes creates distinct temperature zonation, especially during the summer months. During stratification, the lake is divided into an epilimnion near the surface and a hypolimnion above the bottom separated by a temperature gradient called the thermocline, where temperature drops very quickly (Wetzel 2001). Dimictic lakes are categorized by two annual turnovers, one occurring in the spring and one in the fall. Because water is most dense at 4º C, spring and fall turnover are facilitated by warm water rising to the surface and cool water dropping towards the bottom of the lake (Wetzel 2001). See Background section for more information on lake turnover.

STUDY OBJECTIVES

INTRODUCTION

This study is a comprehensive examination of the North Basin of Long Pond and its associated watershed. The Colby Environmental Assessment Team (CEAT) has conducted a water-quality study, road surveys, residence counts, shoreline surveys, and land use assessment in the watershed. This information was used to ultimately determine a water and phosphorus budget for the lake. Our goal was to provide insight for maintenance and improvement of lake health.

LAND-USE ASSESSMENT

Team members worked with a Geographic Information System (GIS) to derive a land-use consensus in the Long Pond North watershed. One team worked to determine the land qualities and characteristics in regards to septic suitability, erosion potential, problem areas, and buffer quality. The second group used GIS to analyze digital orthophoto quadrangles (satellite images of the land) to delineate different land uses existing in the watershed. Use of GIS was important to better evaluate the effects of different land uses, soils, and vegetative covers on lake water quality. Land-use delineation coupled with septic suitability and erosion potential models facilitate future watershed projections.

WATER-QUALITY ASSESSMENT

Throughout the summer and into the fall of 2006, water was tested in Long Pond North at four different sampling sites. These sites were located in different parts of the lake with varying water depths. The deepest site had a depth approximately 20 m, while the shallowest site approximated 4 m depth. The continuous sampling at these sites allowed for monitoring of changes that occurred during the summer as well as the effect of different depths and locations on water quality.

There were several tests performed while in the field. At each site, a Secchi depth, temperature, dissolved oxygen, pH, and turbidity were measured, and water samples were brought back to the lab to be tested for total phosphorus. Surface, mid, and bottom depths were sampled as well as an epi-core sample in which a tube was lowered through the epilimnion to obtain a sample from that portion of water column. These tests were used to monitor changes in lake water throughout the summer, assess lake quality, and provide a check for the lake's phosphorus budget which will indicate the amount of phosphorus that can enter the lake without negatively impacting its health.

FUTURE TRENDS

An important part of understanding this watershed is recognizing its use in the future. An accurate prediction of long-term change can be projected by combining the information gathered from different land and road surveys, septic suitability and erosion potential models created through GIS, and the water and phosphorus budgets. The work performed by CEAT and information gathered through meetings with town officials, data extrapolated from tax maps, and regional population trends should combine to depict an accurate prediction of the watershed area over the next ten to fifteen years. The goal is to maintain the health of the lake as the towns within the watershed progress and change.

ANALYTICAL PROCEDURES AND RESULTS

GIS

INTRODUCTION

A Geographic Information System (GIS) is a combination of computer hardware and software designed to display, analyze, and interpret spatially referenced data. Spatially referenced data are any data that can be viewed as a map. CEAT used ArcGIS 9.1, published by ESRI Software to create maps and spatial models. ArcGIS allows the user to work with data in two primary formats, raster and vector. A raster is a grid of equally sized cells covering a whole surface, with each square encoding a unique value representing a quality such as temperature, soil type, elevation, or slope. The other format is vector data that can be displayed as points, lines, or polygons in shapefiles, coverages, or layers (ESRI 2006). These two formats enable ArcGIS to perform a multitude of functions.

The foundations of GIS analysis are single map files called layers, which contain data pertaining to one theme. Examples of layers include elevation, watershed boundaries, roads, and soil types. Each feature in a layer, such as a stream, is associated with relevant information. For example, the stream name, length, or width could be included in a stream shapefile. Combining several layers in one map and applying mathematical processes to them creates more complex models of space. Through various mathematical algorithms and spatial manipulations, GIS can highlight certain information that was previously obscured in raw data. Since GIS contains data in a quantitative form, objective analyses can be performed regarding distribution, percentages, distances, and elevations.

GIS also has the power to compile themes into new layer files. For example, attributes from soil and slope layers were combined to create a layer showing suitability for septic system installation. This new merged layer represents an intersection of the two themes. Merging themes can create new information from imported data.

Water and watershed studies consist of data typically represented in a spatial dimension. Watershed size, lake shape, and locations of residences all contain important data that GIS is designed to analyze. It is important to note that the maps produced by this system are subject to the inherent errors resulting from differing projections or inconsistencies in the original data.

Maps are intended to provide a generalized view of the watershed, from which future improvements can be suggested.

CEAT used data downloaded from the Maine Office of GIS website, as well as layers produced from data collected in the field. Bathymetry data was derived from the Maine Department of Conservation, Bureau of Parks and Lands. Road quality, buffer quality, duration of occupancy, and road problem areas were surveyed by CEAT. A study site map, septic suitability, erosion potential, land use, and development potential were all mapped using the data layers mentioned above.

WATERSHED LAND-USE PATTERNS

INTRODUCTION

A land-use survey is necessary to develop a comprehensive analysis of a watershed's health and status, as each land-use type affects water quality differently. Each land-use type has unique erosion properties that ultimately influence nutrient flux in the receiving water body

(EPA 1990). Land-use types characterized by dense persistent vegetation, (e.g., coniferous forest, deciduous forest, or mixed forest) absorb rainfall and diminish erosion resulting from rain impacting the soil. Additionally, vegetation roots in these land-use types lend structure to the underlying soil. The combination of these two factors causes areas with significant vegetative cover to experience low erosion potential, and consequently add minimal amounts of nutrients to the receiving water body. In contrast, areas with limited vegetative cover, (e.g., cleared land and residential lots with lawns) absorb less water and provide less stability to the underlying soil. These land-use types have greater erosion potential and contribute significantly more to nutrient loading in the water body (Dennis 1986).

A land-use survey, when compared with similar historical surveys, facilitates understanding of past trends, and can be helpful in predicting future changes in land-use patterns. The current land-use survey, which uses data from 2003, was compared to the survey of Long Pond North completed by CEAT in 1995. The 1995 report analyzed land-use patterns from 1991. Land-use changes between 1991 and 2003 may elucidate historical land-use trends and facilitate future predictions regarding land-use patterns.

METHODOLOGY

To conduct a land-use survey of the Long Pond North watershed, color Digital Orthophoto-Quadrangles (DOQs) were obtained from the Maine Office of GIS (MEGIS). DOQs are computer-generated images made from aerial photographs taken in spring 2003 (MEGIS 2006). The DOQs' image displacement caused by terrain relief and camera angle is removed in order to increase the images' accuracy (USGS 2006). ArcGIS® displayed the imported DOQs and facilitated creation of a layer of digital polygons representing each land-use type. These digital polygons were created until they filled the entirety of a polygon representative of the watershed, obtained from the Maine Department of Environmental Protection. In the 1995 CEAT report, a larger, indirect watershed was used to represent the Long Pond North watershed. As a result, the additional indirect watershed was necessary to establish comparison between the survey completed by CEAT in 2006 and the survey performed by CEAT in 1995.

The land-use categories used in our survey were based primarily on the definitions used by a past China Lake study (CEAT 2005). Modifications were made to previous land-use types since some land-use types in the Long Pond North watershed were not present in the China Lake survey, and vice-versa. The land-use types employed in our survey were agriculture, cleared land, commercial, coniferous forest, deciduous forest, mixed forest, golf course, park, regenerating land, road, non-shoreline residential, shoreline residential, water body, and wetland. A brief description of each land-use type is presented below:

Agricultural land: Land that is cleared except for grasses and has no ordered rows of vegetation, signifying cropland. The only agricultural land in the Long Pond North watershed is pastoral.

Cleared land: Land characterized by low-level vegetation such as grasses or shrubs, or by areas in which no vegetation is present. This land exists after land is cleared for logging or development, but also naturally exists in areas with steep slope.

Commercial: Land characterized by structures of size and situation uncommon to residential lands and also by the availability of parking, often associated with commercial operations. Commercial land designations include the smallest land area encompassing all of the buildings, parking areas, and other areas of identifiable impervious surfaces.

Coniferous forest: Forest composed of primarily coniferous trees, which is signified by a dark green color and a closed canopy in the DOQs.

Deciduous forest: Forest composed of primarily deciduous trees, which is signified by a highly textured, yet slightly transparent, image in the DOQs (this forest type is slightly transparent since the photographs were taken in the spring when deciduous trees lack leaf-cover).

Mixed forest: Forest composed of both coniferous and deciduous trees, which is signified by a mixing of the aforementioned attributes of coniferous and deciduous forests.

Golf course: Land characterized by pristine and uninterrupted grassy strips, which may also have sand traps incorporated.

Park: Similar to cleared land or agricultural land, but is maintained and not used for any agricultural functions.

Regenerating land: Similar to mixed forest but lighter in color and less textured in the DOQs, indicating lack of closed canopy. This generally results from early succession and the reversion of logged areas.

Roads: Either state or camp roads. CEAT downloaded a map of the roads from the Maine Office of GIS into ArcGIS® for viewing, but area measurement was done during road surveys.

Non-shoreline residential: Land farther than 250 ft from Long Pond North that is characterized by the presence of a residence. Residential land was marked as the smallest area containing the central residence and any out-buildings. This area also included the driveway and surrounding lawn.

Shoreline residential: Similar to non-shoreline residential except occurs within 250 ft of Long Pond North.

Water body: Land characterized by water that persists annually.

Wetlands: Transitional land between terrestrial and aquatic states. Wetlands are characterized by proximity to water and darkened saturated soils.

GIS analysis was not the most accurate method for analyzing the road land-use category. DOQs failed to display the entirety of road area and the canopy of the coniferous and mixed forests obscured the area of smaller camp roads. Instead, CEAT performed a road survey in 2006. The road survey was a comprehensive field survey, in which the length and average width of every road was measured, allowing for calculation of the current road area. Since the road survey was completed in 2006, and its information is being compiled with data based on images from 2003, it is possible that the road cover has changed in the interim. However, it can be assumed that the area of roads has changed minimally since no incongruity was evidenced between the road survey and the DOQs. To allow for the addition of the current road area within the watershed, an area of the same size was subtracted proportionately from other land-use types. This method is relatively accurate since during the GIS survey, land-use types that were adjacent to roads were made to extend halfway through the width of the road, thus artificially increasing the area of other land-use types. By proportionately subtracting road area from each other land-use type, any negative effects of adding the current road area were eliminated, and a constant watershed area was maintained.

In the CEAT 1995 land-use survey, two United States Geological Survey (USGS) maps from the 7.5 Minute Belgrade Lakes Quadrangle Series were scanned into MacGIS. One was a topographical map from 1982, describing Long Pond North topography using contour lines at 10 ft intervals. The other was a culture and drainage map, indicating cultural features in the region such as roads, structures, political boundaries, and watershed boundary. These maps were placed in an area that was divided into cells or blocks, each representing an area of 64 ft^2 in the watershed. Using these scanned maps as references, layers representative of a watershed characteristic, (e.g., soil type), could be created.

In order to quantify various land areas, CEAT (1995) used an NIH 1.54 image analysis program. A video camera captured images, which were then transferred onto a computer, where image quality could be enhanced through sharpening. The perimeter of land-use patches on enhanced images was then digitized, and areas of non-residential land-use types were estimated. A Zeiss Interactive Digital Analysis System (ZIDAS) was used to calculate the areas of residential land use. This program measured random samples of shoreline and non-shoreline residential lots. The average lot size for each of these two categories was then multiplied by the number of lots falling under these two categories (CEAT 1995). To make the 1995 survey comparable with the data obtained by this study, residential area was generated by multiplying the number of shoreline lots by 0.5 acres, and the number of non-shoreline residential lots by 1 acre, a method previously suggested by the Maine DEP.

In our 2006 land-use survey, three DOQs of 1 m resolution were downloaded from Maine Office of GIS. These DOQs were already projected with a GIS coordinate system, so they could be imported directly into ArcGIS® without georeferencing. Once imported, the watershed boundary was superimposed. Land-use areas were then identified and polygons were drawn around each land-use area, filling the watershed. Total area for each land-use type was calculated from these polygons.

Identifications of land-use types in our survey were aided by physical surveys, known as ground-truthing. Some land-use areas in the DOQs were difficult to interpret, thus requiring additional information. Ground-truthing consisted of traveling to an area of unknown land-use type and visually confirming the GIS-predicted land-use type for that location. Deciduous forest is an example of a land-use type that was difficult to recognize in the DOQs. Since the photos were taken in the spring, there was no foliage cover to facilitate vegetation identification. This method of visual confirmation presents the possibility of error, since the DOQs date to 2003, while ground-truthing was conducted in 2006. However, the proximity of the DOQs and ground-truthing dates suggested that natural succession would not yet cause any discrepancy. Only anthropogenic changes, such as development, would cause dramatic effects in this regard. In our ground-truthing surveys, CEAT found no land-use types that appeared incongruous with our photo-based designations because of recent human activity or development.

WETLANDS

Wetlands are a transitional environment between terrestrial and aquatic ecosystems and play an essential role in nutrient absorption. Wetlands are more strictly defined by the EPA as regions saturated by water to the extent that they support a vegetative community typical of those adapted to wet soil conditions (EPA 2006b). Wetlands exist in many varieties such as marshes, swamps, and bogs. They provide many functions to both natural and human communities and are thus quite valuable. Wetlands act as effective buffers between the land and water, and in addition to alleviating damages caused by flooding, they absorb nutrients, sediments, and pollutants before they reach the lake ecosystem (EPA 2004). Wetlands also provide habitat for many plants and animals. In order to conserve these important natural resources, wetlands are protected under local, state, and federal zoning ordinances. In Belgrade and Rome, development is prohibited within 250 ft of wetland areas, making it unlikely that large areas of wetlands have been lost since the 1991 study.

The CEAT (1995) study of Long Pond North found that wetlands comprised 251 acres (102 ha) or 4.2 percent of the entire watershed in 1991 (Table 5). Using DOQs from 2003, CEAT determined wetlands to occupy approximately 184 acres (74 ha) or 2.8 percent of the extended watershed (Figure 9). This seemingly significant decrease in wetland area can be explained partially by examining methodological differences between the 1995 and 2006 study.

The 1995 CEAT study relied on a Zeiss Interactive Digital Analysis System (ZIDAS) and an NIH 1.54 Image Analysis program in order to quantify land-use patterns within the watershed. Although these programs can produce results that are representative of the watershed, they lack the accuracy of ArcGIS®. For example, when designating land uses within the Long Pond North watershed, the 1995 CEAT report categorized large tracts of land as pertaining to a single land use when in actuality the areas consisted of multiple uses. Many of the wetland areas in the watershed contained large areas of open water, which this study designated accordingly as water bodies. This discrepancy in methodology most likely accounts for the decline in wetland area, since development within 250 ft of wetlands is prohibited.

Table 5. Total percentage of each broad land-use category (bold) and contributing

land uses from 1991 and the direct and extended watershed of 2003. 1991 information obtained from CEAT 1995.

Land-Use Type	Percent in 1991	Percent in 2003
Cleared Land	**3.4**	**2.4**
Open Land	N/A	1.9
Golf Course	N/A	0.2
Park	N/A	0.01
Agriculture	N/A	0.3
Forest	**71.9**	**85.6**
Coniferous Forest	N/A	22.1
Deciduous Forest	N/A	31.4
Mixed Forest	N/A	32.1
Developed Land	**4.4**	**5.3**
Shoreline Residential	1.9	2.0
Non-Shoreline Residential	2.5	3.2
Commercial	N/A	0.1
Wetland	**4.2**	**2.8**
Regenerating	**15.1**	**2.2**
Road	**0.9**	**1.8**

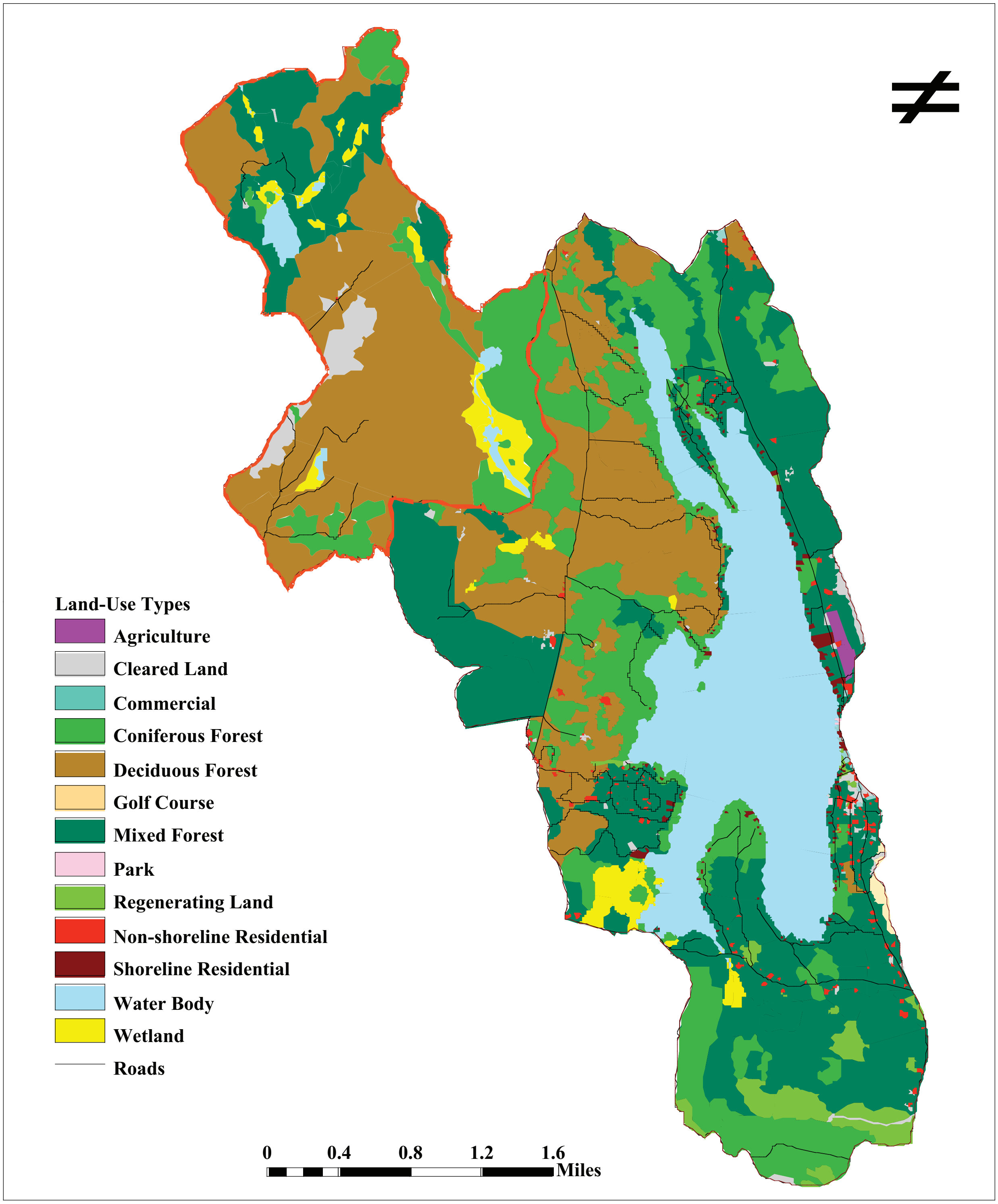

Figure 9. Land-use patterns of Long Pond North watershed in 2003 derived from Digital Orthophoto-Quadrangles downloaded from the Maine Office of GIS. The indirect watershed northwest of the direct watershed is partitioned by a red line.

FOREST TYPES

Land that is at least one acre in extent and covered by no less than ten percent of trees of any size is considered forested land by the U.S. Department of Agriculture Forest Service (USDA Forest Service). Forests are an integral part of the Long Pond North ecosystem and, like wetlands, serve many ecological functions. Forests sequester carbon, act as buffers by reducing runoff and preventing erosion, and sequester nutrients through their root systems. Additionally, forests provide essential habitat for many plant and animal communities whose species composition shift as the forests mature in an ecological process known as succession. Some of the main threats to forests and their inhabitants include logging, habitat conversion, and fragmentation resulting from anthropogenic developments such as roads and residential complexes.

Coniferous forests are composed primarily of evergreen trees, which retain their needles year-round. During the winter months, coniferous trees provide more shelter than do deciduous trees, which lose their leaves after the growing season. This inherent difference between coniferous and deciduous forests has implications for the effectiveness of each to act as buffers. A consistent canopy in a coniferous forest will reduce erosion due to rainfall on a year-round basis, whereas the ability of a deciduous forest to minimize erosion and runoff varies greatly according to season. Forests that are composed of both coniferous and deciduous trees are termed mixed forests. The CEAT (1995) report did not distinguish between forest types.

Forested land within the extended watershed area increased from 71.5 percent (4,119 acres/ 1667 ha) in 1991 to 85.6 percent (5,732 acres/ 2320 ha) in 2003 (Figure 10). In 2003, forests composed 91 percent (4,049 acres/ 1639 ha) of the direct watershed. The direct watershed was comprised of 26.7 percent (1,192 acres/ 482 ha) coniferous forest, 22.8 percent (1,015 acres/ 411 ha) deciduous forest, and 41.3 percent (1,842 acres/ 745 ha) mixed forest (Figure 9). The increase in forested land between 1991 and 2003 can be explained by inspecting local land-use patterns. Significant logging occurred in western areas of the watershed and was completed by 1992 (CEAT 1995). Examination of the 1991 aerial photo indicates that no clear-cutting took place. Since 1992, logging has only occurred on a small scale and has not had a large impact on the watershed. The maturation of regenerating areas since 1991 accounts for the dramatic increase in area of forested land between 1991 and 2003 (Figure 10).

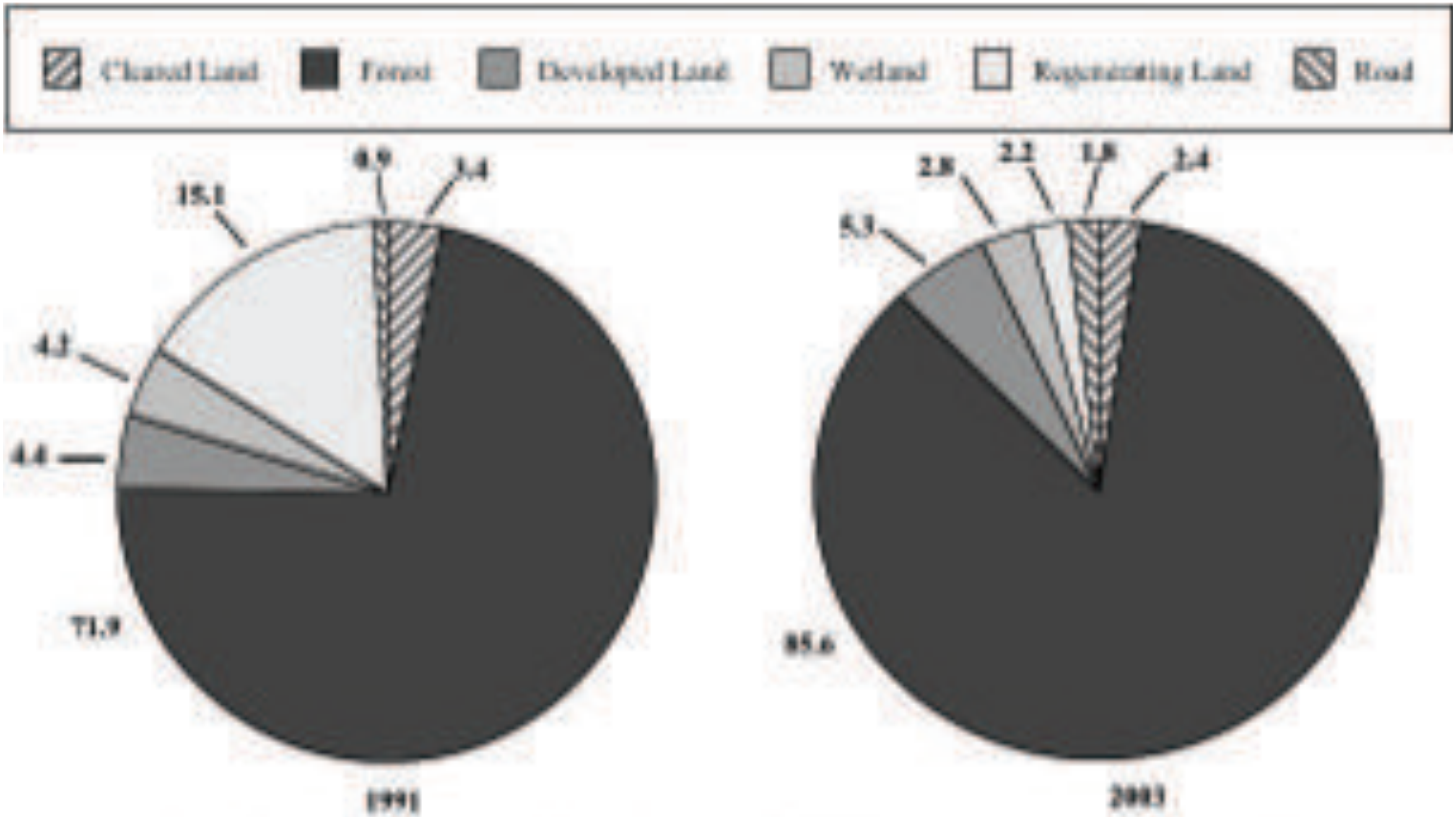

Figure 18. Percent land cover of Long Pond North watershed for 1991 and 2003 as determined using data from the Colby Environmental Assessment Team's 1995 report and analysis of the 2003 Digital Orthophoto-Quadrangles obtained from the Maine Office of GIS.

The Maine Shoreland Zoning Law states that within a ten year period, no more than 40 percent of the total volume of trees exceeding four inches in diameter may be harvested within 250 ft of Maine's rivers, lakes, wetlands and within 75 ft of certain streams. In addition, the Shoreland Zoning Law mandates that the maximum allowable clearing size be 25 percent of a lot or 10,000 ft^2, whichever is larger. Furthermore, the Shoreland Zoning Law states that within shoreland zones clear-cuts greater than 5,000 ft^2 must be separated by a minimum of 100 ft (Brian 1998).

CLEARED LAND

Cleared land is very influential in the impact that a watershed has on a water body. Cleared land, which is mostly, if not completely, free of trees and shrubs, lacks any significant buffering capability and is highly susceptible to stormwater runoff and erosion. Among the various land uses included within the cleared land category are open land, golf course, agriculture, and park. Open land is defined as land that has been cleared for logging or development and is devoid of all vegetation other than grass. Of particular concern to the health of Long Pond North are the golf course and agricultural areas. Both land uses are traditionally phosphorus intensive and may act as potentially significant non-point sources of pollution to Long Pond North.

In 2003, cleared lands comprised 2.4 percent of the extended watershed and 1.7 percent of the Long Pond North direct watershed. Approximately 3.3 percent of the extended watershed in 1991 was designated as cleared land (CEAT 1995) (Table 5). The decrease in the amount of cleared land since 1991 can be partially attributable to the methodological differences explained in the wetlands discussion section. Additionally, some of the cleared land that existed in 1991 has since reverted and is currently classified as regenerating land. The Maine Shoreland Zoning Law states that clearings in the forest canopy cannot exceed 250 ft^2 within 100 ft of great ponds or within 75 ft of tributary streams (Brian 1998). The impacts of cleared land, which can be a significant non-point source of pollution, are greatly reduced by this ordinance.

As was the case in 1995, there are currently no large scale agricultural practices within the watershed. The most notable cleared lands are the horse farm, golf course, and large residential lawn, all of which are in the town of Belgrade. Ground-truthing revealed a recently cleared area on Blueberry Hill in Rome. The area has been cleared of forest cover and only small shrubs remain. The clearing is located on a steep, rocky slope, making it prone to erosion and significant stormwater runoff. This cleared land is buffered, however, by the forested area adjacent to Long Pond North.

REGENERATING LAND

Forested areas that were cut for logging or agricultural purposes and have since begun to revert by growing small shrubs and trees are termed regenerating lands. These lands have characteristics of forested land such as root systems and a developing canopy and are more effective in preventing erosion and reducing runoff than is cleared land.

The percentage of the Long Pond North watershed classified as regenerating land has decreased substantially since 1991. In 1991, 15.1 percent of the watershed was comprised of regenerating land (Table 5). Analysis of the 2003 DOQs revealed that 2.2 percent of the Long Pond North extended watershed is composed of regenerating land. During the twelve year period between 1991 and 2003, regenerating land within the extended watershed decreased by approximately 808 acres (327 ha) (Table 10). Much of what was previously categorized as regenerating land is now classified as forest and is located primarily in the northwestern section of the watershed (Figure 9).

COMMERCIAL AND RESIDENTIAL

To generate the 2003 land-use map, residential and commercial areas were designated using ArcGIS® (Figure 9). Residential and commercial properties were identified on the DOQs by the presence of lawns, docks, cars, roofs, and other indicators of residence. Dense tree cover prevented the identification of every residence and associated lawn within the Long Pond North watershed using GIS. However, manual house counts were performed to improve accuracy in the number of commercial and residential properties. To accurately quantify shoreline and non-shoreline residential areas, the number of residences pertaining to each category was multiplied by a lot size of one acre for non-shoreline and half an acre for shoreline residences as suggested by the Maine DEP (Bouchard pers. comm.). The same calculations were also performed using house counts obtained in the 1995 CEAT report. Ground-truthing was used to discriminate between commercial and residential properties.

Residential and commercial lands have high runoff rates due to their association with lawns and impervious surfaces such as roofs and driveways. Those lands closest to Long Pond North or to tributaries will have the greatest effect on water quality due to runoff.

Developed land occupied 5.3 percent of the extended watershed in 2003 as compared to 4.4 percent in 1991 (Figure 10). This increase in developed land is consistent with Belgrade and Rome's vision of transitioning from seasonal to year-round towns. Future development will focus less on the construction of seasonal residences and more on year-round properties.

The house count found that 20 shoreline and 43 non-shoreline residences have been constructed within the direct watershed since 1995 (Table 6). Clearing land for development, especially for shoreline residences, can significantly impact water quality. Implementation of properly designed buffers, however, can greatly reduce nutrient loss through erosion and minimize residential impact on Long Pond North water quality.

Table 6. A comparison of house counts for both shoreline and non-shoreline residences in Long Pond North watershed in 1995 and 2006. 1995 data collected by CEAT.

	1995	**2006**
Shoreline	247	267
Non-shoreline	169	212

WATERSHED DEVELOPMENT PATTERNS

ROADS

Introduction

The roads in the Long Pond North watershed generally fall into three categories: camp roads, state roads, and municipal roads. The health of these roads is important because they can contribute to erosion and runoff. Camp roads play the largest role in effecting the quality of the lake, in part because they are privately owned and maintained, but also because they were not built to the same standards as state and municipal roads. The construction of new state roads involves the installation of proper culverts, ditches, and crowning, which directly correlate to the quality of the road and its ability to have a lesser impact on its surroundings. Refer to the Background section for a description of each of the above road qualities.

An ideal road possesses several qualities including a crown, ditches, turnouts, and also diversions and culverts where needed. A proper crown provides quick drainage of precipitation, preventing water from traveling along the road and causing erosion. The design of the crown allows water to flow down the slopes to the side of the road where the ditch, in areas where it is required, collects the water. The ditch follows the side of the road until there is opportunity for a turnout, leading the water away from the road into a buffered area. A well-maintained crown and ditch system is absent of berms (collected dirt at the road edge impeding flow off the road) and excess sediment in the ditch, and is shaped to successfully carry water away from the road.

Culverts are also an important component of a healthy road in instances when water runs perpendicular to the road. Culverts are a healthy way for water to pass under the road and most often are plastic, metal or concrete tubes (Figure 11). These cannot perform properly when they are degraded, filled with sediment, or exposed at the road surface (Figure 12). Diversions are critical particularly to roads with steep slopes. Water bars, french drains, or open culverts (see Background) provide an outlet for water to exit the road surface preventing deep channels from forming on the road (Figure 13).

 

Figures 11 and 12. The picture on the left is a representation of a good culvert with proper drainage and depository pool taken during the road problem survey on 19-Sep-06. The picture on the right is a representation of a poorly maintained culvert as it is filled with debris, has no room for runoff, and no collection pool observed during the road problem survey on 19-Sep-06.

Road maintenance falls under several different laws all contributing to standardized management. The Erosion and Sedimentation Control Law requires that all camp roads eroding into a stream or lake must be stabilized by 1-Jul-2010 or sooner if there is significant soil moved on a private property, such as with digging (KCSWD 2000). The Natural Resources Protection Act is another law that mandates the quality of camp roads in areas with major movement of soil on land that falls within 100 ft of the shoreline (KCSWD 2000). Under this mandate, a permit is required from the DEP to perform any drilling, draining, dredging, or major displacement of vegetation, all of which are necessary in road work. The Mandatory Shoreland Zoning Act also has jurisdiction in the regulation of camp roads because it deals with properties within 250 ft of a lake. New camp roads may be required to obtain permits under the Stormwater Management Law or the Site Location of Development Law (KCSWD 2000).

Methods

To assess the general condition of the roads in the Long Pond North Watershed, CEAT sent teams to first perform an overall survey of the roads and then later to determine problem

Figure 13. A diversion of some type and a ditch to carry water away from the road are needed to stop the erosion that has already occurred in the image taken during the road problem survey on 19-Sep-06.

sites along those roads. On 14-Sep-06 during the first part of the analysis, teams documented the roads and recorded names, GPS start and end locations, width, total distance, road type, crown height, ditch shape, and general health. The following week the teams returned to the field and looked specifically for problem areas. This portion of the fieldwork required that teams record the GPS problem location, problem type, and the most feasible remedy. Roads were classified into overall categories including Poor, Fair, Acceptable, and Good. This determination was an on-site evaluation of the road, based on the conditions described above, and was subjected to the interpretation of each survey team. The survey form can be found in Appendix G.

Results and Discussion

Analysis of the data indicated a total of 49 roads found in the watershed. There were 13 state roads, 35 camp roads, and one road labeled as other, namely Club House Drive leading to the Belgrade Lakes Golf Club. It was decided that grouping municipal and state roads would be more descriptive when analyzing the data. There is a total area of 70.13 acres (28 ha) of roads in the watershed. Of that total, 25.22 acres (10.21 ha) are camp roads and 44.91 acres (18 ha) are state roads. State roads are in overall better condition than camp roads (Figure 14). A classification of the state roads by area revealed that 2.43 percent were labeled as Poor, none as Fair, 5.56 percent as Acceptable, and 92.01 percent as Good. This indicates that the overall health of state roads is Good. Camp roads, though the majority of roads are classified as Good, display greater room for improvement with 5.24 percent labeled as Poor, 20.33 percent as Fair, 20.76 percent as Acceptable, and 53.68 percent as Good.

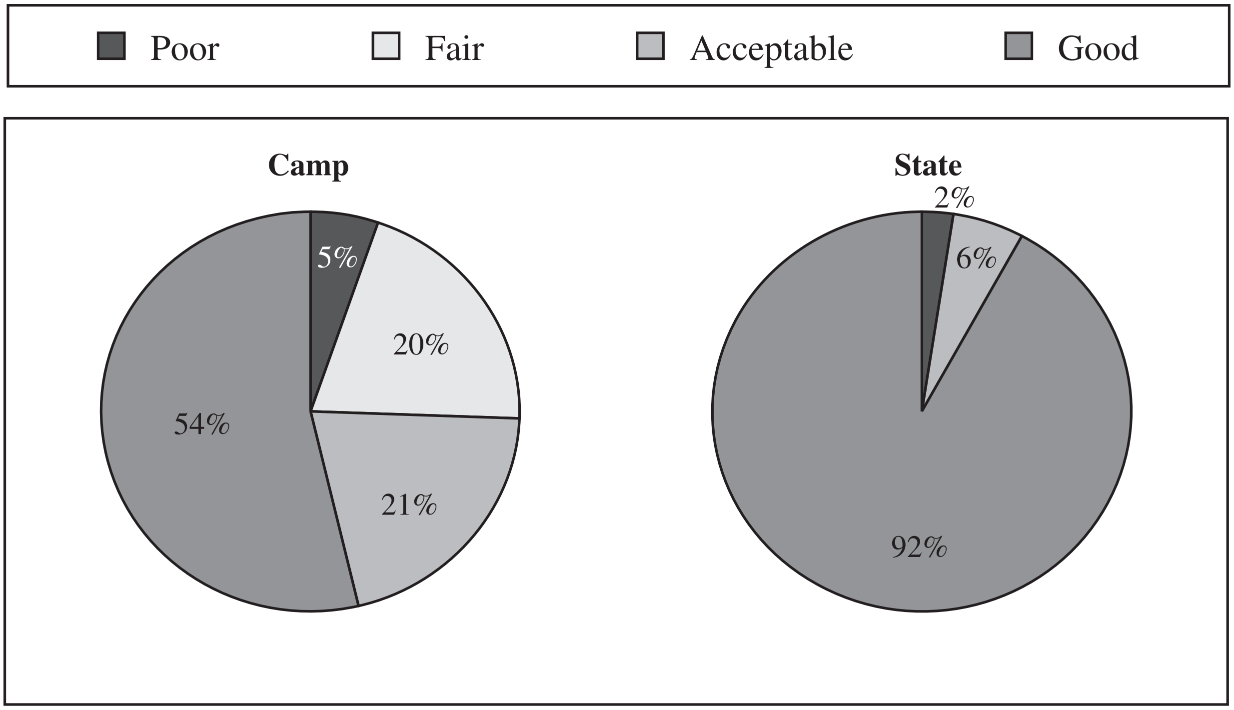

Figure 14. Road Area of state and camp roads by Quality and Type. The distribution of road quality categories described by area found in the watershed using data gathered by CEAT on 19-Sep-06 in the Long Pond North watershed.

Overall, camp roads falling within the Good category make up only half of the total road area, whereas state roads were comprise close to 90 percent of the total road area. There is far more room for improvement among camp roads in comparison to state roads. There are problem areas around the lake, notably in some of the housing developments on the western side (Figure 15). General characteristics of camp roads and their maintenance make problems much more difficult to alleviate from an organizational standpoint. There are challenges in place when dealing with private ownership or with road associations in order to organize a collaborative effort to improve road conditions.

ROAD PROBLEMS

Specific problems that were found during the road problem survey requiring attention are listed below. Figure 16 displays the location of the problems listed.

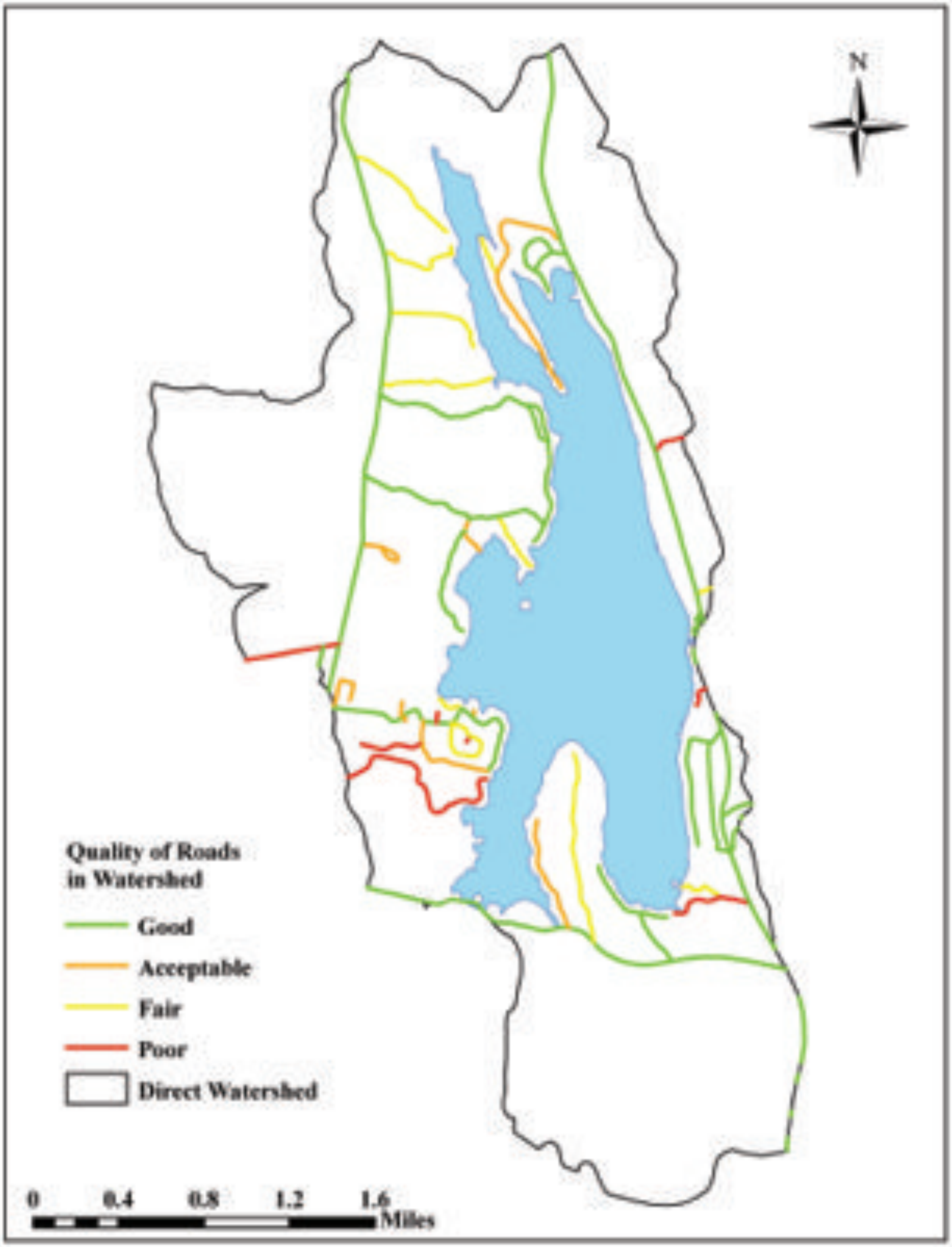

Figure 15. Quality of public roads in the direct watershed of Long Pond North based on a survey done on 14-Sep-06.

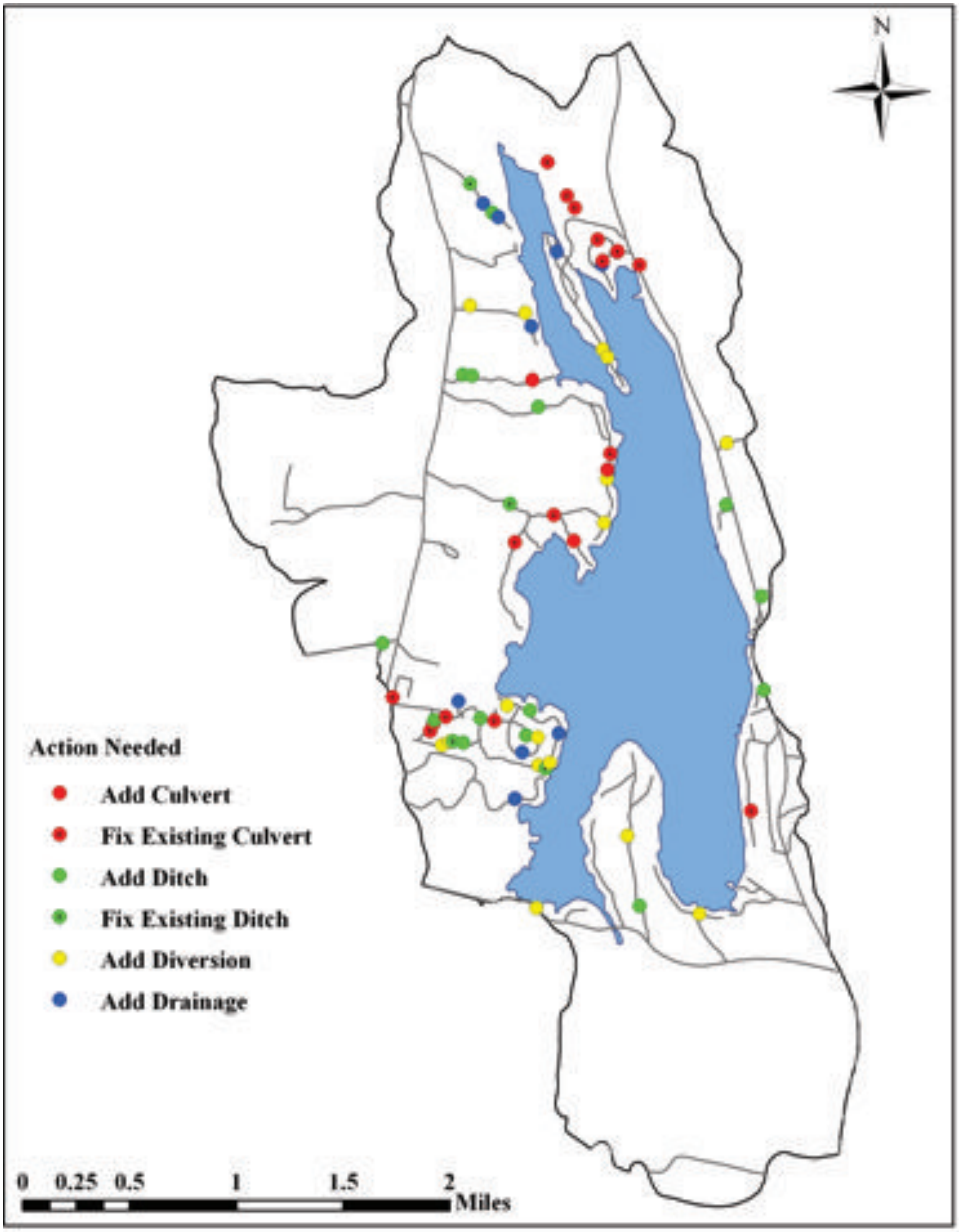

Figure 16. Locations where roads in the Long Pond North watershed need improvement and the specific actions necessary. Information was obtained from the road problem survey completed on 19-Sep-06.

1 Estates

Problem(s): Berms exist on both sides of the road, the ditch is too shallow to handle water flow, there is no drainage area for the water coming out of the ditches, and the culvert is filled with sediment.

Remediation: Grade the road to remove the berms, reshape ditch to make it deeper, install turnouts to pull water away from the road and into drainage areas and clear culvert of sediment and debris.

Ash Estates

Problem(s): Road has tire ruts and overall poor drainage.

Remediation: Grade the road to remove ruts and install proper crown to remove water from the road area.

Aspen Estates

Problem(s): The ditch on the left side of the road is too shallow and there are potholes present in the road.

Remediation: Reshape the ditch for depth, grade the road to remove potholes, and mix soil sediment size.

Augusta Road

Problem(s): One of the culverts drains directly into the lake.

Remediation: Install a diversion into a buffered drainage area so water does not directly drain into the lake.

Balsam Road

Problem(s): There are potholes in the road indicating erosion and standing water.

Remediation: Grade the road and install a proper crown.

Barber and Quaglia

Problem(s): There are berms present along the road, preventing the removal of water.

Remediation: Grade the road, install a proper crown, and create turnouts for water to be directed into a drainage area.

Beaver Brook

Problem(s): There is no ditch on the north side of the road, there is erosion above the culvert, and there are areas where water is flowing across the road.

Remediation: Install a ditch to remove water from the road, replace existing culvert so it is of proper size and sufficiently covered by the road, and install culverts where the water is flowing over the road.

Birch Estates

Problem(s): There are several pot-holes present, and places where the road has eroded and culverts are not covered by sufficient road surface.

Remediation: Grade road to fill in potholes and add road materials to areas where culverts are exposed so they are sufficiently covered.

Birch Lane

Problem(s): Water is not being removed from the road properly and the edges of the road edges are being washed away.

Remediation: Proper ditches need to be installed with diversions and turnouts to redirect water away from the road and into drainage areas.

Blackberry Estates

Problem(s): There is water washing over the road.

Remediation: Install a culvert to safely divert the water under the road.

Blueberry Hill

Problem(s): There is little ditching along the sides of the road and there are berms preventing water from running off the road.

Remediation: Install proper ditches along the roadsides with sufficient turnouts, and grade road to remove berms.

Castle Island Camp

Problem(s): There is asphalt that is eroding into the South Basin.

Remediation: Plant vegetation to slow soil erosion.

Castle Island Road

Problem(s): There is water running off the bridge into the lake.

Remediation: Plant vegetation to slow runoff and possibly create diversions to pull water into buffered drainage areas.

Colonel Bogart's Lane

Problem(s): There are berms present along the side of the road and ditches run straight downhill towards the lake.

Remediation: Grade the road to remove the berms and install turnouts to divert water into buffered areas.

Fawn Point

Problem(s): There is water running down the road directly into the lake. Ditches and culverts are filled with sediment and debris.

Remediation: Install diversions to redirect water off the road and clear the ditches and culverts of sediment and debris.

Fir Estates

Problem(s): There is evidence of standing water on the road surface.

Remediation: Grade the road to install a proper crown and create sufficient ditching along the road.

Granite Estates

Problem(s): There are berms present along the road, the ditches are filled with debris, and there is evidence of water running across the road.

Remediation: Grade the road to remove berms, clear the ditches of sediment and debris, and install culverts where there is evidence of water running across the road.

Hemlock Estates

Problem(s): The road is not properly crowned, there is no ditch on one side of the road, and there are berms on the other side of the road. The culverts are also exposed and filled with sediment and debris.

Remediation: Grade the road to remove berms and install a proper crown. Also, cover culverts with road material so they are not exposed and clear them of sediment and debris.

Jorgenson Estates

Problem(s): The culvert is filled in with sediment and there is evidence of erosion from standing water on the road. Parts of the road indicate water flowing over the road surface.

Remediation: Grade the road to create a proper crown, install culverts where water is passing over the road and remove sediment and debris from existing culverts.

Juniper Circle

Problem(s): There are berms on both sides of the road and there are ruts from channeled water during strong storms.

Remediation: Grade the road to remove berms, improve crown, and install diversions on the steep part of the road to redirect water into drainage areas away from the road.

Lakeshore Drive

Problem(s): The culvert is completely filled in with sediment and debris.

Remediation: Clear culvert of sediment and debris.

Long Lake Lane

Problem(s): There is evidence of improper drainage on the road surface.

Remediation: Grade the road to install a proper crown.

Long Pond Drive

Problem(s): Road is very close to the lake and water can drain directly into the lake from the road.

Remediation: Ditches must be installed with proper turnouts to divert water into buffered drainage area.

Long Pond Estates

Problem(s): There are several culverts that are too close to the surface of the road.

Remediation: Cover the culverts with road materials to sufficiently cover the top of the culverts.

Low's Drive

Problem(s): There are tire ruts present in the road.

Remediation: Grade the road to remove the ruts and install a proper crown.

Lynch Cove

Problem(s): There is a paved driveway that drains directly into the lake.

Remediation: Diversions need to be installed to remove water from the driveway before it directly enters the lake.

Mountain Road

Problem(s): The steep part of the road has water channels running down the middle of the road, and the culvert at the top of the road is filled with sediment.

Remediation: Install diversions to remove water from the road surface and clear the culverts of sediment and debris.

North Peninsula Drive

Problem(s): There are berms on either side of the dirt section of the road, the steep part of the road has channels indicating erosion, and the end of the road is very close to the lake.

Remediation: Grade the road to remove the berms, install diversions to remove water from the surface of the steep part of the road, and install a diversion where the road is close to the lake so it does not drain directly into it.

Poplar Estates

Problem(s): There are berms on either side of the road.

Remediation: Grade the road to remove berms so water can exit the road surface.

Raspberry Estates

Problem(s): The road shows signs of erosion due to improper drainage, and culverts are clogged with sediment and debris.

Remediation: Grade the road to install a proper crown on the road and clear the culverts of sediment and debris.

Spruce Estates

Problem(s): The road is steep in some areas and channels are present, the road contains ruts, and the road sides are eroding into the ditch.

Remediation: Install diversions in the steep part of the road, grade the road to remove ruts, create a proper crown, and reshape ditches to carry water along the road side with turnouts into surrounding vegetation.

Tracy Cove

Problem(s): There are berms on the side of the road and the culverts are rusting and filled with debris.

Remediation: Grade the road to remove berms, install new culverts where there is excessive rusting, and clear culverts of sediment and debris.

Wildflower Estates

Problem(s): There is a significant amount of soil erosion on the road.

Remediation: Grade the road to create a proper crown and install ditches to move water away from the road.

Wildwood Estates

Problem(s): There is erosion on the road, ditches are not present or are improperly formed, and culverts are clogged.

Remediation: Grade the road to create a crown, install ditches, and clear culverts of sediment and debris.

RESIDENTIAL SURVEY

House Count

Introduction

CEAT completed a residential survey to determine the impact of development on the water quality of Long Pond North, specifically in the sensitive shoreline regions. Development affects the watershed by clearing land and contributing nutrients to the water through wastewater disposal systems and fertilizer runoff, while roads and paved surfaces increase runoff and change the drainage pattern. Houses located on the shoreline have a more significant impact on water quality than non-shoreline houses, due to their proximity to the lake. Whether a house is used seasonally or year-round influences the phosphorus loading from septic systems and household use. Year-round residences have a larger impact than those that are seasonal because the septic system is used continuously, rather than for one season. However, seasonal residences affect the watershed during the summer months, when the lake is most sensitive to problems like algal blooms.

Methods

The non-shoreline residences were counted during the road survey completed 14-Sep-2006. CEAT members cataloged the number of houses 250 ft or more from the waterline by driving each road in the watershed (see Appendix G. Road Survey Form). Shoreline houses, which are difficult to count accurately from the road, were counted by boat during the buffer strip survey completed 18-Sep-2006 (Appendix I. Buffer Survey Form). All houses were classified as seasonal or year-round based on general characteristics.

Distinguishing between seasonal and year-round houses is increasingly difficult, as more modern seasonal houses are built and updated to resemble year-round homes in size and amenities such as fireplaces and furnaces. For the purpose of consistent identification, houses with a permanent foundation, a heat source such as a woodpile or an oil tank, and a paved driveway were considered year-round residences. Some recent seasonal residences were likely to be mislabeled as year-round, as they are built with more amenities. While these criteria are not absolute, they do provide a structure for later calculations that help establish the impact of development on water quality.

Results and Discussion

In the Long Pond North watershed, CEAT counted a total of 479 residences (Table 7). Two hundred sixty seven (55.7 percent) of the residences counted are located in the high impact shoreline area. The shoreline residences include 137 (51.3 percent) seasonal and 130 (48.7 percent) year-round houses. There are 212 (44.3 percent) non-shoreline residences, divided into 56 (26.4 percent) seasonal and 156 (73.6 percent) year-round homes. Of the total residences counted, 193 (40.3 percent) are seasonal and 286 (59.7 percent) are year-round. Other building types include commercial camps and shops, but these represent a small fraction of the land use within the watershed.

Table 7. House count data for Long Pond North, gathered by shoreline survey 19-Sep-06 and road survey 14-Sep-06.

Location	Seasonal	Year Round	Total
Shoreline	137	130	267
Non-shoreline	56	156	212
Total	193	286	479

The greatest impact on water quality is derived from shoreline houses, which represented 56 percent of the total residences. Shoreline residences were evenly distributed between seasonal and year-round usage, which indicates higher phosphorus loading from septic systems throughout the year as compared to locations with heavily seasonal populations. Additionally, development trends show that many owners are updating their seasonal houses to support year-round use (Keschl, pers. comm.). This construction has two opposing effects. Updating a house for year-round use subjects it to new legislation, reducing impact on the lake. Simultaneously, year-round use increases phosphorus amounts entering the lake. The net effect of the conversion from existing seasonal to year-round residences increases the impact of the structures.

Shoreline residences are fairly evenly spaced along the developed waterline of the lake, however there are several undeveloped areas along the perimeter. The houses are spaced at a density of 17.5 houses per shoreline mile along the 15.29 mi perimeter of Long Pond North. This residential density is similar to other local lakes (Table 8), but is artificially lowered in Long Pond North by the presence of some wooded areas and no visible development along substantial stretches of shoreline. Removing these undeveloped areas from the perimeter increases the houses per shoreline mile value to 26.6, indicating high development density in many areas along the shoreline.

Table 8. Residential density, shown in houses per shoreline mile, for selected Maine lakes (CEAT 2003, 2004, 2005, 2006).

Lake	Residential Density
Webber Pond	16.6
East Basin of China Lake	30.2
Threemile Pond	20.5
Togus Pond	17.9
Long Pond North	17.5
Only the developed areas	26.6

Non-shoreline houses represent 44.3 percent of the residences in the Long Pond North watershed. The majority are year-round houses (73.6 percent). The phosphorus loading from these houses will depend heavily on the soil type and other septic suitability factors. As a growing population places developmental pressure on the watershed, more of the presently seasonal houses will be modified for year-round residents. Seasonal to year-round conversion will occur particularly in the non-shoreline watershed, where year-round homes are more prevalent and in higher economic demand (Keschl, pers. comm.).

Buffer Strips

Introduction

Buildings near the shore have a significant impact on water quality. Cleared vegetation, exposed soil, impervious surfaces, and loss of canopy all contribute to increased erosion, sedimentation, and nutrient runoff into a lake. The Maine Department of Environmental Protection (Maine DEP) describes adequate vegetative buffers as the best management practice for protecting water quality from these sources of degradation (MDEP 2003c). An adequate buffer removes up to 95 percent of sediment and 60 percent of excess nutrients in runoff (Dreher and Murphy 1996). This protects the lake from the immediate impact of residential regions and from non-point sources like roads. Buffers also preserve privacy, provide natural habitat, and shelter properties from severe weather (MDEP 2003c).

An adequate buffer covers at least 75 percent of the shoreline, going back from the waterline as far as possible. More vegetation between a house or road and the shoreline offers more filtration, and an ideal lot has 65 ft of dense natural vegetation between any clearing and the lake. Since steep slopes are more susceptible to erosion, they require more buffer depth (MDEP 1998). The best buffers contain a mix of ground cover, shrubs, and canopy species and consist mostly of native vegetation (MDEP 2003c). The buffer should have a layer of organic matter on the ground and a consistent canopy to disperse precipitation, thus protecting the soil from erosion (MDEP 1998). Native species are preferred because they require less maintenance, and extend the natural habitat (Figure 17). Finally, the shoreline should be protected with riprap, which attenuates the impact of water against the shore, preventing water from gradually eroding soil.

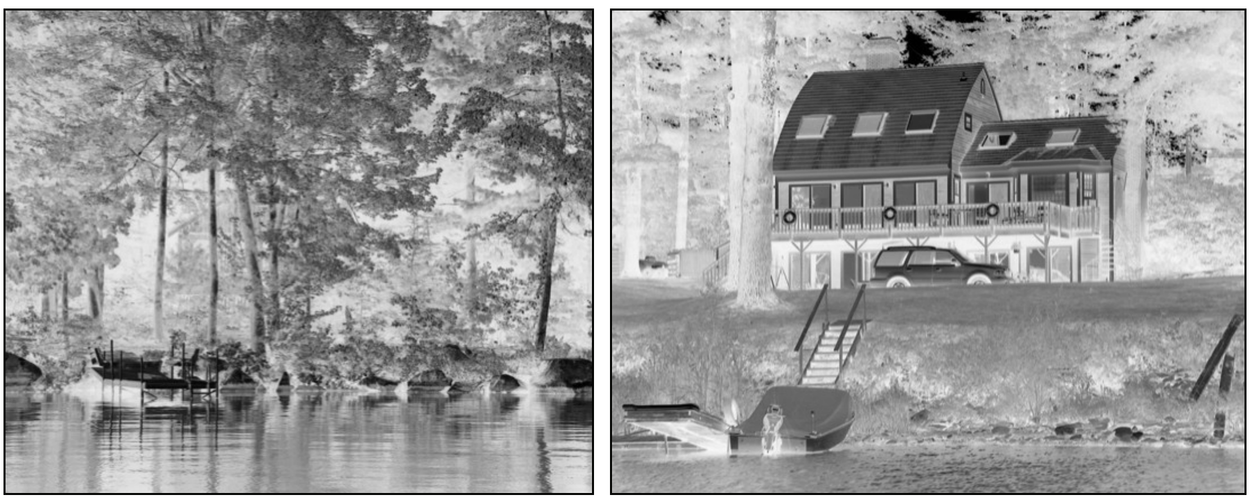

Figure 17. Buffer examples. Photo on left shows a good, adequate buffer. The house is set back from the water, vegetation includes shrub and canopy species, shoreline is protected with riprap. Photo on right shows a poor buffer, with open canopy, mowed grass, a straight path to the water, and little protective vegetation.

Methods

CEAT categorized each property's buffer condition during a shoreline survey conducted by boat on 18-Sep-2006. Residences were evaluated for approximate lot width along the shoreline, percentage of shoreline covered with buffer, composition of buffer, and depth from the shoreline. Additionally, slope of the property toward the water and need for riprap were both considered. The data were recorded in categories based on a numerical value for each characteristic (Appendix I). Each residence was identified as seasonal or year-round and marked by a GPS location for use in mapping software. Areas possessing no visible shoreline development were recorded as wooded areas and GPS locations were taken to mark the start and end of each undeveloped shoreline strip.

The data were analyzed by establishing a buffer quality value for each property. The buffer depth and percentage shoreline covered were deemed most significant to the buffer's effectiveness and were each assigned an importance value of 35 percent. The slope, which affects contact time, was assigned an importance value of 20 percent. Buffer composition, which is the sum of the value for trees and shrubs, comprised the remaining 10 percent of the weighted sum. The total scores were between 0 and 5, with 5 being the best possible buffer score. All properties with a buffer quality between 0 and 1 were labeled Poor, 1.01 to 2 were labeled Fair, 2.01 to 3 were labeled Acceptable, 3.01 to 4 were labeled Good, and buffer qualities above 4 were labeled Excellent. These buffer ratings were used to describe the condition of buffers along the shoreline.

Results and Discussion

A total of 283 properties were surveyed, including 267 shoreline residences and 16 commercial properties. Of these properties, 101 (35 percent) are in Excellent condition, 111 (39 percent) are Good, 48 (17 percent) are Acceptable, 21 (7 percent) are Fair and 5 (2 percent) are classified as Poor (Figure 18). The shoreline lot width determines the proportion of Long Pond North's perimeter fit into each buffer category. For this reason, the buffer quality of larger properties is more significant than buffers found on smaller shoreline lots. The distribution of buffer quality categories by shoreline distance indicates this impact (Figure 19). The largest properties have a good general buffer rating, however lots with 120 ft to 180 ft of shoreline have mostly Good buffers and could be improved. Additionally, all of the Poor quality buffers and most of the Fair buffers are found in lots with 60 ft or less of shoreline. These properties become more significant when considering their prevalence. Properties with 60 ft or less of shoreline compose the largest group (42 percent) of properties, and therefore should be a priority for improvement. Several poor quality buffers are located in the Castle Island camps in the southernmost portion of Long Pond North, near where the North basin drains into the South basin.

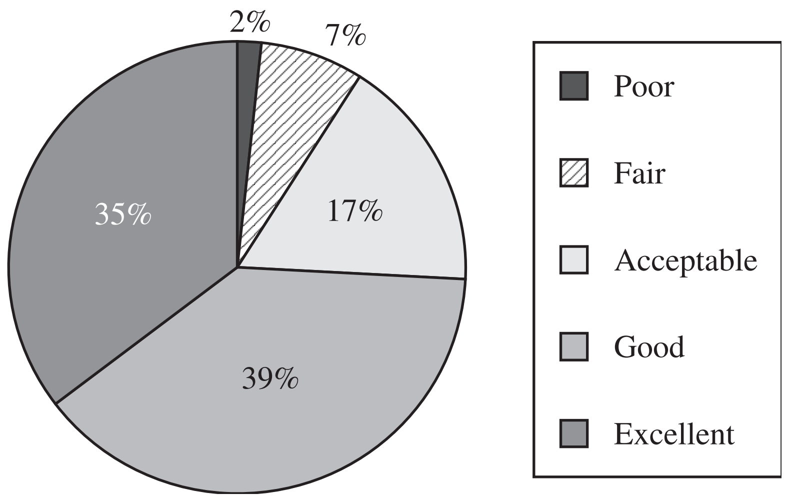

Figure 18. The percentage of properties along the shoreline of Long Pond North, displayed by buffer quality category, from data collected 18-Sep-06.

The properties were color coded by buffer quality and mapped in GIS (Figure 20). Adequate buffers were given smaller points indicating the properties' reduced impact on the watershed, and properties with a more harmful effect on water quality were displayed as larger points.

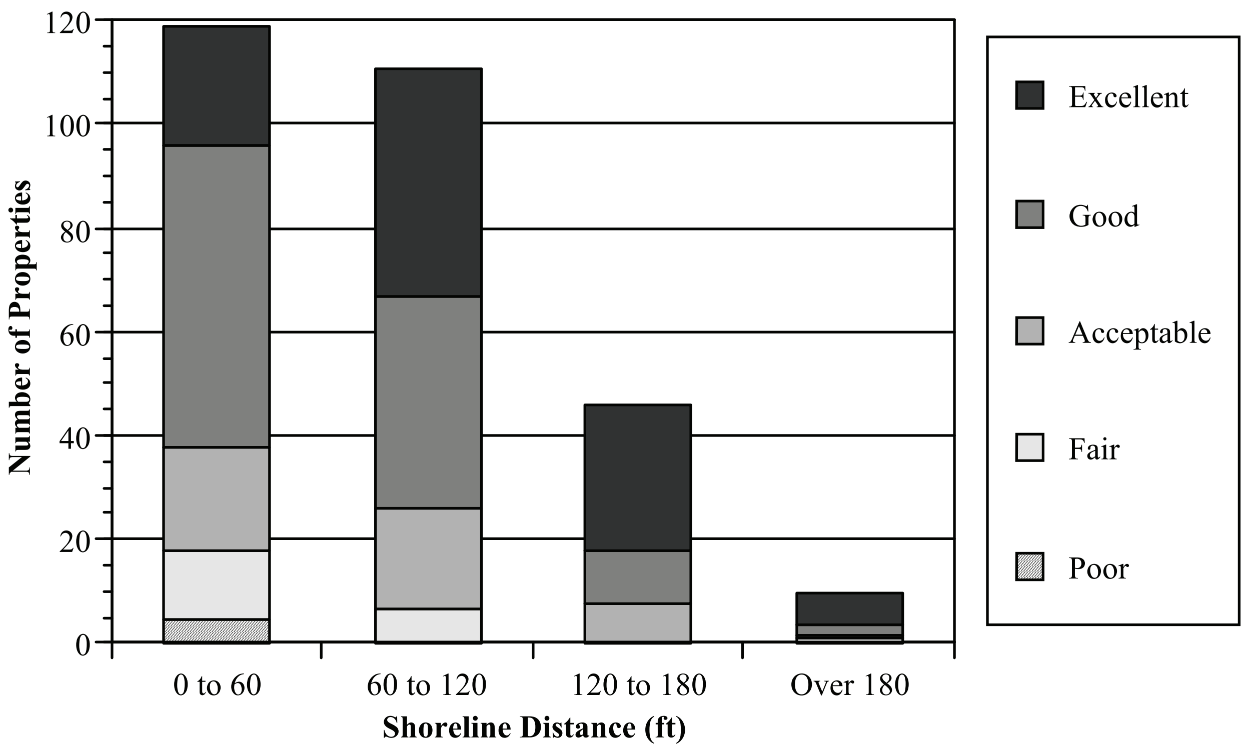

Figure 19. The distribution of properties along the shoreline of Long Pond North in buffer quality categories by lot size. Larger lots have an increased impact on water quality.

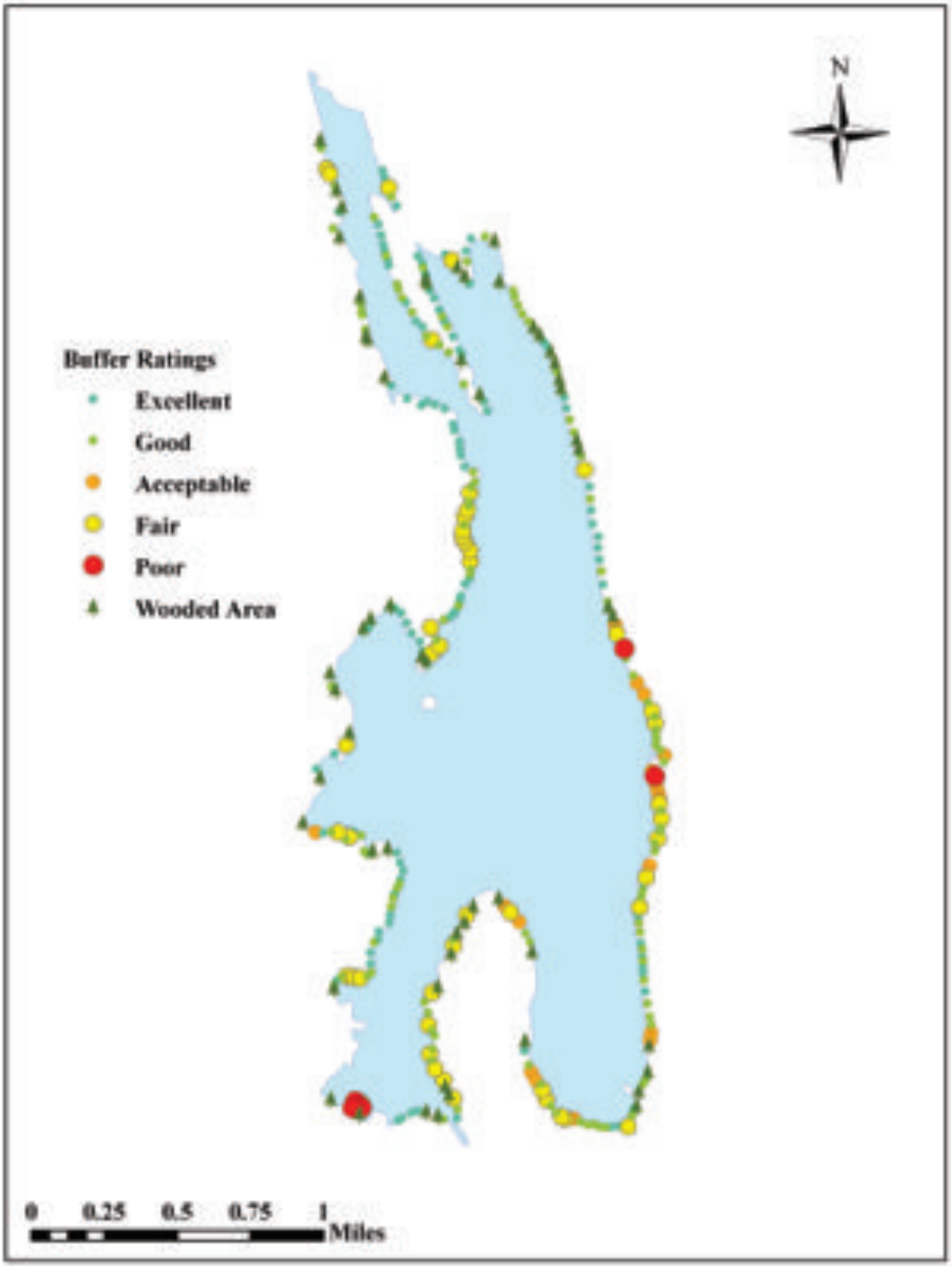

Figure 20. Shoreline residences and forested shoreline on Long Pond North, color-coded by buffer quality. Data from surveys completed on 18-Sep-06.

Subsurface Disposal Systems

Introduction

There are three primary types of subsurface wastewater disposal systems, and all three are found in the Long Pond North watershed. The most common wastewater system is a septic system, in which all wastewater from the house is deposited in a tank. Here effluvia settles and is processed by bacteria. The processed water flows out to a leach field where it is gradually released back into the ground through perforated pipes (see Background: Subsurface Wastewater Disposal Systems). Another type of wastewater disposal system is a holding tank, where waste flows into a solid tank, typically underground, that must be emptied regularly by pumping. The last primary type of wastewater disposal is a pit privy, or outhouse. A pit privy consists of a deep hole where waste is deposited and decomposes. All of these wastewater systems are maintained by the owners of the property, but are regulated by local government and state policies (MDEP 2003b).

Septic tanks and holding tanks both adversely affect the environment when improperly maintained. To prevent this, holding tanks must be pumped regularly. When properly maintained holding tanks have minimal direct environmental impact, because all waste is removed to a separate location for processing. Because the tanks do not process the waste, but are simply reservoirs, they must be checked for leaks or external damage, which could release effluent into the groundwater. Septic tanks are a more common choice for year-round or frequent use, since they need to be pumped and cleaned only once every 3 to 5 years to remove solid waste undigested by bacteria in the system. If a septic system is not pumped and maintained appropriately, then wastewater does not have sufficient time to settle before being released through the leach field and into the ground. Improperly functioning septic tanks can pollute the watershed similarly to leaking holding tanks, and this is particularly harmful near the shoreline.
Properly functioning septic systems still increase the amount of nutrients flowing into the lake, though if septic systems are well maintained they have little adverse effect on water quality (MDEP 2003d). Septic systems are designed to release processed water for absorption into the groundwater. Wastewater is particularly high in phosphorus and nitrogen, and systems located near the shoreline have less soil and plant material through which the wastewater can filter before entering the lake. Shoreline zoning mandates a setback for septic systems, but very porous

soils and inadequate vegetative buffers allow nutrient-rich water to enter the lake from even perfectly maintained septic systems (MDEP 1998, MDEP 2003d).

Methods

The impact of wastewater disposal systems on the water quality of Long Pond North was examined in terms of number of houses, density of development along the shoreline, and condition of the septic systems in the watershed. The Long Pond North watershed and shoreline is located within the townships of Belgrade and Rome. Rome encompasses most of the shoreline. The code enforcement officers (CEOs) from both towns are responsible for all subsurface wastewater disposal and plumbing systems. The CEOs were able to generalize the overall condition of septic systems in the watershed. The town managers for both Rome and Belgrade were consulted for information about shoreline development trends. These interviews served as the basis for establishing septic impact on the watershed.

Results and Discussion

Shoreline residences are dispersed over a shoreline of 15.29 mi, which yields a total residential density of 17.5 houses per shoreline mile. The low shoreline residential density suggests that external phosphorus loading from septic systems will not be as significant a contributor to Long Pond North water quality, as compared to other lakes in the area. However, there are many undeveloped lots in the watershed that are surveyed and approved by the Rome planning board, and if development occurs in those existing lots, residential density will increase dramatically and associated phosphorus loading will significantly damage water quality (Najpauer, pers. comm.).

Shoreline zoning mandates that whenever a wastewater disposal system fails, it must be replaced and updated using the best management practices, which includes a setback from the shoreline to reduce the immediacy of nutrient loading. Typically, these systems are designed to last 20 or 30 years before the ground filtering capacity is compromised, but they may not mechanically fail until after their filtering efficacy has been diminished. Many residences installed updated septic systems as part of new construction, but the existing wastewater disposal practices still vary anywhere from pit privies to holding tanks and septic systems (Fuller, pers. comm.). Presently, there is no legislative pressure to standardize the quality of systems in the watershed. Fortunately, the general condition of the septic systems within the watershed is good.

Wastewater is adequately processed or removed and new septic systems are following the guidelines for environmentally safer installation and utilization (Fuller, pers. comm.).

The Long Pond North watershed is relatively healthy, as evidenced by its current water quality. This trend suggests that Long Pond North will not need to engage in aggressive water improvement methods, such as the septic system remediation program employed by towns on China Lake, as long as the watershed maintains a low residential density and no large-scale developments significantly increase the phosphorus loading. The rising number of year-round residences on the lake, mostly from converting existing seasonal homes, indicates a development trend that could continue to increase pressure on the Long Pond North watershed and may result in deteriorating water quality (Keschl, pers. comm.).

Septic Suitability Model

Introduction

The best way to process septic system effluent is to allow it to slowly leach through appropriate soils. Soil texture and the underlying bedrock both play a role in filtering and processing. Coarse soil, such as sand, drains quickly and does not allow sufficient time for the appropriate biological processing to occur. If the soil is fine, such as clay, it will be almost impermeable and the effluent will run off rather than percolate in and it will not be broken down. Depth to bedrock, water table depth, and the overall likeliness of flooding are also important to consider. If the bedrock is shallow and the water table is high, then the effluent will reach the lake faster.

Slope is the other main factor in determining if an area is suitable for a septic system. High slopes encourage erosion and runoff, both of which lead to effluent rich soil deposition in the lake. As a general rule, septic systems should not be developed on slopes greater than 20 percent (KCSWCD 1990).

To construct a model for Long Pond North showing areas suitable for septic system installation, slope and soil type were combined into a model that weighted both attributes. It is important to note that this model does not account for remediation such as importing better soil, or grading down the slope. The results report only the suitability of a site in its present state, without modifications.

Methods

The soil type map was obtained from the Maine Office of GIS (Figure 21). The resolution of the layer is 10 m by 10 m and includes over 20 soil types. The Kennebec County Soil and Water Conservation District has linked soil types to a relative index of potential for septic construction using Very High, High, Medium, Low, and Very Low as labels (KCSWCD 1990). These categories were assigned respective values of 9, 7, 5, 3, and 1. The indices assigned by KCSWCD took into account permeability, average depth to bedrock, erodibility, nutrient holding capacity, and slope classes. Because the slope classes used on the soils map were classified in wide ranges in comparison to slope data available from the MEGIS, only the septic potential ratings for 0 percent slope were used. For example, if a parcel of "Lyman Loam, 8-15 percent" was in question, the value assigned would be the index given for "Lyman Loam, 0 percent". This allowed more precise slope data to be integrated into the map. The soil index contributed 50 percent of the weighted model.

Slope was obtained from a Digital Elevation Model (DEM) of the watershed from Maine Office of GIS. The DEM is a raster of 10 m by 10 m cells with elevation data. ArcGIS converted that to an identically sized raster displaying slope values. The slopes, possessing values ranging from 0 to 45 percent, were converted into an index of 1 to 9. Cost of construction increases from a base cost at 0 to 3 percent slope, and continues to rise until eventually construction becomes restricted at 30 percent slope.

Results and Discussion

By combining the indexed soil and slope data, CEAT was able to create a septic suitability model for Long Pond North's watershed (Figure 22). This map displays a value of 1 to 9 for every 10 m by 10 m plot of land in the Long Pond North watershed. Most of the watershed is ranked in the 4 to 7 range. A score of seven was assigned to areas most suitable for septic systems, even though an area could theoretically score a 9. Areas with values of 1 to 3 have a combination of soils and slopes that make poor sites for septic systems. Areas in the 5 to 7 range are ideal sites to install new systems. Areas in the middle ranges could house septic systems, but only with remediation such as amending the soil or leveling out a steep area. It is important to note that although some houses may appear to be on land that is "low," they may have taken steps to remediate their situation. Existing septic systems in areas without remediation that

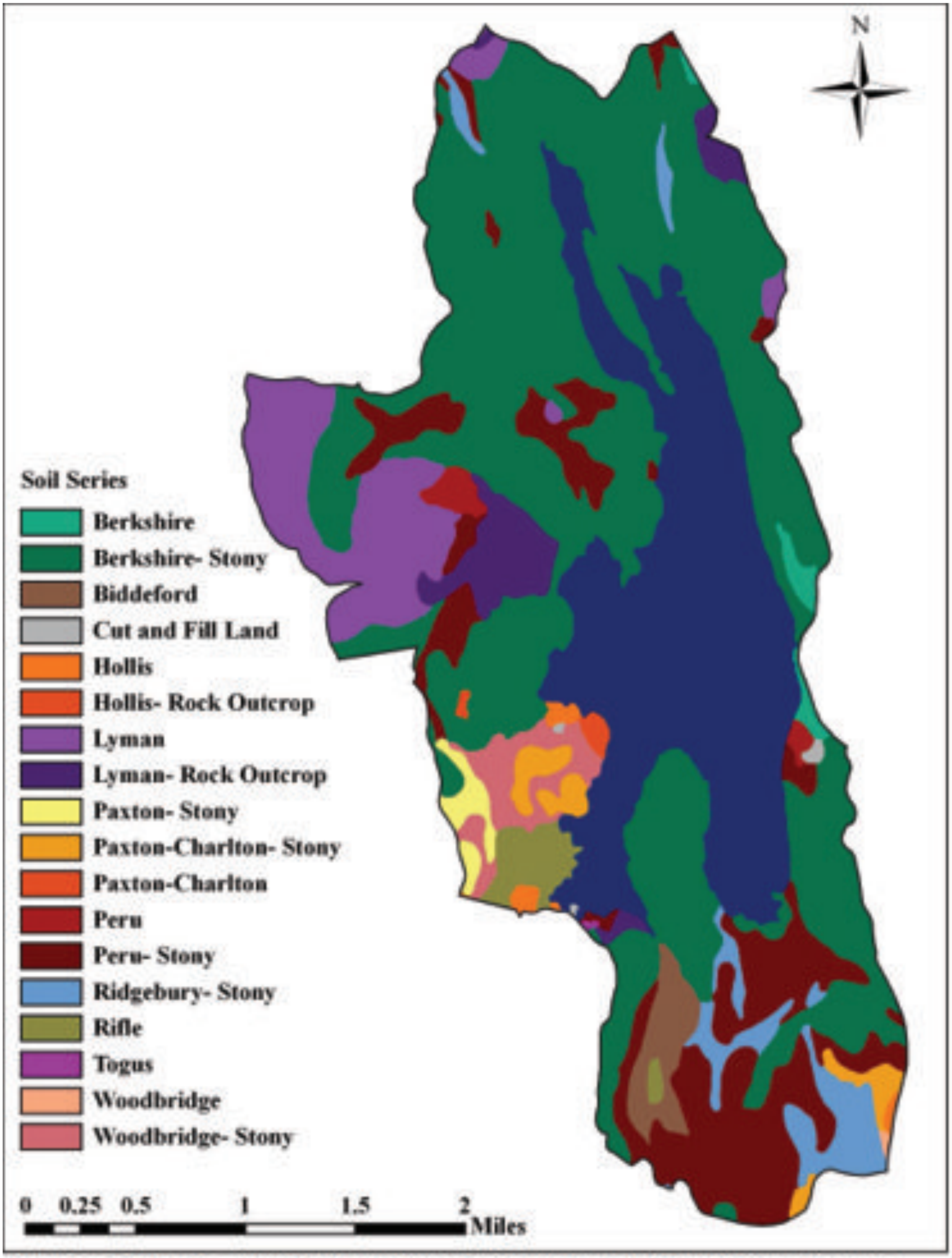

Figure 21. Soil series map of the Long Pond North watershed. Data obtained from the Maine Office of GIS (MEGIS 2006).

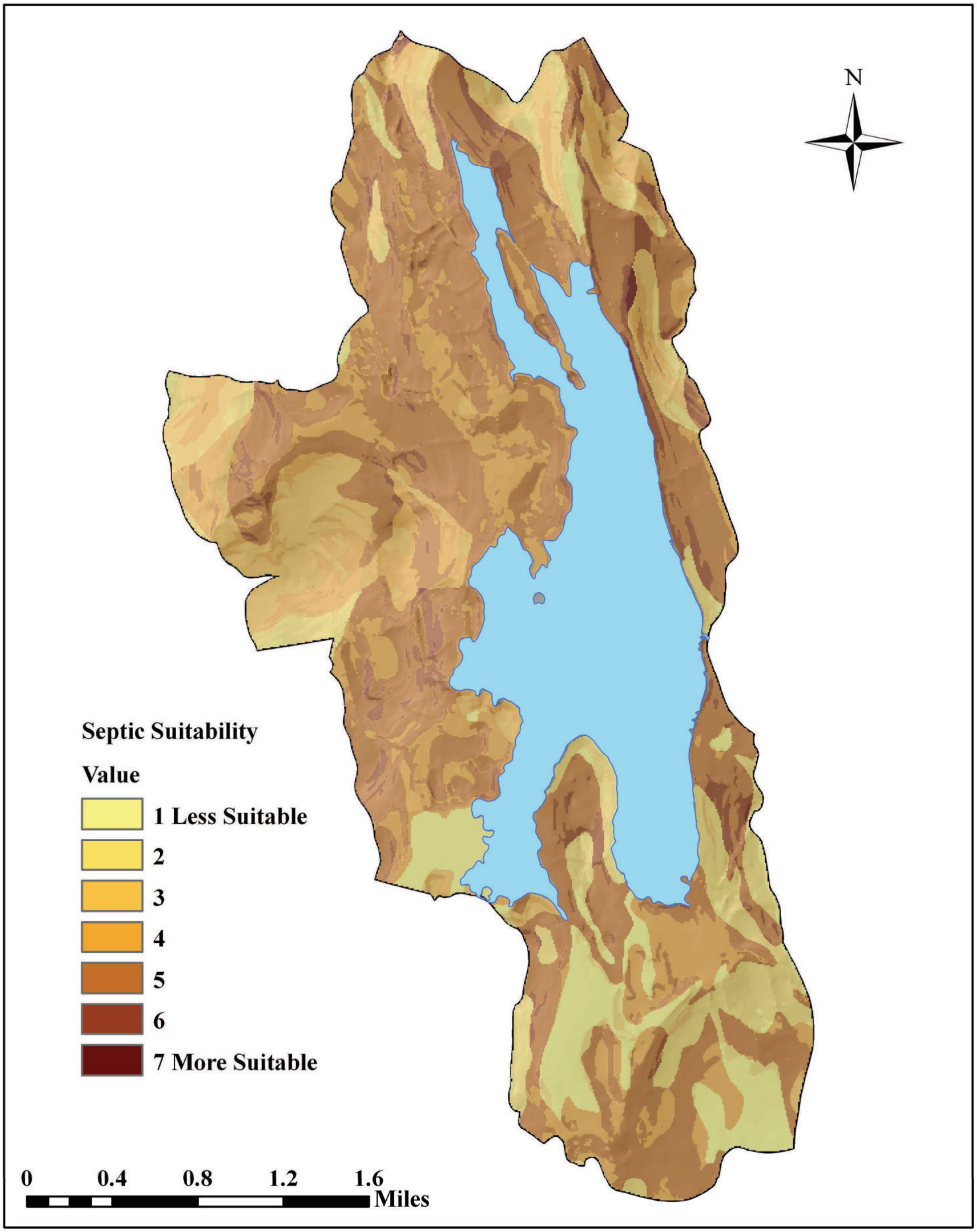

Figure 22. A model showing septic suitability of the Long Pond North watershed which combines soil suitability and slope into an index of 1 (low suitability) through 7 (highly suitable). The index is based on soil type and degree of slope.

appear unsuitable may require close monitoring to ensure no effluent is flowing into the lake, directly or indirectly.

EROSION POTENTIAL MODEL

Introduction

Soil erosion occurs when soil particles are transported away from their original location by water running over the surface of the land. Exposed soil is easily washed away, and some erosion hotspots include construction sites, road banks or ditches, and dirt paths. Erosion leads to sedimentation and nutrient loading in lake systems, both of which can adversely affect the water quality of Long Pond North. Sedimentation occurs when eroded soil is deposited and accumulates elsewhere. This causes problems by reducing the capacity of streams and drainage ditches, thereby increasing the risk of flooding. Nutrient loading refers to the introduction of nutrients such as phosphorus and nitrogen to a water body. Because soils contain naturally occurring nutrients, as well as possible residue from fertilizers, erosion contributes to nutrient loading (see Background: Nutrient Loading). The nutrients deposited in Long Pond North through soil erosion may prove damaging to water quality by promoting undesirable algal growth. In addition, eroded soil may contain traces of herbicides and pesticides, which could harm many aquatic species inhabiting Long Pond North.

There are three main factors that contribute to the susceptibility of any particular region to soil erosion: soil type, slope, and land use. By examining these factors, a model can be developed to predict which parts of the Long Pond North watershed have the greatest erosion potential.

The most important factor affecting erosion potential is soil type. Soil characteristics such as texture, cohesiveness, infiltration capacity, and organic content all contribute to how easily a particular soil type may be eroded (Morgan 2005). Silty soils erode very easily as a result of their small particle sizes, whereas soils with a high percentage of clay and organic matter are more resistant to erosion because they form stable aggregates. (Morgan 2005).

Slope is also an important determinant of erosion potential. If a slope is particularly steep, water will not have enough time to percolate into the soil, and some will instead flow downhill, carrying soil particles with it. As the water flows downhill it gains velocity, and gravity assists in pulling both water and soil downward along the slope. In flat areas, there is less movement of water and consequently less erosion.

Land use can also affect the erosion potential of an area. In many agricultural areas, soil is loosened by plowing and left bare during certain times of the year, making it highly erodible. In a mature forest, however, soil is held in place by the complex root systems of the trees and shrubs, which also help to absorb excess water. Forested areas with well established vegetation cover will thus have very little erosion (see Background: Land-Use Types).

Methods

Soils

To determine the locations of the soil types occurring within the Long Pond North watershed, a soil type layer was downloaded from the Maine Office of GIS for use in ArcGIS® 9.1 (Figure 21). The erosion potential factor (k-factor) for each soil type was obtained from Web Soil Survey, an online resource published by the National Resources Conservation Service (NRCS). The k-factor provides an indication of the susceptibility of each soil type to sheet and rill erosion, and is determined primarily by the relative percentages of sand, silt, and organic matter in the soil, as well as by the soil structure (NRCS 2006). K-factor values range from 0 (low susceptibility to erosion) to 0.69 (high susceptibility to erosion) (NRCS 2006). In the Long Pond North watershed, the soil types are all closely related and have similar k-factors, only ranging from 0 to 0.28.

To make these values easier to interpret and use in the erosion potential model, the k-factors were converted from a range of 0 to 0.69 to a range of 1 to 9 using the following formula:

Soil Erosion Potential Rating = 11.6 x k + 1

Multiplying the k-factor by 11.6 converts the k-factor values to a scale of 0 to 8, and adding 1 shifts the scale to 1 to 9. On this scale, the lowest erosion potential rating in the Long Pond North watershed is 1, and the highest is 4.25. The erosion potential rating for each soil type was added to the attribute table of the soil type map in ArcGIS®.

Slope

Slope data for the Long Pond North watershed was obtained by downloading a Digital Elevation Model (DEM) from the Maine Office of GIS. The DEM consists of a grid of 10 m x10 m squares, each of which has a specific value for elevation. These values were converted into slope values using the Spatial Analyst™ software in ArcGIS®. In the Long Pond North watershed, the slope values range from 0 to 45.3 percent. These slope values were reclassified in ArcGIS® to erosion potential ratings ranging from 1 to 9, with each number representing 1/9th of the total slope range in the watershed.

Land Use

A land-use coverage for the Long Pond North watershed was obtained from the Land-Use team (see Land Use: Methods). Each land-use type was assigned an erosion potential rating on a scale of 0 (low potential) to 9 (high potential) (Table 9). These numbers were determined by considering potential disturbances to the soil and factors that might attenuate runoff.

Table 9. Erosion Potential ratings assigned to each of the land-use types found in the Long Pond North watershed. Values of 0 and 9 represent with very low and very high risks of erosion, respectively. These values were incorporated into the GIS model as 30 percent of the total erosion potential.

Land-Use Category	Erosion Potential Rating
Wetland	0
Mature Forest	1
Commercial	2
Regenerating Land	3
Golf Course	5
Park	6
Cleared Land	7
Agriculture	8
Residential	9

Wetlands were assigned an erosion potential rating of 0. In a healthy wetland, a diverse array of plant species retards water flow, allowing sediments to settle to the bottom. Wetlands thus serve as sediment sinks, and reduce rather than contribute to the erosion problem.

Mature forests were given an erosion potential rating of 1. In a forest, both the canopy and understory vegetation shield soil from the impact of rainfall, which can dislodge soil particles. The complex root systems of trees and shrubs further reduce erosion by stabilizing soil and absorbing excess water.

Commercial land was given an erosion potential rating of 2, because such areas are generally heavily paved and thus have very little soil that can be eroded, although surface sediment is easily carried away.

Regenerating land received an erosion potential rating of 3, because although it lacks the dense vegetation cover or complex root systems of a mature forest, there is still enough vegetation that the risk of erosion is minimal.

Golf courses were rated 5, because the densely planted grass does help stabilize the soil, but there is nothing to slow the fall of rain, and its impact may dislodge soil particles that can then be eroded.

Parks were assigned an erosion potential rating of 6 because they often contain exposed soil along dirt paths and open areas with nothing to break the fall of rain.

Cleared land was assigned an erosion potential rating of 7 because it has limited vegetation to stabilize the soil, which has often been loosened by recent disturbances.

Agricultural land received an erosion potential rating of 8, because grazing and trampling by livestock disturb the soil and facilitate erosion. Also, there is seldom canopy cover to attenuate rainfall and only the limited root systems of grass or crops to stabilize soil.

Residential land is even more susceptible to erosion, earning it a 9, the highest erosion potential rating. Residential areas frequently contain cleared land and thinned vegetation, as well as dirt paths and driveways that can act as channels for runoff and are very easily eroded.

Weighted Overlay

Because soil type is the most important determinant of erosion potential (Morgan 2005), the erosion potential scores were weighted more heavily than slope and land use. In the final weighted overlay, soil type was weighted as 40 percent, and slope and land use were both weighted as 30 percent (Figure 23). The erosion potential map was created by adding the weighted soil type, slope, and land use erosion potential ratings in each 1 m x 1 m grid cell. The new map shows the erosion potential of each area in the Long Pond North watershed on a scale of 1 (low erosion potential) to 6 (high erosion potential).

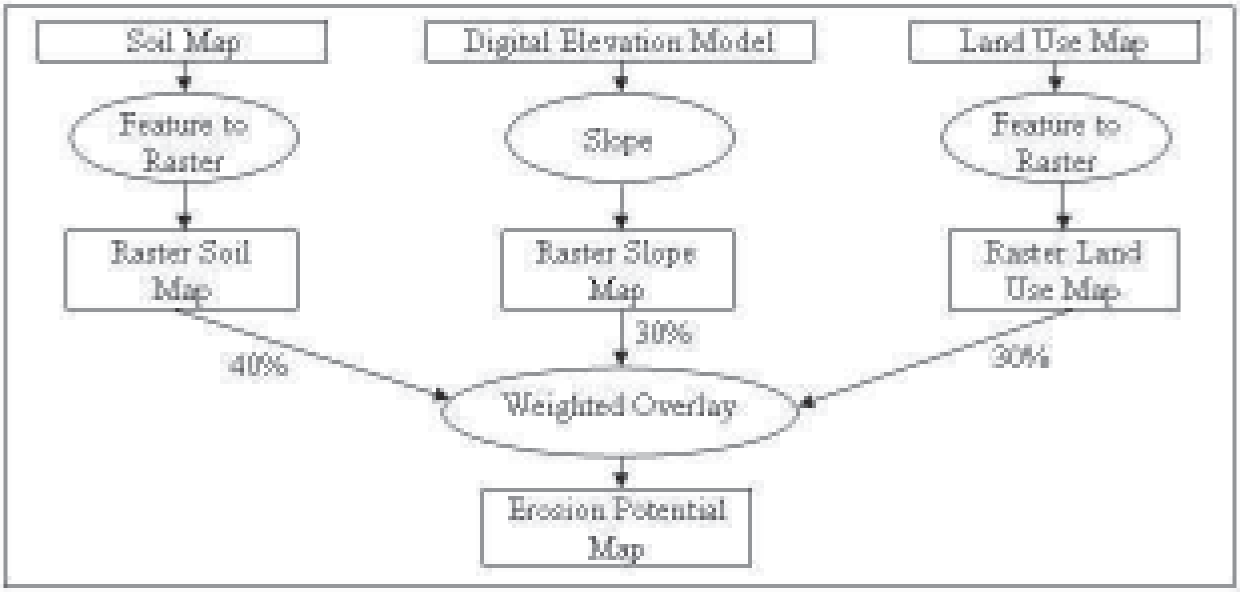

Figure 23. Inputs contributing to the erosion potential model and their relative weights. The three input maps were converted to raster maps in which each 1 m grid cell has an associated erosion potential rating. These values were combined using the weighted overlay function in ArcGIS® 9.1 to determine the erosion potential for the Long Pond North watershed.

Results and Discussion

By combining the erosion potential ratings for soil type, slope, and land use, an erosion potential model was created. The resulting map (Figure 24) shows erosion potential, with areas of low erosion potential represented by light yellow and areas of high erosion potential represented by dark brown. Most of the watershed has a low to moderate erosion potential for two reasons. Firstly, the region is largely covered by mature forest. Secondly, the soil types all have low k-factor values. Areas with a high erosion potential do exist along the eastern shore of Long Pond North, and these correspond to a high instance of residential development or agriculture. Erosion control measures might be necessary in these areas to ensure that little soil washes into the lake.

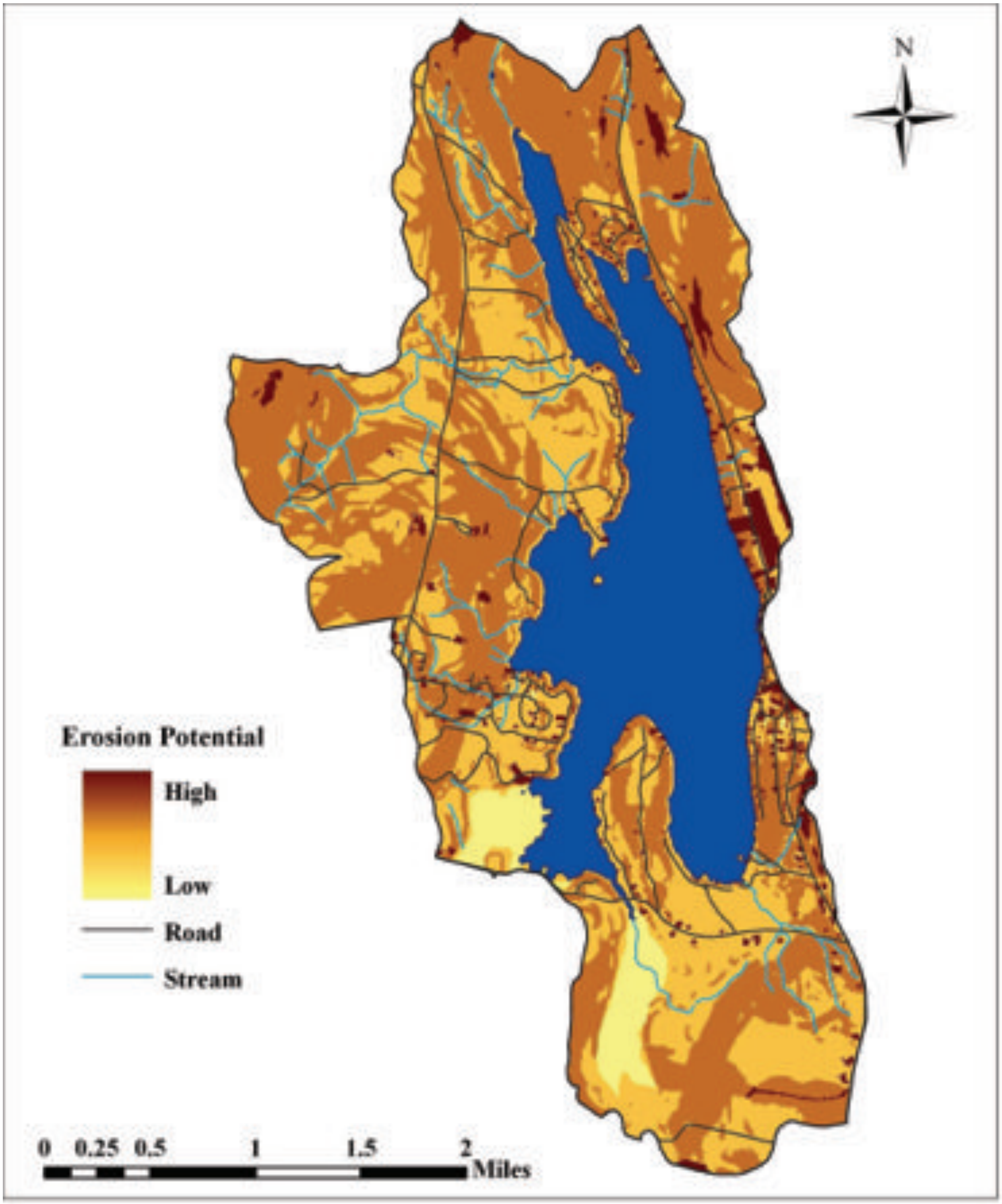

Figure 24. Erosion potential map of the Long Pond North watershed. Erosion potential was calculated by combining the weighted erosion potential ratings for soil type, slope, and land use (see GIS: Erosion Potential Model). Dark brown represents areas that are highly susceptible to erosion, and light yellow indicates areas that are less likely to erode. The streams and roads were obtained from the Maine Office of GIS (MEGIS 2006). The watershed boundary was obtained from the Maine DEP.

EROSION IMPACT MODEL

Introduction

If erosion occurs in an area not adjacent to Long Pond North or one of its tributaries, it is more likely that the moving soil will be stopped by intervening vegetation before reaching the lake. While this does not change the on-site results of soil erosion, it does diminish the effect that erosion occurring far from the lake has on water quality. To highlight the areas where erosion is most likely to impact the water quality of Long Pond North, an impact of erosion model was created. This model combines three factors: erosion potential, proximity to Long Pond North, and proximity to a stream that could carry soil into the lake.

Methods

Erosion Potential

The erosion potential model, which rates an area's susceptibility to erosion on a scale of 1 to 6, was used without modification in the impact of erosion model. An area that is highly susceptible to erosion will have a larger impact on lake water quality than an area with minimal erosion potential, regardless of its distance from Long Pond North.

Proximity Zones

Two different proximity zone maps were created for the Long Pond North watershed. The first indicates proximity to the lake by dividing the watershed into 9 zones. The first zone, which represents the shoreline, is 200 ft wide and was given an erosion impact rating of 9. The remaining area of the watershed was divided into eight equally wide zones, each just over 1000 ft wide. These were assigned erosion impact ratings of 1 to 8, with 8 indicating the zone closest to Long Pond North and 1 indicating the zone farthest from the lake.

The second proximity map indicates areas that are located near streams. A proximity zone of 200 ft on either side of each stream was created, and these were given an erosion impact rating of 8. The remainder of the watershed was given an impact rating of 0, because the erosion impact of this area was already accounted for by the lake proximity map.

Weighted Overlay

For the impact of erosion model, erosion potential, proximity to Long Pond North, and proximity to a stream were weighted as 50 percent, 40 percent, and 10 percent, respectively

(Figure 25). Erosion potential was weighted most heavily because areas that are more susceptible to erosion will have a greater impact on water quality regardless of their distance from the lake. Proximity to Long Pond North was weighted only slightly less, however, because soil eroded near the lake is far more likely to end up in the water than soil eroded in the more distal regions of the watershed. Proximity to a stream was only weighted as 10 percent of the model, because the value for each stream proximity zone was added to the value for the underlying lake proximity zone to account for the distance of each stream section from Long Pond North. Streams do have the potential to carry sediments great distances, especially when swollen with storm runoff, and the high impact rating of stream proximity zones reflects their significant contribution to the impact of erosion on water quality.

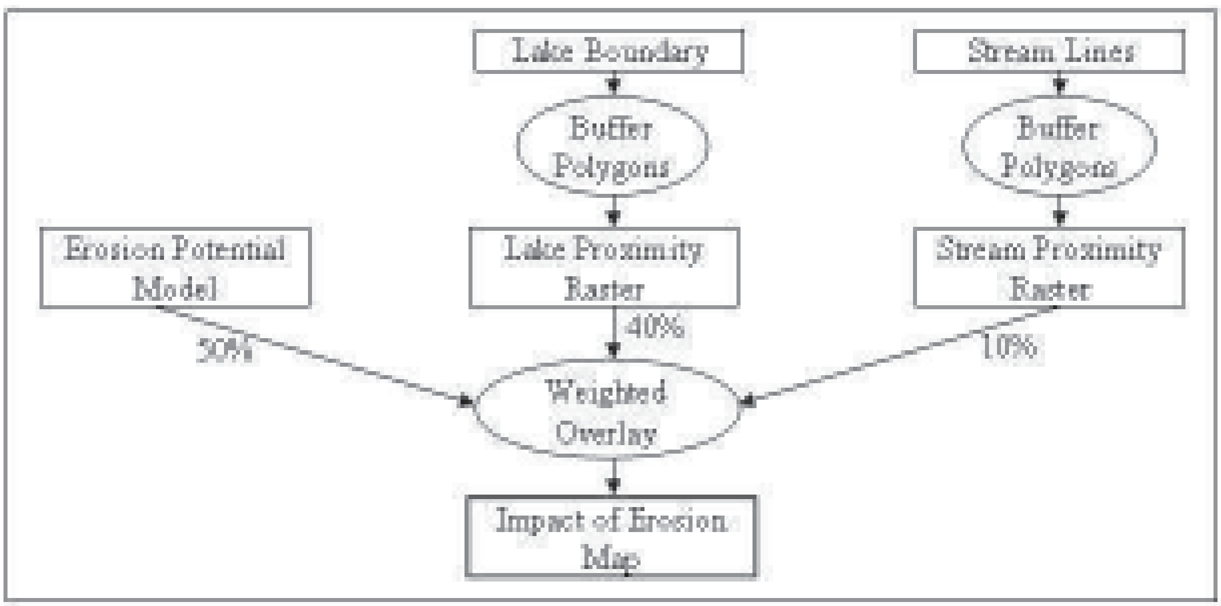

Figure 25. Inputs contributing to the impact of erosion model and their relative weights. Impact of erosion ratings were determined based on proximity to Long Pond North or one of its tributaries. The two proximity maps were combined with the erosion potential model using the Weighted Overlay tool in ArcGIS® 9.1 to determine the areas where erosion is most likely to impact the water quality of Long Pond North.

Results and Discussion

The impact of erosion model combines erosion potential, proximity to Long Pond North, and proximity to a stream to determine the areas that are most likely to have a negative impact on the water quality of Long Pond North as a result of erosion. The map created by this model (Figure 26) shows the areas likely to have a low impact in yellow and those with a potentially high impact in red. The areas with the lowest potential impact of erosion occur at the outer edges of the watershed to the west and south of Long Pond North. The areas with the highest impact of erosion occur along the edges of the lake, especially along streams that feed directly into Long Pond North or in residential areas with a high erosion potential. These areas should be monitored and any sources of erosion addressed. Activities that increase erosion, such as logging, should be avoided where the model indicates a high impact value.

DEVELOPMENT POTENTIAL MODEL

Introduction

A primary area of concern for any lake is the impact of residences on water quality. Present developments have been addressed in the land use section of this report, but future construction is also a source of concern. A development suitability model constructed with GIS is one way to visualize possible future trends and locate potential problem areas. The model combines slope, soil types, roads, protected areas, and distance from the lake to determine areas most prone to development. Areas are categorized with a value of 1 to 5 on a relative index.

Methods

The development suitability model consists of five factors: soil type, slope, distance from a road, distance from the lake, and protected land. Soil types were assigned values in a similar fashion to the septic suitability model (Figure 22). Soil type is an important factor in choosing a building site due to differences between soils in water draining characteristics, ability to settle and compress under load, and erosion potential. Slope was classified based on data from the KCSWCD report. Roads influence development because any land within 250 ft of existing roads will be cheaper to develop since no new roads will have to be paved. Similarly, within certain distances of the lakeshore, residences will be more desirable. Three categories were created to describe proximity to the lake: shoreline to 250 ft, 250 ft to 500 ft, and beyond 500 ft from the lake. Within 250 ft it is possible to have direct access to the lake via a dock. From 250 ft to 500 ft many communities still extend lake access benefits to neighbors by maintaining a

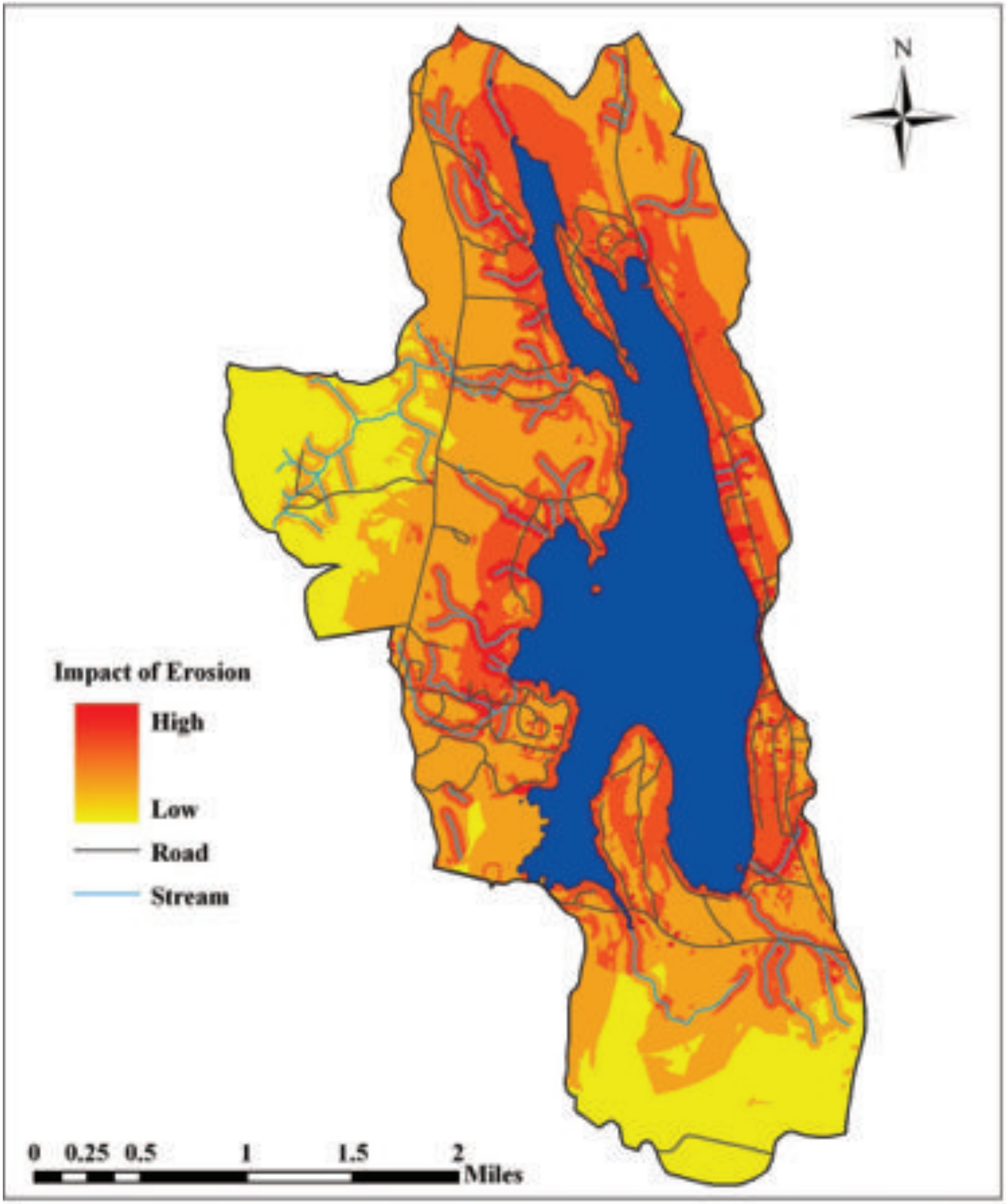

Figure 26. Impact of erosion map for the Long Pond North watershed. The impact of erosion was determined by combining erosion potential ratings with proximity to Long Pond North or one of its tributaries. Areas where erosion is likely to have a high impact on Long Pond North water quality are shown in red, and areas with a low potential impact of erosion are yellow. The streams and roads layerswere obtained from the Maine Office of GIS (MEGIS 2006).

semi-private boat launch area. Beyond 500 ft the draw of the lake becomes less important as lake access becomes more restricted. These four components were rated on a scale of 1 to 5, and then combined into a weighted overlay, with more important components receiving more significance than others. The importance values were 15 percent for soil, 20 percent for slope, 30 percent for roads, and 35 percent for lake proximity. These weights were given based on the influence the characteristic has on development as well as how easy the characteristic is to remediate. These values were combined with a map of protected lands to show the final result. Protected lands where building is restricted include the Kennebec Highlands, Blueberry Hill, and regional wetlands, as well as a town park in Belgrade Lakes.

Results

The finished development suitability model (Figure 27) shows the probability of residences being built on a scale of 1 to 5, and also lists areas where construction is prohibited. The areas noted by the model as having higher potential for future development include the western shore, the area near Peninsula drive in the north, and the southwest basin. The model accurately identified Wildwood Estates as a likely place for development. Most of the areas in the # 5 category have already been developed. An important consideration is that the model does not take into account the influence of preexisting dwellings, because existing development has ambiguous effects on future actions. In some cases, already established infrastructure encourages development. New residences in these areas will not need to include the costs of installing power lines and roads. In other cases, such as in Belgrade Lakes Village, the land may be saturated with residences, thus prohibiting future growth. Each instance needs to be examined case by case, but this model serves as a reasonable guide.

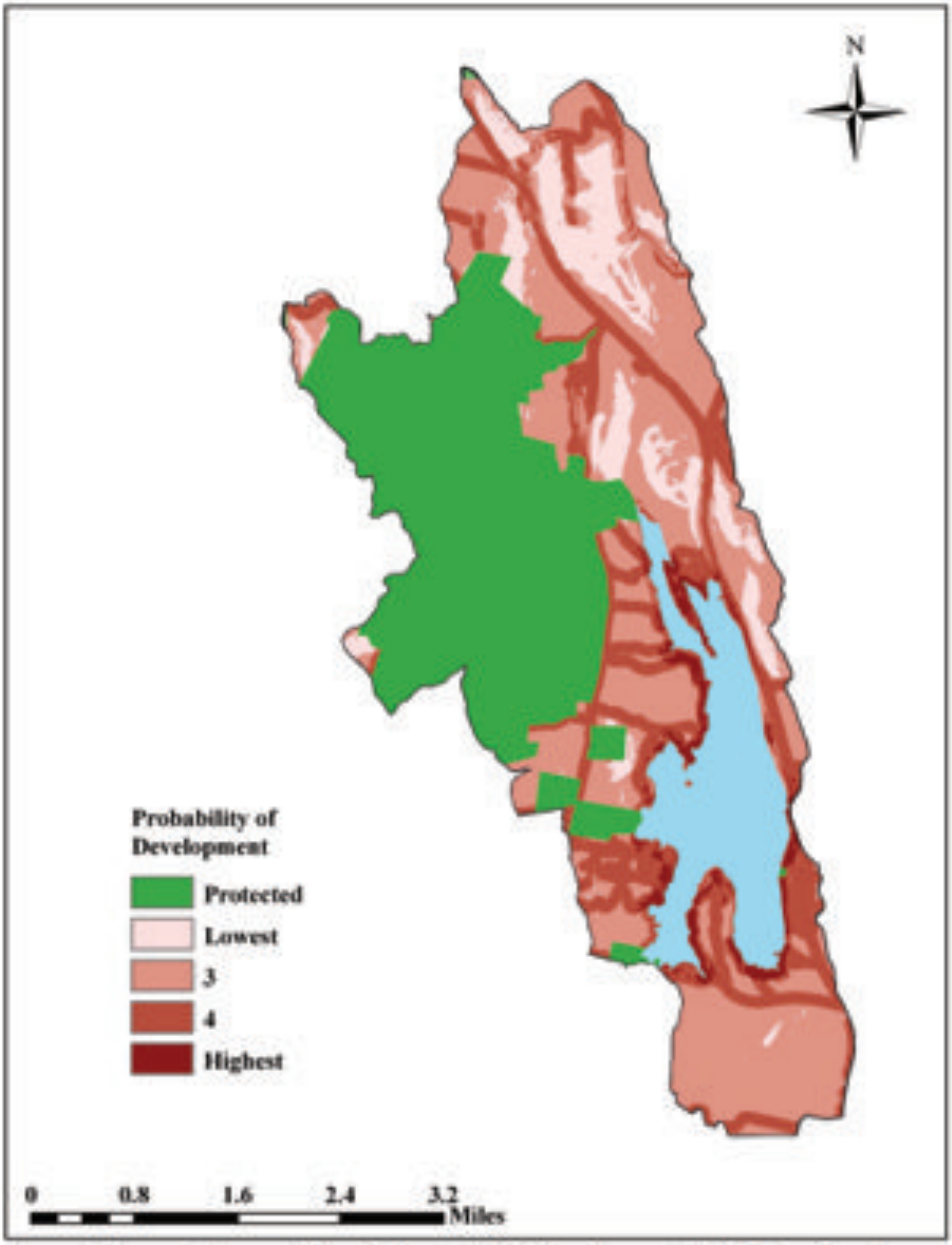

Figure 27. Areas with varying levels of potential for development within Long Pond North's watershed. The model is based on existing roads, distance to the shoreline, slope, and soil type, disregarding current building sites.

WATER QUALITY STUDY SITES

SAMPLE SITES

A total of four study sites were selected for Long Pond North (Figure 28). Sampling occurred from 6-Jun-06 through 30-Aug-06 on a weekly basis. Site 1 was chosen because it represents the deepest part of the lake and would give the most complete representation of the water column. Maine DEP as a sample site also used site 1 in past years, so CEAT's newly gathered data could be compared to historical data. Site 2 is in a bay on the Southerly end and it helps show if any homogeneity occurs between the differently located sampling sites. Because site 2 is located in a bay, it will experience proportionately less mixing and flow than the middle of the lake. Site 3 was chosen for similar reasons to site 2, but it represents the northern end of the lake. Site 4 is located in a narrow bay that never exceeds 6 meters depth, and also has a stream flowing into it at the tip and near its lower end. All four sites possess different characteristics that are representative of the different areas in the lake.

TRIBUTARIES

There are three main inputs to Long Pond's North basin. Beaver Brook enters from the northwest and drains from Beaver Pond, McIntire Pond, Round Pond, and Kidder Pond. An unnamed stream enters from the north, draining from Watson Pond and Whittier Pond. The output from Great Pond flows under Route 27 and enters Long Pond North from the East.

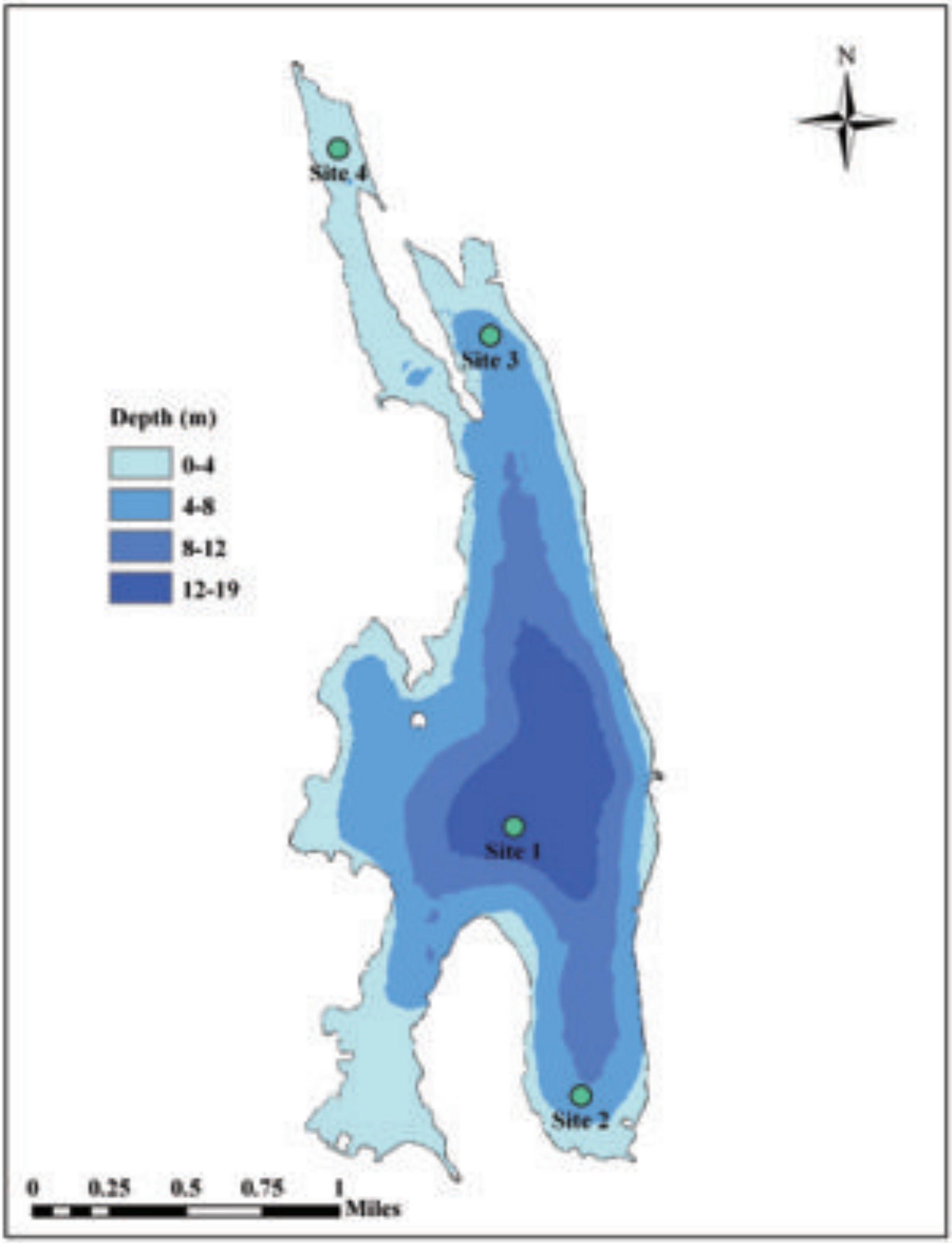

Figure 28. Water chemistry sampling locations used in summer 2006 and the bathymetry of Long Pond North. Depth values taken from Department of Conservation Bureau of Park and Lands map, 1998.

LONG POND WATER QUALITY ASSESSMENT

PHYSICAL MEASUREMENTS

Dissolved Oxygen and Temperature

Introduction

Dissolved oxygen (DO) concentration in a lake is a measurement of the amount of gaseous oxygen (O_2) dissolved in water. Organisms depend on the presence of this oxygen for respiration. Thus, water with a DO concentration of less than one part per million (ppm) is termed anoxic and is considered to be threatening to aerobic life (PEARL 2006b). Water with DO less than five ppm is dangerous for cold-water fish (PEARL 2006b).

The balance of oxygen in the water column is influenced by biological, physical, and chemical variables. Oxygen levels can be depleted by the decomposition of organic matter, microbial activity, and biological respiration (Chapman 1996). DO is also affected by turbulence, a physical disruption of the water surface primarily caused by wind that increases the diffusion of atmospheric oxygen. Various chemical factors, such as increased salinity, depress the solubility of oxygen (NOAA 2006). Additionally, anoxic waters accelerate phosphorus release from iron complexes in the lake bottom sediments (see Background: Water Quality). This release increases algal growth, creating a cycle where dissolved oxygen is further decreased by the decomposition of dead algae. Changes in DO can greatly shift the biotic communities present in a lake and are therefore a good indicator of water quality.

Temperature is a measure of the average energy of molecular motion in a substance at a specific point (Horton 2001). Temperature correlates with dissolved oxygen because decreasing water temperature increases the solubility of gases such as oxygen. Furthermore, higher temperatures increase the respiration rates of organisms, leading to increased rates of decomposition and further DO depletion.

Long Pond is a dimictic lake, thus its water column mixes twice per year (see Background: Lake Characteristics: Annual Lake Cycles). Spring and fall turnover events redistribute dissolved oxygen and homogenize temperature. This mixing limits deep water stratification of anoxic layers that threatens fish species and releases nutrients (see Historical Perspective: Water Quality).

Methods

Temperature and DO measurements were taken by CEAT at sites 1, 2, 3, and 4 on 22-Jun-06, 27-Jun-06, 5-Jul-06, 11-Jul-06, 18-Jul-06, 25-Jul-06, 1-Aug-06, 8-Aug,-06, 14-Aug-06, and 30-Aug-06 (Figure 28). Additional samples were made at site 1 on 6-Jun-06, 15-Jun-06, and 2-Oct-06. Values were recorded at one meter depth intervals using a YSI 650 MDS Sonde probe (see APPENDIX B). Temperature was measured in degrees Celsius (°C) and DO was measured in parts per million (ppm). Historical data for these two parameters were obtained from the Maine DEP (PEARL 2006a).

Results and Discussion

Anoxic waters were only measured at site 1, the deepest site. Profile results indicated that the deepest areas of Long Pond North became anoxic in early August when stratification intensified and remained anoxic until fall turnover occurred (Figure 29-A). On 8-Aug-06, anoxic levels were measured below depths of 16 m. Only one week later, on 14-Aug-06, depths greater than 10 m were potentially anoxic (Figure 30). This represents a noticeable increase from 0.6 percent to 10.1 percent of the volume of the lake or 3.526 x 10^6 m^3 of anoxic water in one week.

Shallower sites did not display a strong layering effect, which indicates more mixing occurred. For example, sites 2, 3, and 4 only reached a minimum of 5 ppm DO (Figure 29-B), thus still supporting the oxygen demand of trout and salmon populations. However, these shallower depths do not provide the cold waters these fish prefer.

Historical DO data display a decrease in the depth of anoxic water around site 1 (Figure 31). As a result of this disconcerting trend, Long Pond was placed on the 2006 Maine DEP's list of impaired lakes (Roy Bouchard pers. comm.). In addition, it is clear that internal phosphorus loading by release from ferric compounds under anoxic conditions is an important contributor to phosphorus levels in Long Pond North where such a large area of lake bottom sediments is in contact with anoxic water (see Analytical Procedures and Results: Phosphorus Budget).

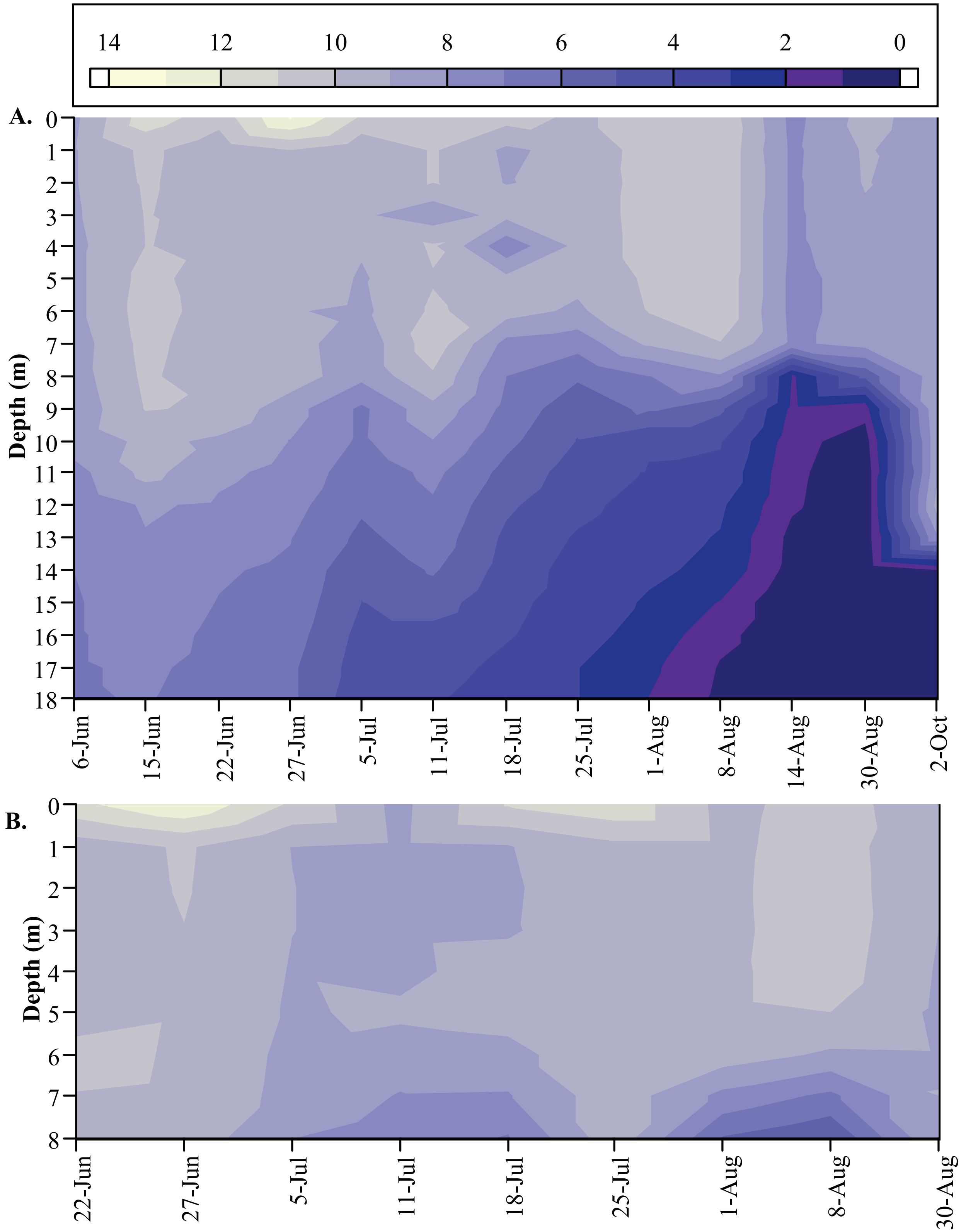

Figure 29. Dissolved oxygen (ppm) profile in 2006 for Long Pond North at site 1 (A.) and site 3 (B.) (see Figure 28 for site locations). Similar patterns to site 3 were also found at site 2 and site 4.

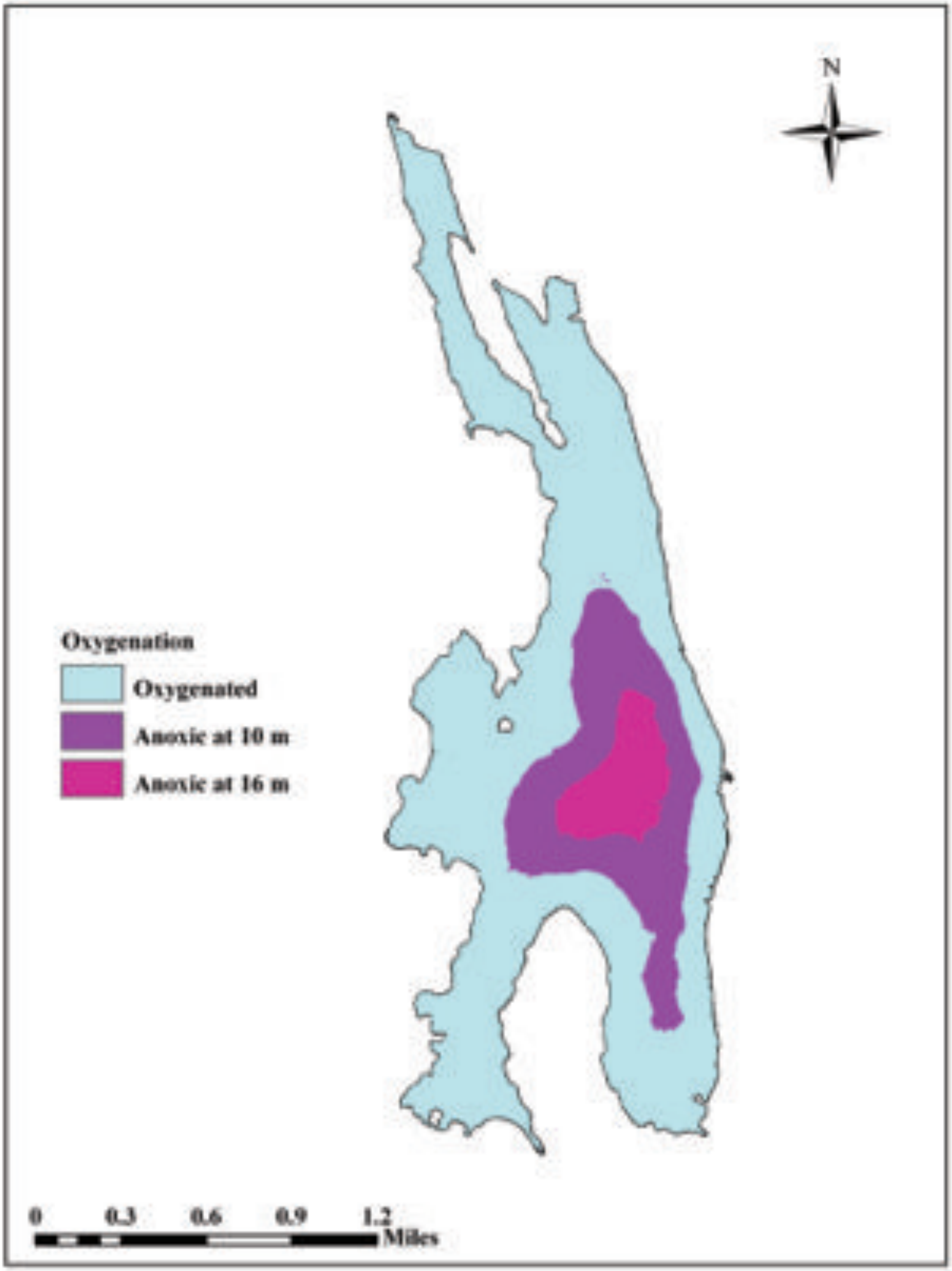

Figure 30. Projected anoxic areas in Long Pond North in summer 2006. DO was below 1 ppm in the pink area on 8-Aug-06 and expanded to the purple area by 15-Aug-06.

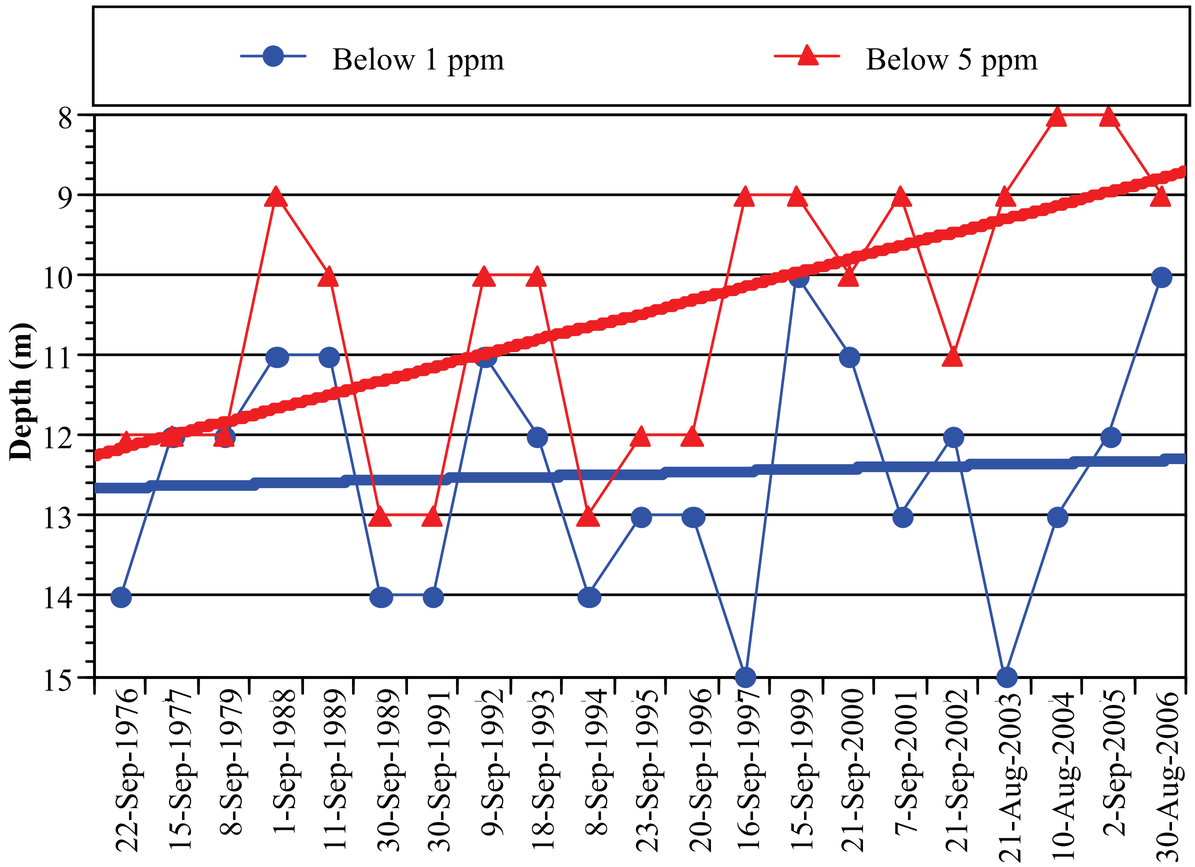

Figure 31. Historic depths at which the dissolved oxygen concentrations were below 5 ppm and below 1 ppm in late August or September for Long Pond North at site 1 (see Figure 28 for site locations). Data collected by the Maine DEP and CEAT.

The temperature profile depicts highly stratified waters from late June to mid August (Figure 32). The thermocline is the area of rapid temperature change with depth found below the wind mixed surface epilimnion. Historical annual temperature data in July indicates that the thermocline consistently occurs at depths between 6 m and 9 m (Figure 33). The region of rapid change in dissolved oxygen concentration mirrors the temperature thermocline, confirming that these two physical parameters are correlated (Figure 34). These two profiles illustrate the rapid decrease in depth of the anoxic layer that occurred in August.

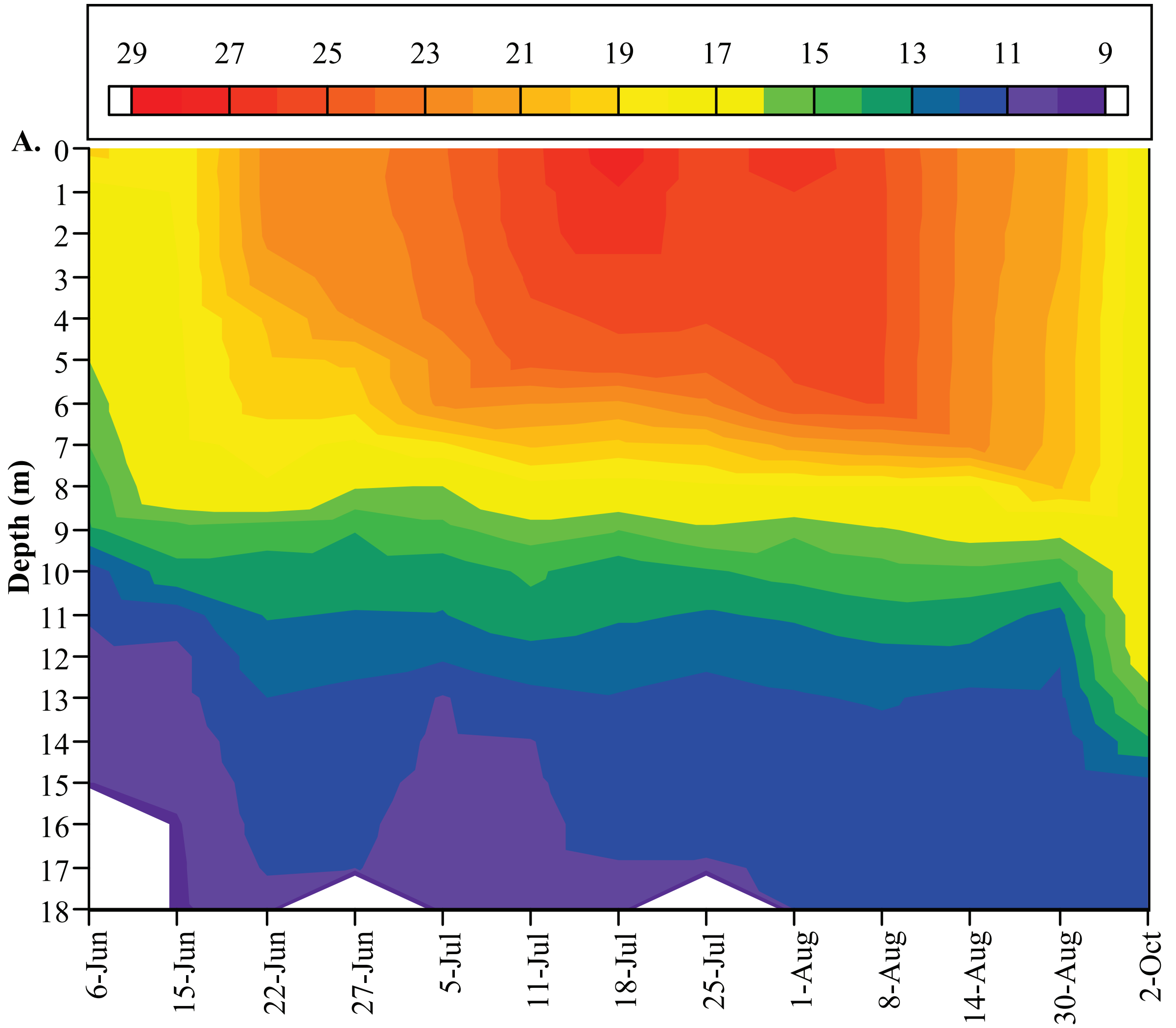

Figure 32. Temperature profile (degrees Celsius) in 2006 for Long Pond North at site 1 (A.) and site 3 (B.) (see Figure 28 for site locations).

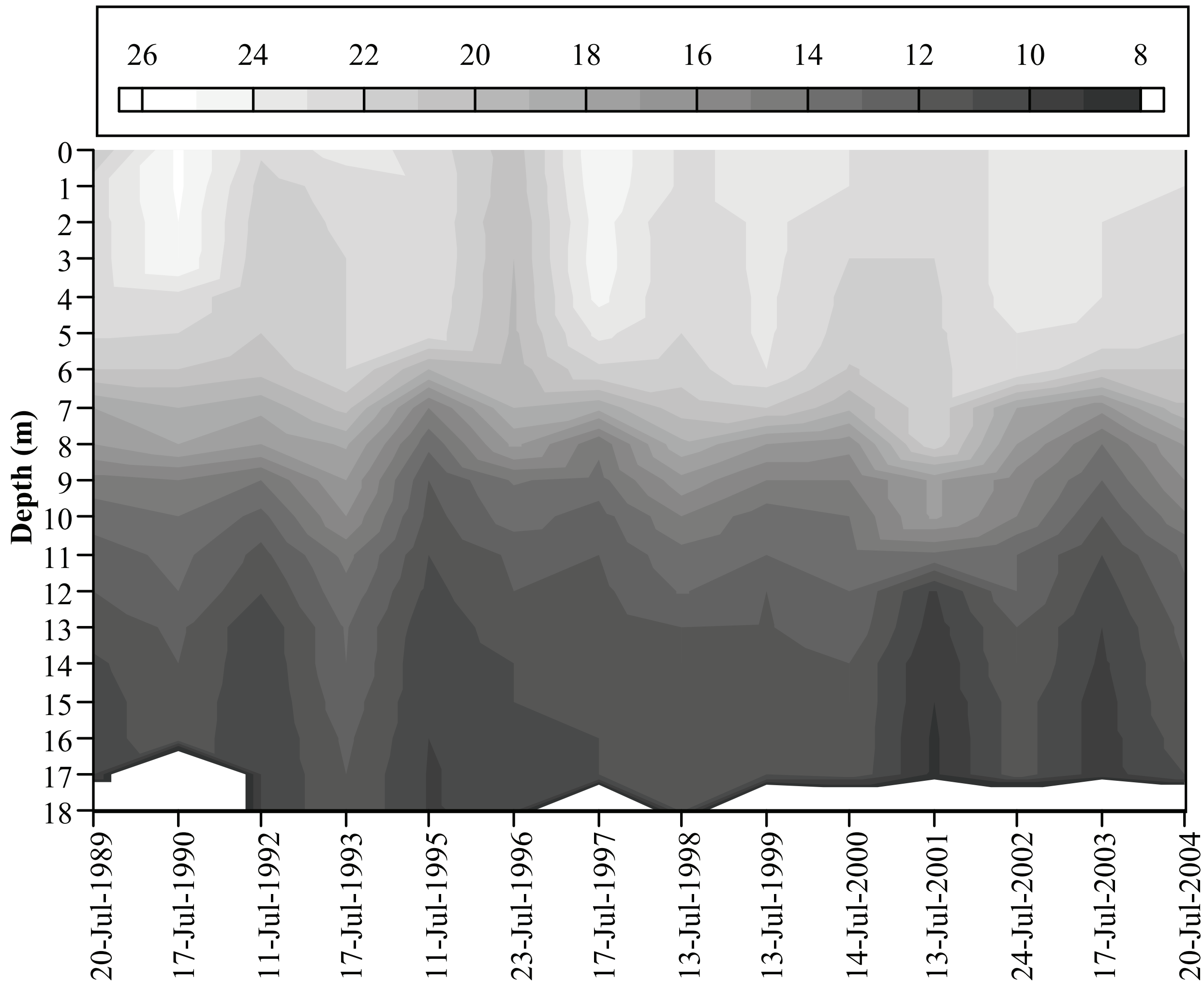

Figure 33. Historic temperature profile (degrees Celsius) in July since 1989 for Long Pond North at site 1 (Figure 28 for site locations). Data collected by Maine DEP.

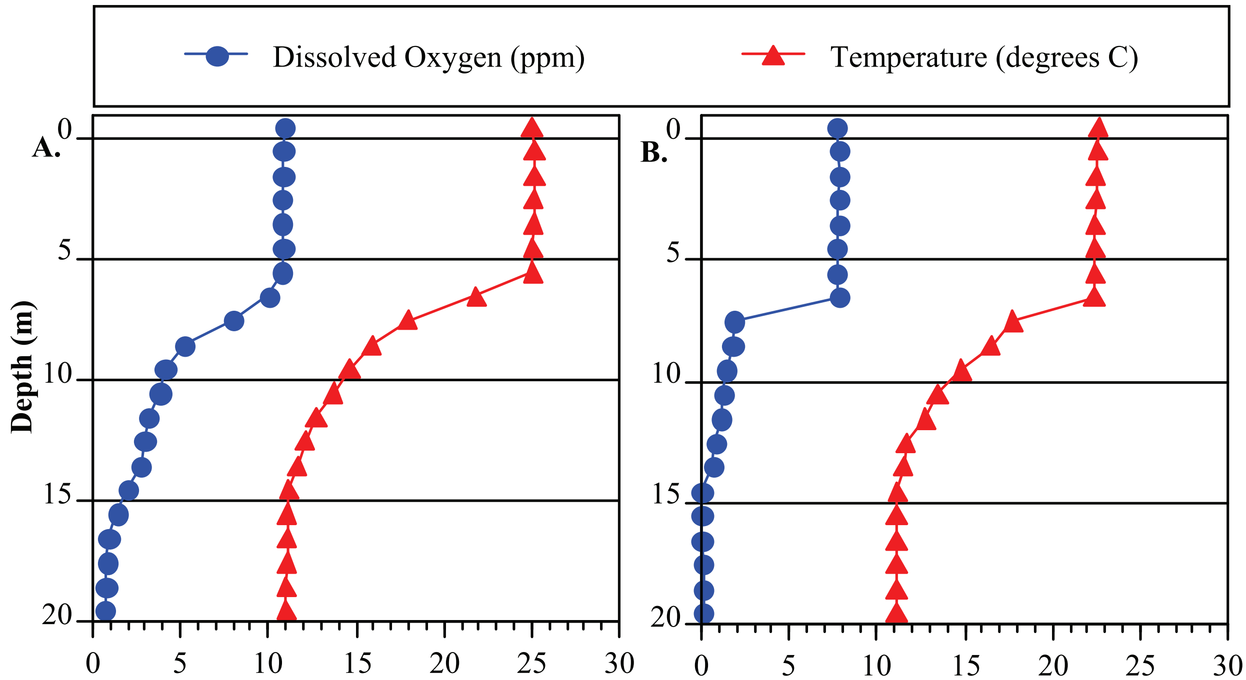

Figure 34. Temperature and dissolved oxygen profiles on 8-Aug-06 (A.) and 14-Aug-06 (B.) for Long Pond North at site 1 (see Figure 28 for site locations).

Transparency

Introduction

Transparency is a measure of visibility in the water column and is typically measured in meters with a Secchi disk. This 20 cm-diameter black and white disk is lowered into the water until it is no longer visible and then raised until it reappears. This is repeated three times to obtain an average depth. Transparency is therefore a function of the reflection of light off the disk, as influenced by the number of suspended particles and the light absorption qualities of water (Wetzel 2001). Secchi depth varies with factors such as the viewer's eyesight, contrast between the disk and the water, and intensity of surface light (Cole 1975). The best time of day to sample is from 10 AM to 2 PM, and measurements should be made from the shady side of the boat (Cole 1975).

The Secchi disk provides a simple, inexpensive measure of lake water quality and changes in algal biomass. Secchi depth is also correlated with light penetration in the water column (Wetzel 2001). A higher measurement indicates clearer waters, greater light penetration, and lower lake productivity, whereas a lower measurement indicates more turbid waters and a decrease in water quality, most often as a result of algal growth (O'Sullivan & Reynolds 2005). In Maine, a lake is considered to have an algal bloom when Secchi depth is less than 2 m (SOS 2005). Mean Secchi depth (SD) can be used to calculate the trophic state index (TSI) for a lake. Dr. Robert Carlson originally derived this index in 1977, and a modified version is still used in order to assess and classify lake productivity or algal biomass:

$$TSI (SD) = 10 [6 – (\ln (SD) / \ln 2)]$$

$$\text{or modified, } TSI (SD) = 60 - (14.41 * \ln (SD))$$

Similar equations exist for TSI that utilize either chlorophyll pigment or total phosphorus measurements. A high TSI is associated with lakes that have low visibility due to high algal growth rates, whereas a lower index value indicates a lake with clear waters and low productivity (PEARL 2006_k). Oligotrophic lakes (low productivity) are assigned a TSI of less than 40, whereas mesotrophic lakes (moderate productivity) have a TSI of 40 - 49 and eutrophic lakes (high productivity) have a TSI of 50^+ (PEARL 2006_a).

Methods

Transparency was measured on a weekly basis with a Secchi disk and an Aqua-Scope (to remove effects of surface glare) from 6-Jun-06 to 30-Aug-06 and on 2-Oct-06 for site 1, from 13-Jun-06 to 30-Aug-06 and 2-Oct-06 for site 2, and from 12-Jun-06 to 30-Aug-06 for site 3 (Appendix A). Site 4 was too shallow for measurement. Historical data were obtained from the PEARL website (2006_a). The 2006 mean Secchi disk measurement (SD) was used to calculate the TSI of Long Pond North using the modified equation.

Results and Discussion

At site 1, transparency ranged from 6.2 m to 3.65 m with a mean of 4.65 m ± 0.20, site 2 ranged from 4.95 m to 3.9 m with a mean of 4.35 m ± 0.14, and site 3 ranged from 6.15 m to 3.9 m with a mean of 4.79 m ± 0.26. There was no significant decrease in average Secchi depth for sites 1 or 3 throughout the summer, but a decrease did occur from June to July for site 2, suggesting a drop in water clarity (Figure 35). Secchi depth never fell below 2 m for sites 1 - 3, indicating that no algal blooms occurred during summer 2006. TSI for Long Pond North was 38, classifying the lake as oligotrophic (less than 40). A significant future increase in productivity could easily increase TSI, placing Long Pond North in the mesotrophic category (40 - 49).

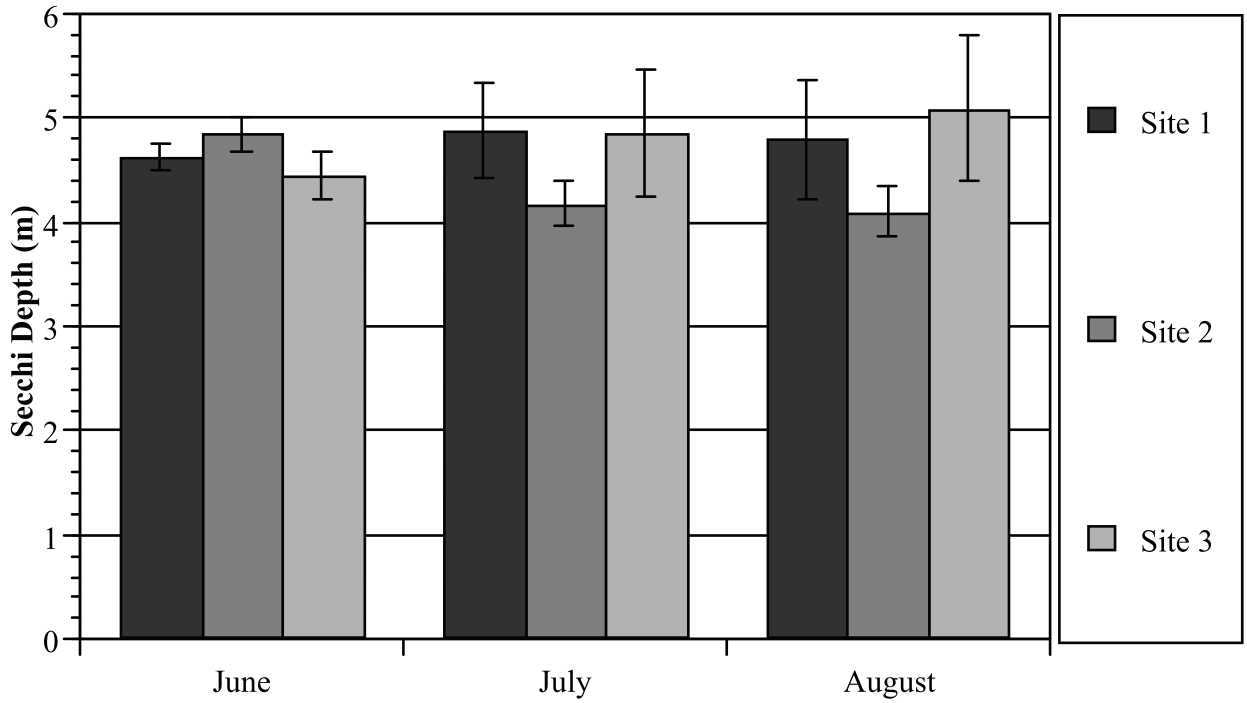

Figure 35. Mean (± SE) Secchi depth (m) in 2006 for Long Pond North sites 1-3 (see Figure 28 for site locations).

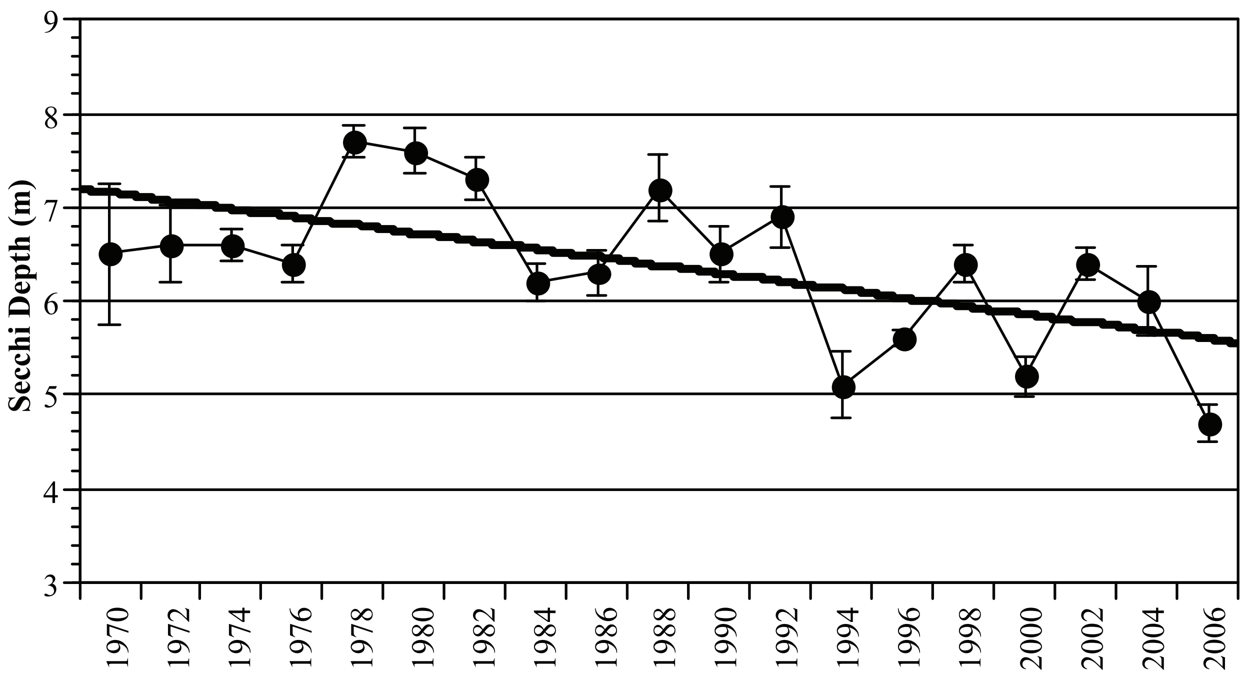

Figure 36. Water clarity as represented by mean (± SE) Secchi depth (m) and linear trendline from 1970 to 2006 for Long Pond North site 1 (see Figure 28 for site locations). Data from 2006 collected by CEAT, all other data from Maine DEP.

From 1978 to 1982, water clarity was high with a mean Secchi depth of more than 7 m (Figure 36). From 1982 through 2006, there was a trend in decreasing mean depth (Figure 36). The 2006 mean visibility was about 3 m less than the 1978 reading. This change indicates that over the past two and a half decades, visibility and water quality have declined. In 2006, Maine DEP listed Long Pond as "impaired" because of this historical decrease in transparency and the increasing anoxia in the bottom waters during late summer (see Figure 29) (Bouchard, pers. comm.).

Turbidity

Introduction

Similar to transparency, turbidity is also a measure of visibility in the water column, but is based upon the interaction of light with suspended particles (Stednick 1991). A beam of light shone through pure water travels undisturbed through the sample. If particles are present in the water, they absorb the light striking them and reradiate light energy in different directions (Stednick 1991). The pattern of light distribution varies with factors such as particle shape and size, wavelength of incident light, and particle concentration (Stednick 1991). A turbidimeter, commonly used to measure turbidity, sends a beam of light through a sample. The suspended particles in the sample scatter light energy in an amount proportional to the turbidity, and this light energy is converted to an electric signal to provide a reading. Turbidity readings are typically reported in Nepalometric Turbidity Units (NTU). High NTU values reflect greater light scattering, higher turbidity, and reduced clarity (MPCA 2006).

A higher turbidity reading indicates more suspended inorganic and organic particles in a sample, which may include clay, silt, fine organic particulate matter, and plankton (Wetzel & Likens 2000). A lack of clarity can arise for several reasons including turbulence, increased algal growth, and pollution. The particles in highly turbid waters may inhibit algal and macrophyte primary production by reducing light penetration, which in turn affects the macroinvertebrates that feed upon them (Rast & Thornton 1979). Filter feeders are also harmed by high turbidities, and lake predators may find it more difficult to locate prey (Rast & Thornton 1979).

Methods

The turbidity of surface, mid, and bottom water samples was measured for sites 1 - 3 on a weekly basis from 6-Jun-06 to 30-Aug-06 (Appendix A). Site 4 was too shallow to collect turbidity samples at depths other than the surface. A Hach™ 2100P Turbidimeter was used to take measurements in Nepalometric Turbidity Units (NTU).

Results and Discussion

Throughout the summer, turbidity readings for site 1 ranged from 0.55 NTU to 2.01 NTU. Mean (± SE) surface turbidity was 0.89 NTU ± 0.11. A major increase in surface turbidity occurred on 27-Jun-06 (Figure 37). This increase was caused by a higher particulate abundance in the water, perhaps resulting from high winds and turbulence or greater levels of algal growth. Average surface turbidity increased as site depth decreased, suggesting turbulence and mixing at the shallower sites (Figure 38).

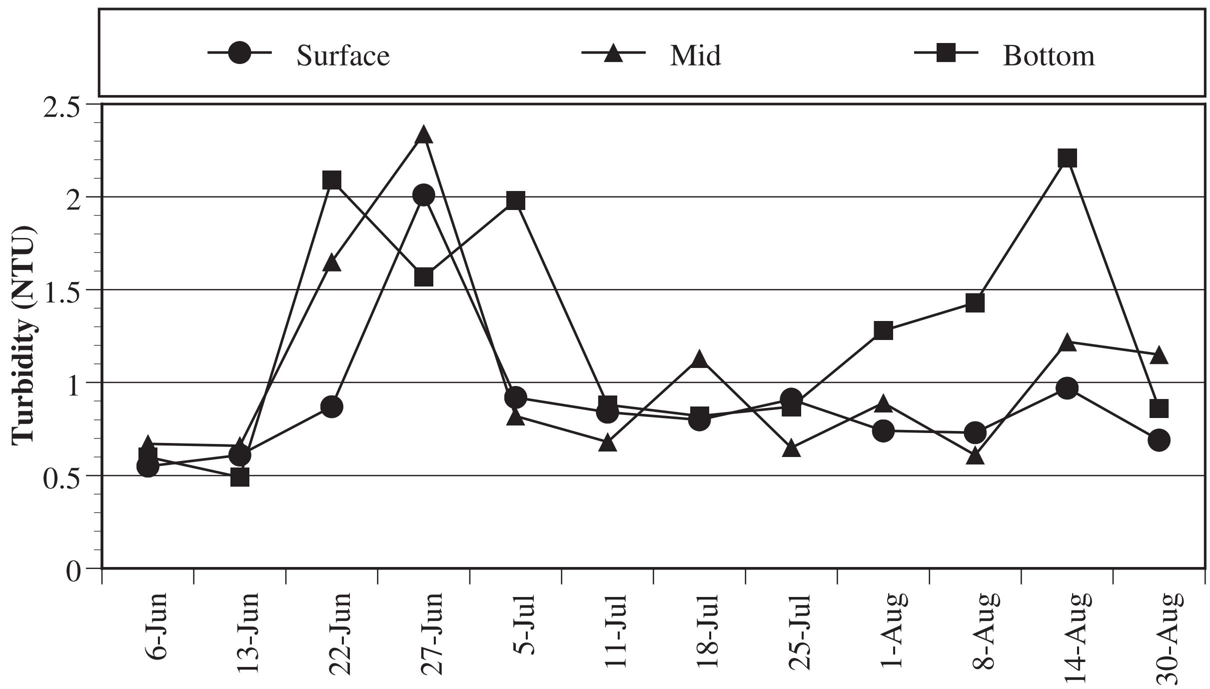

Figure 37. Surface, mid, and bottom turbidity (NTU) in 2006 for Long Pond North site 1 (see Figure 28 for site locations).

Site 1 is the deepest (approximately 20 m) and had the lowest average turbidity, whereas site 4 was the shallowest (approximately 3.5 m) with the highest average turbidity. Sites 2 and 3 were of intermediate depths (approximately 8 and 7 m respectively) and had an intermediate average turbidity. This trend occurs because site 1 is deep enough to stratify, and there is very little mixing between the hypolimnion and the epilimnion. The more shallow sites do not stratify and are wind mixed, which may stir up sediment and decrease water clarity throughout the entire water column.

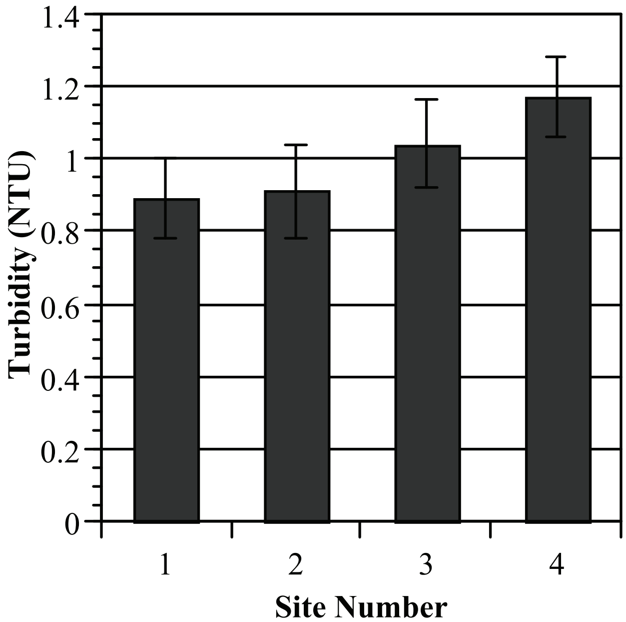

Figure 38. Mean (± SE) surface turbidity (NTU) in 2006 for Long Pond North sites 1-4 (see Figure 28 for site locations).

Bottom turbidity at site 1 ranged from 0.49 NTU to 2.21 NTU, with a mean of 1.26 NTU ± 0.18. Bottom turbidity increased steadily from 25-Jul-06 until it peaked on 14-Aug-06 (Figure 37). Algae populations tend to increase as summer progresses, and as they die, they settle to the bottom to be broken down by decomposers. The higher bottom turbidity measurements in late summer reflect this increase in accumulated organic matter.

CHEMICAL ANALYSES

pH

Introduction

pH is a measurement of the concentration of hydrogen ions (H^+). It is based on a logarithmic scale where a change in pH value by 1 unit refers to a change in ion concentration by a factor of 10 (PEARL 2006j). pH can range from very acidic (value of 1) to very basic (value of 14). The pH in lakes can fluctuate due to pollutants such as acid rain or decomposition of organic matter.

The level of primary production can also influence a lake's pH. Carbon dioxide combines with water to form carbonic acid. Thus, it has an acidifying effect on water by shifting the bicarbonate buffer equilibrium. When respiring plants produce CO_2, they decrease the pH of water. Plants also use CO_2 during photosynthesis and this makes the water more alkaline. Higher net pH values may consequently be an indicator of algal growth (PEARL 2006j).

The acidity or alkalinity of lake water impacts several aspects of the ecosystem. Typical lakes range in pH from 4 to 9. However, lakes with pH levels from 5 to 7 generally have better health since the phosphorus retention of ferric compounds is maximized, thereby reducing a source of excess nutrients (Cooke et al. 1993). In addition, pH can influence lake biota based on optimum species-specific pH ranges.

If a lake is in need of water quality improvement processes because of eutrophication, several of the treatment options are pH dependent. The optimum effectiveness of chemical coagulation, disinfection, softening, and corrosion control are all determined by pH.

Methods

pH profiles were taken at sites 1, 2, 3, and 4 on 22-Jun-06, 27-Jun-06, 5-Jul-06, 11-Jul-06, 18-Jul-06, 25-Jul-06, 1-Aug-06, 8-Aug-06, 30-Aug-06, and additionally at site 2 on 6-Jun-06, 15-Jun-06, and 2-Oct-06 (see Figure 28 for site locations). Data was collected using a YSI 650 MDS Sonde probe at one meter intervals. The instrument was calibrated before use (Appendix B). Annual mean pH values at site 1 were analyzed to gain a historical perspective (PEARL 2006a). Mean surface pH values and the trophic state of Long Pond North were compared with several other area lakes.

Results and Discussion

Surface pH was significantly more basic than benthic levels at all four sites (Figure 39). In deeper waters, less CO_2 is removed through photosynthesis and the pH remains lower. Changes in temperature and dissolved oxygen, over the course of the summer, indicate that the water column becomes increasingly stratified. This trend was observed with pH as well. The pH range of Long Pond North, however, did not substantially change over the course of the summer. Peak pH values occurred at sites 1, 3, and 4 on 8-Aug-06. This date corresponds with high chlorophyll readings relating to an increased photosynthetic rate due to warmer, nutrient-rich waters. The most likely cause of high pH values was the removal of CO_2 from the water as a result of increased levels of photosynthesizing plankton.

In general, lake pH remained above 7 in the first eight meters of water. The more basic surface pH values, particularly at the shallower site 4, should be closely monitored. There is also a historic trend depicting increasing annual mean pH values with the exception of 1988 (Figure 40). The pH of Long Pond North fell within the range for maximum phosphorus retention (pH 5

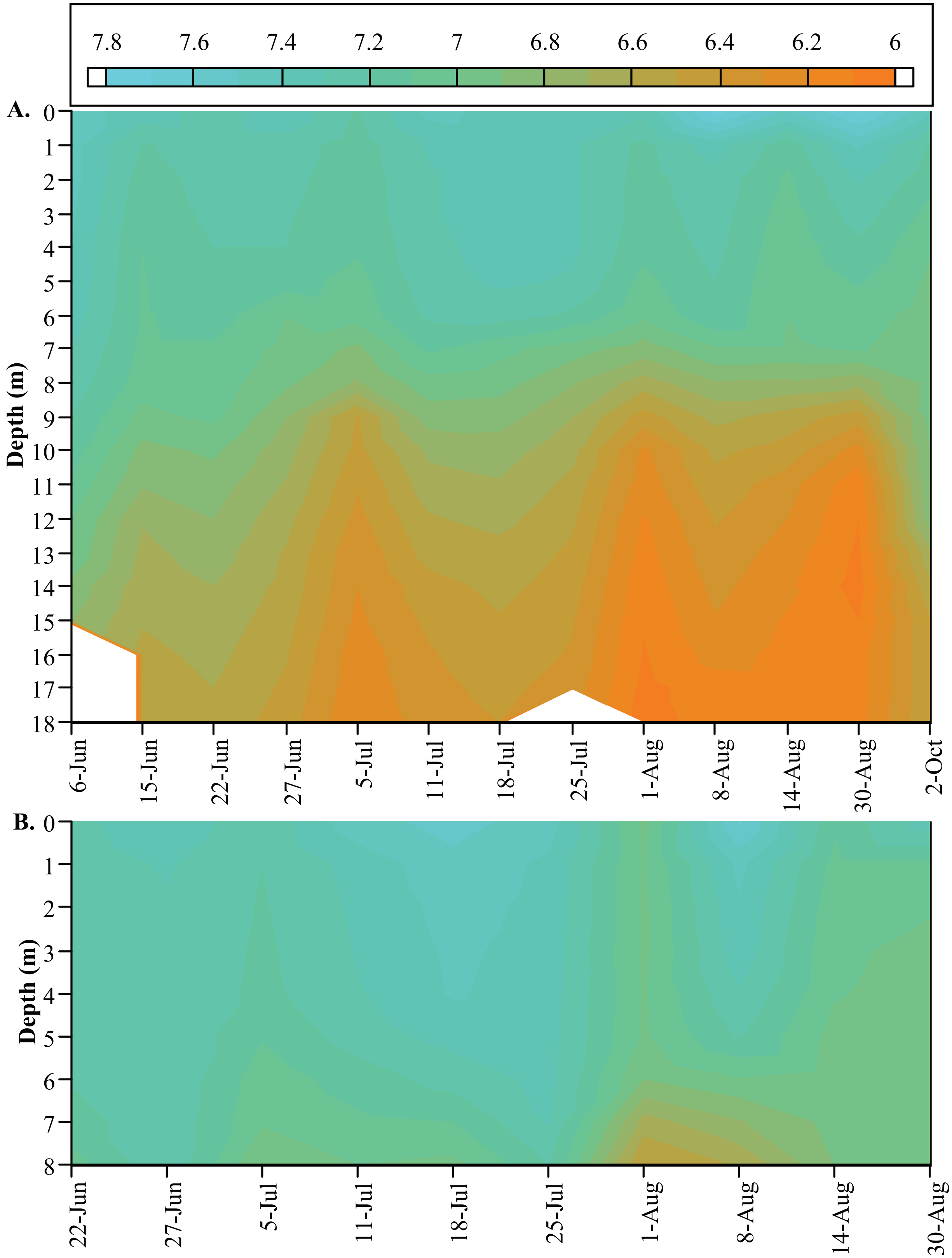

Figure 39. pH profiles in 2006 for Long Pond North at site 1 (A.) and site 3 (B.) (see Figure 28 for site locations).

to 7) at the majority of depths, indicating good overall lake health. Should pH values continue to rise, it is possible that increased phosphorus may be released from the sediments at shallow sites.

The trend of mean surface pH of Long Pond North was interesting when compared with other nearby lakes (Table 10). Great Pond is beginning to show signs of eutrophication and China Lake, East Pond, Webber Pond, and Threemile Pond are all experiencing algal blooms. As higher pH is indicative of algal growth, it is expected that Long Pond North would have lower values than many of the other cited lakes. Higher pH results than anticipated at Long Pond North may in part be attributed to the presence of *Gloeotrichia enchinulata* (see Background: Water Quality).

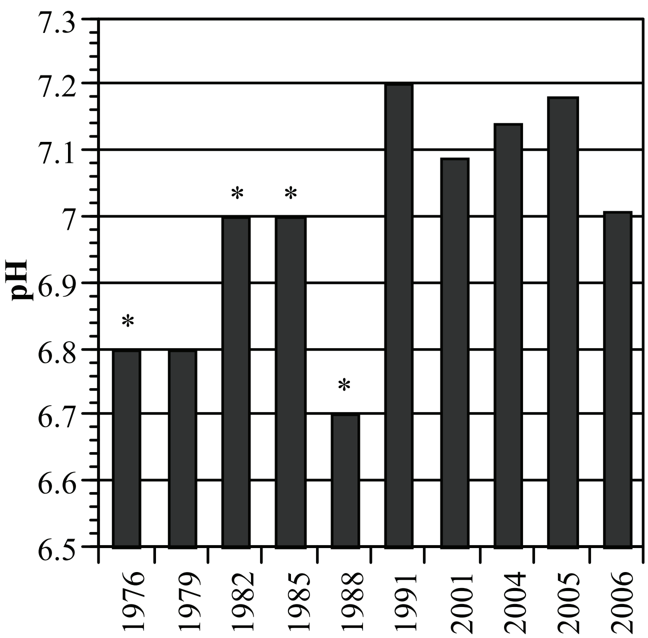

Figure 40. Mean pH values at 7 m and surface (*) in all available years for Long Pond North at site 1 (see Figure 28 for site locations). Data collected by Maine DEP and CEAT.

Table 10. Mean surface pH (± SE) of five nearby lakes (CEAT 1995, 2000, 2004, 2005, 2006; King 2005).

Lake	pH (surface)
Belgrade Lakes Region	
Long Pond North	7.36 ± 0.04 (n = 43)
Great Pond	7.2 ± 0.16 (n = 11)
East Pond	7.43 ± 0.23 (n = 34)
China Lakes Region	
China Lake	7.95 ± 0.19 (n = 19)
Threemile Pond	6.97 ± 0.21 (n = 11)
Webber Pond	7.13 ± 0.31 (n = 10)

Total Phosphorus

Introduction

Phosphorus limits phytoplankton growth and in many lakes it is the main nutrient responsible for eutrophication (Boyd 2000). Increases in phosphorus can result in algal blooms, thereby decreasing water clarity and dissolved oxygen concentrations in the hypolimnion. Oligotrophic lakes tend to have an epilimnion total phosphorus concentration of less than 5 ppb, whereas a eutrophic lake will have phosphorus levels of 30 to 100 ppb (Wetzel 2001).

Common sources of phosphorus include phosphorus-bearing minerals, detergents, fertilizers, sewage, internal loading, and soil runoff (Boyd 2000). Phosphorus is present in lakes as orthophosphate, polyphosphate, and organic phosphate (Tomar 1999). Once dissolved and particulate forms of phosphorus enter a lake, they can be absorbed by plants and incorporated as biomass. After the plants or the animals that consume them die, decomposers release dissolved phosphorus. Phosphorus can then be reabsorbed by plants and continue the cycle or become sequestered in the sediments.

In unpolluted lakes, most of the phosphorus is found in bottom sediments, tied up in aluminum, iron, and calcium complexes (Boyd 2000). The release of phosphorus into the water by these complexes depends upon pH and hypolimnion oxygen levels. When waters become anoxic, meaning dissolved oxygen levels drop below 1 ppm, phosphate complexes are reduced and phosphorus is released into the water (see Background: Phosphorus and Nitrogen Cycles). The solubility of aluminum and ferric phosphates increases at pH higher and lower than 6, whereas carbonate phosphate compounds are less soluble at higher pH (Wetzel 2001). Phosphate absorption by clays occurs mostly at low pH (Wetzel 2001).

Methods

Surface, mid, bottom and epicore water samples were collected by CEAT on a weekly basis from 6-Jun-06 to 30-Aug-06 at site 1. Surface, mid, and bottom samples were taken on a weekly basis from 13-Jun-06 to 30-Aug-06 at sites 2 and 3, and only surface samples were consistently collected each week at site 4 due to shallow depth. See Appendix A for further information on sample dates.

The ascorbic acid method was used to determine the total phosphorus concentration (ppb) of the samples (see Appendix B). After collection, samples were placed on ice and brought back to the laboratory. One mL of 1.75 N ammonium peroxydisulfate and 1.0 mL 11 N sulfuric acid were added to each 50 mL sample, and these were digested in an autoclave at 15 lbs/in^2 and 120˚C for 30 min. This process converted condensed and organic phosphorus to soluble orthophosphate. Post-digestion, the samples were titrated to a pH of 6, and a combined reagent was added. The intensity of the color produced by the reagent reacting with orthophosphate was measured with a Milton Roy Thermospectronic Aquamate Spectrophotometer and converted to phosphorus concentration in ppb. Historical data were obtained from Maine DEP (PEARL 2006_a).

Results and Discussion

Mean (± SE) surface, mid, and bottom total phosphorus for site 1 were 6.6 ppb ± 2.1, 9.5 ppb ± 2.0, and 12.8 ppb ± 2.0 respectively. Mean (± SE) epicore total phosphorus was 7.5 ppb ± 1.7. Mean (± SE) surface, mid, and bottom total phosphorus for site 2 were 8.0 ppb ± 2.8, 7.3 ppb ± 0.95, and 5.6 ppb ± 1.0 respectively. For site 3, mean (± SE) surface, mid, and bottom total phosphorus were 6.6 ppb ± 0.33, 6.7 ppb ± 0.80, and 6.9 ppb ± 0.73 respectively. Site 4 mean (± SE) surface total phosphorus was 5.8 ppb ± 1.2. Total phosphorus at site 1 increased with depth because site 1 is stratified and little mixing occurs between bottom and surface water (Figure 41). Bottom waters are more likely to have higher total phosphorus concentrations because of internal loading from the sediments. Total phosphorus for sites 2 and 3 did not increase with depth (Figure 41). These shallower sites are not deep enough to stratify. Wind mixing of the entire water column prevents the buildup of bottom phosphorus.

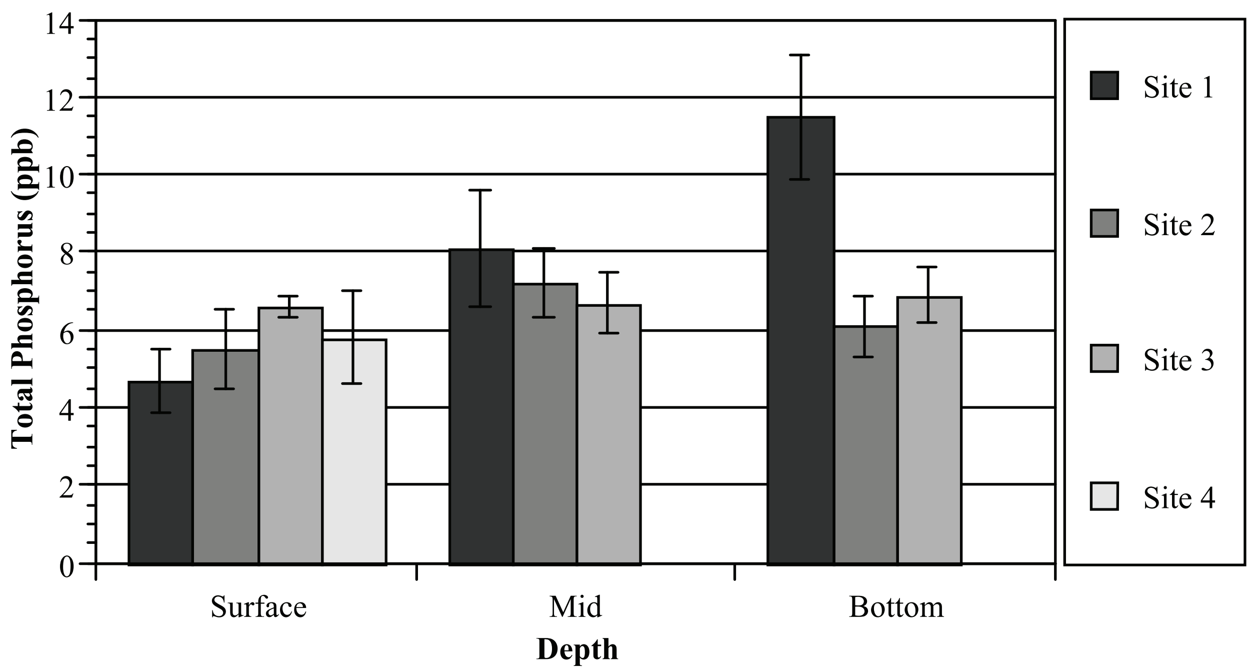

Figure 41. Mean (± SE) surface, mid, and bottom total phosphorus (ppb) in 2006 for Long Pond North sites 1-4 (see Figure 28 for site locations). Italicized values in Appendix C were omitted.

Total phosphorus concentrations at surface, mid, and bottom depths at site 1 were relatively high in June, although standard error was great (Figure 42). The total phosphorus of the site 2 surface sample and the site 1 surface, mid, and bottom samples collected on 27-Jun-07 had unusually high values (see italicized numbers in Appendix C). CEAT believes that these results occurred because of an error in the ascorbic acid testing procedure. Consequently, these values were omitted from any mean calculations. Excluding these values, mean (± SE) surface, mid, bottom, and epicore total phosphorus concentrations for site 1 were 4.7 ppb ± 0.8, 8.1 ppb ± 1.5, 11.5 ppb ± 1.6, and 6.1 ppb ± 0.7, respectively. Mean (± SE) surface total phosphorus concentration for site 1 was 5.5 ppb ± 1.0. From June to July, the surface and mid total phosphorus concentrations at site 1 showed a slight increase, but the greatest increase occurred in bottom concentrations (Figure 42). As summer progresses, phytoplankton die, fall to the bottom, and decompose, causing dissolved oxygen levels in the hypolimnion to become anoxic, as seen at site 1 on 8-Aug-06 (Figure 29). In those conditions, metal phosphate complexes are reduced, releasing phosphorus from the bottom sediments. Because site 1 is stratified, the released phosphorus remains in the bottom waters. This increase in total bottom phosphorus is not observed in the shallower sites (Figure 43) because of mixing and oxygenated waters.

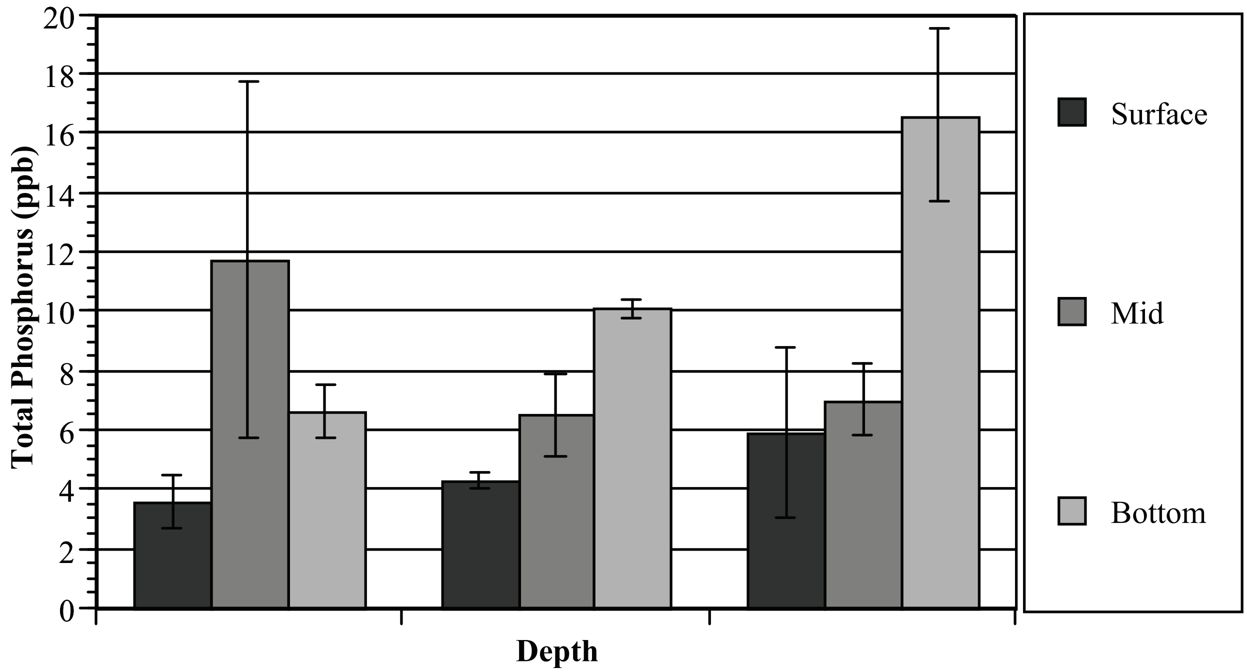

Figure 42. Mean (± SE) surface, mid, and bottom phosphorus concentrations (ppb) in 2006 for Long Pond North site 1 (see Figure 28 for site locations). Italicized values in Appendix C were omitted.

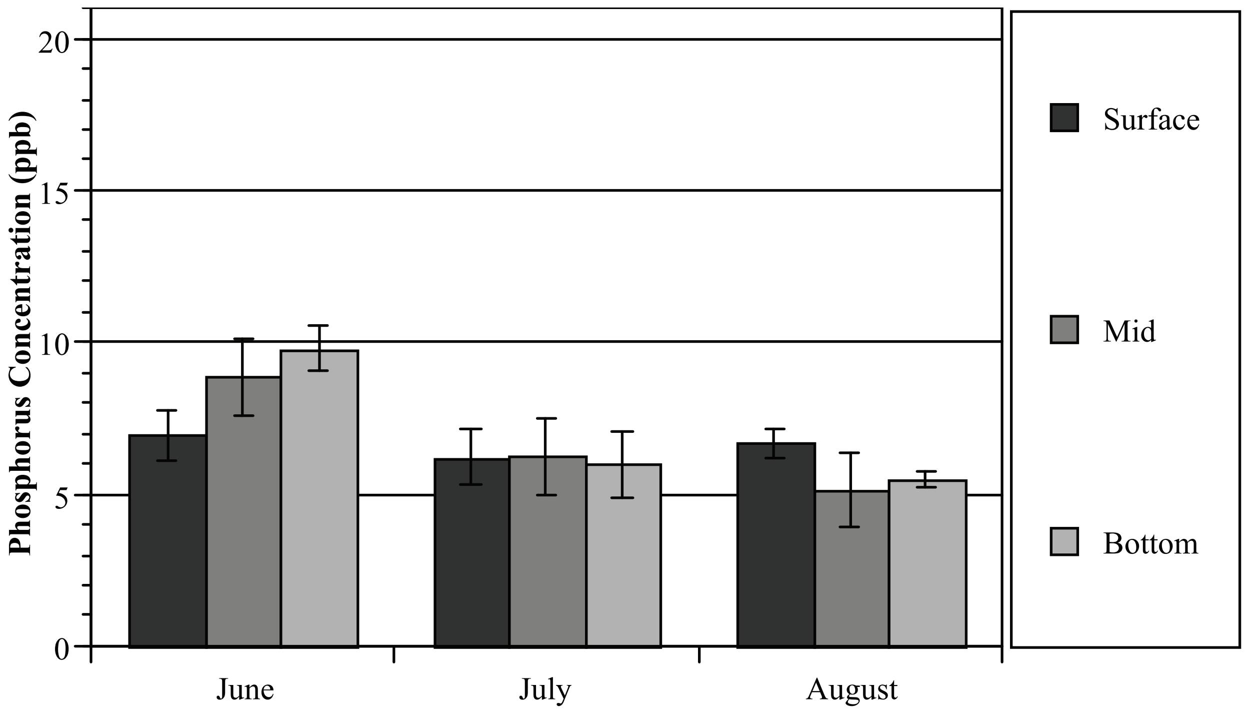

Figure 43. Mean (± SE) surface, mid, and bottom phosphorus concentrations (ppb) in 2006 for Long Pond North site 3 (see Figure 28 for site locations).

There was relatively little historical change in surface or epicore total phosphorus concentrations at site 1, but bottom total phosphorus increased from 1976 to 2006 (Figure 44). Bottom total phosphorus concentration was fairly low until 1982, but thereafter increased until a peak of more than 45 ppb in 1996 (Figure 44). Concentration decreased after that year, but remained higher than the 1976 - 1982 levels (Figure 44). High bottom phosphorus concentrations indicate that the bottom waters become anoxic at some point during the summer, suggesting an overall decrease in water quality. Although several measurements of bottom phosphorus concentration were significantly greater than those of other years, the averages since 2004 have not exceeded 15 ppb. This is a good sign because in other anoxic lakes, bottom total phosphorus levels can become greater than 100 ppb (CEAT 2006).

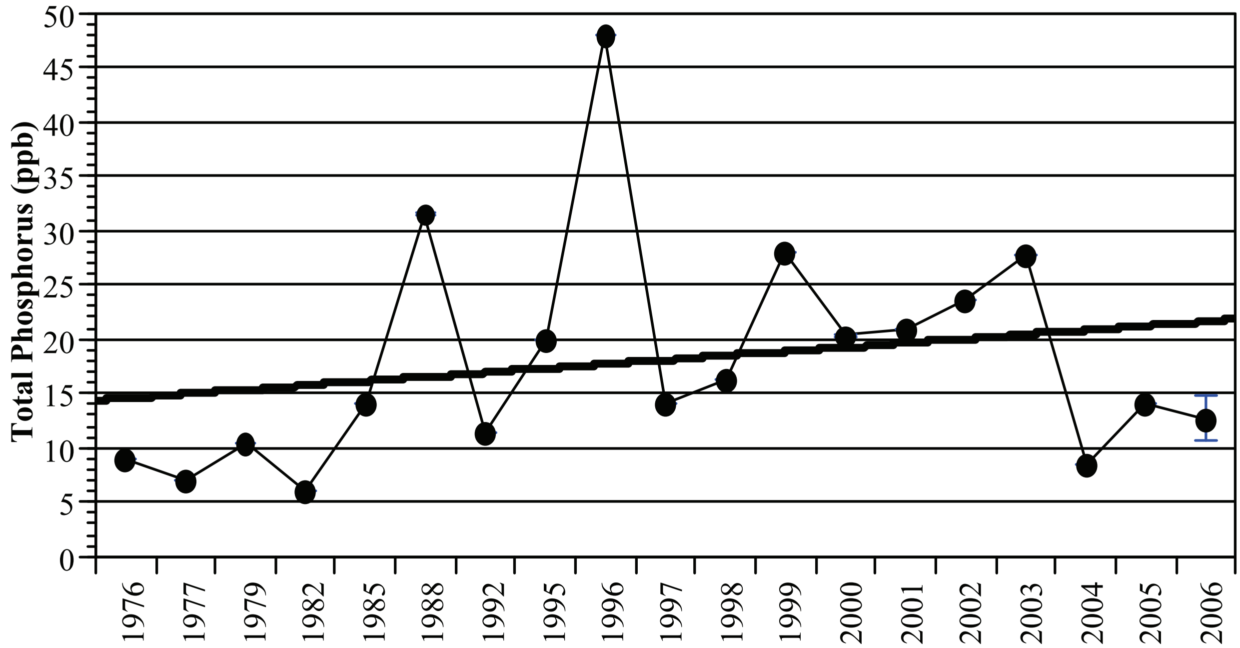

Figure 44. Mean (± SE) bottom total phosphorus concentrations (ppb) and linear trendline from 1976 to 2006 for Long Pond North site 1 (see Figure 28 for site location). Data from 2006 collected by CEAT, all other data from Maine DEP.

<u>BIOLOGICAL PARAMETERS</u>

Chlorophyll-a

Introduction

Chlorophyll is a pigment comprising 1 to 2 percent of the dry weight of photosynthesizing organisms (APHA 2005). It is involved in the pathway that transforms light energy into organic matter. Measurements of chlorophyll-*a* are the most common estimate of relative phytoplankton biomass in a lake, thus providing an indirect estimate of a lake's trophic status (Chapman 1996; Effler et al. 1996). Several factors can influence the growth of algae such as temperature, light (depth), and nutrient levels. Chlorophyll-*a* can fluctuate based on these long-term variables as well as with weather conditions.

Methods

Chlorophyll-*a* profiles were obtained at sites 1, 2, 3, and 4 on 22-Jun-06, 27-Jun-06, 5-Jul-06, 11-Jul-06, 18-Jul-06, 25-Jul-06, 1-Aug-06, 8-Aug-06, 30-Aug-06, and additionally at site 1 on 6-Jun-06, 15-Jun-06, 2-Oct-06 (see Figure 28 for site locations). Fluorescence data was collected using a YSI 650 MDS Sonde probe at one meter intervals. The instrument was calibrated with a zero standard of E-pure water before use (Appendix B). Fluorescence is a more sensitive method to determine the relative chlorophyll-*a* concentration at different sites with respect to the zero standard in parts per billion (ppb). Annual mean chlorophyll concentrations at site 1 were analyzed for a historical perspective (PEARL 2006a)

Results and Discussion

Profile results indicate relatively high chlorophyll concentrations from surface depths down to 9 m (Figure 45). At this level, light is unable to penetrate sufficiently and growth of photosynthetically active algae is limited. As oxygen is a byproduct of photosynthesis, the drop in chlorophyll-*a* correlates with the dissolved oxygen profile (see Figure 29).

The highest chlorophyll-*a* concentrations were found in early August, coinciding with the phosphorus, temperature, and Secchi disk data. These results are indicative that this is the time of peak primary production during the season.

Peak chlorophyll-*a* readings were not correlated directly at surface depths. Ultraviolet sunrays as well as surface turbulence are damaging to cells. The deep hole at site 1 reached maximum chlorophyll-*a* values between 4 m and 6 m. Sites 2 and 3, of intermediate depths reached maximum chlorophyll-*a* values between 4 m and 5 m. The shallowest site, site 4 obtained its highest chlorophyll-*a* levels at 3 m.

Historic mean chlorophyll-*a* concentrations have remained relatively constant below 5 ppb (Figure 46). The highest chlorophyll-*a* level was recorded in 2001 at 9.6 ppb. China Lake, with annual algal blooms, consistently reported values above 10 ppb (CEAT 2006).

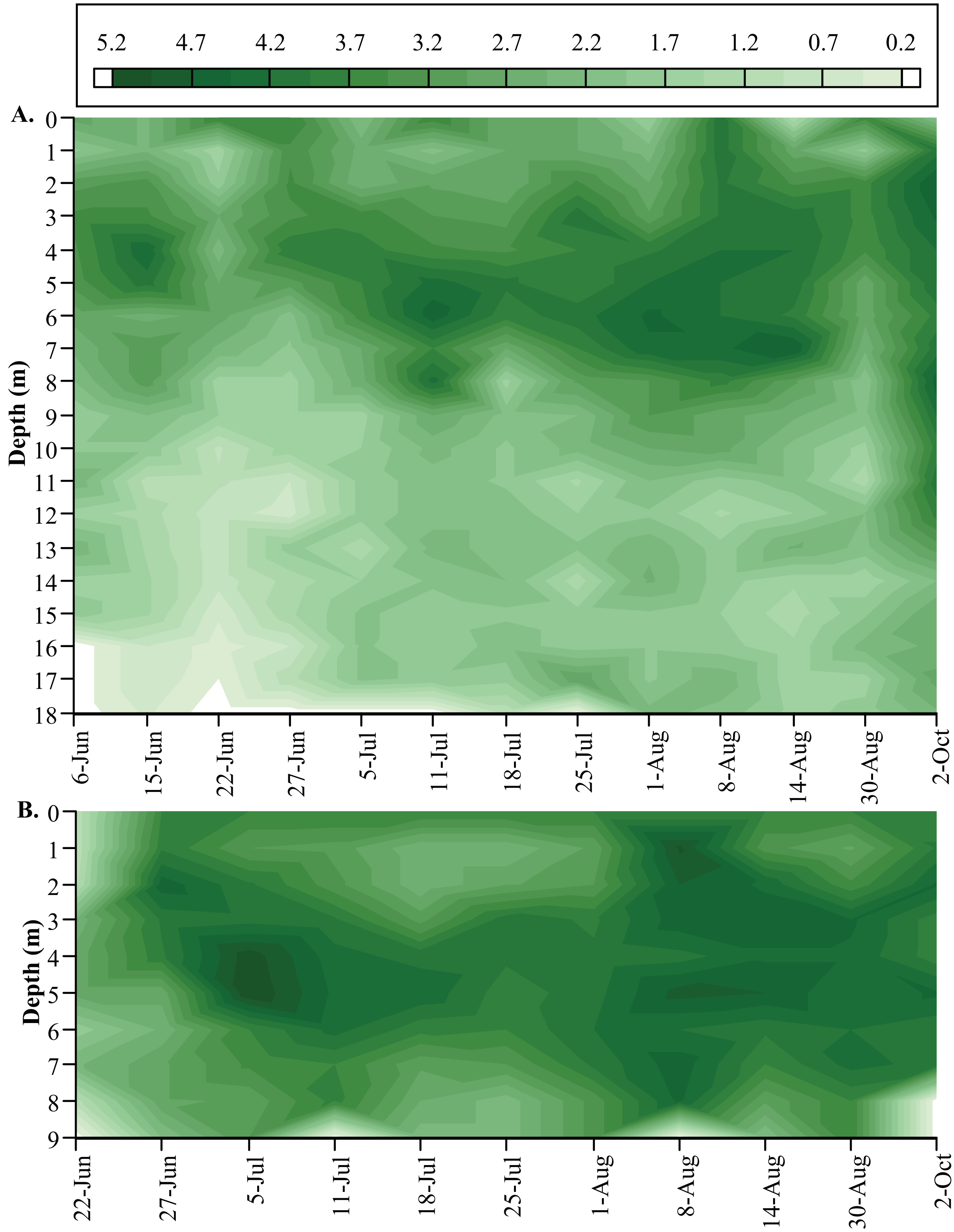

Figure 45. Chlorophyll (ppb) profile in 2006 for Long Pond North at site 1 (A.) and site 2 (B.) (see Figure 28 for site locations).

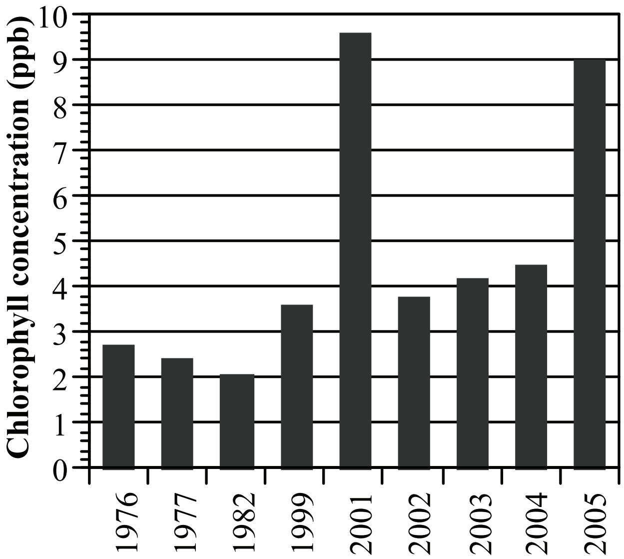

Figure 46. Mean annual chlorophyll concentrations (ppb) at mid-depths in all available years for Long Pond North at site 1 (see Figure 28 for site locations). Data collected by Maine DEP.

WATER BUDGET

INTRODUCTION

A water budget accounts for the inputs and outputs of water in a lake. The primary purpose of calculating a water budget is to determine flushing rate, representative of the annual frequency by which the total volume of lake water is replaced. The flushing rate value is inversely proportional to residence time (length of time the average water molecule remains in the lake) (Chapman 1996).

A water budget provides valuable information for projecting the future lake health under changing land-use practices. The length of time that water is retained in the lake predicts the vulnerability of Long Pond and lake recovery time. All lakes have low flushing rates relative to rivers and streams. As a result, lakes are more susceptible to the accumulation of pollutants and nutrients in the water column, as well as bioaccumulation in aquatic organisms. Relatively low flushing rates among lakes do not alter water quality, but lakes become even more vulnerable as nutrient-loading problems are exacerbated and eutrophication accelerates.

Flushing rate is of primary concern as it influences how quickly nutrients are removed or accumulated. Long Pond South receives water from the North Basin. Any negative changes in Long Pond North will adversely impact the water quality of the south basin in relation to drainage rate. Similarly, Long Pond North is heavily influenced by the water input from Great Pond.

METHODS

The water budget calculates the net water draining into the lake and subtracts the water losses of the lake, resulting in the net input (I_{net}) measured in meters^3/year (see Appendix D). The flushing rate is measured in flushes/year. The following formulas were used to calculate net input and flushing rate (see Appendix D):

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

$$\mathbf{Flushing\ Rate = [(I_{net}\ Long\ Pond) + (I_{net}\ Input_1) + \ldots (I_{net}\ Input_n)] / (volume\ of\ lake)}$$

Lake water level is constantly changing due to seasonal and daily fluctuations in direct rainfall, runoff from the watershed, and evaporation of the lake water. For the purpose of this study, we will use an annual mean water level, assuming that the water entering the lake is equal to the water leaving the lake over the course of a year. I_{net} values were calculated for Long Pond North, as well as for each of the lakes draining into Long Pond North, including Beaver Pond, Great Pond, Kidder Pond, McIntire Pond, Round Pond, Watson Pond, and Whittier Pond (Figure 47). These indirect watershed inputs were added to the direct watershed input and divided by the volume of Long Pond to compute the annual flushing rate.

Calculations of net inputs required several values. The runoff constant (0.62 m/yr) was determined by the Kennebec Regional Planning Commission (KRPC) (unpublished data). The evaporation constant (0.56 m/yr) was based on a study in the Lower Kennebec Basin (Prescott 1969). The mean annual precipitation was measured at the Waterville Treatment Plant and the data supplied by the National Oceanic & Atmospheric Administration (NOAA) over a 10 year period (NOAA 2006).

Characteristics of the watershed of Long Pond, Beaver Pond, McIntire Pond, and Round Pond were calculated using ArcGIS® 9.1 with layers from the Maine Office of GIS (MEGIS 2006). Analysis yielded watershed land area and lake surface area, allowing CEAT to calculate the volume of Long Pond North. For the additional indirect watersheds, Great Pond, Kidder Pond, Watson Pond, and Whittier Pond, information on the lake volume and flushing rates were obtained from the Maine DEP (PEARL 2006c, d, e, f, g, h, i) in order to calculate each I_{net}.

RESULTS AND DISCUSSION

Water enters Long Pond North from spring runoff, storm events, and inflow from other watersheds. Water exits Long Pond North either via evaporation or a culvert beneath Castle Island Road into the South Basin.

The flushing rate of Long Pond North was calculated to be 3.79 flushes/year, such that the water is replaced a little less than 4 times per year. This flushing rate is significantly higher than the average rate of 1 to 1.5 flushes/year for all Maine lakes (MDEP 1996) and the rates of several area lakes (Table 11). The flushing rate of Long Pond North indicates a high cleansing potential and the ability to remove accumulated nutrients, thus helping to explain the high lake

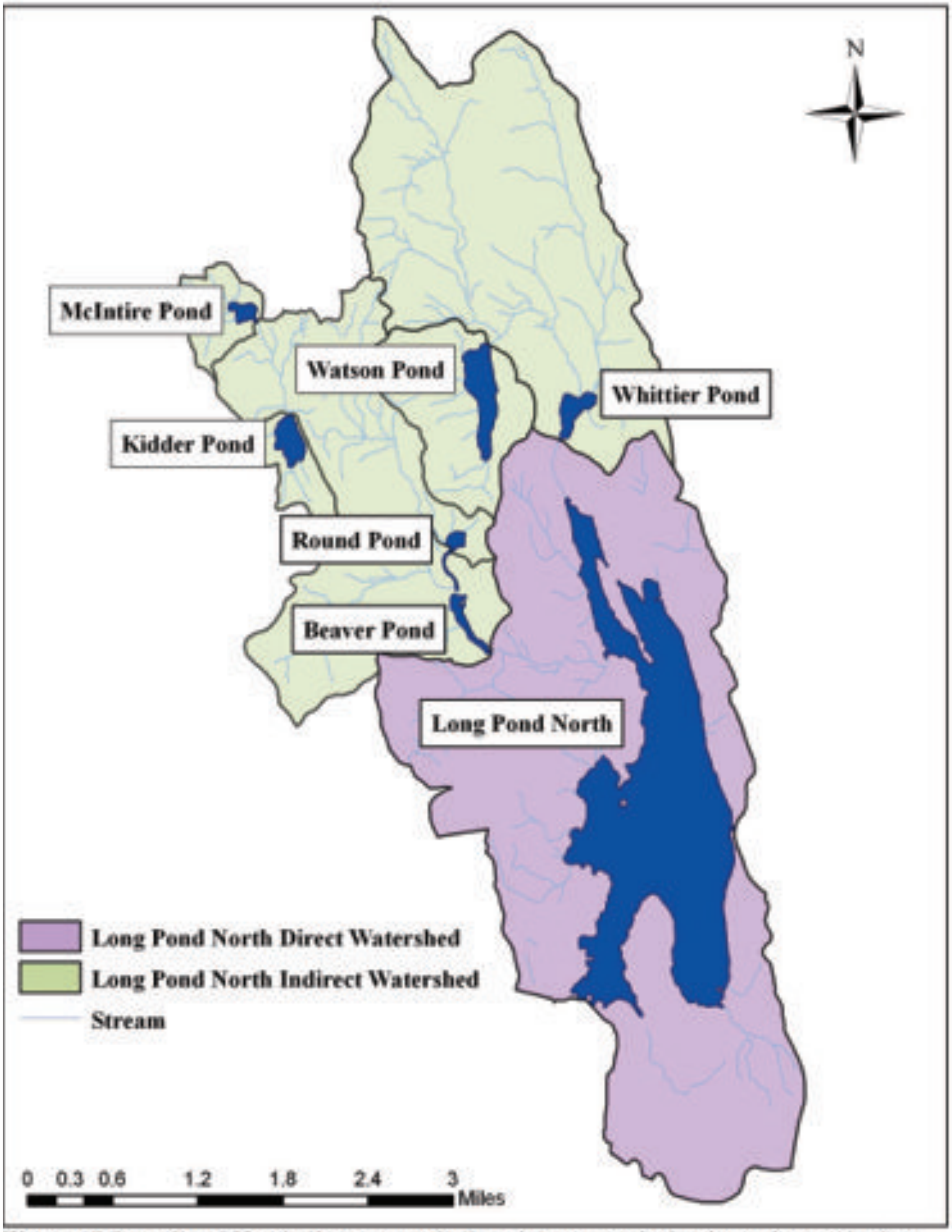

Figure 47. Long Pond North direct watershed, and the watersheds of nearby ponds that feed into Long Pond North. The streams and ponds were obtained from the Maine Office of GIS (MEGIS 2006) and the watersheds were obtained from the Maine DEP.

water quality we observed. The Maine DEP (Pearl 2006a) flushing rate for Long Pond North was slightly lower at 3.5 flushes per year. This slower rate can probably be attributed to a change in what was considered to be the direct and indirect watersheds by the Maine Office of GIS as well as the updated ten year precipitation data.

Table 11. Flushing Rate of Long Pond North and other Belgrade Lakes. Data collected by CEAT (1995, 1997, 1999, 2000, and 2006).

Lake	Flushes/Year	Volume (m^3)	Watershed Area (m^2)
Long Pond, North Basin	3.79	34,922,160	23,161,123
East Pond	0.29	33,848,120	10,598,777
Great Pond	0.43	240,649,445	214,710,000
North Pond	1.36	37,148,856	30,920,000
Salmon Lake/McGrath Pond	0.58	28,410,750	23,126,300

Long Pond is the second to last lake in the Belgrade Lakes chain and is partially dependent on the water quality of all "upstream" lakes. Long Pond receives the majority of its water from Great Pond (77 percent). Thus, Great Pond has a tremendous influence on the water quality of Long Pond (see Phosphorus Budget). CEAT observed that the water input from Great Pond may flow toward the southern outlet and not mix completely with the rest of the lake. If so, the northern lake arms would experience a different turnover rate. They may be more dependent on sediment and surrounding land-use patterns for their water chemistry (see Phosphorus Budget). Further study is necessary.

It is important to monitor the nutrient sources flowing directly into Long Pond North as well as the entire region. As a result of its high flushing rate, Long Pond North is less vulnerable to the accumulation of nutrients and pollutants from its watershed.

PHOSPHORUS BUDGET

INTRODUCTION

A phosphorus loading model can be used to estimate the total amount of phosphorus entering a lake in a given year. This model takes into account factors such as land use, soil type, septic systems, point source pollution, and watershed runoff. A phosphorus budget is helpful in assessing overall water quality and identifying problem areas in terms of phosphorus loading. This model can also be used to predict the effects of future development, land-use changes, and population increases on phosphorus loading.

METHODS

The model used for this study was adapted from Reckhow and Chapra (1983) in order to estimate how much phosphorus enters Long Pond North in a given year:

$$W = (Ec_a \times Area_s) + (Ec_{ag} \times Area_{ag}) + (Ec_{cf} \times Area_{cf}) + (Ec_{df} \times Area_{df}) + (Ec_{gc} \times Area_{gc}) + (Ec_w \times Area_w) + (Ec_c \times Area_c) + (Ec_{cm} \times Area_{cm}) + (Ec_{rl} \times Area_{rl}) + (Ec_{mf} \times Area_{mf}) + (Ec_{pk} \times Area_{pk}) + (Ec_{cr} \times Area_{cr}) + (Ec_{sr} \times Area_{sr}) + (Ec_s \times Area_s) + (Ec_n \times Area_n) + [(Ec_{ss} \times \#\text{ capita years}_n \times (1\text{-}SR_1)) + (Ec_{ns} \times \#\text{ capita years}_n \times (1\text{-}SR_2))] + (Sd_{cs} \times Area_{cs}) + PSI_{gp} + PSI_{bp} + PSI_{wp}$$

W represents the total phosphorus entering Long Pond North in kg/yr. In order to calculate W, export coefficients were first derived. Each coefficient, represented by the Ec term, corresponds to a different land-use type within the watershed and represents how much phosphorus each contributes to the lake in kg/hectare/year. Phosphorus input sources consist of the atmosphere (a), agricultural land (ag), coniferous forest (cf), deciduous forest (df), golf course (gc), wetlands (w), cleared land (c), commercial land (cm), reverting land (rl), mixed forest (mf), park (pk), camp roads (cr), state roads (sr), shoreline development (s), non-shoreline development (n), shoreline septic systems (ss), non-shoreline septic systems (ns), and sediment release (cs). SR_1 and SR_2 are soil retention coefficients and characterize the ability of shoreline and non-shoreline soils to immobilize phosphorus on a scale of 0-1.0 (Reckhow & Chapra 1983). The higher the soil retention coefficient, the more phosphorus is retained and prevented from entering the lake. This value is based on soil phosphorus adsorption capacity, natural drainage, permeability, and slope (Reckhow & Chapra 1983). PSI_{gp}, PSI_{bp}, and PSI_{wp} represent the point-source inputs from Great Pond, Beaver Pond, and Whittier Pond, respectively. See Appendix E for further information about the coefficients used. Each export coefficient was multiplied by the area of its respective land use. A_s represents the surface area of Long Pond North. All other land-use areas were calculated using ArcGIS® 9.1 and 2003 digital orthophoto-quadrangles of the Long Pond North watershed (see Watershed Land-Use Patterns: Methodology).

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 capita year value represents the average number of occupants and average duration of occupancy per household within the watershed. The average number of people per unit was estimated to be 2.54 based a 2000 census (Najpauer, pers. comm.). Year-round and seasonal residences were estimated to be occupied 355 and 95 days of the year, respectively (CEAT 2005).

Low, best, and high estimates of export coefficients were used to provide confidence intervals from possible error resulting from natural fluctuations and estimation. The best estimate coefficients were what CEAT believed to be the best representation for each land-use type. Low, best, and high total phosphorus loading values (W) were calculated with and without sediment release using these coefficients, area of land-use type, and water budget data. The total input of atmospheric and land use phosphorus into Long Pond North (P) was calculated by the following formulas adapted from Reckhow and Chapra (1983):

$L = W / A_s$

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

L is the annual areal phosphorus loading in kg/m^2-yr, derived from dividing the low, best, and high phosphorus loading values (W) by the lake surface area (A_s). This value was then divided by the term ($11.6 + 1.2q_s$), which represents the settling velocity of phosphorus and areal water loading in the lake.

RESULTS AND DISCUSSION

The phosphorus loading model predicted a range of 1303.31 kg to 2259.70 kg phosphorus entering Long Pond North per year from external sources, with a best estimate of 1601.78 kg/yr. The estimate of phosphorus entering the lake from external sources was higher when sediment release (internal phosphorus loading) was taken into account, with a range of 1354.91 kg/yr to 2775.68 kg/yr and a best estimate of 1911.37 kg/yr. The model also calculated total phosphorus concentration, which with sediment release, ranged from 6.2 - 12.7 ppb with a best estimate of 8.7 ppb. The mean total phosphorus concentration for epicore samples collected by CEAT from 6-Jun-06 to 30-Aug-06 at site 1 was 7.6 ppb ± 1.7. This value falls within the range predicted by the model and is close to the best estimate, reinforcing the legitimacy of our model.

To calculate the low, best, and high estimates of phosphorus loading with sediment release, the sediment release export coefficients in the final model were adjusted until their best estimate fell within 7.6 ppb ± 1.7. The sediment coefficient range was 0.1 - 1.0, with a best estimate of 0.6. Compared to studies performed on different anoxic lake sediments, our release rates are very low, but our calculated total phosphorus estimates are overall much lower than the lakes in these studies (Nürnburg 1988, Mattson & Isaac 1999).

The largest sources of phosphorus loading in the Long Pond North watershed are the three point-source inputs from nearby Great Pond, Beaver Pond, and Whittier Pond, altogether contributing 55 percent of the best estimate for total mass phosphorus loading (with sediment release). Most of this phosphorus (a best estimate of 898.72 kg/yr) comes from Great Pond, whose contribution alone equals 47 percent of the best estimate of total phosphorus entering Long Pond North. This finding has significant implications for the health of Long Pond North. Because the majority of external phosphorus is derived from Great Pond, the water quality of Long Pond North is determined to a large degree by the water quality of Great Pond. CEAT found that during summer 2006, surface total phosphorus concentration at Great Pond site 1 (9.34 ppb ± 1.52) was higher than that of Long Pond North site 1 (4.7 ppb ± 0.8). In addition, CEAT observed from satellite images that the water input from Great Pond might flow to the southern basin without mixing with the northernmost waters. Thus, phosphorus loading in the northern and southeast arms may be more affected than the rest of the lake by land-use types and runoff than the center and southwest arms of the lake. Monitoring the water quality of Great Pond is key to maintaining the health of Long Pond North because changes in Great Pond water quality parameters have the potential to significantly affect Long Pond North.

Sediment release accounted for 16 percent of the best estimate for total mass phosphorus loading. Excluding phosphorus input from point sources, the top three phosphorus sources within the direct watershed were shoreline septic, atmospheric input, and camp roads (23, 17, and 15 percent of the best estimate for total mass phosphorus loading, respectively) (Table 12).

Although many of the septic systems around the lake have been updated as a result of new construction or conversion from seasonal to year-round residency, shoreline septic systems still have the potential to contribute a great deal of phosphorus because of their proximity to the lake. Certain sources, such as industry and wood-burning stoves, release phosphorus-containing particulates into the air, which can then enter the lake through precipitation. These particles can travel great distances with wind patterns and consequently may originate from distant sources. Runoff from camp roads may also be a major contributor of phosphorus to a lake because they are mostly unpaved and located close to the shore. Several Long Pond North camp roads were lacking proper drainage or crownage (see Watershed Development Problems: Roads).

Table 12. Percent contribution of phosphorus for all land-use types, determined by low, best, and high estimates of different export coefficients. These calculations do not take into account phosphorus loading from point-source inputs. Values reflect the amount of phosphorus input for each land use under different estimates, relative to the total phosphorus load.

Input Categories	Low Estimate (%)	Best Estimate (%)	High Estimate (%)
Atmospheric	14.8	10.0	6.5
Agricultural	0.3	0.4	0.5
Cleared Land	0.4	0.7	0.9
Coniferous forest	10.9	10.1	7.6
Mixed forest	16.8	19.5	17.6
Deciduous forest	18.5	12.9	9.7
Regenerating land	2.8	2.3	2.6
Wetlands	0.2	0.1	0.1
Park	0.0	0.0	0.0
Golf course	0.4	0.3	0.3
Commercial land	0.3	0.1	0.2
Camp roads	3.3	11.7	13.8
State and municipal roads	1.8	2.8	5.7
Shoreline development	6.0	10.0	7.5
Non-shoreline development	6.8	3.1	4.5
Shoreline septic systems	15.1	13.8	19.5
Non-shoreline septic systems	1.7	2.1	3.0

FUTURE PROJECTIONS

POPULATION TRENDS

HISTORIC POPULATION TRENDS

According to the United States Department of Commerce, Bureau of the Census, the towns of Rome and Belgrade, comprising the Long Pond North direct watershed, underwent significant population growth between 1930 and 2005 (Figure 48). Belgrade's population increased continuously throughout this period. Rome's population, however, displayed some fluctuation. The population of both towns increased dramatically between 1970 and 1980 (Figure 48). Belgrade's Comprehensive Plan suggests that this increase may be attributed to a skewed age distribution during this period. At this time, a number of young adults moved into the township (Town of Belgrade 1987). Similarly, seasonal residences have been converted into year-round residences coinciding with the population increase. Many families, who used their summer camps for seasonal recreation and relaxation, converted their residences into year-round retirement residences as they aged.

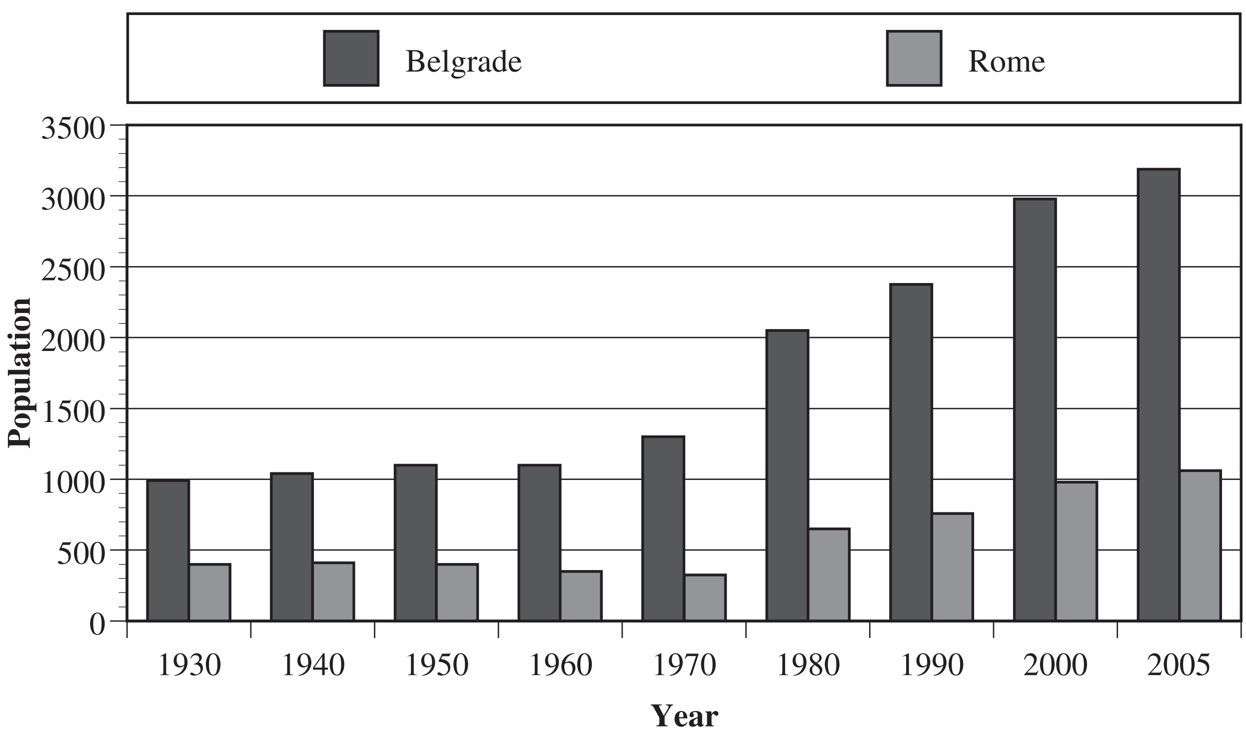

Figure 48. Population counts from the Census Bureau of the United States Department of Commerce for the towns of Belgrade and Rome, Maine for the years 1930-2005 (DOC 1930-2005).

FUTURE POPULATION AND DEVELOPMENT TRENDS

Several factors that contributed to Rome and Belgrade's population boom from 1970 until the present suggest that similar population growth will continue in the future. In the past several decades, the towns of Belgrade and Rome have changed from rural and agriculture-based communities to residential communities. It is unlikely that this trend will change or that farms will be reintroduced into the watershed (Fuller pers. comm.). Development is also likely to continue in the near future. Although many new residences have been constructed in the recent past, many lots are still available and probably will be developed in the future. In a discussion with the Belgrade Code Enforcement Officer Gary Fuller, tax-maps were reviewed, and it was noted that in Belgrade, there are 100 developed lots and 11 lots upon which houses have not been constructed. Although all the lots are owned privately, the 11 undeveloped lots exist where single families own large lots with the potential to be subdivided into multiple lots (Fuller pers. comm.). Mr. Fuller believes that those owners may begin selling their sub-lots as property value rises in the area. Additionally, in Belgrade there is an area with high potential for development bordering the southeastern part of the lake. In Rome, the same phenomenon of development potential exists within the shoreline: there are 262 total shoreline lots, but only 249 are currently developed. Also, in Rome there are two areas currently being developed. In the northwest corner of Long Pond North, development is occurring in Long Pond Estates. Development is also taking place in the southwestern corner of Long Pond North in Wild Flower. In these three development areas, there are several hundred lots that are within 1000 ft of the shoreline. Many of these lots are smaller than the current minimum lot size standard, but these lots may be grandfathered and allowed to undergo development without meeting the new regulations. Even though some development may occur away from the direct shoreline, these structures can still negatively affect water quality, particularly if they are near streams running into Long Pond North.

RECOMMENDATIONS

WATERSHED MANAGEMENT

ROADS

The quality of the camp roads is poorer than that of state roads located in the Long Pond North watershed. Camp roads should be maintained regularly and direct attention should be paid immediately to the problem areas recognized and described in this report.

- Problems should be addressed with attention first paid to those that have greatest effect on the lake.
- Private camp roads should be evaluated annually for crowns, ditches, diversions, turnouts, and culverts, and repair work should be performed accordingly.

LAND USE

All land use within the Long Pond North watershed is likely to affect Long Pond's water quality. The clearing of land for logging, residential, commercial, or agricultural purposes could have the most pronounced effect on Long Pond's trophic status. Deforestation not only eliminates valuable habitat for many plants and animals, but may also lead to greater erosion and results in increased runoff. Forests have the capacity to act as buffers by reducing soil erosion with their canopy and root systems and by sequestering nutrients that may otherwise become incorporated into Long Pond via runoff. Forest clearing will result in the loss of all these ecosystem services.

Agricultural practices typically utilize significant amounts of phosphorus in fertilizers. This phosphorus is highly susceptible to being lost in runoff, and may easily be carried away from the cleared land by stormwater. Agricultural land does not comprise a significant percentage of the Long Pond North direct watershed. Nevertheless, these lands, in addition to the golf course, are potentially important non-point sources of phosphorus and should be considered as such.

In order to maintain acceptable water quality in Long Pond North and to prevent cultural eutrophication, the Colby Environmental Assessment Team (CEAT) recommends that the residents of the Long Pond North watershed consider taking the following actions.

- Continue to monitor residential and commercial development, especially shoreline lots

- Install effective buffer strips to prevent nutrient runoff
- Strictly enforce zoning ordinances in wetland and forested lands
- Monitor phosphorus use in golf course and agricultural areas

BOAT RAMP

The public boat ramp to the south of Castle Island plays an important role in the recreational use of Long Pond. The boat ramp is located in the South Basin and serves as an access point to both basins of Long Pond for many in-state and out-of-state boaters. This ramp is a prime area of concern for accidental introduction of invasive aquatic plants such as milfoil to Long Pond. The Maine Volunteer Lake Monitoring Program (VLMP) frequently conducts surveys and inspects Long Pond in an effort to educate boaters about the hazards of invasive species, as well as to aid with identification of the 11 species considered as threats to the area (VLMP 2006). Public awareness of this issue is a crucial aspect of the prevention process and should continue to be fostered by volunteer programs as well as by other concerned citizens. To prevent invasive species from colonizing Long Pond, CEAT recommends the following.

- Closely inspect boats and trailers for clinging vegetation
- Frequently monitor aquatic vegetation adjacent to the boat ramp
- Remove suspicious plants and report to proper officials
- Increase public awareness of the issue, both at the boat ramp and around Belgrade and Rome

COMMUNITY AWARENESS AND EDUCATION

- The Belgrade Lakes Association (BLA) and their associated programs have performed a lot of work and many service projects.
- There needs to be an effort to involve the entire community. The BLA is based on membership and not all residents are members.
- There has been an effort to include high school students as summer employees on the lake. This program must be expanded.
- The BLA and other organizations should continue to hold demonstrations on good practices within the watershed.

- The Belgrade Regional Conservation Alliance (BRCA) must continue their work to unify the towns and lake alliances in the Belgrade region.
- Belgrade Regional Conservation Corps (BRCC) must continue their work to educate landowners in the art of creating a lake-friendly property.

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APPENDICES

APPENDIX A. WATER-QUALITY MEASUREMENTS AND TESTS

Physical, Chemical and Biological tests preformed between Jun-06 and Oct-06 at various sample sites on Long Pond North (see Figure 28 for site locations).

Measurement or Test	Sample Date	Sample Site
Physical Measurements		
Temperature	22-Jun-06, 27-Jun-06, 5-Jul-06, 11-Jul-06, 18-Jul-06, 25-Jul-06, 1-Aug-06, 8-Aug-06, 14-Aug-06, 30-Aug-06	1, 2, 3, 4
	6-Jun-06, 15-Jun-06, 2-Oct-06	1, 2
DO	22-Jun-06, 27-Jun-06, 5-Jul-06, 11-Jul-06, 18-Jul-06, 25-Jul-06, 1-Aug-06, 8-Aug-06, 14-Aug-06, 30-Aug-06	1, 2, 3, 4
	6-Jun-06, 15-Jun-06	1, 2
	2-Oct-06	1
Transparency	6-Jun-06, 2-Oct-06	1
	13-Jun-06, 6-Jul-06, 12-Jul-06, 18-Jul-06,	1, 2, 3
	22-Jun-06, 27-Jun-06, 1-Aug-06, 8-Aug-06	1, 2, 3, 4
	14-Aug-06	1, 2, 4
	30-Aug-06	1, 3
Turbidity	6-Jun-06, 27-Jun-06, 5-Jul-06, 11-Jul-06	1
	13-Jun-06	1, 2, 3
	22-Jun-06, 18-Jul-06, 25-Jul-06, 1-Aug-06, 8-Aug-06, 14-Aug-06, 30-Aug-06	1, 2, 3, 4
	27-Jun-06	1, 3, 4
	6-Jul-06, 12-Jul-06	2, 3, 4
Chemical Analyses		
pH	22-Jun-06, 27-Jun-06, 5-Jul-06, 11-Jul-06, 18-Jul-06, 25-Jul-06, 1-Aug-06, 8-Aug-06, 14-Aug-06, 30-Aug-06	1, 2, 3, 4
	6-Jun-06, 15-Jun-06, 2-Oct-06	1, 2
Total Phosphorus	6-Jun-06, 11-Jul-06	1
	13-Jun-06, 5-Jul-06	1, 2, 3
	22-Jun-06, 27-Jun-06, 18-Jul-06, 25-Jul-06, 1-Aug-06, 8-Aug-06, 14-Aug-06, 30-Aug-06	1, 2, 3, 4
Biological Analyses		
Chlorophyll-*a*	22-Jun-06, 27-Jun-06, 5-Jul-06, 11-Jul-06, 18-Jul-06, 25-Jul-06, 1-Aug-06, 8-Aug-06, 14-Aug-06, 30-Aug-06	1, 2, 3, 4
	6-Jun-06, 15-Jun-06, 2-Oct-06	1, 2

APPENDIX B. QUALITY ASSURANCE

The Long Pond North study followed a quality assurance plan developed by CEAT to standardize the procedures used. The following document was modified from CEAT (2006).

Bottle Preparation:

1. To make the acid rinse, use 1 L of E-pure and 1 L concentrated hydrochloric acid. The result is a 1:1 ratio HCl:E-pure water.
2. All phosphorus-sample bottles were triple acid rinsed before use to avoid contamination of the sample

Approaching Site:

1. When approaching the test site, accelerate, then turn off the engine and coast to the sampling site to limit stirring the surface water.
2. Always sample into the wind and from the bow of the boat.

Surface Sampling:

1. Remove the 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 horizontally through the water away from the boat.
3. Tilt the bottle upright, remove from water, and replace the cap. Place the bottle in the cooler on ice.

Secchi Disk:

1. Use the Aqua-scope to view the disk.
2. Lower the disk on the shady side of the boat until it disappears from view, then record the depth.
3. Bring the disk back to the surface and repeat the process two more times.

Measuring Depth:

1. Use LCD Digital Sounder (Depth Finder) or boat sonar.
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 three seconds.
4. Point the depth finder straight down. Record this depth.
5. Repeat the process once.

Turbidity:

1. Measure turbidity using the HACH 2100 Portable Turbidimeter (HACH 1999).
2. Used cleaned sample cells included with the portable turbidimeter.

3. Conduct analysis in the field using the calibrated instrument (calibrated with three standards). Follow surface sampling procedure.
4. Samples were read on site.

YSI 560 MDS (Multiparameter Display System) Sonde

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

pH:

A. Calibration: Before any test is performed, the probe of the 650 MDS Sonde must be calibrated using a 2-point calibration method at pH 4 and pH 7. This should be done once during the testing day, provided the calibration entered into the meter is not accidentally deleted.
    1. Press the POWER button. The pH meter automatically enters the measurement.
    2. Press CALIBRATE and ISEI pH. Then press 2 POINT.
    3. Enter the Sonde standard pH value and insert probe into pH 7 solution. Go to Sonde menu.
    4. After calibration, rinse the sensor thoroughly with E-pure water.
    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 5.56.
    7. Be sure to rinse the probe with distilled water prior to and following each measurement.
B. Measurement.
    1. Immerse the Sonde 0.5 m to 1.0 m below the surface.
    2. Go to SONDE RUN in the 650 main menu. Wait for the probe to stabilize.
    3. Highlight "Log One Sample" and press the ENTER arrow at one meter intervals.
C. Quality Assurance.
    1. Take the pH reading twice at each site to assure accuracy.

Dissolved Oxygen:

1. Calibrate the probe of the 650 MDS Sonde in the saturated air chamber after the proper warm-up time.
2. Lower the Sonde into the water, shaking it gently to make sure there are not bubbles around the probe.
3. Immerse the probe until covered. Record measurements as described above.

Mid-depth and Bottom Sample:

1. Pull the 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 the depth reading, lower the sampler to mid-depth to sample.
4. Release the sliding weight to close water sampler.

5. Pull out the water sampler. Open the air valve and the black tap by pushing the outside ring of the tap in. Drain the tap for a few seconds.
6. Fill the sample bottle and place it in the cooler on ice.
7. Empty the water sampler. Repeat the sampling procedure for the bottom sample.
8. Take the bottom sample one meter above the bottom to avoid sediment contamination.

Epicore Samples:

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 for a thermocline, lower the tube one meter below the epilimnion into the thermocline (determined from the DO/temperature profile).
3. For shallow depths, lower the tube to one meter from the bottom.
4. The tape marks on the tube indicate one meter.
5. Crimp the tubing just above the water (best done by bending it tightly, twisting, and then holding it in one hand).
6. Pull the tubing up, making sure that the excess tubing goes into the water and not the boat. 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 to raise the tubing and move towards the draining end.
10. Repeat the process three times, draining all of the water into the epicore mixing bottle.
11. Pour about 125 mL each of this water into two PPM 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 on ice.

Quality Control Sampling:

1. Spike E-pure samples with a known amount of concentrated standard and run against a standard curve to confirm the accuracy of technician before water samples were analyzed. This accuracy test is repeated until the values of the test samples are within 10% of each other.
2. Duplicate samples every tenth sample to test the accuracy of sampling procedures.
3. Split samples every tenth sample in the laboratory to test the lab procedure.
4. Run one control with each set of samples analyzed.

Total Phosphorus:

1. Collect and make splits and duplicates for every ten samples.
2. Make standard solutions of known concentrations with each testing to ensure lab precision.

3. Use reagent blanks 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 has a detection point less than 1 ppb.
5. Preserve water samples for analysis by digesting with sulfuric acid and ammonium peroxydisulfate, and then autoclave at 15 psi for 30 mintues.
6. Conduct analysis within 28 days of sampling date.

APPENDIX C. PHYSICAL MEASUREMENTS AND CHEMICAL ANALYSES OF LONG POND WATER QUALITY

Physical tests: Temperature (˚C) and dissolved oxygen concentration (ppm) at sites 1-4 (see Figure 28 for site locations). Data collected using a YSI Sonde.

	6-Jun-06		15-Jun-06		22-Jun-06		27-Jun-06		5-Jul-06		11-Jul-06		18-Jul-06	
Depth (m)	Temp.	DO	Temp.	DO	Temp.	DO	Temp.	DO	Temp.	DO	Temp.	DO	Temp.	DO
Site 1														
0	19.26	8.73	18.02	11.65	22.33	10.35	22.37	13.12	23.87	10.84	25.69	10.81	27.66	10.41
1	17.64	8.95	18.04	10.22	22.29	9.36	22.55	9.97	23.77	9.22	25.63	10.09	26.92	8.85
2	17.24	8.93	18.02	10.14	22.18	9.35	22.38	9.88	23.51	9.23	25.59	10.08	26.78	8.96
3	17.14	8.87	17.97	10.06	21.71	9.39	22.23	9.86	23.37	9.17	25.15	8.33	25.16	9.35
4	16.82	8.76	17.92	10.03	20.10	9.73	22.07	9.83	23.27	9.10	24.86	10.14	25.09	7.34
5	15.99	8.72	17.835	10.35	19.81	9.47	20.1	9.98	22.34	8.88	24.45	9.925	24.83	9.22
6	15.47	8.72	17.8	10.49	19.47	9.48	19.48	9.08	22.3	8.77	22.04	10.17	21.83	9.40
7	14.99	8.51	17.76	10.34	18.27	9.26	17.83	9.47	18.84	8.29	20.18	10.59	19.70	7.74
8	14.30	8.52	17.41	10.22	17.94	9.23	16.04	9.56	15.98	8.31	17.6	9.86	17.49	7.02
9	13.89	8.28	14.58	10.07	14.49	9.84	14.04	8.42	14.70	6.81	15.56	8.74	15.05	6.73
10	11.52	8.46	13.74	9.19	13.56	8.86	13.58	7.98	13.40	6.83	14.16	7.98	13.38	6.26
11	11.07	7.65	11.53	9.32	13.08	8.24	12.93	7.69	12.96	6.41	13.69	7.25	13.18	5.71
12	10.81	7.31	10.7	8.12	12.59	7.84	12.32	7.36	12.18	6.16	12.58	6.88	12.36	5.19
13	10.54	7.25	10.68	7.94	11.98	7.48	11.73	7.05	10.93	5.79	11.7	6.56	11.93	4.80
14	10.335	7.01	10.52	7.84	11.54	7.11	11.45	6.82	10.84	5.25	10.95	6.11	11.73	4.63
15	9.99	6.89	10.19	7.74	11.47	6.97	11.22	6.65	10.8	4.98	10.88	5.44	11.48	4.29
16	-	-	9.92	7.49	11.34	6.77	11.12	6.47	10.73	4.69	10.75	4.63	11.38	4.11
17	-	-	9.86	7.17	11.07	6.68	11.03	6.21	10.67	4.52	10.73	4.44	10.93	3.72
18	-	-	9.83	7.08	10.73	6.43	-	-	10.66	4.31	10.69	4.12	10.89	3.45

APPENDIX C. (Continued)

	6-Jun-06		15-Jun-06		22-Jun-06		27-Jun-06		5-Jul-06		11-Jul-06		18-Jul-06	
Depth (m)	Temp.	DO	Temp.	DO	Temp.	DO	Temp.	DO	Temp.	DO	Temp.	DO	Temp.	DO
Site 2														
0	-	-	-	-	22.23	10.05	22.06	12.73	23.89	13.19	24.97	11.43	27.26	11.84
1	-	-	-	-	22.14	9.22	21.68	10.24	23.50	9.99	24.62	8.75	26.49	9.36
2	-	-	-	-	21.99	9.25	20.88	10.02	23.16	9.84	24.32	8.83	26.05	9.38
3	-	-	-	-	20.96	9.45	20.25	9.83	23.12	9.69	24.18	8.78	25.87	9.32
4	-	-	-	-	19.91	9.64	19.6	9.8	22.86	9.55	24.00	8.69	25.64	9.25
5	-	-	-	-	19.62	9.65	18.98	9.58	22.77	9.53	23.75	8.68	25.22	9.34
6	-	-	-	-	18.83	9.60	18.02	9.49	21.87	9.28	22.96	8.63	21.65	9.50
7	-	-	-	-	18.03	9.34	17.15	9.16	19.67	9.49	21.27	8.07	19.53	8.30
8	-	-	-	-	16.53	8.83	16.15	8.79	15.97	8.64	17.71	8.09	17.63	7.39
9	-	-	-	-	15.78	8.56	12.67	8.79	15.06	7.67	16.52	7.12	15.67	6.44
Site 3														
0	-	-	-	-	23.05	11.81	23.26	12.88	24.41	10.86	26.04	8.70	29.11	11.08
1	-	-	-	-	23.05	9.41	23.25	10.12	24.27	8.99	25.89	8.77	28.63	8.95
2	-	-	-	-	23.04	9.33	23.18	10.09	24.06	9.01	25.8	8.80	28.50	8.85
3	-	-	-	-	23.02	9.26	23.10	9.98	23.81	9.01	25.6	8.77	28.40	8.88
4	-	-	-	-	22.78	9.06	23.08	9.93	23.70	8.94	25.05	8.72	25.72	9.51
5	-	-	-	-	22.57	9.30	23.05	9.87	22.93	8.89	22.91	9.20	23.82	9.34
6	-	-	-	-	18.52	10.51	23.03	9.81	21.92	8.76	21.78	8.39	22.50	8.73
7	-	-	-	-	16.38	9.93	22.91	9.76	20.29	8.71	20.76	7.95	21.18	7.91
8	-	-	-	-	15.61	9.13	22.87	9.67	18.92	8.01	20.34	7.55	19.99	6.92
Site 4														
0	-	-	-	-	23.15	10.41	23.75	12.71	24.65	9.62	26.32	8.43	29.47	8.66
1	-	-	-	-	23.15	9.57	23.72	9.85	24.37	9.32	26.07	8.51	28.93	8.79
2	-	-	-	-	23.09	9.42	23.7	9.74	24.28	9.29	25.98	8.52	28.74	8.65
3	-	-	-	-	23.04	9.34	23.59	9.62	23.9	9.13	25.88	8.46	28.52	8.54
4	-	-	-	-	22.65	9.50	23.13	9.58	23.71	9.04	25.14	8.33	27.77	8.57
5	-	-	-	-	22.16		23.03		-		23.35		-	

APPENDIX C. (Continued)

	25-Jul-06		1-Aug-06		8-Aug-06		14-Aug-06		30-Aug-06		2-Oct-06	
Depth (m)	Temp.	DO	Temp.	DO	Temp.	DO	Temp.	DO	Temp.	DO	Temp.	DO
Site 1												
0	25.27	9.82	26.79	10.46	25.02	10.93	22.61	7.68	21.41	9.38	16.99	8.445
1	25.26	9.26	25.99	10.43	25.15	10.82	22.57	7.78	21.37	9.11	17.00	8.34
2	25.22	9.24	25.97	10.47	25.14	10.82	22.50	7.82	21.19	9.05	17.00	8.55
3	25.16	9.28	25.70	10.45	25.13	10.8	22.50	7.79	20.96	8.91	17.00	8.60
4	25.08	9.25	25.55	10.44	25.12	10.81	22.45	7.78	20.77	8.66	17.00	8.63
5	24.41	9.25	25.19	10.17	25.06	10.82	22.41	7.68	20.74	8.48	17.00	8.79
6	22.85	8.83	24.82	10.04	25.04	10.76	22.40	7.68	20.73	8.45	17.00	8.78
7	20.03	7.36	21.35	9.19	21.86	9.97	22.38	7.79	20.70	8.43	17.00	8.75
8	17.76	6.15	17.83	6.97	17.97	7.94	17.74	1.85	20.14	5.26	17.00	8.73
9	15.83	5.34	15.15	6.23	15.88	5.21	16.48	1.76	16.37	1.46	17.00	8.76
10	13.87	4.97	14.38	4.11	14.62	4.09	14.81	1.40	14.42	0.44	17.00	8.69
11	12.89	4.54	13.17	3.94	13.71	3.80	13.47	1.22	12.74	0.28	17.00	8.73
12	12.22	4.31	12.33	3.53	12.72	3.19	12.77	1.13	12.07	0.25	17.00	9.33
13	11.64	3.90	11.91	3.34	12.11	2.94	11.68	0.75	11.78	0.18	15.43	7.83
14	11.60	3.59	11.52	3.19	11.68	2.74	11.51	0.62	11.36	0.15	13.85	0.95
15	11.53	3.52	11.29	2.90	11.16	1.93	11.15	0	11.19	0.13	11.69	0.62
16	11.26	3.43	11.18	2.56	11.09	1.37	11.12	0	11.10	0.10	11.62	0.40
17	10.93	3.02	11.08	2.23	11.06	0.90	11.12	0	11.08	0.10	11.51	0.32
18	-	3.02	11.05	1.97	11.05	0.79	11.12	0.1	11.02	0.10	11.48	0.25
19	-	-	11.01	1.77	11.04	0.73	-	0.1	10.99	0.09	11.34	0.25
20	-	-	11.01	1.64	11.02	0.67	-	0.1	-	0.09	-	0.25

APPENDIX C. (Continued)

	25-Jul-06		1-Aug-06		8-Aug-06		14-Aug-06		30-Aug-06		2-Oct-06	
Depth (m)	Temp.	DO	Temp.	DO	Temp.	DO	Temp.	DO	Temp.	DO	Temp.	DO
Site 2												
0	25.44	14.55	26.44	10.2	24.92	11.29	23.18	-	21.46	9.53	16.92	-
1	25.41	9.67	25.85	9.96	24.96	10.81	22.93	-	21.42	9.18	16.95	-
2	25.27	9.67	25.68	10.02	24.96	10.79	22.76	-	21.38	9.17	16.95	-
3	25.11	9.59	25.62	9.99	24.96	10.79	22.62	-	21.33	9.17	16.95	-
4	24.88	9.43	25.57	10.01	24.96	10.88	22.54	-	21.28	9.17	16.95	-
5	23.64	9.51	25.12	9.99	24.95	10.86	22.52	-	21.26	9.18	16.95	-
6	22.29	8.61	23.97	9.30	24.94	10.83	22.51	-	20.90	9.18	16.95	-
7	19.67	7.74	21.63	8.34	24.93	10.86	22.11	-	20.80	9.00	16.95	-
8	16.41	6.33	18.06	6.57	24.87	10.88	18.21	-	20.76	8.805	-	-
9	16.16	5.32	16.45	5.24	-	10.88	16.28	-	20.73	8.81	-	-
Site 3												
0	25.04	11.73	26.76	9.74	22.92	10.42	22.92	-	21.55	9.35	-	-
1	25.04	9.75	26.65	9.77	22.82	10.49	22.82	-	21.48	9.08	-	-
2	24.99	9.81	26.48	9.78	22.84	10.55	22.84	-	21.00	9.10	-	-
3	24.93	9.76	26.25	9.76	22.63	10.59	22.63	-	20.91	9.00	-	-
4	24.91	9.75	26.11	9.80	22.50	10.51	22.50	-	20.85	8.91	-	-
5	24.87	9.76	25.82	9.80	22.44	10.00	22.44	-	20.82	8.83	-	-
6	24.80	9.66	23.95	9.54	22.35	8.83	22.35	-	20.80	8.91	-	-
7	24.76	9.65	20.32	7.72	22.04	6.79	22.04	-	20.79	9.02	-	-
8	22.48	9.64	19.21	5.95	21.97	5.08	21.97	-	-	9.00	-	-
	17.49	-	-	-	-	-	-	-	-	-	-	-
Site 4												
0	25.12	11.69	26.65	9.67	25.60	10.78	22.91	-	21.58	9.01	-	-
1	25.11	9.70	26.34	9.61	25.74	10.82	22.88	-	21.25	8.95	-	-
2	25.08	9.64	26.26	9.64	25.69	10.76	22.73	-	20.95	8.96	-	-
3	25.08	9.66	26.08	9.62	25.52	10.75	22.43	-	20.77	8.89	-	-
4	25.03	9.61	25.70	9.29	25.31	10.42	22.32	-	20.67	8.91	-	-

APPENDIX C. (Continued)

Chemical and Biological Tests: pH and chlorophyll-*a* concentration (ppb) at sites 1-4 (Figure II.D.1.1). Data collected using a YSI Sonde.

	6-Jun-06		15-Jun-06		22-Jun-06		27-Jun-06		5-Jul-06		11-Jul-06		18-Jul-06	
Depth (m)	pH	Chloro.	pH	Chloro.	pH	Chloro.	pH	Chloro.	pH	Chloro.	pH	Chloro.	pH	Chloro.
Site 1														
0	7.44	2.8	7.36	2.4	7.25	3.7	7.38	3.7	7.19	2.2	7.43	3.7	7.37	2.7
1	7.44	1.9	7.19	2.4	7.24	1.5	7.25	3.4	7.15	2.6	7.31	2.1	7.355	2.7
2	7.44	3.1	7.15	3.3	7.24	1.8	7.23	3.5	7.14	2.5	7.29	2.9	7.34	2.7
3	7.42	3.5	7.12	3.5	7.23	2.7	7.21	3.4	7.13	3.6	7.29	3.2	7.35	3.1
4	7.40	3.4	7.10	4.4	7.20	2.3	7.20	3.9	7.12	3.8	7.27	3.5	7.34	3.4
5	7.38	3.3	7.095	4.1	7.18	2.7	7.15	3.1	7.06	3.7	7.26	4.3	7.32	4.0
6	7.35	2.8	7.09	2.6	7.15	2.8	7.00	2.1	7.04	3.6	7.22	4.6	7.24	3.8
7	7.30	2.5	7.08	3.1	7.08	2.4	6.97	1.9	6.88	2.7	7.12	3.7	7.03	2.7
8	7.26	2.2	7.05	3.1	7.05	1.6	6.92	1.6	6.79	2.6	6.96	4.3	6.94	1.6
9	7.20	1.7	6.97	2.2	7.02	1.7	6.80	1.6	6.49	1.6	6.85	2.7	6.84	2.1
10	7.15	1.9	6.87	1.9	6.92	0.9	6.74	1.6	6.47	1.7	6.72	2.3	6.75	1.9
11	7.08	2.4	6.81	1.1	6.85	1.0	6.69	0.7	6.41	1.8	6.66	2.1	6.69	1.9
12	7.01	1.6	6.71	1.3	6.80	0.8	6.63	0.6	6.37	1.8	6.59	2.1	6.63	2.1
13	6.98	2.4	6.67	1.4	6.75	0.8	6.59	1.8	6.32	1.3	6.54	2.3	6.57	2.1
14	6.87	1.6	6.64	1.5	6.70	0.8	6.57	1.3	6.30	1.7	6.46	2.0	6.53	2.2
15	6.81	1.83	6.61	1.5	6.66	0.5	6.54	1.4	6.28	2.0	6.42	1.8	6.49	1.9
16	-	-	6.57	0.7	6.63	0.3	6.51	0.7	6.24	2.0	6.39	1.7	6.46	2.1
17	-	-	6.53	0.7	6.60	0.2	6.48	1.1	6.23	2.0	6.37	1.9	6.43	1.8
18	-	-	6.51	0.5	6.57	-	6.45	-	6.20	-	6.35	-	6.40	1.0

APPENDIX C. (Continued)

	6-Jun-06		15-Jun-06		22-Jun-06		27-Jun-06		5-Jul-06		11-Jul-06		18-Jul-06	
Depth (m)	pH	Chloro.	pH	Chloro.	pH	Chloro.	pH	Chloro.	pH	Chloro.	pH	Chloro.	pH	Chloro.
Site 2														
0	-	-	-	-	7.24	1.0	7.47	3.7	7.30	3.7	7.33	3.7	7.44	3.7
1	-	-	-	-	7.21	1.0	7.30	3.9	7.24	3.2	7.29	3.1	7.42	2.5
2	-	-	-	-	7.20	1.1	7.21	4.6	7.22	4.0	7.28	3.3	7.42	2.5
3	-	-	-	-	7.20	2.5	7.15	4.0	7.21	4.1	7.27	4.0	7.41	3.1
4	-	-	-	-	7.16	2.8	7.10	3.9	7.18	5.1	7.24	4.3	7.40	4.1
5	-	-	-	-	7.13	2.8	7.04	2.8	7.15	5.2	7.24	4.4	7.38	4.4
6	-	-	-	-	7.11	1.8	7.00	2.5	7.10	3.7	7.19	4.3	7.27	3.8
7	-	-	-	-	7.04	2.4	6.93	2.9	7.04	3.5	7.10	3.7	7.12	3.0
8	-	-	-	-	6.96	1.1	6.87	2.9	6.90	3.0	7.01	3.8	6.98	2.7
9	-	-	-	-	6.87	-	6.78	2.2	6.80	3.2	6.94	-	6.88	2.3
Site 3														
0	-	-	-	-	7.27	3.7	7.37	3.7	7.23	2.5	7.46	1.9	7.54	3.7
1	-	-	-	-	7.25	3.4	7.31	3.5	7.20	1.9	7.34	2.5	7.47	2.7
2	-	-	-	-	7.24	3.6	7.29	3.9	7.19	3.1	7.32	2.6	7.44	2.2
3	-	-	-	-	7.23	3.5	7.29	4.6	7.18	4.0	7.31	2.8	7.42	2.2
4	-	-	-	-	7.23	6.3	7.30	4.7	7.17	3.4	7.29	3.2	7.41	3.1
5	-	-	-	-	7.22	4.8	7.29	4.8	7.11	3.2	7.25	3.5	7.34	4.7
6	-	-	-	-	7.21	4.2	7.29	4.9	7.04	3.0	7.15	2.9	7.24	4.1
7	-	-	-	-	7.15	3.0	7.28	4.7	7.01	2.8	7.08	3.0	7.10	3.4
8	-	-	-	-	7.06	2.8	7.28	4.7	6.90	3.0	7.00	2.7	6.97	2.9
Site 4														
0	-	-	-	-	7.24	3.7	7.66	3.7	7.32	2.4	7.74	5.6	7.59	2.4
1	-	-	-	-	7.21	2.7	7.49	3.7	7.28	2.8	7.37	5.7	7.47	1.9
2	-	-	-	-	7.20	3.4	7.45	4.2	7.26	2.9	7.32	5.7	7.41	2.0
3	-	-	-	-	7.18	4.6	7.4	5.7	7.21	4.3	7.28	6.6	7.37	2.4
4	-	-	-	-	7.16	3.3	7.35	3.7	7.18	3.9	7.20	6.3	7.34	2.4

APPENDIX C. (Continued)

	25-Jul-06		1-Aug-06		8-Aug-06		14-Aug-06		30-Aug-06		2-Oct-06	
Depth (m)	**pH**	**Chloro.**	**pH**	**Chloro.**	**pH**	**Chloro.**	**pH**	**Chloro.**	**pH**	**Chloro.**	**pH**	**Chloro.**
Site 1												
0	7.32	2.7	7.32	1.7	7.74	4.1	7.49	1.2	7.72	3.6	7.42	2.1
1	7.32	2.7	7.17	2.3	7.345	4.1	7.14	2.8	7.42	1.8	7.19	4.1
2	7.32	3.5	7.16	2.7	7.27	4.0	7.08	3.4	7.31	3.6	7.14	4.7
3	7.32	4.1	7.15	3.0	7.25	4.0	7.05	4.1	7.25	3.6	7.07	4.5
4	7.32	3.7	7.13	3.9	7.23	4.2	7.03	4.2	7.18	3.5	7.01	4.2
5	7.29	3.7	7.07	4.2	7.20	4.2	7.01	4.1	7.11	2.8	6.98	4.2
6	7.18	4.1	7.02	4.5	7.18	4.2	7.00	3.9	7.04	2.8	6.96	3.8
7	6.95	3.7	6.85	4.4	6.99	4.4	6.99	4.7	7.01	2.5	6.94	4.1
8	6.81	3.0	6.65	3.2	6.79	3.8	6.78	3.0	6.74	2.0	6.93	4.6
9	6.70	2.2	6.45	3.2	6.63	2.8	6.55	2.5	6.45	2.1	6.93	4.2
10	6.63	2.3	6.28	2.7	6.52	2.8	6.46	2.1	6.26	1.6	6.91	3.8
11	6.57	1.4	6.24	2.2	6.47	1.8	6.34	2.1	6.13	1.3	6.9	4.1
12	6.52	1.7	6.19	1.9	6.41	1.4	6.3	1.7	6.10	2.2	6.86	3.8
13	6.48	2.0	6.16	2.4	6.37	1.8	6.25	2.5	6.08	2.1	6.68	3.1
14	6.45	1.3	6.13	2.5	6.33	1.8	6.22	1.5	6.06	1.5	6.57	2.2
15	6.41	1.8	6.11	1.9	6.29	1.7	6.19	1.3	6.10	1.9	6.49	2.7
16	6.39	1.8	6.09	1.9	6.24	1.8	6.17	1.5	6.15	2.3	6.49	2.5
17	6.35	2.9	6.07	1.9	6.15	2.4	6.16	1.5	6.15	1.6	6.49	2.8
18	-	-	6.05	2.3	6.15	2.1	6.15	1.6	6.16	1.8	6.50	2.4
19	-	-	6.03	2.2	6.13	1.8	-	-	6.19	2.2	-	-
20	-	-	-	2.3	6.11	-	-	-	-	-	-	-

APPENDIX C. (Continued)

	25-Jul-06		1-Aug-06		8-Aug-06		14-Aug-06		30-Aug-06		2-Oct-06	
Depth (m)	pH	Chloro.	pH	Chloro.	pH	Chloro.	pH	Chloro.	pH	Chloro.	pH	Chloro.
Site 2												
0	7.44	3.7	7.03	3.7	7.12	3.7	6.99	3.7	6.94	3.7	7.60	3.7
1	7.39	2.5	7.03	3.0	7.05	5.0	6.98	3.3	6.85	2.9	7.10	4.0
2	7.38	2.9	7.05	3.2	7.04	4.7	6.98	4.4	6.84	3.5	7.04	4.5
3	7.37	4.1	7.05	3.9	7.03	4.6	6.98	4.6	6.84	4.5	7.00	3.8
4	7.34	4.0	7.05	4.0	7.03	4.1	6.97	4.4	6.84	4.4	6.97	3.8
5	7.29	3.8	7.01	4.1	7.03	4.8	6.96	4.7	6.84	4.2	6.95	4.5
6	7.12	3.7	6.89	4.2	7.03	4.2	6.96	4.0	6.84	4.2	6.94	4.0
7	6.96	3.2	6.71	4.0	7.03	4.6	6.92	3.7	6.82	4.3	6.93	4.1
8	6.80	2.3	6.52	3.3	7.03	4.5	6.73	3.0	6.80	3.7	6.91	-
9	6.74	2.3	6.43	3.3	7.03	-	6.52	2.2	6.79	3.7	6.91	-
Site 3												
0	7.45	3.7	6.98	3.0	7.61	3.7	7.12	2.9	7.36	1.7	-	-
1	7.38	2.9	6.99	2.7	7.43	3.2	7.07	3.5	7.06	2.6	-	-
2	7.37	3.2	6.98	3.0	7.39	4.4	7.04	4.0	7.01	2.8	-	-
3	7.36	4.2	6.98	3.2	7.36	5.0	7.02	3.8	6.97	3.6	-	-
4	7.35	4.1	6.99	3.0	7.29	5.2	7.01	3.9	6.94	3.6	-	-
5	7.34	3.5	6.98	3.9	7.21	4.8	6.96	3.9	6.91	3.8	-	-
6	7.33	3.8	6.90	4.5	6.99	4.4	6.95	4.1	6.90	4.5	-	-
7	7.31	3.6	6.66	4.3	6.79	3.4	6.93	3.6	6.90	3.0	-	-
8	7.20	3.6	6.49	3.5	6.61	3.5	6.90	5.1	6.90	-	-	-
Site 4												
0	7.52	3.7	6.82	1.4	8.06	0.9	7.14	3.3	7.27	1.8	-	-
1	7.37	2	6.84	2.4	7.53	3.3	7.06	3.0	7.02	2.1	-	-
2	7.32	2.8	6.85	2.3	7.41	3.8	7.02	3.3	6.97	3.8	-	-
3	7.30	3.6	6.84	2.8	7.33	4.2	6.99	3.5	6.93	4.6	-	-
4	7.27	3.3	6.80	3.4	7.21	3.5	6.98	3.2	6.91	3.5	-	-

APPENDIX C. (Continued)

Chemical Tests: Total Phosphorus (ppb) (see Figure 28 for site locations)

	6-Jun-06	13-Jun-06	22-Jun-06	27-Jun-06	5-Jul-06	11-Jul-06	18-Jul-06	25-Jul-06	1-Aug-06	8-Aug-06	14-Aug-06	30-Aug-06
Site 1												
Surface	5.0	3.8	2.0	27.5	7.1	3.7	4.6	1.9	1.4	7.7	9.2	5.2
Middle	21.4	5.2	8.6	24.7	9.8	6.4	5.3	4.5	5.1	5.8	7.2	9.8
Bottom	7.2	5.2	7.5	26.7	9.8	10.7	10.1	9.6	12.5	14.4	15.6	23.8
Epicore	9.0	5.6	6.2	23.9	8.4	9.5	4.4	2.5	3.6	4.7	7.1	6.8
Site 2												
Surface	--	7.0	2.9	30.5	8.3	--	4.0	3.7	3.1	8.4	9.6	2.4
Middle	--	12.4	2.1	8.2	8.8	--	8.3	3.5	7.7	7.2	7.9	6.4
Bottom	--	5.5	0.2	8.3	7.4	--	5.0	6.1	7.8	7.9	7.5	5.3
Epicore	--	6.1	6.4	7.2	--	--	--	--	--	--	--	--
Site 3												
Surface	--	5.7	7.2	7.9	7.1	--	6.8	4.7	5.9	7.7	7.1	6.0
Middle	--	7.5	8.2	10.9	7.1	--	7.4	4.2	3.1	6.3	6.0	--
Bottom	--	11.0	9.3	9.1	6.6	--	4.2	7.1	5.5	5.3	6.1	5.0
Epicore	--	5.3	--	--	--	--	--	--	--	--	--	--
Site 4												
Surface	--	--	4.7	10.2	--	--	3.0	3.2	3.1	10.1	7.5	4.8
Middle	--	--	8.6	12.6	--	--	--	--	--	--	--	--
Bottom	--	--	--	--	--	--	--	--	3.4	3.3	7.2	5.2

APPENDIX C. (Continued)

Sampling conditions and physical parameters: Secchi disk (m) and turbidity (NTU) (see Figure 28 for site locations)

	6-Jun-06	13-Jun-06	22-Jun-06	27-Jun-06	5 & 6-Jul-06	11&12-Jul-06
Cloud Cover		45-70%	35-90%	30-60%	25-60%	10-90%
Wind Speed		5-8 mph	5-11 mph	9-15 mph	5-10 mph	7 mph
Wind Direction		From N	From S	From S	From W	From S
Previous Weather	Rain	Heavy Rain, Sun	Night T-storms, sun	Rain	Sun	Rain, before & after T-storms
Site 1						
Sample Depths (m)						
Epicore	7.0	7.0	8.0	8.0	8.0	8.0
Middle	7.0	7.5	9.0	8.5	9.0	9.0
Bottom	13.5	16.0	17.0	16.5	18.0	17.0
Secchi Disk (m)	4.79	4.37	4.50	4.80	5.60	4.40
Turbidity						
Surface	0.55	0.61	0.87	2.01	0.92	0.84
Middle	0.67	0.66	1.65	2.34	0.82	0.68
Bottom	0.60	0.49	2.09	1.57	1.98	0.88
Site 2						
Sample Depths (m)						
Epicore	-	7.0	8.0	8.0	-	-
Middle	-	4.5	4.5	4.5	4.0	4.0
Bottom	-	8.0	8.0	8.0	8.0	8.0
Secchi Disk (m)	-	4.58	4.95	5.00	3.85	4.28
Turbidity						
Surface	-	0.69	0.73	2.08	1.14	0.92
Middle	-	0.66	0.71	2.59	1.11	1.01
Bottom	-	0.25	1.28	2.73	1.93	3.32
Site 3						
Sample Depths (m)						
Epicore	-	7.0	-	-	-	8.0
Middle	-	7.0	4.5	3.8	4.0	3.5
Bottom	-	4.0	7.0	7.5	7.0	7.5
Secchi Disk (m)	-	4.08	4.65	4.60	3.90	5.50
Turbidity						
Surface	-	0.56	1.03	1.59	1.76	0.92
Middle	-	0.88	1.24	1.90	0.98	1.08
Bottom	-	0.85	0.84	4.63	1.14	1.08
Site 4						
Sample Depths (m)						
Epicore	-	-	-	-	-	-
Middle	-	-	2.0	2.5	-	-
Bottom	-	-	-	-	-	-
Secchi Disk (m)	-	-	4.10	3.90	-	-
Turbidity						
Surface	-	-	1.14	1.70	1.37	1.55
Middle	-	-	1.48	2.07	-	-
Bottom	-	-	-	-	-	-

APPENDIX C. (Continued)
Sampling conditions and physical parameters: Secchi disk (m) and turbidity (NTU)

	18-Jul-06	25-Jul-06	1-Aug-06	8-Aug-06	14-Aug-06	30-Aug-06	2-Oct-06
Cloud Cover	15%	5-10%	50-70%	25-80%	30-90%	5-20%	98-100%
Wind Speed	8-11 mph	8-13 mph	5-11 mph	9-13mph	5-10 mph	5-10 mph	8-13 mph
Wind Direction	From SW	From SE	From S	From N	From S	From N	From N
Previous Weather	Sun	Sun, Sun showers	Sun, Some clouds	Rain previous night	Sun	Previous rain	Previous rain
Site 1							
Sample Depths (m)							
Epicore	9.0	9.0	9.0	-	9.0	10.0	-
Middle	9.0	9.5	9.5	10.0	9.0	10.0	-
Bottom	17.0	18.0	19.0	19.5	18.0	19.0	-
Secchi Disk (m)	4.60	-	4.43	4.51	4.00	6.20	3.65
Turbidity							
Surface	0.80	0.91	0.74	0.73	0.97	0.69	-
Middle	1.13	0.65	0.89	0.61	1.22	1.15	-
Bottom	0.82	0.87	1.28	1.43	2.21	0.86	-
Site 2							
Sample Depths (m)							
Epicore	-	-	-	-	-	-	-
Middle	4.0	4.5	4.5	4.0	4.5	4.3	-
Bottom	8.0	8.0	8.5	8.0	8.5	8.0	-
Secchi Disk	4.40	-	3.90	4.50	3.90	-	4.10
Turbidity							
Surface	0.75	0.89	0.73	0.77	0.78	0.51	-
Middle	1.04	0.96	1.10	0.85	0.89	0.82	-
Bottom	1.60	1.28	0.97	0.69	1.49	0.68	-
Site 3							
Sample Depths (m)							
Epicore	-	-	-	-	-	-	-
Middle	3.5	4.0	4.0	4.0	4.0	4.0	-
Bottom	7.0	7.5	7.0	7.5	7.0	7.3	-
Secchi Disk	5.10	-	4.91	4.20	-	-	-
Turbidity							
Surface	0.75	0.97	1.11	0.83	0.95	-	-
Middle	0.87	0.91	0.72	0.79	0.75	0.66	-
Bottom	0.90	1.00	0.94	0.87	0.95	0.70	-
Site 4							
Sample Depths (m)							
Epicore	-	-	-	-	-	-	-
Middle	-	-	-	-	-	-	-
Bottom	-	-	3.5	3.5	3.5	4.0	-
Secchi Disk	-	-	-	-	-	-	-
Turbidity							
Surface	0.93	1.30	1.30	0.88	0.87	0.64	-
Middle	-	-	-	-	-	-	-
Bottom	-	-	0.92	1.20	0.99	0.76	-

APPENDIX D. WATER BUDGET VALUES AND CALCULATION

1. Physical Parameters of Long Pond North Used in the Water Budget

Physical Parameter	Value	Units
Runoff Coefficient	0.622	meters/year
10 Year Mean Precipitation	1.057	meters/year
Evaporation Coefficient	0.560	meters/year
Watershed Area	2.316×10^7	$meters^2$
Lake Area	5.160×10^6	$meters^2$
Lake Volume	3.492×10^7	$meters^3$

2. Calculating Net Input (m^3/year) of Long Pond North

I_{net} = (runoff * watershed area) + (precipitation * lake area) – (evaporation * lake area)
$I_{net} = (0.622 * 2.316 \times 10^7) + (1.057 * 5.160 \times 10^6) - (0.560 * 5.160 \times 10^6)$

The net input to Long Pond North is 1.697×10^7 cubic meters per year.

3. Input of Lakes Draining into Long Pond North

Lake	Net Input (m^3/year)
Beaver Pond	2.398×10^6
Great Pond	1.034×10^8
Kidder and McIntire Ponds	9.072×10^5
Round Pond	2.257×10^6
Whittier and Watson Ponds	6.208×10^6

4. Flushing Rate (flushes/year)

Flushing Rate = [(I_{net} Long Pond) + (I_{net} $Input_1$) + … (I_{net} $Input_n$)] / (Volume of Lake)
Flushing Rate = $(1.324 \times 10^8)/(3.492 \times 10^7)$

The flushing rate of Long Pond North is 3.79 flushes per year.

5. Total Input (Q) to Long Pond North for Use in Phosphorus Budget

Q (Total) = (I_{net} Long Pond) + (I_{net} $Input_1$) + … (I_{net} $Input_n$)
Q (Total) = 1.324×10^8 cubic meters per year

APPENDIX E. PHOSPHORUS MODEL EQUATION

$$W = (Ec_a \times Area_s) + (Ec_{ag} \times Area_{ag}) + (Ec_{cf} \times Area_{cf}) + (Ec_{df} \times Area_{df}) + (Ec_{gc} \times Area_{gc}) + (Ec_w \times Area_w) + (Ec_{cc} \times Area_{cc}) + (Ec_{cm} \times Area_{cm}) + (Ec_{rl} \times Area_{rl}) + (Ec_{mf} \times Area_{mf}) + (Ec_{pk} \times Area_{pk}) + (Ec_{cr} \times Area_{cr}) + (Ec_{sr} \times Area_{sr}) + (Ec_s \times Area_s) + (Ec_n \times Area_n) + [(Ec_{ss} \times \#\text{ capita years} \times (1-SR_1)) + (Ec_{ns} \times \#\text{ capita years}_n \times (1-SR_2))] + (Sd_{cs} \times Area_{cs}) + PSI_{gp} + PSI_{bp} + PSI_{wp}$$

Ec_a = export coefficient for atmospheric input (kg/ha/yr)

Estimated Range = 0.11 – 0.21 Best Estimate = 0.16

Reckhow and Chapra (1983) derived an estimated atmospheric export coefficient range of 0.15 - 0.6. This study uses a lower range and best estimate based on a recent study of Togus Pond, which is located in the same county as Long Pond North (MDEP & MACD 2005). Air particulate content is most likely low for Long Pond North because it is far from any large city and has relatively little industry or agriculture.

Ec_{ag} = export coefficient for agricultural land (kg/ha/yr)

Estimated Range = 0. 2 – 1.3 Best Estimate = 0.5

This coefficient is based on Reckhow and Chapra's study of Higgins Lake in Michigan (1983). Like Higgins Lake, Long Pond North's agricultural land consists mostly of pasture. The best estimate is adapted from the grassland export coefficient from a past report on China Lake (CEAT 2005).

Ec_{cf} = export coefficient for coniferous forest (kg/ha/yr)

Estimated Range = 0.01 – 0.07 Best Estimate = 0.04

Coniferous forests contribute less phosphorus to lakes than deciduous forests because coniferous trees produce less leaf litter. The estimated range and best estimate are similar to those from a recent study of Togus Pond (MDEP & MACD 2005).

Ec_{df} = export coefficient for deciduous forest (kg/ha/yr)

Estimated Range = 0.02 – 0.09 Best Estimate = 0.06

This range is derived from a past study on Togus Pond, but is adapted to be slightly higher than the coniferous forest coefficient range because deciduous trees contribute more phosphorus to a lake (MDEP & MACD 2005). The best estimate is also higher than that of the coniferous forest for this same reason.

Ec_{gc} = export coefficient for golf course (kg/ha/yr)

Estimated Range = 0.3 – 1.00 Best Estimate = 0.50

For this study, the estimated range is adapted from Reckhow and Chapra's (1983) agricultural export coefficient range of 0.2 - 1.30. The lower end is greater than that of Reckhow and Chapra's because golf courses tend to be large and heavily fertilized. There is virtually no canopy to slow rain before ground impact, resulting in higher erosion rates. A similar range of 0.4 - 1.00 is used in a past report on Great Pond for industrial and municipal land, which mainly took into account the golf course's phosphorus contribution (CEAT 1999).

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

Estimated Range = 0.02 – 0.05 Best Estimate = 0.01

These low values are based upon a past study on Togus Pond, which yielded a range of 0 - 0.05 (MDEP & MACD 2005). Wetlands act as a sink for phosphorus, especially during the summer growing season, and therefore contribute very little phosphorus to the lake.

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

Estimated Range = 0.10 – 1.00 Best Estimate = 0.40

A past Long Pond North report gives cleared land coefficients of 0.10 - 1.00 because at the time, there were no active farms within the watershed (CEAT 1995). The best estimate for this study is on the higher end because the horse farm reopened. Cleared land has higher rates of erosion and phosphorus runoff than forested lands.

Ec_{cm} = export coefficient for commercial land (kg/ha/yr)

Estimated Range = 0.40 – 1.00 Best Estimate = 0.40

The main component of Long Pond North's commercial land is the town of Belgrade Lakes, which sits between Long Pond and Great Pond. The export coefficients are similar to those from a past Great Pond study (CEAT 1999), with a higher best estimate since the town sits near the mouth of one of Long Pond North's main water inputs.

Ec_{cr} = export coefficient for camp roads (kg/ha/yr)

Estimated Range = 0.45 – 6.00 Best Estimate = 2.50

Ec_{sr} = export coefficient for state roads (kg/ha/yr)

Estimated Range = 0.25 – 4.00 Best Estimate = 1.00

These coefficients are adapted from a past study on Togus Pond (MDEP & MACD 2005). Camp roads have a higher best estimate because they are closer to the lake, mostly unpaved, and in poorer condition than the impervious, well-maintained state roads. Many Long Pond North camp roads are lacking proper drainage and crownage (see Watershed Development Patterns: Roads).

Ec_{mf} = export coefficient for mixed forest (kg/ha/yr)

Estimated Range = 0.02 – 0.08 Best Estimate = 0.05

Reckhow and Chapra report a general forest export coefficient of 0.02 - 0.45 in their study of Lake Higgins (1983). This study uses a lower upper limit and best estimate derived from a past Togus Pond study (MDEP & MACD 2005). Being comprised of both deciduous and coniferous trees, mixed forests contribute an intermediate amount of phosphorus to the lake.

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

Estimated Range = 0.50 – 1.3 Best Estimate = 2.00

Reckhow and Chapra assigned Higgins Lake a coeffient range of 0.35 - 2.7 (1983). Like Higgins Lake, Long Pond North is mostly a residential/recreational lake. The bottom limit for this study is higher than the 1983 Higgins Lake study to take increased development into account. A past study on Long Pond North reports an estimated range of 0.80 - 3.00 (CEAT 1995). The coefficient range and best estimate for this study are smaller than the 1995 range because although there has been more development, many of the new houses are built to code with proper septic and buffer requirements.

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

Estimated Range = 0.35 – 1.00 Best Estimate = 0.35

Non-shoreline homes are farther away from the lake and contribute less phosphorus than shoreline homes. Their coefficient range is therefore much less. The export coefficient is derived from a past study on Great Pond because of its similarity to Long Pond North (CEAT 1999).

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

Estimated Range = 0.2 – 0.8 Best Estimate = 0.35

Regenerating land is defined as land that was cleared, but is currently undergoing early to mid-successional stages of growth. The estimated range was based on the reverting land coefficient from a study of Threemile Pond because of the lack of a full canopy (CEAT 2004). The best estimate was chosen to fall between that of forested and cleared land.

Ec_{pk} = export coefficient for park (kg/ha/yr)

Estimated Range = 0.20 – 0.80 Best Estimate = 0.30

Parkland is defined as open, grassy areas used mainly for recreation. The best estimate is less than that of the golf course because of the lack of fertilizer, and less than that of cleared land because parklands tend to be managed and contain very few trees. The estimated range is similar to the export coefficient for reverting land from a past China Lake report because reverting land characteristics are similar to those of parkland (mostly grasses and shrubs with less than 50 percent canopy cover) (CEAT 2005).

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

Estimated Range = 0.40 – 1.20 Best Estimate = 0.50

A study of Great Pond reported a conservative coefficient range of 0.5 - 1.30 because many areas around the lake have soils with poor septic suitability (CEAT 1999). The range for this study has been lowered because many of the septic systems around the lake have been brought up to date due to new construction or conversion from seasonal to year-round residency. Also, the soil around the lakeshore is mostly suitable for septic systems (see Watershed Development Patterns: Residential Survey: Septic Suitability Model). The best estimate is also on the lower end for these same reasons.

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

Estimated Range = 0.30 – 0.90 Best Estimate = 0.40

Non-shoreline septic tank systems should have a lesser effect on phosphorus runoff because of their distance from the shore. This range is based on a past study of nearby Great Pond (CEAT 1999).

SR_1 = soil retention coefficient for shoreline development

Estimated Range = 0.65 – 0.35 Best Estimate = 0.45

SR_2 = soil retention coefficient for non-shoreline development

Estimated Range = 0.90 – 0.75 Best Estimate = 0.80

Soil retention is a measurement of how well the soil can retain nutrients such as phosphorus. This coefficient ranges from 0 to 1 with greater values representing a greater capacity to hold phosphorus. Soils with larger particles tend to retain less and have higher coefficients than those with smaller particles. The soil around the shore consists mostly of Berkshire stony, which has a moderately coarse texture and drains well. This increases the likelihood of septic leakage percolating into the soil and traveling towards this lake. A lower coefficient range similar to Togus Pond is used because its soil is also of moderate permeability and excessively drained (CEAT 2005). The soil retention farther away from the shoreline affects phosphorus runoff less, so a higher coefficient range and estimate are granted to non-shoreline development.

PSI_{gp} = point-source input from Great Pond (kg/yr)

Best Estimate = 898.72

Great Pond flows directly into Long Pond North via a dam on the Long Pond North eastern shore. CEAT calculated from summer 2006 measurements of Great Pond that mean (± SE) epicore total phosphorus is approximately 8.7 ppb ± 1.3. Using the amount of water entering Long Pond North from this lake, the total mass input from this point source was calculated to be 898.72 kg/yr.

PSI_{bp} = point-source input from Beaver Pond (kg/yr)

Best Estimate = 27.6

McIntire Pond empties into Kidder Pond, which flows into Round Pond, which empties into Beaver Pond and eventually flows into Long Pond North via Beaver Brook in the northwest. The surface total phosphorus concentration of Beaver Pond was 10.0 ppb in 2004 (PEARL 2006), whereas Beaver Brook was measured by CEAT to have a surface total phosphorus concentration of 13.0 ppb in 2006. For this point-source input calculation, an average of the two values (11.5 ppb) was used. The total mass input (27.6 kg/yr) was calculated using the amount of water entering Long Pond North from Beaver Pond.

PSI_{wp} = point-source input form Whittier Pond (kg/yr)

Best Estimate = 117.8

Watson Pond empties into Whittier Pond, which flows into Long Pond North via a tributary in the northern-most region of the lake. The epicore total phosphorus of Whittier Pond in 2004 was 19 ppb (PEARL 2006). Using the amount of water entering Long Pond north from Whittier Pond, the total mass input from this point source was calculated to be 117.8 kg/yr.

Areas of Land-Use Components:

Area Symbol	**Area Term**	**Area (ha)**
A_s	Area of Long Pond North	595.00
$Area_f$	Area of mature forest	746.10
$Area_{cf}$	Area of coniferous forest	482.52
$Area_{df}$	Area of deciduous forest	410.94
$Area_w$	Area of wetlands	35.13
$Area_c$	Area of cleared land	17.40
$Area_{rl}$	Area of regenerating land	61.83
$Area_{cm}$	Area of commercial land	3.50
$Area_{pk}$	Area of park land	0.24
$Area_{gc}$	Area of golf course	5.31
$Area_{cr}$	Area of camp roads	33.00
$Area_{sr}$	Area of state roads	18.00
$Area_s$	Area of shoreline residential land	52.81
$Area_n$	Area of non-shoreline residential land	85.80

APPENDIX F. PREDICTIONS FOR ANNUAL MASS RATE OF PHOSPHORUS INFLOW

The phosphorus loading model used by CEAT in this study presents the annual total phosphorus input as a loading per unit lake surface in kg/ha. This was estimated by dividing the total phosphorus inflow (W) by the surface area of Long Pond North (A_s) (Reckhow and Chapra 1983):

$L = W / A_s$

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

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

$q_s = Q_{total} / A_s$

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

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

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

P	= total phosphorus concentration (ppb)

Constants for low, best, and high estimates for Long Pond:

A_s	= 5159746.5 m^2
Q_{total}	= 132387058.4 m^3
q_s	= 25.66 m/yr

Low Estimate:		**<u>Without Sediment Release</u>**	**<u>With Sediment Release</u>**
W	=	1303.31 kg/yr	1354.91 kg/yr
L	=	0.25 kg/ha/yr	0.26 kg/ha/yr
P	=	5.96 ppb	6.19 ppb
Best Estimate:			
W	=	1601.78 kg/yr	1911.37 kg/yr
L	=	0.31 kg/ha/yr	0.37 kg/ha/yr
P	=	7.32 ppb	8.74 ppb
High Estimate:			
W	=	2259.70 kg/yr	2793.52 kg/yr
L	=	0.44 kg/ha/yr	0.54 kg/ha/yr
P	=	10.33 ppb	12.69 ppb

APPENDIX G. ROAD INDEX FIGURES AND SURVEY FORMS

ROAD SURVEY DATA SHEET 2006

DATE: GPS at start of road: GPS at end of road:	SURVEYORS:	ROAD NAME: ROAD TYPE:	 state road camp road other:
ROAD LENGTH (MILES):			
AVERAGE WIDTH (FEET, include shoulders):			
HOUSE COUNT (tally # of houses per road)	Year-Round Not Shore #:		Shoreline:
	Seasonal Not Shore #:		Shoreline:
NOTE COMMERCIAL LAND USE, GPS (gas stations, stores, etc.):			
TALLY # INACCESSABLE LAKEFRONT DRIVEWAYS:			
SLOPE: Draw road profile, label with significant slope range	0-5%, 6-10%, 11-15%, 16-20%, >20% describe any discrepancies		
DESCRIBE CROWN: measurment: 0-2 in 2-4 in 4-6 in 6-8 in			
DESCRIBE DITCH CONDITION: shape: vegetation, stone-lined, mixed dirt/gravel, dirt: clear of debris?			
DESCRIBE ROAD SURFACE CONDITION: surface material (gravel, gravel/sand, dirt, sand/clay, clay, pavement): age of road (new or old) road use (year round or seasonal):			
BASIC SUMMARY:			
OVERALL CONDITION	good	acceptable	fair poor

APPENDIX G. (continued)

Road Survey Data Sheet for Problem areas

Please address these issues for the following problem areas:

Crown- height, edge (berms or ridges preventing water?)

Ditch- depth and width, vegetation, sediments, shape.

Diversion- needed? where does water runoff go?

Culvert- wear (erosion/crushed), diameter, inside, covering material

Problem #					
GPS reading					
Location on road (miles)					
Problem area	crown	ditch	diversion	culvert	other
Summary (address issues above, what needs to be done):					

APPENDIX H. PERSONAL COMMUNICATIONS

Bacon, Earl	Long Pond North resident
Bouchard, Roy	Maine Department of Environmental Protection
Firmage, David	Biology Department, Colby College
Fuller, Gary	Code Enforcement Officer, Belgrade Municipal Office
Keschl, Dennis	Town Manager, Belgrade Municipal Office
Najpauer, William	Code Enforcement Officer, Rome Municipal Office

APPENDIX I. BUFFER STRIP SURVEY

Group Members				Date:		
Reference Number:						
GPS Coordinates:						
% Shoreline w/Buffer	0	1-25	26-50	51-75	Over 75	
	0	1	2	3	4	
Buffer Depth from Shore (ft)	0	1-10	11-33	34-65	Over 65	
	0	1	2	3	4	
Slope Rating		Steep	Moderately Steep	Small Incline	Flat	
		1	2	3	4	
Buffer Composition	100%	75%	50%	25%	0%	
Trees	4	3	2	1	0	
Shrubs/Herbaceous	10	8	6	4	0	
Total						
Building Type	Year Round Residence		Seasonal Residence		Commercial	
Lot Shoreline Distance (ft)	0-60	60-120	120-180	Over 180		
Noticeable Outdoor Septic	Yes		No			
Rip Rap	Exists		Needed			

APPENDIX J. RESIDENTIAL SURVEY FORM

OVERALL ROAD SURVEY DATA SHEET 2006

DATE:	SURVEYORS:		ROAD NAME:	
			ROAD TYPE:	state road
GPS at start of road:				camp road
GPS at end of road:				other:
ROAD LENGTH (MILES):				
AVERAGE WIDTH (FEET, include shoulders):				
HOUSE COUNT (tally # of houses per road)		Year-Round Not Shore #:		Shoreline:
		Seasonal Not Shore #:		Shoreline:
NOTE COMMERCIAL LAND USE, GPS (gas stations, stores, etc.):				
TALLY # INACCESSABLE LAKEFRONT DRIVEWAYS:				
SLOPE: Draw road profile, label with significant slope range			0-5%, 6-10%, 11-15%, 16-20%, >20% describe any discrepancies	
DESCRIBE CROWN:				
measurment: 0-2 in	2-4 in	4-6 in	6-8 in	
DESCRIBE DITCH CONDITION: shape: vegetation, stone-lined, mixed dirt/gravel, dirt: clear of debris?				
DESCRIBE ROAD SURFACE CONDITION: surface material (gravel, gravel/sand, dirt, sand/clay, clay, pavement): age of road (new or old) road use (year round or seasonal):				
BASIC SUMMARY:				
OVERALL CONDITION	good	acceptable	fair	poor

Road Survey Data Sheet for Problem areas

Please address these issues for the following problem areas:

Crown- height, edge (berms or ridges preventing water?)

Ditch- depth and width, vegetation, sediments, shape.

Diversion- needed? where does water runoff go?

Culvert- wear (erosion/crushed), diameter, inside, covering material

Problem #					
GPS reading					
Location on road (miles)					
Problem area	crown	ditch	diversion	culvert	other
Summary (address issues above, what needs to be done):					